Insight by de—sign

A calculus of computation

Einsicht durch Ausschluss

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Introduction

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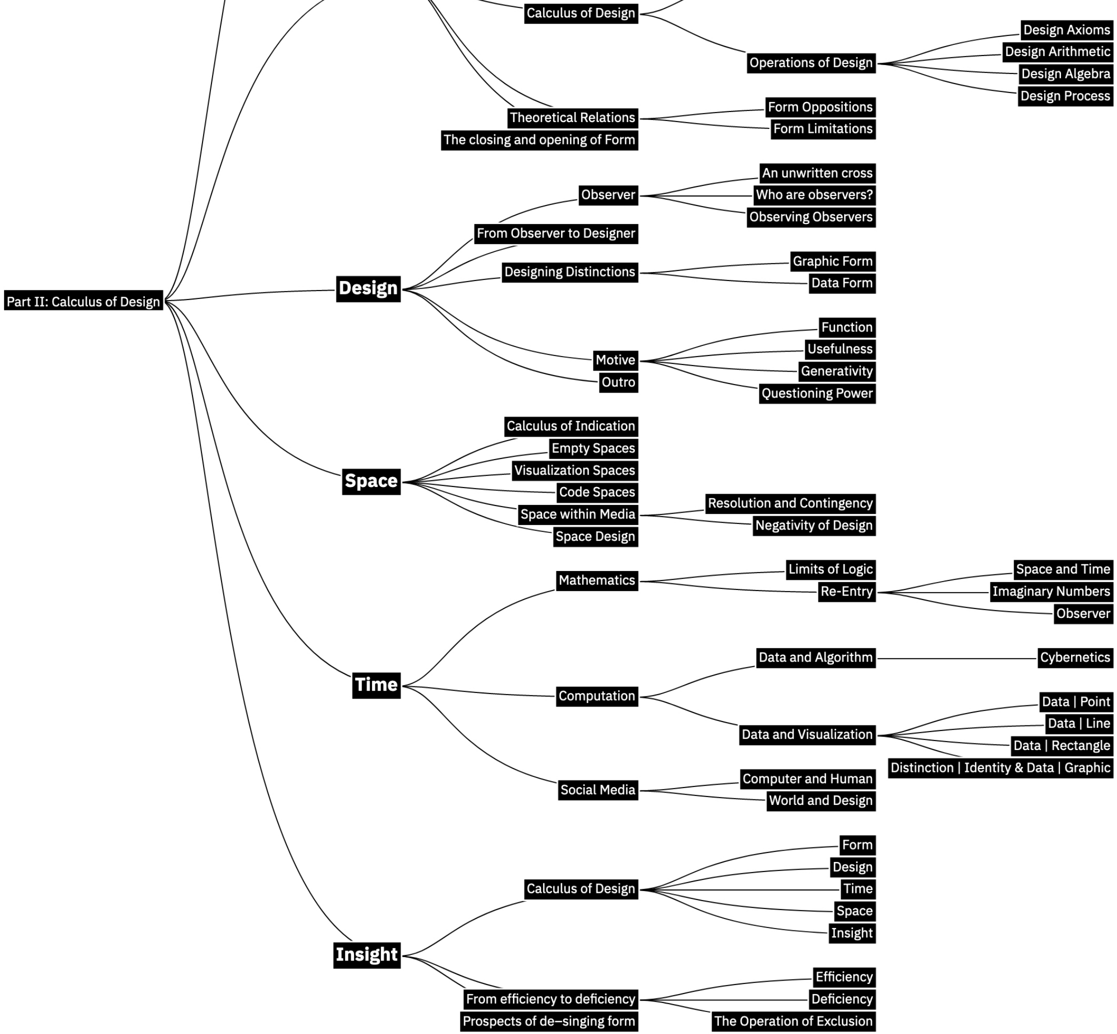

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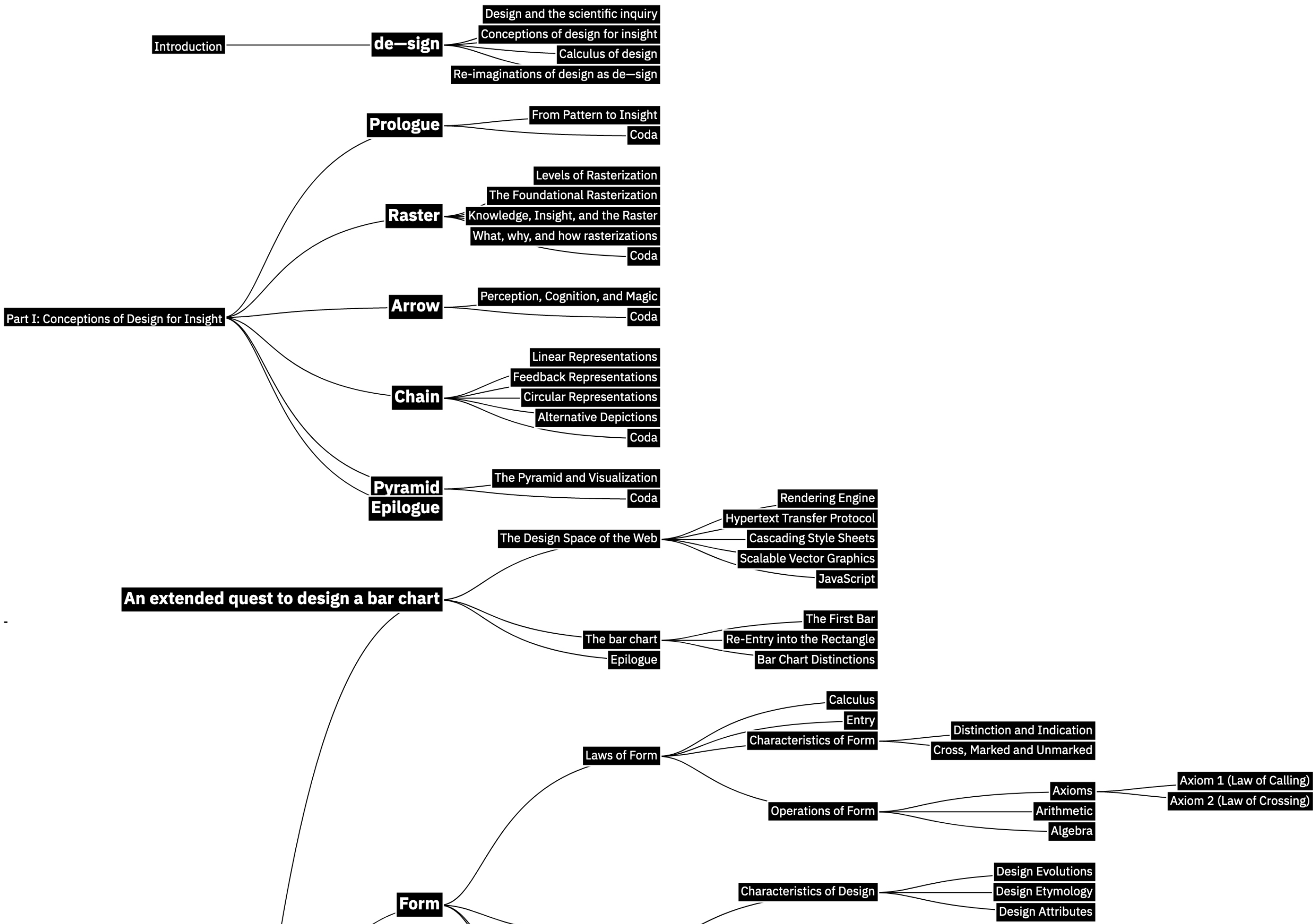
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Acknowledgements

In a world in which a tweet is old after a couple of hours, fashion trends will not last years, but months, and software updates become a daily routine, spending five years on one idea is frightening and at the same time an immense gift. Developing this dissertation was only possible due to a circle of individuals who supported me on many different levels. I want to use these first pages to thank the people on whom all of this is based in one form or another.

First, I want to thank my supervisors Jan Distelmeyer and Birgit Schneider. My background in design made me by no means a usual P.h.D candidate in media studies at the Faculty of Philosophy. Jan and Birgit introduced me to the complexities of the textual medium, its theoretical conceptualizations, and re-imagining what it means to design in the mediated realities from data to visualization. For their guidance, patience, and reflections throughout the process I am tremendously grateful.

A similar kind of attentiveness came from my friend and dissertation fellow Paul Heinicker. Our weekly meetings and rounds of intense discussions and critiques left a deep impression on what this dissertation has become. Additionally, I am grateful for the various colloquia I have been a part of throughout: most prominently, the multidisciplinary discussions with Alice Soiné, Christian Schwinghammer, Daniel Stoecker, and Nicole Schimkus. Furthermore, I want to thank the Potsdam Graduate School for their support, especially Anne Popiel, who corrected the entire dissertation. The path I am on today was guided and alluded to by many mentors prior. I want to thank Boris Müller and Marian Dörk for their interdisciplinary counseling between design and computation and Charles Maggs for his incredible perspective on design which shaped so many of my current perspectives.

A second tremendously influential group of individuals mainly resides across the Atlantic, to be more precise, the greater Boston area. My current research affiliation with metaLAB (at) Harvard over the past four years not only supported my thinking and making, but created an environment that allowed for different kinds of critical and playful engagement with the world. Especially Jeffrey Schnapp, Sarah Newman, Matthew Battles, and Annette Jael Lehmann made it possible for this dissertation to be more than a theoretical construct but rather an undertaking in various forms of mediated projects. From 2015 to 2017, during the time I initialized and formed the conceptions underlying this dissertation, I conducted research at the Center for Complex Network Science. The examination of science from within developed the foundational questions that I have investigated throughout this dissertation. In particular, Albert-Laszlo Barabasi, Mauro Martino, and Isabel Meirelles, as well as my various collaborators on the different projects Burcu Yucesoy, Bruno Coutinho, Michele Coscia, and Roberta Sinatra, among others, shaped my perspective on the interplay of science and design.

The city I am calling home these past four years and beyond, Berlin, deepened my theoretical and artistic engagements and simultaneously reminded me that there is life outside the screen. The monthly datakorn meetings above and beyond theories and applications of visualization design constantly reminded me what it means to be a designer in the 21st century. Christian Laesser, Jonas Parnow, Paul Heinicker, and Sebastian Sadowski all have my deepest gratitude for our heated debates. I wrote most of this dissertation in my studio in Moabit. With my studio neighbor Sati Zech, I not only had good laughs in the most stressful times of writing, but entering her studio also constantly reminded me of the limitations of the approach I conceptualized. The materiality of her work lies far beyond the reductive conceptions of the distinction. The theoretical origins of this dissertation reach back to 2015, when Sebastian Blinn lent me Felix Lau's *Die Form der Paradoxie* in a class project with Marc Tiedemann. This introduction to the *Laws of Form* laid the foundation for what this dissertation has become today.

Finally, my family deserves the most profound gratitude; my parents Iris and Wolfgang, and the broader family, Sven, Sandra, Leo, Frida, Isla, Isobel, Heike, and Jörg: Each of you supported and contributed to this dissertation through often undefinable modalities. Last of all, this dissertation would not exist without Teresa. Her strength, encouragement, and love spread far beyond the scope of this writing. Teresa is a constant reminder to me that life reaches far beyond the distinction.

Introduction

de—sign

The *calculus of design* is a diagrammatic approach towards the relationship between *design* and *insight*.[1] The thesis I am evolving is that *insights are not discovered, gained, explored, revealed, or mined, but are operatively de—signed*.[2] The *de* in design neglects the *contingency* of the *space* towards the *sign*.[3] The — is the *drawing of a distinction* within the *operation*.[4] *Space* collapses through the negativity of the *sign*; the command draws a distinction that neglects the space for the form's sake.[5] The operation to *de—sign* is counterintuitively not the creation of signs, but their removal, the exclusion of possible sign propositions of space. *De—sign* is thus an act of exclusion; the possibilities of space are crossed into form.[6]

Throughout the dissertation, the above provocation is negotiated, supplemented, exemplified, and put into perspective. One quintessential concept elaborated here is that even the most abstracted and objectified view is by necessity drawn by a designer's motives.[7] The examples I have chosen throughout the dissertation to merge theory and practice are all secondary. As a designer myself, I decided that the points would be more vital if I did not discuss personal projects, as this might lead to an uncanny self-reflection in which I was theorizing my work. Simultaneously, as the approach I am introducing will hopefully make apparent, I am always a part of what renders something visible. The first distinction a designer draws without noticing is the distinction between design and designer. For this reason, I choose to use this introduction to inaugurate the theory from a biographical perspective of myself as a design practitioner, merging the theoretical foundations, the approach I developed, and the various projects I

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1 I have identified, theorized, and approached this concpetion thoughout five chapters: *Form*, *Design*, *Space*, *Time*, and *Insight*.

2 The first part of the dissertation disects the verbs of this statement.

3 Covered in the chapters *Design* and *Space*.

4 Chapters *Design* and *Time* develop these conceptions further.

5 Chapter *Space* covers and exemplifies this sentence.

6 From chapter *Form* to chapter *Insight,* the negative operation of *de—sign* is elaborated on.

7 Explained in more depth in chapter *Design.*

worked on during the dissertation. Simultaneously, I am using this introduction to highlight some of the essential readings that shaped my perspective throughout the five-year process.

Design and the scientific inquiry

From 2015 to 2017, I held the visualization design research position in one of the most prestigious laboratories studying complex networks, the *Center for Complex Network Science* led by Albert Laszlo Barabasi at Northeastern University, Boston.[8] During the two and a half years at the laboratory, I designed various visualizations of large quantities of networked datasets in partnership with scientists. The systems I visualized ranged from mathematical, biological, neurological, social, and ecological to the structures of the Universe. I strove for the moments when my colleagues learned something new about their data through the visualizations and interfaces I designed. My motive was to design the data interfaces to highlight something novel about these networks that would otherwise have remained obscured. Finding visual novel perspectives was not an easy task, as most of my collaborators gathered and analyzed the data for years. The findings I was able to design often displayed errors, inconsistencies, and inaccuracies in the data. In addition, there were moments when the graphic representations suddenly shifted a discussion, leading to new research paths. These moments are the foundation of the approach I have developed in this dissertation. The question that increasingly captivated me was simple: *How is it possible that a transformation from data to graphic created novel insights that had remained hidden until this moment in the research process? What am I doing while designing these graphics through which insights surface? Is there a theoretical framework that draws together the design operation and the insights emerging from these interfaces?*

Working in a laboratory with over twenty postdoctoral researchers, mainly with a physics background, I engaged in an enterprise that was rather peculiar to someone coming from graphic and interface design. The sense of dedication in the laboratory was to generating new insights about the world. Publications in

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8 https://www.barabasilab.com/

prestigious journals such as *Science* and *Nature* were the currency of the scientific enterprise I engaged in. At first, the discipline of design seemed distant from this scientific engagement. Design is about creation, bringing something into the world which thus far does not exist. It is taking the world and transforming it on the scale of cities, buildings, products, or communication structures within analog and digital realms. The longer I engaged in the laboratory, the closer design and the scientific inquiry appeared to me. The datasets were carefully designed, drawn together from various sources, brought into relation to one another, simplified on multiple scales, shaped towards analysis, and visualized in various forms. *Each of these steps became rendered in my mind as designed decisions.* The same dataset contained as many perspectives as the scientists drew together. Reflection, re-iterations, and narration are as much a part of design as it is a part of the scientific inquiry. The questions that arose to me were much more extensive than just about the transformation from data to graphics, but questioned our interrelationships with the world with respect to the creation of insights. The very basis of the interactions between design, as the act of drawing something into perspective, and the shaping of insights through a scientific process became foundational to the approach I call the *calculus of design*.

Conceptions of design for insight

The disciplines of visualization research and design contain a bold and often repeated promise:

> *The purpose of visualization is insight, not pictures.*
>
> *— Card, et al.*[9]

The motivation to visualize data becomes nothing less than the representation of insight, knowledge, and truth.[10] The three terms are often named in data visualization book titles and captivating statements. When I started focusing my career on visualizing data, the premise of the representation of insights,

[9] Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann, p. 6

[10] Section *From pattern to insight* elaborates and exemplifies this premis.

knowledge, and truth was omnipresent. The purpose of insights is such a superior and persuasive motive for visualization design compared to other branches of the discipline, such as graphic design, product design, architecture, or interface design. Over time, however, I became more intrigued with how the promise of insight is articulated in detail. How are design and insight related to one another? At this point, the problems began. The closer I inspected the conceptualizations between visualization and insights, the further the two terms drifted apart. Insight, knowledge, and truth are not explained, described, or mentioned beyond titles and catchy statements within visualization research. In applied visualization design research, I could not find a theory or practice naming and explaining how design and insights are related to one another. The more detailed the descriptions of the designed acts from data to graphic became, the further away questions on the motives behind insight, knowledge, and truth drifted.

Other terms emerged, and with them different sets of motives. Throughout the visualization design literature, reoccurring topics became apparent to me, which I investigated and clustered into four narratives in the form of metaphors: *raster*, *arrow*, *chain*, and *pyramid*. Each metaphor is investigated as one chapter throughout the first part, *Conceptions of design for insight*. None of the conceptualizations answered the question I had on the engagement design holds in the pursuit of insights. The striving towards understanding was replaced by other visualization design objectives, most prominently *efficiency*, *effectiveness*, and *functionality*.[11] These motives are objectifiable targets that researchers can measure in terms of *speed*, *accuracy* or *data-ink ratios,* but do not engage in the demanding question of insight. The question of insight and visualization is usually not deliberated on beyond titles and promotional statements. *Visualization design is a discipline with tremendous promise, but once this promise is investigated, it almost entirely disappears.* Throughout the visualization design and research, the relationship between data, graphic, interface, and insight are not articulated. The avoidance of investigating how design and insight relate to one another beyond catchy statements might be explained by the fact that the relationship is filled with complexities and dilemmas that are hard to grasp.

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11 Further elaborated throughout each of the chapters in Part 1, *Conceptions of design for insight*.

Other disciplines, such as *epistemology*,[12] *diagrammatics*,[13] *design theory*,[14] *visual epistemology*,[15] and *science and technology studies,*[16] among others, address the question of visual representations and scientific insights. But, and this is the critical point of my investigation, it is not from a perspective of an applied design approach. While I am drawing from and engaging in the theoretical, philosophical questions of design and knowledge, I am doing so from a theoretical standpoint and an applied approach. I am engaging in the question of mediality, from computational structure to design and from design to insight.

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12 Ref.: Nagel, J., 2014. Knowledge, Oxford: Oxford University Press.

Jung, M., 2014. Wilhelm Dilthey, Hamburg: Junius.

Schnädelbach, H., 2002. Erkenntnistheorie, Hamburg: Junius.

13 Ref.: Bauer, M. & Ernst, C., 2015. Diagrammatik, transcript Verlag.

Bredekamp, H., Dünkel, V. & Schneider, B., 2015. The Technical Image, University of Chicago Press.

Bogen, S., 2005. Schattenriss und Sonnenuhr: Überlegungen zu einer kunsthistorischen Diagrammatik. Zeitschrift für Kunstgeschichte.

Krämer, S., 2009. Epistemology of the line. Studies in Diagrammatology and Diagram Praxis.

Krämer, S., 2016. Figuration, Anschauung, Erkenntnis, Suhrkamp Verlag.

14 Ref.: Hirdina, H., 2005. Design. In Ästhetische Grundbegriffe.

Mareis, C., 2014a. Design als Wissenskultur, transcript Verlag.

Mareis, C., 2014b. Theorien des Designs, Junius.

15 Ref.: Klinke, H., 2014. Art Theory as Visual Epistemology, Cambridge Scholars Publishing.

Latour, B. & Weibel, P., 2002. Iconoclash: Beyond the Image Wars in Science, Religion and Art. Cambridge.

Mersch, D., 2011. Aspects of Visual Epistemology: On the “Logic” of the Iconic.

Schneider, B., 2016. Burning worlds of cartography: a critical approach to climate cosmograms of the Anthropocene. Geo: Geography and Environment, 3(2), pp.e00027–15.

16 Ref.: Carrier, M., 2006. Wissenschaftstheorie, Hamburg: Junius.

Galison, P., 2006. Images scatter into data, data gather into images, Images: A Reader.

Okasha, S., 2002. Philosophy of Science, Oxford: Oxford University Press.

Rheinberger, H.-J., 2007. Historische Epistemologie, Hamburg: Junius.

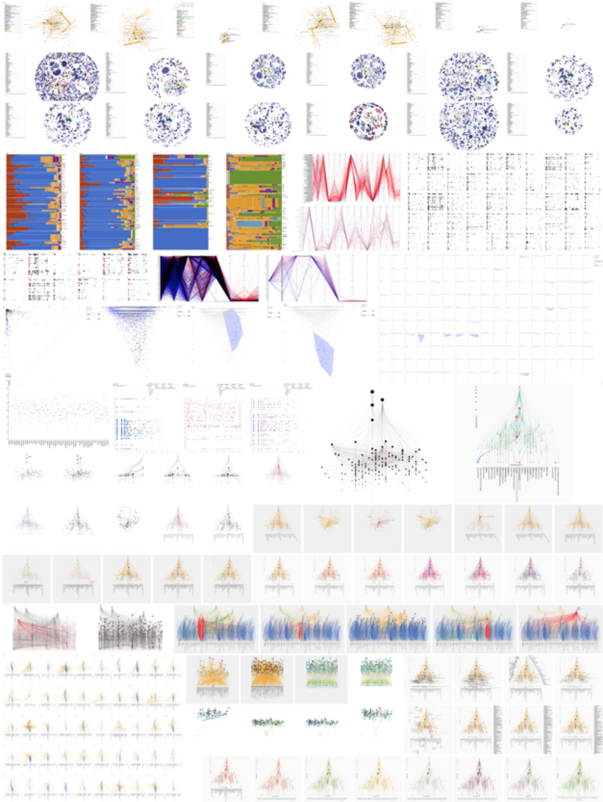
This dissertation aims to dissolve the boundary between theory and practice and engage with both as points of view from which to consider the same mediated and designed structures.

Calculus of design

The relation between design and insights led me to ponder the elementary act of designing. What is a designer doing on a fundamental level in each step of the design process? Is there a term describing the act of designing something on the moment-to-moment scale? In the chapter *Chain*, I have collected and clustered 27 representations of the visualization design process. What they have in common is a holistic, God's-eye view of the design process. In contrast to this, what I am reflecting on is the molecular level of design. What is the atomic scale of design? And, if there is something like this, what are the nucleus and electrons of this act? What would such a molecular level tell me about the relationship between design and insights?

For years, I have been taking screenshots of the stages of a project throughout my design processes. The primary motivation is to have a repository of all the steps that I went through, to move back and forth through iterations of often long processes. One of these long processes became a project named the *Government Structure,* started at the *Center for Complex Network Science* in 2015; we finally published the paper in 2018.[17] Throughout the process, I captured hundreds of screenshots of data visualizations. Oftentimes, these stages are additions and adjustments to something I have already designed; other times, I am rethinking the entire layout, starting a novel perspective. The graphics are all based on the same data, a collection of my explorations within the possibility space from data to graphic.

17 Ref.: Kosack, S. et al., 2018. Functional structures of US state governments. National Academy of Sciences, 115(46), pp.11748–11753.



Screenshot collection of the Government Structure project

I could not have initially foreseen that these often raw and unfinished collections of graphics would lead me to the theory and application of what I have now articulated throughout this dissertation. Navigating from one screenshot to another, I realized that every small change from adding circles to a page to changing the opacity values and adding stroke weights was a change in the graphic outcome and, at the same time, an additional statement on the layer of the code funneling the graphic. Each step on both the code layer and the graphic layer were rendered visible to me as *distinctions I am drawing* in the code layer to re-design the graphic layer. These *distinctions* are decisions for something and against all other possible paths. Drawing the distinction of circles for each data point is simultaneously an operation against rectangles, triangles, or lines. Design is only possible if there are alternatives within the medium that are neglected through the operation. *Design is a game of finding novel combinatorial paths* *through a nested set of pre-defined spaces. The design process renders visible one possible set of distinctions of the medium. Design is an answer to the question of mediation, which is not asked but already answered.*

This basic observation, finding the terminology of the *distinction*, drew my research away from visualization design research and opened up a rich set of research disciplines and theoretical conceptions. Not only the already named fields of *epistemology*, *diagrammatics*, *science and technology studies*, *design theory*, *visual epistemology*, and *history of science* became relevant to my investigation, but furthermore the philosophical discussions of *media studies*,[18] *systems theory*, [19] and

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[18] Ref.: Distelmeyer, J., 2017. Machtzeichen, Bertz + Fischer.

Distelmeyer, J., 2021. Kritik der Digitalität, Wiesbaden: Springer VS.

Heider, F., 2005. Ding und Medium, Kulturverlag Kadmos. Available at: https://www.kulturverlag-kadmos.de/buch/ding-und-medium.html.

Luhmann, N., 2009. Die Realität der Massenmedien, Springer-Verlag.

Münker, S. & Roesler, A., 2008. Was ist ein Medium? Suhrkamp.

Plumpe, M., 2014. Systemtheoretische und konstruktivistische Medientheorien. In J. Schröter, ed. Handbuch Medienwissenschaft. pp. 123–130.

[19] Ref.: Baecker, D., 2018. 4.0, Leipzig: Merve.

Baecker, D., 2013. Beobachter unter sich, Frankfurt am Main: Suhrkamp.

Baecker, D., 2015. Designvertrauen. Merkur, pp.89–97.

Baecker, D., 2019. Intelligenz, künstlich und komplex, Lwipzig: Merve.

Baecker, D., 1993a. Kalkül der Form, Frankfurt am Main: Suhrkamp.

Baecker, D., 2014. Kulturkalkül, Berlin: Merve.

Baecker, D., 1993b. Probleme der Form, Frankfurt am Main: Suhrkamp.

Krämer, S., 1998. Form als Vollzug oder: Was gewinnen wir mit Niklas Luhmanns Unterscheidung von Medium und Form? userpage.fu-berlin.de. Available at: http://userpage.fu-berlin.de/

Luhmann, N., 2011a. Das Medium der Kunst. In Niklas Luhmann Aufsätze und Reden. Reclam.

Luhmann, N., 1998. Die Gesellschaft der Gesellschaft, Suhrkamp.

Luhmann, N., 2011b. Erkenntnis als Konstruktion. In O. Jahraus, ed. Niklas Luhmann Aufsätze und Reden. p. 334.

the movements of *post-structuralism* [20] and *constructivism*.[21] Questions of mediality and design are connected by a commonality that is essential for this dissertation and has been described by Claudia Mareis and Christof Windgätter as an *interface of media studies and design theory*: understanding the production process of knowledge within mediated constituencies.[22]

The *distinction* is a fundamental philosophical concept and a basic component of thinking about thinking in iconographic terms. The contributions and theories on the distinction are vast from Aristotle, Hume, Kant, and Bateson to the 20th-century thinkers like Saussure, Barthes, Althusser, Lévi-Strauss, Foucault, Lacan, Derrida, Deleuze, and many others.

Rather than investigating this vast territory of thoughts and relating it to visualization design, I became captivated by one specific theory: the *Laws of Form* by George Spencer-Brown.[23] The theory and book with the same title first

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Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57.

20 Ref.: Belsey, C., 2013. Poststrukturalismus, Stuttgart: Reclam Sachbuch.

21 Ref.: Foerster, Von, H. & Glasersfeld, von, E., 2007. Wie wir uns erfinden 5 ed., Carl-Auer.

Simon, F.B., 2017. Einführung in die Systemtheorie und Konstruktivismus, Heidelberg: Carl-Auer Verlag.

22 Ref.: Schröter, J., 2014. Handbuch Medienwissenschaft, Springer-Verlag.

23 Ref.: Baecker, D., 2013. Beobachter unter sich, Frankfurt am Main: Suhrkamp.

Baecker, D., 2007. Form und Formen der Kommunikation, Frankfurt am Main: Suhrkamp.

Baecker, D., 1993a. Kalkül der Form, Frankfurt am Main: Suhrkamp.

Baecker, D., 2014. Kulturkalkül, Berlin: Merve.

Baecker, D., 1993b. Probleme der Form, Frankfurt am Main: Suhrkamp.

Baecker, D., 2015. Working the Form: George Spencer-Brown and the Mark of Distinction. Mousse Magazine, pp.42–47.

Krämer, S., 2009. Operative Bildlichkeit. In Logik des Bildlichen. Von der ‚Grammatologie' zu einer ‚Diagrammatologie'? Reflexionen über erkennendes ‚Sehen'. pp. 94–122.

Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag.

Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57.

Plumpe, M., 2014. Systemtheoretische und konstruktivistische Medientheorien. In J.

published in 1969 are different from most other conceptions. They frequently contain corresponding conclusions, yet not ones drawn primarily from philosophy, literature, or humanist perspectives but rather built on the foundation of mathematics. What intrigued me about this concept is that mathematics and philosophy are not separated but deeply intertwined. Philosophy, as a humanistic perspective of the world, and mathematically based sciences are the same, only observed from different perspectives with different motivations and arguments in different directions. The conceptions of the natural sciences are founded on specific constructions that I am investigating through philosophical movements. Along this line of thought, logic is only one possible path of mathematics,[24] and the constituencies of calculation are founded on the observer's perspectives and motives. The command *draw a distinction*[25] contains two directions to investigate. Following the command leads to nested interdependencies, called and crossed stacks of relations, the mathematical, logical, and computational perspectives. Simultaneously questioning the command's pre-definition opens up several conceptions beyond logical, mathematical, and scientific operations, motives, and attitudes, and operational spaces then draw into focus. The *distinction,* and with it the creation of *form* through a *medium,* has captivated me over the last five years. Through the *distinction,* I am drawing into question the smallest unit of mathematics, computer science, and design and, by doing so, opening an interface between diverging disciplines.[26]

The foremost reason why a mathematical theory became so relevant in deriving my approach is the state of design at the beginning of the 21st century. Contemporary design is tied to computation; almost any book layout, advertising campaign, chair, or building is designed on graphical user interfaces of specific programs. Further, interface design and visualization design do not only rely on software programs but are often designed, as in my case too, by writing computer code. The *algorithmic design series* is about the mathematicalization of design and,

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Schröter, ed. Handbuch Medienwissenschaft. pp. 123–130.

Schönwälder, T., Wille, K. & Hölscher, T., 2013. George Spencer Brown, Springer-Verlag.

Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin.

24 This thread is followed in chapter *Time*

25 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin.

26 Ref.: Snow, C.P. & Collini, S., 2012. The Two Cultures, Cambridge University Press.

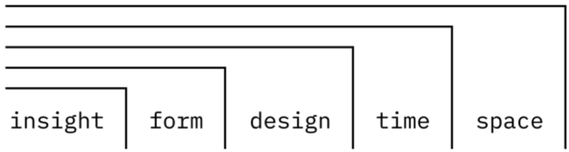
thus, a mathematical interpretation of the world.[27] The design operation I am investigating is based on a very special form of mediality – computation – and, by that, is founded on mathematics. The question then becomes, what is mathematics in the first place? Throughout this dissertation, I am following and elaborating one possible path to draw together mathematics, computation, and design. What follows is a reflection and questioning of computational realities and their boundaries. What are the constraints of investigating the world through computation? The *calculus of design* is my attempt to define and question the limits of computational mediation.

The theory, approach, and diagrammatic consequence I have developed based on the principle of design as the *drawing of distinctions* led me to identify five foundational nested distinctions in which design as an operation is embedded.[28] *Insight* from the approach is not something given in the world that could be mined, discovered, gained, explored or revealed. The designed *insights* of data visualizations are conditioned on a vast set of hidden complexities, a nested set of pre-assumptions, oftentimes neglected but always present in the making. I have identified four prominent layers, namely *form*, *design*, *time*, and *space* to elaborate on the structure in which *insights* are embedded.

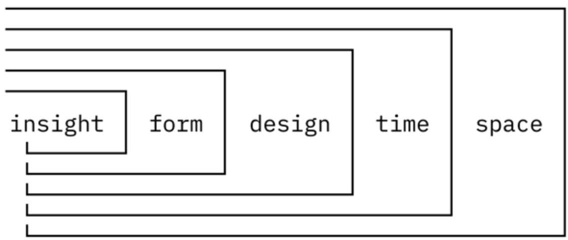
My dissertation's argumentation is mediated through text, but to the same extent through a *diagrammatic form of reasoning*. Each medium restricts the possibilities for expression. Thus, I am not only reasoning through textual mediations but, to an equal extent, through diagrammatic and visual mediations. *The diagrammatic consequence of the calculus of design is a meta-diagram that graphs the design operation and is a central contribution I am proposing to coalesce theory and practice.* The following *form* is the foundational diagram I am developing through the *calculus of design*. Each *cross* is nested within the next, from *insight*, to *form*, *design*, *time*, and *space*.

[27] I introduce the term *algorithmic series* in chapter *Form* to indicate this circumstance.

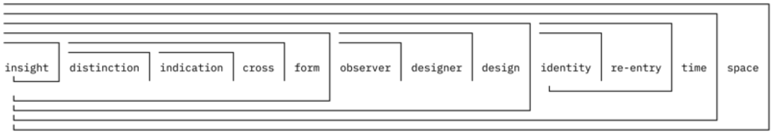
[28] I discuss and examplify each nested layer in its own chapter throughout the dissertation in a slightly different order than theire apperance within the graphic.



The *cross* each term is contained within between the vertical and horizontal lines separates the *space* into *marked* and *unmarked*. *A designer draws a distinction by marking and neglecting the unmarked. The unmarked is continuous; what is left out is always in question.* The *cross* is always open, consisting of two lines, leaving the space open for something else. Furthermore, each layer depends on and interacts with all others, always in negotiation, shifting, and changeable. To include the interdependent relation of flux between the terms, I am extending the diagrammatic representation with the two additional lines of the *re-entry*. Each distinction loops into all others, creating an iterative structure of interdependencies. The *re-entry* into the *cross* renders closer to a rectangle, but not entirely, as the otherness is constantly present.

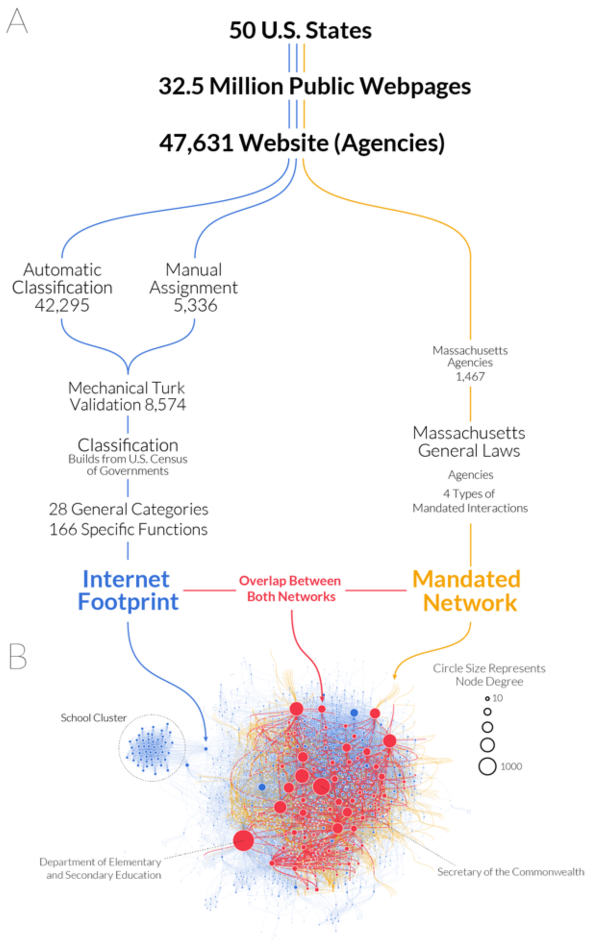


Each of the articulated layers holds further distinctions within it. A difference is always a *collapsed complexity* which dissolves into additional distinctions upon inspection. Nonetheless, throughout the dissertation, I am naming a set of disparities significant for investigating design and insight.



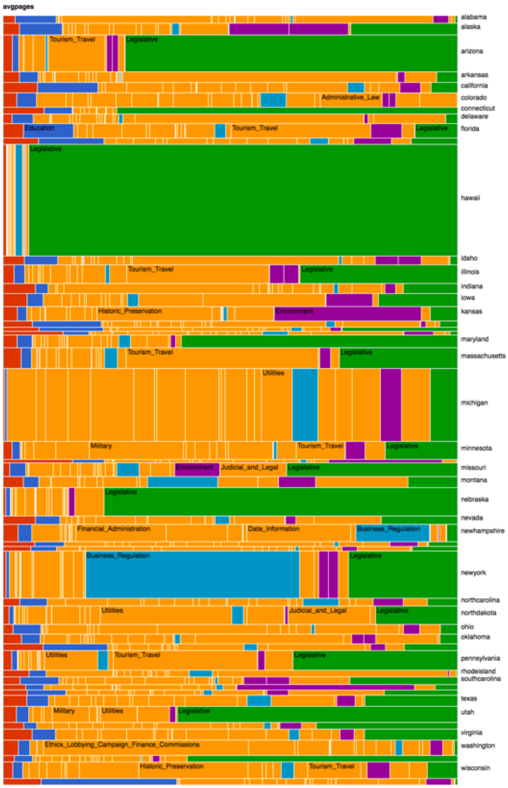
The diagrammatical representations I have briefly introduced above are not only theoretical but become meta-representations of the design process itself. To understand what insights concern design, I postulate that one has to map out the process leading towards the insight. *In all its complexity and nestedness, the designed structure defines what renders in—sight, what becomes mediated and visible. Insights are not given in the world, but nested within the designed systems, rendering them visible.*

For the *Government Network* project, I designed a set of vastly diverging representations from the same dataset. The underlying dataset consists of 32.5 million public U.S. government webpages from 47,631 website domains. Through an elaborate process, my colleagues clustered all the websites into 28 general categories and 166 specific functions. The following figure visually represents the process my collaborators undertook to construct and evaluate the data.



Data construction visualization

The complexity of the dataset allows for vastly different representations. Each mapping I made highlights a specific perspective and, by doing so, neglects all other possible operations. For example, I represented the average number of web pages as rectangles arranged by the state on the vertical axis and the 166 specific functions on the horizontal axis. The representation in visualization design is known as a Marimekko chart:



Marimekko chart

Through this visualization, differences between website state structures are rendered visible. The design process is an interplay of *crossing* into the *form*, through rectangles on the computer screen. Only by iterating the rectangles over time onto the two-dimensional screen does the visualization emerge.[29] Visualizing something is dependent on *differences* and *identity*. In this case, these are differences in position and color and the similarity of the rectangle's repeated symbol. The rectangle's recursion leads to insights into the data through a pattern of simplification from the world to data and visualization. Within the

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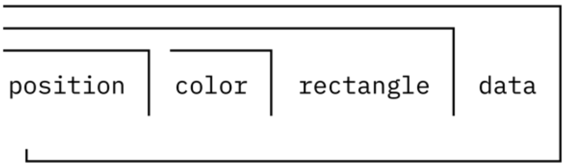
29 Chapter *Time* elaborates on this conception.

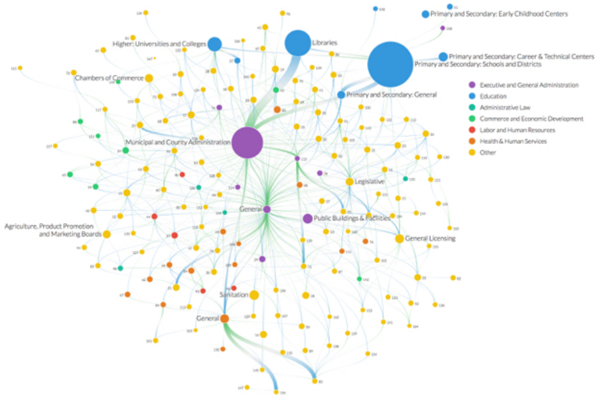
diagrammatic representation of the *calculus of design,* I can map the above Marimekko chart as:



Each distinction contains further distinctions. Color, in this case, maps onto the four most repeated categories plus one color for all other categories. As the chart designer, I have decided on this representation and against others, for example representing all 28 general categories as individual colors. Design only exists as each rectangle, each cross, could also be different. The *space* in which I design pre-defines the possible distinctions I can make. For the project, I designed all charts with the programming language JavaScript, embedded within HTML, the Hypertext Markup Language. These spaces layered above the form are nested within other constraints, such as further software dependencies, web browsers, operating systems, and the hardware dependencies of a CPU, GPU, screen, and keypad. Each cross is always nested within a space. Observing the space changes the possibilities and the perspective.

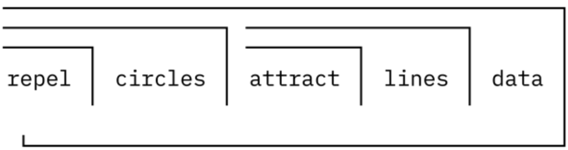
The blank space is not empty at all; it holds all kinds of pre-assumptions. Thus, it is essential to reflect on the drawn distinctions and the space a form operates within. *Space* in the *calculus of design* is a distinction, the distinction a priori, the designer's first drawn cross. Only because there is *contingency*, not necessity and not impossibility, design is practicable. *Design depends on the possibility that something can be different.*

Through the design space of JavaScript, I rendered the visualization as a scalable vector graphics short SVG. The *space* of the SVG markup language pre-defines what I am able to design. SVG contains six graphic primitives: circle, rectangle, line, ellipse, path, and text. These primitives pre-define the *possibility space* of design within the system. One of the first data visualizations I designed for the *Government Structure* project was a so-called *force diagram*. Each specific function of the government repels all the others, visualized as circles on the page. If a line connects two circles, they attract one another.

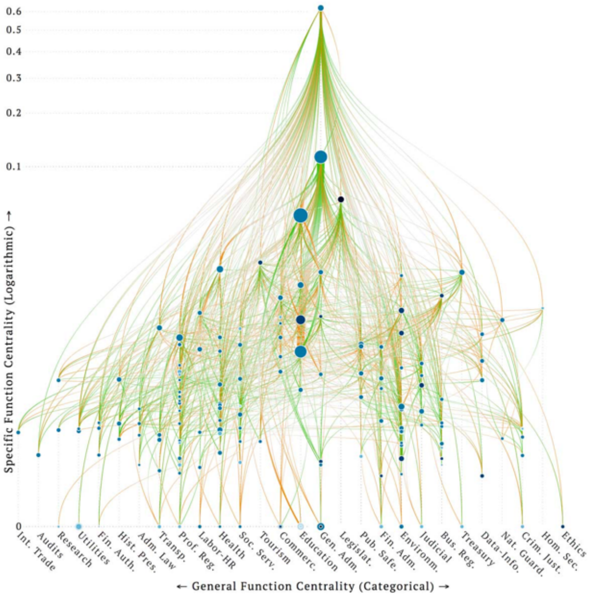


Force Diagram

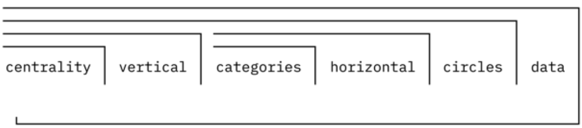
The distinctions drawn in the design process are twofold, following the principles of repelling and attracting.



Throughout the project, I drew many iterations and alternative representations of the network. The following graphic is based on the same dataset, but this time it is not a force that holds the nodes together, but two data dimensions. On the horizontal axis, the specific functions are clustered by the 28 general categories as circles. On the vertical axis, I calculated a network centrality for each specific function compared to all the others.



Centrality Network Visualization



The question becomes: What distinctions are drawn throughout the design operation? The same data can be iterated differently throughout the process, thus arriving at a different form. Each chart highlights specific aspects of the data while moving all other possible representations into the *unmarked*. When I showed the second network representation to my colleagues, they asked me whether the graph was normally distributed. I did not know the answer to this, but generated various datasets of network models within the same graphic system. Both the Erdos Renyi graph and the Barabási–Albert model[30] appeared very different, less hierarchical, than the government websites' data.

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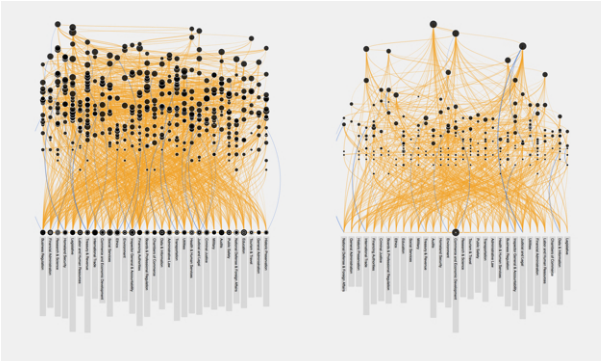
30 Ref.: Barabási, A.-L., 2012. Graph theory and basic terminology Learning the language.



Left, the Erdos Renyi model; right, the Barabási–Albert model

This insight changed the direction of the research. My colleagues calculated that almost the entire network was structured hierarchically, as written in the paper: *The 50 networks also reflect a second characteristic of modern government bureaucracies: hierarchical principal–agent relations*.[31] The project was renamed from *Government Networks* to *Government Structure* and a large part of the paper was re-written. The designed change in visual representation led the research in a new direction. The questions raised about the data changed through a visual representation; the visualization called the network's metaphor into question.

Design is the operation of drawing distinctions within a pre-defined mediation of possibilities. It is a choice for something, the mark, and against every other possible distinction, the *unmarked*. All other possibilities are neglected by choosing one color, shape, style, algorithm, or interface element. Insights depend on the operatively designed structure, the possibility space for something and against something else. To explore what renders *in–sight*, I propose the *diagrammatic form of reasoning* of the *calculus of design*. *The calculus of design does not*

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barabasilab.neu.edu. Available at: http://barabasilab.neu.edu/courses/phys5116/content/Class2_NetSci_2012/02_Class_2012_Graphs.pdf Accessed April 19, 2014.

Barabási, A.-L., 2005. The origin of bursts and heavy tails in human dynamics. arXiv.org, cond-mat.stat-mech(7), pp.207–211.

Barabási, A.-L. & Yan, G., 2015. Spectrum of Controlling and Observing Complex Networks. pp.1–18.

31 Ref.: Kosack, S. et al., 2018. Functional structures of US state governments. National Academy of Sciences, 115(46), pp.11748–11753.

claim that there is no outside, no world, beyond the distinction. This is not a theory embedded in epistemic skepticism; I do not question the possibility of knowledge. Insights are far from random; there is something past the form, but to encounter this something, the cultural setting of data, visualization, interfaces, computation, and language all operate on the act of drawing and re-entering distinctions. The vast infrastructures of nested differences are drawn distinctions of how someone or something encounters reality. *Insight only exists as a set of conceptions within the realm of computation, data, and visualization as designed distinctions. Design as de–sign is the act of choosing something as opposed to everything else. Epistemic insights emerge from a chain of operations, not a given but an interrelational structure. Design is the operation of drawing form; the reflection of form creates insight. This operational loop is a gradual re-designing of the understanding of the world we are embedded in.*

Re-imaginations of design as de—sign

In the summer of 2017, I changed my research affiliation and started a new position at the metaLAB (at) Harvard under Jeffrey Schnapp's direction; since 2020, I am a principal of the group.[32] The metaLAB is far from a physics lab and is even hard to define within one clear category; it is in the broadest sense an experimental laboratory at an interface with data from humanistic perspectives. This new academic and conceptual space allowed me to create projects that re-imagine what it means to design through the *calculus of design* approach. Rather than a purely textual examination of this epistemological design theory, I put these ideas into practice. The conceptualizations of my dissertation turned into visualization projects of various kinds. I will not go into detail about any of these projects but only highlight my change of perspective, which I have adapted from the *calculus of design* to put into perspective some possible paths visualization design can be re-imagined as.

The crosses of the *calculus of design* are meant as a method to render visible the design choices given from a specific perspective. Equally important, the calculus

32 https://metalabharvard.github.io/

can draw out the nested structure layered above the form, drawing in to view the *spaces* within which a design distinction is embedded. A large portion of my research at metaLAB focused on visualizing the otherwise pre-assumed visualization design spaces. I will briefly introduce the various projects from the last four years that I have developed in tandem to question the given crosses of data and computation on multiple scales. These often playful, sometimes philosophical modes of reflexive computation all question the constituencies of the form. All projects follow the notion of *computational deconstruction* by mapping the *space* above the *form* to re-imagine and re-iterate its embeddedness. It is a counter-mode to data as given. Data and computation are then called into question, iterating layers above the given distinctions usually considered. This kind of approach contains some self-circularity in the reflection of data, computation, and visualization. It is reflected through data, computation, and visualization, questioning given crosses of 21st-century infrastructure. The *space* of the *form* is not the given but the field of the form itself.

The first project of this kind was *Artificial Senses*, a visual interpretation of live sensor data in everyday devices, laptops, smartphones, and how these systems render the surroundings visible through their electric sensorial apparatus. In visualization design, data is mostly taken for granted.[33] *Artificial Senses* questions space by simultaneously recording and representing data.[34]

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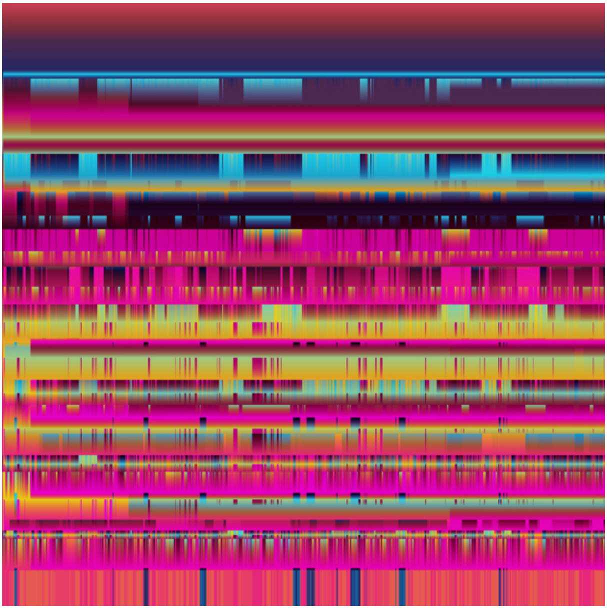
33 On the visualization design processes, I explored in chapter *Chain* how of the 27 processes, ten start with data or the acquisition of data. In visualization design, that is often taken literally as the *given*.

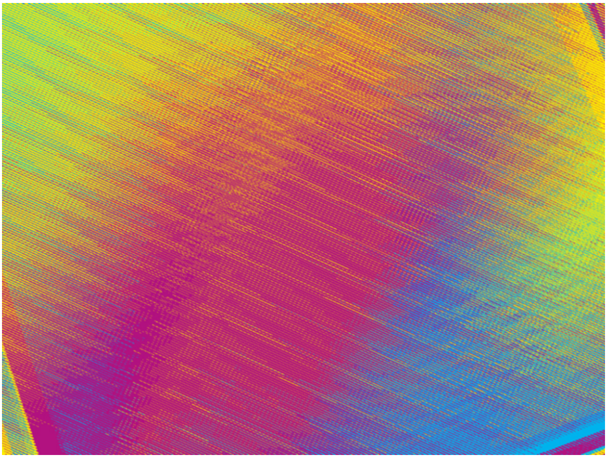
34 Ref.: Albrecht, K., 2017. Artificial Senses. Available at: https://artificial-senses.kimalbrecht.com/ Accessed February 19, 2020.



Artificial Senses

The *Distinction Machine* is directly applied from the *calculus of design* approach. I reflected the command *draw a distinction* back into the computer. The project is based on a simple problem within 3D rendering: If two surfaces with different colors are rendered at the same position, which color is displayed and which is hidden? By drawing multiple forms at the same position, the computer itself needs to draw a distinction for the one and against the other; in computer science, this is known as z-fighting. I aesthetically explored this phenomenon to render and question the pre-assumptions that computation draws onto the world. I designed an operation in which the command to *draw a distinction* is reflected on the system from which it originates.[35]

35 Ref.: Albrecht, K., 2019. Distinction Machine. Available at: http://distinctionmachine.kimalbrecht.com/ Accessed February 19, 2020.



Distinction Machine

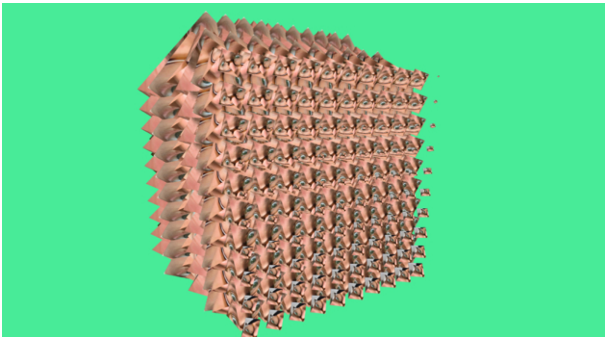
In *Watching Machines,* I rendered visible the unmarked side of an image within the process of facial recognition. What is not considered when an algorithm detects faces? The project reflects on the negativity of the media, the unmarked algorithmic operations. From the perspective of the *calculus of design,* I questioned and represented the unmarked side of facial recognition algorithms.[36]

[36] Ref.: Albrecht, K., 2020. Watching Machines. kimalbrecht.com. Available at: https://watching-machines.kimalbrecht.com/ Accessed April 12, 2021.

Watching Machines

At the beginning of 2020, the question of computation and its effects on how reality becomes visible reached a stage previously unimaginable just a couple of months prior. The circumstances of the COVID-19 pandemic turned video conferencing into the normative mode of human interaction, from work meetings, friendships, education, and love relationships to family gatherings. *Hypercam* is a mode of visual resistance against the squared-off talking heads that we have all become; it converts the interface flatland into a multidimensional space of play. From the perspective of the *calculus of design*, again, I am not representing data in the first place but questioning the constituencies given by computational constraints.[37]

[37] Ref.: Albrecht, K., 2020. Hypercam. kimalbrecht.com. Available at: https://hypercam.kimalbrecht.com/ Accessed April 12, 2021.



Hypercam

Over the last two years, I started another approach, much less self-circular but similarly questioning the relationship between data and visualization. Both data and visualization are founded on the act of drawing distinctions: Something is more important than something else. Social media captures this very prominently in likes, followers, and re-tweets. Data is constructed on the premise that something is more important than something else. But, what if this conception is wrong in the first place in specific instances? What I am currently intrigued about in my research questions the core of mathematics: What if numbers in particular social settings do not matter in the form of addition and multiplication? What is the *unmarked*, what becomes invisible when rendering the world as quantifications? Is there a mode of visualizing that works by neglecting drawn distinctions?

In 2020 after the death of George Floyd, Matthew Battles and I worked on a website visualizing 28,000 fatal encounters with police in the USA. Various visualizations of databases collected these often gloomy and horrible fatalities. The design operation I introduced was one of removing distinctions rather than adding them within visualization design; rather than displaying fatalities on a map, in bar charts or other visual forms, the page consists of 28,000 names rendered as text in equal size. Not counting, but removing possible drawable distinctions became the motivation behind the design.[38]

While writing this introduction, I am currently working on a new project presently identified as *Situating #MeToo*. It is a collaboration with Catherine

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[38] Ref.: Albrecht, K. & Battles, M., 2020. Their Names. Their Names. Available at: https://theirnames.org/ Accessed April 12, 2021.

D'Ignazio, Nicole Martin, and Matthew Battles. The design motive currently emerging is to explore the *anti-network* of the #MeToo movement on the social media platform Twitter. The concept is that the metrics given by Twitter poorly define the structure of the movement. #MeToo is not about the most liked, the most commented, or the most re-tweeted. The uncommented, often neglected masses of survivors are not represented in the metrics of social media. The project renders visible the marginalized, the invisible, the *anti-network* of what the metrics highlight. The examples are only the first beginnings of a novel approach towards design as *de—sign*.

The *calculus of design* is not only a conceptualization, a theory, an approach, or a diagrammatic method of visualization, but deals with design in a much broader sense. Any drawn distinction within a mediated space is an act of *de—sign*. Here, I am exemplifying the approach to visualization design, as the relation to *insight* is so prominently expressed. Throughout the dissertation, these other design areas are regularly instantiated.

The *de—sign* offers one mode of investigating the presumptions and the design operation. It is an approach to question and reflect on the mediations that design utilizes to create form. While such a reflexive take on design is by no means necessary, it provides a moment to question the status quo, to reflect on what is rendered visible and, by doing so, what is neglected. The *calculus of design* is a constant reminder that perspectives can always be different.

Following these personal remarks, I have structured the dissertation into two parts: the *Conceptions of Design for Insight* and the *Calculus of Design*. In the first part, I research the state of visualization design theories and practices. The question of why humans visualize data leads to four metaphors that I have clustered and investigated: the *raster*, *arrow*, *chain*, and *pyramid*. The second part introduces the *distinction* as the smallest unit of design within chapter on *form*. From the *form*, I name and investigate three conceptions resulting from the distinction as a design unit. Each of these three concepts is discussed in its chapter, namely *Design*, *Space*, and *Time*. The final chapter, *Insight*, is nested within all the others and results from the other chapters' argumentation. With these introductory notes on my personal development through the *calculus of design*, its limitations, and additions, I very much hope this perspective will draw a difference that makes a difference.

Part I: Conceptions of Design for Insight

Prologue

> *"Knowledge plays a vital role in our life in that it reflects how we understand the world around us and thus determines how we act upon it. In this sense, knowledge is of particular importance for designers because they act to shape our world."*
>
> — *Kristina Niedderer* [1]

When I look around, it is hard to find an object that has not been designed: from the computer I am sitting in front of to the software I am writing this text with and the keyboard I am typing on. Also, the table and the chair and all other objects around me are planned and intentionally created. Even the trees outside my window are carefully placed to follow the guidelines of the city. Everything is seemingly designed, from nail design to spacecraft design.[2]

Throughout this introduction, I will argue that within this planned, structured, and systemized environment, visualization design carries a specific condition. Chairs are designed for humans to sit on; pens are designed for writing; lamps are designed to illuminate spaces; magazines are laid out to communicate the interplay between image and text. Most objects, concepts, areas are designed for a specific human need.

Data visualization is the representation of data or information using the fundamental graphical elements of points, lines, and areas on a two-dimensional plane. Textual elements often add another layer in these representations. Researchers have found cartographic cave paintings that date back more than 40,000 years,[3] and the technique of visualizing statistical datasets flourished in

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1 Ref.: Niedderer, K., 2007. Mapping the meaning of knowledge in design research.

2 Ref.: Colomina, B. & Wigley, M., 2016. Are We Human?

Latour, B., 2008. A Cautious Prometheus?

3 Ref.: Utrilla, P. et al., 2009. A palaeolithic map from 13,660 calBP: engraved stone blocks from the Late Magdalenian in Abauntz Cave (Navarra, Spain). Journal of human evolution, 57, pp.99–111.

the 17th century with the rise of statistical population registration.[4] Visualizing information has a long history.

Over the last decades, the rise of computation, databases, internet networks, and graphical user interfaces turned a craft from hand-drawn graphs into computer-generated graphics. The process of creating these graphics had always been generative,[5] based on a system of rigorous executable rules. The time for the performance changed from days and months of work with pen and paper to an error-free execution within split seconds on a computer. The annihilation of human labor and time between systemization and execution turned visualizing data from a niche academic activity to a worldwide phenomenon in business, journalism, and academia. Additionally, this split-second execution allowed for changing variables in the graphic Representation,[6] switching datasets, filters, and forms of representation on the computer screen with almost no delay in execution. The rise of computer systems and the internet led to a rise of graphic information representations as the creation and variability became computerized and their spread mediated globally through the internet.

So, if design has clear objectives toward fulfilling human needs, why do humans design visualizations? What is the purpose of these graphic data representations? Why does someone visualize data? One of the most cited writings[7] in academic visualization research makes a clear statement about the reason for these graphic representations:

> *"The purpose of visualization is insight, not pictures."*
>
> — Card, S.K., Mackinlay, J.D. & Shneiderman, B. [8]

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4 Ref.: Rendgen, S., 2019. The History of Information Graphics, Taschen.

5 Ref.: Dragicevic, P., 2012. 1968 – Jacques Bertin's Reorderable Matrices. dataphys.org. Available at: http://dataphys.org/list/bertins-reorderable-matrices/ Accessed January 10, 2020.

6 Usually, this change in variables is called 'Interactivity.' I am avoiding this word here, as interaction implies so much more than the ability to change data dimensions or system variables.

7 20 years after the publication of "Readings in Information Visualization," the text has over 6000 citations on the academic search engine google scholar by November 2019.

https://scholar.google.de/citations?user=ccCNF08AAAAJ&hl=en

8 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann, p. 6

From this perspective, the motive to design visualizations is insight. Visualization connects the discipline of design with one of humankind's most significant philosophical and scientific endeavors: the quest for insight, knowledge, and truth. Design is no longer about providing a place to sit, a light to shine, or a newspaper to read. Design becomes entangled in creating the highest human good, the desire to understand our embedding in this world.

Throughout the following pages, I have collected, sorted, and categorized statements from visualization participants concerning the goals and reasons for visualizing data around the topics of insight, knowledge, and truth. Data visualization is an interdisciplinary metascience beyond one specific discipline. For that reason, this collection spans the spectrum from neuroscience to computer science, geography, design, journalism, industry cooperation, and state defense. The questions I investigate are the following:

- How do visualizations relate to insight and knowledge?
- What is the role of design from data to insight?
- What kind of processes are occurring here, and how are they expressed?
- What are the terms describing the visualization design process from data to insight?

Figure 1 gives an overview of the collected quotes, the three themes of insight, knowledge, and truth, the authors of the quotes, and the verbs used to describe the connection between visualization design and the themes. The next section will cluster and analyze these statements.

This proposal investigates the entanglements of data, design, and insight. How do the given (data), the created (design), and the realities of our own existence relate to one another?

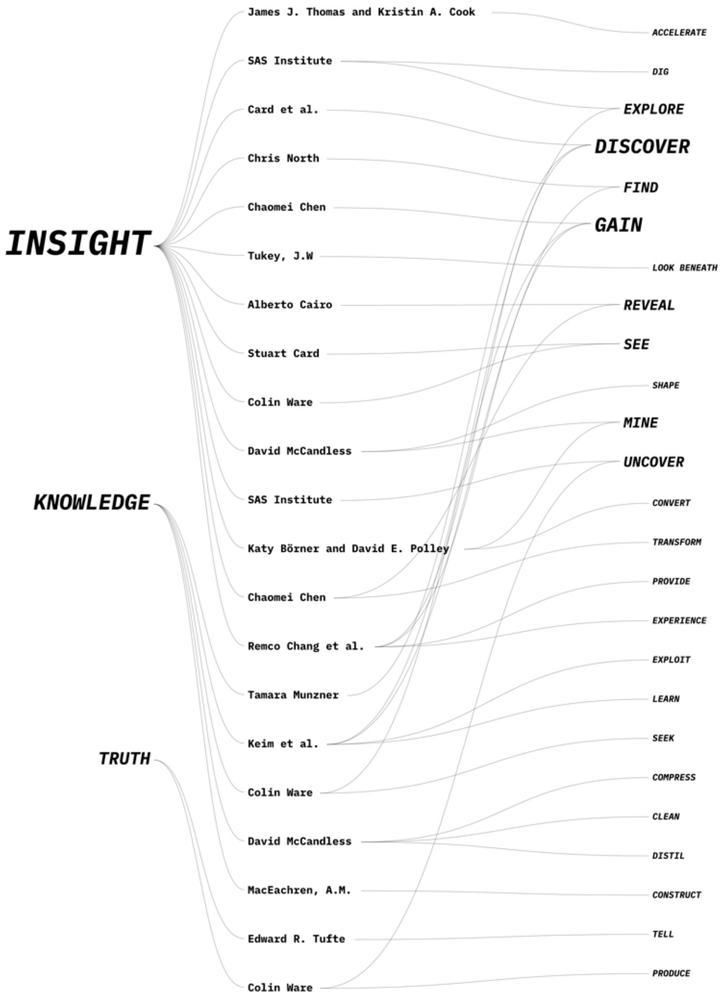

Figure 1: Collected Quotes

From Pattern to Insight

If data visualization is the design discipline connecting humanity to insights, how is it doing so? This section looks at the metaphors, analogies, and verbs describing the relationship of visualization with the three objectives: insight, knowledge, and truth. This literature review covers 25 books, research papers, blog posts, and talks from industry, research, and design. Statements are clustered and arranged by the verbs used to describe the relationship between visualization and the three objectives. Verbs are arranged from the lowest to highest interventions. For example, I am proposing that seeing is less interventional than uncovering; uncovering is then less interventional than digging. In the preface to Colin Ware's book Information Visualization from 2004, Stuart Card writes:

> *"I see what you mean. This common expression illustrates the deeply-held intuition that vision and artful images are an alternate and seemingly direct route to insight, which is itself another of the many words or phrases relating to vision and understanding."*
>
> *— Stuart Card* [9]

This first quote opens the question of design. What does Card mean by a direct route from vision to understanding? How does design fit into the direct route? Later in the same book, Colin Ware himself also connects seeing to insights:

> *"In data exploration, seeing a pattern can often lead to a key insight, and this is the most compelling reason for visualization."*
>
> *— Colin Ware* [10]

Of all our senses, seeing holds an exceptional position from the perspective of visualization research. Data visualization is not about touching data,[11] hearing data,[12] tasting data[13] or smelling data.[14] It is about vision, seeing a pattern.[15]

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9 Ref.: Ware, C., 2013. Information Visualization, Elsevier.

10 Ref.: Ware, C., 2013. Information Visualization, Elsevier.

11 Neuroscientist David Eagleman is creating interfaces such as his sensory vests to connect our skin to data. https://www.ted.com/talks/david_eagleman_can_we_create_new_senses_for_humans?referrer=playlist-rethinking_how_we_use_the_sens.

12 Data sonification is its own field of research.

From the perspective of perception studies, the reason for focusing on sight in comparison to all other senses is clear. Ware argues that about 20 billion neurons in the brain are devoted to analyzing visual information.[16] Our visual pattern finding is such a strong cognitive activity within the brain that it utilizes more neurons than all other senses together. Yet, both quotes perform something beyond the explanation of vision. Seeing is connected to insight in the quote by Stuart Card, and Colin Ware connects patterns to insight. Their writing is devoted to explaining the connection between our visual cortex and pattern recognition (Chapter 3), but there is no further explanation on how the creation of patterns, their design, influences insights. Throughout the book, the term 'insight' is used eight times in over 500 pages, each time without any definition of what is meant by insight or how it becomes apparent from recognizing patterns. This is a common thread throughout this literature review. The terms 'insight,' 'knowledge,' and 'truth' are used without any further explanation of what they mean and how they come about.

In the book Illuminating the Path: The Research and Development Agenda for Visual Analytics published by the IEEE Computer Society in 2005, the authors write:

> *"The use of visual representations and interactions to accelerate rapid insight into complex data is what distinguishes visual analytics software from other types of analytical tools."*
>
> — *Illuminating the Path: The Research and Development Agenda for Visual Analytics* [17]

The authors very openly state their motivations in the book. The insights they seek are into Homeland Security based on the terrorist attacks of September 11, 2001. No other paper or book states so clearly the political dimensions of

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13 Data Cuisine is a project by Susanne Jaschko and Moritz Stefaner which explores food as a medium for information. http://data-cuisine.net/

14 For example, Smell Maps by Kate McLean 67

15 Colin Ware is the Director of the Data Visualization Research Lab at the University of New Hampshire with a background in computer science and a Ph.D. in psychology of perception 107.

16 Ref.: Ware, C., 2013. Information Visualization, Elsevier.

17 Ref.: Cook, K.A. & Thomas, J.J., 2005. Illuminating the Path: The Research and Development Agenda for Visual Analytics, IEEE Computer Society, Los Alamitos, CA, United States(US).

insights. The agenda of the book is to analyze terrorist threats, safeguard borders, and prepare for emergencies. Visual analytics has a political dimension. In this context, the quote clearly states that the reason for visualizing data is to accelerate rapid insight. Visualization is narrated as a tool for efficiency, speed, and acceleration, an information weapon to know more, faster. The design process, from data to insight, receives no comment at all.

Computer scientist Chris North inquires in “Toward measuring visualization insight” 2006 as to the purpose of visualization and identifies insight as the reason. North’s definition of insight is a list of characteristics in “the spirit of gaining understanding”: complex, deep, qualitative, unexpected, and relevant. For instance, North writes on the topic of complexity:

> *“For example, complexity is determined by how much data is involved in the insight. Simple insights, such as finding minimum or maximum values, involve simple answers that require only one data value.”*
>
> — *Chris North* [18]

I am using North’s request for new evaluation methods for measuring insight as an opportunity to distinguish between his and my personal questions regarding visualization and insight. This thesis will not measure insight but theorize the process towards it. What are the necessary steps to gaining or finding insights? What is data visualization a priori, what pre-defines any representation of data? What is the role of design in this process? And how do these pre-definitions determine the possible insights?

The research group around Daniel Keim, who specializes in visual analytics and data mining, makes a similar statement in the paper “Knowledge Generation Model for Visual Analytics”:

> *“During the visual analytics process analysts try to find evidence for existing assumptions or learn new knowledge about the problem domain. In general, knowledge learned in visual analytics can be defined as ‘justified belief.’”*
>
> — *Sacha, D. et al.* [19]

In the quote, new knowledge is found evidence. The paper is the only reference within the corpus that makes an attempt to connect visualization design to an

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18 Ref.: North, C., 2006. Toward measuring visualization insight. ieeexplore.ieee.org.

19 Ref.: Sacha, D. et al., 2014. Knowledge Generation Model for Visual Analytics. Visualization and Computer Graphics, IEEE Transactions on, 20(12), pp.1604–1613.

epistemological theory. Knowledge as justified true belief is a tripartite analysis consisting of truth, belief, and justification. The sufficiency for this theory is very much in question since Edmund Gettier's paper "Is Justified True Belief Knowledge?" from 1963.[20] In Chapter 4, visualization and justified true belief will be discussed further.

While the terminology of seeing and finding assume that insights and knowledge are waiting to be encountered, gaining insights supposes a different condition. 'Gain' originates from the Middle French gagner, 'obtain as profit'.[21] While in the late 1520s the verb was used in agriculture, in the 2010s work, business, and profit are gained from data. Information Scientist Chaomei Chen, who wrote books like *Mapping Scientific Frontiers: The Quest for Knowledge Visualization.*[22] or *Representing Scientific Knowledge: The Role of Uncertainty*,[23] writes in a 2010 article:

> *"The holy grail of information visualization is for users to gain insights."*
>
> *— Chaomei Chen* [24]

The quote introduces a religious connotation of information visualization concerning insights. The holy grail is a medieval legend, the cup or platter used by Jesus at the Last Supper. In the final chapter of the aforementioned book Information Visualization by Colin Ware, information is also gained:

> *"One way to approach the design of an information system is to consider the cost of knowledge. Pirolli and Card (1995) drew an analogy with the way animals seek food to gain insights about how people seek information. Animals minimize energy expenditure to get the required gain in sustenance; humans minimize effort to get the necessary gain in information."*
>
> *— Colin Ware* [25]

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20 Gettier, E., 1963. Is justified true belief knowledge? Analysis, Volume 23(Issue 6), p. 121–123.

21 Ref.: Harper, D., gain | Search Online Etymology Dictionary. etymonline.com. Available at: https://www.etymonline.com/search?q=gain Accessed January 23, 2020.

22 Ref.: Chen, C., 2003. Mapping Scientific Frontiers, Springer Science & Business Media.

23 Ref.: Chen, C. & Song, M., 2017. Representing Scientific Knowledge, Cham: Springer.

24 Ref.: Chen, C., 2010. Information visualization. Wiley Interdisciplinary Reviews: Computational Statistics, 2(4), pp.387–403.

25 Ref.: Ware, C., 2013. Information Visualization, Elsevier.

Seeking information to gain insight positions data visualization as a transformational power changing an inquiry into a profit. Visualization is a more economical way to attain knowledge compared to alternative methods. The accelerative narrative of visualization becomes evident once more. The question of knowledge becomes one about costs; the role of design is again neglected.

> *"We want to simply and effectively exploit and use the hidden Explore & Exploit opportunities and knowledge resting in unexplored data sources."*
>
> *— Keim et al.* [26]

Effective exploitation is an extreme term considering the verb's attachment to slavery, oppression, cheating, and victimization. Exploitation might be a valuable term in the context of data, visualization, and insight by considering current research into surveillance capitalism[27] or the new dark age.[28]

The multinational analytics software developer SAS Institute quotes the Head of Customer Value Modeling from a large bank in the UK in a blog post with the title "Data Visualization: What it is and why it matters":

> *"Data visualization is going to change the way our analysts work with data. They're going to be expected to respond to issues more rapidly. And they'll need to be able to dig for more insights – look at data differently, more imaginatively. Data visualization will promote that creative data exploration."*
>
> *— SAS Institute* [29]

Concerning the levels of intervention, digging is the first of many verbs that expect to find data, insights, and knowledge in the ground. Data is the new Oil is turned from metaphor into method here. Again, it is about responding to issues more rapidly. And again, the underlying reason for visualization is acceleration. Chaomei Chen defines data visualization by its aim to reveal insights:

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[26] Ref.: Keim, D. et al., 2008. Visual Analytics: Definition, Process, and Challenges. In Information Visualization. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, Berlin, Heidelberg, pp. 154–175.

[27] Ref.: Zuboff, S., 2019. The Age of Surveillance Capitalism. pp.1–717.

[28] Ref.: Bridle, J., 2018. New Dark Age, Verso.

[29] Ref.: SAS Institute, 2019. Data Visualization: What it is and why it matters. sas.com. Available at: https://www.sas.com/en_sa/insights/big-data/data-visualization.html Accessed March 1, 2019.

> *"For many of us, information visualization can be broadly defined as a computer-aided process that aims to reveal insights into an abstract phenomenon by transforming abstract data into visual-spatial forms."*
>
> *— Chaomei Chen* [30]

Visualization in the above quote is transforming the abstract into form to reveal insights. This pattern is common to many of the collected quotes. Data is something hidden that needs to be dug up, revealed, exploited or uncovered. Visualization has the transformative capability to make the resulting insight evident. Alberto Cairo[31] notes in *The Truthful Art*:

> *"It is insightful, as it reveals evidence that we would have a hard time seeing otherwise."*
>
> *— Alberto Cairo* [32]

Revealing insights or revealing insightful evidence both describe the process of visualizing data as a disclosure. Chen has a background in Computer Science, while Cairo is trained in Journalism. This is something I found throughout this entire analysis: When it comes to describing the epistemological power of visualization, different disciplines use the same language. Revealing simultaneously has connotations of leaking or betraying, surveillance and countersurveillance activities of the first decades of the 21st century, from the NSA to Wikileaks an Edward Snowden. Similar to revealing, on the same interventional level, is discovery:[33]

> *"The main goals of this insight are discovery, decision making, and explaination."*
>
> *— Card et al.* [34]

15 years after this publication, another computer scientist, Tamara Munzner, uses the same terminology in her book *Visualization Analysis & Design*:

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30 Ref.: Chen, C., 2002. Information visualization.

31 Professor at the School of Communication of the University of Miami in Visual Journalism.

32 Ref.: Cairo, A., 2016. The Truthful Art, New Riders.

33 All three authors of the following quote, Stuart K. Card, Jock D. Mackinlay, and Ben Shneiderman, are computer scientists by training.

34 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann, p. 6

"The discover goal refers to using vis to find new knowledge that was not previously known."

— Tamara Munzner [35]

In the chapter "Why: Task Abstraction," Munzner lists three reasons to consume visualizations: to discover, present, and enjoy. While the distinction between discover and present – or often, explore and explain – is common, listing enjoy as a goal for visualization in a scientific publication is rather unique. This might also hint at the development of visualization as a medium. Nowadays, many news organizations rely on data visualization as a method to communicate specific stories. Among other developments, data journalism is moving visualization design out of a purely scientific realm and into a more public arena.

Visual analytics, defined as the science of analytical reasoning facilitated by interactive visual interfaces,[36] is one use case for interactive data visualization.[37] But, visual analytics is not only a scientific, but very much also a business undertaking. The Statistical Analysis Systems Institute, for short SAS, claims about insights and visual analytics on their website:

"Once a business has uncovered new insights from visual analytics, the next step is to communicate those insights to others."

— SAS Institute [38]

On the same interventional level as revealing and discovering is uncovering. Colin Ware is not only uncovering insights, but also truth:

"Uncover fundamental truths and test theories. This is the holy grail of research—a fundamental truth that forever changes how we think of the world. Even small truths are to be prized. Because visualization techniques often produce patterns that do not exist in nature, or rarely do, studies of such techniques can be part of the new discipline of information psychophysics."

— Colin Ware [39]

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35 Ref.: Munzner, T., 2014. Visualization Analysis and Design, CRC Press, p. 47

36 Ref.: Wong, P.C. et al., Visual Analytics. IEEE Computer Graphics.

37 Many of the computer scientists listed here name visual analytics as their research field.

38 Ref.: SAS Institute, 2019. Data Visualization: What it is and why it matters. sas.com. Available at: https://www.sas.com/en_sa/insights/big-data/data-visualization.html Accessed March 1, 2019.

39 Ref.: Ware, C., 2013. Information Visualization, Elsevier.

Like Chen, Ware articulates research concerning the religious connotation of the *holy grail*. The scientific and business perspectives do not differ too greatly in the last two quotes. The claim is the same: *The power of visualization uncovers insight and truth.* Ware goes a step beyond most other theorists. It is no longer a matter of insight, but rather the production of patterns, which do not exist in nature, to uncover truth. Ware, in comparison to most other authors, states that patterns are produced. It is a hint of the artificiality of data and its visualization. Truth is the goal, designing patterns the method. Similar to uncovering, discovering, and digging, American mathematician John Tukey looks beneath in his book Exploratory Data Analysis in 1977 to find insights:

> *"...looking at data to see what it seems to say. It concentrates on simple arithmetic and easy-to-draw pictures. It regards whatever appearances we have recognized as partial descriptions, and tries to look beneath them for new insights. Its concern is with appearance, not with confirmation."*
>
> *— Tukey, J.W.* [40]

But, not only computer scientists, mathematicians, cognitive scientists, and cooperations are talking about visualization and insights. David McCandless, a self-taught designer[41] and author of the two books *Information Is Beautiful* (2009)[42] and *Knowledge Is Beautiful* (2014), [43] claims in his talk "The beauty of data visualization" at TED-Global in 2010:[44]

> *"Data is the kind of ubiquitous resource that we can shape to provide new innovations and new insights, and it's all around us, and it can be mined very easily."*
>
> *— David McCandless* [45]

The metaphors hidden behind uncovering, discovering, digging, and looking beneath, becomes explicit in the quote. Data is characterized as an omnipresent

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40 Ref.: Tukey, J.W., 1977. Exploratory Data Analysis, Pearson College Division.

41 Ref.: McCandless, D., About — Information is Beautiful. informationisbeautiful.net. Available at: https://informationisbeautiful.net/about/ Accessed 2019.

42 Ref.: McCandless, D., 2012. Information is Beautiful, Collins Publishers.

43 Ref.: McCandless, D., 2014. Knowledge is Beautiful, HarperCollins.

44 Over the last nine years, this 18-minute talk has received over 2.8 million views on ted.com 64.

45 Ref.: McCandless, D., 2010. The beauty of data visualization. TED.

mineable resource. Data is verbalized in the same way as metals, coal, oil, limestone, or chalk. Such connections are also drawn in research by Katy Börner and David E. Polley, who published a book with the title *Visual Insights* and in the first chapter assure:

> *"This book teaches you how to use advanced data mining and visualization techniques to convert data into insights."*
>
> *— Börner, K. & Polley, D.E.* [46]

Coda

The collected, sorted, and discussed quotes from the most frequently referenced research papers and books on data visualization embrace a straightforward narrative: Mined data is converted into insight through visualization. The terminology of many of these quotes hints at one metaphor: Visualization is the refinery that converts crude oil into fuel, data into insight. This thesis will investigate whether this is the right metaphor to describe the relationship between data, visualization, and insight. The theory is structured around finding an alternative vocabulary and a new perspective on imagining the connections between design, data, and insight.

Visualization design in this literature review is the transformation from data to graphical representations, and through this transformation insights, knowledge, and truth arise. The collected, sorted, and discussed quotes range from business to journalism, research, and state defense, and all of the quotes postulate a similar transformative power to that of these graphics. Data is metaphorically described as a material condition. "Data is the new Oil" is reflected in most verbs describing the relationship between data visualization and insight. The two overarching themes are 'discover' and 'transform.' There are critical voices towards these beliefs within the field of data visualization, for example, the article "Defining Insight for Visual Analytics" states:

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[46] Ref.: Börner, K. & Polley, D.E., 2014. Visual Insights, MIT Press, p. 2

> *"In the visualization community, researchers often talk about discovering insight, gaining insight, and providing insight. This implies that insight is a kind of substance, and is similar to the way knowledge and information are discussed. In the cognitive science community, on the other hand, the wording is more often experiencing insight, having an insight, or a moment of insight. In this context, insight is an event."*
>
> *— Chang, R. et al* [47]

The material condition is questioned in this quote. Insight becomes an event rather than a substance. Another example comes from the closely related field of geovisualization:

> *"Geovisualization, from my perspective, is about the use of visual geospatial displays to explore data and through that exploration to generate hypotheses, develop problem solutions, and construct knowledge."*
>
> *— MacEachren, A.M.* [48]

In the above quote, knowledge is not something that already exists, but rather a created construct. This is a different perspective on how insights are generated in our society, and offers an alternative view on otherwise homogeneous viewpoints of how knowledge and visualization are connected. The theory, which I will develop throughout the second part of this thesis, will investigate insights as processes and, more specifically, as an operation of drawing distinctions. In the second part I will also name and introduce various alternative voices that question the status quo presented throughout this section.

Design is an act of creation, of bringing something into the world that was not there before. But, is this not a problem in itself? Is there a path to connect the words 'insights,' 'knowledge', or 'truth' with the concept of design? In this first literature review, the relation between design and visualization is carefully avoided in all instances. Can knowledge be designed, and if so, is there something like knowledge design? Many of the collected statements suggest that insights, knowledge, and truth already exist, and visualization only uncovers, transforms, and reveals the insights. Throughout almost all the quotes presented above, the

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47 Ref.: Chang, R. et al., 2009. Defining Insight for Visual Analytics. ieeexplore.ieee.org.

48 Ref.: MacEachren, A.M., 2001. An evolving cognitive-semiotic approach to geographic visualization and knowledge construction. Information Design Journal, 10(1), pp.26–36.

metanarrative is: visualization as a metaphorical refinery cleaning, compressing, distilling, exploiting, transforming, or mining insights. One noteworthy observation here is the homogeneity of the motives behind data visualization. While I ordered these quotes from least to most interventional, the terminology from neuroscience, computer science, design, journalism, industry cooperation, and state defense is highly homogeneous.

The next four chapters of this section will further investigate common visualization metaphors to develop an understanding of how visualizations and knowledge relate to one another. I have identified four analogies between design, visualization, and knowledge. These metaphors are the raster, the arrow, the chain, and the pyramid. Throughout the next four chapters, I will discuss these metaphors and look at their implications to grasp how design, data, visualizations, and insight might relate. If visualization holds the potential to represent insights, what theories describe these graphics' creation? The following chapters analyze depictions of the design of visual representations. What are the images and metaphors used to discuss visualization research and practice? How do these images explain how visualization represents insight, knowledge, and truth? In case they do not represent insights, knowledge, or truth, what are the substituted new objectives? The questions I have will remain the same: What are the necessary steps to achieving insights? What is data visualization a priori, what pre-defines any representation of data? And how do these pre-definitions determine the possible insights? What is the role of design in this process of approaching insight?

Raster

If insights, knowledge, and truth are the objectives for designing data visualizations, how is the transformation from data to graphic theorized? In the prologue, I examined how 20th-century metaphors of digging, mining, or revealing influence how we talk about data and its transformation into insight. Visualization, in this metaphor, is part of the industrial complex processing the raw material into an accessible human good. The following chapters will survey four theories within this industrial complex to grasp the interplay between insights and design.

This section outlines the taxonomies encompassing data visualization. Taxonomies order objects and phenomena into groups and classes. They are a systematization of observed experience. Visualization research often combines multiple categorization schemes, as visible in the collection of diagrams throughout this section. I will call visual representations of more than one categorization schema rasterizations. Rasterization turns observations into vertical and horizontal categories placed on a two-dimensional grid. Each object in the resulting raster connects two or more categorization schemes. One early approach toward rasterizing visualization elements and variables goes back to the *Semiology of Graphics*[1] by Jacques Bertin from 1967. The survey conducted here is only a brief look into the systemization, classification, and rasterization of graphic representations of data. It is not my pretense to map and discuss all the taxonomical systems within the field of visualization research. Instead, this chapter examines the outcomes and mindsets of these rasterizations. What are the underlying objectives of these rasterization schematics? Moreover, how is this rasterization connected to the question of design and insight?

1 Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press.

Levels of Rasterization

Before analyzing specific taxonomical systems, I want to showcase the variability and similarities of categorizations in visualization design.

In the book *Graphical Perception* from 1984, William Cleveland and Robert McGill list ten properties that a visual mark can possess.[2] Figure 2 exemplifies these ten properties.

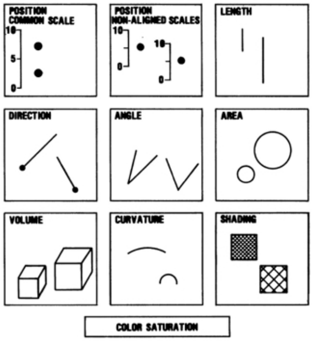

Figure 2: From the book Graphical Perception by William Cleveland and Robert McGill, 1984 [3]

In the three representations in Figure 3, visual variables (position, size, and shape) are compared to visual elements (points, lines, and areas). Figure 3c also names text as an additional visual element. While most visual variables are named in all three graphics, each graphic has its specificities. The number of visual variables in each of these graphics already highlights this, namely : 7, : 9, : 12.

2 Ref.: Cleveland, W.S. & McGill, R., 1984. Graphical Perception and Graphical Methods for Analyzing Scientific Data, American Association for the Advancement of Science.

3 Ref.: Cleveland, W.S. & McGill, R., 1984. Graphical Perception and Graphical Methods for Analyzing Scientific Data, American Association for the Advancement of Science.

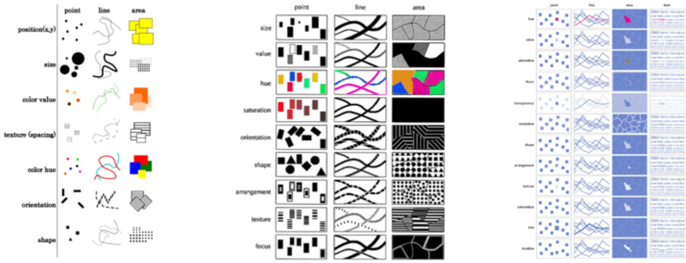

Figure 3: Visual elements & visual variables mappings: 3a: Krassanakis and Vassilopoulou,[4] 3b: Krygier,[5] 3c: Robinson [6]

Another rasterization compares data types with visual variables. Data types categorize how the individual data points compare to one another, such as Quantitative for numbers (4, 8, 13), Ordinal for sorting (1,2,3), and Nominal for grouping (R, 5, q). Such rasterization is less precise than the data types in the programming language python, for instance, in which numbers alone are subcategorized as integers, real, and complex.

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4 Ref.: Krassanakis, V. & Vassilopoulou, V., 2018. Introducing a data-driven approach towards the identification of grid cell size threshold (CST) for spatial data visualization: An application on marine spatial planning (MSP). Journal of Urban and Environmental Engineering, (12).

5 Ref.: Krygier, J.B., Geography 353 Cartography and Visualization, https://krygier.owu.edu/krygier_html/geog_353/geog_353_lo/geog_353_lo08.html

6 Ref.: Robinson, A.C., 2013. Highlighting in Geovisualization. Cartography and Geographic Information Science, 38(4), pp.373–383.

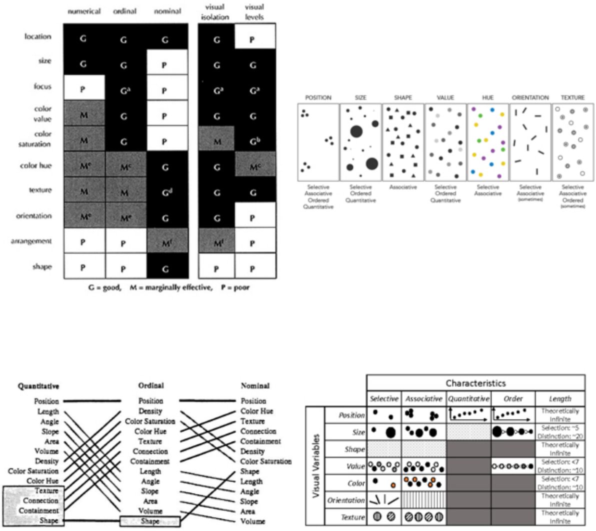

Figure 4: Data types & visual variables mappings: 4a: Krygier,[7] 4b: Heyman et al.,[8] 4c: Mackinlay,[9] 4d: Bernstein et al. [10]

The overlaps and distinctions between the rasterizations are visible in Figure 4. Both data types and visual variables are somewhat fluid, created systems rather than fixed and universal rules. These rules consist of an interplay between inclusion and exclusion, naming and categorizing certain aspects while neglecting others.

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7 Ref.: Krygier, J.B., Geography 353 Cartography and Visualization, https://krygier.owu.edu/krygier_html/geog_353/geog_353_lo/geog_353_lo08.html

8 Ref.: Heyman, D. et al., Visual Variables. axismaps.com. Available at: https://www.axismaps.com/guide/general/visual-variables/ Accessed December 7, 2019.

9 Ref.: Mackinlay, J., 1986. Automating the design of graphical presentations of relational information. ACM Transactions on Graphics (TOG), 5(2), pp.110–141.

10 Ref.: Bernstein, W.Z. et al., 2015. Mutually Coordinated Visualization of Product and Supply Chain Metadata for Sustainable Design. Journal of Mechanical Design, 137(12), p.090301.

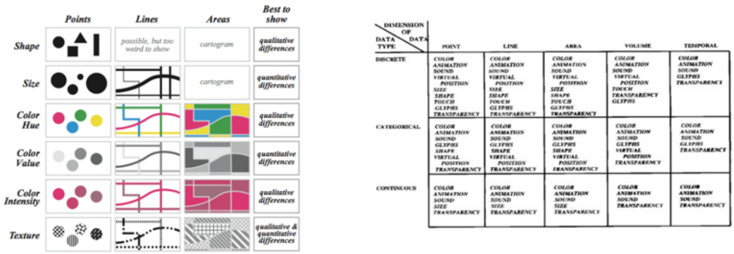

Figure 5: Data types, visual elements & visual variables: 5a: Krygier and Wood,[11] 5b: Clarke & Teague [12]

There are also graphical representations that combine all three categorization schemes analyzed so far. Figure 5 compares two examples of rasterizations in which data types, visual elements, and visual variables connect.

A fourth categorization scheme acts one hierarchical level above the rasterizations analyzed so far. Both visual elements and visual variables describe the individual graphic symbol and its possible property space. Data types connect the graphic symbols to the underlying information. Categorization schemes of graphic representations describe the interplay of a conglomerate of graphic symbols. If visual elements are the letters of a visualization language and the connections to visual variables create words, graphic representations are the statements or narratives of visualization design. Jaques Bertin called this level of classification Imposition.[13] Yuri Engelhardt mapped eight different graphic representation categorization schemes against one another in his book *The Language of Graphics* (2002).[14] Here is a list of Engelhardt's collection:

- Jaques Bertin, 1967: symbol, map, network, diagram[15]
- Edward R. Tufte, 1983: data map, relational graphic, time series (narrative of space time), table[16]
- James C. Richards, 1984: symbol, pictorial illustration, diagram[17]

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11 Ref.: Krygier, J. & Wood, D., 2011. Making Maps, Guilford Press.

12 Ref.: Clarke, K.C. & Teague, P.D., 1998. Cartographic symbolization of uncertainty. ACSM Annual Conference.

13 Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press.

14 Ref.: Engelhardt, Y., 2002. The Language of Graphics, Yuri Engelhardt.

15 Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press.

16 Ref.: Tufte, E.R., 1983. The Visual Display of Quantitative Information, Graphics Press.

- Nigel Holmes, 1993: diagram, map, chart[18]
- Stephen M. Kosslyn, 1994: diagram, map, chart, graph[19]
- Lohse et. al., 1994: icon, picture, map, cartogram, network chart, graph, time chart, table[20]
- Trevor Bounford, 2000: symbol, pictorial diagram, relational diagram, organizational diagram, graph and chart, time diagram, table[21]
- Yuri Engelhardt, 2002: symbol, pictorial diagram, relational diagram, symbol, picture, map, statistical map, link diagram, statistical chart, time chart, table[22]

Once more, we can see the shifting nature of these categorization systems. Both the number of categories and their content shifts throughout this 35-year development of categorizations of graphic language. Some of the most intriguing visualizations break all of the above systems. An example is the map "Carte figurative des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812–1813"[23] by Charles Joseph Minard, published November 20, 1869, visible in Figure 6.

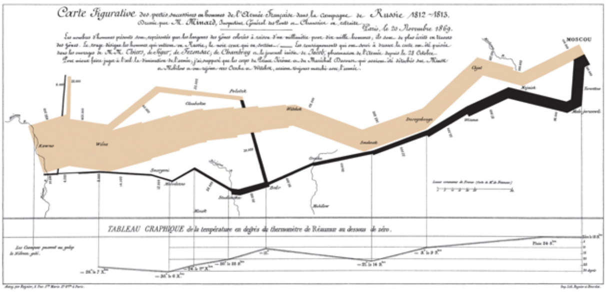

Figure 6: Charles Joseph Minard, 1869 [24]

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18 Ref.: Holmes, N., 1993. The Best in Diagrammatic Graphics, Rotovision/Quarto.

19 Ref.: Kosslyn, S.M., 1994. Elements of Graph Design, W H Freeman & Company.

20 Ref.: Lohse, G.L. et al., 1994. A classification of visual representations. Communications of the ACM, 37(12), pp.36–49.

21 Ref.: Bounford, T., 2000. Digital Diagrams, Watson-Guptill.

22 Ref.: Engelhardt, Y., 2002. The Language of Graphics, Yuri Engelhardt.

23 Translation: Figurative Map of the successive losses in men of the French Army in the Russian campaign 1812–1813

24 Ref.: Minard, C.J., 1869. Carte figurative des pertes successives en hommes de l'Armée

Minard's map, which Edward Tufte called "the best statistical graphic ever drawn",[25] combines a geographical map, a time series, and multiple sources of statistical data. So, a map drawn in 1869 exceeds all the categorical systems above. The book *Design for Information* by Isabel Meirelles from 2013 accounts for the overlapping of these categorical systems. Meirelles identifies five categories:

- Isabel Meirelles, 2013: Hierarchical Structures, Relational Structures, Temporal Structures, Spatial Structures, Textual Structures[26]

The book shows overlaps of Spatio-Temporal Structures to highlight the interwovenness of these categorization systems. This listing of rasterizations within the field of visualization research highlights four categorization and rasterization schemas:

- Data Types: Quantitative, Ordinal, Nominal, …
- Visual Elements: Points, Lines, Areas, …
- Visual Variables: Color, Position, Texture, …
- Graphic Representations: Diagram, Map, Chart, …

The shifting nature of these systems, their uncertainty, become visible by placing the rasters next to one another. These systems function as building blocks for designing data visualizations. They operate as overviews and boundaries of the graphic design space from which a visualization designer chooses. This analysis of visual rasterizations does not get us closer to the question of how these images connect to the objective of visualization: to create insights, knowledge, and truth. To interpret the motives and objectives of the raster, I will investigate three prominent books highlighting the rasterization of visualization research.

Française dans la campagne de Russie 1812–1813,

25 Ref.: Tufte, E.R., 1983. The Visual Display of Quantitative Information, Graphics Press.

26 Ref.: Meirelles, I., 2013. Design for Information, Rockport Publishers.

The Foundational Rasterization

In 1967, Jacques Bertin, a French cartographer and theorist, published the book *Semiology of Graphics*.[27] The book introduces a set of rules for the graphic communication of data. Throughout the first part of the publication, Bertin develops a graphic system. His work dissects the constitutive factors that define a visual representation. Semiotics is the study of sign processes. The Semiology of Graphics is a theory of signs that becomes a language in itself. Bertin rasterizes the elements that are needed to graph information on a two-dimensional plane. The basic units in this theory are marks, and Bertin categorizes ways to arrange and transform them on the plane's surface. The fundamental question Bertin asks is: How can we vary marks? The three answers Bertin articulates are then involve the location where marks are placed, how the marks are placed there, and their visual characteristics. Bertin introduces all four levels of rasterization discussed in the previous section in the Semiology of Graphics.[28]

Figure 7 provides an overview of Bertin's rasterization system. Rather than re-iterate the rasterization, I want to investigate the motives and objectives articulated in the book. Do the given reasons for visualizing data insight, knowledge, and truth relate to Bertin's Semiology of Graphics? If so, how? If not, what alternative motives come into play?

The question Bertin asks with respect to the motives and objectives of Efficiency rasterizations is how the designer should decide which symbolic transformation to use when there are large numbers of possible combinations from data to graphic representation. In his system, designing graphics becomes a

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[27] Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press.

[28] 1. Data Types; Bertin discusses the data types as characteristics of visual variables.

2. Visual Elements; Bertin calls them elements of the plane.

3. Visual Variables; the term most probably goes back to Bertin, as he called them exactly that.

4. Graphic Representation; discussed in the Semiology of Graphics as Imposition.

combinatorial structure of the various categorizations. The Table of properties of the retinal variables in Figure 7 gives an overview of his framework and its possible combinations. From this rasterization, Bertin sets out rules of applications as he writes:

> *"For a graphic to be 'useful,' it must be 'efficient.' The rules governing graphic efficiency stem from the properties of visual perception."*
>
> — *Jacques Bertin* [29]

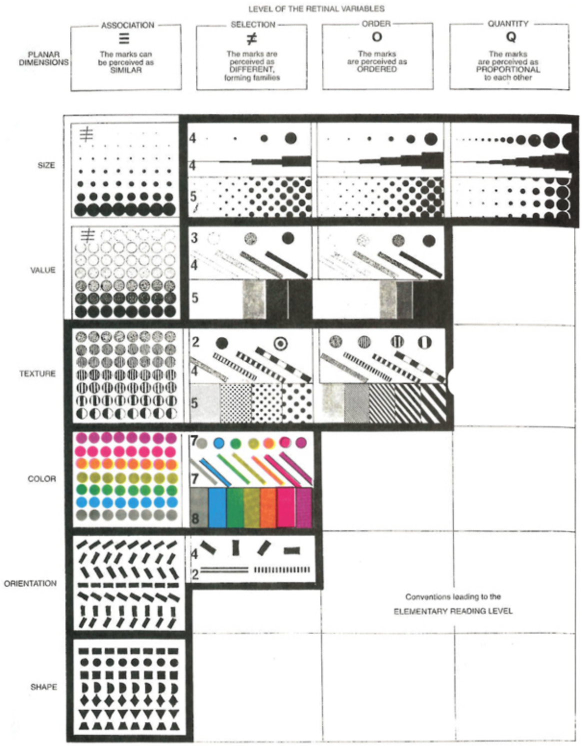

Figure 7: "Table of properties of the retinal variables," p. 96 [30]

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[29] Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press, p. 99

[30] Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press, p. 96

The problem Bertin identifies is that the designer can represent the same information in many variations. Figure 8 illustrates the transition from data to a hierarchical structure of graphic possibilities. The first branch is split between a diagram and a map representation of the data. Each step separates and refines the visual representation. Throughout the chapter, Bertin visualizes one dataset on workforce data from the 90 France departments with eight data dimensions. The dataset is sophisticated enough for Bertin to sketch 100 alternative combinations based on his previously introduced system. Figure 9 shows all the graphics Bertin sketched out over 35 pages together in one illustration. From the results of the laborious hand-drawn work, Bertin formulates the same conclusions but this time elaborates further:

> *“We have just examined a hundred graphics in terms of the correspondence between components and graphic variables. Some of the graphics are ‘good,’ others ‘worse,’ others simply ‘bad.’ But these opinions are purely subjective. We need only submit a dozen maps for evaluation by a group of readers in order to discover that each person will have a different opinion, based most often on considerations of an aesthetic nature. It is important, therefore, to define a precise, measurable criterion which we can use to class constructions, determine the best one for a given case, and explain why readers prefer different constructions. We will call this criterion ‘efficiency.’ EFFICIENCY is defined by the following proposition: If, in order to obtain a correct and complete answer to a given question, all other things being equal, one construction requires a shorter observation time than another construction, we can say that it is more efficient for this question.”*
>
> *— Jacques Bertin* [31]

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[31] Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press, p. 139

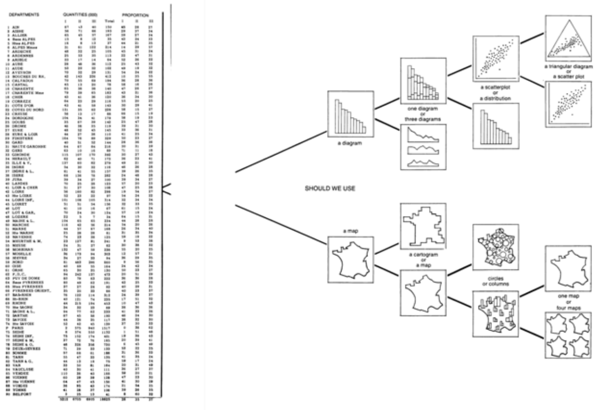

Figure 8: On the left, the data table used to create the graphics. On the right, a sketch showing how to think about the different combinatorial possibilities.[32]

Jacques Bertin started his Semiology of Graphics with the rasterization of visual and perceptual elements, discussing the constitutive components of information graphics. The design process is the method to explore the diversity of possible outcomes of the arrangement of the elements. Studies into human perception are used to determine the efficiency of the variety of graphics. In Bertin's semiology, the raster sets the boundaries of the design space, and human perception guides the design toward the most efficient graphic outcome. Semiology of Graphics itself does not draw any conclusions regarding insight, knowledge, or truth. Efficiency becomes the main objective in choosing a path through the design space. Jaques Bertin's concepts have influenced a large body of visualization research until today, and I will investigate two more contemporary books to highlight their objectives and motives.

32 Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press, p. 100-101

Raster

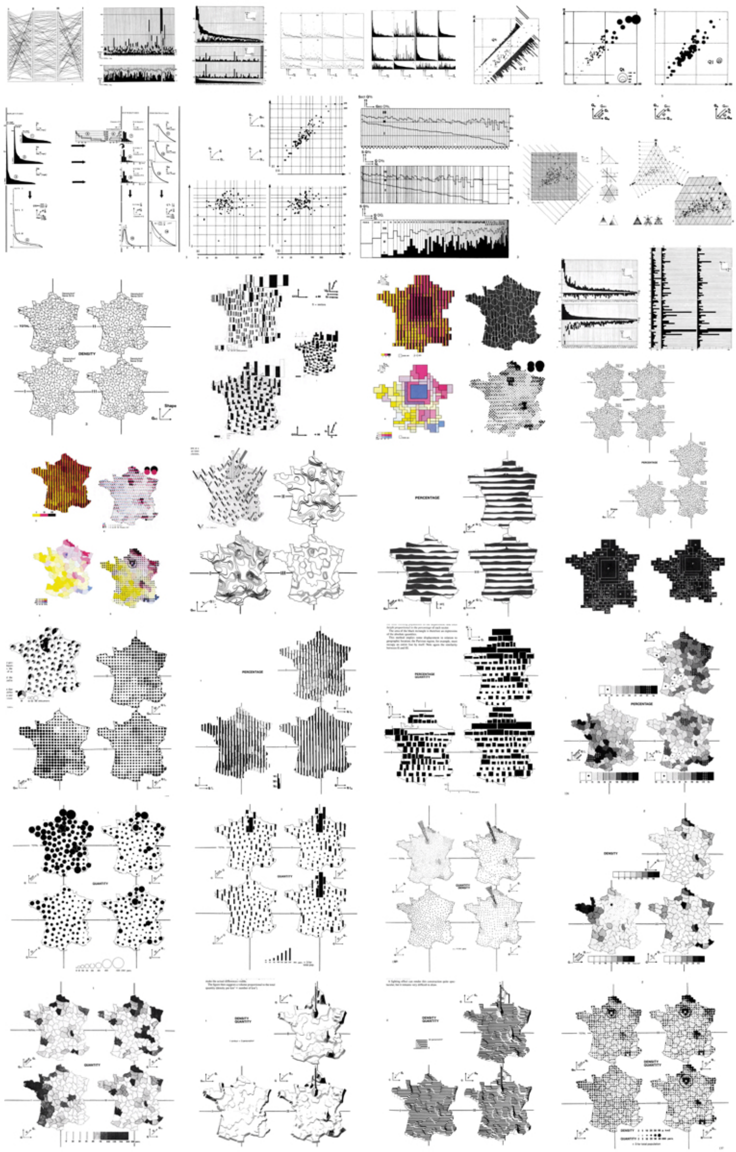

Figure 9: A collection of all graphics Bertin made from one dataset. , p.102-137

Knowledge, Insight, and the Raster

In the Semiology of Graphics, Bertin dissects the mark into spaces of possibilities. Through his distinctions, the design process becomes an interplay of combinations to develop the most efficient graphic. However, one crucial aspect has been left out in this analysis of Bertin's work: the question of insight and knowledge. Two books by Katy Börner, *Atlas of Knowledge* (2015) [33] and *Visual Insights* (2014),[34] continue the work of Bertin and hold our objectives in their titles. The Atlas of Knowledge references Bertin's work on rasterizing graphical elements. Figure 10 illustrates how Börner expands the work on rasterizing the graphic design space. The content displayed in the figure spans over four pages in the original book (p. 36 to 39). I collected the pages here to present an outline of the vast rasterization Börner developed. It is a vast extension of Bertin's work.

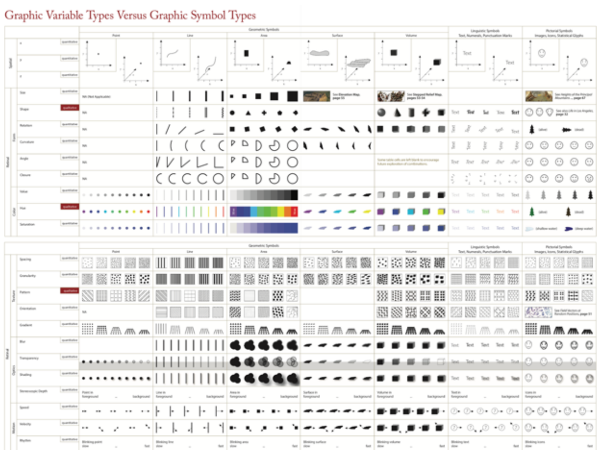

Figure 10: Graphic variable types versus graphic symbol types by K. Börner [35]

[33] Ref.: Börner, K., 2015. Atlas of Knowledge, MIT Press.

[34] Ref.: Börner, K. & Polley, D.E., 2014. Visual Insights, MIT Press.

Börner extends Bertin's categorizations in many directions. For example, the three elements of the plane point, line, and area have in Börner's taxonomy the additions surface, volume, linguistic symbols, and pictorial symbols. Regarding t question of how rasterization is connected to the creation of knowledge and insights as the titles of the two books indicate, the preface of Visual Insights states:

> *"The Atlas aims to feature timeless knowledge (Edward Tufte called it 'forever knowledge'), or, principles that are indifferent to culture, gender, nationality, or history."*
>
> — *Katy Börner* [36]

Observing decades-old maps makes it hard for me to imagine an atlas of timeless knowledge. Is it possible that today's data visualizations will still be valid in 200 years? The book's ambitious aim is hard to underestimate, as it suggests unbiased and perspective-free data visualizations.[37] Moreover, the first chapter of the Atlas of Knowledge starts with a quote:

> *"Measurement is the first step that leads to control and eventually to improvement. If you can't measure something, you can't understand it. If you can't understand it, you can't control it. If you can't control it, you can't improve it."*
>
> — *H. James Harrington* [38]

Measurement, understanding, control, and improvement are thought of together in this quote. H. James Harrington writes books with titles like Business Process Improvement, High-Performance Benchmarking, and Streamlined Process Improvement. The book Atlas of Knowledge starts with a quote from a writer on management systems with a particular ideology around how understanding arises. In the same first chapter, "Science and Technology from Above," the word 'knowledge' is used in two different settings:

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36 Ref.: Börner, K., 2015. Atlas of Knowledge, MIT Press, p. ix.

37 This is a highly contested claim. An excellent introduction to data perspectives and power structures is *Data Feminism* by Catherine D'Ignazio and Lauren F. Klein. I will get back to Data Feminism in the second part of the book.

38 Ref.: Börner, K., 2015. Atlas of Knowledge, MIT Press, p. 1

"In the online world, maps of topical spaces reveal the extent and structure of our collective knowledge, depict bursts of activity, and help us identify pathways of ideas and innovations."

— Katy Börner [39]

The first chapter already discussed the action of revealing knowledge. The second quote below adds another metaphorical degree to the interpretation from data to knowledge.

"We try to swim gracefully through this expanding sea of data, to make informed decisions and stay rationally afloat, but the threat of drowning seems to remain ever present. This is where advanced data-mining techniques and well-designed visualizations come to the rescue—by helping us to interlink and make sense of existing data, knowledge, and expertise in order to make decisions about what to do, when, where, and with whom."

— Katy Börner [40]

Receiving data, swimming in data, drowning in data: The above quote naturalizes data while data-mining techniques and well-designed visualization will rescue us from the natural forces of data. Apart from the above quotes, the term knowledge rarely appears throughout the 210-page book. While the publication's title contains the word 'knowledge,' knowledge is neither discussed, explained, or connected to visualization in detailed terms throughout the book. *Knowledge is seemingly elusive, often used in bold claims and headlines but never described in the context of data visualization.*

Visual Insights, which is more of a textbook for teaching data visualization, makes similar claims as Jaques Bertin's *Semiology of Graphics*:

"We urgently need more effective ways to make sense of this massive amount of data —to navigate and manage information, to identify collaborators and friends, or to notice patterns and trends."

— Börner, K. & Polley, D.E. [41]

Rather than efficiency, effectively becomes the objective in the quote above. While both words have similarities, there are also distinct features that separate them. Efficiency produces results with minimal use of effort. The best outcome is

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39 Ref.: Börner, K., 2015. Atlas of Knowledge, MIT Press, p. 2

40 Ref.: Börner, K., 2015. Atlas of Knowledge, MIT Press, p. 2

41 Ref.: Börner, K. & Polley, D.E., 2014. Visual Insights, MIT Press, p. 2

the one that uses the least resources. Form follows function. Effectiveness does not contain such an economic reference. If an intended result is achieved, it was effective without the consideration of its use of resources. The shift in objective from Bertin to Börner is subtle but distinct. While the two books from Börner hold insight and knowledge in their titles, the books themselves clearly leave out the question of how visualization arrives at insights or knowledge.

What, why, and how rasterizations

Tamara Munzner's *Visualization Analysis and Design*[42] from 2014 also strongly relies on rasterizing the design process of data visualization. While both Jaques Bertin and Katy Börner focus mainly on the rasterization of graphical elements, Munzner's approach has a much wider scope. Her three main categories are: 'What,' 'Why,' and 'How.' The almost 400 pages are the fullest account of rasterization I have found throughout my research. One extensive leap Munzner takes is to move from Bertin's static, paper-based visualizations into the realm of interactive computer-generated graphics. Again, I will not go into detail on the actual levels of rasterizations, but rather observe and analyze the articulated motives and objectives of visualizing data within Munzner's conception. The third chapter Why: Task Abstraction looks at why someone would visualize data. Munzner's task abstraction chapter is split into two main categories: actions and targets.

For Munzner, visualization has a much wider scope than only finding or creating insights. Presentation, enjoyment, or the production of new data through visualization, as well as visualization for searches, open up a different space for possibilities than the concepts collected in the introduction of this chapter. Visualization for insight and knowledge is for Munzner only a subcategory located in Actions > Analyze > Consume > Discover as she writes:

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42 Ref.: Munzner, T., 2014. Visualization Analysis and Design, CRC Press.

> *"The discover goal refers to using vis to find new knowledge that was not previously known. Discovery may arise from the serendipitous observation of unexpected phenomena, but investigation may be motivated by existing theories, models, hypotheses, or hunches."*
>
> *— Tamara Munzner* [43]

Munzner's perspective is quite extensive, adding various layers that have not been illustrated before. However, the question of how visualizations discover knowledge is neither answered nor addressed in this section. Munzner's third category, 'How?' is the section closest to the previously encountered rasterizations. The three chapters discuss encoding, manipulation, and reduction. In the chapter on encoding, Munzner categorizes similar graphical notations as Bertin: color, size, angle, shape, etc. This three-level categorization, with all its sub-branching and classification, is meant as an analysis tool for visualization projects. Similar to the way biologists categorize beetles or plants, Munzner's idiom space allows us to classify, rasterize, and evaluate visualizations by asking the questions: What? Why? How? The first chapter of the book starts with a definition of visualization, which shows us the motivation behind this elaborate systematization of visualizations:

> *"This book is built around the following definition of visualization— vis, for short: Computer -based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively. ... Vis design is full of trade-offs, and most possibilities in the design space are ineffective for a particular task, so validating the effectiveness of a design is both necessary and difficult. Vis designers must take into account three very different kinds of resource limitations: those of computers, of humans, and of displays. Vis usage can be analyzed in terms of why the user needs it, what data is shown, and how the idiom is designed."*
>
> *— Tamara Munzner* [44]

47 years after Jaques Bertin's first publication, the motivations for visualizing data or information remain similar: to help people carry out tasks more effectively. While Bertin asks for efficiency, Munzner, similar to Börner, asks for effective visualizations. Over the next couple of pages, Munzner redefines this notion to some extent with sentences like: *"Vis allows people to analyze data when*

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43 Ref.: Munzner, T., 2014. Visualization Analysis and Design, CRC Press, p. 47

44 Ref.: Munzner, T., 2014. Visualization Analysis and Design, CRC Press, p. 1

they don't know exactly what questions they need to ask in advance". Munzner also relates the question of effectiveness to the issue of design:

> *"The most fundamental reason that vis design is a difficult enterprise is that the vast majority of the possibilities in the design space will be ineffective for any specific usage context."*
>
> — *Tamara Munzner* [45]

Design becomes a search for the most effective representation. The more we explore the space, the more effective our visualizations will be. Rasterizations set the limits of visualization design possibilities, and with it, the scope of explorable design alternatives.

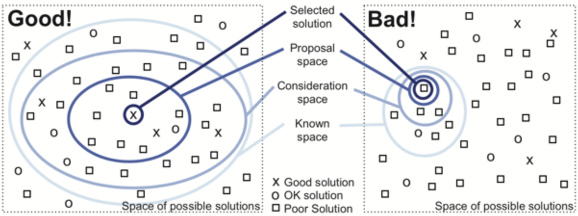

Figure 1.5. A search space metaphor for vis design.

Figure 12: "A search space metaphor for vis design" [46]

Coda

The rasterization of graphic symbols is driving visualization design toward a seemingly more effective and efficient visual representation. It is not about insights anymore, but rather efficiency and effectiveness. Speed becomes the optimizing factor between graphic symbols and the human observer. The accuracy between the datum, graphic symbol, and understanding drives the design process. Visualization design becomes a discipline with clear goals and the impression of optimal solutions. Deep-rooted categorization schemes are

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45 Ref.: Munzner, T., 2014. Visualization Analysis and Design, CRC Press, p. 12

46 Ref.: Munzner, T., 2014. Visualization Analysis and Design, CRC Press, p. 13

seemingly layered onto one another to determine the design space. Rasterization has a strong influence on the discipline of information visualization. Design becomes a search problem within these defined matrices.

Knowledge and insight have a ghostly appearance within the rasterization of visualization design. The terms are mentioned, used in book titles, and definitions, but are never described or discussed in detail. Rasterization is measured by its efficiency and effectiveness rather than the insight and knowledge it provides. Such a perspective is a shift in the objective of visualization. As habitual as it may be to claim that visualization creates insight, knowledge, and truth, it appears, so far, impossible to describe how these graphics do so only by analyzing the raster.

Arrow

The rasterization of graphic elements led Jaques Bertin[1] and other visualization researchers [2] to study perception. Visualization design became less about finding insights and truth and more about optimizing graphic representations to efficiently and effectively communicate information. The connection between our brains and the graphic is guiding visualization design research toward the psychology of perception. Figures 13, 14, and 15 showcase a number of representations that illustrate the interaction between our cognitive internal processes and the external graphic representation of data.

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1 Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press.

2 For example:

Ref.: Clarke, K.C. & Teague, P.D., 1998. Cartographic symbolization of uncertainty. ACSM Annual Conference.

Krygier, J.B., Geography 353 Cartography and Visualization,

Krygier, J. & Wood, D., 2011. Making Maps, Guilford Press.

Mackinlay, J., 1986. Automating the design of graphical presentations of relational information. ACM Transactions on Graphics (TOG), 5(2), pp.110–141.

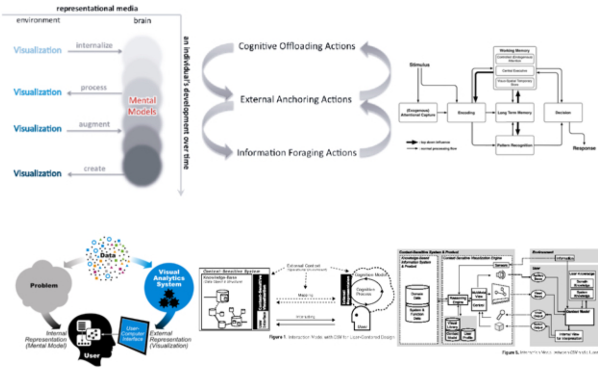

Figure 13: Perception and representation diagrams: 13a: Liu and Stasko,[3] 13b: Liu and Stasko,[4] 13c: Patterson et al.,[5] 13d: Greitzer,[6] 13e: Jung and Sato,[7] 13f: Jung and Sato [8]

In each of these representations, the arrow becomes the connection between the internal cognitive processes and the external graphical representation. Figures 13a and 13b label the arrows between the visualization and mental models with verbs such as internalize, process, augment, create, offload, anchor, and forage.[9] Figure 13c maps a path with arrows from 'timulus' to 'response.' In Figure 13d, the arrow links the data with the user. Figure 13e draws arrows between the user interface and the internal representation with the labels 'mapping,' 'interacting,' and 'external context.' Figure 13f visualizes a three-part organization of

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3 Ref.: Liu, Z. & Stasko, J.T., 2010. Mental Models, Visual Reasoning and Interaction in Information Visualization: A Top-down Perspective. ieeexplore.ieee.org.

4 Ref.: Liu, Z. & Stasko, J.T., 2010. Mental Models, Visual Reasoning and Interaction in Information Visualization: A Top-down Perspective. ieeexplore.ieee.org.

5 Ref.: Patterson, R.E. et al., 2014. A human cognition framework for information visualization. Computers & Graphics, 42, pp.42–58.

6 Ref.: Greitzer, F., 2011. Defining a Framework for Visual Analytics. vacommunity.org. Available at: http://www.vacommunity.org/article28 Accessed December 11, 2019.

7 Ref.: Jung, E.C. & Sato, K., 2006. Context-Sensitive Visualization for User-Centered Information System and Product Design.

8 Ref.: Jung, E.C. & Sato, K., 2006. Context-Sensitive Visualization for User-Centered Information System and Product Design.

9 Ref.: Liu, Z. & Stasko, J.T., 2010. Mental Models, Visual Reasoning and Interaction in Information Visualization: A Top-down Perspective. ieeexplore.ieee.org.

environment, user, and system. The arrow in each of these cases represents the interface between the mental and the visual.

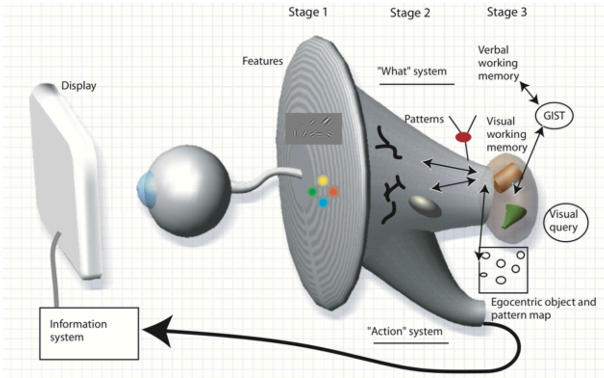

Figure 14: *"A three-stage model of human visual information processing"*[10]

Another example is Colin Ware's research on human information processing on the use of the arrow.[11] Ware writes:

> *"Why should we be interested in visualization? Because the human visual system is a pattern seeker of enormous power and subtlety. The eye and the visual cortex of the brain form a massively parallel processor that provides the highest-bandwidth channel into human cognitive centers. At higher levels of processing, perception and cognition are closely interrelated, which is the reason why the words 'understanding' and 'seeing' are synonymous."*
>
> — *Colin Ware* [12]

This quote features two points worth noticing. First, the human brain is described as a computer, a *massively parallel processor* with the *highest-bandwidth channel*. And second, Ware writes that *understanding* and *seeing* are synonymous. The question of how we make sense of graphically represented information becomes neglected, as seeing is understanding from this perspective. Visualization design becomes an optimization process for the best representation

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10 Ref.: Ware, C., 2013. Information Visualization, Elsevier, p. 21

11 Colin Ware is an expert in the psychology of perception with a background in Computer Science, and has written two books on the perception of visualization design: *Visual Thinking for Design* and *Information Visualization: Perception for Design*.

12 Ref.: Ware, C., 2013. Information Visualization, Elsevier, p. xxi

for our pattern-seeking visual system. The arrow becomes the symbolic representation of the path from within our mind to the surface of the designed pattern. *Information Visualization: Perception for Design* maps a schema showcasing visual information processing in the form of arrows between our eyes, brain, and display; see Figure 14. As already quoted in the prologue, Ware writes:

> *"In data exploration, seeing a pattern can often lead to a key insight, and this is the most compelling reason for visualization."*
>
> — *Colin Ware* [13]

Throughout the book, Ware does not address what an insight is nor how design relates to its emergence. Again, insight is used in bold claims but is not discussed further in its complexity. Colin Ware's *Information Visualization* is a tremendous resource in explaining our vision's cognitive processes. It explains why specific colors, shapes, and patterns are more visible to us than others. Colin Ware researches cognition and pattern but does not further investigate how patterns relate to insight.

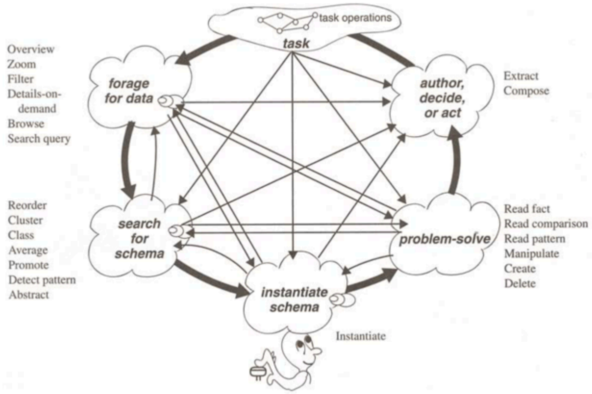

FIGURE 1.15
Knowledge crystallization.

Figure 15: Card et. al., Figure 1.15, "Knowledge Crystalization" [14]

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[13] Ref.: Ware, C., 2013. Information Visualization, Elsevier

[14] Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann, p. 10

Still, if data visualizations represent insight, knowledge, and truth, the arrow and its underlying research in cognitive psychology might hold answers to the question of how design and insight are intertwined. To further investigate the arrow's depiction, I will examine Diagram 15 in more detail. The book in which the diagram was published carries a twist regarding the question of design and insight.

Perception, Cognition, and Magic

In the first chapter of the 1999 book *Readings in Information Visualization: Using Vision to Think*, [15] the authors, Jock D. Mackinlay, Ben Shneiderman, and Stuart Card introduce a definition of information visualization. Three aspects are proposed to determine what it means to visualize information:

- External cognition to enhance our cognitive abilities.
- Graphical means of visual perception to discover and communicate an idea.
- The computer as a medium to create new methods for amplifying cognition.

For the authors, these threads lead to "*new means for coming to knowledge and insight about the world*" (p.1). Information visualization is defined as:[16]

> *"The use of computer-supported, interactive, visual representations of abstracted data to amplify cognition."*
>
> *— Card et. al.* [17]

15 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann.

16 This definition of information visualization established in the first chapter is heavily referenced. At the beginning of 2021, the book had over 6,300 citations listed on the web platform google scholar. See https://scholar.google.com/scholar?oi=[bibs&hl=en&cites=12191840292477206207&as][_][sdt=5]

17 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann, p. 7

External cognition in this context signifies that humans overcame the limits of their reasoning by outsourcing some of the workload from the brain to the exterior world. This idea comes from Don Norman's book *Things That Make Us Smart* from 1993,[18] as he writes:

> *"The power of the unaided mind is highly overrated. Without external aids, memory, thought, and reasoning are all constrained. But human intelligence is highly flexible and adaptive, superb at inventing procedures and objects that overcome its own limits. The real powers come from devising external aids that enhance cognitive abilities. How have we increased memory, thought, and reasoning? By the invention of external aids: It is things that make us smart."*
>
> *— Don Norman* [19]

Card et al. reference this paragraph to explain what they call *external cognition*. A series of examples from pen and paper, slide rulers, nomographs, and nautical charts exemplify the concept. The last *visual aid presented* is diagrams. Here, the authors refer to an example from Edward Tufte's book *Visual Explanations* (1997) to not only show how diagrams can lead to insights but also obscure insights, as they quote:

> *"There are right ways and wrong ways to show data; there are displays that reveal the truth and displays that do not."*
>
> *— Edward Tufte* [20]

Edward Tufte's story is about communication, knowledge, and interdisciplinary connections. A narration about various levels, forms, and readings of insights. The description from Card et al. leaves out some of the critical points from my perspective. For this reason, I will go through it from a design perspective, as it contains an intriguing narrative regarding design and insight.

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18 Don Norman has a background in engineering and cognitive science and is well known for his books on design, like *The Design of Everyday Things* (1988) or *Living with Complexity* (2010).

Ref.: Norman, D., 2013. The Design of Everyday Things, Hachette UK.

Norman, D.A., 2010. Living with Complexity, MIT Press.

19 Ref.: Norman, D.A., 1993. Things that Make Us Smart, Basic Books.

20 Ref.: Tufte, E.R., 1997. Visual Explanations, Graphics Press USA, p. 45

The third book by Edward Tufte,[21] *Visual Explanations*, discusses in the chapter "*Visual and Statistical Thinking: Displays of Evidence for Making Decisions"* discusses the launch of the Space Shuttle Challenger and how information visualization played a role in the takeoff. Seventy-three seconds after the rockets were ignited, the Challenger exploded on January 28, 1986. The day before the launch, the ambient temperatures were predicted for the next day to be around -1° Celcius (20°F), and the engineers who designed the rocket opposed the start of the shuttle. Tufte's narrative of the explosion is centered around the communication between the engineers who knew about the dangers of low temperatures for launching the shuttle and the managers at NASA who could not be convinced of the problem. The arguments against the takeoff failed, for Tufte, due to a set of 13 charts in which the analysis and presentation of the data around the temperature problem were not convincing. Tufte writes:

> *"Displays of evidence implicitly but powerfully define the scope of the relevant, as presented data are selected from a larger pool of material. Like magicians, chartmakers reveal what they choose to reveal. That selection of data—whether partisan, hurried, haphazard, uninformed, thoughtful, wise—can make all the difference, determining the scope of the evidence and thereby setting the analytic agenda that leads to a particular decision."*
>
> *— Edward Tufte* [22]

Tufte's narrative allows for a nuanced look at the topic of externalizing cognition. The Challenger explosion happened due to the lack of plausible communication between the engineers and the management. In the chapter, Tufte presents a number of charts he redesigned, which give alternative views of the link between low temperatures and rocket failures. For Tufte, the engineers had the information to make an argument against the launch but were unable to get their argument across due to their failure to communicate their concerns through the data. This case study is not as much about externalizing cognition as about the rhetoric used in visually communicating an argument. Tufte shows how the design process from the data to a series of visual representations can result in very different narratives and views. This is a story not only about amplifying

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[21] Edward Tufte calls himself *"a statistician and artist, and Professor Emeritus of Political Science, Statistics, and Computer Science at Yale University."* 99 He wrote four books on the visualization of information, *The Visual Display of Quantitative Information* 100, *Envisioning Information* 103, *Visual Explanations* 101, and *Beautiful Evidence* 102.

[22] Ref.: Tufte, E.R., 1997. Visual Explanations, Graphics Press USA, p. 45

cognition, but furthermore about the design process and how this process can result in different perspectives for different viewers. In this context, the designer becomes a *magician*, deciding what to show, how to show it, and what to leave out. Visualization becomes a magic trick rather than merely an externalization of cognitive processes. Tufte understands that there is more to the process of visualizing something, selecting information, and inscribing it to a two-dimensional surface than pure externalization.

Card et al. reference this example but do not discuss the full story Tufte is telling. The question of the design process, which is focused on adding, transforming, and alternating rather than purely externalizing, is left out. Tufte's discussion of the Challenger tragedy offers a nuanced look at the mediations between our internal and external worlds that shape the experience and knowledge we can accomplish through these graphics. The magic of showing, hiding, and leaving out happens within the transformation of the design process. The argument I will develop further is thus that *insight emerges operatively through design choices of representation.* Card et al., on the other hand, write:

> *"The progress of civilization can be read in the invention of visual artifacts, from writing to mathematics, to maps, to printing, to diagrams, to visual computing. ... It is clear that the visual artifacts we have discussed so far have profound effects on peoples' abilities to assimilate information, to compute with it, to understand it, to create new knowledge. Visual artifacts and computers do for the mind what cars do for the feet, or steam shovels do for the hands."*
>
> — *Card et. al.* [23]

This short inspection of the design process in the Challenger tragedy hints that there is more to visualizing data than a direct transformation from data to knowledge. Visual artifacts might not only do to our mind what cars do to our feet.

The externalization and amplification of cognition leads to what Card et al. call knowledge crystallization. This crystallization consists of multiple steps, from gathering information to constructing a representational framework to make sense of the information, communication, and action. Figure 15 illustrates this knowledge crystallization and the arrow operates as the connecting symbol

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[23] Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann.

between the steps. For their argument, the authors mainly rely on a reference from *The Illusion of Reality* by Howard L. Resnikoff, (1987).[24]

Knowledge crystallization in this framework has three constitutive factors: data, a task, and a schema. The idea that visualization only functions within such operative settings of task, schemata, and data searches creates a set of intriguing questions that are not considered in *Using Vision to Think*. The arrow becomes the graphic symbol of the connection between the mind, its cognitive processes, and the externality of our maps, graphs, and computer screens. A closer look at the example of the Challenger tragedy hints that the connection between data visualization and knowledge might be more than crystallization. The symbolism of the arrow might not tell the entire story of how visualizations create insight. The arrow hints at a seemingly perfect transmission between cognition and representation, between data and knowledge. Visualization becomes an invisible and undisturbed channel of communication.

Coda

The diagrams presented and investigated in this section have one common thread: They connect cognitive processes to the graphical representations of data. This connection is visually represented by the symbol of the arrow, from the mental to the graphical. The underlying assumption for visualizing data in these representations is to find patterns. From this perspective, visualization design means optimizing our pattern-seeking visual system. The efficiency in grasping patterns is the core of this research. The rasterization of visual elements in Chapter 2 creates a toolbox of visual possibilities within the design space of graphical representations. The arrow narrows down this toolbox by connecting our cognition to these visual elements. *Good design is determined by the efficiency of seeing patterns within data.* Both diagrams in Figures 13e and 13f start with the knowledge base. Again, visualization makes knowledge evident, but knowledge is already given in this conception. The interlude of Edward Tufte's notion of the visualization designer as magician interrupted this apparent connection from data to insight. The Challenger example hints that there is more to visualizing data than a direct transformation. The arrow neglects the actuality that

24 Ref.: Resnikoff, H.L., 2012. The Illusion of Reality, New York, NY: Springer Science & Business Media.

visualizations are designed, created artifacts and not simple arrows from paper or screen to our perception and cognition. In the second part of this work, my forthcoming theory will investigate what Tufte calls ‘magic,’ the relationship between design and insight.

Chain

My initial question as to how insight, knowledge, and truth become apparent by visualizing data has not been answered by categorizing visualization constituents nor by studying the cognitive processes. One finding of this investigation so far is that the more detailed the research becomes, the further it departs from the objective of attaining insight. Other goals, such as efficiency, effectiveness, and finding patterns, suddenly come into focus. These questions are not unrelated to insight, but do avoid the actual issue at hand.

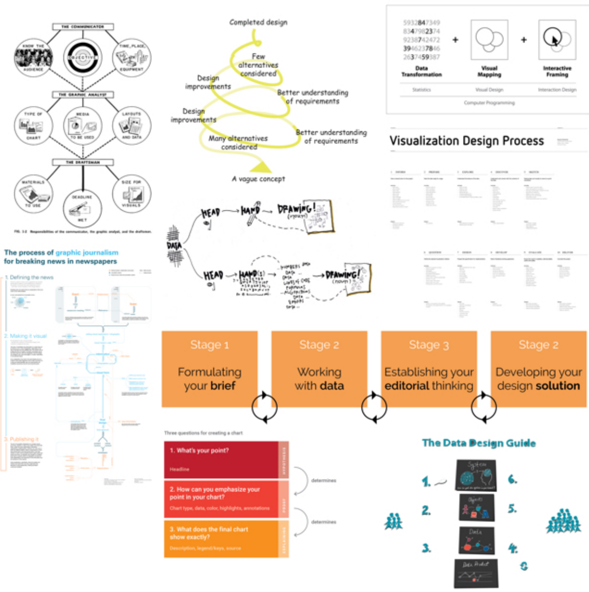

Figure 16: Linear representations

This third investigation looks at the conceptualizations of the visualization design process. I compare, categorize, and discuss 27 diagrams throughout this chapter. This chapter will be longer than the previous ones, as it lies at the center of the question I am investigating: How can the process of creating a data visualization create otherwise unseen insights? [1]

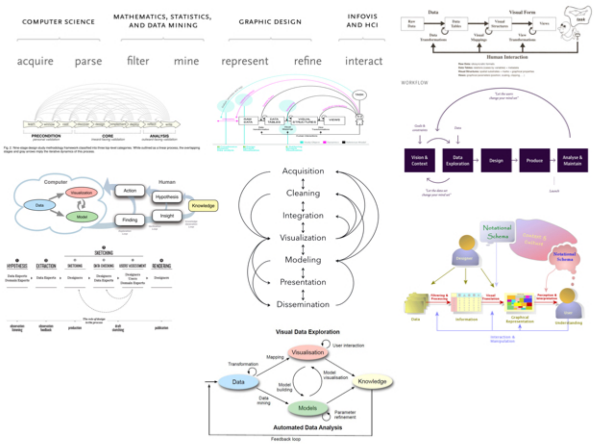

Figure 17: Feedback representations

What follows is an overview of all diagrams. Of the 27 representations, 24 depict the design process with two basic elements: orbs and links. Orbs are circles or boxes that contain text elements. The links are arrows or lines that connect the orbs; seldom are these also labeled. Each orb represents one task within the process, and the arrows signify the connections between the stages. This interplay between orbs and arrows is what I specify as the symbol of the chain. Apart from the linear horizontal pathways through the chain, there are often backchannels, arrows that leap from a task back to previously accomplished steps. Designing information visualizations becomes an interplay of interlinked tasks.

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1 This is likely the largest collection of visualization design process representations existing today. I originally started with five diagrams, but the networked community on Twitter very much expanded my perspective, and the list grew tremendously with this tweet: https://twitter.com/kimay/status/1097793415222362113 . This tweet received over 55,000 responses in one year and very much set the foundation for this chapter. I want to thank everyone who commented, suggested processes, and shared this request. The reach of this question not only impresses me but also shows how relevant this topic is for many people.

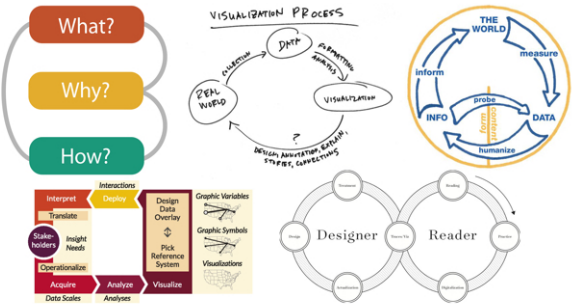

Figure 18: Circular Representations

The similarity, not in content but in representation, is striking considering that these diagrams are created from vastly different fields of research and application. The areas these graphics emerged from range from computer science and design to cognitive science and journalism. In all fields, the design process is imagined similarly. The representation of design at its most fundamental level as chains is not restricted to visualization design. Mapping the design process as this figurative expression has a long-lasting history. The book *How do you design? A Compendium of Models* [2] from 2004 by Hugh Dubberly collected 100 design processes with similar stages from input and process to output. Most of these processes are chains. The oldest process Dubberly found dates back to the 1920s and maps the process of developing a battleship for the Royal Navy.

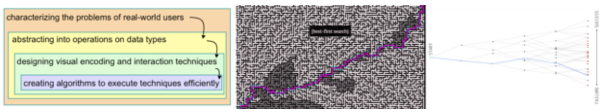

Figure 19: Alternative Depictions

Similar to the previous chapters, I will examine the representations and accompanying descriptions to identify motives and objectives. I first categorize the representations into four metaphors, *linear*, *feedback*, *circular*, and *alternatives*. Within each category, I will order each process depiction by the date of creation, from the earliest to the most recent.

2 Ref.: Dubberly, H., 2004. How do you design?

Linear Representations

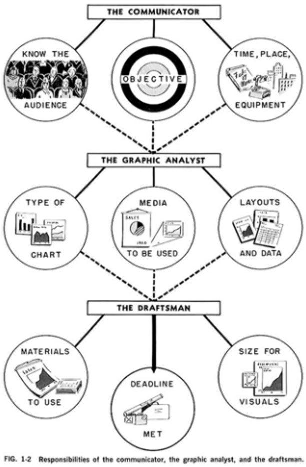

Figure 20: *Practical Charting Techniques* [3]

Practical Charting Techniques, published by Mary Eleanor Spear in 1969, is the earliest representation in this collection. The graphic depicts a networked interplay of stakeholders, media, and objectives of information visualizations within the publishing industry. The graphic focuses on charting techniques in journalism. The final stage of the diagram is ‘deadline met,’ efficiency over insight.

3 Ref.: Spear, M.E., 1969. Practical charting techniques, McGraw-Hill Companies.

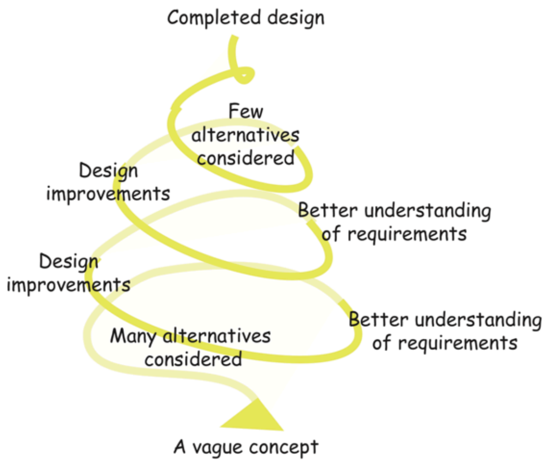

Figure 21: *Visual Thinking* [4]

The design process in Colin Ware's book *Visual Thinking* is something in-between a linear and a feedback depiction of a linear, rising spiral. Ware leaves out some of the most common features of most representations, as he depicts neither data nor visual mappings in the graphic. Instead, the diagram focuses on design improvements and iterations toward a completed design. I see similarities to the graphic by Munzner in Figure 12 discussed in Section 2.4 in explaining the design space. Ware's version is a three-dimensional depiction of a path through the design space.

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4 Ref.: Ware, C., 2010. Visual Thinking, Elsevier.

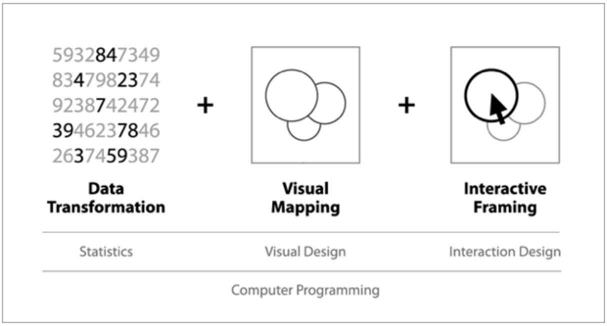

Figure 22: *Information Visualization Framework* [5]

The diagram by Manuel Lima lists three disciplines as the basis for data visualizations. Statistics, visual design, and interaction design are all bound together by computer programming. Data visualization becomes the interplay between statistics, design, and computer science. In the blogpost connected to this representation, Lima asks for a structural foundation of data visualization consisting of theory, taxonomy, and evaluation.

By observing the first three depictions, an intriguing difference becomes observable: Each process depiction illustrates a process over time, but each graphic does so on a different spatial dimension. The first graphic (Figure 20) moves from top to bottom, the second one (Figure 21) from bottom to top, and the third one (Figure 22) from left to right. I will not comment on this for each depiction, but while orbs and arrows are identical, the time dimension is in flux throughout the graphics.

Interaction designer Benjamin Wiederkehr[6] wrote his MA thesis between 2012 and 2014 at the Zurich University of the Arts.[7] [8] Part of the thesis was a ten-point

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5 Ref.: Lima, M., 2011. Information Visualization Framework. visualcomplexity.com. Available at: http://www.visualcomplexity.com/vc/blog/?p=1076 Accessed December 17, 2019.

6 Wiederkehr is founding partner of the Swiss-based design studio Interactive Things.

7 Wiederkehr writes that this ten-step guide is based on interviews with visualization participants like Gregor Aisch, Mike Bostock, Paolo Ciuccarelli, Amanda Cox, Jérôme Cukier, Nicholas Felton, Wes Grubbs, Ben Hosken, Sha Hwang, Andy Kirk, Aaron Koblin, Manuel Lima, Michal Migurski, Deroy Peraza, Sheila Pontis, Stefanie Posavec,

8 Ref.: Wiederkehr, B., Benjamin Wiederkehr's Master Thesis - Visualization Design

Visualization Design Process.[9] In his writing, Wiederkehr emphasizes the iterative nature of the process. Two leaps are essential: iterations from the question to preparation and repetition from evaluation to design. While the graphic representation suggests a linear approach, the concept is intended to be based on feedback. What is interesting to me is the difference between this process and the one Ben Fry (Figure 31) and well as Card et al. (Figure 29) suggest. While the first two are similar in perspective, Fry's is a more refined version of that of Card et al. Wiederkehr offers a slightly different angle. Inform, discover, sketch, and question have a less technical perspective and inform the human interactions throughout the process. The terminology from the introduction chapter *"From Pattern to Insight"* is repeated in Wiederkehr's design process with the terminology exploration and discovery.

Casey Reas, Kim Rees, Robin Richards, Moritz Stefaner, Jan Willem Tulp, and Marius Watz110.

Process. master.benjaminwiederkehr.com. Available at: http://master.benjaminwiederkehr.com/journal/design-process Accessed February 27, 2019.

[9] The following stages are part of Wiederkehr's process:

1. Inform: Have a shared vision for the project.

2. Prepare: Have the data ready for usage.

3. Explore: Understand the texture of the data.

4. Discover: Understand and connect with the contents of the data.

5. Sketch: Test ideas out visually to come to a quick conclusion.

6. Question: Verify the selected visualization method.

7. Design: Prepare the specification for implementation.

8. Develop: Build a flawlessly working application.

9. Evaluate: Ensure the result is readable, understandable, useful, and usable.

10. Deliver: Conclude the project.

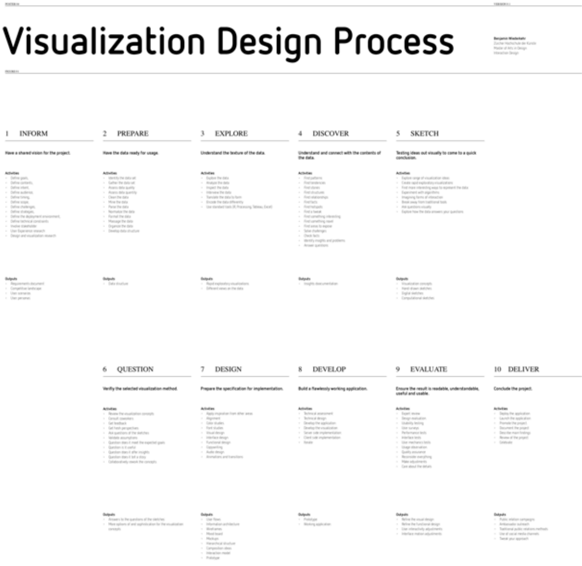

Figure 23: Design process by Benjamin Wiederkehr, 2014 [10]

The diagram *The process of graphic journalism for breaking news* by Irene de la Torre Arenas is the most detailed of all the collected representations. The graphic focuses on the process of visualizing data within breaking news journalism. One feature of the graphic, which is neglected by all other diagrams, are the values of the designer. Irene de la Torre Arenas lists three: honesty, clarity, and visual appeal.

10 Ref.: Wiederkehr, B., Benjamin Wiederkehr's Master Thesis - Visualization Design Process. master.benjaminwiederkehr.com. Available at: http://master.benjaminwiederkehr.com/journal/design-process Accessed February 27, 2019.

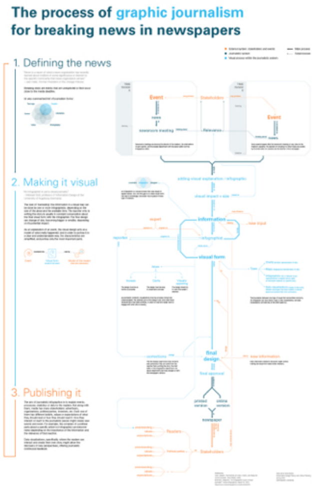

Figure 24: The process of graphic journalism for breaking news, Irene de la Torre Arenas, 2016 [11]

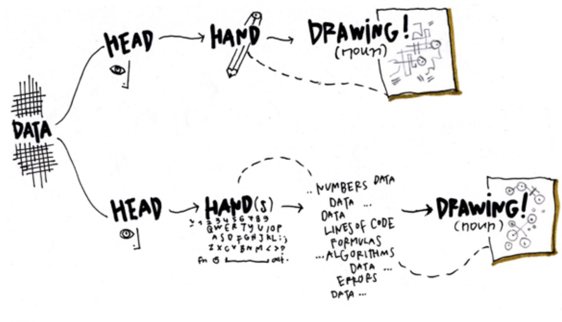

Figure 25: “Data, head, hand, drawing,” Giorgia Lupi, 2016 [12]

11 Ref.: de la Torre Arenas, I., 2016. The process of graphic journalism for breaking news... behance.net. Available at: https://www.behance.net/gallery/37259457/The-process-of-graphic-journalism-for-breaking-news Accessed December 17, 2019.

12 Ref.: Lupi, G., 2016. How Accurat's Giorgia Lupi Approaches Data-Viz Design. Available at: https://www.tableau.com/about/blog/2016/3/drawing-and-data-visualizations-tool-allow-connections-be-made-51060 Accessed February 27, 2019.

Designer Giorgia Lupi[13] sketches out her design process in four steps: data, head, hand, and drawing. The blogpost accompanying the graphic discusses a more complex process than the one outlined as Lupi writes:

> *"I see design as a way to translate a structural concept for a specific audience through a specific medium; design for me is also the process of visual planning and organizing the choices made along the way of a project, given its specific boundaries."*
>
> *— Giorgia Lupi*[14]

In this quote, I would interpret the process Lupi is describing more like this: structural concept > specific medium > specific audience. Suddenly, head, hand, and drawing are replaced by structure, planning, and organization. For Lupi, drawing is an essential ingredient in her design process. She writes:

> *"Drawing becomes design when you start tracing lines that help you rationalize what you think and envision as a possible solution."*
>
> *— Giorgia Lupi*[15]

Only two other diagrams throughout all processes mention drawing, Wiederkehr in his fifth point *"Sketch: Testing ideas out visually to come to a quick conclusion."*[16] and the EMAPS diagram.[17] Lupi turns drawing into her principal constituent, which gives the above quote even more relevance in her connection of drawing, design, and rationalization. While the diagram suggests a human intervention into data with its handwritten appearance and four-stage process, the quotes offer an

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13 Lupi is co-founder and Design Director of Accurat studio and co-author of the project 'Dear Data,' which was acquired by the Museum of Modern Art in New York in 2015.

14 Ref.: Lupi, G., 2016. How Accurat's Giorgia Lupi Approaches Data-Viz Design. Available at: https://www.tableau.com/about/blog/2016/3/drawing-and-data-visualizations-tool-allow-connections-be-made-51060 Accessed February 27, 2019.

15 Ref.: Lupi, G., 2016. How Accurat's Giorgia Lupi Approaches Data-Viz Design. Available at: https://www.tableau.com/about/blog/2016/3/drawing-and-data-visualizations-tool-allow-connections-be-made-51060 Accessed February 27, 2019.

16 Ref.: Wiederkehr, B., Benjamin Wiederkehr's Master Thesis - Visualization Design Process. master.benjaminwiederkehr.com. Available at: http://master.benjaminwiederkehr.com/journal/design-process Accessed February 27, 2019.

17 Ref.: Electronic Maps to Assist Public Science, 2012. EMAPS » Design process. emapsproject.com. Available at: http://www.emapsproject.com/blog/archives/1397 Accessed December 17, 2019.

alternative perspective. Structure, planning, organization, and rationalization suddenly become prominent. Sketching becomes a vehicle rather than a counterargument toward a structuralist and rationalist view of the design process.

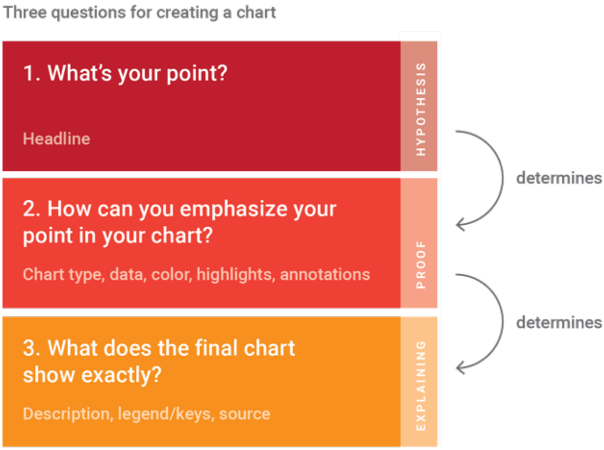

Figure 26: "Data Vis Workflow," Lisa Charlotte Rost, 2017 [18]

The first question in the "Data Vis Workflow" (Figure 26) by designer Lisa Charlotte Rost is, "What's your point?" Its emphasis is on expressing a specific viewpoint as visualized in and around the graphic. The diagram, in contrast to most other representations, emphasizes a subjective view. The article explaining the process does not explicitly mention a departure from objectivity, but the diagram and text do aim in that direction.

Figure 27: "The Four Stages of the Visualisation Workflow," Andy Kirk, 2016 [19]

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[18] Ref.: Rost, L.C., 2017. What Questions to Ask When Creating Charts. blog.datawrapper.de. Available at: https://blog.datawrapper.de/better-charts/index.html Accessed December 17, 2019.

[19] Ref.: Kirk, A., 2018a. Data Visualisation - A Game of Decisions with Andy Kirk, https://

The *“Four Stages of the Visualisation Workflow”* come from a 2016 book by Andy Kirk, titled *Data Visualisation: A Handbook for Data Driven Design*.[20] His design workflow mantra is *”Effective decisions, efficiently made”* .[21] Kirk combines the discussed transformation from Bertin to Munzner (Chapter Raster) in one sentence. Similar to the design process by Rost, [22] the orbs contain a subjective perspective. The starting point is the formulation of a brief, and especially the third point on editorial thinking for the development of a design solution suggests a viewpoint from which visualizations are designed.[23] The notion that someone is involved in the design process, that there is a perspective involved, should not be a groundbreaking idea, yet it is neglected in most of the previous chapters.

www.youtube.com/watch?v=GVkXbQOzKNs

Kirk, A., 2018b. Data Visualisation: A Game of Decisions. In Sage webinar.

20 Ref.: Kirk, A., 2019. Data Visualisation, SAGE.

21 Ref.: Kirk, A., 2018. Data Visualisation: A Game of Decisions. In Sage webinar.

22 Ref.: Rost, L.C., 2017. What Questions to Ask When Creating Charts. blog.datawrapper.de. Available at: https://blog.datawrapper.de/better-charts/index.html Accessed December 17, 2019.

23 A webinar hosted by the SAGE publishing company with Andy Kirk is titled “Data Visualisation: A Game of Decisions” 47. As I will show later, multiple authors refer to design as decision making, and this perspective will be examined further throughout the argument in the second part of this thesis.

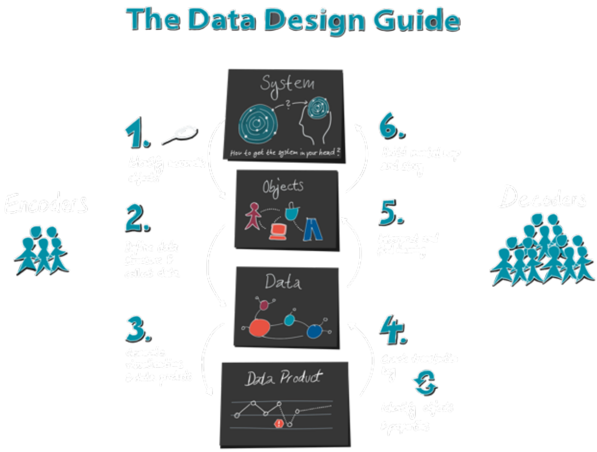

Figure 28: “The Data Design Guide,” Designation Agentur München, 2019 [24]

The starting point of the *“Data Design Guide”* sets its process apart from all other presented diagrams, as it begins with a *system* rather than a concept, data, or world. Placing systems as the foundation of any data visualization pre-configures the possible design space. Systems in comparison to *world* or *concept* imply a necessary structure, order, and arrangement of anything designed after that; previously named terms such as structure and organization become the starting point of this process depiction. A second significant feature of the *“Data Design Guide”* is a two-perspective view of encoders and decoders. The encoding and decoding are the same steps but reversed. The *“Data Design Guide”* maps out the process from both the creators and the perceivers’ perspective. Subjectivity concerning organization and structure performs an alternative narrative to that of efficiency and effectiveness.

[24] Ref.: Designation Agentur München, 2019. Why does no-one understand my data visualization?

Feedback Representations

While most diagrams in Section 4.1 already mention the iterative nature of the design process, the representations collected here indicate the iterative process of design within the graphic itself.

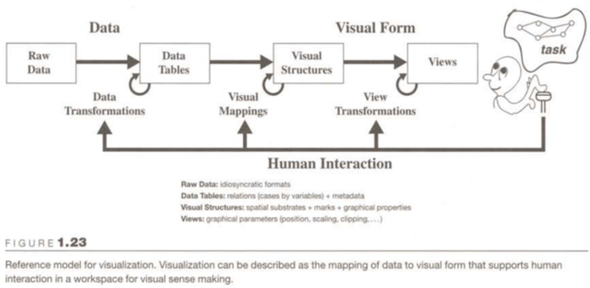

Figure 29: The interaction within the visualization interface, Card et al., 1999 [25]

Published in 1999, *Using Vision to Think* by Card et al., which I already discussed in the last chapter, introduces a *reference model for visualization*. The graphic does not directly address the design process, but rather the interaction process. However, it is still interesting to observe, as this diagram has directly or indirectly influenced many other representations. The first orb in the process is raw data, defined by idiosyncratic formats. Data transformations remove individuality from the raw data. The narrative from this first orb already links back to the previous finding of the design process as a creating structure. Coherent data tables with relations and metadata are the desired outcome of the first step. These related, aligned data tables are ready for visual mappings through the structures of the raster, discussed in Chapter 2. The proposed backchannel is the human interaction that connects back to every arrow within the system.

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25 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann.

While Card et al. postulate that insight is the purpose of visualization, as discussed in Section 3.1, the process diagram ends with tasks. The divergence between the goal of *insight* and the diagrammatic motive of *tasks* is prominent.[26] It is also intriguing to observe where this model unfolds from: The outside world from which data is collected is non-existent. Raw data is the foundation that needs to be cleaned up by removing idiosyncratic formats. The world is streamlined into the data table's raster, structure, and organization, again motivating the design process to visualize data.

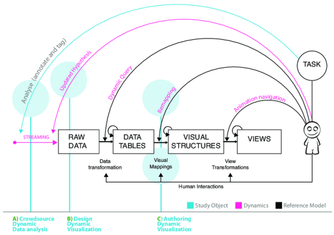

Figure 30: "Dynamic Visualization Pipeline," Samuel Huron, 2016 [27]

The "Dynamic Visualization Pipeline" by Samuel Huron maps the visualization design process for streaming data. The orbs in this process map are the same as the ones in the process by Card et al.[28]. Another layer of feedback arrows depicting the graphic, streaming, design dynamics, and data analysis become prominent parts of the representation.

Figure 31: Ben Fry's seven-step process from the acquisition of data to the interaction within the visualization interface [29]

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26 The contribution of this book offers one way to close the gap between high-level purpose and low-level process.

27 Ref.: Huron, S., 2014. Constructive Visualization : A token-based paradigm allowing to assemble dynamic visual representation for non-experts.

28 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann.

29 Ref.: Fry, B., 2004. computational information design.

Benjamin Fry's[30] dissertation *"proposes that the individual fields be brought together as part of a singular process titled Computational Information Design."*[31] Fry developed his thesis around a seven-step process from the acquisition of data to the interaction within the visualization interface. The different orbs in the diagram are allocated to various fields of research, from Computer Science to Mathematics, Statistics, and Data Mining, to Graphic Design, InfoVis, and HCI. The design process through the orbs becomes a journey through different fields of research and different mindsets.

30 One of the two founders of the creative programming environment "Processing," who also established the fathom design studio and completed his Ph.D., supervised by John Maeda, at the MIT Media Laboratory in 2004.

31 Ref.: Fry, B., 2004. computational information design.

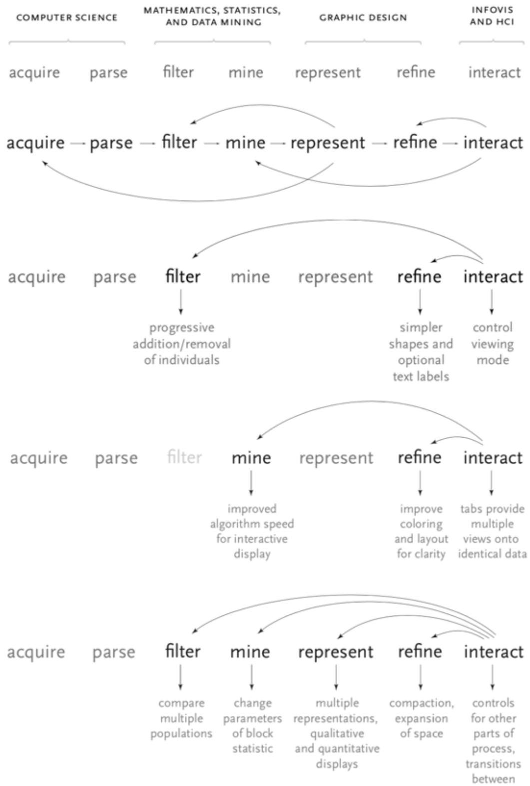

Figure 32: A collection of all five schemas from the book. The various iteration leaps are drawn from actual projects discussed throughout the thesis. [32]

The first step in Fry's process is the acquiring stage. This step asks the question of where the data comes from. Rather than asking who collected the data or for what purpose, Fry discusses the question in technical terms. Different data sources that are listed and described are analog signals, file on disk, stream from a network, relational database or an entire field.[33] The steps following the acquiring stage, *parsing*, *filtering*, and *mining*, all structure and organize. The

32 Ref.: Fry, B., 2004. computational information design.

33 The acquiring stage seems like the right place to ask questions about who collected the data and for what reason. What is the agency of the collection? What political

Computational Information Design process is not just about representing the given data. Data is clustered, transformed, and mathematically enriched. Mathematical and statistical methods can alter and turn the previously given into something different, which did not exist before this step. The fifth and sixth steps *represent* and *refine* are concerned with the graphical representation of the data. These two orbs are guided by questions such as: *"How can this be shown most cleanly, most clearly?"* or *"Why is that ugly and confusing?"*.[34] Benjamin Fry refers here to Edward Tufte, who is known for quotes like the following:

> *"Graphical excellence is that which gives to the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space."*
>
> *— Edward R. Tufte* [35]

Clarity, efficiency, and simplicity are the motivations behind graphical excellence. Such a perspective is known in other design areas and is famously postulated by Dieter Rams in the dogma *As Little Design as Possible* (2011).[36] Rams writes:

> *"Good design is as little as possible. Less, but better, because it concentrates on the essential aspects, and the products are not burdened with non-essentials. Back to purity, back to simplicity."*
>
> *— Dieter Rams* [37]

Fry makes the connection very clear when he writes:

motivations drive this viewpoint? These questions are not addressed within this framework.

34 Ref.: Fry, B., 2004. computational information design, p. 110

35 Ref.: Tufte, E.R., 1983. The Visual Display of Quantitative Information, Graphics Press.

36 *Are We Human?* by Beatriz Colomina and Mark Wigley 22 offer a compelling alternative reading of what design could be outside of the frames quoted here. Their viewpoint will be picked up later in this book.

37 Ref.: Lovell, S., 2011. Dieter Rams: As Little Design as Possible, Phaidon Press.

“The focus should be on what is the smallest amount of data that can be collected, or represented in the final image, to convey something meaningful about the contents of the data set. Like a clear narrative structure in a novel or a well orated lecture, this type of abstraction would be something to boast about. A focus on the question helps define what that minimum requirements are.”

— Ben Fry [38]

Tufte, Rams, and Fry all search for simplicity in the design process. Tufte makes clear that this search for simplicity has the same underlying objective of efficient design. *Minimalism is the aesthetic of efficiency.* Fry’s quote contains the fitting noun *abstraction* in this respect. To reach abstraction, Fry turns to *contrast and differentiation* in graphic displays:

“The goal of information design is to show comparisons between elements.”

— Ben Fry [39]

For Fry, a comparison is highlighted through three variables: contrast, hierarchy, and grouping. Size, color, and placement are the three methods Fry identifies as most effectively creating differentiation. The last orb in the ”Computational Information Design” process is *Interact*. The compelling aspect of the Computational Information Design process is its multidisciplinary approach and its application in the design process. The framework and the applied design process merge. Fry embeds the leaps between various steps from data to interaction into actual projects. The schema emerges from projects, which inform the reflection structure of the modeled process, to discuss and reiterate the schema. Fry creates a symbiosis between the theoretical framework and its application.

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38 Ref.: Fry, B., 2004. computational information design, p. 90

39 Ref.: Fry, B., 2004. computational information design, p. 110

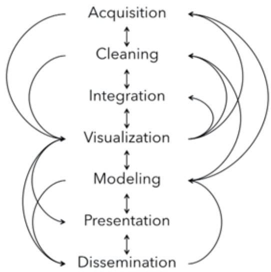

Figure 33: “Constructing Charts and Graphs,” Jeff Heer, 2018 [40]

Jeff Heer’s feedback chain has much in common with the process Ben Fry mapped out 14 years earlier. Something unique about the process is that *visualization* is followed by *modeling*. In a public talk by Heer,[41] the two steps and the relation between them are not clarified.

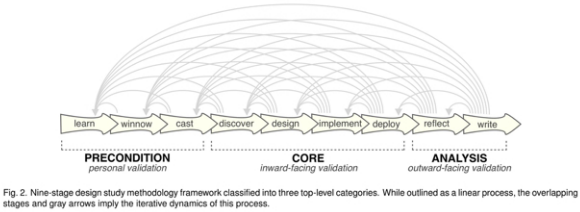

Figure 34: “Nine-stage design study methodology framework,” Michael Sedlmair, Miriah Meyer, and Tamara Munzner, 2012 [42]

The “Nine-stage design study methodology framework” outlines the process of conducting visualization design studies, which gives this diagram a different perspective than all the others. The framework is divided into three main

40 Ref.: Heer, J., 2018. Constructing Charts and Graphs. In Revisiting Cybernetic Serendipity. Washington.

41 Ref.: Heer, J., 2018. Constructing Charts and Graphs. In Revisiting Cybernetic Serendipity. Washington.

42 Ref.: Sedlmair, M., Meyer, M. & Munzner, T., 2012. Design Study Methodology: Reflections from the Trenches and the Stacks. IEEE Transactions on Visualization and Computer Graphics, 18(12), pp.2431–2440.

sections: “precondition,” “core,” and “analysis.” Most of the other presented models focus on the second part, “core,” on designing a graphic from data. The “discover” stage in the model investigates “if and how visualization can enable insight and discovery.” This is the first of all the design processes discussed here that mentions insight, not inside the graphic, but in the text. Insight from this perspective precedes the design stage and its data abstraction, visual encoding, and interaction. Visualization from this perspective only narrates the insights that become visible.

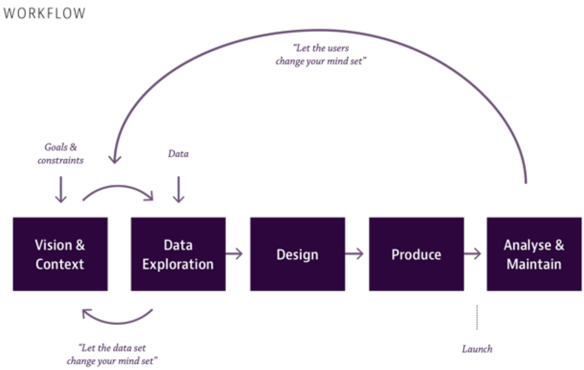

Figure 35: “Workflow,” Moritz Stefaner, 2014 [43]

The self-proclaimed *truth and beauty operator* Moritz Stefaner in an interview with David Bihanic for the book *New Challenges for Data Design*[44] discussed and mapped out his design process. Similar to Wiederkehr but different to Ben Fry and Card et. al., Stefaner maps the process from an applied perspective.[45] The orbs *Vision & Context* and *Data Exploration* loop into one another in this depiction, as Stefaner

43 Ref.: Bihanic, D., 2014. New Challenges for Data Design, Springer.

44 Ref.: Bihanic, D., 2014. New Challenges for Data Design, Springer.

45 Stefaner proposes the following set of questions:

- Why are we doing this?
- What are you hoping to achieve?
- Who are we targeting?
- How is the end product going to be used?
- How are we publishing?

notes: *"Let the data set change your mind set."* The last orb loops back into the first, as Stefaner writes: *"Let the users change your mind set."* Stefaner closes his design process with *analyse and maintain*; neither *truth* nor *beauty* are mentioned in the process.

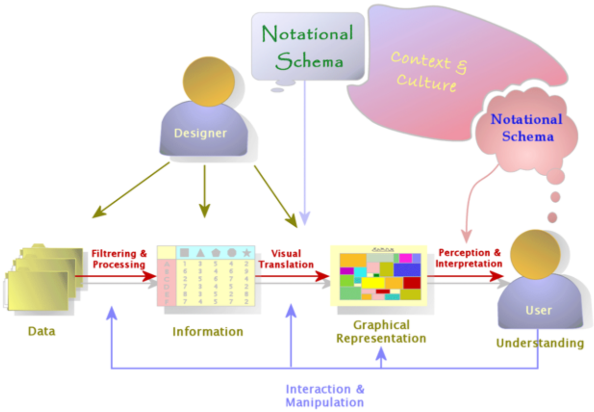

Figure 36: "InfoVis Diagram," Juan C. Dürsteler and Yuri Engelhardt, 2007 [46]

While the orbs and arrows in the depiction from Juan C. Dürsteler and Yuri Engelhardt hold similarities to that of Card et al. (Figure 29), their adjustments have consequences. The final orb *user* contains the sub-line *understanding*. Besides this, the two schema bubbles above the orbs are unique for including the

- What data do we have available?
- Which other existing materials should we take into account?
- Which constraints do we have?
- Who is responsible for what?
- Who else is doing something similar?

These questions are less driven by data transformations and more driven by goals and motivations.

46 Ref.: Dürsteler, J.C. & Engelhardt, Y., 2007. InfoVis Diagram. infovis-wiki.net. Available at: https://infovis-wiki.net/wiki/2007-02-15:_New_issue_of_Inf@Vis!_(infovis.net)_on_%22InfoVis_Diagram%22_available Accessed December 17, 2019.

designer, *context* and *culture*. The *designer* creates a schema from information to a graphic that the *user* encodes. Both need to share an encoding and decoding space given by culture and context. This perspective holds similarities to that depicted in Figure 28, as it not only looks at the designer but also includes decoding and encoding as a subjective perspective within the process. Structure and subjectivity are set in relation with one another by Juan C. Dürsteler and Yuri Engelhardt.

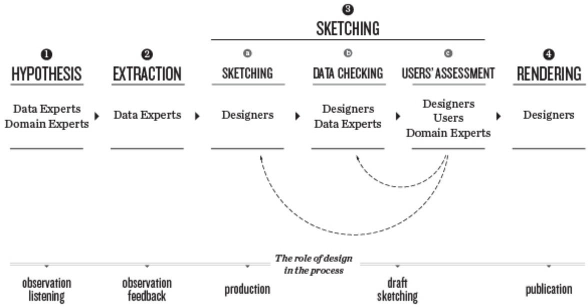

Figure 37: "Design Process," EMAPS project, 2012 [47]

The "Design Process" by the EMAPS project emphasizes what they call the "sketching" part of the process, similar to Figure 25 and Figure 23. The process map originated from a workshop in the context of mapping controversies. The starting point of the diagram is a *hypothesis*.

[47] Ref.: Electronic Maps to Assist Public Science, 2012. EMAPS » Design process. emapsproject.com. Available at: http://www.emapsproject.com/blog/archives/1397 Accessed December 17, 2019.

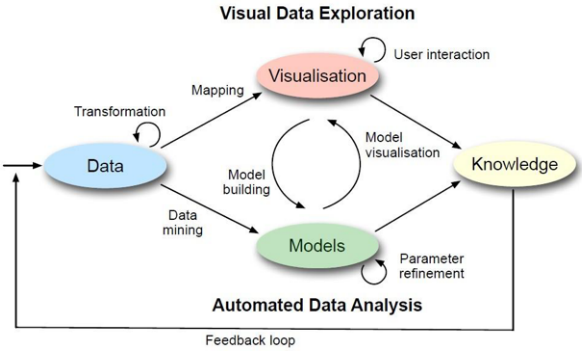

Figure 38: “Visual Data Exploration,” Daniel Keim, 2008 [48]

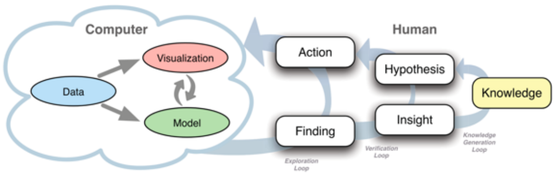

Figure 39: “Knowledge Generation Model for Visual Analytics,” D. Keim et al., 2014 [49]

The two representations from the research group *Data Analysis and Visualization* around Prof. Dr. Daniel A. Keim are the only depictions that include *knowledge* as a result of the design process in their diagrams. The paper “*Visual Analytics: Definition, Process, and Challenges*” [50] follows the same rhetoric as the collected quotes in the prologue. Knowledge is *resting in unexplored data sources* or *advanced knowledge discovery algorithms have been employed*. What is meant by knowledge is neither defined nor discussed.

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48 Ref.: Keim, D. et al., 2008. Visual Analytics: Definition, Process, and Challenges. In Information Visualization. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, Berlin, Heidelberg, pp. 154–175.

49 Ref.: Sacha, D. et al., 2014. Knowledge Generation Model for Visual Analytics. Visualization and Computer Graphics, IEEE Transactions on, 20(12), pp.1604–1613.

50 Ref.: Keim, D. et al., 2008. Visual Analytics: Definition, Process, and Challenges. In Information Visualization. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, Berlin, Heidelberg, pp. 154–175.

The paper "*Knowledge Generation Model for Visual Analytics*" , [51] published six years after the first article, defines knowledge and truth. The authors refer to knowledge as *justified belief*. In the introduction of this section, I already discussed this definition of knowledge and the accompanying Gettier problem in Chapter 1. In short, the Gettier problem states that justified and true opinion can also be true by *accident*. Justified belief does not provide a convincing and problem-free answer on how to understand knowledge; furthermore, in data visualization, *the reference to justified belief does not indicate the role of design in creating insight.* The definition of insight in the paper develops a unit of information from previous domain knowledge. Patterns allow for insights, and trusted insights create knowledge. Another concern I have about these two depictions is the starting point of both diagrams: data. While the definition of knowledge as *justified belief* has conceptual problems, both models also neglect the process of moving from the external world into the computer and its data structures. Keim et al. apply data from its Latin root, *the given*.[52]The role of mapping, transforming, and designing are not mentioned. *Knowledge generation* is a seamless act that neglects design.

In the prologue, I have shown how *insight*, *knowledge*, and *truth* are often named as central reasons for visualization design. Only a handful identify these terms as an outcome of the design process. Both representations come from the same research group. Insight, knowledge, and truth are terms that make bold statements, but these terms almost disappear in the observation of the articulated processes. Structure and organization appear as the motives of the design process in almost all representations.

Circular Representations

The third category of representations I have identified is circular representations. From steps and iterations, the graphics depict the process as never-ending loops. Start and endpoints are not defined but intermingle with

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51 Ref.: Sacha, D. et al., 2014. Knowledge Generation Model for Visual Analytics. Visualization and Computer Graphics, IEEE Transactions on, 20(12), pp.1604–1613.

52 Johanna Drucker proposed the term *capta*, *the taken* instead of data 27 and Bruno Latour suggested *sublata*, that is, of *achievements* 55, p. 55.

each other. Most models in this category contain larger categorizations and, intriguingly, consist of fewer orbs.

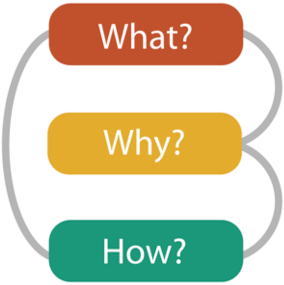

Figure 40: Three-part analysis framework for a vis instance, Tamara Munzner, 2014 [53]

The three-step model by Tamara Munzner, "What?, Why?, How?" guides her book *Visualization Analysis and Design*. Parts of the book are discussed in Section 2.4. Munzner's process consists of a broad scope with vast untangling and articulations within each of the three categories.

[53] Ref.: Munzner, T., 2014. Visualization Analysis and Design, CRC Press, p. 17

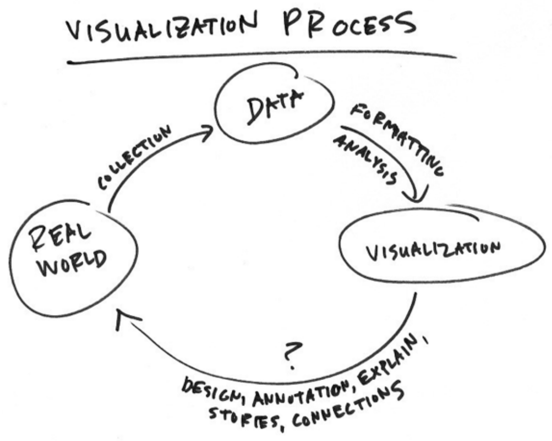

Figure 41: "Visualization Process," Nathan Yau, 2016 [54]

Nathan Yau's visualization design process diagram is one of the simplest; like Munzner's, it only contains three orbs. Yau writes on his blog:

> *"Whatever it is you're looking for, remember this path to reality."*
>
> — "Visualization Process," *Nathan Yau* [55]

Of all the design process diagrams, only three include some attachment to the real world;[56] the majority of representations start with data.

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54 Ref.: Yau, N., 2016. Shorten the Visualization Path Back to Reality. flowingdata.com. Available at: https://flowingdata.com/2016/09/14/shorten-the-visualization-path-back-to-reality/ Accessed December 17, 2019.

55 Ref.: Yau, N., 2016. Shorten the Visualization Path Back to Reality. flowingdata.com. Available at: https://flowingdata.com/2016/09/14/shorten-the-visualization-path-back-to-reality/ Accessed December 17, 2019.

56 Ref.: Andrews, R.J., 2019. Info We Trust, John Wiley & Sons.

Munzner, T., 2014. Visualization Analysis and Design, CRC Press, p. 17

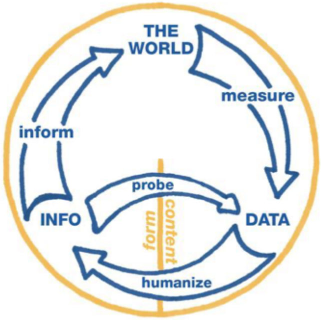

Figure 42: *Info We Trust*, RJ Andrews, 2019 [57]

The design process diagram by RJ Andrews from his book *Info We Trust* consists of two loops: one small loop between *data* and *info* and one larger loop additionally including *the world*. Andrews separates the data/info loop in terms of content and form. The arrows between data and info are labeled *humanize* and *probe*. Data and information are distinct from humanization in this representation.

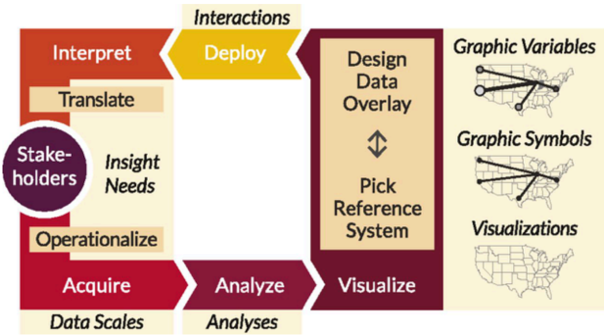

Figure 43: “Data Visualization Construction and Interpretation,” Katy Börner, Andreas Bueckle, and Michael Ginda, 2019 [58]

57 Ref.: Andrews, R.J., 2019. Info We Trust, John Wiley & Sons.

58 Ref.: Börner, K., Bueckle, A. & Ginda, M., 2019. Data visualization literacy: Definitions, conceptual frameworks, exercises, and assessments. National Academy of Sciences, 116(6), pp.1857–1864.

The *"Data Visualization Construction and Interpretation"* diagram by Börner et al. places a particular emphasis on the stakeholders. Apart from that of the Konstanz research group, this is the only diagram that mentions insight as a term within the chart. The two books by Börner are discussed in Section 2.3.

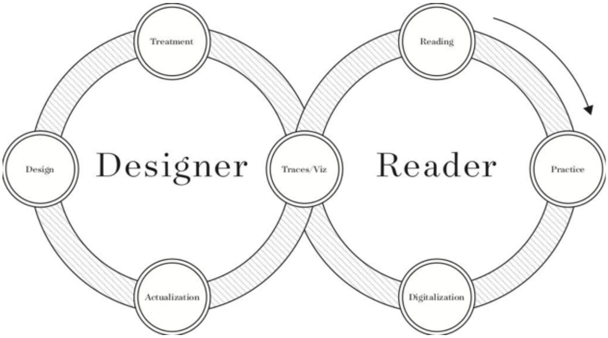

Figure 44: "The Hermeneutic Circle of Data Visualization," Dario Rodighiero and Alberto Romele, 2019 [59]

The *"Hermeneutic Circle of Data Visualization"* by Dario Rodighiero and Alberto Romele consists of two loops that are anchored by *Traces/Viz*. While multiple processes include the reader, viewer, and user in the design process diagram, this representation places equal emphasis on and gives both views the same amount of space in the graphic. The graphic and its accompanying paper hold intriguing humanistic and epistemological perspectives on visualization design. The paper reflects the constituencies between the human, technology, and the world. Visualization is described as a trace in relation to the world. The authors write: "*representations must be 'read' in order to access the world".*[60]

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[59] Ref.: Rodighiero, D. & Romele, A., 2020. The Hermeneutic Circle of Data Visualization: the Case Study of the Affinity Map. Techné: Research in Philosophy and Technology, 24(2).

[60] Ref.: Rodighiero, D. & Romele, A., 2020. The Hermeneutic Circle of Data Visualization: the Case Study of the Affinity Map. Techné: Research in Philosophy and Technology, 24(2).

Alternative Depictions

My last category consists of design process representations that do not fit the *orb/ arrow* distinction. It is noteworthy that only three of the entire 27 graphs fall into this subsection.

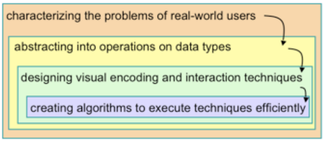

Figure 45: "A Nested Model for Visualization Design and Validation," Tamara Munzner, 2009 [61]

Tamara Munzner's "*Nested Model for Visualization Design and Validation"* nests boxes into one another, from *real-world users* to *data*, *encoding*, and the *algorithmic processes* behind the encoding. The dif ferent stages are nested into one another rather than chained. This perspective is more exhaustive than most other processes, even if it only contains four steps. First, it starts from *real-world users*, so there is anchoring in the world rather than a data-based perspective. Second, it includes the algorithmic processes behind the encoding. This diagram is the only process highlighting the algorithmic.

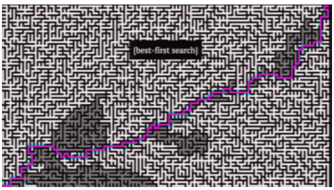

Figure 46: "Design is a Search Problem," Mike Bostock, 2014 [62]

61 Ref.: Munzner, T., 2009. A Nested Model for Visualization Design and Validation. IEEE Transactions on Visualization and Computer Graphics, 15(6), pp.921–928.

62 Ref.: Bostock, M., 2014. Design is a Search Problem. In OpenVis Conference.

Mike Bostock's[63] representation is the furthest away from the image of the chain of any of the diagrams discussed here. His metaphor visualizes design as a maze exploration, the design process as a quest through a labyrinth from where we are to where we want to be. Bostock acknowledges that the reduction of design to a question of efficiency is not sufficient. He describes design as subjective, not reducible to a simple logical system, as it contains the complexity of human factors[64] and is a biological problem, not just a mathematical one. At the same time, he asks for an algorithm to explore the design space more efficiently and calls for better practices to do so. Bostock defines his metaphor for the design space as *a tree that branches out and fills the entire space*.[65] Just like Ben Fry on the question of the objective of design, Bostock refers in his talk to Dieter Ram's notion that *good design is as little design as possible*: [66] the design process as a branching of a tree to search for the simplest possible solution.

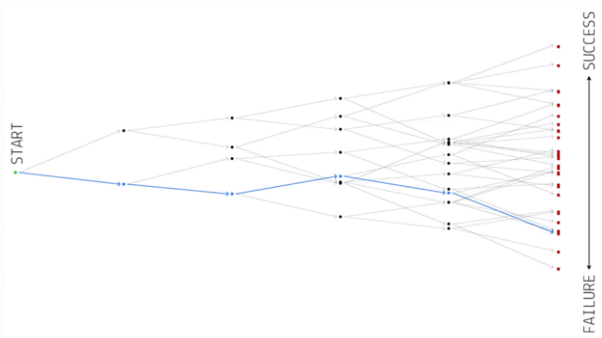

Figure 47: "The Keys to a Successful Data Design Process," Scott Murray, 2014 [67]

In 2014, Scott Murray created a survey on the visualization design processes. [68] One result of this effort was a talk titled "The Keys to a Successful Data Design Process." Similarly to Jaques Bertin's design process, Figure 8 on page 23, for

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63 From the keynote talk at the OpenVis Conference 2014.

64 Aspects of cognition, psychology, perception.

65 Ref.: Bostock, M., 2014. Design is a Search Problem. In OpenVis Conference.

66 Ref.: Lovell, S., 2011. Dieter Rams: As Little Design as Possible, Phaidon Press.

67 Ref.: Murray, S., 2014. The Keys to a Successful Data Design Process with Scott Murray, https://www.youtube.com/watch?v=ZMB_6OeCEP8

68 Ref.: Murray, S., 2014. data-vis-process. github.com. Available at: https://github.com/alignedleft/data-vis-process Accessed January 9, 2020.

Murray, the design process is a set of decisions. Each decision made branches out to other choices and determines the final design on a scale from success to failure. Similar to Mike Bostock, the metaphor of the design process is a branching tree of design choices.

Coda

Rather than thinking about the micro-scale combinations of points, lines, and areas, this view looks at the temporal interplay from a source to an outcome. It is intriguing to look at what is considered within these systems to ask what has been neglected.

Of the 27 processes, ten start with data or the acquisition of data. Only three diagrams name the actual world that we live in within the process.[69] Data is the source, rather than an already created product of a design process. Data is taken as 'the given' in this context. Another group of diagrams starts from a hypothesis, concept, briefing, situation, or context. While it is often not mentioned in the texts describing the processes, the underlying implication is one of a specific perspective. The starting point of data compared to starting from a perspective showcases a divide between objectivity and subjectivity throughout the depictions.

The last orb of the chain is also intriguing: Insights, facts, understanding, knowledge, truth, and wisdom are not mentioned in most processes. Only four of the 27 diagrams mention one of these terms. [70] And in four cases, the terms are not discussed either in much detail or at all in accompanying texts. *The design*

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69 Ref.: Andrews, R.J., 2019. Info We Trust, John Wiley & Sons.

Munzner, T., 2009. A Nested Model for Visualization Design and Validation. IEEE Transactions on Visualization and Computer Graphics, 15(6), pp.921–928.

Yau, N., 2016. Shorten the Visualization Path Back to Reality. flowingdata.com. Available at: https://flowingdata.com/2016/09/14/shorten-the-visualization-path-back-to-reality/ Accessed December 17, 2019.

70 Ref.: Börner, K., Bueckle, A. & Ginda, M., 2019. Data visualization literacy: Definitions, conceptual frameworks, exercises, and assessments. National Academy of Sciences, 116(6), pp.1857–1864.

Dürsteler, J.C. & Engelhardt, Y., 2007. InfoVis Diagram. infovis-wiki.net. Available at:

process and the claimed finding, revealing, discovering, and gaining of insights are disconnected. The resulting orbs' terminology is instead coupled with production: deliver, publish, produce, maintain, solution, stakeholders, task. The significance of visualization design being about insights, knowledge, and truth has often vanished once its design process conceptions are observed. *Visualization design is missing a theoretical foundation for how insights emerge from the design process.* Other meta-narratives have emerged, most prominently the articulations of design as creating *structure* and *order* as well as the drive toward simplicity in the graphics. Another narrative observed is the subjective view of both the designers and the observers of the diagrams. The previously identified goals of efficiency and effectiveness only play a minor role in the process depictions. This chapter's emerging question is: *How does structure, organization, simplicity, and subjectivity relate to insights?*

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https://infovis-wiki.net/wiki/2007-02-15:_New_issue_of_Inf@Vis!_(infovis.net)_on_%22InfoVis_Diagram%22_available Accessed December 17, 2019.

Sacha, D. et al., 2014. Knowledge Generation Model for Visual Analytics. Visualization and Computer Graphics, IEEE Transactions on, 20(12), pp.1604–1613.

Sacha, D. et al., 2014. Knowledge Generation Model for Visual Analytics. Visualization and Computer Graphics, IEEE Transactions on, 20(12), pp.1604–1613.

Pyramid

”where is the wisdom we have lost in knowledge? where is the knowledge we have lost in information?”

— “The Rock,” *Eliot, T.S.*, 1934 [1]

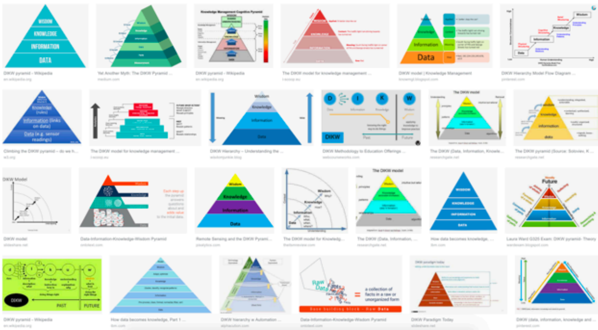

Figure 48: A screenshot of the first set of results from a google image search “DIKW.” Symbolic representations from data to wisdom.

Until this point, the state of the research showed a divide between the findings presented in the prologue to this thesis and the three metaphors examined in the subsequent chapters. The prologue showcased statements that identified insight, knowledge, and truth as the objectives of visualization design. Throughout the investigation of these three metaphors, the raster, the arrow, and the chain, this connection predominantly disappeared and other objectives emerged. The fourth metaphor discussed here offers one narrative on the relationship between data and knowledge. This chapter explores the connections and objectives of what is known as the *Knowledge Pyramid* and its relationship to visualization design.

The *Knowledge Pyramid* is a class of models that describe structural and functional relationships between data, information, knowledge, and wisdom. It is also

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1 Ref.: Eliot, T.S., 2015. The Poems of T. S. Eliot Volume II, Faber & Faber.

known as *Knowledge Hierarchy*, the *Information Hierarchy* or the *DIKW pyramid*. It is a widely recognized model in information management, information systems, and knowledge management.[2] The underlying assumption behind these models centers on the transformation of data into information, information into knowledge, and knowledge into wisdom.

Some readers will recognize the quote at the beginning of this chapter from Thomas Stearns Eliot as the first indication of the knowledge pyramid.[3] The origins, it appears, of the *Knowledge Pyramid* are based on a play first performed at Sadler's Wells Theatre in London. Eliot was a poet, essayist, publisher, playwright, and literary and social critic.[4]

In academic writing, the text *"From Data to Wisdom"* by Russell Ackoff (1989) is one of the first to publicize this transformational power. Ackoff writes:

> *"An ounce of information is worth a pound of data. An ounce of knowledge is worth a pound of information. An ounce of understanding is worth a pound of knowledge."*
>
> *— Russell Ackoff*[5]

Ackoff suggests a pyramid based on the following aspects: Data are symbols, usefully processed data that becomes information, which is useful when it provides answers to Who, What, Where, and When questions. Knowledge is the application of information to answer How questions. Wisdom and understanding ask questions about the Why, an evaluated understanding. Three years before Ackoff, Robert S. Taylor already wrote:

> *"Data are numerical entities or readily verifiable facts. Information is about adding relationships between elements of data. Knowledge emerges when humans interpret, analyze, and judge information, and can be used to inform or to help drive decision making."*
>
> *— Taylor* [6]

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2 Ref.: Rowley, J., 2007. The wisdom hierarchy: representations of the DIKW hierarchy. Journal of Information Science, 33(2), pp.163–180.

3 Ref.: Figueroa, A., 2019. Data Demystified—DIKW model. Available at: https://towardsdatascience.com/rootstrap-dikw-model-32cef9ae6dfb Accessed January 9, 2020.

4 Ref.: Bush, R., 1985. T.S. Eliot, Oxford University Press, USA.

5 Ref.: Ackoff, R., 1989. From Data to Wisdom. Journal of Applied Systems Analysis, pp.3–9.

Ackoff and Taylor espouse alternative narratives on the connections between the different levels. Ackoff postulates the relationships between Who, What, Where, When, How, and Why as defining the DIKW pyramid. Taylor further adds relationships, interpretation, and judgment to bridge the layers. These two views overlap on many levels, but also offer distinctions between questioning and networking. However, Ackoff also makes a statement that is crucial concerning all the previous chapters in this thesis, by writing:

> *"The value of the objective(s) pursued is not relevant in determining efficiency, but it is relevant in determining effectiveness. Effectiveness is evaluated efficiency. It is efficiency multiplied by value, efficiency for a valued outcome. Intelligence is the ability to increase efficiency; wisdom is the ability to increase effectiveness."*
>
> *— Russell Ackoff*[7]

In every metaphor I have investigated so far, the raster, the arrow, and the chain, one objective constantly reappears: *the striving toward efficiency and effectiveness.* In the above statement, Ackoff relates knowledge to efficiency and effectiveness. Ackoff's interpretation of the DIKW pyramid provides the missing link between the divergent objectives of visualization design.

The Pyramid and Visualization

The literature on knowledge management and its relation to the DIKW pyramid is extensive, and there are numerous divergent and alternate definitions. This chapter will not further investigate the research within these fields, but will instead observe the DIKW pyramid and visualization design's implicit and explicit relationships.

Some of the design process models in the previous chapter on the chain seem to unwittingly reference the DIKW pyramid. Both metaphors consist of layers of transformational processes to turn data into visualization and, by doing so, transform data into knowledge and truth. From Card et al.'s transformations from

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7 Ref.: Ackoff, R., 1989. From Data to Wisdom. Journal of Applied Systems Analysis, pp.3–9.

raw data to data tables and visual structures,[8] Benjamin Fry's *Computational Information Design* and its seven stages, [9] or *Visualization Design Process* by Wiederkehr,[10] all these processes include similar assumptions of the transformation from data to knowledge. The *raster*, as well as the *chain*, with their explicit goals of efficiency and effectiveness, fit well with Ackoff's theory without explicitly creating the reference.

Apart from these implicit relations between visualization design and the knowledge pyramid, there are also explicit connections. In a SAS company blog post named *"Data Visualization: From Information to Wisdom"*, Panagiota Vyrgioti writes:

> *"Unstructured information means reality, the world out there is organized in bits spinning around and coming to us in all the possible ways. Data are the records of this information that are encoded to structured information. This is the level that data visualization comes into the picture to enable the data communicators to give shape to data so that relevant patterns will become visible to the information consumers. Information consumption from structured information can lead to higher knowledge on the part of the audience. The role of the data visualization expert in this phase is to anticipate this process and generate order before people's brains try to do it on their own. Finally, wisdom is reached when we combine a deep understanding of the acquired knowledge, we blend new information with prior experience."*
>
> — SAS Blog, *Panagiota Vyrgioti* [11]

Data visualization is explicitly described as a tool to give shape to data and turn data into information and information into knowledge. What the quote directly addresses is frequently assumed in numerous other metaphors. The intriguing part of the above quote is the described role of the information designer to

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8 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann.

9 Ref.: Fry, B., 2004. computational information design.

10 Ref.: Wiederkehr, B., Benjamin Wiederkehr's Master Thesis - Visualization Design Process. master.benjaminwiederkehr.com. Available at: http://master.benjaminwiederkehr.com/journal/design-process Accessed February 27, 2019.

11 Ref.: Vyrgioti, P., 2016. Data Visualization: From Information to Wisdom. blog.sas.com. Available at: https://blogs.sas.com/content/brightdata/2016/08/01/data-visualization-from-information-to-wisdom/ Accessed March 14, 2019.

anticipate this process and generate order before people's brains try to do it on their own. The story in Chapter *arrow*, from Tufte reemerges here: *The designer makes specific choices in showing something and hiding something else. What Vyrgioti implicitly acknowledges here is the political power of design to turn data into a graphic representation.* The relation between the DIKW model and visualization in a business context is something not only SAS acknowledges. IBM has a three-part series on the DIKW model, databases, and Artificial Intelligence,[12] as well as an article on the connections between DIKW and visualization.[13]

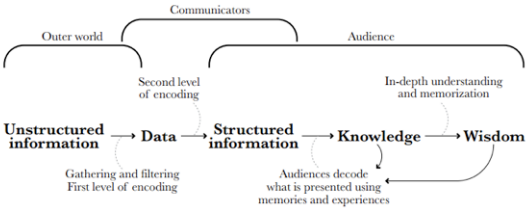

Figure 49: Alberto Cairo, *The Functional Art* [14]

Not only the business context, but also the data visualization context contains references to the knowledge pyramid. In the book *The Functional Art*, Alberto Cairo is directly referring to the DIKW Hierarchy. Cairo makes a connection to Richard Saul Wurman, a professor of architecture in North Carolina, who coined the profession of the *information architect* in the 1970s.[15] For Wurman, an *information architect* helps to avoid *information anxiety,* the *'black hole between data and knowledge'* .[16] The gap from data to knowledge becomes a space for creation, for architecture and design to bridge from the one to the other.[17] The first point in Cairo's diagram, visible in Figure 49, is *unstructured information*. Above the first

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12 Ref.: Rao, V.R., 2018. From data to knowledge. ibm.com. Available at: https://www.ibm.com/developerworks/library/ba-data-becomes-knowledge-1/index.html Accessed March 14, 2019.

13 Ref.: IBM Cloud Garage, Data and analytics for insights and visualization. ibm.com. Available at: https://www.ibm.com/cloud/garage/architectures/dataAnalyticsArchitecture/ Accessed March 14, 2019.

14 Ref.: Cairo, A., 2012. The Functional Art, New Riders.

15 Ref.: Wurman, R.S., 1997. Information Architects, Graphis Incorporated.

16 Ref.: Wurman, R.S., 1990. Information Anxiety, Bantam Books.

17 What I am interested in here is: If architecture and design can bridge the gap between data and knowledge, how does this 'bridge' influence the knowledge that we are

point is a bracket labeled *outer world*. The visual assumption is that the world is based on unstructured information. This is nothing Cairo made up himself, but rather a pattern observed across the literature on DIKW models. How can we assume the world is based on unstructured information? Is not information something we create and which only exists as structure? Cairo writes: *“In the diagram, unstructured information means reality, the world out there in all its glorious complexity. Every phenomenon that can be perceived or measured can be described as information.”* The second assumption contained within this quote is that every phenomenon is measurable and expressible as information. How does Cairo know these things? The second point, *data*, is achieved through gathering and filtering and leads from the *outer world* to the realm of *communication* through signs and symbols. Cairo claims:

> *“Data can be encoded as symbols (numbers and words) that describe and represent reality.”*
>
> *— Alberto Cairo* [18]

The relationship between symbols and reality is much more complex than as presented in the above quote. The idea that symbols describe and represent reality has been investigated by philosophers since at least the time of Socrates, Plato, and Aristotle. *Cratylus* written by Plato is a dialogue on whether language consists of arbitrary signs or rather an intrinsic relation to the world.[19] More recently, various trends in the literature have formulated arguments concerning the relationship between the symbolic and reality. For example, the *linguistic turn* [20] or the study of *semiotics* [21] showcase that this is not at all a solved question the way Cairo is describing it. The second step from *data* to *structured information* is the representation of *data in a meaningful way, using text, visuals, or other means.* In Cairo’s words: “*We can also say that this communicator has given shape to data, so that relevant patterns become visible.”*[22]

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obtaining? How are the medium of data and the medium of visualization contributing to the way we think about the world?

18 Ref.: Cairo, A., 2012. The Functional Art, New Riders, p. 16

19 Ref.: Sedley, D., 2003. Plato's Cratylus, assets.cambridge.org.

20 Ref.: Rorty, R., 1992. The Linguistic Turn, University of Chicago Press.

21 Ref.: Peirce, C.S., 1974. Collected Papers of Charles Sanders Peirce, Harvard University Press.

22 Ref.: Cairo, A., 2012. The Functional Art, New Riders, p. 16

Knowledge, for Cairo, is achieved when the audience is *"able to perceive the patterns or meaning of data"*. Knowledge, again, is coupled with the perception of patterns in this context. Wisdom is the connection to prior experience, leading to better assumptions about future situations. *What is left out of the discussion and where my research begins is the question of how giving shape influences patterns. How does the translation influence what we see? And how does this influence the knowledge we get out of these images?* What is the *'meaningful way'* Cairo talks about? Cairo summarizes his diagram:

> *"Every step in our diagram implies higher order. When we see the world, we unconsciously impose organization on the unstructured information that our eyes gather and transmit to the brain. We create hierarchies. We don't perceive everything in front of us at once..."*
>
> *— Alberto Cairo* [23]

Imposing order and organization onto the world as the principle leading to wisdom is the underlying narrative behind Cairo's description. My theory and approach, which I will explain in the next part of this book, will address a question that Cairo leaves open: "*How does imposing organization, as a process, relate to insights?"*[24] A quote by the founding executive editor of *Wired* magazine Kevin Kelly closes Cairo's chapter *"From Information to Wisdom"*:

> *"Minds are highly evolved ways of structuring the bits of information that form reality. That is what we mean when we say a mind understands; it generates order."*
>
> *— Kevin Kelly*[25]

During the investigation of all the metaphors throughout the last three chapters, knowledge was an elusive term. The knowledge pyramid offers a perspective on how visualization generates knowledge. Visualization is a method of structuring and placing order onto the world. *Order generates knowledge.*

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23 Ref.: Cairo, A., 2012. The Functional Art, New Riders, p. 17

24 The book by Dieter Mersch *Ordo ab chao – Order from Noise* investigates the connections between freemasonry, cybernetics, and the imposing of order onto the world. Chapter *Time* will relate to these concepts.

Ref.: Mersch, D., 2013. Ordo ab chao - Order from Noise.

25 Ref.: Kelly, K., 2010. What Technology Wants, Penguin.

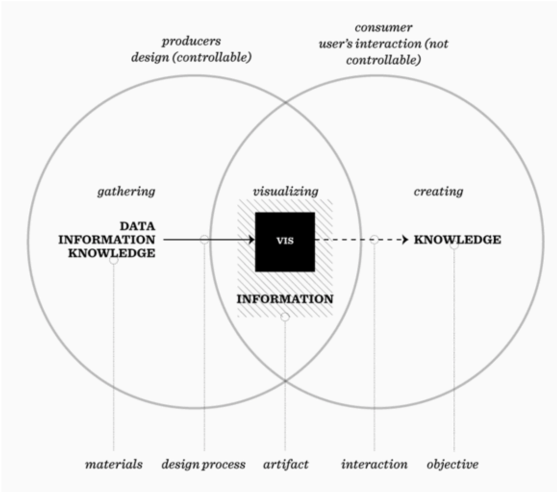

Figure 50: Density Design Research Group, *"From Data to Knowledge"*[26]

A scientific paper that discussed the DIKW pyramid in the context of visualization is "*From Data to Knowledge"* by the Density Design Research Group in Milano, Italy. In the paper, visualization is not seen as outcomes representing data, information or knowledge, but rather part of a process leading from data to knowledge:

> *"From a designer's perspective visualizations represent the process that moves from data to knowledge, where each visualization is seen as a transformation artifact within the data-information-knowledge continuum."*
>
> *— Masud, L. et al* [27]

Again, the transformational power of visualization is highlighted. Figure 50 implies that visualization represents an artifact between materials and objectives. The authors mention the political dimension of such a transformation:

[26] Ref.: Masud, L. et al., 2010. From data to knowledge-visualizations as transformation processes within the data-information-knowledge continuum. ieeexplore.ieee.org.

[27] Ref.: Masud, L. et al., 2010. From data to knowledge-visualizations as transformation processes within the data-information-knowledge continuum. ieeexplore.ieee.org.

> *“Visualizing means deciding what and how to show of a given data set or information.”*
>
> *— Masud, L. et al* [28]

The notion that visualization has to do with decisions was already hinted at multiple times in Chapter *chain*. Both Mike Bostock [29] and Scott Murray [30] refer to design as a tree of decisions, and Andy Kirk titled his talk *“Data Visualisation: A Game of Decisions”*.[31] The above quote goes one step further, as deciding *what and how to show* implies a political dimension. The question becoming apparent is the question of what Tufte called *magic*.

Is it possible for me to theorize the magic, the drawing of distinctions, the organization, and structuring design entails? If visualization design is about decisions, it is about a political act of deciding what to show, what to hide, and how to show something. What kind of knowledge can these graphics represent? If design is about creating structure, how does this affect insight? What concept of knowledge is guiding such research? In the next part, I will address these questions and formulate a novel theory on the relation between design and insight.

Coda

This chapter presented a short introduction to the DIKW pyramid, analyzed two explicit connections to visualization design, and showcased how implicit ideas embedded in the pyramid’s theory resonate with the previous chapters. The principles of knowledge and wisdom emerge from data and information as a way of ordering and structuring the world. Creating structure means creating knowledge within these models. The DIKW pyramid joins back into the prologue. The transformational power of visualization started with the image of design as a refinement from data to insight. This transformational power, structuring, and ordering are also for the knowledge pyramid the path toward knowledge. While over the last three chapters the connection between visualization and knowledge

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28 Ref.: Masud, L. et al., 2010. From data to knowledge-visualizations as transformation processes within the data-information-knowledge continuum. ieeexplore.ieee.org.

29 Ref.: Bostock, M., 2014. Design is a Search Problem. In OpenVis Conference.

30 Ref.: Murray, S., 2014. The Keys to a Successful Data Design Process with Scott Murray, https://www.youtube.com/watch?v=ZMB_6OeCEP8

31 Ref.: Kirk, A., 2018. Data Visualisation: A Game of Decisions. In Sage webinar.

mostly remains obscure, the knowledge pyramid highlights one idea of how to move from data to insights. The pyramid suggests that the more data we have, the more wisdom we can achieve. The theory is the perfect justification for massive data centers, big data, and the surveillance state. The distillery operates on the masses of data to create knowledge.

The first part of this chapter presented multiple variations on how the different layers within the pyramid are connected. Whether or not one can draw such a clear hierarchical connection between data, information, knowledge, truth, and wisdom is in question. Turning the one into the other could also be read as a contemporary version of alchemy. Just like transforming lead into gold, we might not be able to transform data into wisdom. And even if design can distill data into knowledge, how do the two relate to reality? DIKW leaves out the reality that we all inhabit. Data is the foundation without reflecting its relation to the outside world.

The objectives of this chapter were pre-determined: knowledge and wisdom. The narrative around how to realize this objective was declared clearly: Generating order, structuring the world, measuring, and sorting will guide humankind toward wisdom. In the second part, I will introduce a meta-theory of design, asking about the smallest unit contained within the act of designing a structure. By doing so, I will be able to question the relationship between insights and organization. *How does the act of organization influence what is known?*

Epilogue

The last five chapters observed, clustered, and analyzed the articulated reasons to visualize data, from business, design, and journalism to various scientific discourses such as neuroscience, computer science, mathematics, and statistics. The authors named in the prologue identified the motive behind data visualization as nothing less than the representation of insight, knowledge, and truth. I investigated the rhetorical bonds between visualization and insight, knowledge, and truth. The articulated reasons for visualizing data applied the terminology of the 20th-century industrial revolution and the 15th-century Age of Discovery. Data is explored, uncovered, revealed, transformed, and distilled into insight, knowledge, and truth through visualization.

The relation between design and insights led me to the investigation of four foundational metaphors within data visualization. How are visualization designers and researchers describing various stages of creating these graphics, and how are insights articulated in that process? This question was the common thread throughout the four chapters on the raster, the arrow, the chain, and the pyramid. What became visible was a shift in the articulated objectives of visualization design.

The taxonomical research on visualization design described in Chapter *Raster* and compressed into the image of the raster is a shift from the prologue. Knowledge, insight, and truth in that context are neglected, and new objectives of efficiency and effectiveness become central in studying the elements of visualization design.

The metaphor of the arrow made an inquiry into the research on cognitive processes and visualization design. While the term *insight* was used by Card et al.,[1] the authors did not specify what is meant by it. Instead, other objectives following the narrative of *efficiency* and *effectiveness* continued. Allowing observers, users, and viewers to find *patterns* became the core of the research on the arrow

1 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann.

between the brain and the screen. *Optimization* aimed at our pattern-seeking neurons became the objective.

Chapter *Chain* then maps, clusters, and discusses 27 visualization design process diagrams. Most of the diagrams are based on two visual elements: orbs and arrows. I named the interlocking of these two elements the chain. Like the previous chapters, the epistemological questions of insight, knowledge, and truth did not receive much attention. Of the 27 diagrams, only four contained one of the terms. The design process often ended with the graphical representation or included practical tasks such as analyzing, maintaining, delivering, or publicizing. A new objective apart from the optimization of efficiency and effectiveness emerged, the striving toward *minimalism*, *order*, and *structure*. The objective shifted toward the modern conception of good design, meaning as little design as possible.

The fourth symbol, the pyramid, has two distinguishing features that set it apart from the previous research. First, it is not a symbol of visualization design research but is rather something adapted from the information sciences. Second, the objectives of insight, knowledge, and truth are directly confronted. While there are direct references and usages from visualization designers and researchers, even more there seem to be implicit connections, as many of the statements from the previous chapters fit the implications of the pyramid. Since its conception in the 1980s, the pyramid has been a debatable concept. The connections between the different layers from data to wisdom are not absolute. Even if they were, data is represented as the ground truth of the pyramid. Data from this perspective is taken from its Latin origin meaning *the given*. But, where does data come from?

Throughout all five chapters, only two approaches have emerged that connect visualization design with epistemological theories. First, the DIKW pyramid, and second, the assumption of 'justified belief.' A field in which some of the largest technology companies are engaged, and which is becoming mainstream in journalism, spanning various research fields, and as investigated in Chapter 1 identifies as its core objective *insights*; this is a shortfall. Frequently, the closer my research cam to the actual act of visualizing data, the further away the goal of knowledge seemed. Insight, knowledge, and truth are used in marketing like statements such as *truth and beauty operator* [2] or *The purpose of visualization is*

[2] Ref.: Stefaner, M., Truth & Beauty - Data visualization. truth-and-beauty.net. Available

insight, not pictures,[3] while any closer conception and critical reflection of how visualization relates to insights are missing.

The next part of the book will further investigate the design process to introduce a theory on how visualization design relates to insights. To do so, I will inquire into the smallest act of design and question its constituent parts and assumptions.

at: https://truth-and-beauty.net/ Accessed February 28, 2019.

3 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann.

Part II: Calculus of Design

An extended quest to design a bar chart

On the logical operations of designing with the computer

The following chapter suggests a way to connect the basics of writing computer code, philosophical discussions on logic and structuralism, systems theory, and—most importantly—a theory of design. The chapters following this one will go into more detail on the topics of *form*, *design*, *space*, *time*, and *insight,* relating to design using the computer and especially data visualization. This section will not go into detail in any of these topics, but rather provide one path as to how these subjects can be contemplated together; I will mention many things without examining them in depth.

Thinking and making—theory and praxis—mare not separated here, but conceptualized together. To do so, I will describe the fundamentals of creating a web-based data visualization and simultaneously introduce parts of a theoretical approach I call the *calculus of design*. This chapter will introduce a way in which to conceptualize the process of designing a bar chart as one of *drawing distinctions* and *re-entering* these distinctions within a *space*. Design becomes a pre-binary process of an operation: *Draw a distinction*. On a larger scale, this undertaking ponders together *aesthetics* and *epistemology* through three terms: *distinction*, *space*, and *re-entry*.

To understand how insight and data visualization relate to one another, I would first like to observe the process of designing a common data visualization type. I will analyze a tutorial on how to design one of the most ubiquitous and well-known kinds of visualization: the bar chart. This chart type is one of the most universal and widely used. William Playfair (1759-1824) already utilized this graphing technique in his book *The Commercial and Political Atlas* from 1786.[1] The method of plotting data in two dimensions is much older than the invention of the computer screen and *graphical user interfaces*. However, the computer turned data and visualization into something ubiquitous. While manually re-drawing a

1 Ref.: Playfair, W., 1786. The Commercial and Political Atlas.

bar chart with a new dataset would take hours, days, or even months, the computer re-calculates and displays these changes within a split second.

The chapter on *the chain* in the previous section showcased how various designers conceptualize their process on an abstract level. Here, I will look at this process in detail, on the level of graphic and code-based operations. Tutorials and instructions on how to design such a graphic provide a detailed account of how data turns into a visualization. Programming tutorials are well suited for this undertaking, as they meticulously explain every step of the process. There are many contemporary tutorials on the internet and in books on how to design data visualizations. Most of them are usually centered around specific programs, programming languages, or programming libraries.[2] The process from a blank page to a graphic representation is similar throughout all these programs and code environments. However, the processes differ in their level of granularity. This granularity is a trade-off between the amount of effort it takes to design the graphic and the control over the graphic. The fewer options you have, the easier the creation.[3] This is what will be analyzed as *contingency of space* throughout the chapter.

While I could explain the process of how to design a bar chart myself, making the point through an already existing tutorial from an established author allows me to step back, observe, and analyze. In this first observation, I'll discuss the section "*Making a bar chart"* from the book *Interactive Data Visualization* by Scott Murray.[4] The main reason for this tutorial over alternatives is that Murray goes through the process of creating graphics in great detail. Many tutorials make great leaps and skip entire parts of the design process. This slow pace is essential for *understanding what designers do while creating a data visualization*.

Before Murray draws anything visual, the tutorial operates in several invisible *spaces*.[5] The full title of the book is *Interactive Data Visualization for the Web,* which furthermore defines the *space*. The *Web* or World Wide Web (WWW) consists of three cornerstone technologies: the Hypertext Markup Language (HTML), Cascading Style Sheets (CSS), and JavaScript (JS), which are all distributed

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2 An overview of d3.js tutorials can be found at: https://github.com/d3/d3/wiki/Tutorials

3 This is a very rough observation, which I will define further in the chapter *Space*.

4 Ref.: Murray, S., 2013. Interactive Data Visualization for the Web, O'Reilly Media, Inc.

5 The term *space* is essential for the theory I am establishing; we will return to this in more detail in the chapter on *space*.

through the Hypertext Transfer Protocol, short HTTP. HTML is the language in which static web-based documents are written, CSS is the description of the presentation of these documents, and JS enables interactivity within the system.

The Design Space of the Web

Hypertext Markup Language

> *This textual information is never revealed to the user; instead, it is kept hidden, interpreted as a graphical Web page.*
>
> — *Alexander R. Galloway* [6]

The question that leads this section is the following: What are the invisible and unobserved boundaries of designing data visualizations for the web? What are the given restrictions, the given infrastructures, before any data is turned into a graphic representation? This section will briefly observe and analyze various layers of designing for the web and slowly introduce the theory I call the *calculus of design*. To that end, I will go through various nested layers of web design from the *Hypertext Markup Language* to *rendering engines* and various abbreviations such as *HTP*, *CSS*, *SVG*, and *JS*. What sets my observations apart from other introductions to these topics is that I am investigating these terms and terminologies from a theoretical consideration of philosophical differences.

Throughout this discussion, I will use the medium of the text to interpret the creation of graphics, but furthermore to also offer alternative representations. The first one is the computer code, from the perspective of the designer writing code. An HTML page consists of the three main spaces `<html>`, `<head>`, and `<body>`:

```
<!DOCTYPE html>
<html>
```

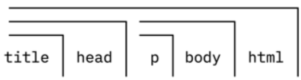
[6] Ref.: Galloway, A.R., 2006. Protocol, MIT Press, p. 65

```
  <head>
  </head>
  <body>
    <p>Hello world!</p>
  </body>
</html>
```

The anthropometric[7] distinction between `<head>` and `<body>` within our `<html>` bracket defines the basic syntax for the browser's render engine. The code block above represents the HTML version of a »Hello, World!« program, a simple program to display the message »Hello, World!« within the system.[8] The first line is the document type declaration, for short `DOCTYPE`; it declares to the browser the HTML render mode. This render mode starts the space of the Hypertext Markup Language, which contains a head and a body space. A web browser renders the text file containing our »Hello, World!« program and the filename extension *.html* as follows:

Hello world!

We can observe how different these two modes of representation are. From the entire code, only the text within the `<p></p>` paragraph brackets appears. In addition to the code and the browser-rendered representation, I will offer a third diagrammatic notation system:



This perspective focuses on the drawn *distinctions* and how they relate to one another. In this case, it is a simplified version of the HTML structure. There are

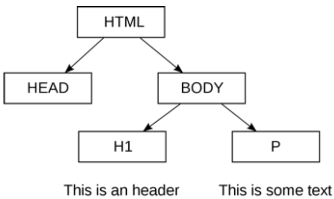
7 The code terminology is highly adapted from the human body. Strange metaphors.

8 Explore http://helloworldcollection.de/ for a collection of Hello World programs in various languages.

only two modes, either into one another or next to one another. These are the two forms of operation: *within* and *next to*. Throughout the subsequent chapters, I will further explain how this notation system can diagrammatically represent the design process.

The representation excludes the actual text that appears in the browser window.[9] It is a hierarchical perspective on how the various *distinctions* relate to one another. I adapted this notation system, which I call the *calculus of design,* from the book *Laws of Form*. It was written by mathematician George Spencer-Brown in 1968. The vertical and the horizontal line together are called a *cross*. These crosses are nested sets of distinctions and offer a third form of representation in addition to the text and the web browser renderings.

For a programmer or designer working in HTML, the diagrammatic representation will probably be familiar. The *document object model*, or short *DOM*, conceptualizes HTML's hierarchical structure. Each bracket defines one element of the structure and, just like in the notation system from Spencer-Brown, objects either nest into one another or are placed next to each other. Here are two alternative graphical representations of the DOM from Wikipedia:

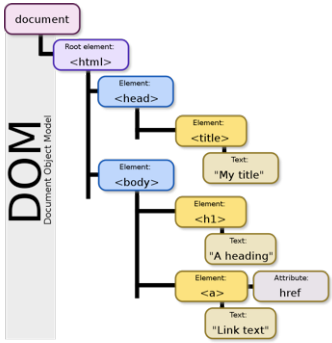


Simple HTML page DOM[10]

These visualizations of the document object model are alternative displays of the same structure as expressed in our calculus of form and our »Hello world!« code.

9 I could easily add it back in, as I will explain later on.

10 Image from: https://it.wikipedia.org/wiki/Document_Object_Model



Document Object Model[11]

The next section observes the *render engine,* which *interprets* the *DOM tree* and displays it in the browser window.

Rendering Engine

The browser engine, also called the layout engine or rendering engine, transforms the document object model into the interactive visual representation. In our case, this will be the text »Hello world!«. The various browsers have different browser engines, such as Gecko in Mozilla Firefox, WebKit for Apple Safari, and Google Chrome until version 27. Since 2013, Google Chrome renders the DOM in a rendering engine named Blink similar to Opera or Microsoft Edge. This list could go on. The point is that the drawn distinctions always nest inside other distinctions. This has consequences when designing webpages, as each render engine interprets the DOM differently. Websites, or in our case web-based visualizations, will not look the same in different browsers. Designers and programmers invest a lot of time and energy into writing code that gets interpreted similarly by different engines.[12]

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11 Image from: https://en.wikipedia.org/wiki/Document_Object_Model#/media/File:DOM-model.svg

12 Behind the scenes of modern web browsers: https://taligarsiel.com/Projects/howbrowserswork1.htm

A Reference Architecture for Web Browsers: https://grosskurth.ca/papers/browser-refarch.pdf

Hypertext Transfer Protocol

Another nested structure for our HTML website is HTTP. The Hypertext Transfer Protocol prefixes an additional header to the HTML file with information about the date, server, connection, and content type. I will not go into detail here, as our focus is to design a bar chart.[13,14] However, I will provide a quick overview of the technological layers involved to showcase the structure behind the building of a graphic, the space of operation. The TCP/IP is a set of rules to facilitate peer-to-peer communication between computers. The Transmission Control Protocol (TCP) creates a connection between the sender and receiver consisting of two commands: "SYN" (synchronize) and "ACK" (acknowledge). The Internet Protocol (IP) is responsible for moving packets of data called "datagrams"[15] from the sender to the receiver. In the terminal of a Mac computer, the command `traceroute google.com` returns all IP calls to display the website google.com. The DNS (domain name server) connects the IP addresses from numbers to names, such as google.com.[16]

The white background of the browser window, the empty space, is everything but empty. A vast structure of conceptual presumptions and physical infrastructures are concealed within the blank page. The designer is already embedded in the

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13 Longer discussionns on the topic explained from a technical perspective can be found, for example, at:

https://taligarsiel.com/Projects/howbrowserswork1.htm

Or from a media-theory perspective, for example, in the book *Protocol* by Alexander R. Galloway referenced here.

14 Ref.: Grosskurth, A. & Godfrey, M.W., 2005. A reference architecture for web browsers. On pp. 661–664.

15 Ref.: Postel, J., 1981. Internet Protocol. Available at: https://tools.ietf.org/html/rfc791, p. 1.

16 There are multiple articles written about ›What happens when you type google.com into your browser's address box and press enter?‹ for example:

https://github.com/alex/what-happens-when

https://dev.to/antonfrattaroli/what-happens-when-you-type-googlecom-into-a-browser-and-press-enter-39g8

https://www.html5rocks.com/en/tutorials/internals/howbrowserswork/

superstructure of computation before the first line of code, the first drawn distinction.

Cascading Style Sheets

From the layers of the spaces above the HTML page, I will now move back to designing within HTML. Cascading Style Sheets (CSS) are included in the `<head>` of the HTML document and define the visual representation of the elements on the page:

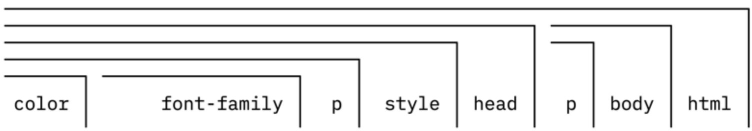
```
<!DOCTYPE html>
<html>
  <head>
    <style type="text/css">
      p{
        color: gray;
        font-family: sans-serif;
      }
    </style>
  </head>
  <body>
    <p>Hello world!</p>
  </body>
</html>
```

The instructions within the `<style>` bracket alter the rendering of the `<body>` bracket. In this case, the tone changes from black to gray, and instead of a serif font, the website now displays the standard sans-serif font of the system. This command leaves the interpretation to the render engine and `sans-serif` will display as the standard font face of the system. In Firefox 75.0 on a MacBook Pro with macOS Catalina, the rendered text displays as follows:

Hello world!

As the distinction `sans-serif` is not an actual font family but rather a font style, the operating system interprets the distinction. macOS El Capitan and newer versions use the typeface *San Francisco*.[17] Web browsers interpret so that code that is undefined or not specific enough does not lead to errors but to decisions someone else makes. This is important, as it questions and reflects the agency and the status of the infrastructure of the system. HTML, CSS, and SVG are more than languages, they are systems. The agency of design and designer is not easily definable, as the intricacy of the system is vast.

The representations in the user interface, the browser window, depend on the underlying textual description of the CSS transformations. Through CSS, the textual code layer contains instructions for the graphic representation within the browser window. For someone writing HTML code, such an observation is so commonplace that it might sound banal. Yet, it is quite something. Every possible form of representation in the browser window and, more broadly, on the computer screen must be writable within these underlying text-based languages. *The HTML code layer is text-only*. There are no tables, images, rectangles, or font styles within this space. It instead contains text-based instructions for tables, images, rectangles, or font styles; everything is abstracted as text. As the name *Cascading Style Sheets* indicates, again, it is a nested, in this case called cascading, structure. I am adding these CSS layers to our diagrammatic notation.



Throughout this section, various terms refer to the same. *Elements*, as Murray calls them in his book, refer to the same thing called *objects* in the *document object model*. Objects are further defined by *properties* through the CSS transformations.

17 Ref.: Sava, A., 2019. Operating systems default serif fonts. fontsarena.com. Available at: https://fontsarena.com/blog/operating-systems-default-serif-fonts/ Accessed March 3, 2021.

Within the interface layer, in this case the browser-rendered HTML page, this separation of objects `Hello world!` and properties `color: gray;` are seemingly intuitive, but on the code layer, each of these commands is a line of code. So, is the distinction between elements and objects suitable? Is the <p>, the paragraph, an object? Is an operative instruction for the computer an object? Do *object s*and *properties* have a universal underlying principle? Is there something unifying about these commands?

The diagrammatic notation of the Laws of Form nest each code block in relation to one another. The diagram removes the difference between elements, such as <p> and visual representations of the `font-family`. Within the *Laws of Form*, each is an *indicated distinction*. Distinctions become the *operative form*, represented by the diagrammatic notation.

Both *objects* and their *attributes* are *distinctions* in this theory. This new layer, *the distinction*, above objects and their attributes, introduces the pre-binary[18] notation of the form. *The all-embracing design principle of writing computer code is the design of form by drawing distinctions.* Within the *Laws of Form,* both *objects* and *attributes* follow the same command: *draw a distinction*.

On the level of the web browser interface, the pre-binary notion of form might seem like a counterintuitive change, as the `Hello world!` text changed from *black* to *gray* and from *serif* to *sans-serif*. So, the separation between objects and properties do apply, but in the code layer both elements and representations are commands. *Each command draws a new distinction within the nested space of the interface.* On this code-based textual level, each instruction redefines the interface layer.

In the code below, I have added a new line of code to the CSS that underlines the paragraph text of our `Hello world!` code:

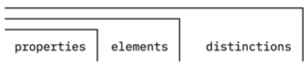
```
<!DOCTYPE html>
<html>
  <head>
    <style type="text/css">
      p{
```

[18] There are only distinctions. Binary consists of two distinctions: true/false, on/off.

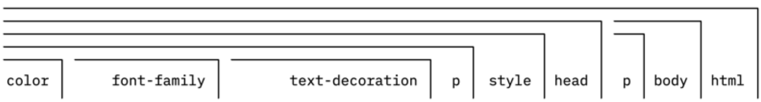
```
      color: gray;
      font-family: sans-serif;
      text-decoration: underline;
    }
  </style>
</head>
<body>
  <p>Hello world!</p>
</body>
</html>
```

Underneath the `Hello world!` text in the browser rendering, a line appears. Is this an object or a visual representation of the object text? The line itself one can argue is an object in itself. From the logic of HTML and *CSS rules*, it is only a description of how the text is displayed.

By switching the terminology from objects and their visual representations to form, every change, every line of code, is a distinction within space. The differentiation into *elements* and *properties* are pre-designed distinctions. Anything designed is a form of difference. Elements and properties are nested distinctions:



The form diagram captures the design process of drawing distinctions. By underlining the paragraph, a new distinction is made within the space of operation.



To observe both objects and their properties as *designed distinctions* might seem like a small change but has epistemic consequences for visualization and offers a possible insight. The difference is the building block for a theory on visualization design and insight. A vast set of drawn distinctions necessarily bounds any knowledge arising from graphic representations of data. From measuring and sensing as cresting data to computational systems, the visual display of the data, and the graphic's interactant, each step needs someone or something to draw distinctions. *Insight, in this theory, is not something given in the world, but a design process.*

Where I am adapting and applying the Laws of Form as a design theory, Niklas Luhmann applied Spencer-Brown's mathematical theory to sociology. Luhmann points out the significance of a change in perspective from objects to distinctions by writing:

> *Die am tiefsten eingreifende, für das Verständnis des Folgenden unentbehrliche Umstellung darin, dass nicht mehr von Objekten die Rede ist, sondern von Unterscheidungen.*
>
> — *Niklas Luhmann*[19,20]

Scalable Vector Graphics

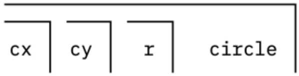
In HTML, there are multiple technologies to render graphic elements such as points, lines, and areas. The *Canvas*, the related *WebGL (Web Graphics Library),* and *shader* operate on the level of pixel values. In this section, I will look at the so-called *Scalable Vector Graphics* or *SVG for short*. Vector graphics describe images not based on pixels on the x-axis and y-axis, but rather distinctions drawn through mathematical descriptions of shapes. For example, a circle has a center on the x-axis, a center on the y-axis, and a radius. These three numerical values are the most simplistic description of a circle within SVG. On the code level, the basic instructions for a circle are:

```
<circle cx="100" cy="100" r="80"/>
```

---

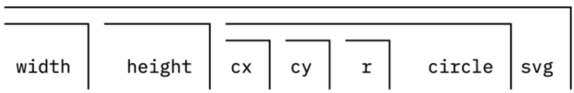
19 Ref.: Luhmann, N., 1998. Die Gesellschaft der Gesellschaft, Suhrkamp, p.60

20 Translation: *The most profound change, indispensable for the understanding of what follows, is that we no longer speak of objects, but of distinctions.*



The property cx stands for the center position on the horizontal axis. Similarly cy describes the center position on the vertical axis, and r the radius of the circle. Each command, cx, cy, and r is a distinction within the distinction of the circle—the circle is nested inside the difference of the SVG. The SVG needs a minimum of two differences itself, width and height.

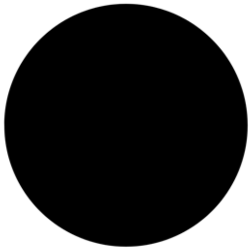
```
<svg width="200" height="200">
    <circle cx="100" cy="100" r="80"/>
</svg>
```



The <body> of the HTML page is nested within the SVG element:

```
<!DOCTYPE html>
<html>
  <head>
  </head>
  <body>
    <svg width="200" height="200">
      <circle cx="100" cy="100" r="80"/>
    </svg>
  </body>
</html>
```

This code renders the following representation in the browser:



The code-based and diagrammatic representations are nested, from the circle and its distinctions `cx`, `cy` and `r` to its embedding within the SVG element and its nested position in the HTML structure. The HTML itself is embedded in other arrangements, as pointed out. Within the Laws of Form, distinctions are drawn inside a *space*. This space itself is also a distinction. *Space is the distinction within which a designer operates but which is at that point not observed.* By drawing a difference, one always operates within a space, within another distinction.

This notion of space as the operational distinction relates to both computer science and philosophy. In computing, the term *software stack* defines the set of subsystems and components needed to run an application. In web development, this includes even more components than described throughout this chapter, such as the operating system, web server, database, and programming language. The concept of space includes but goes beyond the *software stack*. Space includes lower levels, such as code written within the stack, and higher layers outside the computer. The *stack* is a *distinction* of *space* in itself. In philosophy, the concept postulated here relates to questions of epistemology as well as media theory. The *space* as an *a priori*, operational realm within which form is designed. The *a priori* denotes a reality condition under which possible statements may be drawn.[21]

As distinctions are drawn within a space, this space is the design *a priori*. The *space* is defined by the possible distinctions one can draw at that point. While it is impossible to define all possible distinctions in the world, *within the computer,*

21 Ref.: Foucault, M., 2012. The Archaeology of Knowledge, London and New York: Routledge, p. 142-150

space is unconditionally defined.[22] For example, within SVG, Murray identifies six graphic elements or graphic primitives.[23] We already observed the circle; besides that, there is the rectangle:

```
<rect x="25" y="25" width="200" height="200" />
```

The rectangle is defined by four parameters, the x-position, y-position, height, and width. The line, however, is coded as:

```
<line x1="50" y1="50" x2="200" y2="200" />
```

Just like the rectangle, the line indicates the x and y starting position until the x and y end position. Similar to the circle is the ellipse:

```
<ellipse cx="100" cy="100" rx="80" rx="60" />
```

In comparison to the circle, the ellipse contains a radius for the width and height. The path looks like this:

```
<path d="M 10 10 H 90 V 90 H 10 L 10 10"/>
```

The path element holds a more elaborate set of distinctions than the other elements. `M` stands for `move to` with the `x` and `y` positions of the move. There are three commands to draw lines: `L` stands for `line to` `x` and `y` position, `H` draws a horizontal line defined by `x`, and `V` draws a vertical line with the ending point defined by `y`.[24] And the text reads thus:

```
<text x="100" y="100">Hello world!</text>
```

---

22 This is extremely important, especially regarding ideas of ›Artificial Intelligence.‹ The computer is just like a game with well-defined rules. In reality, humans make these rules.

23 Other sources define the set differently. For example, Murray does not distinguish between the polyline and polygon graphic primitives. Distinctions are always drawn by the observer. In computer systems, this language is totally defined but varies, such as in the SVG version number.

24 Ref.: MDN contributors, 2021. Paths. developer.mozilla.org. Available at: https://developer.mozilla.org/en-US/docs/Web/SVG/Tutorial/Paths Accessed March 3, 2021.

The textual elements function differently from the other forms. They contain a bracket for the text itself.

These six distinctions, *circle*, *rectangle*, *line*, *ellipse*, *path*, and *text*, are all transformations from the text-based code layer to their graphic representations on the interface layer. Each of these distinctions contain other distinctions concerning the appearance and transformation of the form. These six distinctions are the graphic primitives of the *space* of *Scalable Vector Graphics*. Any graphic within the system is based on a multitude of these symbolic representations. *The design space in SVG is absolute. Any form of expression that cannot be represented by a combination of these forms is impossible within the space of SVG. The design space within the computer is absolute.* While the design space offered by combinations of these symbols is vast, it is finite. Such an understanding of the design space might seem arbitrary, as the combinatorial logic is so immense. However, any designer using specific spaces for a long enough time has a good intuition regarding the spaces used for a particular representation.[25] The aesthetics of a specific space is so forceful that I can usually determine whether a project is rendered in SVG, canvas, or WebGL, despite the distinctions drawn by the designer. For anyone working with these systems, that does not seem to be a magic trick. But, it does showcase how strong the effect of the space is on design.[26]

The distinctions within the SVG space behave differently to the space of this text you are reading right now. While there are only six types of symbols specified here, the Latin alphabet consists of 26 letters. However, each of the six SVG elements is defined through further distinctions. *The symbolic language of shapes is nested.* I have only represented the minimal requirements for each of the six SVG elements, but there are many more. From this perspective, the combinatorial possibility space of SVG is larger than the Latin alphabet, as the nestedness of the sign system allows for more combinations.

What I have observed and analyzed in this section on *Scalable Vector Graphics* has strong similarities to the chapter on *the raster*. The research discussed in that chapter throughout history, from Bertin to Munzner, redefined the distinctions between elements and appearances—or, as Bertin called them, *visual elements* and

---

25 I will describe various design spaces in a later chapter on the design process.

26 In the chapter on space, I will provide examples to showcase the influence of the space on the actual design.

visual variables.[27] In contrast, this section analyzed how these abstract concepts manifest within the computer and, more precisely, within the SVG distinction in the Hypertext Markup Language.

JavaScript

Until this point, this chapter has discussed *HTML*, *CSS*, and *SVG*, as well as the layers above, *HTTP* and *rendering engines*. Each of these interacting layers are *nested distinctions*. These distinctions operate within a *space*. I defined space as the unobserved distinction above the distinction. In web design, the *document object model* describes this nested space of forms within and next to another. The diagrammatic notation of the *Laws of Form* visualizes the form of distinction and space. The diagrams display the *logical operation of design processes within a space*.

The scripting language JavaScript adds another layer from the perspective of the Laws of Form. JavaScript is capable of not only operating within *space* but also through *time*. Theories of logic frequently neglect the operational possibilities of form. Something is either true or false. Something happened on the 5th of October, 1842, or it did not.[28]

> *Die Welt ist alles, was der Fall ist. … 1.13 Die Tatsachen im logischen Raum sind die Welt.*
>
> — *Ludwig Wittgenstein*[29,30]

In the *Laws of Form*, time emerges out of the operative act of drawing distinctions. A basic example for the emergence of time through space is a clock. As the three hands on an analog clock move, the observer draws a distinction, the clock stays the same, and time emerges from the observed difference of the moving hands. Time emerges as a perceived difference between two states of the same distinction. Process-based, iterative programming languages such as JavaScript operate in time and thus outside of the realms of most logical systems.[31] The

27 Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press.

28 Ref.: Tydecks, W., 2019. A commentary on Laws of Form from Spencer-Brown. tydecks.info. Available at: http://www.tydecks.info/online/themen_e_spencer_brown_logik.html Accessed December 2, 2020.

29 Ref.: Wittgenstein, L., 1922. Tractatus Logico-philosophicus.

30 Translation: *The world is all that is the case. … 1.13 The facts in the logical space are the world.*

31 I will explore this further in the next chapters.

Laws of Form not only include operations but also provide a mathematical theory of how time emerges from the drawing of distinctions.

To make sense of how programming and time merge in the theory of form, I will finally start recreating the bar chart from Scott Murray's book *Interactive Data Visualizations for the Web* and examine how to design a bar chart. It will be simpler to explain the process within JavaScript and what I mean to operate within time by looking at an example rather than at the language in general, as this chapter did with HTML, CSS, and SVG.

Murray uses a JavaScript Library named D3.js, which stands for data-driven documents. JavaScript libraries became an essential part of web programming. Within the logic of the Laws of Form, I will define a code library as a pre-drawn set of distinctions that simplify the drawing of new distinctions. D3.js is a library that streamlines the process of transforming data into graphic representations. The complexity of writing code is reduced, functions become simpler to write. A library, from the perspective of the laws of form, is a set of distinctions to shortcut the process of designing new distinctions. The space of D3.js collapses many layers of distinctions into a simplified set of distinctions.

For example, the *D3.v5.js* library allows one to write the following:

```
var x = d3.scaleLinear()
    .domain([10, 130])
    .range([0, 960]);
```

These three lines of code transform a given domain value into a corresponding range value. For example, the function `x(20)` returns `80`. The domain value maps onto the range value. Scales are fundamental in mapping data from the initial values, such as 8 am to 6 pm, or €0 to €100, to the size of the graphic. These three lines of code trigger an entire set of distinctions within the library of D3.js. To showcase the nested interdependencies within the system, I will examine the first three nested functions.[32] The command `d3.scaleLinear` triggers a function named `linear$2`. This function loops into another three functions:

32 I actually wanted to showcase all dependencies but quickly realized that this would take up far too many pages.

```
function linear$2() {
  var scale = continuous(identity$6, identity$6);

  scale.copy = function() {
    return copy(scale, linear$2());
  };

  initRange.apply(scale, arguments);

  return linearish(scale);
}
```

These three functions loop into other nested sets of functions, which again loop into more operations. JavaScript libraries reduce complexity and define a new space within the space of JavaScript. In computational processes, complexity is reduced through pre-defined distinctions, by abstracting and nesting complex functions into simple ones. This process, by design, reduces possible distinctions.

The computer's various layers of infrastructures in general and of web development in particular evolved to reduce the complexity of sets of distinctions. Simplifications of processes allow connectivity to other processes—a giant web of assemblages and dispositions, controls, and arrangements.[33] Design operates within a space of contingency, the space of what is possible and impossible within the nested layers of distinctions.

The Bar Chart

The First Bar

I started this chapter with the promise to present a tutorial on the design of a bar chart. So many pages later, not a single bar chart has appeared. And this is the

33 Ref.: Distelmeyer, J., 2017. Machtzeichen, Bertz + Fischer.

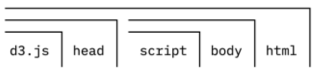
case while I only scratched the very surface of the underlying spaces behind a bar chart. This introduction briefly explored the two terms *distinction* and *space* and their relationship to HTML, CSS, and SVG. Such an investigation could unfold much further. But now, let us draw the first distinction and visualize a rectangle.

The following HTML structure displays all the drawn distinctions before writing JavaScript. `D3.js` is given in the header, and the `script` in the `body` is the space in which our code will run.

```
<!DOCTYPE html>
<html>
    <head>
        <script type="text/javascript" src="js/d3.js"></script>
    </head>
    <body>
        <script type="text/javascript">


        </script>
    </body>
</html>
```

Or, within the diagrammatic form of distinctions, as follows:



I will now collapse the HTML structure and only draw distinctions within the script distinction. By collapsing the differences, they become the space of operation. Space[34] is the collection of invisible differences within which the designer operates.

The first line of code is a set of distinctions called an array. The variable or `var` holds the differences of our `dataset`. The bracket, `[ ]`, contains the predefined—in this case, made up by Murray—data values separated by commas.

---

34 Is space the medium, as Luhmann argues? Or is the medium still something else? I will elaborate on this question in the chapter *Space*.

```
var dataset = [ 5, 10, 13, 19, 21, 25, 22, 18, 15, 13, 11, 12, 15, 20,
18, 17, 16, 18, 23, 25 ];
```

This one line of code holds twenty numerical differences. Next, Murray calls the distinction of the SVG element into the `body` of our `HTML`.

```
var w = 500;
var h = 100;

var svg = d3.select("body")
   .append("svg")
   .attr("width", w)
   .attr("height", h);
```

D3.js selects the `body` and `appends`, calls, or creates an SVG element in the distinction of the `body`. The SVG's width and height are defined by two variables: `w` and `h`. Selecting and appending are the most basic functions d3.js is providing. As mentioned, JavaScript libraries hold sets of distinctions, which makes it easier to draw new distinctions. They simplify the process and define our space of possibility.

At this point, the browser window is still a seemingly empty space.—a blank white page, called within the Laws of Form the *unmarked space*. Hidden on the level of code, an SVG element with a width of 500 pixels and a height of 100 pixels waits to be filled with one of the six possible graphic elements SVG allows. The Laws of Form start with a command:

> *Draw a distinction*
>
> — *George Spencer-Brown*[35]

And this is what Murray does, drawing the first bar:

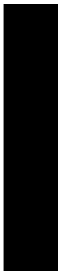
```
svg.selectAll("rect")
   .data(dataset)
   .enter()
   .append("rect")
```

---

[35] Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p.3

```
    .attr("x", 0)
    .attr("y", 0)
    .attr("width", 20)
    .attr("height", 100);
```

The variable `svg` makes an empty selection `selectAll,` as there are no rectangles to select. The `enter` command enters our dataset, and `appends` for each data value a rectangle. Each rectangle has the same size and position. Rendering this in the browser window looks like the following:



While on the level of code, our SVG element now looks like this:

```
<svg width="500" height="100">
   <rect x="0" y="0" width="20" height="100"></rect>
   <rect x="0" y="0" width="20" height="100"></rect>
   <rect x="0" y="0" width="20" height="100"></rect>
   …
   <rect x="0" y="0" width="20" height="100"></rect>
   <rect x="0" y="0" width="20" height="100"></rect>
</svg>
```

On the code level, Murray drew the twenty distinctions of our `dataset`, but all with the same size and position. The recalling of equal signs correlates to the first axiom of the Laws of Form, *the law of calling*:

> *Axiom I (law of calling): The value of a call made again is the value of the call.*
>
> *— George Spencer-Brown*[36]

With no distinctions between rectangles, drawing 1 or 100 rectangles does not *mark* any difference for the viewer of the graphic. If I drew thousands of rectangles in the same position, the computational resources would be substantial, but in the graphical user interface no difference would be visible. I am utilizing, as before, Niklas Luhmann's systems theory for computational design. Luhmann writes about Spencer-Brown's law of calling:

> *The 'law of calling'. If I repeat the same distinction (the same mark) several times, then the value of the repeated distinctions taken together is equal to the value of one single distinction.*
>
> — *Niklas Luhmann*[37]

Re-Entry into the Rectangle

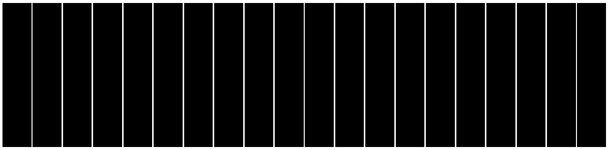
On the code layer, no distinctions separate the rectangles within the space. Only by introducing a *difference* do the bars become distinct. At this point, `functions` come into play, and with them the operation of time within our diagrammatic representation. The computer will `loop` through our dataset with the `function(d, i)` on the x-position of each rectangle to differentiate the bars from one another. The `d` stands for each data value, and the `i` is the count of these values from zero to 19. This operation executes twenty times, once for each data value. The code behind `return` indicates the calculation the function returns. Both the `d` and the `i` are not static, but throughout *time* iterate through the array of the `dataset`.

```
.attr("x", function(d, i) {
    return i * 21;
})
```

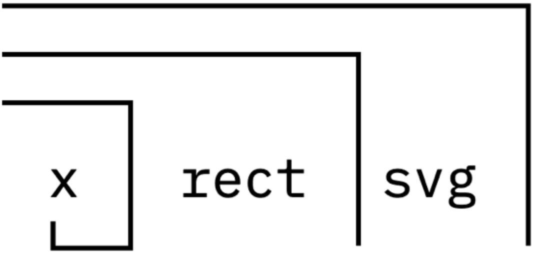
Each rectangle is now distinct along the horizontal axis. Each bar is 20 pixels wide, as previously defined. The program multiplies our counter *i* by 21 pixels; between each bar, a gap of one pixel appears. The rendered set of rectangles looks like the following:

---

37 Ref. Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57, loc. 135-136



Our diagrammatic representation would already become large, with the twenty rectangles nested within our SVG. For such loops, the Laws of Form extend the distinction of the mark by two lines, the *re-entry*:



Here, I am interpreting the re-entry to some extent. The computer always deals with a finite number of operations.[38,39] In our case, this limited number is twenty, as that is the size of the dataset the computer is iterating through. In the Laws of Form, the *re-entry* is often used as an infinite oscillation between values.[40] I want to make the point that the primary form of a computer `function` and the *re-entry* of the Laws of Form both *operate* the same way, as *time* through *space*. As the chapter *Time* will elaborate, the conception of time within computer functions emerges from the iteration `i = i + 1`. *The equal sign does not represent equality, but rather an interplay between identity and distinction.*

---

38 As Kittler defines well in this Transmediale Keynote: https://transmediale.de/content/keynote-3-friedrich-kittler-finiteness-of-algorithms

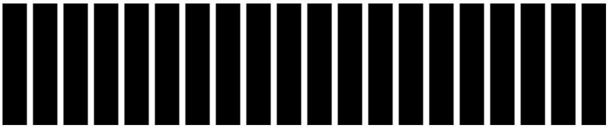
39 Ref.: Kittler, F., 2007. Die Endlichkeit der Algorithmen | transmediale. transmediale.de.

40 We will come back to this later. This statement refers to the connection between imaginary numbers such as x = -1/x with results if x is 1 in 1 = -1. The values oscillate between two states. This is highly related to the loop. It is just like for a Loop, in which `i = 0; i++` The basic fundamentals of computer science break with mathematical logic.

Bar Chart Distinctions

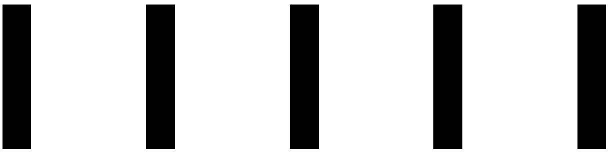
From this point onwards, Murray draws more distinctions in the space; he *designs*. First, he replaces the function x `i * 21` with `i * (w / dataset.length)` so the horizontal position of each bar adjusts dynamically to the number of data points in the array. This operation enlarges the space between the rectangles.

```
.attr("x", function(d, i) {
    return i * (w / dataset.length);
})
```



If the `dataset` only holds five values, the visualization changes accordingly:

```
var dataset = [ 5, 10, 13, 19, 21 ];
```



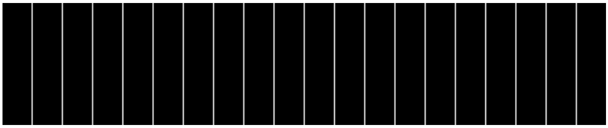
Below the two variables that define the width and height of the SVG element, Murray adds a third predefined variable called `barPadding`. This is an additional distinction in the JavaScript space.

```
//Width and height
var w = 500;
var h = 100;
var barPadding = 1;
```

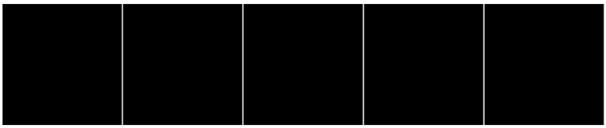
Murray draws another distinction by adjusting the `width` of each rectangle according to the width of the `svg` element divided by the number of shapes minus the newly created variable `barPadding`. This new distinction is not a re-entry, as this is static; the same holds for each value.

```
.attr("width", w / dataset.length - barPadding)
```

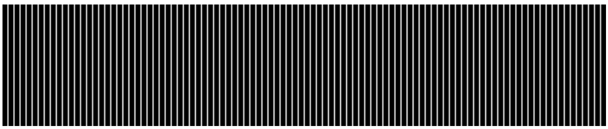
These changes do not affect the graphic representation at first:



But, by changing the number of distinctions within our `dataset`, the graphic representation changes dynamically. The same code with only five values in our array:



The same code with one hundred values:



The *re-entry*, the function `x`, which loops through the dataset, allows for *feedback* within the system. Feedback is a foundational concept of cybernetics as Alexander R. Galloway writes in *Protocol*:

> *The theory of cybernetics began with the simple idea of feedback. Feedback means that certain processes, having both a beginning and ending point, should be able to receive new input about their surroundings throughout their duration. The process is then able to change itself according to data received from its surroundings.*
>
> *— Alexander R. Galloway*[41]

41 Ref.: Galloway, A.R., 2006. Protocol, MIT Press, p. 59

I am arguing that the essential function of the computer loop is directly connected to the theory of cybernetics, first introduced by Norbert Wiener in 1948. Feedback is constitutional to any operation on the computer, from data visualization to the interface. The recursive computational procedure is the most crucial difference between drawing data graphics manually and designing visualizations with the computer.

The `dataset` array is separated from the form of the rectangle and the re-entry of our horizontally distributed `function x`. *Data* and *visualization* operate together apart from one another. Until now, the actual values within our dataset did not matter as long as commas separated them. So, the dataset below would also display five equally spaced rectangles.

```
var dataset = [ contrast, dissimilarity, dissimilitude, divergence,
variance ];
```

As the code so far only counts `i` from zero to `dataset.length`, the array's actual data is neglected. So far, the JavaScript code of the rectangle distinguishes between the horizontal `x` position and the width of each rectangle. As discussed in the section on SVG, the definition of a rectangle at minimum needs four values, `x`, `y`, `width`, and `height`. By drawing another distinction, Murray enters the dataset values into the form of the rectangle:

```
.attr("height", function(d) {
    return d;
});
```

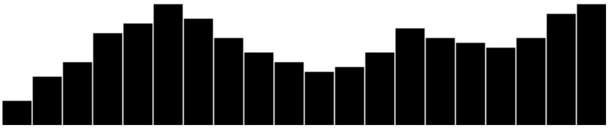
The numerical values of the dataset now re-enter the rectangles through `d`.

To enlarge the vertical height, Murray multiplies each `d` value by four, `return d * 4`.

The process of drawing distinctions and re-entering these distinctions is so far the entirety of what it means to design visualizations within the computer, and this process continues. By drawing another re-entry on the vertical axis,

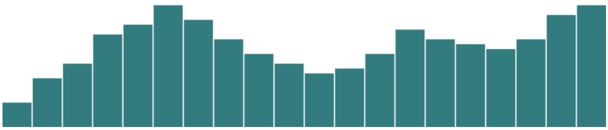
```
.attr("y", function(d) {
    return h - d;
})
```

the distinctions between the rectangles face upwards:



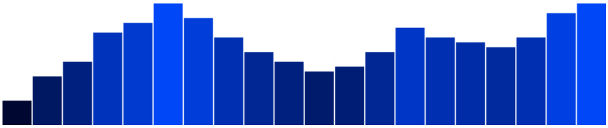
By drawing another distinction, the rectangles turn from black to teal.

```
.attr("fill", "teal");
```

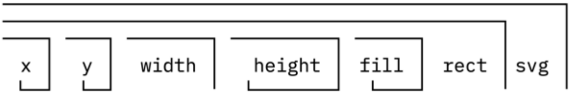


Rather than having a static color by looping through, by re-entering the dataset the color adjusts to the value within the dataset:

```
.attr("fill", function(d) {
    return "rgb(0, 0, " + (d * 10) + ")";
});
```



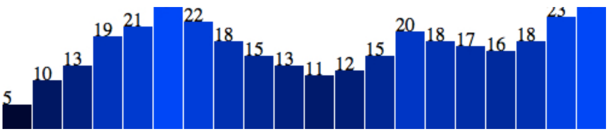
The diagrammatic notation of the form allows us to observe each step of the design process:



Murray `appends` another element to the form of the SVG.

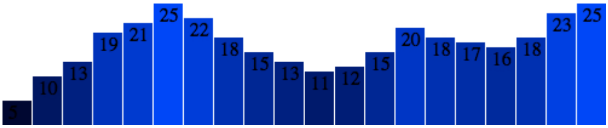
```
svg.selectAll("text")
   .data(dataset)
   .enter()
   .append("text")
   .attr("x", function(d, i) {
        return i * (w / dataset.length);
   })
   .attr("y", function(d) {
        return h - (d * 4);
   })
   .text(function(d) {
        return d;
   });
```

The *space* of the SVG now holds two distinctions: a rectangle and a text element.



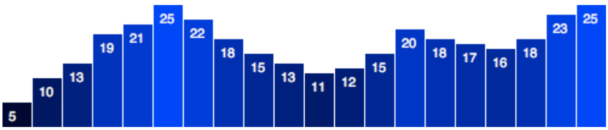
Murray next adjusts the text distinction by multiple parameters, first changing the position of the `text`:

```
.attr("x", function(d, i) {
     return i * (w / dataset.length) + 5;
})
.attr("y", function(d) {
     return h - (d * 4) + 15;
});
```



second, by drawing three more distinctions within each `text` element:

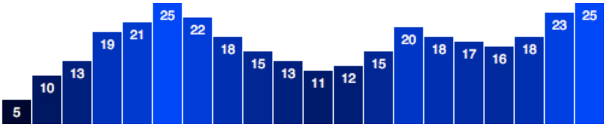
```
.attr("font-family", "sans-serif")
.attr("font-size", "11px")
.attr("fill", "white");
```



and third, by re-adjusting the position of each text element:

```
 .attr("text-anchor", "middle")
 .attr("x", function(d, i) {
        return i * (w / dataset.length) + (w / dataset.length -
barPadding) / 2;
     })
 .attr("y", function(d) {
        return h - (d * 4) + 14;
     })
```

This results in Murray's final bar chart of the tutorial.



This chapter introduced how to conceptualize the process of designing a bar chart as one of drawing distinctions and re-entering these distinctions within a space. Design becomes a pre-binary process of an operation:

> *Draw a distinction.*
>
> — *George Spencer-Brown*[42]

The *space* predefines the possibility of drawing distinctions. The *re-entry* loops through forms and, as showcased, is the fundamental method of constructing visualizations by re-entering data.

Epilogue

Throughout this chapter, I observed and analyzed how drawing distinctions creates form in the space of the Hypertext Markup Language. The logical operation of *drawing distinctions* reflected on the process of designing a graphical representation of a bar chart. I introduced the three terms *distinction*, *space*, and *re-entry* and related each of these terms to the design process of writing code. A distinction is an operative textual command on the code layer. Space is the framework within which the distinctions are drawn. The re-entry is a loop that iterates through a distinction within itself. In the text *Memories,* Vilém Flusser describes the transformation from oral to written language:

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[42] Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p.3

> *Air has the advantage of being readily accessible; moreover, we have organs which seem to have been made to transform airwaves into signs (to make "phonemes" out of them)… . Hard objects (stones and bones) have the advantage of storing information recorded in them for a relatively long time… . Approximately three thousand five hundred years ago (in other words, only a short time ago), an important step was taken; the alphabet was invented. It is a system which recodes the phonemes of spoken languages into visual signs, allowing them to be engraved into hard objects.*
>
> — *Vilém Flusser* [43]

For Sybille Krämer, this transition from oral history to the alphabet indicates the transition into a digital society.[44] The alphabet is a set of distinctions. I can write either ›a‹ or ›b‹ but cannot interpolate between the two. The cultural form of the distinction, the digital, from this perspective is older than the computer. However, the computer is the first technology in which the *re-entry* holds such an explicit status. The nested looping structure is what makes the computer into the general-purpose machine that it is.

This chapter contemplated together the design of graphic representations of data, the space of web design, and the logical operation of the form. By *drawing distinctions,* form iterates through data. The design process in computer systems is a process of drawing distinctions within a space, creating form. The theory behind the form, its logical and epistemological consequences, and the praxis of designing visualizations need further investigation. Until this point, no *insight* has emerged from the drawing of distinctions. This chapter introduced the theory that the distinction is the form of design operations. Its relation to the insight will be further investigated in both theory and praxis.

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43 Ref.: Druckrey, T., 1999. Ars Electronica, MIT Press, p. 203.

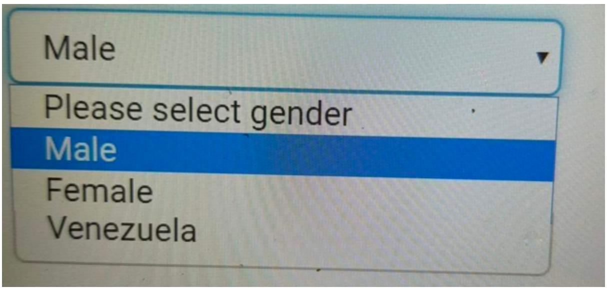
44 Ref.: Krämer, S., 2020. Cultural history of digitisation. Making Sense of the Digital Society. Available at: https://www.hiig.de/en/events/sybille-kraemer-cultural-history-of-digitisation/.

Form

Logic has interests in abstract forms. Science investigates extant forms. Design initiates novel forms.

— Lionel March[1]

The command *please select gender* glows on my computer screen. Irritated, I am observing the three choices the web interface has pre-defined: *Male*, *Female*, and *Venezuela*. When something is not adjusted to my daily categorization systems, when binary gender concepts clash with a republic on the northern coast of South America, the *form* extends into sight and question.



Please select Gender[2]

1 Ref.: March, L., 1984. The Logic of Design. In Developments of Design Methodology. New York: John Wiley.

2 Image Source: https://i.redd.it/0dx8pzq2vc541.jpg

The four metaphors of visualization design discussed in the first part of this thesis, *raster*, *arrow*, *chain*, and *pyramid*, created a set of questions that I was unable to answer by organizing, relating, and investigating visualization design research and practices. *How do data visualizations represent insights? What kind of insights can data visualizations represent?* Not only have these topics remained unanswered, they have also resulted in more questions. The most intriguing to me relates to the design process and insights: *What is design's role within a process toward achieving insights?* Various others emerge in the *a priori*, in the presumptions of data, visualization, and design: *What is data visualization a priori, what pre-defines any representation of data? And how do these pre-definitions determine the possible insights?* Besides these, others arise on the topic of organization and structure: *If design is about creating structure, how does this affect insights? How does organization influence what is known? How does structure, organization, simplicity, and subjectivity relate to insights?*

While I could not come across answers in visualization research and design, I became inspired by a mathematical theory called the *Laws of Form*. From my perspective, this theory offers intriguing principles that I have extended and applied to the design and especially to designing with the computer.

Throughout the next five chapters, I will postulate a theory called the *calculus of design*, relating to and contrasting with the design and data visualization concepts analyzed thus far. I will suggest one possible path toward answering these interrelated questions through an epistemological design theory. Five terms will be addressed in each chapter, presenting the theory's foundation, namely: *form*, *design*, *space*, *time*, and *insight*. In each of the five chapters, I will introduce the mathematical foundations and reformulate them as a theory of design. The terms will become tractable and relatable to various fields, such as media theory, mathematics, sociology, science studies, art history, philosophy, and design theory and practice.

The term discussed in this chapter is *form*. I will structure the chapter into three subchapters:

- *Laws of Form*: Introduces the foundational concepts, axioms, and arithmetic and algebraic operations of form within mathematical theory.
- *Calculus of Design*: Draws analogies between design theories and practices and my interpretation of the mathematics of form.

- *Theoretical Relations*: Accompanies the design perspective of *form* relating philosophy to design theory.

This chapter will not answer any of the questions listed above but will introduce a theoretical framework that leads in their direction. *The chapter's objective is to introduce a theory on the smallest act of design and question its constituencies and assumptions.*

Laws of Form

Before introducing the *Laws of Form*, I will provide a brief introduction to the book's historical reception and, thus, how I came to understand the theory. George Spencer-Brown described himself as a *mathematician, consulting engineer, psychologist, educational consultant and practitioner, consulting psychotherapist, author, and poet*.[3] After ten years of work, he released the *Laws of Form* at the beginning of 1969 through the London-based publisher *Allen and Unwin Ltd*.[4] The book's first response was an enthusiastic comment by Heinz von Foerster in the *Whole Earth Catalog* in the same year.[5] In 1973, the *American University of Masters* at Esalen organized a conference around the book.[6,7] Following this initial reception, the book never reached the international popularity in mathematics, logic, or philosophy that Spencer-Brown had hoped for.[8,9]

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3 Ref.: Spencer-Brown, G., Vita. lawsofform.org. Available at: https://web.archive.org/web/20040611164702/http://www.lawsofform.org/gsb/vita.html Accessed February 11, 2021.

4 Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag, p. 9

5 Ref.: Brand, S., 1969. Whole Earth Catalog S. Brand, ed., Menlo Park: Portola Institute, Inc. Available at: http://www.westdenhaag.nl/information/publications/Alphabetum/Laws_of_Form/Alphabetum_III_V8_ONLINE.pdf.

6 The conference included not only Spencer-Brown and von Foerster but individuals such as Kurt von Meier, Cliff Barney, Gregory Bateson, Alan Watts, John Lilly, Douglas Kelly and Karl Pribram.

7 Ref.: Spencer-Brown, G., 1973. AUM Conference Transcript Session One. AUM Conference.

8 Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag, p. 20

9 Ref.: Tydecks, W., 2019. A commentary on Laws of Form from Spencer-Brown.

While there are undoubtedly various reasons why this book never reached a wider audience, one reason might be how Spencer-Brown wrote the book. The *Laws of Form* are written in a didactic method of mathematical instruction. The central part of the book is written as a set of diagrammatic commands. In the introduction of the 1997 German edition of the book, Spencer-Brown makes only one statement that describes *how something is*:

> *...dass es in diesem Text nirgendwo einen Einziegen Satz gibt, welcher besagt, was oder wie irgend etwas ist.*
>
> — *Spencer-Brown*[10,11]

Every other sentence of the book is written as a command for the reader to explore independently. While such a pedagogical move is intriguing, it is, at the same time, challenging to understand. The book primarily consists of a diagrammatic notation system of lines and their operations.

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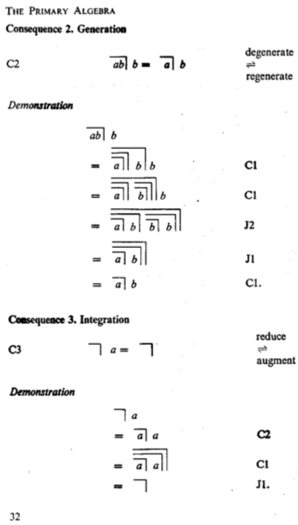
tydecks.info. Available at: http://www.tydecks.info/online/themen_e_spencer_brown_logik.html Accessed December 2, 2020.

10 Ref.: Spencer-Brown, G., 1997. Laws of Form German Language edition, Bohmeier Verlag, p. x

11 Translated: *...that nowhere in this text is there a single sentence that says what or how anything is.*



Page 32 of the *Laws of From*

At the University of Bielefeld in Germany, over ten years after the initial publication, in 1980 a group of researchers around Niklas Luhmann started reading and applying the *Laws of Form* to sociology. Luhmann adapted parts of the mathematical concept toward his *systems theory*, first articulated in his book *Soziale Systeme* in 1984.[12] Following *Soziale Systeme,* Luhmann published books on a vast range of fields from law[13] to science,[14] art,[15] religion,[16] and politics,[17] among others. A transcript of one of Luhmann's lectures,[18] which I will repeatedly reference throughout this introduction, outlines his systems theory's foundation based on the notion of difference and distinction adapted from Spencer-Brown.

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12 Ref.: Luhmann, N., 1987. Soziale Systeme, Frankfurt am Main: Suhrkamp.

13 Ref.: Luhmann, N., 1995. Das Recht der Gesellschaft, Frankfurt am Main: Suhrkamp.

14 Ref.: Luhmann, N., 1992. Die Wissenschaft der Gesellschaft, Frankfurt am Main: Suhrkamp.

15 Ref.: Luhmann, N., 1995. Die Kunst der Gesellschaft, Frankfurt am Main: Suhrkamp.

16 Ref.: Luhmann, N., 2000. Die Religion der Gesellschaft, Frankfurt am Main: Suhrkamp.

17 Ref.: Luhmann, N. & Kieserling, A., 2002. Die Politik der Gesellschaft, Frankfurt am Main: Suhrkamp.

18 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57.

As Luhmann became a significant figure in German sociology in the 20th century,[19] today, some secondary literature exists on the mathematics of the *Laws of Form*. These books and papers made the *Laws of Form* accessible and allowed me to understand, apply, and extend the theory to design without a background in theoretical mathematics.[20]

While Spencer-Brown was born in 1923 in Grimsby, Lincolnshire, England, his popularization through Luhmann created a boundary. Most of these books have never been translated into any language other than German. The secondary literature allowed me to engage with the mathematical, sociological, and philosophical perspectives of the *Laws of Form* and reinterpret the theory from a design perspective. In visualization design, Johanna Drucker allocated an extensive footnote in her book *Graphesis* to the *Laws of Form*.[21] For me, an essential introduction to the *Laws of Form* concerning design and diagrams came from philosopher Sybille Krämer. She devoted several papers to the theory and its

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19 Ref.: Bechmann, G. & Stehr, N., 2002. The legacy of Niklas Luhmann. Society, 39(2), pp.67–75.

20 A list of books and papers that predominantly shaped my conceptions:

- Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag.

- Schönwälder, T., Wille, K. & Hölscher, T., 2013. George Spencer Brown, Springer-Verlag.

- Baecker, D., 1993. Kalkül der Form, Frankfurt am Main: Suhrkamp.

- Baecker, D., 1993. Probleme der Form, Frankfurt am Main: Suhrkamp.

- Baecker, D., 2007. Form und Formen der Kommunikation, Frankfurt am Main: Suhrkamp.

- Baecker, D., 2013. Beobachter unter sich, Frankfurt am Main: Suhrkamp.

- Baecker, D., 2014. Kulturkalkül, Berlin: Merve.

- Krämer, S., 2009a. Epistemology of the line. Studies in Diagrammatology and Diagram Praxis.

- Krämer, S., 1998. Form als Vollzug oder: Was gewinnen wir mit Niklas Luhmanns Unterscheidung von Medium und Form?

- Krämer, S., 2009b. Operative Bildlichkeit. In Logik des Bildlichen. Von der ‚Grammatologie' zu einer ‚Diagrammatologie'? Reflexionen über erkennendes ‚Sehen'. pp. 94–122.

21 Ref.: Drucker, J., 2014. Graphesis, Harvard University Press.

relation to diagrammatics.[22,23,24] Dirk Baecker wrote at least two articles relating the *Laws of Form* to design from a sociological perspective.[25,26] Apart from these references, there are few connections between the *Laws of Form* and design or data visualization to my knowledge. For this reason, it became so intriguing to me to reinterpret and extend the conceptual ideas into design. I was finding similarities but also differences and problems from theory to application. I will begin this chapter by introducing the form's fundamental concepts and mathematical operations within the *Laws of Form* before drawing similarities to design.

Calculus

The Latin word calculus means *pebble* or *little stone*.[27] In mathematics, a calculus is a formal system that determines the rules of symbol operations.[28] Spencer-Brown defined the calculus of the *Laws of Form* as a *system of constructions and conventions that allows calculation*. Further, he described calculation as *a procedure by which, as a consequence of steps, one form is exchanged for another*.[29] *The Laws of Form define a set of rules to change one form into another.*

The *Laws of Form* define a formal system consisting of three foundational distinctions to calculate: *axioms*, *canons*, and *theorems*.

Axioms are untestable, self-evidently true statements that precede the operation. The Greek *axíōma* means *that which commends itself as evident*.[30] Axioms precede

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22 Ref.: Krämer, S., 2009a. Epistemology of the Line. Studies in Diagrammatology and Diagram Praxis.

23 Ref.: Krämer, S., 1998. Form als Vollzug oder: Was gewinnen wir mit Niklas Luhmanns Unterscheidung von Medium und Form?

24 Ref.: Krämer, S., 2009b. Operative Bildlichkeit. In Logik des Bildlichen. Von der ‚Grammatologie' zu einer ‚Diagrammatologie'? Reflexionen über erkennendes ‚Sehen'. pp. 94–122.

25 Ref.: Baecker, D., 2015. Designvertrauen. Merkur, pp.89–97.

26 Ref.: Baecker, D., 2017. Mindful Design in the Humanities.

27 Ref.: Stevenson, A. & Lindberg, C.A., 2010. New Oxford American Dictionary 3rd Edition, Oxford University Press.

28 Ref.: Hofstadter, D.R., 1979. Godel, Escher, Bach, Basic Books, p. 40

29 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. 9

30 Ref.: Stevenson, A. & Lindberg, C.A., 2010. New Oxford American Dictionary 3rd

the formal system and can be justified by nothing other than the interpretation from which they originate. They are assumed and define the initial placements of a calculus.[31]

Rules, also called *canons* (Greek: *rule*), define which operations are allowed within the system. The axioms and canons set the possibilities of the calculus, the formal system.[32,33]

Logically derived signs from the axioms and rules are called theorems.[34] *Theorems* are the result of reasoning within the set system of axioms and canons. They are configurations that the formal system can produce. The calculus is a method of generating formal sign systems based on the axioms and canons.[35] Spencer-Brown calls the calculus of the *Laws of Form* the *calculus of indication*; his devotion is nothing less than a foundational theory of mathematics:

> *... mathematical texts generally begin the story somewhere in the middle, leaving the reader to pick up the thread as best he can. Here the story is traced from the beginning.*
>
> — *Spencer-Brown*[36]

Entry

For Spencer-Brown, the beginning of mathematics is not numerical. The *Laws of Form* do not have an explicit notion of numbers. The axioms and canons are too fundamental for numbers, but can lead to them. The *calculus of indication* starts

Edition, Oxford University Press.

31 Ref.: Hofstadter, D.R., 1979. Godel, Escher, Bach, Basic Books, p. 40

32 Ref.: Stevenson, A. & Lindberg, C.A., 2010. New Oxford American Dictionary 3rd Edition, Oxford University Press.

33 Ref.: Hofstadter, D.R., 1979. Godel, Escher, Bach, Basic Books, p. 40

34 Ref.: Hofstadter, D.R., 1979. Godel, Escher, Bach, Basic Books, p. 40

35 Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag, p. 9

36 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. V

with the *entry* by creating a first indication in an *unmarked space*.[37,38] Luhmann imagines the *unmarked space* as a white sheet of paper:

> *It helps me (I am not sure that others feel the same way) to imagine that there is first of all a white sheet of paper; then the marks are put down on the sheet and thereby gain a peculiar independence: one mark and another one, the second one copied in part from the first and so forth.*
>
> — *Niklas Luhmann* [39]

This chapter will take the space for granted and devote another chapter, *Space*, to investigate the concept. Spencer-Brown's entry into the mathematical theory of form starts with a command:

> *Draw a distinction.*
>
> — *Spencer-Brown*[40]

Characteristics of Form

Drawing a distinction creates *form*. The *form* does not stand on its own, but consists of four essential characteristics present at once: *distinction*, *indication*, *boundary*, and *space*.

Distinction and Indication

The first sentence of the first chapter in the *Laws of Form* introduces the notion of *distinction* and *indication*:

> *We take as given the idea of distinction and the idea of indication, and that one cannot make an indication without drawing a distinction.*
>
> — *Spencer-Brown*[41]

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37 Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag, p. 30

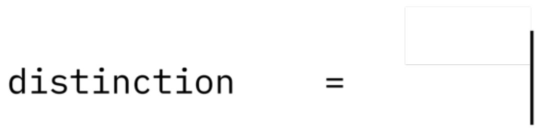
38 The meaning of *space* is so vast that I will devote an entire chapter to the concept. At this point, imagine the unmarked state is the blank page in a writing application, an empty canvas in design editing software, an unstructured wood block. Or, more generally, the unmarked, undesigned space one works within.

39 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57, loc. 131-134

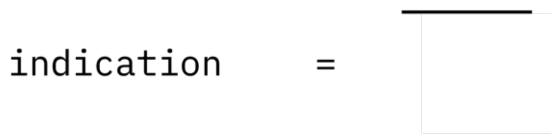
40 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p.3

In the theory, an *indication* is never on its own but rather accompanied by a *distinction*; they are different but always a unit. The *distinction* separates the *space*, creating an invisible *boundary*.[42] The distinction is invisible, a division of the space. The indication marks one side of the division and, through that, is drawn into observation. Without the distinction, only the entire space could be indicated. Without the indication, there would only be an invisible boundary without a marked side. In the *Laws of Form,* indication and distinction must happen together but need to be imagined separately. The boundary is the effect of the interplay between distinction and indication.

The calculus of indication is a mathematical conception and a diagrammatic notation system consisting of two lines drawn together. A vertical line marks the distinction:

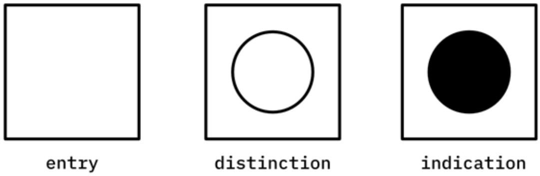


The representation of the indication is a horizontal line emerging from the upper part of the distinction, indicating the left or right side of the distinction:



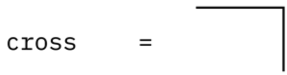
To clarify this point, I will illustrate the three steps in the figure below. The *entry* into the *space* is visualized as a circle without anything contained within it. The *distinction* is exemplified by a line separating the *space*. Here, it is crucial to note that the representation is flawed. The division within the *calculus of indication* is invisible. Only the *indication* renders the *distinct* visible.

42 Just like the example of the bar chart, the underlying scalable vector graphics distinguish inside from outside.

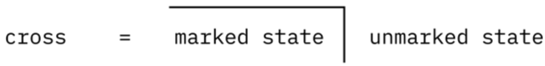


Cross, Marked and Unmarked

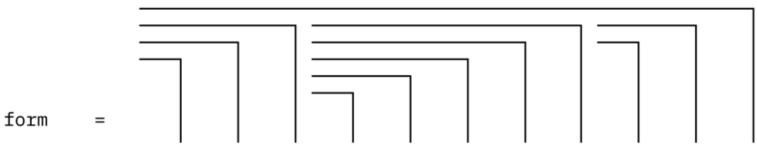
Distinction and indication together create the *cross*. It emerges by drawing two lines together, the line of distinction and the line of indication.



The *cross* separates the *marked state*, the indicated side, from the *unmarked state* by the *boundary*:



Form is the conglomerate of crosses within a *space*. It describes the entirety of operations of marked and unmarked crosses in the space.



The notion of *form* does not mean anything in particular. It is an abstract mathematical concept of how *form* divides *space*. *Distinction*, *indication*, *boundary*, and *space,* as well as the *marked state* and *unmarked state,* are the foundational components of the theory.

Operations of Form

The *axioms*, *arithmetic*, and *algebra* of the *Laws of Form* describe the possible operations through which forms change from one state into another. The foundations of the *calculus of indication* is about *processes* from one state of *form* to another.

Axioms

A calculus is *a procedure by which, as a consequence of steps, a form is changed for another*.[43] The *axioms* of the calculus define its fundamental operations; they precede the formal system. Their justification is based on nothing other than the interpretation from which they originate. They are assumed by the author and define the basic principles of a calculus.[44] Aristotle described axioms as those *from which demonstration arises*.[45,46,47,48] Axioms are the fundamental deductive

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43 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p.3

44 Ref.: Hofstadter, D.R., 1979. Godel, Escher, Bach, Basic Books, p. 40

45 One axiom by Aristotle from the book *Analytica posteriora* is the principle of non-contradiction. An object cannot have a quality and, at the same time, not have that quality.

46 Ref.: Ross, S.D., 2004. Aristotle, Routledge.

47 Euclid of Alexandria set a historical mark in axiomatic thinking. Euclid's elements contain five Axioms:

Axioms:

1. To draw a straight line from any point to any point.

2. To produce (extend) a finite straight line continuously in a straight line.

3. To describe a circle with any centre and distance (radius).

4. That all right angles are equal to one another.

5. The parallel postulate: That, if a straight line falling on two straight lines make the interior angles on the same side less than two right angles, the two straight lines, if produced indefinitely, meet on that side on which the angles are less than two right angles.

48 Ref.: Heath, T.L., 2015. The Thirteen Books of Euclid's Elements, Cambridge University Press.

rules of the system they develop. The *Laws of Form* only contain two axioms, two untestable self-evidently true statements, which precede the operation. In the paper *Axiomatisches Denken,* David Hilbert summarizes the importance of axioms as follows:

> *Everything that can be the object of scientific thinking in general, as soon as it is ripe to be formulated as a theory, runs into the axiomatic method and thereby indirectly to mathematics. Forging ahead towards the ever deeper layers of axioms in the above sense we attain ever deepening insights into the essence of scientific thinking itself, and we become ever more clearly conscious of the unity of our knowledge.*
>
> — *David Hilbert*[49,50]

Hilbert's quote anticipates the relation between axioms and knowledge, to which I will return in the final chapter *Insight*. I am presenting the passage at this point to highlight the importance of axioms for my research questions.

Axiom 1 (Law of Calling)

The first axiom in the *calculus of indication* is specified as the *law of calling*:

> *Axiom I (Law of Calling): The value of a call made again is the value of the call.*
>
> — *Spencer-Brown*[51]

In *System as Difference,* Niklas Luhmann reformulated the law as:

> *The 'law of calling'. If I repeat the same distinction (the same mark) several times, then the value of the repeated distinctions taken together is equal to the value of one single distinction.*
>
> — *Niklas Luhmann*[52]

Or, in my own words, repetition without making a difference does not mark a difference. *To recall equals the call.*

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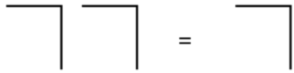
49 Ref.: Hilbert, D., 1996. Axiomatic thought. In From Kant to Hilbert. Oxford: Oxford University Press, pp. 1114–1115.

50 Ref.: Mazur, B., 2018. Axiomatic Reasoning, Harvard University. Available at: http://people.math.harvard.edu/

51 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p.1

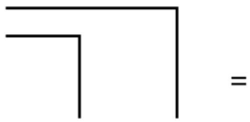
52 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57, loc. 135-136.



Axiom 2 (Law of Crossing)

The second axiom is named the *law of crossing*:

> *Axiom II (law of crossing): The value of a crossing made again is not the value of the crossing.*
>
> — *Spencer-Brown*[53]



Luhmann formulates in the context of the second axiom:

> *The 'law of crossing'. A mark can be crossed within the boundary it marks and thus, as it were, be negated. This means that a second distinction can be applied to the first one in such a manner that the original distinction is 'cancelled'.*
>
> — *Niklas Luhmann*[54]

Opposite forms that fit into one another cancel each other out, leaving the observer in the unmarked space. Louis H. Kaufmann articulates the concept in his foundations on the *Laws of Form* in the following terms:

> *The Law of Crossing indicates how opposite forms can fit into one another and vanish into the Void, or how the Void can produce opposite and distinct forms that fit one another, hand in glove.*
>
> — *Louis H. Kaufmann*[55]

---

53 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p.2

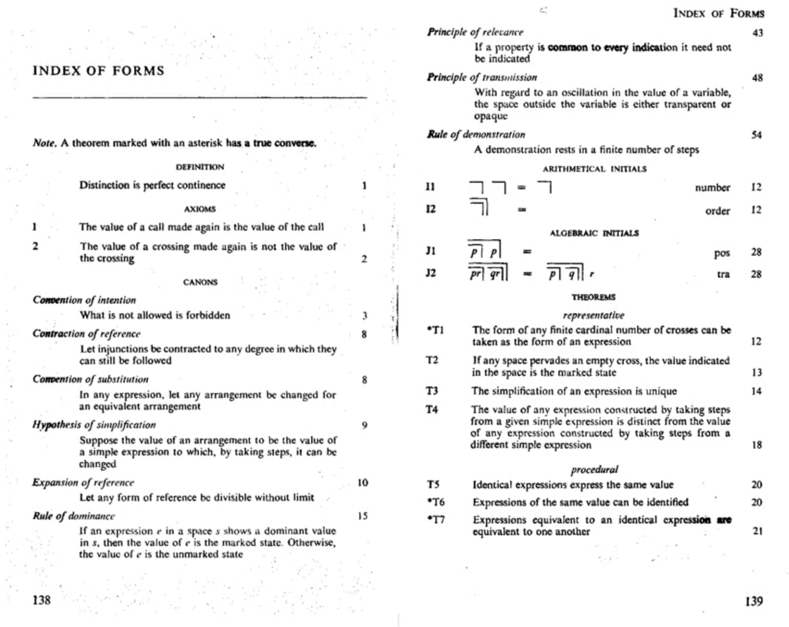
54 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57, loc. 137-142.

55 Ref.: Kauffman, L.H., 2006. Laws of Form - An Exploration in Mathematics and

Two instances of the form become equivalent to no instance if one form negates the other. Crossing from marked into unmarked erases the mark.

The two axioms, *to recall equals to call* and *to cross equals no call* are the calculus' foundations. Spencer-Brown develops in 12 chapters three branches of mathematics from these two axioms: *arithmetic*, *algebra*, and *theorems of the second order*. As I want to investigate the *Laws of Form* as a design theory, I will name theorems and canons at appropriate points but will not review them in this introduction. At the end of the book *Laws of Form,* Spencer-Brown listed an index of all *axioms*, *canons*, and *theorems,* namely the following:

Foundations, Available at: https://homepages.math.uic.edu/, p.7



INDEX OF FORMS

Note. A theorem marked with an asterisk has a true converse.

DEFINITION

Distinction is perfect continence 1

AXIOMS

1 The value of a call made again is the value of the call 1

2 The value of a crossing made again is not the value of the crossing 2

CANONS

Convention of intention 3
What is not allowed is forbidden

Contraction of reference 8
Let injunctions be contracted to any degree in which they can still be followed

Convention of substitution 8
In any expression, let any arrangement be changed for an equivalent arrangement

Hypothesis of simplification 9
Suppose the value of an arrangement to be the value of a simple expression to which, by taking steps, it can be changed

Expansion of reference 10
Let any form of reference be divisible without limit

Rule of dominance 15
If an expression *e* in a space *s* shows a dominant value in *s*, then the value of *e* is the marked state. Otherwise, the value of *e* is the unmarked state

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Principle of relevance 43
If a property is common to every indication it need not be indicated

Principle of transmission 48
With regard to an oscillation in the value of a variable, the space outside the variable is either transparent or opaque

Rule of demonstration 54
A demonstration rests in a finite number of steps

ARITHMETICAL INITIALS

I1 $\overline{}|\ \overline{}| = \overline{}|$ number 12

I2 $\overline{\overline{}|}| =$ order 12

ALGEBRAIC INITIALS

J1 $\overline{\overline{p}|\ p}| =$ pos 28

J2 $\overline{\overline{pr}|\ \overline{qr}|}| = \overline{\overline{p}|\ \overline{q}|}|\ r$ tra 28

THEOREMS

representative

*T1 The form of any finite cardinal number of crosses can be taken as the form of an expression 12

T2 If any space pervades an empty cross, the value indicated in the space is the marked state 13

T3 The simplification of an expression is unique 14

T4 The value of any expression constructed by taking steps from a given simple expression is distinct from the value of any expression constructed by taking steps from a different simple expression 18

procedural

T5 Identical expressions express the same value 20

*T6 Expressions of the same value can be identified 20

*T7 Expressions equivalent to an identical expression are equivalent to one another 21

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Arithmetic

The origins of the term *arithmetic* lie in the ancient Greek expression *rhuthmós*, rhythm or flow, and *arithmós* for counting.[56] The two axioms of *calling* and *crossing* the form allow for the arithmetic operations of *addition*, *subtraction*, *multiplication*, and *division*. Compared with Boolean algebra, consisting of one and zero, only one sign is needed, the cross. The cross attributes the marked and unmarked state. For this reason, I am calling the *Laws of Form* a pre-binary method of sign processing. There are only crosses in the *calculus of indication*, no counterparts.[57]

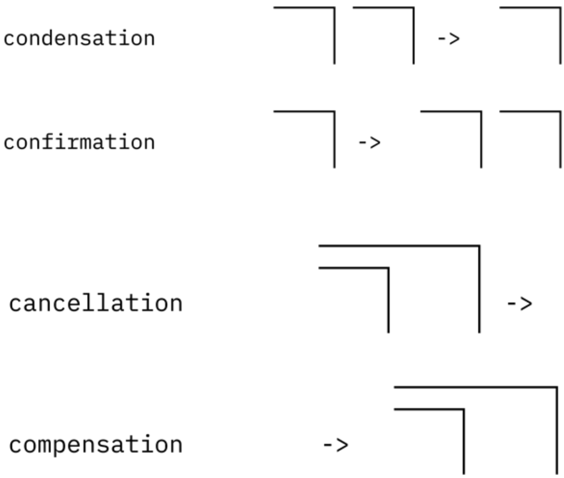
56 Ref.: Harper, D., 2021. arithmetic (n.). etymonline.com. Available at: https://www.etymonline.com/word/arithmetic#etymonline_v_16998 Accessed February 16, 2021.

57 Charles Sanders Peirce also developed a pre-binary algebra: Charles Sanders Peirce: A Boolean Algebra with One Constant (1880). In: Charles Hartshorne, Paul Weiss (Hrsg.):

The *fifth canon* of the *Laws of Form* is called the expansion of reference. The two axioms are expanded to operate forward and backward. To do so, Spencer-Brown introduces a symbol for the operation *is changed to*.

`->     =    is changed to`

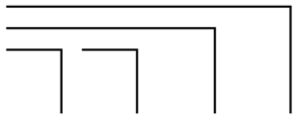
With this new symbol, the axioms operate to introduce, expand, and cancel crosses through four operations: *condensation*, *confirmation*, *cancellation*, and *compensation*.



These operations lead to two arithmetic *initials*, two starting points of calculation. The first initial creates *numbers* by means of *condensation* and *confirmation*, and the second initial generates *order* through *cancellation* and *compensation*. These two operations allow arithmetic transformations of the form.

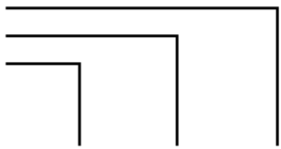
Let me provide an example of *condensation* and *cancellation* of *form* to showcase the procedure by which one form is changed into another as a consequence of steps. The first form consists of four nested crosses:

Collected Papers of Charles Sanders Peirce. Vol. 4: The Simplest Mathematics. MA: Harvard UP, Cambridge 1933, S. 13–18



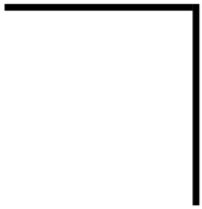
I will operate from left to right and bottom to top. The two crosses on the left side of the diagram stand next to one another. Through *condensation,* the two crosses can become one. Both crosses are indicated in light gray in the next diagram:

The arithmetic operation of *condensation* draws two crosses into one, leaving three instead of four crosses.



The next two crosses on the left side in the diagram are nested into one another, again highlighted in gray:

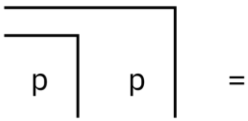
The operation of *cancellation* changes the two crosses into none, leaving one cross within the form, which cannot be further reduced by *condensation* or *cancellation*.



Condensation and cancellation on the arithmetic level of transforming form lead to two possible states, marked or unmarked, void or form. In this case, the result of the operation is one marked cross within the form.

Algebra

Algebra originates from the Arabic *al-jabr* and stands for a reunion or a resetting of broken parts.[58] The algebra of the *calculus of indication* introduces variables such as *a, b* or *p, q, r*. These variables stand as distinct crosses in the space. In theorem 8, *invariance,* and theorem 9, *variance*, Spencer-Brown introduces the basic algebraic operations. The two initials, starting points of calculation, of Spencer-Brown's algebra are *position*:



The theorem of *invariance* confirms that the arithmetic operation of *condensation* still applies to the algebraic process. The canceling repetition of the form still applies.[59]

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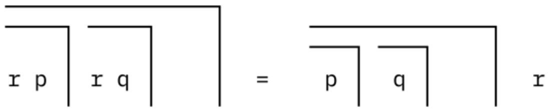
58 Ref.: Harper, D., 2021. algebra (n.). etymonline.com. Available at: https://www.etymonline.com/word/algebra#etymonline_v_8140 Accessed February 16, 2021.

59 Ref.: Baecker, D., 2013. Beobachter unter sich, Frankfurt am Main: Suhrkamp.

The initial *transposition* from theorem 9 postulates that *variances* of an expression are equivalent even if they are differently distributed without changing the relationship towards one another.[60]



From the axioms and arithmetic and algebraic operations, Spencer-Brown explores various consequences, distinct patterns. The procedures of the form lead him, for example, to one solution of the four-color theorem without the use of a computer.[61] The proof for the two theorems spans three pages, and I will not detail the operating steps here but rather apply these concepts towards a theory of design. I will name and discuss various design and visualization practices and theories related to the fundamental concepts I have described so far.

Calculus of Design

While Spencer-Brown's motive was to formulate a theory on the foundations of mathematics, the further I researched, the more comprehensive the relations to design theory and practice became. I arranged the fundamental findings and arguments into seven sections within two subchapters, *Characteristic of Design* and *Operations of Design*:

1. *Design Evolutions*: From a historical standpoint, various *design evolutions* have been distinctly observed throughout the last 100 years. This section will focus on the relation between mathematics and the rise of computation in the design process.
2. *Design Etymology*: From an *etymological* standpoint, I will investigate the origins of the term *design*. There are various intersections of *design* and the

60 Ref.: Baecker, D., 2013. Beobachter unter sich, Frankfurt am Main: Suhrkamp.

61 Ref.: Kauffman, L.H., 2001. Reformulating the Map Color Theorem. arXiv.org, math.CO. Available at: http://arxiv.org/abs/math/0112266v2 Accessed February 16, 2021.

language Spencer-Brown uses for terms such as *mark*, *indication*, *distinction*, and *form*.
3. *Design Attributes*: In this section, I will relate the characteristics *distinction*, *indication*, *boundary*, and *space,* as well as *marked state* and *unmarked state,* to various design theories.
4. *Design Axioms*: The fourth section investigates the *axioms* of the *Laws of Form* concerning the structure and organization of data, design, and visualization.
5. *Design Arithmetic*: This section exemplifies the *arithmetic operations* from one form to another exemplified by phenomena in the design of data graphics and maps.
6. *Design Algebra*: I will examine the setting and re-setting of interface politics concerning the *algebraic operation* of drawing distinctions.
7. *Design Process*: The last section relates various visualization design processes from the chapter *Chain* to the evolved theory of design as an operative drawing of distinctions.

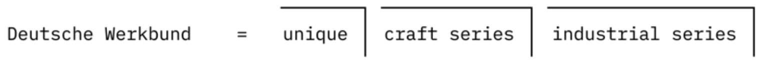
Within these seven sections, I will demonstrate the commonalities and extensions of design concerning the *calculus of indication*. I will call my conceptualization the *calculus of design*. The theory will allow me to rename, observe, and analyze design as a performative calculus based on operations. I will introduce the axioms, rules, and theorems of the *Laws of Form* and reformulate these towards a theory of design. Modeling design as a formal system allows one to observe the rules, the underlying assumptions of the language. The model is not reality, but the strength of the *calculus of design*, as I will explain in later chapters, is that it not only accounts for this gap but is constructed upon the difference between model and reality. The following sections' objective is to organize the fundamental conceptions, the smallest acts of design, into a theory of the *calculus of design*.

Characteristics of Design

This subchapter contains two lines of argumentation. First, I will introduce the historical synergies between design and mathematics. In *Design Evolutions,* I will put forward the argument that contemporary design is at its core a mathematical operation evolved from a set of serial evolutions. Both chapters, *Design Etymology* and *Design Attributes,* relate the terminology of the *Laws of Form* to design theories and practices from both a historical and a contemporary perspective.

Design Evolutions

From a historical, sociocultural perspective, the term *design*, as planning or creating a system, provides a blueprint for later production. Design from this perspective relates to various industrial revolutions.[62] Heinz Hirdina names the separation of planning and production as a crucial distinction of design from art. Artists perform drafting and production together; design separates the two.[63] Design, in this sense, is reusable. It applies the marks, the blueprint, the plan, over again. The creation of an object, a vase, a spaceship, or a smartphone application is distinct in two processes; the plan is separated from the production. The designer creates a blueprint for the chair, which gets manufactured. Between 1907 and 1914, the *Deutsche Werkbund* defined three distinctions, the *unique object* (Unikat), *craft series* (handwerkliche Serie), and *industrial series* (industrielle Serie).



In the diagram above, I introduce the diagrammatic notation system of the *calculus of indication* towards the categorization of the *Deutsche Werkbund*. The *unique object* is *distinct* and *indicated* separately from the *craft series* and the *industrial series*. The distinction between the *craft series* and the *industrial series* marks a difference in production. In the *industrial series*, the design is executed mainly by machines. Design and production become a human–machine interplay.

The three-fold *form* of the *Deutsche Werkbund* dates over a century back. Since then, another revolution has been distinctly categorized as the *third industrial revolution* or the *digital revolution*.[64,65] Computers, microprocessors, digital cellular phones, and the internet are the technologies derived from this revolution.[66]

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62 Ref.: Mareis, C., 2014. Design als Wissenskultur, transcript Verlag, p. 25-26.

63 Ref.: Hirdina, H., 2005. Design. In Ästhetische Grundbegriffe.

64 Ref.: Rifkin, J., 2011. The Third Industrial Revolution, St. Martin's Press.

65 Ref.: Rifkin, J., 2004. The End of Work, Tarcher.

66 Ref.: Bojanova, I., The Digital Revolution: What's on the Horizon? IT Professional, 16(1), pp.8–12.

Within the design context, Boris Müller postulated *four design revolutions*.[67] The *printing press* as the *zeroth industrial revolution*, the *first industrial revolution* defined by the *steam engine,* and the *second industrial revolution*, surrounding *electricity*. Müller argues that the *second industrial revolution* brought *functionalism* into design, and the notion of *form following function*. The *third industrial revolution* relates to interface and interaction design. For Müller, it is the automatization of thought:

> *The object of the digital revolution is not to simulate the human hand but the human mind.*
>
> *— Boris Müller*[68]

Müller refers to Frieder Nake, who stated in *Sichtweisen der Informatik*:

> *computers are the mechanisation of intellectual labour*
>
> *— Frieder Nake*[69]

Müller and Nake's statements align well with the concepts analyzed in the chapter *Arrow*. Computers to *amplify cognition,*[70] the interface as *external cognition*.[71] Admittedly, Nake's and Müller's statements are nuanced; both *simulate* and *mechanization* indicate that thought itself is not what is at stake here. Concerning the *digital revolution,* I want to postulate a fourth distinction regarding the categorization of the *Deutsche Werkbund*, the *algorithmic series*.

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67 Ref.: Müller, B., 2017. Design in Four Revolutions. medium.com. Available at: https://medium.com/@borism/design-in-four-revolutions-fb0f01a806d2 Accessed February 16, 2021.

68 Ref.: Müller, B., 2017. Design in Four Revolutions. medium.com. Available at: https://medium.com/@borism/design-in-four-revolutions-fb0f01a806d2 Accessed February 16, 2021.

69 Ref.: Coy, W. et al., 2013. Sichtweisen der Informatik W. Coy et al., eds., Wiesbaden: Springer-Verlag.

70 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann.

71 Ref.: Norman, D.A., 1993. Things that Make Us Smart, Basic Books.

`unique` | `craft series` | `industrial series` | `algorithmic series`

I am introducing the term *algorithmic series* as a separation from the previously postulated conceptions of *simulations of the human mind* or *mechanization of intellectual labor*. The essence of the *algorithmic series* is not about the human mind, but rather about the mathematicalization of design. With the *algorithmic series*, design becomes a set of mathematically defined rules. In interface and visualization design, the designer establishes a set of rules, and the execution is one of computational labor. The computing machine becomes the producing factor executing the plan. Each time we visit a website, the computer reproduces the designed rules written in *CSS*, *HTML*, and *JavaScript*. The underlying principle of the algorithmic series is mathematical. The constraint of producing a chair is given by the materials and the possibilities of industrial machines. The materials and the potentialities of computation limit the *algorithmic series*. Step–by–step procedures of calculation constitute the plan, the design. The term *algorithm* describes these mathematical procedures, the *calculus*. An algorithm is a method expressed as a finite list of defined nested and interlinked instructions for calculation.[72] The algorithmic series does not only apply to fields such as interface design or visualization design, but also any design which is mediated through a computer. Almost any contemporary design blueprint is conceptualized with mathematical machines in the 2020s, from architecture to industrial design and graphic design. The computer is a mathematical calculation machine. It is not about a simulation of the human mind, but *design as a mathematical operation*. Even if the designer is not writing functions herself but using programs, the design remains a mathematical operation. Any design involving computer code or computer programs is mathematical. *The algorithmic series is about the mathematicalization of design and, thus, a mathematical interpretation of the world, not of the human mind.*

I propose that the *algorithmic series* operates in the form and organization of the distinction. Computation contains numerous nested sets of distinctions on various scales—for example, the *document object model* that structures websites. *Scalable Vector Graphics* are also organized as nested distinctions. Similarly, *folder*

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72 Ref.: Rogers, H., 1987. Theory of Recursive Functions and Effective Computability, Cambridge: MIT Press.

structures in operating systems, *interface elements* of the drop-down menu, and *smartphone tiles* are arranged next to and within one another. *Image files* are structures of color values placed inside a grid. The same holds for data structures such as comma-separated files (*CSV)* or the JavaScript Object Notation, (*JSON)*. While designing using the computer, the system of next to and within becomes evident. The theory of form and its two axioms provide an operational conception of how the spaces of the *algorithmic series* operate from one form to another.

Design Etymology

This section will examine the historical origin of *design*, its etymology, and its connection to terms such as *mark*, *indication*, *distinction*, and *form*. The *Oxford English Dictionary* first published an entry on *design* in 1885. The contemporary version holds two definitions of the term:[73]

1. to decide how something will look, work, etc., by drawing plans, making computer models, etc.
2. to think of and plan a system, a way of doing something, etc., usually for a particular purpose or use

Both definitions relate design to the act of planning, of creating systems. While such a perspective is not wrong, it reconfigures the question: What is the process of planning? What does it mean to create a system?

To elucidate one possible path towards answering these questions, I will inspect the origins of the term. Its Italian root became popularized in the 16th century; *disegno* is translated as sketch or drawing. Art historian Wolfgang Kemp names the line as the foundation of design as *disegno*. The line sets the rules of a plan, a spiritual foundation, a prerequisite for all human activity. For Kemp, on the lowest level, design is the act of imitating nature, a formal principle defined by the use of the line. The distinct *form*, divided by lines, is from Kemp's perspective, a general principle of human action.[74]

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[73] Ref.: Stevenson, A., 2010. Oxford Dictionary of English, Oxford University Press.

[74] Ref.: Kemp, W., 1974. Disegno. In Marburger Jahrbuch für Kunstwissenschaft. Beiträge zur Geschichte des Begriffs zwischen 1547 und 1607. pp. 219–240. Available at: https://www.jstor.org/stable/1348597.

The French *dessein* since the late 18th century means drawing, pattern, or plan. The French and the Italian are both derivations of the Latin *disegnare,* its verb form *designare,* and its first-person singular *designo*. *Designare* means to *mark*, to *trace*, or to *indicate*. The Latin root goes back to *signum*, signal, sign or mark, to cut.[75] The origins of the term *design* are in alliance with the *mark* and the *indication*. The designer from this etymological perspective is someone who indicates, who marks.

In reflection on the First Design World Fair in London in 1851, Hartmut Vinçon and Bernd Meurer refer to design as a *distinction within spacial dimensions*. The spatial dimensions are both three-dimensional objects in the world and two-dimensional information objects.[76]

In addition to the etymological relations to *mark*, *indication*, and *distinction,* design relates to *form*. Muthesius refers to design as the *aesthetic formation* and the designer as an *individual with the capacity to form*.[77] Paul Klee associates design with the *process of formation*:

> *Die Lehre von der Gestaltung befaßt sich mit den Wegen, die zur Gestalt (bzw. Form) führen. Es ist die Lehre von der Form, jedoch mit Betonung der dahin führenden Wege. Das Wort Gestaltung charakterisiert das eben Gesagte durch seine Endung. ›Formlehre‹, wie es meist heißt, berücksichtigt nicht die Betonung der Voraussetzungen und der Wege dahin … .*
>
> — *Paul Klee*[78,79]

The contemporary usages of the term *design* as planning, as systematizing, hides the underlying principles of what it means to design. The word's origins relate to *mark*, *distinction*, *indication*, and *form*. There are, of course, other possible interpretations of the terminology. Still, at this point, it is intriguing to notice the

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75 Ref.: Kluge, F., 2019. Etymologisches Wörterbuch der deutschen Sprache A. Schirmer, ed., Walter de Gruyter GmbH & Co KG.

76 Ref.: Meurer, B. & Vincon, H., 1990. Industrielle Ästhetik, Anabas-Verlag.

77 Ref.: Muthesius, H., 1909. Kultur und Kunst, Jena: Eugen Diederichs, p.46

78 Ref.: Klee, P., 2014. Der Begriff der Gestaltung. In Information über Gestalt. Braunschweig/Wiesbaden: Birkhäuser.

79 Translated: *"The doctrine of design is concerned with the paths leading to design (or form). It is the doctrine of form, but with emphasis on the ways leading to it. The word Gestaltung characterizes what has just been said by its ending. 'Theory of form,' as it is usually called, does not take into account the emphasis on the preconditions and the ways leading to it … ."*

correlation between the *calculus of indication* and the etymological origins of design.

Design Attributes

Example of *Rubin's Vase* & *Rubin's Face*

From the etymological and historical perspectives, I will now draw together the terminology of the *Laws of Form* concerning research and applications of design. The notions of *distinction*, *indication*, *boundary*, *marked*, and *unmarked* are well known in design practices but described differently. Negative space in design is the area around and between the subject(s) of an image. It was a psychologist, Edgar Rubin, who developed one of the most prominent examples of negative space in the book *Synsoplevede Figurer*.[80] The image *Rubin's Vase* shows a white vase on a black background. The image *Rubin's Face* shows two silhouettes of faces with a white area in the center. Both distinctions are the same image. Rubin writes in his doctoral thesis:

80 Ref.: Rubin, E., 1915. Synsoplevede figurer, studier i psykologisk analyse. København og Kristiania: Nordisk forlag.

> *When two fields have a common border, and one is seen as figure and the other as ground, the immediate perceptual experience is characterized by a shaping effect which emerges from the common border of the fields and which operates only on one field or operates more strongly on one than on the other.*
>
> — *Edgar Rubin*[81,82]

Rubin names all three elements of the form within this quote but designates them differently. The *marked state* is the *figure*, the *unmarked state,* the *ground*, and the *boundary* is the *border*. Or, in the notation of the form:

The marked state is switched with the form's unmarked state, but cannot indicate both sides simultaneously. The observer marks the vase or the face, but not both at the same time.

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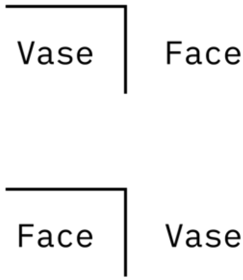
81 Ref.: Rubin, E., 1915. Synsoplevede figurer, studier i psykologisk analyse. København og Kristiania: Nordisk forlag.

82 Ref.: (translation) Yantis, S., 2001. Visual Perception, Psychology Press, p. 225



In typography, *negative space* is often referred to as *white space*. It is the area that lies in-between characters, words, sentences, or syllables. The form is both the marked and unmarked states or, as type designer Adrien Frutiger writes:

> *The white surface of the paper is taken to be "empty," an inactive surface, despite the visible structures that are present. With the first appearance of a dot, a line, the empty surface is activated. A part, if only a small part, of the surface is thereby covered. With this procedure, the emptiness becomes white, or light, providing a contrast to the appearance of black.*
>
> *—Adrien Frutiger*[83]

Black is not added to the page but obscures the light. The interrelationship between *marked* and *unmarked* is for Frutiger not an addition, but a subtraction. By adding something to the page, something is taken away, depending on the viewpoint. The observer draws the distinction between what is *form* and what is *space*. In *The Art of Looking Sideways* (2001), Alan Fletcher talks about the *negative space* in painting, sculpture, poetry, theater, and music:

> *Space is substance. Cézanne painted and modelled space. Giacometti sculpted by "taking the fat off space". Mallarmé conceived poems with absences as well as words. Ralph Richardson asserted that acting lay in pauses... Isaac Stern described music as "that little bit between each note - silences which give the form"... The Japanese have a word (ma) for this interval which gives shape to the whole. In the West we have neither word nor term. A serious omission.*
>
> *—Alan Fletcher*[84]

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83 Ref.: Frutiger, A., 1989. Signs and Symbols, New York: Van Nostrand Reinhold, p. 21

84 Ref.: Fletcher, A., 2001. The Art of Looking Sideways, Phaidon, p.370

Roughly translated, *Ma* means *space*, *pause* or *gap* and creates the awareness that the *marked* needs the *unmarked*; form only exists in the interplay of the two. The mathematical notion of the *calculus of indication* names the *distinction*, *indication*, *boundary*, and *space,* as well as *marked state* and *unmarked state,* as the foundational constituents of the *form*. This terminology is well reflected in design concepts. In the *calculus of design*, the negative space, white space, or Ma is the *distinction* of the *unmarked state* of the *cross*.

However, there is one fundamental change from the design concepts named in this subchapter and the *calculus of design*. *The unmarked is continuous.* One cannot indicate without creating an unmarked state. But, once the negative space, white-space, or Ma is marked, the form opens again, creating the unmarked again. It always exists in the *calculus of design*. Once the unmarked is observed, the recursive performance continues. There is no indication, no distinction without the unmarked. *The unmarked, what is left out, is always in question.* Design continuously inquires into the non-indicated, but only one step up from the drawing, the chair, the interface. In the *calculus of design,* these crosses are part of further crosses. The marked only exists in opposition to the unmarked.

Operations of Design

From the relations between design and mathematical characteristics of the *calculus of indication*, I will investigate the form's operation. The *calculus of design* is always a time-based process. One form changes into another through a series of steps, from one state into another. The following four sections will introduce and exemplify the principles of this time-based operation.

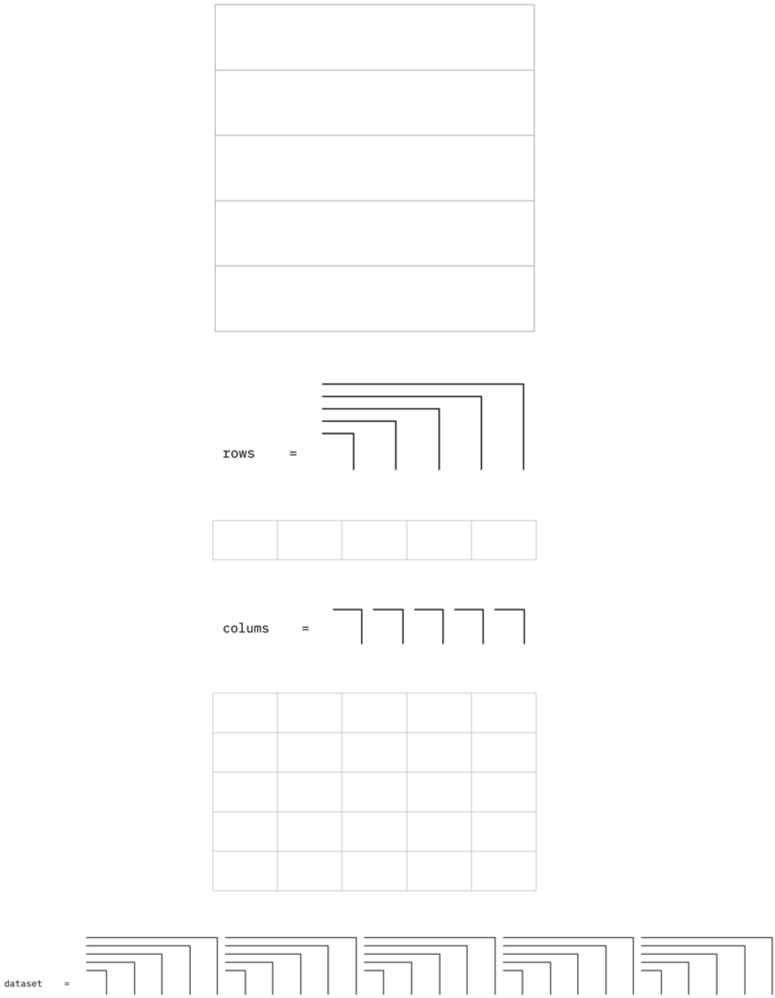
Design Axioms

The two *axioms* of the *Laws of Form* allow two operations, *to call* and *to cross*. Only three operational modes arise: One can recall a distinction, observe no change, introduce further differences within a distinction, or cross the distinction to draw new distinctions outside the current distinction. The resulting system is one of a two-fold organization: *within* and *next to*.

within =

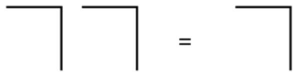
next to =

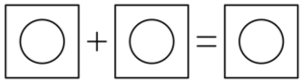
On various levels, this two-fold operation applies to computational structures. An elementary example is the *data table*. Data was, in numerous data visualization processes, the starting point as analyzed in the chapter *Chain*. Here, I will draw out the similarities between the *calculus of indication* and the foundational structure of data. The grid structure of data, just like the axioms of the *Laws of Form*, allows for two operations, the creation of an additional column or row. New columns move outside the current distinction, while new rows add layers within.



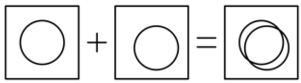
The two kinds of diagrammatic representations of data tables are, without being embedded in the more extensive theory, only alternating visual representations. Rows and columns are represented as sets of distinctions within a form. The two axiomatic operations, to *call* and to *cross*, create an operational system of structure and organization. To call is to draw a distinction within a distinction, to cross is to leave the distinction and enter into another difference. To recall does not change the form.

The *axioms* to *call* and to *cross* manifest themselves well in design practices. *Axiom I* of the *Law of Calling* postulates that the value of a call made again is the value of the call. In graphic design and visualization design, redrawing or duplicating a circle at the same position does not mark a difference.[85]





Only by introducing a distinction in size, color, opacity, or position do the circles become distinct.



The chapter on the *raster* provides various models and categorizations of how symbols can be distinct. I am not concerned about how these variations' functions fluctuate, which works better or worse, but about the fundamental observation that distinctions and indications are the essential operations behind the *raster*.

This first axiom does not only apply to a sheet of paper with symbols. If I read a news article for the first time, it is new to me. Niklas Luhmann applies the logic to mass media: By repeating the same information without marking a difference, no

85 This is not entirely true, which is interesting. Redrawing the same circle many times in an SVG file would make a difference in computation. Even without making a difference in the interface, each circle is stored in a file. The same is true for paper. Redrawing circles in the same position would add more ink—slowly blurring the edges and breaking the paper.

further information is transmitted.[86,87]

> *Information is information only if it is not just an existing difference; it is information only if it instigates a change of state in the system.*
>
> — *Niklas Luhmann*[88]

From the first axiom, *Big Data*, as large quantities of information, is not as relevant as it seems. What is relevant are the distinctions made, no matter how large the dataset. The elementary unit of information[89] is as Gregory Bateson states:

> *a difference which makes a difference*
>
> — *Gregory Bateson*[90]

In this context, Catherine D'Ignazio and Lauren Klein write in the book *Data Feminism*:[91] *›Big Data‹ prioritizes size over context*. Redrawing the same distinctions does not lead to more differences: to recall equals the call. The predefined differences determine data, not the number of drawn distinctions.

Axiom II, the *law of crossing,* postulates that the value of a crossing made again is not the value of the crossing. Crossing the distinction without drawing a new distinction cancels both distinctions.

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86 Ref.: Luhmann, N., 2009. Die Realität der Massenmedien, Springer-Verlag.

87 Again, this might be questionable. The song *Around the World* by *Daft Punk*, from the album *Homework* (1997), repeats the line *Around the World* 144 times. The song would not be the same with only three repetitions.

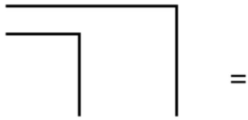
88 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57, loc. 104-105

89 Luhmann and others (Daniel Dennett) are citing Bateson that information is ›a difference which makes a difference.‹ But Batson never said so. In *Steps to an Ecology of Mind: Collected Essays in Anthropology,* Bateson talks about ›the elementary unit of information‹ (p.460) and ›A "bit" of information is definable as a difference which makes a difference‹ (p. 321).

It is strange to me that Luhmann misquotes Bateson in this respect, as a ›bit‹ of information fits much better into the Laws of Form.

90 Ref.: Bateson, G., 1972. Form, Substance and Difference. In Steps to an Ecology of Mind. University of Chicago Press, p. 460

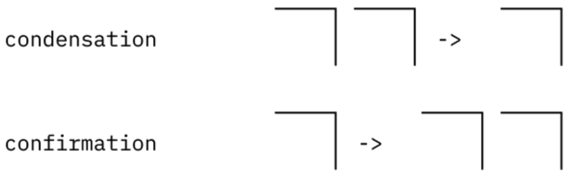
91 Ref.: D'Ignazio, C. & Klein, L., 2019. Data Feminism, MIT Press Open, p. 33



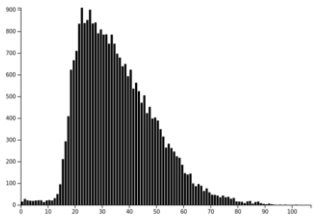
In design, the circle is once again a simple example of this process. A white circle on a black background plus a black circle on a white background cancel each other out, creating an unmarked black space.

Design Arithmetic

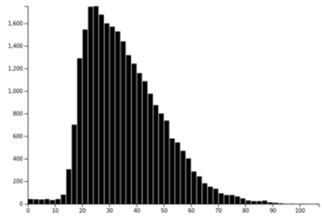
The *arithmetic operations* of the *Laws of Form* seem abstract. I will argue that *condensation*, *confirmation*, *cancellation*, and *compensation* are habitual design operations, especially in data visualization. One statistical example of the *arithmetic operations* is binning. Through *condensation* and *confirmation*, continuous data points are distinct or deduced.



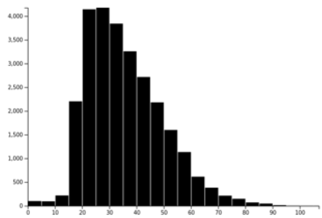
For instance, in a list of birthdates, each entry can be grouped by birth year, by decade, by months, by day, or by quarter. Binning takes the distinction of each birthdate and condenses it by specific parameters. A more extensive set of differences is reduced through condensation into a smaller set of distinctions to make it representable. For example, the following histogram contains one hundred bins:



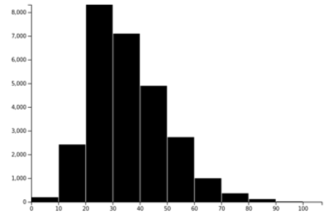
In the second graph, the number of bins is reduced by half to 50:



The third one contains 25 bins. By condensing data points into fewer rectangles, the actual change in the graphic takes place in the vertical axis on the left. Fewer bins result in higher condensation and larger numbers on the vertical axis.



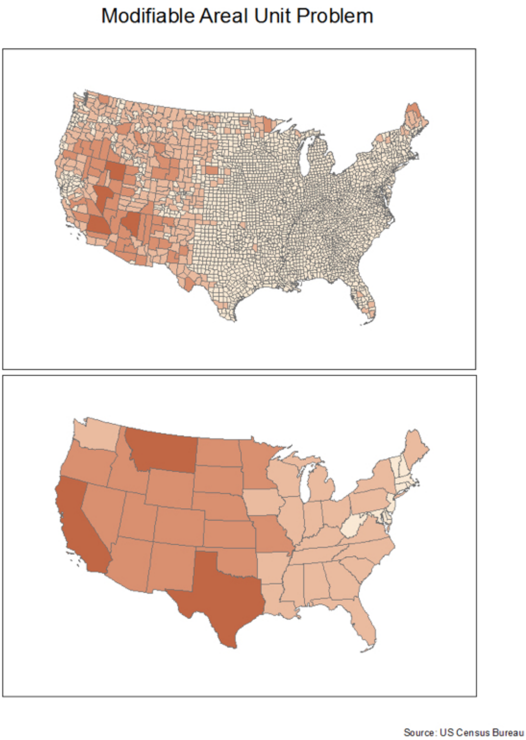
The fourth graph contains ten distinctions in the form of rectangles. The condensation of differences abstracts the graphic into fewer distinctions.



What data science calls the *cleaning of messy data* follows the operations of cancellation and condensation. Distinctions are merged and set apart. Data dimensions are reduced or further distinguished. Binning is only one of many examples of this. Drawing a distinction, canceling a distinction, and condensing a distinction remove differences. *Creating sameness permits computation.*

In geographic information systems, a similar phenomenon is called the *modifiable areal unit problem*.[92] The two charts below from the US Census Bureau render the same data on two levels of distinctions:

[92] Ref.: Pietrzak, M.B., 2014. The Modifiable Areal Unit Problem - Analysis of Correlation and Regression, Institute of Economic Research.



Example of the modifiable areal unit problem[93]

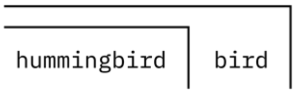
The number of distinctions determines the graphic outcome. One map is not more correct than the other. Both represent the same dataset. Through *condensation* and *confirmation* of distinctions, the data changes its form—the number of crosses drawn changes the observer's perspective on the underlying data.

93 Image Source: http://wiki.gis.com/wiki/index.php/File:MAUP_Demo.png

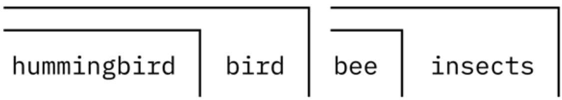
Design Algebra

The algebra of the *calculus of indication* introduces variables such as *a, b* or *p, q, r* to the operation of drawing distinctions. The variables may not only be single letters of the alphabet but also distinct concepts. For example, I can observe and distinguish a bird outside my window.

By specifying, another distinction is drawn, for example, by distinguishing the bird as a hummingbird.

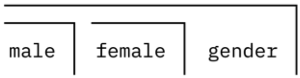


Or, I reject my first distinction by crossing it and draw a distinction outside the first distinction: This is not a bird; it is a bee. By doing so, I am crossing the line of the distinction *bird* and entering the distinction of *insects*.



The operational form is so fundamental that these examples are close to obsolete. At the same time, the implications are vast. *What I am postulating here is to reduce the fundamental act of design to a two-fold operation of calling and crossing.* The result is an organizational structure of *within* and *next to*. *My thesis is that visualization design operates on the two axioms of calling and crossing visual spaces.* Binning exemplifies the *arithmetic design operations* of numbers. The calling and crossing of linguistic categorizations illustrate the *algebraic operations of design*. The examples are instances of operational drawn distinctions, of inclusion and exclusion. From a perspective of mathematical set theory perspective, it is about what is in and outside of collections.[94]

Each drawn distinction holds consequences for how visualizations relate to the world. Gender studies might seem distant to the algebraic operations of form, but the historical discussions highlight how vast the implications of drawing distinctions are. The binary gender distinction of male and female:



All three forms drawn in the diagram above contain a marked and an unmarked state. Through cancellation and condensation, none of the above distinctions are fixed but are only operational entities of observation. As such, *all three forms are questionable and unstable; graphing the distinctions within the open crosses makes this evident*. In her book *Graphesis*, Johanna Drucker exemplifies the entity of gender by mentioning the constant struggle of the Olympic committee to determine reliable distinctions between male and female athletes.[95] It is up to the observer[96] to draw the distinctions through cancellation and condensation. So, gender could also be:

Or simply:

94 Ref.: Kauffman, L.H., 2019. The Semiotics of Laws of Form. Available at: https://www.researchgate.net/publication/331672992_The_Semiotics_of_Laws_of_Form,p.3

95 Ref.: Drucker, J., 2014. Graphesis, p. 129

96 The observer will be described in detail in the next chapter.

gender

In 2014, Facebook added 50 gender alternatives to its interface.[97]

`Agender, Androgyne, Androgynes, Androgynous, Bigender, Cis, Cis Female, Cis Male, Cis Man, Cis Woman, Cisgender, Cisgender Female, Cisgender Male, Cisgender Man, Cisgender Woman, Female to Male, FTM, Gender Fluid, Gender Nonconforming, Gender Questioning, Gender Variant, Genderqueer, Intersex, Male to Female, MTF, Neither, Neutrois, Non-binary, Other, Pangender, Trans, Trans Female, Trans Male, Trans Man, Trans Person, Trans*Female, Trans*Male, Trans*Man, Trans*Person, Trans*Woman, Transexual, Transexual Female, Transexual Male, Transexual Man, Transexual Person, Transexual Woman, Transgender Female, Transgender Person, Transmasculine, Two-spirit`

The set of distinctions Facebook created varies across time and country. This struggle is an example that distinctions are not fixed but operational. Distinctions can be[98] set and reflected on. The notation of the form with its openness of the unmarked and the operations of cancellation and condensation show that forms are not platonic. *Form is not given, but designed.* The distinctions within graphic representations, datasets, data visualizations, and interfaces matter; the dropdown options in an interface, the categorization systems within data, and visualization are all significant.

The arithmetic and algebraic operations of form and its diagrammatic representation display and question the quantity and nesting of drawn distinctions. Both edge cases, if everything is distinct from everything else and nothing is distinct, lead to computation's impossibility. *The mathematically defined*

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97 Ref.: Sparkes, M., 2014. Facebook sex changes: which one of 50 genders are you? The Telegraph. Available at: https://www.telegraph.co.uk/technology/facebook/10637968/Facebook-sex-changes-which-one-of-50-genders-are-you.html.

98 The vaguenss of *can be* is by design in this case. There are too many distinctions that are not in question, especially in gender but also in many other categorical systems.

form of the computer always operates within sets of distinctions. The diagrammatic notation of the form provides one method to visualize this underlying, all-encompassing system.

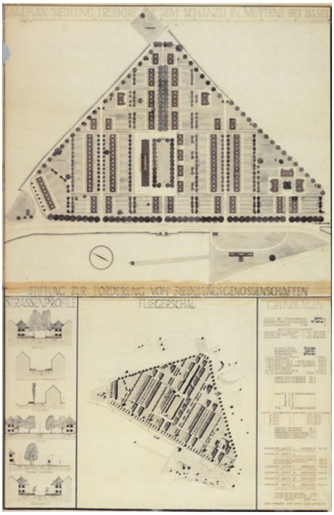
Design Process

The notion that organization and structure are the constituents of design is older than the *algorithmic series* of the *digital revolution*. One pivotal moment in design history is the early 20th century: methods developed at the Bauhaus and the constructivist movement in architecture. In the *program of the constructivists,* Ivan Cichold states:

> *Die Konstruktion (die Gestaltung) ist eine bis zum Äussersten gehende, formende Tätigkeit: die Organisation des Materials.*
>
> — *Ivan Cichold*[99]

For Cichold, to form is to *organize material*. In the language of the *calculus of design*, a form is created by drawing distinctions in space. This perspective ignores the surfaces of design. *Design is not about objects and subjects, but about processes and structures.* With the *calculus of design*, I am naming two operations as the constituents of organization and structure: calling and crossing. Design becomes the act of ordering and drawing crosses within a form. The diagrammatic notation of the form provides an observation of the design process as a structural system of *calling* and *crossing*.

99 Ref.: Cichold, I., 1925. Programm der Konstruktivisten. Elementare Typographie.



Hannes Meyer, Siedlung Freidorf. Lageplan, Fliegerschau Axonometrie, Straßenprofile und Erläuterungen zur Ausführungsplanung, 1920.

The second director of the Bauhaus following Walter Gropius, Architect Hannes Meyer, ran the school from 1928 to 1930. In his design ethos, organization is a critical function of design. An organization stands for the *functioning of design in life processes*. Design from his perspective is not about expression, subjectivity, or spontaneity, but is determined by the laws of organization.[100] Meyer organized the motives for building a house into twelve categories:

> *»1. sex life, 2. sleeping habits, 3. pets, 4. gardening, 5. personal hygiene, 6. weather protection, 7. hygiene in the home, 8. car maintenance, 9. cooking, 10. heating, 11. exposure to the sun, 12. services - these are the only motives when building a house. We examine the daily routine of everyone who lives in the house and this gives us the functional diagram - the functional diagram and the economic programme are the determining principles of the building project.«*
>
> — *Theo Van Leeuwen*[101]

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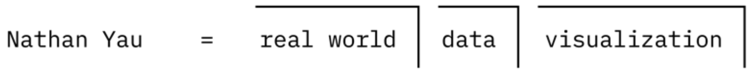
100 Ref.: Meyer, H., bauen H. Meyer, ed. bauhaus. Zeitschrift für Gestaltung, 4. Available at: https://monoskop.org/images/c/c8/Bauhaus_2-4_1928.pdf, p. 13

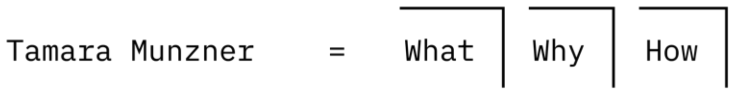
101 Ref.: Van Leeuwen, T., 2005. Introducing Social Semiotics, Psychology Press, p. 71

Meyer conceptualizes a building's design as an organizational principle and manifests this within the *functional diagram*. I will postulate the argument that the organizational and structuralist ideas of design from the early 20th century onward are the foundational components of contemporary visualization research and design. The idea that building a house can be categorized into twelve architectural distinctions has been adapted, not for building homes, but for designing insights, knowledge, and truth.

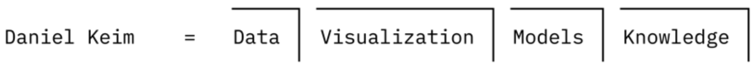
In the chapter *Chain*, I discussed, analyzed, and compared various conceptualizations of the visualization design process. What they all have in common is that they represent sets of operative distinctions to conceptualize data visualizations. Nathan Yau distinguishes between *real world*, *data*, and *visualization* in his visualization process:



Tamara Munzner, in her *Three-part analysis framework*, distinguishes between *What*, *Why*, and *How*:



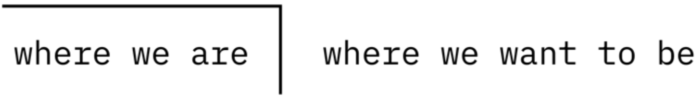
Or Daniel Keim, in his *Visual Data Exploration* framework, distinguishes between *Data*, *Visualization*, *Models*, and *Knowledge*.



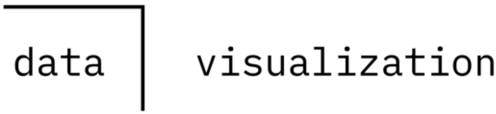
What *linear*, *feedback*, and *circular processes* all have in common is the separation into chained distinctions, which from the perspective of the *calculus of design* are sets of drawn distinctions. One concept is separated and hierarchically related to other differences. The last two process descriptions in the chapter *Chain concerning the postulated theory of form are captivating*. Bostock described design as a process from *where we are > .... > where we want to be*

— *Mike Bostock*[102]

From *where we are* to *where we want to be* is the *operational* constitution of design. The operation is the process, the working order, the nested set of distinctions. *Where we are* in the *calculus of design* is the marked space of the cross, while *where we want to be* is unmarked. Design becomes an act of crossing from the distinct into the indistinct, from the marked into the unmarked.



Visualization design, in this logic, is the crossing from data into the unmarked visualization.



Bostock describes and visualizes the design space through a maze metaphor, which the designer explores: *a tree that branches out and fills the entire space*.[103] The correlations I conceptualize between Bostock's maze and the *calculus of design* are the following: Each decision to turn left or right in a labyrinth is a decision based on a previously defined two-fold distinction: wall or path, black or white rectangle. Also notable is Bostock's use of the term *space*. A designer can only draw distinctions in space. Space is not Euclidian space like the three-dimensional space we inhabit, top-down, forward-backward, and left-right; the design space is conceptual. *Space pre-determines the set of possible distinctions the designer can draw; the designer chooses one path through the maze.*

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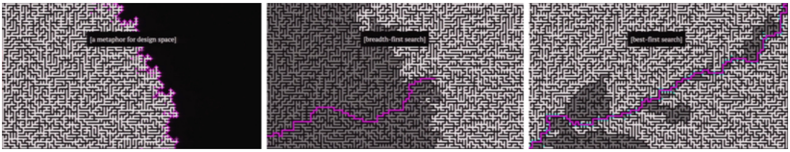
102 Ref.: Bostock, M., 2014. Design is a Search Problem. In OpenVis Conference.

103 Ref.: Bostock, M., 2014. Design is a Search Problem. In OpenVis Conference, 15:50 min



Bostock’s maze metaphor

Bostock ends his talk by asking for concepts to analyze and conceptualize the design space: *We need a better practice for exploring our designs*.[104] The *calculus of design* is my answer to Bostock's request. With the two-fold operations of *calling* and *crossing*, I have introduced a theory on the smallest unit of design constituencies. Throughout the next four chapters, I will extend this elementary system into a novel conceptualization encompassing design and insights.

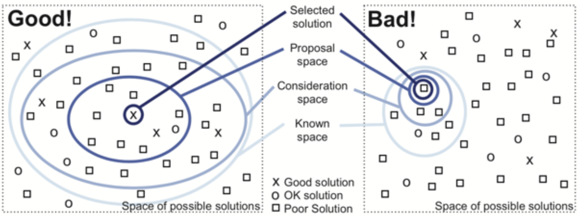


Figure 1.5. A search space metaphor for vis design.

Tamara Munzner’s search space metaphor for vis design

Tamara Munzner, in her book *Visualization Analysis & Design*, utilizes a metaphor similar to Bostock’s. I will briefly reexamine the concept from the perspective of the *calculus of design*.[105] Munzner’s representation, *a search space metaphor for vis design*, is not one of a maze, but rather a scatterplot with different areas for *good* and *bad* solutions. In Munzner’s conception, the more design possibilities that are explored, the more informed the final solution can be. *My goal is not to state what good or bad design is but to understand what constitutes the activity in the first place.* What is relevant here is that design is again conceptualized as a process. Similarly, Scott Murray highlights the proceduralism of design in his talk *The Keys*

104 Ref.: Bostock, M., 2014. Design is a Search Problem. In OpenVis Conference, 16:50 min

105 See chapter *Raster, what, why, and how rasterizations*.

to a Successful Data Design Process: *Design is a process, not a product.*[106] Murray represents the design process as a branching of points and lines.

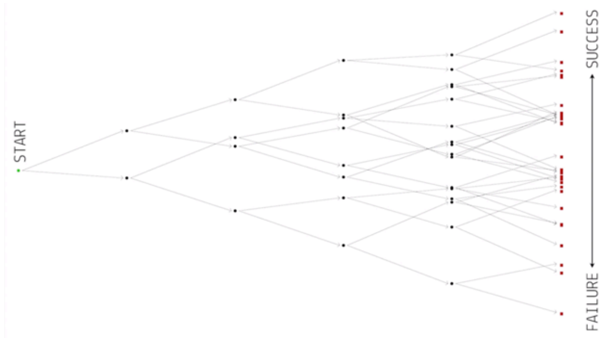


Diagram of decision making within the design process by Murray

Each possible branch is one distinction the designer draws. For Murray, these distinctions can go up or down, leading to better or worse decisions. Similar to Munzner, the conception of design as a process is about good or bad design. Murray embeds various other conceptualizations of the visualization process into his own, for example, the ones from Card et al.[107] and Ben Fry.[108]

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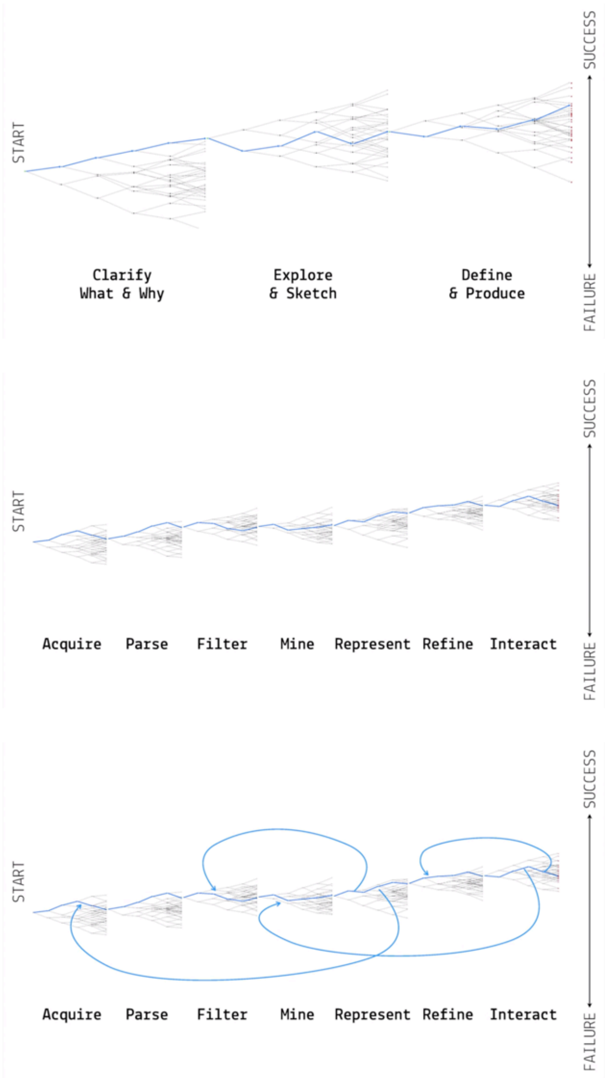
106 Ref.: Murray, S., 2014. The Keys to a Successful Data Design Process with Scott Murray, 1:08min

107 Ref.: Card, S.K., Mackinlay, J.D. & Shneiderman, B., 1999. Readings in Information Visualization, Morgan Kaufmann.

108 Ref.: Fry, B., 2004. computational information design.



The *calculus of design* is annexing to design constituents, not to the consequences, good or bad. The theory allows one path towards the question of what the design consists of in the first place. What are the underlying presumptions of design as a process? Crosses encompass both *distinction* and *indication*. The conglomerate of crosses is the *form* designed within *space*. Each cross holds three attributes, the *marked*, the *un-marked*, and the *boundary* between the two. Spencer-Brown argued that most *mathematical texts generally begin the story somewhere in the middle, leaving the reader to pick up the thread as best he can*.[109] I postulate that the same is valid for design theories. The entirety of the visualization design concepts that I have analyzed in the previous chapters, from the *raster*, *arrow*, and *chain* to the *pyramid,* start somewhere in the middle. These theories explain visual elements, visual variables, perception studies, design processes, and conceptions from data to wisdom but never explore what it means to design in the first place. *The thesis postulated here is that the smallest unit of design becomes the cross's pre-binary form by setting an indication, drawing a distinction. Most substantial is the negation of the distinction; the unmarked is inevitably part of the form. The negation of design matters.*

Theoretical Relations

Thus far, the notion of *form* as a drawing of distinctions conceptualizes a fundamental theory regarding the encounters in the first part, *Conceptions of Design for Insight*. Design creates a structure in the unstructured by drawing crosses of what is marked and unmarked. The following two chapters will sharpen this conception of form and question its limitations.

With *form oppositions,* I will highlight the novelty and otherness of the concept of *form* that I have introduced concerning philosophical conceptions of form. *Form limitations* will address a design movement well-aligned with the conception of form as creating structure and its abandonment. I am exploring its novelty and limits to lay the foundations for the chapters ahead.

Form Oppositions

The previous subchapter drew similarities between the foundational theory of the *Laws of Form* and design as processes. In the theory developed here, the *calculus of design*, *form* is operationally drawn by *calling* and *crossing distinctions*. The two operations allow a change from one *form* into another. *Form* is a *performative* and *time-based operation*. To *draw a distinction* means to *design*, to *mark*

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109 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p.V

a *space*, and leave other possibilities *unmarked*. Every step in the design process reconfigures *form* by drawing crosses. *Form is specific, an operation in the moment.* The form allows for a pre-binary symbol operation.

From a philosophical perspective, the interpretation of *form* postulated here in the words of Klaus Städtke *calls into question the notion of form in its meaning*. Städtke goes so far as to ask whether Spencer-Brown's theory, and its interpretation by Luhmann, might indicate the form terminology's end.[110,111] The fundamental change of form as a pre-binary momentary operation regards the history of the term as addressed by philosopher Sybille Krämer. She analyses the differences in Spencer-Brown's conception in contrast to western philosophical traditions in her essay *Form als Vollzug*. Krämer names five philosophical characteristics that are in opposition to the articulated concept of *form* that I applied to the design process: *timelessness* (Platonian Model), *universality* (Aristotelian Model), *generative power* (Leibniz Model), *transcendence* (Kantian Model), and *idealism* (Husserlsche Model).[112] I will focus on the Platonian timeless concept of *form,* as it portrays the most substantial contrast to the postulated notion. The Platonic model of form holds various diverging conceptions: it is an abstract, transcendental and timeless ideal. While material matter continually transforms, the underlying forms are eternal and unchanging. Forms are the non-physical essences of all things underlying the material world we experience.[113] The *Allegory of the Cave* provides a precedent of the platonic ideal. In the dialogue of the Republic,[114] a group lived their lives chained to a wall in a cave facing a blank wall. The individuals only experience the outside world through the shadows the actual world casts on the cave wall inside.

> *The struggle to understand form is like men in a cave guessing at shadows in firelight.*
>
> — *Plato*[115]

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110 Ref.: Städtke, K., 2005. Form. In Ästhetische Grundbegriffe. J. B. Metzler Verlag, p. 463

111 Ref.: Baecker, D., 1993. Probleme der Form, Frankfurt am Main: Suhrkamp, p.46

112 Ref.: Krämer, S., 1998. Form als Vollzug oder: Was gewinnen wir mit Niklas Luhmanns Unterscheidung von Medium und Form? userpage.fu-berlin.de. Available at: http://userpage.fu-berlin.de/

113 Ref.: Städtke, K., 2005. Form. In Ästhetische Grundbegriffe. J. B. Metzler Verlag, p. 466, Vgl. PLATON, Rep. 598b.

114 Ref.: Plato, 1943. Plato's The Republic, New York: :Books, Inc, 514a–520a

In the Platonian model, *form* expands beyond the world as we experience it. The notion of *form* that I have articulated throughout this chapter identifies form as the created, the actual, the designed. Form consists of the crosses someone or something draws to make sense of the world. Let me draw out the difference between these two understandings of *form* through the 2017 published videogame *Everything*, developed by David OReilly. In the simulation, the player can morph between objects, from a cow to a stone to an insect. From the subatomic level of particles, the player can morph from object to object until the player is an entire Universe. The smallest, subatomic, and most extensive layers, Universe, connect through a *platonic layer* of abstract mathematical forms. From the platonic perspective, the segment that connects the Universe and the subatomic is the layer of the *platonic forms*. The objects that hold the subatomic and the Universe together are what we would see once we free ourselves from the chains.

In the *calculus of design*, the entire game is a set of distinctions, a collection of crosses within the game's form. Each layer, from subatomic to cosmic, are distinctions. The form is all the objects one can merge into, the cow, the stone, the insect, the subatomic, and the Universe. For the *calculus of design*, the form equals all the crosses contained within the game. At the same time, *everything* does not contain everything. OReilly included an absolute set of distinctions in the game. The unmarked side of the form represents what is excluded. The platonic and the calculus notions of form are vastly different. The platonic form is *timeless*, *abstract*, and *universal,* while *form* in the *calculus of design* is *performative*, *actual*, and *particular*.

The notion that form is not an abstract layer of reality but concrete also exists in design theory, as Otl Aicher writes:

> *ist die welt das einzelne und konkrete, oder ist sie das allgemeine und abstrakte? diesen konflikt hat das bauhaus nicht ausgetragen, konnte es nicht austragen, solange der begriff kunst nicht enttabuisiert war, solange man einem unkritischen platonismus der reinen formen als weltprinzipien verhaftet blieb.*
>
> — *Otl Aicher*[116,117]

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116 Ref.: Aicher, O., 2015. die welt als entwurf, John Wiley & Sons, p. 91

117 Translated: *is the world the individual and concrete, or is it the general and abstract? the bauhaus did not carry out this conflict, could not carry it out, as long as the concept of art was not de-tabooed, as long as one remained attached to an uncritical platonism of pure forms as principles of the world.*

The *calculus of design* is my answer to Aicher's critique of *pure forms*. The notion of form is not the *abstract* but the *actual*. The diagrammatic form of the *calculus of design* allows one to notate the *operational*, *performative*, and *time-based* structure of the *form*.

Form Limitations

This chapter postulates the concept that the creation of *order* and *structure* is a step-by-step process, a *calculus*, based on two *axioms*, *calling* and *crossing*. The *calculus of design* provides a theory of design components as *marks*, *indications*, and *distinctions*. This subchapter will relate the postulated theory to the *conceptions of design for insight* and inspect their limitations. Until this point, the *calculus of design* is affirmative towards the previous chapters' propositions, particularly the *raster* and the *chain*. There is an intriguing complication in the notion of design as the creation of *order* and *structure* which emerged throughout the 1960s and early 1970s in design theoretical discourses.

The *Conference on Systematic and Intuitive Methods in Engineering, Industrial Design, Architecture and Communications* was held for the first time at the Imperial College of London in 1963.[118] In *Design als Wissenskultur*,[119] Claudia Mareis[120] interprets this conference as the beginning of the so-called *Design Methods Movement*. The movement was initiated by such individuals as Christopher Alexander, Bruce Archer, Nigel Cross, or Horst Rittel. My research interest is driven by the conceptual and methodological theories of design and their relations to visualization design theories. While the following analysis triangulates all chapters of the first part, *raster*, *arrow*, *chain*, and *pyramid*, I will exemplify the relations through the *raster* as it provides the most graphic example.

A key objective behind the *Design Methods Movement* was the striving to push towards the rationalization of design.[121,122] Like visualization design research, the *Design Methods Movement* structured and ordered design into taxonomies and

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118 Ref.: Jones, J.C., 1963. Conference on Design Methods.

119 Translated: Design as a culture of knowledge

120 Ref.: Mareis, C., 2014. Design als Wissenskultur, transcript Verlag.

121 Ref.: Alexander, C., 1964. Notes on the Synthesis of Form, Harvard University Press.

122 Ref.: Asimov, M., 1976. Introduction to Design

anthologies, mapping out all possible elements against one another. The movement was inspired by biological morphology, which is the study of an organism's form and structure.[123] The *morphological analysis* became its human counterpart. Complexity is reduced by systemizing and rasterizing design. The morphological analysis was articulated as *a method for investigating the totality of relationships contained in multi-dimensional, non-quantifiable problem complexes*.[124] Within it, rasters are used to map and, in an algorithmic fashion, find solutions to complex problems. The graphic representations in the chapter *Raster* hold striking similarities to the *morphological boxes* of the 1960s movement. Grids of related and interconnected parameters define the visual representation of the *morphological box*, equivalent to the graphical representations of Bertin,[125] Börner,[126,127] Munzner,[128] and others from the chapter *Raster*.

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123 Ref.: Oxford Dictionaries, morphology | Definition of morphology in English by Oxford Dictionaries. oxforddictionaries.com. Available at: https://en.oxforddictionaries.com/definition/morphology Accessed March 22, 2019.

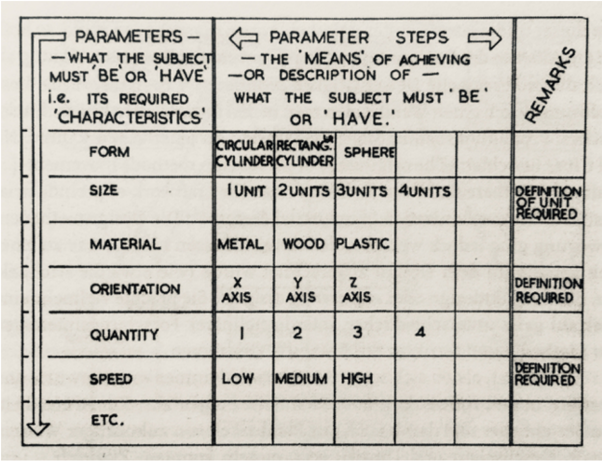
124 Ref.: Ritchey, T., 2002. General Morphological Analysis. swemorph.com

125 Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press.

126 Ref.: Katy Börner. Atlas of Knowledge. English. Anyone Can Map. MIT Press, Mar. 2015.

127 Ref.: Katy Börner and David E Polley. Visual Insights. English. A Practical Guide to Making Sense of Data. MIT Press, Jan. 2014.

128 Ref.: Tamara Munzner, Visualization Analysis & Design, 2014



PARAMETERS — WHAT THE SUBJECT MUST 'BE' OR 'HAVE' i.e. ITS REQUIRED 'CHARACTERISTICS'	PARAMETER STEPS — THE 'MEANS' OF ACHIEVING — OR DESCRIPTION OF — WHAT THE SUBJECT MUST 'BE' OR 'HAVE.'					REMARKS
FORM	CIRCULAR CYLINDER	RECTANG. CYLINDER	SPHERE			
SIZE	1 UNIT	2 UNITS	3 UNITS	4 UNITS		DEFINITION OF UNIT REQUIRED
MATERIAL	METAL	WOOD	PLASTIC			
ORIENTATION	X AXIS	Y AXIS	Z AXIS			DEFINITION REQUIRED
QUANTITY	1	2	3	4		
SPEED	LOW	MEDIUM	HIGH			DEFINITION REQUIRED
ETC.						

Ken Norris, 'The Morphological Approach to Engineering Design'

In 1963 Ken Norris published a diagram in an article titled *The Morphological Approach to Engineering Design*.[129] Norris adapted this morphological box from the Astrophysicist Fritz Zwicky, who wrote:

> *Morphological analysis is simply an ordered way of looking at things.*
>
> *— Fritz Zwicky*[130]

The expectation of the *design methods movement* was that the combinatorial perspective on complex subject matters with fixed parameters creates an instrumental and objective basis for design. Visualization design research is founded on similar conceptions to rationalize design. The *raster*, *arrow*, *chain*, and *pyramid* all provide frameworks, modes of distinguishing good from bad design choices. The significance of the similarities between the design methods movement and visualization design arrived in the 1970s. Key players of the movement abandoned its ideals asserting that design can be systemized. John C. Jones, an advocate of the movement, wrote in his book *Design Methods*:

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129 Ref.: Norris, K.W., 1963. The Morphological Approach to Engineering Design. Conference on Design Methods.

130 Ref.: Zwicky, F., 1948. Morphological Astronomy. The Observatory, 68(845).

In the 1970s, I reacted against design methods. I disliked the machine language, the behaviorism, the continual attempt to fix the whole of life into a logical framework.

— John C. Jones[131]

Similarly, Christoph Alexander argued:

I've disassociated myself from the field. ... There is so little in what is called 'design methods' that has anything useful to say about how to design buildings that I never even read the literature anymore... I would say forget it, forget the whole thing.

— Christoph Alexander[132]

Design theoretician Nigan Bayazit reflected on the movement in 2004 by writing:

Design methods, people were looking at rational methods of incorporating scientific techniques and knowledge into the design process to make rational decisions to adapt to the prevailing values, something that was not always easy to achieve.

— Nigan Bayazit[133]

The abandoning of the *design methods movement* seemed omnipresent, from graphic design and product design all the way to architecture. *The logical frameworks of rasterizing design into scientifically defined operations could not accommodate the realities of the invented objects.* However, one branch of design seemingly continued to uphold the design methods: computational design. In the 1970s, the subbranch of software development kept adapting and applying design methods. Christoph Alexander's term *design pattern* is still in use today in computer science[134] but not much within other fields. Through computational design, which I have described as the *algorithmic series*, the rationalization of design continued to exist while other fields moved towards other theories. As I have argued in *design evolutions*, the *algorithmic series* today influences nearly all design areas, as computation underlies most processes, from book layouts to architectural plans. The design methods movement encountered an unexpected and unreflected comeback essential to all contemporary design operations through the algorithmic series. *Interface design and visualization design return as an ideology of structure and systems.* The *semiology of graphics* still leads the narratives of

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131 Ref.: Jones, J.C., 1992. Design Methods, John Wiley & Sons, p. xi

132 Ref.: John Christopher Jones. The State of the Art in Design Methods. English. 1970, p. 5

133 Ref.: Nigan Bayazit. "Investigating Design: A Review of Forty Years of Design Research." English. In: dx.doi.org 20.1 (Mar. 2006), p. 19

134 Ref.: Ralph Johnson, Erich Gamma, John Vlissides, and Richard Helm. Design Patterns. English. Elements of Reusable Object- Oriented Software. Addison-Wesley, 1995.

visualization design. *Visualization design research, intentionally or unintentionally, is based on abandoned premises of design research.*

Architects and designers abandoned these conceptions in the 1970s because the methods could not deal with the complexity and messiness of the actual world. The heretofore conceptualized *calculus of design* mirrors the efforts of visualization design research and the *design methods movement* in the sign of the *cross*. In the *calculus of design,* structure emerges by *drawing distinctions*. The *axioms* of *calling* and *crossing* offer a logical operation on how rasterized systems emerge as nested sets of differences.

But, there are further complexities in the theory, which I will analyze in the following four chapters. Various levels of the continuously drawn line between the *marked* and the *unmarked* strive towards complexities beyond the raster. *The openness of the form does not state how things are, as rasterizations imply, but ask how they could be otherwise.*

The closing and opening of Form

This chapter started with a promise to articulate a theory on the *smallest act of design and question its constituents and assumptions.* The *calculus of design* is based on the axioms of *calling* and *crossing*. The mathematical notation of a *form*, its *axioms*, *arithmetic applications,* and *algebraic operations,* became the organization principles of the smallest act of design following the command:

> *Draw a distinction.*

I have analyzed the relations between design and the mathematical theory of the *Laws of Form* on various levels. The *etymological origins* of the term *design* originates from its Latin root *designare* meaning to *mark*, *trace*, and *indicate*.[135] The *design historical perspective* introduced the *algorithmic series* and with it the mathematicalization of design. The contemporary plans of design for later production became formalized within mathematical operations executed on

135 Ref.: Friedrich Kluge, Etymologisches Wörterbuch der deutschen Sprache, 2002.

demand. I have derived the *etymological origins* of *design* as a *mark*, *indication*, *distinction*, and *formation*. The *design characteristics* related *marked*, *unmarked*, and *boundary* to design applications. The *unmarked*, in contrast to other terminologies such as *negative space*, *white space*, and *ma*, questions what is left out not from a specific level, but in general. *The unmarked is always in question.*

The *axiomatic*, *arithmetic*, and *algebraic* readings on the terminology of *form* introduce the *operative*. *Form* becomes a *performative calculus*, a step-by-step process of *calling* and *crossing*. *Order and structure of nested distinctions are the result of operation.*

The last two chapters on *opposition* and *limitations* explained the theory's novelty using philosophical notions of *form* and its current design theoretical limitations. The aforementioned *calculus of design* provides an approach to design as an organizing principle. The *Design Methods Movement* and its abandonment is a warning sign of attempts *to fix the whole of life into a logical framework*.[136]

On a granular level, I am proposing an adaptation of concepts from *difference theory* to be used in understanding design. In *Form, Substance and Difference,* Gregory Bateson questions what a difference is:

> *But what is a difference? A difference is a very peculiar and obscure concept. It is certainly not a thing or an event. This piece of paper is different from the wood of this lectern. There are many differences between them-of color, texture, shape, etc. But if we start to ask about the localization of those differences, we get into trouble. Obviously the difference between the paper and the wood is not in the paper; it is obviously not in the wood; it is obviously not in the space between them, and it is obviously not in the time between them. (Difference which occurs across time is what we call 'change.') A difference, then, is an abstract matter.*
>
> — *Gregory Bateson*[137]

Throughout the next four chapters, I will extend the *calculus of design* to various levels. The above quote from Bateson already mentions concepts that I will further elaborate on throughout the next chapters. How one form is drawn into another, wood to paper, data to visualization, is not only determined by the calculus explored thus far, but is interwoven into sets of pre-determinations. I will outline one possible path to naming, operating, and questioning these pre-

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136 Ref.: Jones, Design Methods. 1992, p. xi

137 Ref.: Bateson, G., 1972. Form, Substance and Difference. In Steps to an Ecology of Mind. University of Chicago Press.

determinations. The next chapter investigates the designer of the form and how drawn distinctions are not fixed entities, but human and non-human determinations of *designed distinctions*.

Design

> *I am now among the oldest professors of medicine; I have been teaching my science for more than thirty years … I have honestly worked on myself, to do away with ever more of my subjective being and to steer myself ever more into objective waters. Nonetheless, I must openly confess that it has not been possible for me to desubjectivize myself entirely. With each year, I recognize yet again that in those places where I thought myself wholly objective I have still held onto a large element of subjective views. – my opinions, my representations, my theory, my speculation.*
>
> — *Rudolf Virchow*[1]

The sign, the mark, is drawn into perspective by reducing possibilities, the *de* within *design*. By typing a letter on my keyboard, I choose one sign and momentarily neglect all other possible letters. The performative, step-by-step operation for one sign and against the others defines the possibilities for drawing a distinction by the *designer*.

The previous chapter conceptualized *form* as a two-fold operation of crosses consisting of *distinction* and *indication*. The cross draws three attributes: the *marked state*, the *unmarked state*, and the *boundary*. These elements of the cross are the fundamental principles of the *calculus of design*. My theory allows for the two operations of *calling* and *crossing* and results in nested sets of distinctions, a systematic, categorical organization. *Design becomes an operational, algorithmic, and mathematical play of schematic rules.*

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1 Ref.: Virchow, R., 1877. Die Freiheit der Wissenschaft im modernen Staat

While the previous chapter postulated a theory of the constituents of form, this chapter is the first of two that investigate *a priori* unwritten crosses. This chapter inquires about the form of the *observer* and *designer*. The following chapter examines the cross of the *space*. Reducing this chapter into one sentence, I would bluntly state: *Form is never given but always marked by the cross of the designer.* The outermost cross surrounding a conglomerate of distinctions is the designer. For a form to exist, there needs to be someone or something to draw the form's distinction. Design is the operative act; to form, to design means to mark a space. Following my appropriation of the Spencer-Brownian logic to investigate the theories, traditions, and conditions of design, the first sentence of the second chapter in the *Laws of Form*[2] can be read as an instruction for design:

> *Draw a distinction.*

Following this command, I argue that form has to be drawn in order to exist. There are no distinctions contained within the world; someone or something has to draw them. Without an actor, there is no form. For a book, paragraph, sentence, word to be read, someone must have written it, and prior to that someone must have invented each term. For a lamp to shine, for an interface to function, for a visualization to appear, someone had to design it. From a design perspective, this seems trivial, but it has consequences.

From a design theoretical standpoint, the notion that any designed distinction[3] is brought into existence by someone or something is not astonishing. But, as discussed in the previous chapter, Spencer-Brown's *Laws of Form* are a theory on the foundations of mathematics, and as such, this procedure is remarkable. By imagining the smallest unit of mathematics as the form of the distinction and placing its origin within the operative instruction to *draw a distinction*, the objectivity of mathematics is in question. The discussed, analyzed, and extended theory connects to discussions in Science and Technology Studies on who is marking and what is left unmarked. *The compelling part of the calculus of design is that it does not create dualistic oppositions of objectivity and subjectivity, of scientific versus humanistic perspectives, but is rather a theory that imagines these dualisms as a unity of form.* It is not the one or the other but an interrelation of both at the same time. I am not arguing that there is no world outside of thought, such as a radical

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2 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin.

3 While designed distinction is a tautology from the emerging theory, the term *distinction* is a move away from subject-object distinctions.

constructivist might state, but at the same time, *we can only interact with the world by design, by drawing distinctions into the world.*

Observer

> *Und das ist das Tolle am Bildermachen: dass es immer erst durch den Betrachter vollendet wird. Ohne Ursprung und Empfänger sind Bilder ohne Zusammenhang, also völlig bedeutungslos. Nur dadurch, dass sie etwas auslösen, bekommen sie eine Bedeutung, die nicht immer mit Worten zu benennen ist. … Die Wichtigkeit der Beobachtung ist mir durch die Astronomie klar geworden, durch Beobachtung an der Grenze des Sichtbaren.*
>
> — *Wolfgang Tilmans*[4,5]

Spencer-Browns *Laws of Form* and theories based on it, such as Niklas Luhmann's *system theory*[6,7] or Dirk Baecker's *catjects,*[8] call the designator of the distinctions the *observer*.[9] This section collects and compares notions of the observer within these conceptions to articulate how design intersects these theories in the next part, *redrawing the observer*.

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4 Ref.: Tilmans, W., 2017. Lichtjahre. Zeit Magazin, 23. Available at: https://www.zeit.de/zeit-magazin/2017/23/wolfgang-tilmans-fotograf-kuenstler/seite-2.

5 Translation: *And that's the great thing about making pictures: that it is always only completed by the observer. Without origin and recipient, pictures are without context, i.e. completely meaningless. Only through the fact that they trigger something, they get a meaning that cannot always be named with words. … The importance of observation has become clear to me through astronomy, through observation at the border of the visible.*

6 Ref.: Luhmann, N., 2011. Erkenntnis als Konstruktion. In O. Jahraus, ed. Niklas Luhmann Aufsätze und Reden. p. 334.

7 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57.

8 Baecker uses the term *Cateject* as an alternative mark between objects and subjects as distinct categories.

Ref.: Baecker, D., 2018. Why Catjects? catjects.wordpress.com. Available at: https://catjects.files.wordpress.com/2018/01/whycatjects3.pdf *Accessed September 4, 2020*.

9 Dirk Baecker even wrote a book called *Beobachter unter sich*, freely translated: *Observers among themselves*.

Ref.: Baecker, D., 2013. Beobachter unter sich, Suhrkamp Verlag.

An unwritten cross

In the second part of the *Laws of Form*, Spencer-Brown writes:

> *Suppose any S0 to be surrounded by an unwritten cross.*
>
> — *George Spencer-Brown*[10]

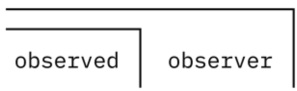
S0 in the statement above is the set of outermost crosses within the form. All other crosses nest within the S0. An unwritten cross surrounds the outermost cross within the form. After this statement about the unwritten cross, Spencer-Brown only mentions the observer three times in the final Chapter 12. He writes:

> *The second, or implicit, reference is to an outside observer. That is to say, the outside is the side from which a distinction is supposed to be seen.*
>
> — *George Spencer-Brown*[11]

This outside, the unwritten cross, is the observer drawing distinctions. As the calculus of indications only contains one symbol, the mark, Spencer-Brown writes:

> *An observer, since he distinguishes the space he occupies, is also a mark.*
>
> — *George Spencer-Brown*[12]

Above any distinction is the unwritten cross of the observer. Instead, I can notate the unwritten cross as:



Spencer-Brown further states:

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10 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin. p. 7

11 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin. p. 69

12 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin. p. 76

> *We see now that the first distinction, the mark, and the observer are not only interchangeable, but, in the form, identical.*
>
> — *George Spencer-Brown*[13]

The drawn distinction is identical to the observer. The form reflects how someone or something observes. The observer in this statement is not an unwritten cross above the distinction. The observer and the distinctions are identical. The observer is identical to the form itself. Niklas Luhmann articulates the concept as:

> *...there is no difference between self-reference and observation. For he who observes something must distinguish himself from that which he observes.*
>
> — *Niklas Luhmann*[14]

The observer can only be observed as the form. Form and observer are identical. The observer is neither a marked state, unmarked state, boundary, nor the space in which the distinction is drawn. The observer is the operative performance of drawing a distinction. By setting a boundary, separating marked from unmarked within the space, the observer becomes interchangeable with the distinction itself. The fundamental principle of the observer is the freedom to be capable of setting other distinctions within the space.[15] If this freedom is neglected, no observer would be necessary; the world would be set. Yet, it is not.[16] The drawn form always contains the observer who drew the distinction. As identified in the previous chapter on *form*, the observer only has three methods of operating within the space: to call, to recall, and to cross.

Four years after the first publication of the *Laws of Form* in March 1973, an American University of Masters Conference, short AUM, took place at the Esalen Institute. The conference was structured around multiple sessions surrounding the Laws of Form, and George Spencer-Brown discussed his thoughts with Gregory Bateson and Heinz von Foerster among others.[17] The conversational mode of the gathering turned some of the book's mathematical proofs into

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13 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin. p. 76

14 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), p.37–57., loc. 160-161

15 Ref.: Baecker, D., 2013. Beobachter unter sich, Suhrkamp Verlag.

16 The freedom will be further investigated in the chapter on *space* and the operative contingency of it.

17 Ref.: Spencer-Brown, G., 1973. AUM Conference Transcript Session One to Four. AUM

conversational and more comfortable to understand sets of distinctions. Spencer-Brown states:

> *It is not about how things are but about how we observe.*
>
> — *George Spencer-Brown*[18]

Someone always draws the form. The unwritten distinction above any other distinction is the distinction of the observer. *Call form your distinction of the distinction of an observer,* as Dirk Baecker articulates it.[19] Apart from these statements by Spencer-Brown, all other interpretations of the observer will depend on interpretations of the theory. There is no further evidence on the observer in the book of the Laws of Form.

Who are observers?

The form the observer draws is not limited to shapes. It includes points, lines, rectangles, triangles, and circles, but also sounds, words, colors, and emotions. Anything that someone or something can distinguish from something else is a cross within the nested set of the form. Dirk Baecker lists visual, auditory, tactile, olfactory, emotional, and rational types.[20] Mathematician Felix Lau defines

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Conference.

Available at:

https://web.archive.org/web/20060821204917/http://lawsofform.org/aum/session1.html

https://web.archive.org/web/20060821185718/http://lawsofform.org/aum/session2.html

https://web.archive.org/web/20060821204906/http://lawsofform.org/aum/session3.html

https://web.archive.org/web/20060822000552/http://lawsofform.org/aum/session4.html

18 Ref.: Spencer-Brown, G., 1973. AUM Conference Transcript Session Two. AUM Conference. Available at: https://web.archive.org/web/20060821185718/http://lawsofform.org/aum/session2.html

19 Ref.: Baecker, D., 2013. Beobachter unter sich, Suhrkamp Verlag.

20 Ref.: Baecker, D., 2015. Working the Form: George Spencer-Brown and the Mark of Distinction. Mousse Magazine, p. 8

distinctions as anything one can perceive with one's senses. Anything one can draw one's attention to through perception, from thoughts to bodily experiences and feelings.[21] Dirk Baecker lists as observers: the mathematician, computer scientist, cyberneticist, automata theorist, game theorist, biologist, sociologist, or anthropologist, and finally, anyone and everyone who can participate in communication.[22]

Baecker makes a critical point regarding the observer, which this chapter has hinted at by writing *someone or something*. Observers are not only humans. A family, organization, nation, culture, or society can act as observers on a larger scale than the individual. On a smaller scale, our consciousness, our brain, and our organism observe themselves. Baecker additionally mentioned ghosts, angels, and mice. From this perspective, an apparition of a dead person or spiritual beings can act as observers drawing distinctions.[23] I am not convinced by Baecker's scope, but am intrigued about considering technological sensing devices as observers. *Machines, computers, and robots that observe, sense, and as such draw calculated distinctions. Computational sensing* is defined by the interfaces of human and computational procedures to register, record, and analyze computational distinctions.[24] In the project *artificial senses,* I created live mappings of the six most common and accessible smartphone sensors to draw into perspective the difference between human and machine sensing.[25,26]

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21 Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag. p. 153

22 Ref.: Baecker, D., 2007. Form und Formen der Kommunikation, p. 31

23 Ref.: Baecker, D., 2007. Form und Formen der Kommunikation, p. 32

24 Ref.: Distelmeyer, J., 2020. Interface II. Zur Programmatik leitender Prozesse der ‚digitalen Gegenwart'. In Wovon sprechen wir, wenn wir von Digitalisierung sprechen? Frankfurt am Main: CompaRe, pp. 59–73.

25 Ref.: Albrecht, K., 2017. Artificial Senses. Available at: https://kimalbrecht.github.io/ai-senses/ Accessed February 19, 2020.

26 Ref.: Museums, H.A., 2017. Lightbox Gallery Talk: Artificial Intelligence in Art and Design | Harvard Art Museums. harvardartmuseums.org. Available at: https://www.harvardartmuseums.org/visit/calendar/lightbox-gallery-talk-artificial-intelligence-in-art-and-design Accessed June 1, 2018.

Observing Observers

In the sociological and cybernetic readings of the *Laws of Form*, another distinction of the observer becomes pertinent, the distinction between the first and second-order observers.[27] This distinction was adopted from the cybernetic theory of the second-order observer by Heinz von Foerster,[28] who was the first to write a review on the Laws of Form in the Whole Earth Catalogue.[29] Niklas Luhmann adapted various conceptions of the *Laws of Form* in the essay *System as Difference.* Luhmann separates his two distinctions of the observer as follows:

> *The observer can make his appearance in two ways: as an external observer who sees that another system is observing itself, or as a self-observer, which is to say somebody who observes himself, refers to himself and states something about himself.*
>
> — *Niklas Luhmann*[30]

Observers can observe internally as calling, recalling, and crossing, or as a second-order observation, observing their own or other observations.[31] For any creative act, the distinction between first and second-order observation is uncomplicated at first: A painter can either draw on her canvas as a first-order observer[32] or reflect on what she has drawn as a second-order observer. Similarly, a writer can either place sentence after sentence as a first-order observer or reread the sentences as a second-order observation. The first-order observer draws distinctions, the second-order observer reflects on the

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27 Ref.: Foerster, Von, H., 2003. Cybernetics of Cybernetics. In Understanding Understanding. New York: Springer, New York, NY, pp. 283–286.

28 Ref.: Foerster, Von, H., 1993. KybernEthik, Merve Verlag.

29 Ref.: Brand, S., 1971. The Last Whole Earth Catalog, Available at: https://archive.org/stream/B-001-013-719#mode/2up, p. 12

30 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57, loc. 448-452

31 The second-order observation relates to a concept that this text will cover in the chapter *Re-entry*. For now, I will exlude *re-entry* as even without it there are some interesting points to be made on the two distinctions.

32 I will come back to the one problem I see in this conception in the section *redrawing the observer*. In this section, I will trace and narrate the conceptualizations of the so-called *observer*.

distinctions drawn. The drawing of distinctions is distinct from the observation of the distinctions that have already been drawn.[33] The second-order observer can either accept the distinction or reject it and critique the set of drawn distinctions. Without a first-order observer, there is no second-order observer. To reflect on a distinction, the distinction has to have been drawn in the first place.

This distinction between the two observers features one complication, which turns the second-order observer into something more compelling. Dirk Baecker defines the problem by writing:

> *The observer who observes himself is thereby his own blind spot. He cannot observe himself. He can only observe something with which he mistakes himself.*
>
> *— Dirk Baecker*[34]

By observing our own or other drawn distinctions, one mistakes the form for the form. They are never the same. The act of reflecting on a distinction separates one from the other. Thus, the observation of a distinction is never equal to the act of drawing it. When you, dear reader, read these words, they are not the same as when I wrote them. Even when I reread my text, it is not the same. The operational act of drawing a distinction and reflection on a drawn difference is never the same. The blind spot of the distinction between first and second-order observations is based on an interpretation of the form. From such a reading of the calculus of indication, objectivity holds a two-fold fallacy: The first observation is based on the drawing of distinctions. A distinction can only be drawn by a level of freedom within the space; thus, it is never given but always drawn. Second, the re-observation of a drawn distinction is never the distinction itself.

From Observer to Designer

The last section on the *observer* analyzed Spencer-Brown's concept of the observer and its various interpretations. In this section, I want to distinguish the

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33 Ref.: Baecker, D., 2013. Beobachter unter sich, Suhrkamp Verlag.

34 Ref.: Baecker, D., 2015. Working the Form: George Spencer-Brown and the Mark of Distinction. Mousse Magazine, p. 8

calculus of indication from my conception of the *calculus of design*. While I agree with most of the points made, there seems to be one fallacy within the *Laws of Form*. To address my concern, I will postulate one distinction beyond those discussed so far. The problem is simple: *Is the act of drawing a distinction an act of observation?* Especially the use of the term *drawing* indicates that *observation* might not be what is at stake.[35,36] The command is not to *make a distinction* or to *observe a distinction,* the character of *drawing* is a graphic operation.[37]

I am questioning whether the *observer* is the right etymological concept for this chapter's discussions. In the section *Who Observes*, Dirk Baecker and Felix Lau interpret an observation as visual, auditory, tactile, olfactory, emotional, rational, perception, thoughts, bodily experiences, or feelings.[38,39] *My argument is that mere recognition is not sufficient for drawing a distinction. The operative act of drawing distinctions performs beyond observation.* The act of *drawing a distinction* goes beyond perception. This text can be read, not by my mere thoughts but by putting these words into a program on my computer and distributing it over various communication channels in the future so that someone else can read them and draw further distinctions. The Latin origin of the term *observare* as *watch over*, *note*, *heed*, *look to*, *attend to*, *guard*, *regard*, *comply with*, from *ob-* as *in front of*, *before*

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35 The transcripts of the AUM conference illude how careful Spencer-Brown was in his terminology. At the beginning of the second session, Heinz von Foerster asks Spencer-Brown to elaborate on the distinction between algebra and arithmetic within the Laws of Form. Spencer-Brown's reply illustrates his etymological thinking:

> *I was going to say, "make the distinction plain," which means to put it on a plane. I suppose that most people know that the meaning of the word "plain," if you look at its root, is just another word for plane, plane like blackboard. To make plain is to put it on a plane. So that's what I will do. I will try to put this distinction between algebra and arithmetic on a plane.*
>
> ––– *Spencer-Brown*

36 Ref.: Spencer-Brown, G., 1973. AUM Conference Transcript Session Two. AUM Conference. Available at: https://web.archive.org/web/20060821185718/http://lawsofform.org/aum/session2.html.

37 Ref.: Krämer, S., 2009. Operative Bildlichkeit. In Logik des Bildlichen. Von der ‚Grammatologie' zu einer ‚Diagrammatologie'? Reflexionen über erkennendes ‚Sehen'. p. 100.

38 Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag, p. 153

39 Ref.: Baecker, D., 2015. Working the Form: George Spencer-Brown and the Mark of Distinction. Mousse Magazine, p. 8

and *servare, to watch*, *keep safe*, from the root *ser-* as in *to protect*[40] does not capture the act of drawing or marking a space. An observer might perceive a distinction, but the act of drawing a distinction goes beyond that.

The calculus of design supplements the intermission of the observer with the designer's conception, design as designation, as marking and naming distinctions. Design is the drawing of distinctions in a world that does not hold differences; it needs the designator to turn the observed into the marked and distinguishes it from the unmarked. The previous chapter discussed the etymological roots of the term *design*.[41] Design from its Latin root refers to an *indication*, *marking*, as in *creating form*. The verb *drawing* encapsulates more than perception. I am proposing *design* as the term beyond mere observation towards the *drawing* of distinctions.

Before writing the *Laws of Form*, Spencer-Brown worked on transistors counting modules for British Rail. The theory of the *calculus of indication* evolved from this work on computational counting. The job title Spencer-Brown held was *Chief Logic Designer*.[42] The *Laws of Form* evolved from Spencer-Brown's profession labeled as a designer. In this thesis, I am developing the *calculus of indication* into a theory of the operation of design. Dirk Baecker hints at the role of design in our current and coming society:

> *Stammeskulturen hatten Vertrauen in die Magie, antike Hochkulturen in die Götter und die Moderne in die Technik. Die nächste Gesellschaft hat nur noch Vertrauen in das Design.*
>
> — *Dirk Baecker*[43,44]

While Baecker does not understand the command to *draw a distinction* as a design theoretical function, what he does is emphasize the term by requesting that design become a human right.[45,46]

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40 Ref.: Harper, D., 2020. observe. etymonline.com. Available at: https://www.etymonline.com/word/observe

41 *Design etymology* in the chapter *Form*.

42 Ref.: Baecker, D., 2015. Working the Form: George Spencer-Brown and the Mark of Distinction. Mousse Magazine, pp.42–47.

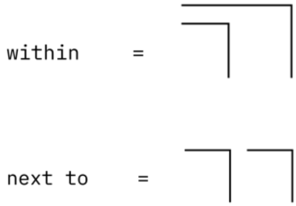
43 Ref.: Baecker, D., 2015. Designvertrauen. Merkur, pp.89–97.

44 Translation: *Tribal cultures had faith in magic, ancient civilizations in the gods, and modernity in technology. The next society has faith only in design.*

45 *Vielleicht müssen wir die nationalen und internationalen Verfassungen dieser Welt, aber auch*

46 Ref.: Baecker, D., 2015. Designvertrauen. Merkur, pp.89–97.

The extension of the designer to the terminology of the observer is straightforward: *Design is the act of turning observed distinctions into drawn distinctions.* Only designed distinctions stand on their own. One can read this text without me being present. I can write on an Apple computer without Jonathan Ive, Steve Jobs, or anyone else nearby who worked on the laptop I am writing on. Design is the act of externalizing distinctions into the world. While this is a vast definition of design, it is, at the same time, narrow. There are only three possible moves to be made: to *call*, to *recall*, and to *cross*, an operational, three-fold process of formation. The operations create a two-fold structure of *within* and *next to*.



It is not uncommon to define *design* in such broad strokes within design theories and practices. A similar extensive definition of design comes from Beatriz Colomina and Mark Wigley published in the book *are we human?* with the subtitle *notes on an archaeology of design*:

> *We literally live inside design, like the spider lives inside the web constructed from inside its own body.*
>
> — *Colomina & Wigley*[47]

Even this definition is too short-sighted for the theory developed here, as not only humans draw distinctions. The plants on my desk continuously draw their distinctions of light and soil. An individual seed distinguishes ground from air to grow roots into one and a stem in the other direction. The *calculus of design* provides a single operation, the drawing of distinctions, to articulate and observe

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die Zulassungsregeln von Organisationen und Projekten aller Art um ein Menschenrecht auf Design erweitern. Damit wir uns wenigstens darauf verlassen dürfen, misstrauisch werden zu können.

––– *Dirk Baecker*

47 Ref.: Colomina, B. & Wigley, M., 2016. Are We Human?, p. 9

the web that humans and non-humans construct around themselves to make sense of the world.[48,49]

Drawing a distinction is the smallest act of design. It goes beyond observation. To observe a difference in value and call it is to design something. I am interpreting design as the act towards the negative of the sign, *de* and *sign*, as signing off from everything else. The term *design* is used in such a wide variety of applications that nothing but such an extensive definition would apply. *Drawing distinctions is the fundamental process of what it means to design.* Design, in this sense, is a first-order designation. The second-order reflection is one of observation, as long as no alternative distinctions are drawn from the observation. Design is tied to the process of drawing distinctions; the reflection on those distinctions is observation.

The conception of design developed here as the operation of drawing distinctions is extensive. However, this theory is not the only one that works with such a comprehensive understanding. There are many design theories with similar ambitions. I will contextualize several voices as a reflection of this calculus of design. Moholy-Nagy writes in *Von Material zu Architektur*:

> *das gestalterische problem setzt erst da ein, wo die freiheit beginnt, wo die von uns übersehbare funktion nicht mehr oder noch nicht restlos die gestalt bestimmt.*
>
> — *Moholy-Nagy*[50,51]

The *freedom*, or as I will define in the chapter on *space*, *contingency* of which Moholy-Nagy speaks is the freedom to draw alternative distinctions. Moholy-Nagy's freedom matches the registration and reduction of complexity of the *form*. Design is not only the conscious processing of experience, but the naming, distinction, and indication of a perspective, which could also have been distinct

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48 In relation to this, Spencer-Brown states:

> *If a content is of value, a name can be taken to indicate this value.*
>
> ––– *Spencer-Brown*
>
> *Thus the calling of the name can be identified with the value of the content.*
>
> ––– *Spencer-Brown*

49 Ref.: Spencer-Brown, G., 1969. Laws of Form, First Edition, London: Allen & Unwin., p. 1

50 Ref.: Moholy-Nagy, L., 1929. von material zu architektur, p. 69

51 Translation: *the design problem only emerges where freedom begins, where the function we can overlook no longer determines the design, or does not yet do so completely.*

otherwise. *Design is only possible if alternatives can be neglected.* Designer and design philosopher Victor Papanek noted that *all men are designers. All that we do, almost all the time, is design, for design is basic to all human activity.*[52] Within the *calculus of design*, the operation of drawing distinctions can leave an unmarked space. Not only do men do so, any human being, animals, plants, machines, and anything capable of sensing draws distinctions, separates space.

The term *Existenzdesign*[53] includes the entire material reality of the living world as a task of construction. Otl Aicher titled one of his books *die welt als entwurf,*[54] or the English version *the world as design,*[55] in which he writes that *there is a world. No doubt. But we need to de—sign this reality to make it apparent. Thus, how we mark becomes the most prominent act in interacting with the world.*[56]

The calculus of design defines one theory of how reality is designed. There is a world, but only by drawing distinctions do we act upon it. Without design, the space remains unmarked. Paul Klee emphasizes that *Gestaltung,* which I take as a synonym for *design,* is about the operation rather than the existing form:

> *Die Lehre von der Gestaltung befaßt sich mit den Wegen, die zur Gestalt (bzw. Form) führen. Es ist die Lehre von der Form, jedoch mit Betonung der dahin führenden Wege.*
>
> *— Paul Klee*[57,58]

Design theorist Heinz Hirdina has commented on the elusiveness of the term *design* since the 1970s. The term moved from a technical denotation into a wide variety of fields and meanings. Disciplines range from watches to drugs, fashion to chemistry. For Hirdina, the common factor of the usage of the term lies in the *artificial*, artificial in the sense of styled, whether chemical synthesis, cosmetic

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52 Ref.: Papanek, V., 1971. Design for the Real World

53 Ref.: Kellner, H. & Heuberger, F., 1988. Zur Rationalität der Postmoderne und ihrer Träger in Kultur und Alltag. Soziale Welt, (6), pp.325–337.

54 Ref.: Aicher, O., 2015. die welt als entwurf, John Wiley & Sons.

55 Ref.: Aicher, O., 2015. The World as Design, John Wiley & Sons.

56 Ref.: Aicher, O., 2015. The World as Design, John Wiley & Sons.

57 Ref.: Der Begriff der Gestaltung, Klee, P. in Schneider, M., 2014. Information über Gestalt, Birkhäuser.

58 Translation: *The study of design is concerned with the paths that lead to form. It is the teaching of form, but with emphasis on the paths leading to it.*

procedures or cosmetic surgery.[59] I agree with Hirdina and further put forth that the artificial operation is the *operation of the form*. *The artificial is the distinction, and the calculus of design offers a theory to observe and analyze its attributes and consequences.* Along this line of reasoning, Bruno Latour interlinks the *sign* in *design* with the acceleration of computation: *The transformation of objects into signs has been greatly accelerated by the spread of computers.*[60]

Latour narrates a reading away from objects and towards disputed assemblages.[61] My suggestion is that the drawing of distinctions within the form is the structure of assemblage. The unmarked is the dispute within the calling and crossing of the form. Rather than *drawing distinctions,* Latour models design as an act of *drawing things together*.[62] This is not an opposition but rather a repositioning of perspective. Crosses are drawn together within the form; from the perspective of each line, crosses are drawn distinctly. The designed form draws together the distinct.

The *calculus of design* and its diagrammatic form of distinctions offer one modality of mappin out the operations of design. To draw the underlying distinctions, one uses it to make sense of the world. The two lines of distinction and indication allow for a mapping of the perspectives taken to design a logo, a chair, a data visualization, but also questions of society, such as rules and regulations, constitutions, legislations, or scientific and technological operations of data sets, interfaces, software procedures, and algorithms. The questions remain the same. *Who is drawing which distinctions, and what forms result from these operations? What complexities are reduced by the inclusion and exclusion of the drawn borders?*

Herbert Simons draws a distinction between *Natural* and *Artificial Worlds* to introduce what he calls the *science of the artificial*. The term Simons adds to our current understanding of design is the distinction of the *interface*:

> *We would look toward a science of the artificial that would depend on the relative simplicity of the interface as its primary source of abstraction and generality.*
>
> *— Herbert Simons*[63]

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59 Ref.: Hirdina, H., 2005. Design. In Ästhetische Grundbegriffe. p. 44

60 Ref.: Latour, B., 2008. A Cautious Prometheus?, p. 4

61 Ref.: Latour, B., 2008. A Cautious Prometheus?, p. 6

62 Ref.: Latour, B., 2008. A Cautious Prometheus?, p. 12

63 Ref.: Simon, H.A., 1996. The Sciences of the Artificial, MIT Press. p. 12

The interface is the relative simplicity of a system concerning the actual complexity of the world. If a dataset distinguishes between various countries such as India, Spain, or Madagascar, the interface, the terms hold an undefinable complexity. The inclusion and exclusion, the seemingly clear boundaries, hold vast and almost certainly impossible points of definition.[64] The interface is the distinct crossed within a form of observation. Furthermore, the interface terminology indicates an interrelation between the *calculus of design* and computation.[65] Jan Distelmeyer's four divisions of the interface terminology offer one perspective on how the scope of the interface lies beyond the screen:[66]

1. Interfaces between hardware and software
2. Protocol-driven interfaces, co-action of hardware and software
3. Interface operations between computers and non-computer forms of interconnected materiality
4. Interface operations of humans using computers

Each of the four distinctions relocate the perspective of observation. The diagrammatic form of the calculus of design allows us to map the reduced complexities of what is marked and what stays unmarked. In the Mac OS X operating system terminal, the command `traceroute` outputs all the IP addresses between my computer and the requested web page. While the networked protocol-driven interface is a foundational technology of the World Wide Web, it is an unmarked distinction from the daily human operations of using web browsers. The most common connotation of *interface design* locates the observation from Distelmeyer's fourth point, the interface operations of humans using computers. Redrawing the form through another layer draws a different complexity into the form. What is marked and unmarked within the form is a choice of design that influences how one can relate to the unmarked complexities. The next theoretical step is to observe the motive behind certain operations within the calculus of design. But before doing so, I want to offer some applied, non-theoretical examples of marking specific spaces.

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64 Ref.: Baecker, D., 2017. Mindful Design in the Humanities.

65 The introduction *How to Design a Barchart* elaborated on this interdependency of drawing distinctions and data, computation, and visual artifacts.

66 Ref.: Distelmeyer, J., 2018. Drawing Connections – How Interfaces Matter F. Hadler, A. Soiné, & D. Irrgang, eds. Interface Critique Journal, Vol. 1, pp.1–11.

Designing Distinctions

Not only design theories strengthen my argument of design as a drawing of distinctions, but also procedural design practices. In this subchapter, I will narrate and examine two articulated design processes. The first example is John Maeda's exemplification of the *powers of design* within *graphic form*. The second design example comes from the New York Times graphics department and relates data and form.

Graphic Form

> *Designers talk about the relationship between form and content, content and form. Now what does that mean?*
>
> — *John Maeda* [67]

Former MIT Media Lab Professor John Maeda presented a talk titled *How art, technology and design inform creative leaders* at a TED conference in 2012. In the presentation, Maeda provides an example of what he calls the *power of design*, through a set of typographic transformations. I captured some of Maeda's design operations and interpreted these changes in the diagrammatic form of the *calculus of design*.

Maeda starts with the four-letter word *fear* written in the typeface *Helvetica Light*. Maeda's first operation is a redrawing from *Helvetica Light* to *Helvetica Ultra Light*.

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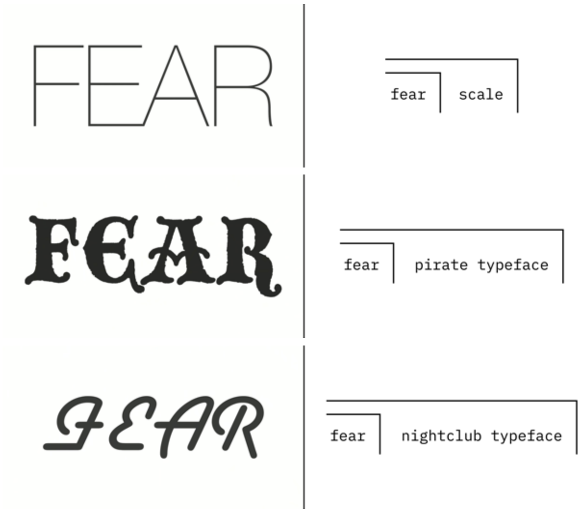
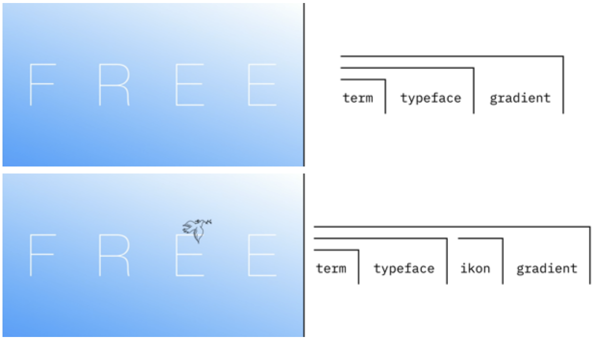
[67] Ref.: Maeda, J., 2012. How art, technology and design inform creative leaders. TEDGlobal. Available at: https://www.ted.com/talks/john_maeda_how_art_technology_and_design_inform_creative_leaders

The designer, Maeda, draws a distinction from one typeface weight to another and, by doing so, transforms how the term *fear* is marked. Maeda applies several operations, from scaling to various typefaces, labeling them *pirate typeface* and *nightclub typeface*.



In the *calculus of design*, each modification follows the command to draw a distinction. Within each distinction, the designer can draw other distinctions, *calling*. The typeface differentiates them into specific shapes, typefaces, scales, padding, spacing, capitalizations, and technical operations as the keynote software Maeda uses; the form is always performative. The level of observation is based on the values of the designer and observer. From changing typefaces, scale, and spacing, Maeda turns to the word itself and changes one letter from *fear* to *free*. In addition to the change of words, Maeda *crosses* the form and draws a gradient onto the unmarked space, the white background. Finally, Maeda adds a dove into the graphic.



A design draws distinctions by excluding other possibilities. From a vast space of typefaces, Maeda made specific selections. Someone, in this case Maeda, draws distinctions to mark the unmarked. Without drawing distinctions, no form exists. This example is elementary and narrowly defined within a narrow operation of graphic design. *Form* is more general than points, lines, and areas. *The form is the conglomerate of separations of space, the marked and the unmarked.* Maeda finishes his presentation on the power of design by declaring: *So you see that -- form, content, design, it works that way. It's a powerful thing. It's like magic, almost, like the magicians we've seen at TED. It's magic. Design does that.*[68]

With Maeda's conclusion—*It's magic*—this example connects to Edward Tufte's statement from the *Conceptions of Visualization Research* chapter *Arrows*. Tufte writes:

> *Like magicians, chartmakers reveal what they choose to reveal.*
>
> — *Edward Tufte*, [69]

[68] Ref.: Maeda, J., 2012. How art, technology and design inform creative leaders. TEDGlobal. Available at: https://www.ted.com/talks/john_maeda_how_art_technology_and_design_inform_creative_leaders, min 6:50

[69] Ref.: Tufte, E.R., 1997. Visual Explanations, Graphics Press USA.

I am redefining both Tufte and Maeda. It is not magic that is at stake here. *Designers draw distinctions by marking and neglecting the unmarked.*

Data Form

Mike Bostock, the developer behind the data-driven document javascript library, short d3.js,[70] worked from 2012 to 2014 for the New York Times. In his talk *design is a search problem* at the OpenVis conference,[71] Bostock showcased multiple design processes collected in the NYTimes GitHub repository. I captured 96 visually distinct states of one data visualization process of the New York Times.[72] I will not list nor comment on all 96 stages of the graphic but rather showcase various drawn distinctions to demonstrate the vast space of design using one dataset.

Data is the nested set of distinctions from which the visualization is drawn. The dataset consists of 36 US states over six decades; each data point is one law to reshape government policy. The dataset includes a time distinction and multiple categorical distinctions such as states, topics, and parties.

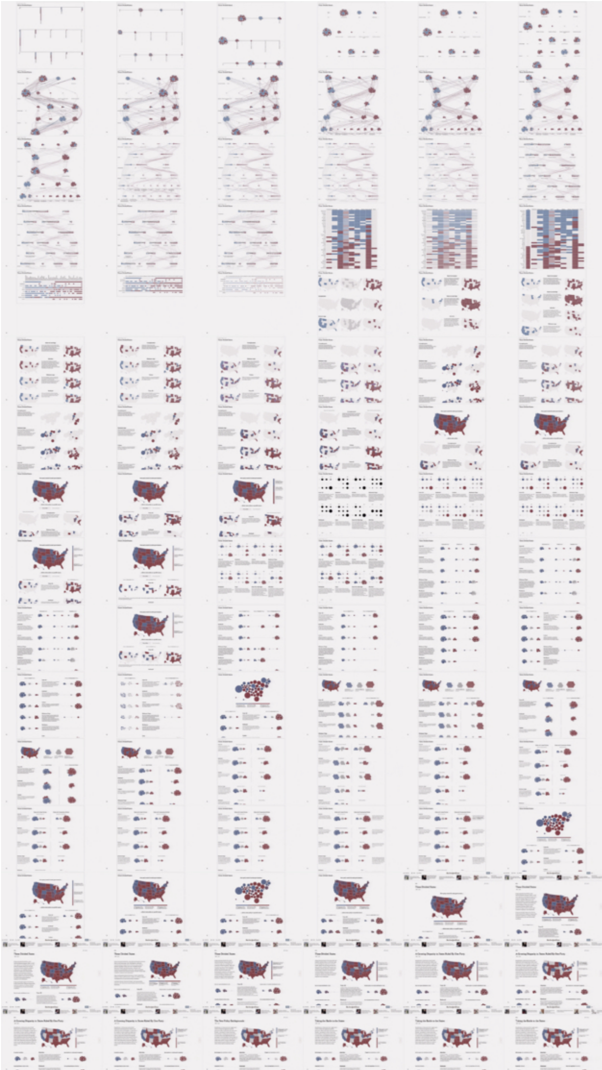
[70] Which I already introduced in the chapter *Chain*.

[71] Ref.: Bostock, M., 2014. Design is a Search Problem, Available at: https://www.youtube.com/watch?v=fThhbt23SGM

[72] The final news article is available online: Taking the Battle to the States

By observing the iterations, it becomes clear how strong each operation transforms the graphic.[73] I collected all 96 variations the New York Times team saved through the process into the following figure.

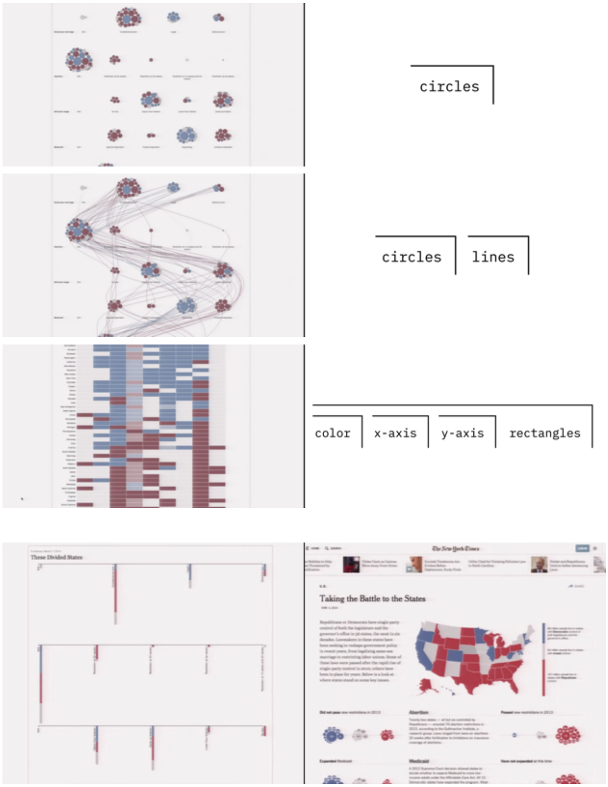
[73] Bostock does not comment on each iteration. It is not easy to make a precise statement on what is mapped in each stage. The following diagrams of distinctions only represent a small observable section of the actual differences; they are caricatures rather than actualities.



96 steps of generating one graphic.

Design is drawing distinctions, marking space, and through that, constructing the observed. The form changes throughout the process; circles turn into rectangles, into geographic maps. Each drawing of spatial differentiation alters the graphic.

While the underlying data remains identical, its appearance is designed. Often, the changes are subtle; sometimes they are drastic. *What renders something visible is not an unchangeable truth but rather a performative operation of drawing distinctions.*



Each distinction matters as it alters the form of the represented data. Drawing distinctions does not only operate on the level of visualization. The data itself is a reduction of complexity within the world into distinctions. Someone or something decided what a data point consists of and what differences it contains, such as states, laws, categories. *The entirety of data and visualization can be observed as nested sets of designated distinctions.* The final graphic has little in common with the first, even if they operate on the same data.

Motive

From the processual operation of form in *typography* and *data visualization*, I ask why someone draws a particular distinction and does not place the boundary somewhere else. Distinction and indication turn other possible operations into the unmarked. The designer draws a border and chooses the marked and unmarked states. Such an act must be driven by motivation. For some reason, something is chosen over something else. It is always a motivated act, or as Spencer Brown writes:

> *There can be no distinction without motive and there can be no motive unless contents are seen to differ in value.*
>
> — *Spencer-Brown* [74]

The constitution of Spencer-Brown's calculus of indication is two-fold. First, there needs to be something to distinguish; some differentiation the designer can carry out. And secondly, there needs to be a motive to distinguish in a specific way. To have a motive presupposes that one judges, and to judge is based on a difference in value.[75,76] The number of distinctions is so vast and allows for so many differentiations that it is a question of motive how one distinguishes. *A designer continually reduces the complexity of the world by drawing distinctions.* Niklas Luhmann captures the reduction in his theory by writing:

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74 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. 1

75 Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag. p.41

76 For example, next to the computer I am writing this text on stands a glass of tea. I am distinguishing the tea glass from the table it is standing on, the laptop I am writing on, the books and pencils lying around. I could also indicate the kind of tea, in this case, a lapacho tea made out of the tabebuia tree's bark. Another act of distinction would be to say that a container holds millions of hydrogen + 2 oxygen molecules, infused with an herbal ingredient. Another difference might be the temperature of the beverage, around 70 degrees. None of the aesthetic appearances I just described are wrong. My motivations for description drive them. The observer draws a distinction in the space; it is about the marked and the unmarked. I did not observe the computer, the desk, the books, or pencils. The tea differs in value to me from the rest of my surroundings. Without making the distinction Tea, it does not exist in my observation.

Erfassung und Reduktion von Komplexität. Sie dienen der Vermittlung zwischen der äußeren Komplexität der Welt und der sehr geringen, aus anthropologischen Gründen kaum veränderbaren Fähigkeit des Menschen zu bewußter Erlebnisverarbeitung.

— Niklas Luhmann[77,78]

Design theory and theories of visualization design specifically tend not to ask about the designer's motive but rather define specific motives. Throughout the first part of this writing, the *Conceptions of Visualization Research*, and its chapters *raster*, *arrow*, *chain*, and *pyramid*, I investigated and identified various motives, such as *performance*, *efficiency*, *effectiveness*, *optimization*, *overview*, and *minimalism*. *Performance*, *efficiency*, *effectiveness*, and *optimization* all contain the motive of *progress*. In algorithm design, the quest for the most performative set of instructions becomes the operative objective.

The *calculus of design* allows for reflection on this. Is the fastest algorithm the most desirable one? What is marked by this motive, and what is left unmarked? *The question of motive, just like the distinction as the smallest design unit, precedes most design theories and applications.* The reflection of the drawn distinctions of a specific operative form leads to the question of motive. *The calculus of design does not state a rationale in the first place, but asks for it.* Rather than claiming a text should be as legible as possible, the algorithm as fast as possible, the question of what is motivating a particular set of distinctions comes into focus. Why does someone choose extra light Helvetica over a pirate typeface? Why is minimalism, the most reduced set of differences, more significant than a solution with more distinctions? Why should efficiency and effectiveness be the motives to aim towards in visualization design?

The following four sections observe, compare, and analyze various conceptions from design history and visualization theories. The list of motives is not comprehensive, nor is each motive genuinely separated from the others. I choose the motives to provide a broader scope of imaginable reasons to draw distinctions. As such, I chose each example to discuss, reformulate, and reflect on the notion of *form* developed throughout the last chapter.

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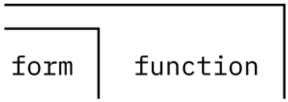
77 Ref.: Luhmann, N., 1970. Soziologische Aufklärung 1, Wiesbaden: VS Verlag für Sozialwissenschaften, p. 116

78 Translated: *Capture and reduction of complexity. They serve to mediate between the external complexity of the world and the very low, for anthropological reasons hardly changeable ability of humans to consciously process experience.*

Function



In the late 19th and early 20th centuries, a design motive became predominant: *form follows function*. The *Chicago School of Architecture* and, most prominent, the firm *Adler & Sullivan* in their conception and building of skyscrapers, defined this motive.[79] Art and design researcher Annette Geiger indicates that the terminology, *form follows function*, references back to sculptor Horatio Greenough (1805 - 1852);[80] the motive has a history prior to the 21st century. The first articulation of *form follows function* as a design motive was made by Louis H. Sullivan in the text *The Tall Office Building Artistically Considered*. Sullivan writes: *All things in nature have a shape, that is to say, a form, an outward semblance, that tells us what they are, that distinguishes them from ourselves and from each other.*[81]

In this statement, Sullivan connects *form* to the *distinction*. The difference between the motive of *form follows function* and the *calculus of design* is that form is given for Sullivan. Forms are in the world, *all things in nature have a shape*. The calculus, the operation, of design starts with an instruction: *draw a distinction,* as such form is never given but is operationally distinguished by someone or something. The crossover of *form follows function* and the *calculus of design* is the concept of *form as distinction*. The contrast of the two theories lies in a given, objective perspective and an observed, subjective perspective on the form. Three paragraphs later, Sullivan remarks: *Whether it be the sweeping eagle in his flight or the open apple-blossom, the toiling work-horse, the blithe swan, the branching oak, the winding stream at its base, the drifting clouds, over all the coursing sun, form ever follows function, and this is the law.*[82]

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79 Ref.: Mareis, C., 2014. Theorien des Designs, Junius. p. 70

80 Ref.: Geiger, A., Hennecke, S. & Kempf, C., 2005. Spielarten des Organischen in Architektur, Design und Kunst, p. 55

81 Ref.: Sullivan, Louis H., 1896. The Tall Office Building Artistically Considered

82 Ref.: Sullivan, Louis H., 1896. The Tall Office Building Artistically Considered

Sullivan's law *form ever follows function* takes the form as a given. This chapter revealed that the form of the distinction is always drawn by someone or something. The form of the drifting clouds Sullivan mentions could also be distinguished as evaporated molecules of H2O or the cloud nymph Nephele whom Zeus created in the image of Hera; the indication of *drifting clouds* is never given, but always drawn.

The calculus of design draws into question the essence of the motive *form follows function*. A function can only be distinct from the perspective of a designer in relation to an observer. Even if designed to be used for hanging picture frames, a hammer's function can also be used to murder another human being. As Sullivan's notion of form is static instead of performative, its motive is too. *A function can only be a motive concerning the specificities of the marked and the unmarked of the form. But nothing can stop others from crossing the mark and drawing a new distinction to overcome the specific function.*

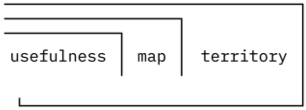
Usefulness

In *Science and Sanity*, Alfred Korzybski identifies another motive of design that relates to cartography and data visualization. Korzybski writes:

> *A map is not the territory it represents, but, if correct, it has a similar structure to the territory, which accounts for its usefulness.*
>
> — *Alfred Korzybski*[83]

The map–territory distinction relates to drawing distinctions, as both theories reduce the complexity of the world they represent. A difference divides space into marked and unmarked. The form always excludes the unmarked, and the resulting sign neglects complexities. Similarly, the map never represents the full complexity of the territory. It reduces the world it symbolizes by signs to specifically highlighted distinctions. The intriguing part of Korzybski's statement is the motive of maps: their *usefulness*. The diagrammatic form of the motive of usefulness, the map–territory relationship, might be expressed as follows:

83 Ref.: Korzybski, A., 1958. Science and Sanity, Institute of GS, p.58



The *territory* distinction in the diagram above includes two additional lines, the *re-entry*, of the *territory* into *usefulness*. This text will cover *re-entry* in a subsequent chapter. Its usage at this point is comprehensible as follows: The map is designed in an operative, iterative process to become as useful as possible concerning the territory. The map designer iterates the drawn distinctions with the aim of expanding the map's usefulness for the observer. If a map's use is to find the quickest path from A to B, other aspects are neglected to increase its usefulness. The usefulness motive relates to functionalism in the form of *as little design as possible*.

One intriguing aspect of the *map–territory* is its various interpretations by artists and philosophers. I will name a couple of these interpretations to draw out the difference between the calculus of design and the *map–territory* relationship. Belgian surrealist artist René Magritte conceptualized the *map–territory* relationship throughout various paintings, most famously the *La trahison des images* or in English *The Treachery of Images*. The artwork shows a pipe, and below the pipe Magritte wrote:

> *Ceci n'est pas une pipe.*
>
> — *René Magritte*[84,85]

A seemingly straightforward concept: the image of a pipe is not a pipe. Magritte earned some criticism for the statement, as he wrote: *How people reproached me for it! And yet, could you stuff my pipe? No, it's just a representation, is it not? So if I had written on my picture 'This is a pipe', I'd have been lying!*[86]

Within the map–territory logic, the image of the pipe is the map. The text below the picture is a map too. The territory is the real pipe, the stuffable, smokable pipe. Within the form's logic, the distinction between map and territory only operates within the distinction of the form itself. *From the standpoint of the calculus*

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84 Ref.: Magritte, R., 1929. La Trahison des images.

85 Translation: *This is not a pipe*

86 Ref.: Magritte, R. & Torczyner, H., 1977. Magritte, ideas and images, p. 71

of design, the map, the territory, and the actual pipe are all distinctions. Pipes are just one categorization, one drawn distinction. The pipe can refer to *briar*, *calabash*, *corncob*, *chibouk*, *chillum*, *hookah*, *kiseru*, *midwakh* or *sebsi*.[87] Each of these relates to regional or specific usages. Pipes are just what we distinguish as a pipe. Is a hookah the territory of Magritte's pipe? Or does a designator draw these two distinctions? There is no direct territory for the image of the pipe Magritte drew. It is us differentiating between what is included in the word *pipe* and Magritte's image. Michel Foucault summarized this in the following statement:

> *Designation and design do not overlap one another...*
>
> *— Michel Foucault*[88]

The pre-binary notion of the distinction only contains distinctions. The seemingly actual, the pipe, is just another drawn distinction, a mark which neglects the unmarked. *The calculus of design only includes form, and the drawn distinction of the territory is a crossing from the form into the unmarked.* The unmarked is crossed by drawing another distinction within the form outside the cross. There is no outside. The form continuously evolves through this operation. There is no observable or designable territory as an outside reality.[89,90] An ever self-extending pattern of operational form marks the basis of the *calculus of design*.

In the poem *The Hunting of the Snark*,[91] Lewis Carroll portrays a group of sailors navigating the sea by a map they can all understand. A map that reduced the complexity of the *conventional signs* until it was a *perfect and absolute blank*.[92]

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87 Ref.: Stevenson, A., 2010. Oxford Dictionary of English, Oxford University Press.

88 Ref.: Foucault, M., 1983. This is not a Pipe, University of California Press, p. 27

89 This concept relates to Derrida's criticism of Levi Straus' duo of *signified* and *signifier*. The *signifier* does not exist, rather *signifiers* nest inside one another as a *signifying chain*.

90 Ref.: Derrida, J., 1978. Writing and Difference, University of Chicago Press.

91 Ref.: Carroll, L., 1876. The Hunting of the Snark

92 *He had bought a large map representing the sea,*

Without the least vestige of land:

And the crew were much pleased when they found it to be

A map they could all understand.

What's the good of Mercator's North Poles and Equators,

Tropics, Zones, and Meridian Lines?

So the Bellman would cry: and the crew would reply

Carroll's poem is a parody of the reduction of complexity, reducing the environment until there are no distinctions left. His map ends where the distinction of the form begins, the unmarked space. Jorge Luis Borges makes the opposite point in his short story *Del rigor en la ciencia*, in English *On Exactitude in Science*:

> *In that Empire, the Art of Cartography attained such Perfection that the map of a single Province occupied the entirety of a City, and the map of the Empire, the entirety of a Province.*
>
> *— Jorge Luis Borges*[93]

Borges's story portrays one more difference between the map–territory concept and the form's notion. The map is seen as an abstraction of the territory, something that is either close to reality or reduced and abstracted from it. Yet, there is a territory that the map is imitating abstractly in order to be useful for the observer. *In the calculus of design, the map cannot become the territory, as there always needs to be a designed distinction. Only by drawing distinctions does the territory reveal itself.* There is no form outside the form of distinctions. The *calculus of design* does not neglect the world outside the difference, but one cannot interact with it without drawing a distinction. The territory itself is a drawn distinction. As no distinctions exist without an observer, without a designer, the territory itself does not exist without a viewpoint, without a perspective. The unmarked only comes into perspective through the mark. Its neglect, the *de,* determines the existence of the *sign* within *design*.

There are even accounts in which the map predetermines the territory. Mapmakers sometimes add fictional places to their plans as copyright traps for their competition. Once another mapmaker adds the trap to the copied map, the originators know and can take legal action against the competitor. In the 1930s, mapmakers Otto G. Lindberg and Ernest Alpers combined their initials and

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They are merely conventional signs!

Other maps are such shapes, with their islands and capes!

But we've got our brave Captain to thank

(So the crew would protest) "that he's bought us the best—

A perfect and absolute blank!"

93 Ref.: Borges, J.L., 1972. A Universal History of Infamy, Argentina: Editorial Tor.

added the fictional village named ‘Agloe’ to one of their maps in Delaware County. A few years later, one main competitor published a map with an indication for the town Algoe. The mapmakers threatened to sue the competition, but they protested and argued that Agloe exists. The Agloe General Store opened after the intersection became frequently visited due to usage of the map.[94] *The map created the territory and the question becomes to what extent design predetermines the relation to the world.*

> *As an explanation of how chance can arise in a world which he regarded as strictly deterministic, Henri Poincare drew attention to insignificant causes which produced very noticeable effects. Sea coasts provide an apt illustration.*
>
> *— Lewis F. Richardson*[95]

Something as simple as measuring the length of a coastline shows how observation influences what is meant to be the territory. In the 1960s, scientist Lewis Fry Richardson researched the relationship between the length of a common border shared by two countries and the probability that these two nations will go to war. In this process, he found substantial inconsistencies between various sources of international borders. These discrepancies arise out of the way the border is measured. The shorter the ruler one uses to measure, the longer the resulting coastline. This might seem counterintuitive, but the shorter each measuring unit is, the more landscape features the observer can acknowledge. As a coastline has features on every scale, the more fine-grained the measurement becomes, the longer the shoreline. *The mode of observation, the designed apparatus, defines the length of measurement.* The fractal structure of something like a coastline means that the analysis determines the extent of it. *Our designed distinctions assess our observations.*

In *Form, Substance and Difference,* Gregory Bateson questions the notion of the territory by writing:

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94 Ref.: Jacobs, F., 2014. Agloe: How a Completely Made Up New York Town Became Real. bigthink.com. Available at: http://bigthink.com/strange-maps/643-agloe-the-paper-town-stronger-than-fiction

95 Ref.: Richardson, L. F., 1961, The problem of contiguity: An appendix to Statistic of Deadly Quarrels in Richardson, L.F., Ashford, O.M. & Drazin, P.G., 1993. The Collected Papers of Lewis Fry Richardson: Volume 1, CUP Archive.

> *We say the map is different from the territory. But what is the territory? Operationally, somebody went out with a retina or a measuring stick and made representations which were then put on paper. What is on the paper map is a representation of what was in the retinal representation of the man who made the map; and as you push the question back, what you find is an infinite regress, an infinite series of maps. The territory never gets in at all. ... Always, the process of representation will filter it out so that the mental world is only maps of maps, ad infinitum.*
>
> — *Gregory Bateson*[96]

Our retina, measuring sticks, sheets of paper are all drawn distinctions. The map–territory relationship suggests an end, some ground truth at some level. The notion of the form continuously questions observation and asks: Which distinction has been drawn for this specific form? *The map is not the territory; there is no territory. There is only form, sets of operationally nested distinctions. Within the operation of the distinction, there is only form.* There is no territorial entity that one can imitate in the most useful way. There is only form drawn by the motives of the designer.

Generativity

In 2014, the *metaLABprojects*[97] series published Johanna Drucker's book *Graphesis*. In the introduction, Drucker states:

> *All information visualizations are metrics expressed as graphics. Visualizations are always interpretations - data does not have an inherent visual form that merely gives rise to a graphic expression.*
>
> — *Johanna Drucker* [98]

The statement contains multiple intriguing concepts. First, Drucker defines information visualization as *metrics in graphic form*; second, she draws attention to the *operationality* of these forms. Third, she states the *subjective character* of the

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96 Ref.: Bateson, G., 1972. Form, Substance and Difference. In Steps to an Ecology of Mind. University of Chicago Press, p. 429

97 For transparency: Since 2017 I am a design researcher at metaLAB (at) Harvard and since 2020 principle of the group.

98 Ref.: Drucker, J., 2014. Graphesis, Harvard University Press , p. 7

visual expressions. The *calculus of design* is a theory and diagrammatic representation to express the questions Drucker articulates. While the *calculus of design* offers an operational diagrammatic notation system to reflect on drawn distinctions, Drucker is asking for the graphics themselves to become evidential operations. She calls for a design motive of generative artifacts as she writes:

> *Most information visualizations are acts of interpretation masquerading as presentation. In other words, they are images that act as if they are just showing us what is, but in actuality, they are arguments made in graphical form.*
>
> *— Johanna Drucker* [99]

For Drucker, the results of design processes too often hide their interpretative, operational act. The rhetorical power of information visualizations disappears from the outcome and presents itself as objective.[100] The course of action to overcome the seemingly objective within the subjectively drawn distinctions are for Drucker *generative graphics*, graphics that do not provide one reading, but rather various combinatorial possibilities, *knowledge generators*. These combinatorics can arise from graphical user interfaces and static graphics, which allow multiple readings from observing variables in contrast to one another.[101] From the perspective of the *calculus of design,* Drucker is asking designers to draw forms that will enable further distinctions observers can draw on their own; *generativity* stands in contrast to the motive of *function*. While function reduces distinctions to the smallest set, generativity opens up the form towards engagement of the mind,[102] a motive of operation rather than the motive towards a product.

Drucker mentioned George Spencer-Brown's *Laws of Form* in a detailed footnote[103] and this was one of the readings that inspired me to engage with the calculus of indication and its relation to knowledge and design. The association between Drucker's generativity and the *calculus of design* is not coincidental. Drucker writes:

> *The ground is not passive, but active and generative.*
>
> *— Johanna Drucker*[104]

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99 Ref.: Drucker, J., 2014. Graphesis, Harvard University Press, p. 10

100 Ref.: Drucker, J., 2014. Graphesis, Harvard University Press, p. 66

101 Ref.: Drucker, J., 2014. Graphesis, Harvard University Press, p. 107

102 Ref.: Drucker, J., 2014. Graphesis, Harvard University Press, p. 111

103 Ref.: Drucker, J., 2014. Graphesis, Harvard University Press, p. 202, footnote 84

Drucker's *ground* within the *calculus of design* is the unmarked space, which the designer can enter by crossing the boundary: generativity, not just in the creation of graphics, but in their observations. The quest is a design operation that allows for various perspectives in its observation. *The motive of generativity is to design forms that open up to enable distinctions of observation within them.*

The quest for generativity asks design to mark the space in ways that leave space for the observers to mark it for themselves. It questions design in light of openness and interpretation. Jan Distelmeyer identifies interfaces as interplays between *fügen* (comply) and *verfügen* (rule).[105] The designed world that the observer, in the case of interfaces often called *user*, enters is one of strictly defined choices.[106] The playground of the designed interface is both the user's autonomy and the form's compulsive order.[107] *The two modes of crossing and calling define the rules of the game on the playground of the power of the interface*[108] and relate to the motive discussed in the next section. *What is allowed and what is not permitted are the reflexive moments of design.* The motive of generativity asks to open up the form to interpretation, to recombinations an observer can draw into the designed form.

Questioning Power

On the surface, the *calculus of design* and its diagrammatic representation are a method to observe and notate the structure of the design operation. It is meant as a reflection on who draws what distinctions. Questioning power, even if not named explicitly, is foundational to the concept. This section investigates Catherine D'Ignazio's and Lauren Klein's book and conception of *Data Feminism*.[109] The theory not only asks for a diagrammatic system to reflect power, but moreover identifies the motive for data and visualization to do so on their own. As such, the motives behind *data feminism* and the *calculus of design* share similarities in distinct principles. The two authors write:

105 Ref.: Distelmeyer, J., 2017. Machtzeichen, Bertz + Fischer, p. 82 - 92

106 Ref.: Rushkoff, D., 2010. Program Or be Programmed, OR Books, p.51

107 Ref.: Distelmeyer, J., 2017. Machtzeichen, Bertz + Fischer, p. 68

108 Ref.: Distelmeyer, J., 2017. Machtzeichen, Bertz + Fischer, p. 62

109 Ref.: D'Ignazio, C. & Klein, L., 2019. Data Feminism, MIT Press Open.

> *Data Feminism is a book about power in data science. Because feminism, ultimately, is about power too. It is about who has power and who doesn't, about the consequences of those power differentials, and how those power differentials can be challenged and changed.*
>
> — *Catherine D'Ignazio and Lauren Klein*[110]

If a form does not exist on its own but rather as drawn operations by someone or something, the question of power is omnipresent. The instruction to *draw a distinction* is the ubiquitous reminder that forms never exist on their own. D'Ignazio and Klein ask:

> *Who makes maps and who gets mapped?*
>
> — *Catherine D'Ignazio and Lauren Klein*[111]

From the perspective of the calculus of design, I reframe the question as:

Who draws which distinctions?

The strength of the book *Data Feminism* lies in vast numbers of examples that illuminate both the securing and contesting of power. The examples include non-existing pregnancy and childbirth datasets in the USA,[112] Mimi Onuoha's project on Missing Datasets[113], Joy Buolamwini's project on facial detection algorithms[114] that have only been trained on pale and male faces, and the discriminatory practice of redlining.[115] *Data Feminism* comments on the problems of data and visualization in ways similar to Johanna Drucker's motive of *generativity*: *But the "trick" is that the bodies who helped to create the visualization – whether through providing the underlying data, collecting it, processing it, or designing the image that you see it –have themselves been rendered invisible. There are no bodies in the image anymore.*[116]

The problem of who drew a particular set of distinctions and from what motive becomes invisible in the form itself; the diagrammatic notation of the design calculus is one

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110 Ref.: D'Ignazio, C. & Klein, L., 2019. Data Feminism, MIT Press Open, p. 13

111 Ref.: D'Ignazio, C. & Klein, L., 2019. Data Feminism, MIT Press Open, p. 132

112 Ref.: D'Ignazio, C. & Klein, L., 2019. Data Feminism, MIT Press Open, p. 17-20

113 Link: https://github.com/MimiOnuoha/missing-datasets

114 Link: https://medium.com/mit-media-lab/the-algorithmic-justice-league-%203cc4131c5148

115 Ref.: D'Ignazio, C. & Klein, L., 2019. Data Feminism, MIT Press Open, p. 130-132

116 Ref.: D'Ignazio, C. & Klein, L., 2019. Data Feminism, MIT Press Open, p. 32

approach to rendering these structures of power visible. Questioning power in design and, more specifically, mapping and data visualization practices, relates to two other voices. The book *All Data are Local* by Yanni A. Loukissas and Donna Haraway's term *situated knowledges*. In the 2019 publication *All Data are Local,*[117] Loukissas exemplifies the theory, as the title suggests, that *data is always created and thus embedded in specific localities*. Rather than focusing on the representational and rhetorical aspects of data from a distance, Loukissas engages with the knowledge systems that construct and maintain data. The book, just like *Data Feminism*, is centered around a set of examples observing five datasets Loukissas examines from a local perspective. One intriguing change in attitude the book asks for is from *data sets* to *data settings,* as Loukissas writes: *In practice, accepting that all data are local means engaging with data settings instead of simply data sets.*[118]

This change in perspective connects well to the *calculus of design*. The term *calculus* is an examination of the operational steps. *Calculus* is defined in the chapter *form* as a set of step-by-step procedures from one form to another. The change from *set* to *setting* asks for a similar transition from rhetorical to operational.[119] *Data and visualization only exist as a practice of operations.* The reflection on the processes reveals the designer. Loukissas cites feminist theorist Sandra Harding, who states: *Postcolonial histories and studies of contemporary projects have shown that in important respects modern sciences and technologies, no less than other cultures' traditions of systematic knowledge, are local knowledge systems.*[120]

The *local* is not merely a question of geolocation, of place, but also questions the embeddedness of data and its construction. The motive of questioning power within Loukissas' work emerges from questions of the locality of the sign and the designer. It is a change away from the set and towards the setting. *The diagrammatic form of the calculus of design provides a method to map the drawn distinctions, render a meta-diagram, observe the setting, the marked, and question what is left unmarked.* Locality, from my reading, is a question of designation. Who or what is drawing the distinctions one takes for granted?

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117 Ref.: Loukissas, Y.A., 2019. All Data Are Local, MIT Press.

118 Ref.: Loukissas, Y.A., 2019. All Data Are Local, MIT Press, p. 23

119 Ref.: Loukissas, Y.A., 2019. All Data Are Local, MIT Press, p. 17

120 Ref.: Harding, S.G., 1998. Is Science Multicultural? Indiana University Press, p. 55

While Loukissas focuses on the local, Donna Haraway's concept of *situated knowledges* observes the social material of the embeddedness. Data, visualization, maps, and design in general, as well as *scientific and technological, late-industrial, militarized, racist, and male-dominant societies*[121] embrace the *view from nowhere*: a seemingly objective observation of the world. As Haraway suggests, this view from nowhere has far-reaching theoretical consequences that need to be carefully examined. Again, the motive I am extracting from the debate is the questioning of power, design reflecting on its embeddedness, rejecting the objective observer's concept for the observation and designation of an operational design calculus. *To draw a distinction is more than a command towards the form; it is the only possibility for a form to exist in the first place.* The diagrammatic notation of the calculus of design is one possibility to render this act visible.

In *Data Feminism*, D'Ignazio and Klein write that data scientists *rarely find their dominance challenged, their neutrality called into question, or their perspectives open to debate. Their privilege renders their bodies invisible– in datasets, in algorithms, and in visualizations, as in their everyday lives.*[122] The motive of *questioning power*, just like *generativity*, needs alternative forms, away from *function*, *usefulness*, *performance*, *efficiency*, *effectiveness*, *optimization*, *overview*, or *minimalism*. Or, in D'Ignazio's and Klein's words:

> *Are minimal charts really "better," as Edward Tufte has claimed?*
>
> *— Catherine D'Ignazio and Lauren Klein*[123]

As discussed in the chapter *arrow*, Tufte declared that visualizations are a form of *magic*. The minimalist, functional motive of design hides the magic, the subjective perspective of drawing distinctions by creating forms that contain as *few distinctions as possible*.[124] From the perspective of the *calculus of design,* power is questioned on two levels. First, who is drawing distinctions, and for what purpose? But secondly, what is the power structure of the form in itself? What is the form excluding through its possible steps of operation? What cannot be expressed by calling and crossing distinctions? Are there problems that cannot

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[121] Ref.: Haraway, D., 1988. Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. Feminist Studies, 14. p. 581

[122] Ref.: D'Ignazio, C. & Klein, L., 2019. Data Feminism, MIT Press Open, p. 32

[123] Ref.: D'Ignazio, C. & Klein, L., 2019. Data Feminism, MIT Press Open, p. 47

[124] Adapted from Dieter Rams ten commandments of good design: *As Little Design as Possible*

Ref.: Lovell, S., 2011. Dieter Rams: As Little Design as Possible, Phaidon Press.

be addressed by structuring the world into form? *What is the ever-elusive, the forever unmarked, of the operative form itself?* Less abstractly, *What is ineffable in the format of data, computation, and visualization?* These questions veer too far away from the current observations of design motives, but I will circle back to them in the following chapters.

Outro

> *Es zeigt sich, daß hinter dem sogenannten Vorhang, welcher das Innere verdecken soll, nichts zu sehen ist, wenn wir nicht selbst dahinter gehen, ebensosehr damit gesehen werde, als daß etwas dahinter sei, das gesehen werden kann.*
>
> — *Georg Wilhelm Friedrich Hegel*[125,126]

While the previous chapter on *form* introduced a comprehensible calculus of design, this chapter introduced the first complication. From the straightforward command *draw a distinction* adapted from the book *Laws of Form* emerged the observer. The observer is represented within the crosses she draws. *System theories* affirmed the notion of the observer and extended its meaning. Observation from this perspective is not exclusive to humans — animals, plants, stones, ghosts, computers, and anyone or anything capable of drawing distinctions is called an observer. Niklas Luhmann's *system theory* draws another difference between first and second-order observations.[127] The first-order observer draws distinctions within the world. The second-order observer observes already drawn observations. A crucial nuance is that the cross of the first and second-order observations are never the same. *The observation of observation never equals the initial observation. Observing a mark, remarks the mark.*[128]

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125 Ref.: Hegel, G.W.F., 1807. Phänomenologie des Geistes, Bamberg und Würzburg.

126 Translation: *It shows that behind the so-called curtain, which is supposed to cover the inside, nothing is to be seen, if we do not go behind it ourselves, just as much as that something is behind it, which can be seen.*

127 I will get back to this in chapter on *time*.

128 Jacques Derrida's *différance* as a critical outlook between the relationship of text and meaning relates to the ever-elusive mark.

Ref.: Derrida, J., 1978. Writing and Difference, University of Chicago Press.

The *calculus of design* distinguishes itself from the *calculus of indication* in the terminology of the *observer*. *Observation is not sufficient to draw distinctions. Design is taken literally as signing space. The de in design reflects the unmarked, the alternatives left out by the operation of the mark.* The result is a continuous shift between design, interpretation of design, and observation. *The form is never given, but always marked by the cross of the designer. The operation of design results in interfaces that conceal complexity within form.*

The calculus of design manifests the possibilities of what it means to design. The four elements of the dualism between *indication* and *distinction* of the *form* are the *constitution of design*. Space restricts the potentials; the form is the topicality. Design is the act of redrawing topicalities — an operational act of finding form within space. *The attention towards the form is, at the same time, attention towards the designer.* Drawing a distinction is only possible if space allows for a difference. Without it, the sign is set and cannot be reduced, no *de*, only *sign*.

The freedom of space leads towards the motive of the designer. *The question of form becomes a question of motive.* The *Conceptions of Design for Insight* investigated multiple design motives, such as *performance*, *efficiency*, *effectiveness*, *optimization*, *overview*, and *minimalism*. This chapter inquired into *function*, *usefulness*, *generativity*, and *questioning power*. The discussion of these motives was not supposed to lead to any particular outcome, but rather question and narrate differing approaches. *Function* as well as *usefulness* only lead to further questions within the motives themselves. *Generativity* asks about a form that opens the space for distinctions within themselves for the observer to draw. *Questioning power* asks the designer to reveal herself, himself, itself, within the design.

The design motives *function*, *usefulness*, *generativity*, and *questioning power* all have in common that they present *reasons* to design. Each motive leads to alternative operations, alternative distinctions to draw. This chapter's underlying concept on *design* is based on the theory and exemplification that form is not given but observed and designed by someone or something. Without the command *draw a distinction,* no distinctions are marked. The form is drawn into existence by the designer.

The designer only gets to know the representations she draws, rather than *things* existing in the world. The question of where someone or something draws a distinction is older than the conception of design and is deeply rooted in philosophy. *Die Dinge an sich*, the things themselves, only become observable as they appear to us, not as they are. This doctrine was analyzed in great detail by German philosopher Immanuel Kant as *transcendental idealism* in the 18th century. For Kant, knowledge encompasses two sides. First, the axioms, rules, and theorems, the rationalist perspective,[129] and second, the empiricist's view that knowledge comes about only through experience and the senses, the observation and designation of the world. In the terminology of the *calculus of design*, objects only become observable through the distinctions one draws within the world. For Kant, our minds start from our innate intuition of space[130] and time.[131,132]

The empirical border is not absolute but drawn by the motive of reason. [133] The experience, the designation of the pre-binary distinction, and the resulting form not only mark but postulate the unmarked. Without the freedom to exclude, there is nothing to be observed. The external world does not give the border between marked and unmarked but is subjectively set by the *Principium der Vernunft*. *Order is drawn into existence through design.*

> *Die Ordnung und Regelmäßigkeit an den Erscheinungen, die wir Natur nennen, bringen wir selbst hinein, und würden sie auch nicht darin finden können, hätten wir sie nicht, oder die Natur unseres Gemüts ursprünglich hineingelegt.*
>
> — *Immanuel Kant*[134,135]

While Kant uses the term *hineingelegt*, *to put something in*, the *calculus of design* postulates the expression *design* as the fundamental ordering principle. The subjective viewpoint of observation and as re-marking the world as designation become the origin of order. The motive of drawing a distinction separates the form into marked and unmarked; it cannot be motivated by the world. The reason for design will stay ever elusive. *Function*, *usefulness*, *generativity*, and *questioning power* set forth instructions on how to distinguish within the freedom of design; the quest for its underlying *reason* remains obscure.

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129 Discussed concerning the *calculus of design* in the chapter *Form*.

130 The notion of *space* within the calculus of design will be discussed in the next chapter.

131 Time will be forther defined and discussed in the chapter *Time*

132 Ref.: Quian Quiroga, R., 2012. Borges and Memory, MIT Press. Loc. 2131-2136

133 Ref.: Kant, I., 1956. Kritik der reinen Vernunft, B537

134 Ref.: Kant, I., 1956. Kritik der reinen Vernunft, AA IV 92

135 Translation: *The order and regularity in the phenomena which we call nature, we bring in ourselves, and would not be able to find it in it, if we had not put it in, or the nature of our mind originally put it in.*

The clarification this chapter provided is on the addition of the design operative act and its contrast with observation. The notion that observed marks never equal the mark itself introduces the sign's *realphantasma*.[136] Observing designed marks does not equal the marks themselves. The designer's withdrawal within the system vanishes, with every mark trying to capture the designer's sign, the *kobold* of the form. Marking the marker is an ever-elusive operation. As such, *questioning power* as a motive, even if desirable, is still indefinable. In the book *Objectivity,* Lorraine Daston and Peter Galison state:

> *Yet Rorschach designed his plates, at least ostensibly, to be "random" —that is, without any direct reference to the world —precisely so they would serve as the screen onto which the subject would make visible (objective) his or her pure subjectivity.*
>
> *— Lorraine Daston and Peter Galison*[137]

Daston and Galison's statement hints at the notion of *insight* that the *calculus of design* is striving towards. *Without drawing distinctions, there is no insight.* However, before this theory draws further associations between *design* and *insight*, I will discuss and elaborate two other concepts: First, a second unmarked cross, the *space*, which is so crucial in its conception of the form that I already mentioned it various times without elaborating its concept. And second, a graphic addition to the diagrammatic cross; the distinction and indication are supplemented by the *re-entry*, two additional lines *re-entering* the cross itself, creating *time* within the theory.

136 Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag. Peter Fuchs, Vorwort, p.6

137 Ref.: Daston, L. & Galison, P., 2010. Objectivity, New York: Zone Books, p. 361

Space

Once you have entered your coins into the vending machine, a keypad interface offers a choice between various snacks arranged in a grid formation. The space this chapter will discuss predefines the potential possible distinctions. It is not geographical but procedural. The space of the vending machine is the combinatorial possibility of the machine keypad. You can enter any combination, but if it is not a combination pre-programmed for the snack machine, the system will not serve you.

Mask Vending Machine, Berlin 2021

The last chapter, *designer,* investigated two unwritten crosses, observer and designer, which equal the form that is designed. The observer notices a specific form. The designer is someone or something drawing a distinction. This chapter will discuss and sharpen the already often used but not adequately discussed expression of *space* within the theory I am developing, the *calculus of design*.[1]

First, this chapter will discuss the notion of *space* that Spencer Brown articulates in his *calculus of indication*. Second, I will discuss, debate, and examine three examples, *empty spaces*, *visualization spaces*, and *code spaces*. Furthermore, I will connect the results from the three samples to media theoretical and philosophical perspectives. Fourth and last, I will draw conclusions for the *calculus of design*, for what space means for a theory of design, theoretically and in practice.

1 I elaborated the concept in the chapter *Form*, subchapter *Calculus of Design*.

Calculus of Indication

While Spencer-Brown only used the term *observer* four times throughout his theory, the *calculus of indication*, the word *space* is used extensively. Throughout the 140 pages of the book, the term appears on 50 of them. And still, the concept of space is not defined but is instead used as an operational term within the form's mathematical procedures. To illustrate my point, I will name a couple of examples of Spencer-Brown's usage of the word. Space is first called in the introduction:

> *It is possible to develop the primary algebra to such an extent that it can be used as a restricted (or even as a full) algebra of numbers. There are several ways of doing this, the most convenient of which I have found is to limit condensation in the arithmetic, and thus to use a number of crosses in a given space to represent either the corresponding number or its image.*
>
> — *Spencer Brown*[2]

Space in this context is the given, the preexisting in which Spencer-Brown draws algebraic and arithmetic distinctions. Five pages later, he writes:

> *The theme of this book is that a universe comes into being when a space is severed or taken apart.*
>
> — *Spencer Brown*[3]

The theory's scale is rendered visible in the above statement—a universe that comes into being by serving a space. The two quotes display the scope Spencer-Brown navigates. From mathematical algebraic operations to the metaphysics of the universe. *Space is the underlying assumption of logical, mathematical operation and the a priori of our understanding of the structures that an observer takes apart. Space is what allows forms to be drawn.* In the twelve chapters of the Laws of Form, the term *space* fulfills its role in the form's mathematical operations. For example, in the second chapter to introduce the term *depth*:

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2 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. xxiii

3 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. xxix

> *In an arrangement a standing in a space s, call the number n of crosses that must be crossed to reach a space sn from the depth of sn with regard to s.*
>
> — *Spencer Brown*[4]

Or in the 8th theorem *Invariance*:

> *If successive spaces sn, sn+i, sn+2 are distinguished by two crosses, and sn+i pervades an expression identical with the whole expression in sn+i, then the value of the resultant expression in sn is the unmarked state.*
>
> — *Spencer Brown*[5]

This subchapter will not discuss the mathematical and logical conceptions of Spencer-Brown's theory. There is a multitude of secondary literature doing so, such as Felix Lau's discussion of the mathematical theories of the Laws of Form,[6] the book *George Spencer Brown: Eine Einführung in die »Laws of Form«,*[7] or in the English language the writings by Louis H. Kauffman.[8]

The term *space* is so commonly used in everyday language, it is essential to note what the term does not mean within the calculus of indication. *Space in this theory is not strictly spatial as in occupying a geographical location. Space is not a place; space is an unwritten cross within which one draws a distinction.* Distinctions can only be drawn within a space; it is the unwritten cross nesting all drawn crosses. Spencer-Brown writes:

> *Call the space in which it is drawn the space severed or cloven by the distinction.*
>
> — *Spencer-Brown*[9]

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4 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. 7

5 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. 22

6 Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag. Available at: https://www.carl-auer.de/programm/artikel/titel/die-form-der-paradoxie/.

7 Ref.: Schönwälder, T., Wille, K. & Hölscher, T., 2013. George Spencer Brown, Springer-Verlag.

8 Ref.: Kauffman, L.H., 2006. Laws of Form - An Exploration in Mathematics and Foundations.

9 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. xxix

Space is what is severed into marked and unmarked by drawing a distinction. The crucial point is that the space within which one chooses to design predefines the possible distinctions one can draw. In this respect, Niklas Luhmann writes:

> *Spencer Brown draws circles in his book but in the process, he always takes the white sheet of paper for granted.*
>
> — *Niklas Luhmann*[10,11]

The white sheet of paper is the space. Without it, Spencer-Brown would be unable to draw a circle. Space is the a priori structure necessary for the command *draw a distinction*. While Spencer-Brown does not elaborate further on the conception of space, it opens up an intriguing perspective on the field of *media theory* in general and specifically the study of interfaces and its relation to the theory of design instigated here.

Empty Spaces

A light switch only contains two options; its space is two-fold, on or off. Drawing distinctions always happens within spaces, the given constraints, the realm of design possibilities.

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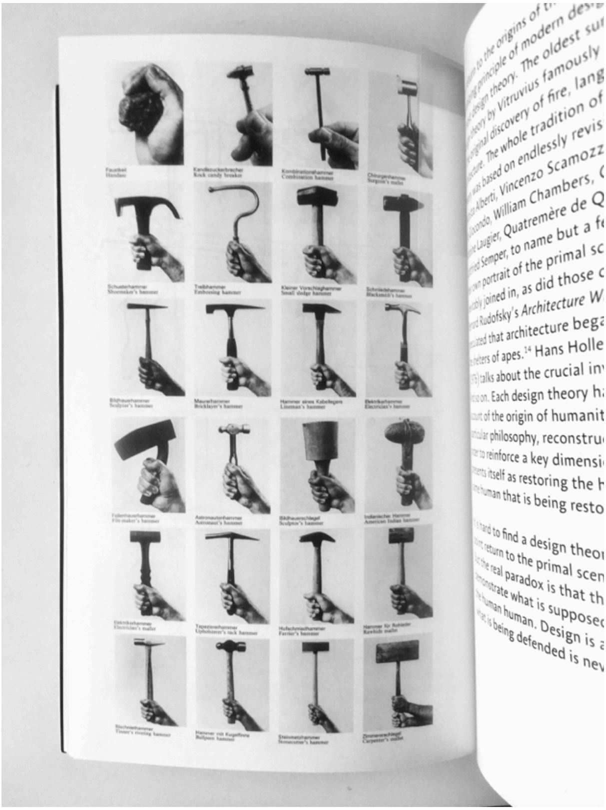
10 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57.

11 I want to note here that Luhmann writes *Spencer Brown* and not, as in this thesis, *Spencer-Brown*. Spencer-Bown added the hypen himself throughout his lifetime to draw a distinction so that his books would not be catergorized under *Brown* in liberaries but under *Spencer-Brown*. I am following this addition throughout this thesis.



Hans Hollein, Man TransFORMS [12]

For the 1976 exhibition *Man TransFORMS,*[13,14] Hans Hollein collected designed objects of similar categories. Each of Hollein's collected hammers has specific purposes and ways of being used. However, each can also be misused, for

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12 Ref.: Colomina, B. & Wigley, M., 2016. Are We Human?, p. 140

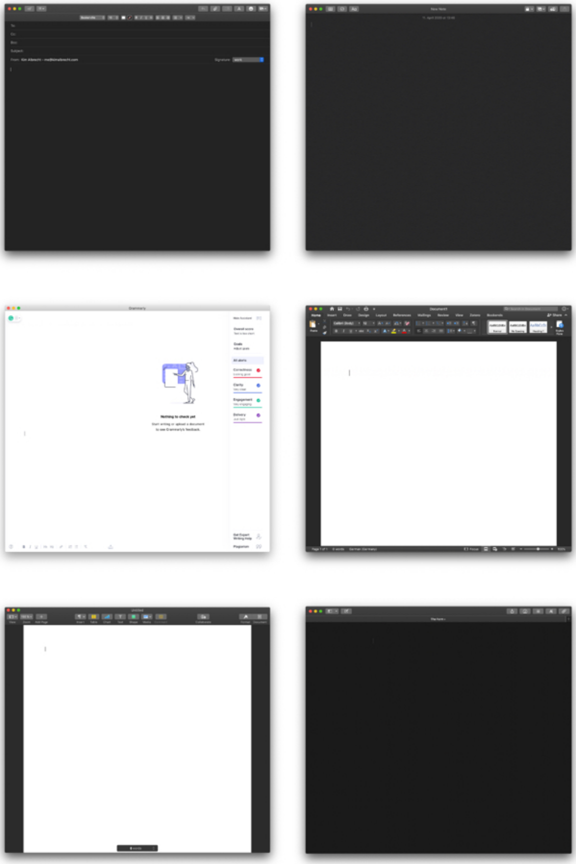
13 Ref.: Hollein, H., 1974. MANtransFORMS. hollein.com. Available at: https://www.hollein.com/ger/Schriften/Texte/MANtransFORMS Accessed October 26, 2020.

14 Ref.: BMIAA, 2016. “MAN transFORMS: The Documents” Hans Hollein in the new space created by Petra Blaisse. bmiaa.com. Available at: https://www.bmiaa.com/man-transforms-the-documents-hans-hollein-in-the-new-space-created-by-petra-blaisse/ Accessed October 26, 2020.

example, as a door stopper or in the fatal sense to kill someone. Graphical user interfaces and more general designing on the computer hold a specificity in this respect. There is very little room to move between space's given possibility and the system's destruction. Jan Distelmeyer names the turn of a page as an example. While there are millions of ways to turn a page in a physical book and most likely no page turn will ever equal the next, the algorithmic page turn, the *programmatic procedures*, in a pdf reader always operates the same.[15] *A set of programmed functions are executed, and there is no alternative motion within the gesture.* This becomes peculiar, as the surfaces of graphic user interfaces for creation often present themselves as empty boundless spaces. The suggestion is: *anything is possible*.

The following personal collection of screenshots displays various applications on my computer and their interface states of new documents, the empty spaces in which I am offered the opportunity to draw distinctions.

[15] Ref.: Distelmeyer, J., 2020. Kontrollieren – (Inter-)Aktivitäten in, mit und von Computerspielen. In Videospiele als didaktische Herausforderung, p. 88-90

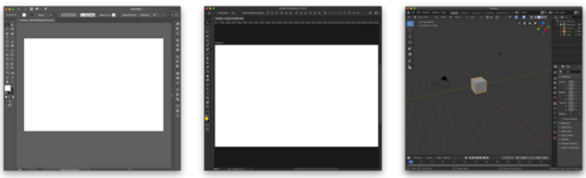


Writing: Apple Mail, 13.0, Apple Notes, 4.7, Grammarly, 1.5.61, Microsoft Word for Mac, 16.35, Pages, 10.0, Ulysses, 2.8.2

From email writing to various text editor competitors, each interface presents itself as an empty rectangle one can draw distinctions within. By clicking in the rectangle, the program allows the user to write. This gesture already hints at the only seemingly empty rectangle. Not everything is possible; space only allows what is not forbidden; in this case, placing letters and spaces one after another, line by line. Writing on a computer means pushing the various pre-defined buttons on a keyboard or touch screen. It is an interplay of the hardware and software *interface spaces* so that a user can *draw distinctions* within the system.

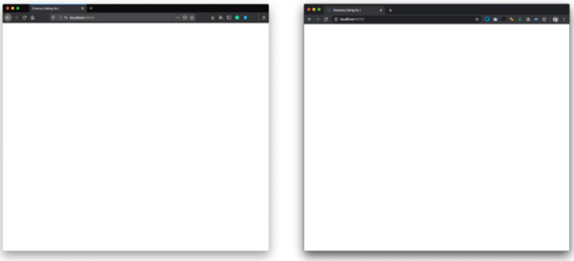
Coding: Jupyter Notebook, 5.7.8, Sublime Text, 3.2.2, Terminal, 2.10

At first glance, the programming environments appear further reduced in comparison to the writing applications. These systems are applications to write computer code. Their *empty spaces* contain no more than blank screens. Almost no visible interface elements are contained within them. The software/hardware spaces of input and representation allow the user to draw forms within these systems.



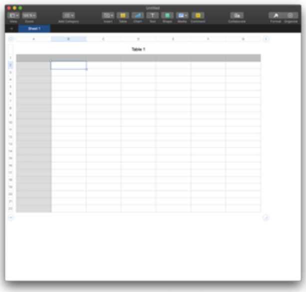
Graphic: Adobe Illustrator CC, 21.0.0, Adobe Photoshop CC, 2017.0.1, Blender, 2.8.0

Coding and writing applications only hinted at their constraints, with reduced navigation bars above the creation's empty spaces. Interfaces for creating graphics such as Illustrator for vector graphics, Photoshop for raster graphics, and Blender for 3D graphics contain a richer set of instructions. There are various options to select in several side panels. Unlike Illustrator and Photoshop, Blender already pre-renders the first object onto a raster; it does not start with an empty space but with a lonely cube at the center of the rasterized interface. The dominant hardware input for coding spaces is the keyboard; within the presented graphic spaces, it is the computer mouse or the touchpad. Space is severed through point-and-click within the side panels.



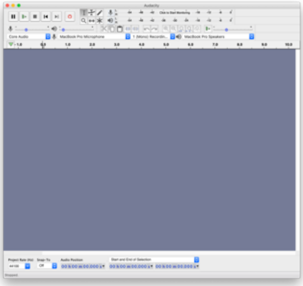
Browser: Firefox, 74.01, Google Chrome, 80.0.3987.163

In web development, a <head> and a <body> tag define a website's basic skeleton. These first two code distinctions render a blank webpage. The difference in the code and representation layer from two distinctions to none hint at the notion that space might not be that empty after all.



Tabular: Apple Numbers, 10.0

The blank spreadsheet view diverges to some degree from the previous blank spaces. It is not an empty space that emerges once a new document is opened, but one with an agenda. The raster is already pre-defined. The creator can only fill and extend the pre-defined structure. To some degree, this might be the more truthful state; no, not everything is possible here. The grid is the structure, and the user has to obey this predefinition.



Sound: Audacity, 2.3.2

The space of Audacity is different from the other empty spaces. The space does not react to clicking or dragging. One cannot write or sketch within it. The first distinction the user has to make is by loading or recoding a sound file before further distinguishing the form.

The seemingly empty interfaces contain interdependent, pre-defined operations. The screen-based interface, the graphical user interface, short GUI, is determined by the pixels and their color values. The *input space* of the GUI is the keyboard, computer mouse, touch screen, or touchpad. Each input space contains its restrictions of clicking, pressing, or dragging. I have curated various *software spaces*; each of these holds alternative settings of pre-defined distinctions. The *hardware space* allows for the software spaces in the first place. The possible number of calculations and storage limits the software operations. The configurations between these various spaces authorize the drawing of distinctions. I am naming these computational interdependencies *interface spaces*.

The underlying system of these spaces is the cross: the inclusion and exclusion, distinction and identity. The form's crosses are drawn *in—sight* as rows and columns within the tabular software arrangements, or the crosses are rows, columns, and pixel values within pixel-based graphic software. The nested crosses define the form; the designer can cross each distinction and indication by moving to another cell, another pixel, another software application, another coding environment. The open, two-lined rectangular cross pre-defines an arrangement within a given space.

Visualization Spaces

The blank graphical interface surfaces suggest an indistinct space that allows users to draw any distinctions they want. But is this the case? The question arises, what is possible in these empty spaces? How is the space pre-defining the possibility of drawing distinctions? The last section has explored how the empty space is not something particular in interface design, but ordinary. There is a vast difference between a sheet of paper and the interface analogy of the blank space. To narrow down, discuss, and steer towards these questions, I became intrigued by three blog posts by visualization designer Lisa Charlotte Rost.[16,17,18] In 2016, she recreated the same scatterplot with 24 different visualization tools and libraries.[19]

Describing the blog post's motivation, Rost writes: *To maybe discover better tools than the ones we use; but also to reassure us that the tools we use ARE really the best (so far).*[20] I am intrigued by the comparison not in order to find new charting tools, but as *a showcase of the boundaries of interface spaces*. The dataset and visualization from which Rost's work emerges is a prominent example of visualization design.[21] The Gapminder graph compares life expectancy in years on the vertical axis and income per year per person on the horizontal axis.

16 Ref.: Rost, L.C., 2016. One Chart, Twelve Tools. lisacharlotterost.de. Available at: https://lisacharlotterost.de/2016/05/17/one-chart-tools/ Accessed October 26, 2020.

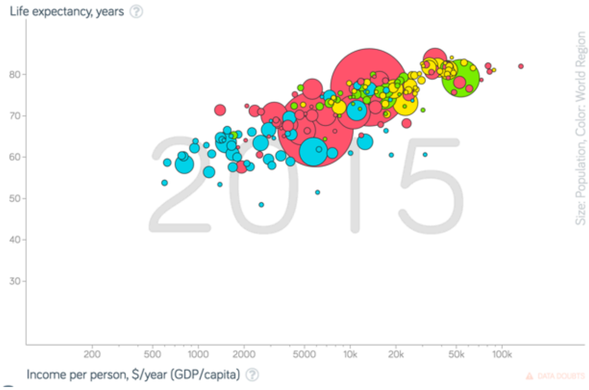
17 Ref.: Rost, L.C., 2016. One Chart, Twelve Charting Libraries. lisacharlotterost.de. Available at: https://lisacharlotterost.de/2016/05/17/one-chart-code/ Accessed October 26, 2020.

18 Ref.: Rost, L.C., 2018. One Chart, Nine Tools – Revisited. lisacharlotterost.de. Available at: https://lisacharlotterost.de/datavistools-revisited Accessed October 26, 2020.

19 In 2017 Lisa Charlotte Rost added another version from the tool ›Datawrapper.‹ So the list here contains 25 visualizations.

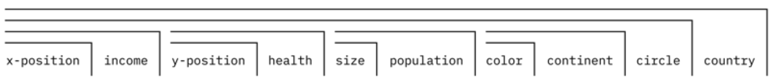
20 Ref.: Rost, L.C., 2016. One Chart, Twelve Tools. lisacharlotterost.de. Available at: https://lisacharlotterost.de/2016/05/17/one-chart-tools/ Accessed October 26, 2020.

21 Ref.: Rosling, H., 2006. The best stats you've ever seen. ted.com. Available at: https://www.ted.com/talks/hans_rosling_the_best_stats_you_ve_ever_seen.



Original visualization from the Gapminder tool.

This visualization is probably the most famous visualization by Hans Rosling and is displayed over two pages in the international bestseller *Factfulness*, co-authored by Anna Rosling Rönnlund and Ola Rosling.[22] *Within the diagrammatic form of distinctions, the chart is rendered as a nested set of differences.* The primary distinction is to render countries as circles; all other distinctions are nested within the first distinction.



Rost gave herself several rules. First, to represent the *Gapminder chart as well as possible* with the tool at hand without using any other application; she did not try to make all charts look as similar as possible, but used the shortest path to get to a scatterplot within the given system. This point is crucial when discussing this collection concerning the notion of space within the calculus of design. Second, Rost leaves the data as it is without changing the dataset beforehand in other applications.

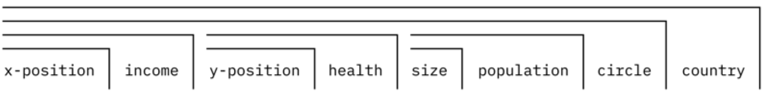
22 Ref.: Rosling, H., Rönnlund, A.R. & Rosling, O., 2018. Factfulness, Flatiron Books.

	A	B	C	D	E	F
1	country	income	health	population		
2	Afghanistan	1925	57.63	32526562		
3	Albania	10620	76	2896679		
4	Algeria	13434	76.5	39666519		
5	Andorra	46577	84.1	70473		
6	Angola	7615	61	25021974		
7	Antigua and Barl	21049	75.2	91818		
8	Argentina	17344	76.2	43416755		
9	Armenia	7763	74.4	3017712		
10	Australia	44056	81.8	23968973		

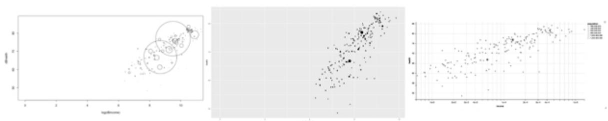
Screenshot of the first ten rows of the dataset used by Lisa Charlotte Rost.

The drawn distinctions from data to graphics are the same for each scatterplot. The x-axis represents GDP per capita and the y-axis health expectancy in years. The size of the bubbles will represent the population of each country. The first intriguing point, the Gapminder visualization, draws another distinction not included in the dataset Rost uses. The colors of each bubble represent the continent of each country. The data does not include this distinction, so none of Rost's visualizations differentiate between colors in her remakings.

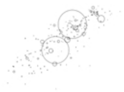
While Rost, in her articles, explains each of the tools and gives a brief statement about her experiences, I have categorized the libraries by their underlying computational languages. The important factor is that each visualization that follows is based on the same set of drawn distinctions.



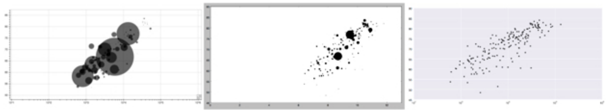
Libraries



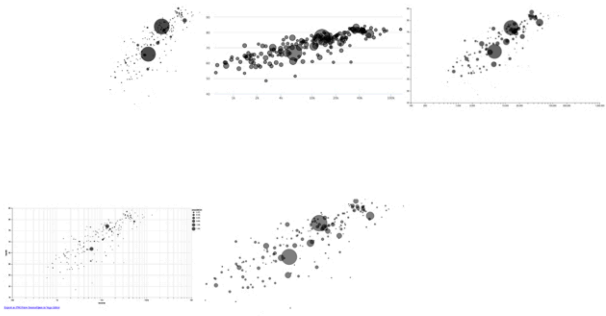
R: R – native, ggplot2, ggvis



Java: Processing

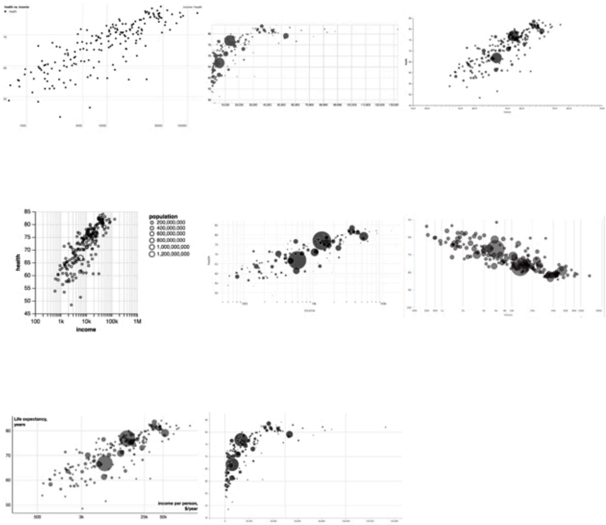


Python: Bokeh, matplotlib, Seaborn

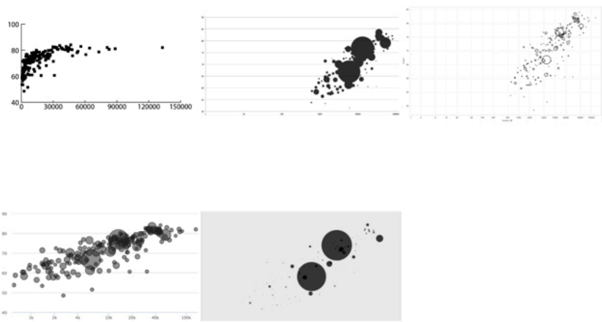


JavaScript: D3.js, Highcharts.js, Vega, Vega Lite, D3.js Templates

Tools

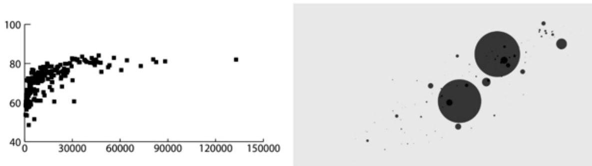


Web-Based Applications: Google Sheets, RAW by DensityDesign, Lyra, Polestar, Plotly, Highcharts Cloud, Datawrapper, Quadrigram



Stand-alone Applications: Adobe Illustrator, Excel, Tableau Public, Easychart, NodeBox

The same designer uses the same data and the same set of distinctions with various tools and libraries, or as I name them, interface spaces, and each rendered graph looks *different.*[23] There is not one pair in the collection that produced the same image. Even more drastically, the visualizations look so different that they might lead to alternative judgments from each of the graphs. *The blank space is not empty at all; it holds all kinds of pre-assumptions. Thus, it is essential to reflect on the drawn distinctions and the space a form operates within.* It is difficult to grasp that the visualization created with Illustrator represents the same data as the graph created in NodeBox:



Left: Adobe Illustrator; Right: NodeBox

The tools, the empty spaces, are not empty after all. They are filled with pre-assumptions and pre-configurations. Drawing the same distinctions from the same data leads to results that are vastly different. *Space within the calculus of design is a distinction too, the distinction a priori the designer's first drawn cross.* Space is the realm in which a designer draws distinctions, in this case, a set of 25 visualization tools and libraries. *The space holds vast implications for the possible distinctions one draws.*

The diagrammatic notation of the calculus of design continuously leaves open the next distinction above the distinction, the space a form occupies. The diagrammatic form of the distinction only consists of two lines, distinction and indication. In comparison, a rectangle consists of four lines, enclosing the space. The form leaves open two sides; it is adaptable,[24] constantly questioning its opening to both the inside and, in the case of the space, the outside. Form only exists within space; I am indicating the unwritten cross of the space as a gray cross:

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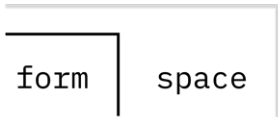
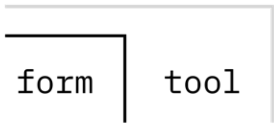
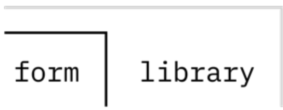
23 Explained in the introduction of this subchapter, *Visualization Spaces*.

24 The German language has the fitting term *anschlussfähig*, *capable of adapting*.



The designer can draw distinctions within the space or move upwards and question it. In the example of Rost, the spaces she explored above the form are two-fold, tools and libraries:





The movement towards the outside of the form could continue further, for example, by questioning not only the tools and libraries but also the data at hand:

From questioning data, the designer could ask what is allowing the entirety of the form, graphing library, and data? One answer might be computation:

As I will discuss in the next section, space is not a stable entity like the distinction. The designer observes and draws distinctions outside the form, deciding what is form and what is space.

Code Spaces

The *space/form* relationship is not something that only applies to graphical user interfaces, but, as I argue, to the entire infrastructure of designing on the computer. *Every computer language is designed on a specific set of possible instructions drawn one after another. What is not contained within these languages is forbidden.* Code is not only law, but at the same time execution. The separation of powers between law and implementation is drawn together within *interface spaces*. *Crossing* allows the user to redraw the code, to create an alternative entanglement between command and execution within the confinements of *programmability* between hardware and software. The *interface spaces* pre-define and allow the user to overcome the current settings.[25]

The contemporary structure of computer environments is absolute in terms of the distinctions within which a designer can draw. The operational space is fully defined and, as such, entirely restricted. This is not the case in the world we as humans inhabit. A sheet of paper also holds specificities, but they are indistinct. The space of possibilities of a white sheet of paper can never be entirely determined. It can be used to write a letter or draw a picture, but it can also be crumpled or turned into a paper plane. It would be impossible to fully define all the possible usages of a sheet of paper. Even if the possibilities are vast, the space of the computer is fully specified, vast but finite. A computer screen cannot be turned into a paper plane without breaking the entire system.

25 Ref.: Distelmeyer, J., 2017. Machtzeichen, Bertz + Fischer.

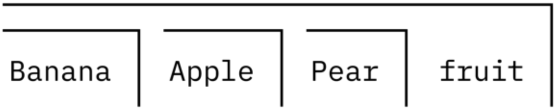
Every computer language contains specific commands; anything not contained within that language is unpronounceable. In the calculus of design, space is the term that describes the realm of possibility for drawing distinctions. For example, JavaScript contains several data types:[27]

- Numbers — `var age = 23;`
- Variables — `var x;`
- Text (strings) — `var a = "init";`
- Operations — `var b = 1 + 2 + 3;`
- True or false statements — `var c = true;`
- Constant numbers — `const PI = 3.14;`
- Objects — `var name = {firstName:"John", lastName:"Doe"};`
- Arrays — `var fruit = ["Banana", "Apple", "Pear"];`

The graphical user interface often hides the computational, mathematical, and operative structure of these systems. When visiting a social networking website, like Facebook or Twitter, it is uncommon to think of it as a mathematical act, but it is. At its core, the operational act draws distinctions, next to and within, calling and crossing. It is a nested hierarchical structure within a designed space, again consisting of nested sets of distinctions. Computation in its most general form as well as in all its specificities follows the command: *draw a distinction, but only the one the system is designed for. Space pre-defines the form.*

Arrays are the most common form of *next-to operations*. The array `var fruit = ["Banana", "Apple", "Pear"];` within the diagrammatic form of the calculus of design renders as:

27 List adapted from: https://websitesetup.org/javascript-cheat-sheet/



In JavaScript, fourteen commands allow for the removal, addition, and alternation of the drawn distinctions:[28]

- Join several arrays, distinctions, into one — `concat()`
- Return to the first position at which a given element appears in an array — `indexOf()`
- Combine distinctions of an array into a single string and return to it — `join()`
- Give the last position at which a given distinction appears in a set of distinctions — `lastIndexOf()`
- Remove the last element of a set of distinctions — `pop()`
- Add a new distinction at the end — `push()`
- Sort distinctions alphabetically — `sort()`
- Sort distinctions in a descending order — `reverse()`
- Remove the first distinction of an array — `shift()`
- Pull a copy of a portion of an array into a new array — `slice()`
- Add distinctions in a specified way and position — `splice()`
- Convert distinctions to strings — `toString()`
- Add a new distinction to the beginning — `unshift()`
- Return to the primitive value of the specified distinction — `valueOf()`

These operations relate to contemporary graphical interface operations, such *follow*, *unfollow*, *friend*, and *unfriend* within the realm of social media applications. Following someone on the platform *Twitter* is a `push()` operation, adding the account to the array list of followed accounts.[29]Similarly, each command relates to a combinatorial set of callings and crossings. Human relationships are turned

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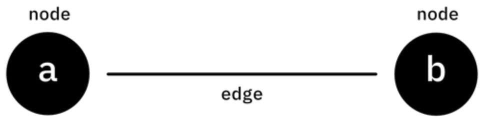
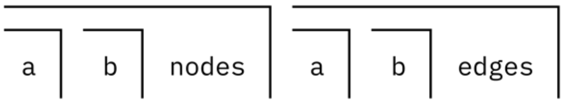
[28] List adapted from: https://websitesetup.org/javascript-cheat-sheet/

[29] Of course, the actual operations on a large-scale social media network such as *Twitter* contain an oparative space, a software/hardware interdependency considerably more complex than an individual `push()` command.

into mathematical operations of inclusion and exclusion through one underlying command: *draw a distinction*.

While friendships in the world we inhabit are tested and obscured upon each encounter and the lack thereof, friendships and relationships in the network are distinctly in opposition to this and are structured into inclusion and exclusion arrays. The network within the calculus of design is a two-fold set of relational distinctions of nodes, points, and edges, lines connecting the dots.

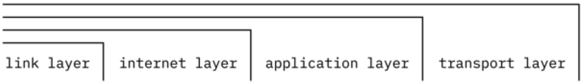




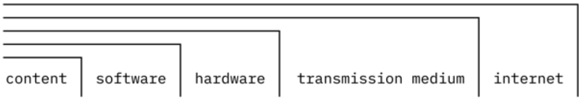
The two diagrams above render versions of the simplest form of a network of two nodes, *a* and *b*, connected by one edge between them. The first diagram renders the nodes as circles and the edge as a line. The second diagram nests the structure as distinctions. While it is undemanding to draw this basic network component, mapping the network and interface layers of the actual global system is challenging, and, depending on the observer, the form is drawn. The *interface space* depends on the observer naming and drawing into sight the network's layered structures. To clarify my point, I will draw various articulations of the internet's constituents in the diagrammatic form of the *calculus of design*. As already discussed in the previous chapter, Jan Distelmeyer distinguishes between four interface terminologies.[30]

30 Ref.: Distelmeyer, J., 2018. Drawing Connections – How Interfaces Matter. F. Hadler, A. Soiné, & D. Irrgang, eds. Interface Critique Journal, Vol. 1, pp.1–11.

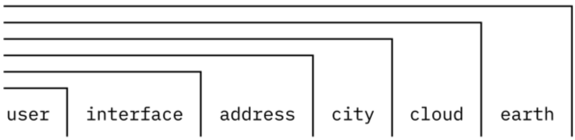
The RFC,[31] on *Requirements for Internet Hosts,* defines four primary communication layers for internet protocols:[32]



While Distelmeyer's interface layers lie next to one another, mutually dependent on one another, the RFC's internet layers are nested within one another. The initiator of the world-wide-web, Tim Berners-Lee, described a slightly different model:[33]



In the 2016 book *The Stack | On Software and Sovereignty*, Benjamin H. Bratton identifies six layers of planetary-scale computation: *Earth*, *Cloud*, *City*, *Address*, *Interface*, *User*.[34] Bratton's stack diverges from the other diagrams of layered spaces in terms of scale.



Professor of Entrepreneurial Legal Studies at Harvard Law School, Yochai Benkler, finds three layers:[35]

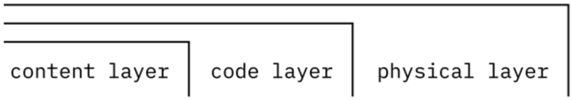
31 RFC stands for *Request for Comment*, a memorandum on internet standards.

32 Ref.: Braden, R., 1989. Requirements for internet hosts--communication layers.

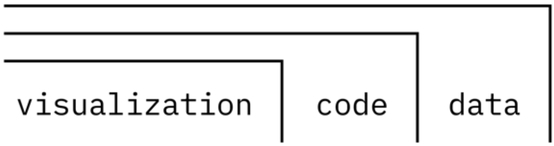
33 Ref.: Berners-Lee, T. & Fischetti, M., 2008. Weaving the Web

34 Ref.: Bratton, B.H., 2016. The Stack, MIT Press.

35 Ref.: Benkler, Y., 2000. From consumers to users: Shifting the deeper structures of



The previous section on visualization spaces stands in contrast to this three-layered system, as data plays a significant role next to the code layer. The three steps can be graphed as:



In the 1980s, artist and computer scientist Frieder Nake outlined a two-layer model, writing:

> *Die Computerdinge existieren doppelt in dem Sinne, daß sie eine uns sinnlich zugängliche und eine uns sinnlich nicht zugängliche Seite aufweisen: Farberscheinung (also Licht) und Speicherinhalt im Falle des Bildes.*
>
> *— Frieder Nake* [36,37]

regulation toward sustainable commons and user access. Federal Communications Law Journal 52.

36 Ref.: Nake, F., 2001. Vilém Flusser und Max Bense des Pixels angesichtig werdend. In Fotografie denken. Eine Überlegung am Rande der Computergrafik. pp. 169–182. Available at: https://archive.compart.uni-bremen.de/2006/agis-website/ARCHIV/Publikationen/FlusserBense.pdf.

37 Translation: *The computer things exist twice in the sense that they have a side accessible to us sensually and a side not accessible to us sensually: Color appearance (i.e. light) and memory content in the case of the image.*

sensory accessible | sensory not accessible

In 2001, Lev Manovich constructed a similar distinction in his book *The Language of New Media*[38] between a *cultural layer* and a *computer layer*:

cultural layer | computer layer

This section aims not to rank or discuss these various conceptions, but to elaborate on the difficulties of defining space. As soon as a form reaches numerous interdependent distinctions, naming and describing the layered spaces becomes a subjective act of drawing distinction itself. *Space, just like distinctions, is not given but created, and the conceptualizations of the nested dependencies matter.*

Space within Media

The set of examples of *empty spaces*, *visualization spaces*, and *code spaces* adapted the mathematical concept of space from the calculus of indication and applied it to various interface design layers. Through these examples, the abstract mathematical concept of *space* turned into a concrete notion within the design calculus, the step-by-step operation from one form to another.

The exemplified space relates to various concepts of media theory and philosophy. The last two chapters on *form* and the *designer* laid out an operational design theory. *This chapter argues that such a design theory cannot be thought of without space. The pre-defined settings within distinctions are drawn.* The *calculus of design* as a drawing of distinctions is inevitably embedded within space, permitting the operation in the first place. Rendering this space visible means observing the layers above the drawn distinctions.

[38] Ref.: Manovich, L., 2001. The Language of New Media, MIT Press.

This subchapter will relate the *calculus of design* to specific media theoretical and philosophical concepts. Two interrelations will be at the center of this investigation—first, theories relating to the elaborated notion of space as a conception within media theory. Second, a set of relations is formed between media and design theoretical discussions relevant to the *calculus of design*. This subchapter aims to introduce several terms that allow for a constructive usage of the *space* terminology, its restrictions and possibilities.

Resolution and Contingency

I am interested in a specific conception articulated by psychologist Fritz Heider within the field of media theory. Niklas Luhman, who applied the calculus of indication towards his systems theory, adopted the notion of the *medium* from Heider, especially from his 1926 essay *Ding und Medium*.[39,40] One of Heider's main quests was to understand how humans perceive without perceiving perception in the first place. Heider illustrates his concepts with specific examples. He starts by discussing the air vibrations, which mediate the ticking of a clock. An observer hears the clock, but the mediation of the air stays unobserved while it constitutes the observation. Heider argues that any *Erkenntnisprozess*[41] is distinct in the observed objects and their constitutional mediations, allowing the observation to take place. Without elaborating on Heider's entire theory, I will adapt various of his conceptions to the relationship with design and *interface spaces*. Concerning design and its German translation *Gestaltung*, Heider writes:

> *Ein genaues Abbilden, Aufzwingen, Aufdrücken einer Gestaltung ist ganz allgemein nur möglich, wenn das Aufgezwungene, oder das, dem etwas aufgezwungen wird, aus vielen voneinander unabhängigen Teilen besteht.*
>
> — *Fritz Heider*[42,43]

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39 Translated into English *Thing and Medium*

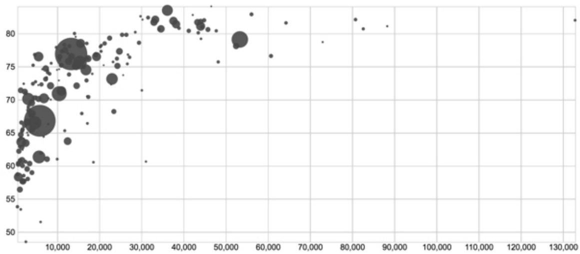
40 Ref.: Heider, F., 2005. Ding und Medium, Kulturverlag Kadmos.

41 German term for the operational process towards insight and knowledge. Commonly, the term is translated as *cognitive process*, but such a translation does not capture the essence of the interrelationship between insight and operation.

42 Ref.: Heider, F., 2005. Ding und Medium, Kulturverlag Kadmos, p. 42

43 Translation: *An exact depiction, imposition, imprinting of a design is generally only possible if*

I want to distance myself from Heider's language of the *forced*; the *pushed* towards design. With deliberation, I am calling the process of design a *drawing of distinctions*. There is nothing *forced* in the step-by-step process from one form to another. It is the *freedom* given within a system to *draw* distinctions. Simultaneously, I am intrigued by the interrelationship I can adapt from Heider to the previously discussed *interface spaces*. Rost's redesign of one scatterplot with various interface tools and libraries exemplifies how the pre-defined settings influence the resulting form. For example, Raw Graphs' web interface allows one per drag and drop to design scatterplots, but only as allowed by the interface's restrictions. The interface does not contain a logarithmic scale, which Gapminder used on the horizontal axis for income per capita. Due to this constraint, Rost's graphic created with the Raw interface has a different appearance than that of the original chart. The interface possibilities pre-define the resulting graph.



RAW by DensityDesign

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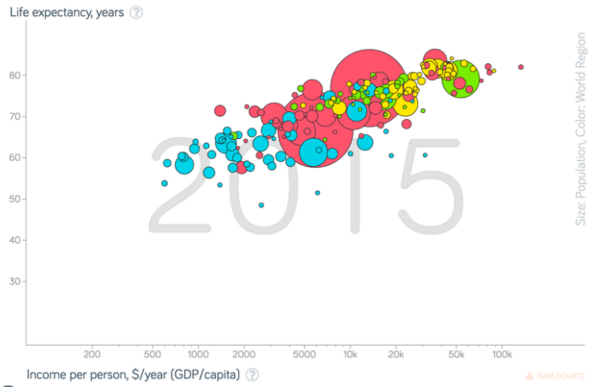
the imposed thing, or the thing on which something is imposed, consists of many independent parts.



Original visualization from the Gapminder tool.

Like air vibrations that allow us to hear the clock's ticking, the interface space of visualization software makes it possible to design and observe visualizations. The observer *overlooks* the interface spaces used in its creation, but they pre-define the result. The various possible interface and computational layers discussed at the end of the section *code spaces* hint at the interlocked complexities of nested spaces. Each layer adds its own drawn, pre-defined distinctions before any act of drawing distinctions on the part of the designer operating within the system. The designer compresses the space's possibilities into form by drawing distinctions within the settings, the *independent parts*.[44] The larger the combinational space the designer operates within, the larger the number of possible forms. *Space restricts the freedom of the form into the possible and the impossible.*

Heider divides the medium into two categories of coupling, loose and fixed. For example, Heider mentions a chain that lies as close to a rounded surface as the individual links allow. A pole on the other side does not hug the surface but only touches the two outermost points. The chapter *designer* exemplified this with the coastline paradox. The shorter the measuring stick used to measure the length of a coastline, the longer its shore. Measuring depends on the mediations used to draw distinctions. In the example of *visualization spaces,* the phenomena of *independent parts*, the coupling of interface and coding spaces, became evident. The larger and more fine-grained the options of Rost's visualization tools and

44 German: *unabhängigen Teilen*

libraries became, the closer the graphic came towards the original graph. Loose and fixed coupling in interface design operate on a scale between possibility and complexity. With its drag-and-drop interface, Raw Graphs can be learned within minutes, while the programming library d3.js takes months or years to develop a comprehensive idea of how to use the system.

Niklas Luhmann adapts this theory and introduces several terms significant for the interplay of form, space, and medium. Two terms are relevant for the calculus of design,[45] *resolution* and *contingency*. Luhmann characterizes media by writing:

> *Medien unterscheiden sich von anderen Materialitäten dadurch, daß sie ein sehr hohes Maß an Auflösung gewärleisten.*
>
> — *Niklas Luhmann*[46,47]

Media, as in means of mass communication such as broadcasting, publishing, and the internet, are defined by their high measures of resolution. *Resolution* in this context means the number of drawable distinctions. While the light switch only contains two possibilities, mass communication allows for vast numbers of configurations. Anything loosely coupled, allowing for variation, can become a space for something else. Design as drawing distinctions is the operation towards a form within the possibile *space of resolution*. The loose coupling of the independent parts mediates a designed form. A single brick block on a concrete floor, due to gravitational constraints, can only be placed on one of its four sides; only four distinctions could be drawn. Thousands of brick blocks can be designed into statues, buildings, or walls. One brick is tightly coupled; many bricks are loosely coupled, as each brick adds resolution. The conglomerate of bricks creates form.

> *Medien bestehen immer aus sehr vielen Elementen, und zwar aus so vielen, daß jede Wahrnehmung und jede operative Kombination selektiv vorgehen muß. Formen dagegen reduzieren Größe auf das, was sie ordnen können.*
>
> — *Niklas Luhmann*[48,49]

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45 Others will follow in later chapters, such as *paradox* in the next chapter and *umwelt* in the final chapter on insight.

46 Ref.: Luhmann, N., 2011. Das Medium der Kunst. In Niklas Luhmann Aufsätze und Reden. Reclam, p. 198

47 Translation: *Media differ from other materialities in that they provide a very high degree of resolution.*

48 Ref.: Luhmann, N., 2011. Das Medium der Kunst. In Niklas Luhmann Aufsätze und

In this process, the medium allowing the form fades into the background as the form emerges. An observer notices statues, buildings, or walls, but not the building blocks constituting the structure in the first place. The notion of resolution relates to data visualization and graphical user interfaces, as the smallest unit is the entity of a pixel. A screen with 1920×1080 pixels, also known as Full HD, contains 2,073,600 points, each a progression of a red, green, and blue (RGB) channel from zero, black, to 255, full brightness. Visualization and graphic interface design is the play of finding novel distinctions within the constraints of the space of the computer screen. The vast combinatorial possibility space of the computer screen, `2,073,600 * 3^3`, acts as a medium to draw distinctions within. Luhmann uses the term *contingency* to discuss the combinatorial possibility of the space as *not necessary and not impossible*:

> *Kontingent ist etwas, was weder notwendig noch unmöglich ist; was also so, wie es ist (war, sein wird), sein kann, aber auch anders möglich ist. Der Begriff bezeichnet mithin Gegebenes (zu Erfahrendes, Erwartetes, Gedachtes, Phantasiertes) im Hinblick auf mögliches Anderssein; er bezeichnet Gegenstände im Horizont möglicher Abwandlungen.*
>
> — *Niklas Luhmann*[50,51]

The entirety of design is based on contingency — *it could also be different*. When it comes to product design and forms of daily usage such as cups, chairs, or window frames, this allows for a vast design space of (sometimes or often unnecessary?) possibilities. But, when it comes to the relationship between *design* and *insight,* the notion *it could also be different* might be frightening, alarming, or at least concerning. Contingency allows for designs to exist in the first place. Simultaneously, it questions the fundamental relationship between the observer, the designer, and the world. Our relationship with the world is one that allows for

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Reden. Reclam, p. 201

49 Translation: *Media always consist of very many elements, in fact of so many that every perception and every operative combination must proceed selectively. Forms, on the other hand, reduce size to what they can order.*

50 Ref.: Luhmann, N., 1987. Soziale Systeme, p. 152.

51 Translation: *Contingent is something that is neither necessary nor impossible; that can be as it is (was, will be), but is also possible in a different way. The term thus designates given things (things to be experienced, expected, thought, fantasized) with regard to possible otherness; it designates objects in the horizon of possible variations.*

contingency; the other is never excluded. Certainty is only reachable within the bounds of contingency; it could always, at any time, also be different.

Before continuing the argument, I want to make my distinction between space and media explicit. The distinction I am drawing is in the first place simple and allows for a greater clarification between various complexities. *Space* is the immediate next layer of distinction above the form. In visualization spaces, the forms are the actual graphics; the spaces are the libraries and tools to design the graphs. *Media* is the conglomerate of all definable and undefinable, subjective and objective spaces above the form, all interconnected and interlocked systems and non-systems that allow the form to exist. *Space* can often be distinguished a comprehensive whole. *Media* is the ever-elusive stack of distinctions above the distinction, a conglomerate of interdependencies.[52] The section *code spaces* tried to hint at the complexities of defining the stack of spaces above forms created on the computer.[53]

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52 Foucault's notion of the *dispositif* as *the said as much as the unsaid* comes to mind:

What I'm trying to pick out with this term is, firstly, a thoroughly heterogeneous ensemble consisting of discourses, institutions, architectural forms, regulatory decisions, laws, administrative measures, scientific statements, philosophical, moral and philanthropic propositions–in short, the said as much as the unsaid. Such are the elements of the apparatus. The apparatus itself is the system of relations that can be established between these elements.

Ref.: Foucault, M., 1980. The Confession of the Flesh C. Gordon, ed. PowerKnowledge Selected Interviews and Other Writings.

53 The notion of space and media discussed in this chapter relate to media ecology theory:

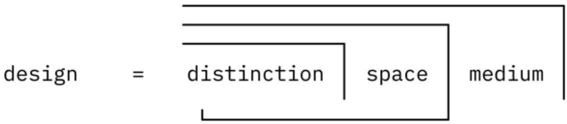
...if in biology a 'medium' is something in which a bacterial culture grows (as in a Petri dish), in media ecology, the medium is a technology within which a culture grows.

Ref.: Postman, N. (2006). Media Ecology Education. Explorations in Media Ecology, 5(1), 5–14. doi:10.1386/eme.5.1.5_1

... embedded in every great technology an epistemological, political or social prejudice. Sometimes that bias is greatly to our advantage. Sometimes it is not. The printing press annihilated the oral tradition; telegraphy annihilated space; television has humiliated the word; the computer, perhaps, will degrade community life.

Ref.: Postman, N., 1998. Five Things We Need to Know About Technological Change. The New Technologies and the Human Person Communicating the Faith in the New Millennium. Available at: https://student.cs.uwaterloo.ca/

Within the diagrammatic notation of form, I will indicate the relationship between *design*, *medium*, *space*, and *distinction* as:[54]



Negativity of Design

> *das gestalterische problem setzt erst da ein, wo die freiheit beginnt, wo die von uns übersehbare funktion nicht mehr oder noch nicht restlos die gestalt bestimmt.*
>
> — *Moholy-Nagy*[55,56]

In the first part of this writing *Conceptions of Design for Insight*, the chapter *raster* introduced Tamara Munzner's *search space metaphor of vis design*.[57] The notion of *space* this chapter discussed affirms Munzner's metaphor. However, the questions regarding the design space are divergent. Munzner, as quoted before, writes:

> *Only a very small number of possibilities are in the set of reasonable choices, and of those only an even smaller fraction are excellent choices. Randomly choosing possibilities is a bad idea because the odds of finding a very good solution are very low.*
>
> — *Tamara Munzner*[58]

Munzner's quest is to find the best solution within the design space. Similarly, Mike Bostock uses the metaphor of a *maze* to explain a similar concept in his talk *Design is a Search Problem*.[59] Both concepts elaborate on the freedom of the

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54 The *re-entry*, the two lines entering the *space* in the *distinction*, have not been discussed; this will occur in the next chapter.

55 Ref.: Moholy-Nagy, L., 1929. von material zu architektur, p. 69

56 Translation: *the design problem only sets in where freedom begins, where the function we can overlook no longer or not yet completely determines the design.*

57 Ref.: Munzner, T., 2014. Visualization Analysis and Design, CRC Press.

58 Ref.: Munzner, T., 2014. Visualization Analysis and Design, CRC Press, p.12

59 Ref.: Bostock, M., 2014. Design is a Search Problem

designer to draw distinctions within the systems they are using and search for the best solutions within the *space*.

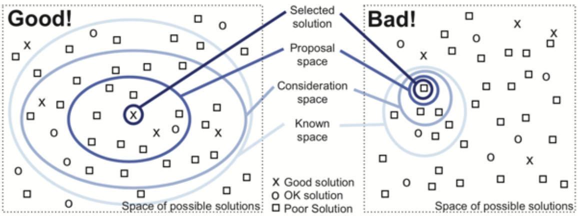

Figure 1.5. A search space metaphor for vis design.

Tamara Munzner's search space metaphor of vis design

I am not investigating what will lead to the best solution, but instead examine and analyze the predefinitions and constituents of space. Each system a designer operates within requires *contingency*. Without the freedom to do something differently, design as drawing distinctions would be obsolete. At the same time, *contingency* restricts freedom. Something that is not an option is impossible. In the figure above, Munzner divides the space into *known space*, *consideration space*, *proposal space*, and *selected solution*. While each distinction is valuable, this chapter is concerned with the dotted rectangle around the points, the *a priori* of space itself. By choosing one of the *empty spaces*, the interface application, the design, is already pre-defined by the *contingency* this interface necessitates.

Only because there is *alterity*, otherness, which becomes obscured through the design operation, design exists in the first place. Without exclusion, without the option to choose otherwise, the term *design* could be neglected.

Design is the act of neglecting possibilities for the sake of the sign.

The prefix *de* is an active word-forming construct as the pure privative *not, do the opposite of, undo*.[60] *The de in design neglects the contingency of the space for the sign.* The *space*, the operative possibilities, is neglected through the design process. In this context, I want to postulate rewriting *design as de—sign*. I am introducing the form of the line into the term *de—sign* to accentuate the negativity of the operation through the intermission drawn together.

---

60 Ref.: Etymology Dictionary, de. etymonline.com. Available at: https://www.etymonline.com/word/de- Accessed October 26, 2020.

de—sign

Within the analyzed *visualization spaces,* Rost reduced the *contingencies* of the libraries and tools, the *spaces*, to the *form* of the scatterplot. Their *alterity* is excluded by drawing distinctions, through the *de—sign* operation. The notion of *space* and *media* in relation to the negativity of *de—sign* correspond to what Dieter Mersch calls *negative media theory*.

> *... Medialität zeigt sich als jene Unbestimmbarkeit, von der immer nur neue Skizzen gemacht werden können und deren Zeichnung und Risse vor allem quer laufenden Performanzen oder Friktionen und Unterbrechungen entspringen, die gleichsam von der Seite kommen und in die Strukturen und ihre Prozesse eingreifen, um dabei laufend neue Wiedersprüche und »Sprünge« zu erfinden.*
>
> — *Dieter Mersch*[61,62]

The operation of *de—sign* neglects all the medium's possibilities except the drawn form. *Space collapses through de—sign; the command to draw a distinction neglects the space for the form's sake.* Space permanently pre-defines the form. The diagrammatic representation of the *calculus of design* accounts for this relationship.

The examples of *empty spaces*, *visualization spaces*, and *code spaces* have revealed that these questions and concerns are not theoretical and abstract, but are rather evident within any design process—the fully defined and absolute restrictiveness of designing with a computer shows that the most comprehensively.

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61 Ref.: Mersch, D., 2006. Medientheorien zur Einführung, Hamburg: Junius, p. 224

62 Translation: *... Mediality reveals itself as that indeterminacy of which only new sketches can ever be made and whose drawing and cracks arise above all from transversely running performances or frictions and interruptions that come, as it were, from the side and intervene in the structures and their processes, thereby constantly inventing new contradictions and "leaps".*

Space Design

The *form* restricted design operations to a three-fold, *call*, *re-call,* and *cross*; this chapter opens design in the opposite direction of nested distinctions, design as *de—sign*, crossing the form into space. *The operation to de—sign is not the creation of signs, but rather their removal, excluding possible sign propositions of space. De—sign is an act of exclusion, where the possibilities of space are reduced to form*. The invention of drawing distinctions is restricted by the allowance of the *interface spaces*. Space is the layer above the form, one level of the mediated stack of interdependencies. Thus, the theoretical considerations of the calculus of design can only be thought of as embedded within media theory. In this regard, Matthias Plume relates perception and medium:

> *Wahrnehmung ist in diesem Sinne Differenzerfahrung, wobei die eine Seite der Unterscheidung – das Medium – im Wahrnehmungsprozess unsichtbar und damit unbezeichnet bleibt.*
>
> — *Matthias Plume*[63,64]

By opening Illustrator, Photoshop, a coding environment, a specific library, or any other tool, the space of operation is set. Or, as Douglas Rushkoff writes:

> *all we see is a world of choice.*
>
> — *Douglas Rushkoff*[65]

The diagrammatic form of the distinction and its notion of space as a distinction above the first drawn distinction allows for reflection on the predefinitions, the already distinct and pre-defining distinctions. Not only can forms be crossed, but the space of operation can be crossed too. The form-space relationship is one of perspective. The designer chooses where to enter the *stack* of form/space relationships. By crossing into space, space turns into a distinction of the form itself, with another space layering above.

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63 Ref.: Plumpe, M., 2014. Systemtheoretische und konstruktivistische Medientheorien. In J. Schröter, ed. Handbuch Medienwissenschaft. p. 128

64 Translation: *Perception in this sense is experience of difference, whereby one side of the distinction - the medium - remains invisible and thus unrecognized in the process of perception.*

65 Ref.: Rushkoff, D., 2010. Program or be Programmed, OR Books, p. 51

While working in *Raw Graphs*, the designer can cross the distinction of this specific interface. The application itself is designed in JavaScript, with the help of the d3.js library.[66] By moving out of the distinction, the spaces of a specific application become visible for the designer. New possibilities and complexities open up. *Design as de—sign acquires a new direction, crossing the pre-defined sets of settings.*[67] *The unmarked space in which design operates to draw distinctions pre-defines the possible operations.* While the form equals the designer, space pre-defines the potential signs. *Space pre-defines design—a*nd with it, the skills of the designer and the knowledge of the designed objects. The *medium* is ever-elusive, as crossing a *space* into a form only moves up one level in the nested, subjective conglomerate of spaces.

The notion of *space* adds another complexity to the *calculus of design*; simultaneously, it allows the design operation to cross into its pre-definitions. Both Dieter Mersch[68] and Niklas Luhmann[69] understand the operation outside the form, questioning the form as the potential of art to act as media paradoxes. Niklas Luhmann distinguishes between art and natural sciences through such a notion:

> *Auf diese Weise hat auch die neuzeitliche Wissenschaft die Natur als Medium des Zugriffs von Theorien entdeckt: als ein Medium, das sich verschiedenen (aber nicht beliebigen) Möglichkeiten der Synthetisierung öffnet. Die Kunst ist, gerade im Blick auf ihre erfolgreiche Schwester, erpicht, es anders zu sehen und zu machen. Das legt nahe (muß aber nicht besagen), daß sie die Technik nun negativ beurteilt — im Unterschied zu einer vermeintlich positiven Beurteilung durch die Wissenschaft.*
>
> *— Niklas Luhmann*[70,71]

---

66 *»RAWGraphs is an open web tool to create custom vector-based visualizations on top of the amazing d3.js library by Mike Bostock. It has been developed by DensityDesign Research Lab (Politecnico di Milano) and Calibro, and sustained through a corporate stewardship by ContactLab.«*

From: https://github.com/rawgraphs/raw

67 Ref.: all data are local

68 Ref.: Mersch, D., 2006. Mediale Paradoxa. Zum Verhältnis von Kunst und Medien. Sic et Non. zeitschrift fur philosophie und kultur, pp.1–18.

69 Ref.: Luhmann, N., 2011. Das Medium der Kunst. In Niklas Luhmann Aufsätze und Reden. Reclam.

70 Ref.: Luhmann, N., 2011. Das Medium der Kunst. In Niklas Luhmann Aufsätze und

71 Translation: *In this way, modern science has also discovered nature as a medium for accessing*

Crossing into space provides design with a theoretical construct to operate towards the outside of the form. This approach opens up design to reflect its constituents.[72] The philosopher, writer, and journalist Vilém Flusser acknowledged such a reflection towards photography by writing:

> *Freiheit ist, gegen den Apparat zu spielen.*
>
> — *Vilém Flusser*[73,74]

Opening design towards the drawing of distinctions within and outside of spaces allows for reflection on the nested embeddedness of design as *de—sign*.

> *de—sign*

The prefix *de* transcodes the neglected operation for the sake of the *sign*. Design as *de—sign* makes the neglect visible. *The de in de—sign neglects the contingency of the space towards the sign.* I am introducing the form of the line into the term *de—sign* to accentuate the negativity of the *de—sign* operation. The — enacts a visual reinterpretation of the operation from *space* to *form*. *The — is the drawing of a distinction within the de—sign operation.*

The *medium* is the ever-elusive; as it needs form to become perceivable, it is always excluded. While we can conceptually map various stacked spaces,[75] media

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Reden. Reclam, p. 207

theories: as a medium that opens itself to various (but not arbitrary) possibilities of synthesization. Art, especially in view of its successful sister, is eager to see and do it differently. This suggests (but does not have to say) that it now judges technology negatively - in contrast to a supposedly positive assessment by science.

72 While working on this theory I had the pleasure and freedom to work as a design researcher at metaLAB (at) Harvard and to expore this direction of design. Various projects emerged from this reflection on space:

Artificial Senses: https://artificial-senses.kimalbrecht.com/

Distinction Machine: https://distinctionmachine.kimalbrecht.com/

The Hairs of your Head are Numbered: http://hairs.kimalbrecht.com/

Watching Machines Loving Grace: https://watching-machines.kimalbrecht.com/

Hypercam: https://hypercam.kimalbrecht.com/

73 Ref.: Flusser, V., 1997. Für eine Philosophie der Fotografie, European Photography, p. 73

74 Translation: *Freedom is to play against the apparatus.*

75 As done in the section *code spaces*.

ecologies, they only exist as forms, as conceptual renderings of the mediations. This is the first paradox of space/form relationships. The next chapter will investigate *time* within *space* and corroborate the notion of the paradox.

Time

The ticking clock moves in circles, adding up seconds into minutes and minutes into hours. The clock's circular arrangement is a visualization of data representing the earth's rotation around its axis. Our understanding of time, seconds, minutes, hours, days, weeks, months, years, decades, centuries, etc., is based on circularity, loops, re-entries of distinction, and identity. Time in these conceptions all unfolds through space.

The chapter *form* defined calculus as *a procedure by which, as a consequence of steps, one form is changed for another*.[1] The *calculus of design* is, in its conception, a time-based process. This chapter investigates a specific phenomenon of time. Time emerges from the looping, re-entering, re-observing, and re-designing of form. Distinctions become recursive through time, not fixed in their conception.

This perspective allows an extension of the theory of *de—sign* with the computer and an extension to questions such as *How does the computer influence the design process?* Or, in other words, *What does it mean to design involving computation?* This chapter extends the principle of the distinction based on circularity, the *re-entry* of a form into itself.

1 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. 9

Mathematics

From a mathematical perspective, the calculus of indication, discussed in the chapter *form*, from which I am evolving the *calculus of design*, has not introduced much novelty as a mathematical theory. The cross, consisting of distinction and indication, its axioms, and theorems, can also be expressed in boolean algebra or other set theories. Even the notion that the distinction only consists of one symbol, and not two like in boolean algebra, is not new. Charles Sanders Peirce already introduced a pre-binary notation system in 1880.[2,3]

The final two chapters, eleven and twelve, of the *Laws of Form* introduce the *re-entry*, adding two lines to the symbol of the cross. This symbol allows the expression of certain infinite mathematical expressions within the finite sign of the *re-entry*.

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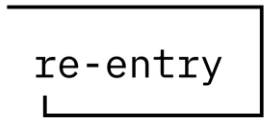
2 Ref.: Peirce, C.S., 1933. A Boolean Algebra with One Constant. In C. Hartshorne & P. Weiss, eds. Collected Papers of Charles Sanders Peirce, Volume The Simplest Mathematics.

3 Within the article *The Mathematics of Charles Sanders Peirce*, mathematician Louis H. Kauffman compares and discusses both Peirce and Spencer-Brown's one valued calculuses.

Ref.: Kauffman, L.H., 2001. The Mathematics of Charles Sanders Peirce. Cybernetics and Human Knowing, 8, pp.79–110.



To understand the meaning and significance of the *re-entry,* it is necessary to understand the limits and problems of logical and metamathematical theories at the beginning of the 20th century.

Limits of Logic

> *Anyone who denies the law of non-contradiction should be beaten and burned until he admits that to be beaten is not the same as not to be beaten, and to be burned is not the same as not to be burned.*
>
> — *Avicenna*[4]

The early 20th century introduced a crisis of mathematics in the search for its foundations.[5,6] At the center of this crisis are self-contradictory entities called paradoxes. An ancient and straightforward linguistic example of this is the liar paradox:

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4 Ref.: Priest, G., 2014. Beyond true and false E. Lake, ed. aeon.co. Available at: https://aeon.co/essays/the-logic-of-buddhist-philosophy-goes-beyond-simple-truth Accessed December 2, 2020.

5 Ref.: Benacerraf, P. & Putnam, H., 1984. Philosophy of Mathematics, Cambridge University Press.

6 Ref.: Hacking, I., 2014. Why Is There Philosophy of Mathematics At All? Cambridge University Press.

This statement is false.

— Eubulides

The liar paradox is self-referential, as the statement discusses its own constitution. If the statement is true, it states about itself that it is false. If one anticipates that the statement is false, the sentence's conception becomes true. The result is an oscillation between true and false, a self-referential structure. A mathematical example of this paradox is the formula `x = –1 / x`. If `x = +1,` the equation results in `+1 = –1 / +1 = –1`. If `x = –1,` the variable turns positive `–1 = –1 / –1 = +1`. The result of the self-referential x results in an oscillation of `–1 = +1`.

There is an entire range of paradoxes found throughout the history of mathematics. A well-known one is *Russell's Paradox,* articulated in 1901 by Bertrand Russell.[7,8] The problem Russell encountered can be stated as the following question: *Is the set of all the sets that are not members of themselves a member of itself? If it is not a member of itself, then it is. But if it is not, then it is.*[9] Formulated even more simply: *There is no set of all sets,* as it is a set itself, which would need to contain itself. Again, the problem is one of self-reference, in- and exclusion of distinctions. *Mathematical paradoxes lead to situations in which the result cannot be described as either true or false but only self-referential.* The result leads to another outcome of the equation. In collaboration with Alfred North Whitehead, Russell worked on a foundational mathematical theory that disallowed paradoxical statements. This effort led to the publication of *Principia Mathematica* in the years 1910 – 1913. The book is a fortress against the allowance of paradoxes in mathematics. Its base is so complex that it takes 362 pages to introduce the proof `1 + 1 = 2`.[10]

7 Ref.: Russell, B., 1980. Correspondence with Frege. In Gottlob Frege: Philosophical and Mathematical Correspondence. University of Chicago Press.

8 Ref.: Russell, B., 1996. The Principles of Mathematics, New York: W. W. Norton & Company.

9 Ref.: Hofstadter, D.R., 2007. I Am a Strange Loop, Hachette UK.

10 In the first edition. 362 pages in the 2nd edition and 360 in the abridged version.

362 PROLEGOMENA TO CARDINAL ARITHMETIC [PART II

***54·42.** $\vdash :: \alpha \in 2 . \supset :. \beta \subset \alpha . \exists ! \beta . \beta \neq \alpha . \equiv . \beta \in \iota``\alpha$

Dem.

$\vdash . *54{\cdot}4 . \quad \supset \vdash :: \alpha = \iota\text{‘}x \cup \iota\text{‘}y . \supset :.$

$\beta \subset \alpha . \exists ! \beta . \equiv : \beta = \Lambda . \vee . \beta = \iota\text{‘}x . \vee . \beta = \iota\text{‘}y . \vee . \beta = \alpha : \exists ! \beta :$

[*24·53·56.*51·161] $\equiv : \beta = \iota\text{‘}x . \vee . \beta = \iota\text{‘}y . \vee . \beta = \alpha$ (1)

$\vdash . *54{\cdot}25 . \text{Transp} . *52{\cdot}22 . \supset \vdash : x \neq y . \supset . \iota\text{‘}x \cup \iota\text{‘}y \neq \iota\text{‘}x . \iota\text{‘}x \cup \iota\text{‘}y \neq \iota\text{‘}y :$

[*13·12] $\supset \vdash : \alpha = \iota\text{‘}x \cup \iota\text{‘}y . x \neq y . \supset . \alpha \neq \iota\text{‘}x . \alpha \neq \iota\text{‘}y$ (2)

$\vdash . (1) . (2) . \supset \vdash :: \alpha = \iota\text{‘}x \cup \iota\text{‘}y . x \neq y . \supset :.$

$\beta \subset \alpha . \exists ! \beta . \beta \neq \alpha . \equiv : \beta = \iota\text{‘}x . \vee . \beta = \iota\text{‘}y :$

[*51·235] $\equiv : (\exists z) . z \in \alpha . \beta = \iota\text{‘}z :$

[*37·6] $\equiv : \beta \in \iota``\alpha$ (3)

$\vdash . (3) . *11{\cdot}11{\cdot}35 . *54{\cdot}101 . \supset \vdash . \text{Prop}$

***54·43.** $\vdash :. \alpha, \beta \in 1 . \supset : \alpha \cap \beta = \Lambda . \equiv . \alpha \cup \beta \in 2$

Dem.

$\vdash . *54{\cdot}26 . \supset \vdash :. \alpha = \iota\text{‘}x . \beta = \iota\text{‘}y . \supset : \alpha \cup \beta \in 2 . \equiv . x \neq y .$

[*51·231] $\equiv . \iota\text{‘}x \cap \iota\text{‘}y = \Lambda .$

[*13·12] $\equiv . \alpha \cap \beta = \Lambda$ (1)

$\vdash . (1) . *11{\cdot}11{\cdot}35 . \supset$

$\vdash :. (\exists x, y) . \alpha = \iota\text{‘}x . \beta = \iota\text{‘}y . \supset : \alpha \cup \beta \in 2 . \equiv . \alpha \cap \beta = \Lambda$ (2)

$\vdash . (2) . *11{\cdot}54 . *52{\cdot}1 . \supset \vdash . \text{Prop}$

From this proposition it will follow, when arithmetical addition has been defined, that $1 + 1 = 2$.

***54·44.** $\vdash :. z, w \in \iota\text{‘}x \cup \iota\text{‘}y . \supset_{z,w} . \phi(z, w) : \equiv . \phi(x, x) . \phi(x, y) . \phi(y, x) . \phi(y, y)$

Dem.

$\vdash . *51{\cdot}234 . *11{\cdot}62 . \supset \vdash :. z, w \in \iota\text{‘}x \cup \iota\text{‘}y . \supset_{z,w} . \phi(z, w) : \equiv :$

$z \in \iota\text{‘}x \cup \iota\text{‘}y . \supset_z . \phi(z, x) . \phi(z, y) :$

[*51·234.*10·29] $\equiv : \phi(x, x) . \phi(x, y) . \phi(y, x) . \phi(y, y) :. \supset \vdash . \text{Prop}$

***54·441.** $\vdash :: z, w \in \iota\text{‘}x \cup \iota\text{‘}y . z \neq w . \supset_{z,w} . \phi(z, w) : \equiv :. x = y : \vee : \phi(x, y) . \phi(y, x)$

Dem.

$\vdash . *5{\cdot}6 . \supset \vdash :: z, w \in \iota\text{‘}x \cup \iota\text{‘}y . z \neq w . \supset_{z,w} . \phi(z, w) : \equiv :.$

$z, w \in \iota\text{‘}x \cup \iota\text{‘}y . \supset_{z,w} : z = w . \vee . \phi(z, w) :.$

[*54·44] $\equiv : x = x . \vee . \phi(x, x) : x = y . \vee . \phi(x, y) :$

$y = x . \vee . \phi(y, x) : y = y . \vee . \phi(y, y) :$

[*13·15] $\equiv : x = y . \vee . \phi(x, y) : y = x . \vee . \phi(y, x) :$

[*13·16.*4·41] $\equiv : x = y . \vee . \phi(x, y) . \phi(y, x)$

This proposition is used in *163·42, in the theory of relations of mutually exclusive relations.

***54·442.** $\vdash :: x \neq y . \supset :. z, w \in \iota\text{‘}x \cup \iota\text{‘}y . z \neq w . \supset_{z,w} . \phi(z, w) : \equiv . \phi(x, y) . \phi(y, x)$ [*54·441]

Page 362 of Principia Mathematica.

Russell and Whitehead designed a strict linguistic hierarchy to exclude any self-references within the logic of *Principia Mathematica*, the ramified theory of types. References are only allowed on different nested layers within the system, not within the same level. Ludwig Wittgenstein, as well as Kurt Gödel, pointed out various problems and inconsistencies of the theory.[11]

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11 Ref.: Gödel, K., 1929. Über die Vollständigkeit des Logikkalküls. University of Vienna.

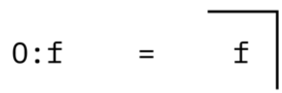
Russell's and Whitehead's fortress against self-references was not as stable as hoped.[12] I will not go into detail here on the problems of the foundations of mathematics. The intriguing point here is that George Spencer-Brown reversed these problems and turned them into his theory's assets.

Re-Entry

> *The nature of things is to have no nature; it is their non-nature that is their nature. For they have only one nature: no-nature.*
>
> *— Nagarjuna*[13]

The two final chapters of Spencer-Brown's *Laws of Form* articulate an alternative path for mathematics by allowing self-referential statements and embracing them by designating a symbol for self-referentiality, the *re-entry* into a form.

What is at stake here is nothing less than the infiltration of a distinction through self-referentiality. A mathematical theory in which a difference can re-enter itself leads to memory functions, tautologies, oscillation, and paradoxes. The concept of re-entry states that a distinction can self-reference what is distinguished.[14]



Oscillator Function (Spencer-Brown, 1969)

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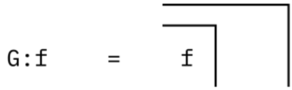
12 This chapter is not about the history of mathematics. For a longer argument of the mathematical problems of self-referenciality, I recomend Douglas Hofstadter's book *I am a strange loop*.

Ref.: Hofstadter, D.R., 2007. I Am a Strange Loop, Hachette UK.

13 Ref.: Priest, G., 2014. Beyond true and false. aeon.co. Available at: https://aeon.co/essays/the-logic-of-buddhist-philosophy-goes-beyond-simple-truth Accessed March 2, 2021.

14 Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag, p. 87-88

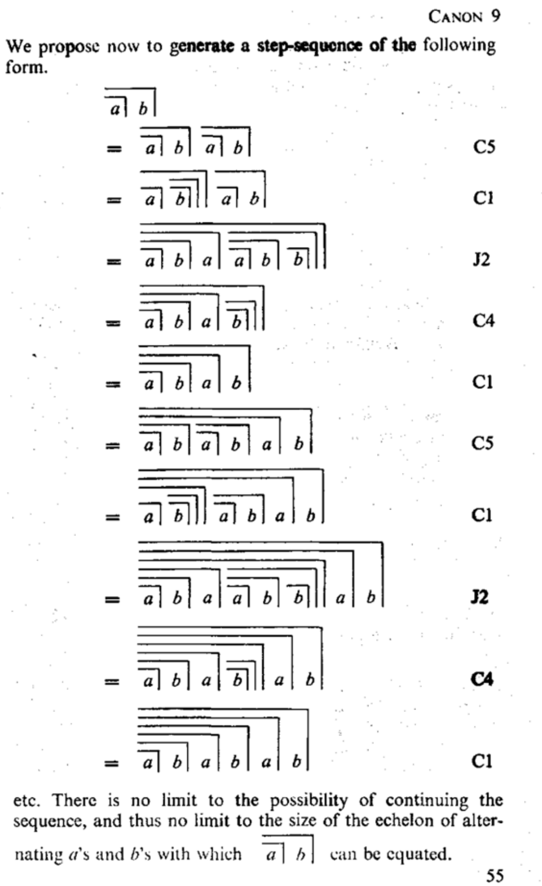


Memory Function (Spencer-Brown, 1969)

Space and Time

In Chapter 11, *Equations of the second degree,* Spencer-Brown generates a step-sequence of the form using the algebraic initials[15] and three of the nine resulting consequences:

[15] Discussed in the chapter *Form*.


CANON 9

We propose now to generate a step-sequence of the following form.

C5
C1
J2
C4
C1
C5
C1
J2
C4
C1

etc. There is no limit to the possibility of continuing the sequence, and thus no limit to the size of the echelon of alternating *a*'s and *b*'s with which can be equated.

55

Through ten operations, the distinction a|b turns into a|b|a|b|a|b. For Spencer-Brown, there *is no limit to the possibility of continuing the sequence, and thus no limit to the size of the set of alternating a's and b's*.[16] As the form of a|b and a|b|a|

16 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. 55

b | a | b is identical at every depth, Spencer-Brown regards the operation as a *re-entry* of the form into itself, a continuous loop between two distinctions.

For Spencer-Brown, the *re-entry* of one or more distinctions into itself is how *time* emerges in *space*. In the mathematical theory of *the calculus of indication*, time is the act of a form copying itself into itself, the operative re-entry. The oscillation between states allows, as Heinz von Foerster remarks,[17] not a collision between true and false but a square wave between the two conditions. The space of the statement *this statement is false* supposedly holds two possible outcomes, true and false. If it is true, it must be false. If it is false, it must be true. The complexity the re-entry introduces is that imaginary states oscillate between two values over *time*. Rather than forbidding self-referentiality, the calculus of indication embraces it by introducing time as the oscillating variable.[18] Thus, Spencer-Brown concludes that self-referentiality enables the expression of infinite statements within a finite form.

I am interpreting the *re-entry* as an interplay of identity and difference. The notion of time is based on change. *Time is the observation of the change of a distinction within identity.* By not drawing a new distinction of a flying bird or a driving cyclist, that is by keeping its identity, the movement's change creates time. While everything is in flow, identity generates time by fixing distinctions. This notion of time does not contain an idea of speed. Speed would need the recognition of units to be measurable.

Identity is a distinction, a cell within a spreadsheet, a circle within a visualization, which could be distinguishable; still, it is set as a distinction even when it is in *constant flux*. A country can be divided into its citizens, square meters, or cities and countryside. A country is an ever-evolving distinction, its identity ever elusive, but by calling it, by collapsing its complexity into one term, it becomes operational. Cultural identity, gender identity, national identity, and online identity are all operations of forming an identity, drawing a distinction, collapsing complexity, marking, and in so doing leaving everything else unmarked.

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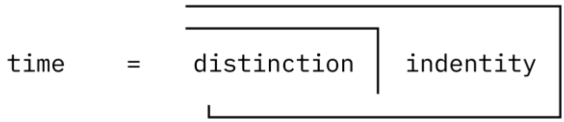
17 Ref.: Brand, S. ed., 1969, Spring. Whole Earth Catalog, p. 14

18 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. xiv



The introduction of time in space leads Spencer-Brown towards a renegotiation of logic and mathematics. The Laws of Form allow two possibilities to be valid as an oscillation of time between true and false, a complex statement. From this reasoning, Spencer-Brown identifies a specific relationship between mathematics and logic:

> *Logic, in other words, is itself not mathematics, it is an interpretation of a particular branch of mathematics, which is the most important non-numerical branch of mathematics. There are other non-numerical branches of mathematics. Mathematics is not exclusively about number. Mathematics is, in fact, about space and relationships. A number comes into mathematics only as a measure of space and/or relationships.*
>
> *— George Spencer-Brown*[19]

Spencer-Brown determines the relation between logic and mathematics not as two separate disciplines, two connected entities, but as a nested set of entities, considering logic to be one particular branch of mathematics. The notion of time as a recursive distinction onto a distinction becomes the path for mathematics to operate outside of logic.

Imaginary Numbers

> *... quelquefois seulement imaginaires c'est-à-dire que l'on peut toujours en imaginer autant que j'ai dit en chaque équation, mais qu'il n'y a quelquefois aucune quantité qui corresponde à celle qu'on imagine.*
>
> *— René Descartes* [20,21] [22]

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19 Ref.: Spencer-Brown, G., 1973. AUM Conference Transcript Session One. AUM Conference. Available: https://web.archive.org/web/20060821204917/http://lawsofform.org/aum/session1.html

20 Ref.: Descartes, R., La Géométrie, 1637.

21 *... sometimes only imaginary, that is one can imagine as many as I said in each equation, but*

The separation Spencer-Brown performs of mathematics from logic is for him a renegotiation of boolean algebra:

> *What we do in Chapter 11 is extend the concept of Boolean algebras, which means that a valid argument may contain not just three classes of statements, but four: true, false, meaningless, and imaginary.*
>
> — *George Spencer-Brown*[23]

Boolean algebra consists of two truth values: `true` and `false` or conjunction and disjunction. Rather than calling any argument not resulting in `true` or `false` meaningless, Spencer-Brown extends the concept from three to four states.[24] To understand what he means by *imaginary,* it is necessary to understand various types of numbers. *Natural Numbers* are positive integers (1, 2, 3, 4, 5, ...). *Whole Numbers* also include zero. *Integers* extend the number line into the negative numbers (-3, - 2, -1). *Rational numbers* additionally include fractions of integers (1/2, 3/4, 1/12). *Real numbers* extend these conceptions by any value expressed as a decimal (0.2, 5.37319, -23.54914). Each of these notions of numbers appeared and evolved throughout history. While the Egyptian numerals already contained zero in 1770 BC,[25] its transmission to Europe was only 2900 years later by the Italian mathematician Fibonacci in 1202.[26] Spencer-Brown's notion of the *re-entry* symbolizes numbers that re-enter themselves and thus operate outside of the framework of previous number lines. The re-entry allows for form calculations outside of arithmetic or algebra as a theory of *imaginary numbers*.[27] Negative self-references, such as `x = -1/x`, are not excluded from the system but allowed as re-entries over time as `+1 = -1/+1 = -1` and `-1 = -1/-1 =`

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sometimes there exists no quantity that matches that which we imagine.

22 Ref.: Descartes, R., 1954. The Geometry of René Descartes, Courier Corporation.

23 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. xi

24 Buddism contains the logical argument of *catuskoti*, meaning 'four corners.' Within this logic, there are also four possible states regarding any statement: true, false, both true and false, or neither true nor false.

Ref.: Jayatilleke, K.N., 1967. The Logic of Four Alternatives. Philosophy East and West, 17, pp.69–83.

25 Ref.: Joseph, G.G., 2011. The Crest of the Peacock, Princeton University Press.

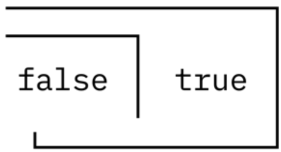
26 Ref.: Grimm, R.E., 1973. The Autobiography of Leonardo Pisano. Fibonacci Quarterly, pp.99–104.

27 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57. Loc. 297-299

`+1`. The symbol of the sign = no longer represents equality. As Spencer-Brown notes,

> *= may stand for the words ›is confused with‹*
>
> — *Spencer-Brown*[28]

Time allows for operations outside of equality and resolves paradoxical relations, such as `-1 = +1,` as functions of time. A distinction that re-enters itself can lead to the paradox that the difference is not the same as the distinguished.[29] *The conception of time, one distinction after the other, dissolves the simultaneity of paradoxical relationships.*[30] This notion of time is thus far without measure. It is an oscillation, a back and forth, a flip-flop, between values of conditions.[31]



Observer

While Chapter 11 of the Laws of Form introduces the re-entry as a self-referential system into distinctions, Spencer-Brown re-enters the observer's distinction in itself at the end of Chapter 12. The last sentence of the final chapter of the Laws of Form is:

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28 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. 69

29 Ref.: Luhmann, N., 2006. System as Difference. Organization, 13(1), pp.37–57. Loc. 442-443

30 Hermann Minkowski applied time as a factor in Einstein's special relativity as an imaginary value. As noted by Felix Lau

Ref.: Lau, F., 2015. Die Form der Paradoxie, Carl-Auer Verlag, p. 93

31 Ref.: Baecker, D., 2002. Wozu Systeme? Berlin: Kulturverlag Kadmos, p. 77

> *We see now that the first distinction, the mark, and the observer are not only interchangeable, but, in the form, identical.*
>
> — *Spencer-Brown*[32]

The chapter is almost entirely diagrammatical, consisting of circles and their relationships. What Spencer-Brown articulates is that the origins of the two axioms of the calculus are self-referential to the observer following the command to *draw a distinction*. Spencer-Brown uses the *re-entry* to self-reference the given idea of distinction and indication. The untestable self-evidently true statements, axioms, which precede the operation, re-enter themselves. For a distinction to occur, the observer must already be present. The observer re-enters the form by drawing a distinction within itself. Or, as Spencer-Brown expresses it:

> *We must also indicate where the observer is supposed to be standing in relation to the expression.*
>
> — *Spencer-Brown*[33]

The first distinction is already a re-entry of the observer into the observation. Observation is a two-fold act: *first, or explicit, reference is to the value of a side, according to how it is marked* and *second, or implicit, reference is to an outside observer. That is to say, the outside is the side from which a distinction is supposed to be seen.*[34]

The first and already drawn distinction is the observer, commanded to *draw a distinction*. The fundamental difference is the distinction between observer and observed. The observer emerges from an observation. An entry, the first command to *draw a distinction*, is already a *re-entry* of the observer into the observed.

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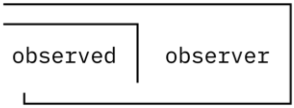
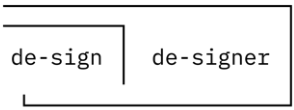
32 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. 76

33 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. 103

34 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. 69



In my theory of the *calculus of design,* there is no distinction without a de—signer drawing the distinction. The act of de—sign renders the distinction visible. De—sign is only drawn into existence by a de—signator. *Thus, the negative act of drawing a distinction, choosing something over all other possibilities of space, separates the de—sign from the de—signer.* The first distinction is a *re-entry* of the distinction between de—sign and de—signer.



The declaration of the distinction, indication, and its two axioms re-enter and self-affirm their constitution. Introducing the re-entry to the *calculus of indication* is an insult to logic theories, which exclude paradoxical statements at all costs. The re-entry suggests that theories inevitably constitute themselves at the expense of a paradoxical origin. By drawing a distinction, marked and unmarked separate, but only one side is observed. The observer positions her, him or itself by this act. The observer re-enters through the observation.[35,36]

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35 Niklas Luhmann applied the concept of re-entry to describe social systems. His application might help us understand this theoretical construction. For example, in Luhmann's theory, the scientific system differentiates itself based on true and false. By developing a theory of science, the distinctions between true and false are applied to the system of science itself. Scientists who observe science are performing a *re-entry* into their system. The distinction is applied to itself. But, by doing so, the distinction is simultaneously identical (scientific system) and distinct (new theory). Identity and difference are copied into one another; observing distinctions changes the distinction but upholds the identity. The addition of time as the *re-entry* of a distinction into itself permits one to overcome the paradox inhabiting such concepts.

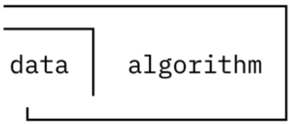
36 Ref.: Luhmann, N., 1992. Die Wissenschaft der Gesellschaft, Suhrkamp.

Computation

The question that might emerge is: Why are these metamathematical discussions around the inclusion and exclusion of paradoxes relevant to a theory of design? My answer in one word: computation.

To render how the concept of *re-entry* relates to computational design, I will exemplify this on four scales of computational reflexivity: data | algorithm, data | visualization, computer | human, and world | design.

Data and Algorithm



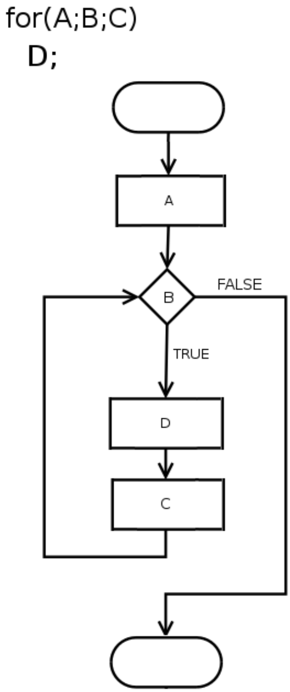
One of the most fundamental computational concepts is the loop, such as *do while loop*, *while loop*, *for loop*, *for each loop*, or *infinite loop*. In the first chapter of this section, the introduction *An extended quest to design a bar chart,* I exemplified the *loop* in visualization design as the data iterated through a symbol. The algorithm iterates through each data row to draw rectangles at different horizontal positions and distinct heights, drawing the data values into visual form. *The loop is a re-iteration of a chain of commands until a particular condition is served. The loop is profoundly temporal, a control flow statement, iterating a set of commands through time.* These *control flow statements* all contain similarities to Spencer-Brown's *re-entry*. In JavaScript, a *for loop* can be written as:[37]

```
for (var i = 0; i < 5; i++) {
    // ...
}
```

Similar to `C++`, three expressions are contained within the loop.

[37] There are several variations, but none of them contradict the argument.

1.Variable: `i = 0`
2.A while statement: As long as `i` is smaller than five
3.Addition: Add 1 to `i`, `i++` is short for `i = i + 1`



For Loop Diagram Ref.: Zdziarski, P., 2006. For loop flow diagram, wikipedia.org. Available at: https://en.wikipedia.org/wiki/For_loop#/media/File:For-loop-diagram.png.

Without a time-based operational process, computation is impossible. Computation needs operation. Only time allows for the software/hardware interplay of the machine. In the essay *On Software, or the Persistence of Visual Knowledge,* Wendy Chun asks what *Microsoft Word* is. Is it the source code, the software on a hard drive, or its execution?[38] My answer is that only the execution,

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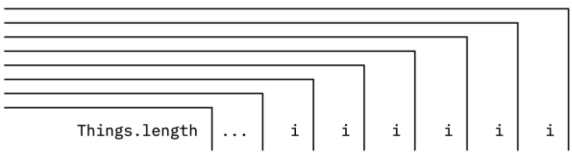
38 REF: Chun, W.H.K., 2005. On Software, or the Persistence of Visual Knowledge. Grey Room, (18), pp.26–51.

the operational looping functions, and its screen-based interactive representation of sheets and buttons allow *Word* to be usable. Without *execution*, without *time*, without *operation,* computation is impossible; this is why *time* is so immensely important for understanding de—sign as an operative process.

A fundamental principle of programming is change, the iteration of numbers over time. *In computer science, the statement* `i = i + 1` *is not a contradiction but an essential feature of calculation.* Programming languages operate in time; statements do not consist of fixed entities but of operational calculi, which are only logical because space[39] is iterated through time. These machines do not function outside of logic, but include a logic that would be impossible without time. Thus, the equals sign in computation is used as an operative sign, representing *is confused with*. The equals sign in computer loops does not mean equality, in the sense that one side equals the other, but as assignment statements. One side sets and/or re-sets the stored value in the storage location of the variable. The computer language ALGOL 1958, later popularized by Pascal, used the sign **:**= instead of = for *assignment statements*. I notate the computer loop within the diagrammatic notation of the form as:



Or its short form:

In this notation, distinctions are not fixed but can change, reverse, and alter over time. Our encounter with computation is at its core outside of timeless set-

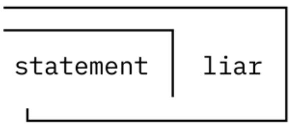
39 The notion of *space* is the *contingency* discussed in the previous chapter and should not be confused with more general statements on *space*.

theoretical concepts, but *iterating space through time*. *The sign i in a computer loop is not a placeholder for an arbitrary number as in mathematics, but is a storage location that changes during the program's operation.* The double connotation of *i* is that it stands for the value and at the same time for the storage location.[40]

Switching a boolean variable *in time*, throughout the operation, from `true` to `false` is something omnipresent in the daily usage of the computer that it feels close to banal to discuss. I can write Eubulide's Liar Paradox *this statement is false* in JavaScript as a looping `if-else` statement:

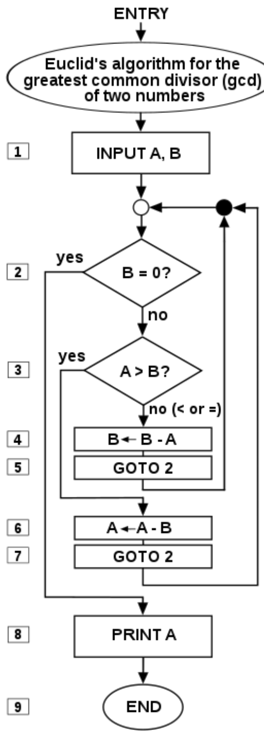
```
function liar(statement) {
    if (statement) {
        liar(false);
    } else {
        liar(true);
    }
}

liar(true);
```

The above function does not contain an end, as `liar` calls itself. The function enters itself, iterating the boolean data `statement` as `true` or `false`. I will notate the liar paradox within the diagrammatic notation of the form as:



The paradox of recursivity leads in computation, similar to the calculus of indication, to an oscillation between data values. In this case, the two boolean values `true` and `false`.

[40] Ref.: Tydecks, W., 2019. A commentary on the Laws of Form from Spencer-Brown, tydecks.info. Available at: http://www.tydecks.info/online/themen_e_spencer_brown_logik.html Accessed December 2, 2020.



Visualization of Euclid's algorithm for calculating the greatest common divisor. Two nested feedback loops interact with one another until B = 0.[41]

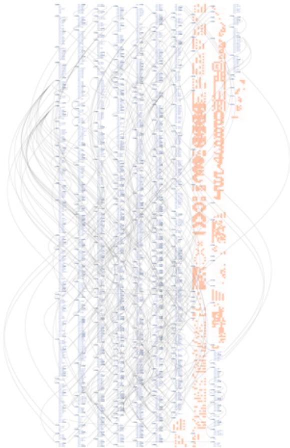
Datasets and databases are structured systems of nested distinctions. They are storage units of differentiation. Recursive, algorithmic loops make data operational. *Computation is an existential, performative, time-based operation.* The algorithm *re-enters* the distinct data for the purpose of representation, transformation, modeling, or prediction. The distinction between data and algorithms as the set and the settings defines the concept of computation. Algorithms *re-enter* data, datasets, or databases to operate with them. Yet, while there are conceptual similarities between algorithmic operations and the re-

41 Source: Euclid's algorithm Inelegant program, https://commons.wikimedia.org/wiki/File:Euclid's_algorithm_Inelegant_program_1

entry, there are also divergences between them. British logician and computer scientist Robert Kowalski defined an algorithm using the simple formula:

> *Algorithm = logic + control*
>
> *— Robert Kowalski* [42]

The calculus of indication questions the foundation of logic and claims that statements can be classified as either *true, false, meaningless, or imaginary*. The algorithm on the other side for Robert Kowalski equals logic plus control, and not just for Kowalski. Behind computer systems lies a narrative of control through self-referentiality, namely cybernetics.



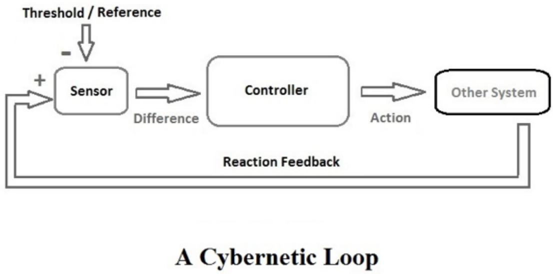
Visualization by Ben Fry on top of the computer code for the video game Pac Man. The lines represent the self-referential structures of the code. [43]

[42] Ref.: Kowalski, R., 1979. Algorithm = logic + control. Communications of the ACM, 22(7), pp.424–436.

[43] Ref.: Fry, B., distellamap. benfry.com. Available at: http://benfry.com/distellamap/ Accessed May 30, 2018.

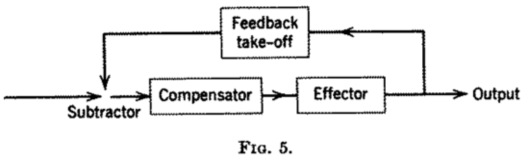
Cybernetics

> *It is the purpose of Cybernetics to develop a language and techniques that will enable us indeed to attack the problem of control and communication in general, but also to find the proper repertory of ideas and techniques to classify their particular manifestations under certain concepts.*
>
> *— Norbert Wiener*[44]



A Cybernetic Loop [45]

The first description of *cybernetics* originates from Norbert Wiener, who defined it *as the scientific study of control and communication in the animal and the machine* in 1948. The basis of cybernetics is a circular, causal relationship within a system.



Cybernetics Or Control and Communication in the Animal and the Machine [46]

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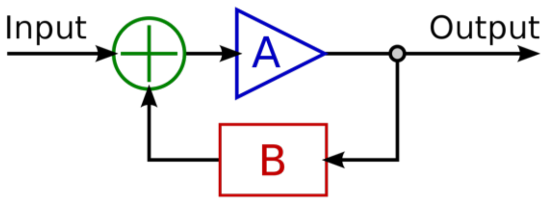
44 Ref.: Wiener, N., 1988. The Human Use Of Human Beings, Hachette UK.

45 Ref.: Ref.: Baango, 2015. A Cybernetic Loop, wikipedia.org. Available at: https://en.wikipedia.org/wiki/Cybernetics#/media/File:Cybernetics.jpg.

46 Ref.: Wiener, N., 1948. Cybernetics Or Control and Communication in the Animal and the Machine, MIT Press, p. 112

The theoretical concept of cybernetics began with the notion of feedback. The latter can be described as, the process from input to output, which changes itself according to the newly received data throughout time.[47] The origins of the term *cybernetics* stem from the greek *kybernḗtēs*, the steersman.[48] Timothy Leary named the *cyberpunk* the *individual as reality pilot*.[49] Governing and control lie at the forefront of the theory. The steersman governs the feedback. The cybernetician does not operate outside of control, but within. The system stays within its bounds, defined by nodes and links, circles, and arrows, which refer to one another. *In logic, self-reference can lead to paradoxes; in cybernetics, the steersman controls feedback.* While feedback and self-referentiality are similar in conception, mathematical problems and cybernetic foundations search for control with vastly alternating constitutions. In mathematics, the *re-entry* can spiral out of the boundary of the excluded middle, leading to paradoxes that mathematics tries to avoid at all costs. In contrast, cybernetics places *feedback* at the center of its theory *to attack the problem of control*.[50] On the one hand, self-referentiality leads to paradoxes in logic. On the other hand, order emerges out of feedback in the automated mathematical self-control of cybernetics.[51] *While computation is based on the foundation of mathematics, its execution spirals out of non-paradoxical, timeless conceptions.*



Simple feedback model [52]

[47] Ref.: Galloway, A.R., 2006. Protocol, MIT Press, p. 59

[48] Ref.: Etymology Dictionary, 2018. cybernetics (n.). etymonline.com. Available at: https://www.etymonline.com/word/cybernetics Accessed December 2, 2020.

[49] Ref.: Leary, T., 1991. The Cyberpunk: the individual as reality pilot. In Storming the Reality Studio. Duke University Press.

[50] Ref.: Wiener, N., 1988. The Human Use Of Human Beings, Hachette UK.

[51] Ref.: Mersch, D., 2013. Ordo ab chao - Order from Noise, p6

At this point, the question I have is the following: *How is it possible that the basic principle of feedback in cybernetics is associated with control, while in mathematics self-referentiality created vast problems not even thirty years earlier?* Mathematics defines the basis of computation. Simultaneously, the computational loop exceeds its mathematical foundations. *The essential concept of the loop always operates out of the clear distinctions between true and false through time.*

Thus far, the chapter has introduced and compared three theories:

- The mathematical set theory
- Its counter-theory of the calculus of indication
- The narrative of control within cybernetics

While Russell and Whitehead forbade self-referentiality, the calculus of indication used it to calculate complex numbers, a departure of mathematics from logic. Cyberneticians authorize themselves above the loop to steer it. I want to put forward the theory that the divergence of cybernetics from set theory is possible through several implicit and explicit assumptions that allow feedback to be steered in a desired direction. It is not a disallowance of self-referentiality in the first place but a more complex set of boundaries. Terms such as *serialization*, *repetition*, and *normalization*[53] or *determinacy*, *determinism*, and *termination*[54] capture the steering of feedback.

These concepts from the 1950s and 1960s have vast implications for understanding computer systems in the 2020s. Networks, apps, smart phones, smart homes, self-driving cars, social media, and artificial intelligence are all operated by the concept of controlling feedback. But, might the steering of the re-entry also have its limits? Throughout the following sections, I will discuss various examples of three re-entries of two-fold distinctions: *data | visualization*, *interface | human*, and *world | design* to elaborate on feedback and control, investigating where feedback leads to control and where to paradox.

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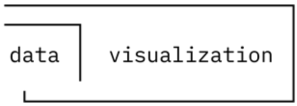
53 Ref.: Mersch, D., 2013. Ordo ab chao - Order from Noise, p.11-32

54 Ref.: Kittler, F., 2007. Die Endlichkeit der Algorithmen | transmediale. transmediale.de.

Data and Visualization



The consideration I am postulating in this section is that *the very essence of data visualization is based on the re-entry*, the repetition of the cross. To consolidate and clarify this theory, I will discuss well-known historical data visualizations. By choosing historical examples, I can, in addition to explaining the re-entry of visuals into data, make the point that algorithmic[55] thinking, procedural feedback, is older than microprocessor computation. The computer multiplied the concept many times over, but visualization designers applied its very essence long before electronic media.

Each example is essential for the identity of contemporary visualization practices. The visualizations last throughout history as they make visible something about the world that was previously unseen . These examples have been discussed extensively, but I will provide an alternative perspective on how these graphics operate in their very essence. What I am interested in is the method of representation these graphics all have in common.

55 The term *algorithm* goes back to the 9th-century mathematician Muḥammad ibn Mūsā al-Khwārizmī.

Data | Point

Cholera Map by Dr. John Snow[56]

In the first days of September 1854, Dr. John Snow plotted deaths related to the cholera epidemic in London. Snow marked each death on a geographic map and located the area's water pumps in the same graphic. Within the language of the *calculus of design*, Snow marked each fatality with a dot in addition to eleven crosses representing water pumps in the area. The map allowed him to make quantitative comparisons between the locations of pumps and deaths. Snow concluded that cholera occurred almost entirely among those who drank from the Broad Street water pump. On the morning of September 8, the handle to the water pump was removed. Up to this point, the story is known and well documented.[57,58]

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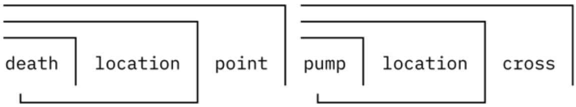
56 Source: https://de.m.wikipedia.org/wiki/Datei:Snow-cholera-map

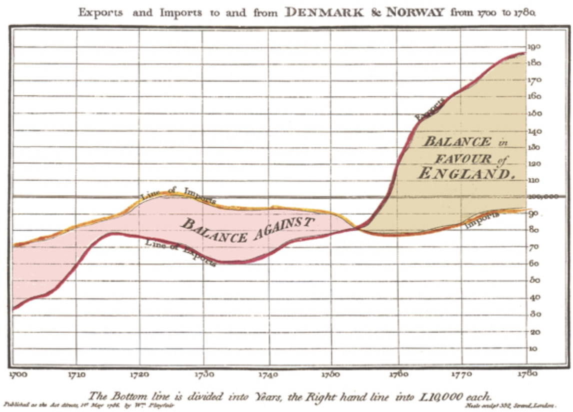
57 Ref.: Gilbert, E.W., 1958. Pioneer Maps of Health and Disease in England. The Geographical Journal, 124(2), p.172 -183.

58 Tufte, E.R., 1997. Visual Explanations, Graphics Press USA, p. 27-37

I am interested in how John Snow came to this conclusion by visual means. The map consisted of a road network of central London; Snow added dots for deaths and crosses for pumps using latitude and longitude coordinates. *The recursion of two symbols leads to the insight through a pattern of simplification.* Two distinctions, pumps and deaths, are iterated over geographic coordinates, symbolized by dots and crosses. The complexity of the actual streets of London, the complexities of each individual, are neglected. The map's insight emerged not only through the drawing of distinctions but also through the re-entry of two differences, dots and crosses, at their geographic locations.



Data | Line



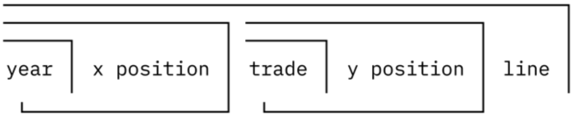
William Playfair's *difference chart*[59]

59 Source: https://de.wikipedia.org/wiki/William_Playfair#/media/Datei:Playfair_TimeSeries.png

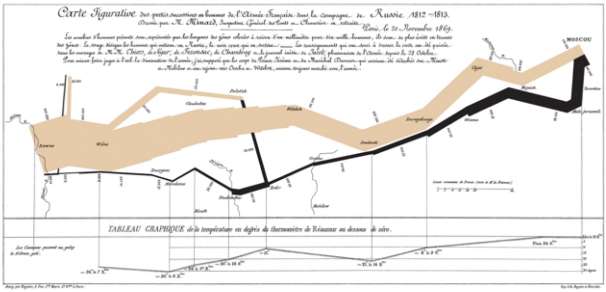
In the 1786 book *The Commercial and Political Atlas*,[60] engineer and political economist William Playfair designed various novel visualization techniques. One example is the graphic above, nowadays known under the term *difference chart*. One line in the visualization represents imports and the other exports to and from England in opposition to Denmark and Norway from 1700 to 1780. Each line's movement over the horizontal axis is determined in years, on the vertical axis in trade amounts.

While in John Snow's cholera map each datum represented one point on the map, Playfair manipulated each line using various data points. An array of data points iterates one graphical symbol. *The line is a point in continuous motion through the two-dimensional area of time and trade difference.* The line is an artifact of the re-entry, the looping of points connected into a line. Again, it is not only the distinction between the time and trade deficit of one data point, but the repetition of the two values against one another that allows for the graph in the first place. Time in this example has a double encoding: first as a data dimension represented in the graphic on the horizontal axis, and second as the line's recursion through data.

60 Ref.: Playfair, W., 1786. The Commercial and Political Atlas.



Data | Rectangle



Charles Joseph Minard's 1869 chart[61]

In 1869 Charles Joseph Minard, a civil engineer, published a map on Napoleon's Russian campaign of 1812. Edward Tufte said about the visualization that it *may well be the best statistical graphic ever drawn* as it tells a *coherent story with its multivariate data*. Minard plotted six data variables in the visualization: *the size of the army, its location on a two-dimensional surface, the direction of the army's movement, and temperature on various dates during the retreat from Moscow*.[62,63]

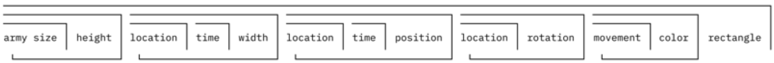
The main feature of the graphic are rectangles, iterated, transformed, and stacked. To represent the various data variables, Minard manipulated the height, width, position, rotation, and color of each of the rectangles representing the army's movement, location, and size. The iteration of manipulating the rectangle over the page abstracts the death of over 400,000 individuals. The width of a rectangle becomes a representation of death. Only the repetition of rectangles

61 Source: https://de.wikipedia.org/wiki/Datei:Minard

62 Ref.: Ref.: Tufte, E.R., 1983. The Visual Display of Quantitative Information, Graphics Press, p. 40

63 Ref.: Rendgen, S., 2018. The Minard System, Chronicle Books.

allows the story to emerge. One rectangle alone would not be sufficient as a visualization. The relation between signs looped through data establishes the relational structure of the graphic in the first place. Minard interlinks rectangles across the page through the repetition and manipulation of data dimensions by visual representation. The distinct data variables iterate through manipulations of the rectangle. *Data visualization is a re-entry of the symbol into data.* While the diagrammatic notations of the previous graphics consist of two re-entries, Minard's graphic comprises five. The excellence Turfte recognizes in the visualization is due to the high number of meaningful re-entries.



Distinction | Identity & Data | Graphic

The distinction of a symbol and its variables, such as size, color, or position, is not the entirety of what makes visualization design possible. *Iteration is central for visualization. Without at least one repetition of the symbolized, a graphic is not a visualization.* A bar chart only becomes meaningful through multiple rectangles. A scatterplot needs at least two entries. A line chart cannot even be drawn without two points connecting the line. *The re-entry of the symbol into the data allows for visualization in the first place. Difference and identity constitute each other within the graphic representation of data. The re-entry, the repetition, of data into the symbol creates this identity, a conglomerate of sameness.* Without it, visualization would be meaningless. The re-entry of the visual into data is not an infinite paradox but a *normalized*, *serialized*, and *deterministic process*. The procedural re-entry of data into visualization diverges from Spencer-Brown's theory. It is not an infinite repetition, but a looping on the array length of the underlying dataset. *Data visualizations are not only forms of distinctions but are equally forms of identity. Without sameness, there would be neither data nor visualization.*

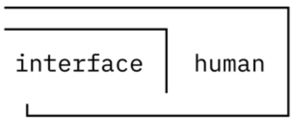
The re-entry grasps this entanglement between difference and identity, data and graphic — a finite, iterative, steered processing of data through graphic representation. The finite operation of the defined distinctions of data and visuals allows for the steering of the manifestation of control. *Data visualizations are serialized repetitions of normalized datasets in graphic form.* What lies behind the understanding of data and graphics is serialized automation. Repetition allows for these visual forms.

Social Media

> *Our seemingly distinct form is like a mirage, a relatively slow-moving effect of countless exchanges.*
>
> *— Beatriz Colomina and Mark Wigley*[64]

The foundational concept of computation, the *loop*, operates outside of strictly defined notions of true and false, as fluctuating iterations over time within the software/hardware complex. Its theory, unnoticed, undermines the basic formulation of how western society conceptualizes logic by introducing a third state, complexity through time, in addition to the binary oppositions of true and false. The mathematical *re-entry* and computational *loop* are initiated and *de—signed* by humans, but outside of the loop itself. The following section will perform a significant leap, as humans not only create but are part of the *re-entry* itself: from designing loops to being *in the loop*. The human falls into the spiral itself, just like Charlie Chaplin into the gearwheels in the 1936 movie *Modern Times*.

Computer and Human



> *The idea of feedback, of being involved in one's own participation, in one's own audience participation, is a natural product of circuitry. Everything under electric conditions is looped. You become folded over into yourself. Your image of yourself changes completely.*
>
> *— Marshall McLuhan*[65]

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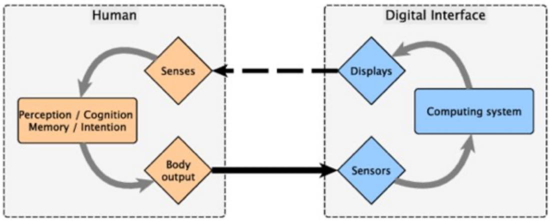
64 Ref.: Colomina, B. & Wigley, M., 2016. Are We Human?, p. 222

65 Ref.: McLuhan, M., 1965. The Future of Man in the Electric Age. Min.: 7:00 Available at: http://www.marshallmcluhanspeaks.com/interview/1965-the-future-of-man-in-the-electric-age/

The research field of human–computer interaction studies the design and use of computer technology. I argue that the basis of the term *interaction* is the cybernetic feedback loop. As quoted from Marshall McLuhan: *Everything under electric conditions is looped.*[66] This time, it is not only as a mathematical iteration of data or graphic symbols but as an iteration through humans. While data visualization loops data through graphic symbols, *interfaces re-enter computation through the realities of being human.* Interaction with the computer means to be involved in the operational possibilities and restrictions of the software/hardware relation, the *interface space*.[67] The freedom to act is given by the possibilities of drawing distinctions, but only within the constraints of the *space*. The *loop* not only operates under the surface of the software/hardware relationship, but also through the human under the terminology of *interaction*. In depictions of human-computer interaction, the loop is omnipresent, for example:



Design and Perceptual Investigations of Audio-Tactile Interactions

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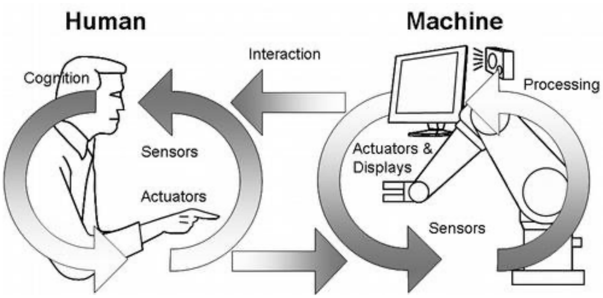
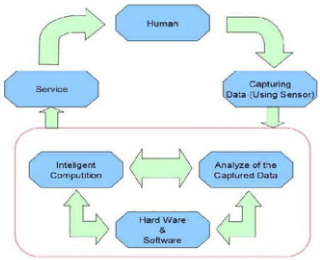
66 Ref.: McLuhan, M., 1965. The Future of Man in the Electric Age. Min.: 7:00 Available at: http://www.marshallmcluhanspeaks.com/interview/1965-the-future-of-man-in-the-electric-age/

67 Ref.: Distelmeyer, J., 2017. Machtzeichen, Bertz + Fischer, p. 88



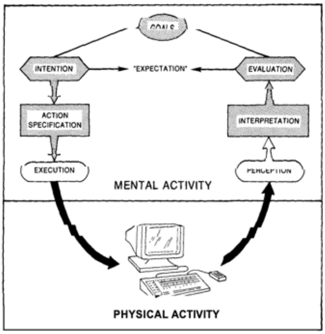
A Survey on User Interfaces for Interaction with Human and Machines



A New Approach to Architecture of Human-Computer Interaction

The images above are just three examples of a vast array of human-computer feedback depictions. One of the earliest representations I found within my research concerning interaction design is Don Norman's 1986 article *Cognitive Engineering*. The paper contains various graphics of feedback relationships, such as the following:[68]

[68] Ref.: Norman, D.A., 1986. Cognitive Engineering. In User Centred System Design. Lawrence Erlbaum Association.



The focus of Norman's feedback loop is not on the machine but on the human. The focus lies on flesh, between perception, execution, interpretation, evaluation, intention, action, and goals. He envisions cognition similarly to computational assignment statements. The chapter *Arrow* already identified and discussed research based on Norman's assumptions concerning cognition and data visualization. This chapter confines these thoughts within the theory of the *calculus of design*. The *arrow* between humans and machines holds similarities to Spencer-Brown's envisioning of a new mathematical foundation. Again, the intriguing part of the connection I am drawing is the vastly different problem spaces from which the theories emerge. In mathematics, it is the handling of paradoxes, in cybernetics and computer science, control.

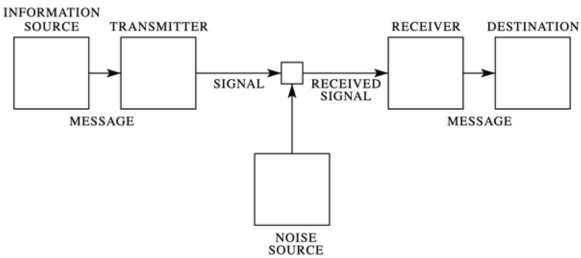


Fig. 1 — Schematic diagram of a general communication system.

The foundational 1948 paper *A Mathematical Theory of Communication*,[69] by Claude E. Shannon, later published as a book with Norbert Wiener and Warren Weaver, is

[69] Ref.: Shannon, C.E., 1948. A Mathematical Theory of Communication. The Bell System Technical Journal, 27, pp.379–423.

known for its general communication system diagram, Figure 1, from source to receiver.

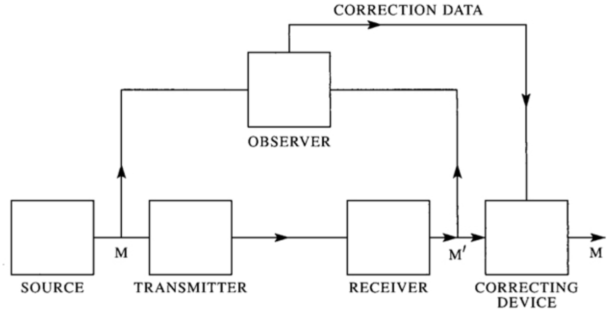


Fig. 8 — Schematic diagram of a correction system

The eighth figure in the paper is a diagram of what they called a *correction system*. Like Spencer-Brown's *Laws of Form*, the *observer* is the first instance of feedback in the depiction. The early conceptualizations of computation contained the concept of feedback, the loop. In the form of the loop, the time-based re-entry of a distinction into itself is critical to interactive media. The feedback loop includes an alternating view of Claude E. Shannon's diagram of a general communication system. The sender-receiver relationship is not a given, but rather something ever-changing, always in negotiation. Everyone is a sender and receiver at the same time. The book, the television channel, the radio station, the newspaper publication all have in common a relatively clear distinction between who is a sender and who is a receiver. Someone is either creator/sender, or consumer/receiver, but not both at the same time. The content in one channel's communication is homogeneous for various listeners, readers, or watchers.[70] The envisioning of feedback, the time-based looping of distinctions, changes this once humans re-enter the system. Shannon's eighth figure contains a very different concept of communication than in the first figure.

70 What I am only hinting at in this paragraph is in itself a vast discussion within media theory. For example:

Hans Magnus Enzensberger envisioned media as an interactive network in *Baukasten zu einer Theorie der Medien*.

Ref.: Enzensberger, H.M., 1997. Baukasten zu einer Theorie der Medien, p. 116.

The conception of *interaction* between humans and machines frequently equals that of feedback. Wendy H. K. Chun proposes the concept of *habitual repetitions* to comprehend digital media.[71] The *interaction* in human–computer interaction for Chun can more precisely be labeled as command and control.[72] Both *command* and *control* function through *distinction* and *re-entry*. The human spirals into the machine's pre-designed distinctions: like, follow, unfollow, swipe left, swipe right.

This chapter contained three similar but divergent conceptions: the mathematical *re-entry*, cybernetic *feedback*, and computational *loop*. The mathematical self-referential *re-entry* leads out of the realm of true and false states and into that of paradoxes. *Feedback* has enabled cyberneticians to attack the problem of control through self-referentiality. The computational recursions of *loops* allow for transformations between data and algorithms as well as from data to graphics, all following normalized, serialized, and deterministic processes. The significant difference between Spencer-Brown's *re-entry* and the thus far explored *feedback* and *loops* is that Spencer-Brown envisions his theory as infinite. For Friedrich Kittler, finiteness is the difference between mathematics and computation, as he states:

> *Now, finiteness is—at least hopefully—what separates algorithms from mathematics in general.*
>
> *— Friedrich Kittler*[73]

It might be the finiteness that creates control. The numerical value of the ratio of a circle's circumference to its diameter, PI, is under control within the machine as long as the output is finite: from 7,480 digits in 1957 to 1 million in 1973,[74] to 31 trillion digits in 2019.[75]

The narrative of finiteness and computation is in question in graphical interface design, as social media companies such as Facebook, Instagram, or Twitter follow a design paradigm named *infinite scroll*. The participants of these networks receive a seemingly *infinite* stream of new content. The algorithm adds more

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71 Ref.: Chun, W.H.K., 2016. Updating to Remain the Same, MIT Press.

72 Ref.: Chun, W.H.K., 2005. Control and Freedom, MIT Press.

73 Ref.: Kittler, F., 2007. Die Endlichkeit der Algorithmen | transmediale. transmediale.de.

74 Ref.: Arndt, J. & Haenel, C., 2012. Pi - Unleashed, Berlin, Heidelberg: Springer Science & Business Media.

75 Ref.: Kleinman, Z., 2019. Emma Haruka Iwao smashes pi world record with Google help. BBC. Available at: https://www.bbc.com/news/technology-47524760.

content to the page without an end by sliding text, images, or videos across the screen. Within the paradigm of *infinite scroll,* social media websites become bottomless.

The argument I want to postulate is not about interaction design discussions on the pros and cons of infinite scroll versus pagination, but rather a mindset of vast social media-driven content. An Instagram, Facebook, or Twitter *scroller* will never arrive at the bottom of the page with a message: *everything seen* or *the end*. An algorithmic feedback of likes and scrolls leads to a media infinity. In the same way that the scroll never ends, YouTube's recommendation system will always suggest new content. The paths YouTube creates through its visitors' network are known and investigated under the term *rabbit hole*.[76] Recommendations within the platform infrastructure are aimed at infinity. There is always another recommended video, another tweet, another post within the internet's rabbit hole. *While the computer loop needs to be finite, the vast infrastructure of software/hardware spanning a global network of codes and cables aims towards infinity.*

While the statistics I found varied tremendously, it is fair to say that the social media platforms such as Facebook, Instagram, YouTube, Twitter, Snapchat, and TikTok have millions of content additions in the form of photos, videos, tweets, and comments per day. While this is not infinite, it is too much for a single human being to consume. To exemplify my argument, I visited three social media platforms and used a script to screenshot these platforms' perspectives rendered visible in the infinite scroll. Due to the continuous load of new content, I had to stop the script at some point before it overloaded the random-access memory of my laptop; the definiteness of the 16-GB memory crashed with the nearly infinite load of content.

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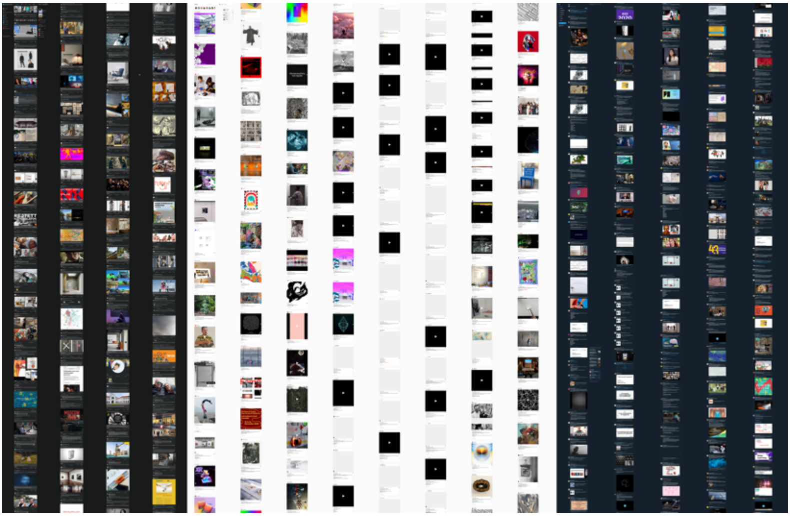
76 Ref.: Roose, K., 2020. Welcome to the "Rabbit Hole." New York Times. Available at: https://www.nytimes.com/2020/04/16/technology/rabbit-hole-podcast-kevin-roose.html.



Facebook Infinite Scroll, Instagram Infinite Scroll, Twitter Infinite Scroll

Zooming out of individual *feeds*, observing the *infinite scroll* from a distance reveals the similarities with the analysis of data visualizations in the previous section. The mechanisms are again the same normalized, serialized, and deterministic processes. Zooming out reveals the sameness of social media. The ever-repeating distinctions, the eternally same options determine how the visitors are capable of moving in and re-entering social media. The difference is the recursion of feedback through the mind. *Data visualization loops data through graphic symbols; social media re-enters computation through the realities of being human. The loop not only structures the time-based processes within the computational operation, but extends into the fabric of society.* Time determines computation on scales of split seconds as looping distinctions of functions to render the interface visible. But, this also occurs on a human scale of seconds, minutes, and hours of interacting within the *interface spaces* of clicking, writing, or scrolling.

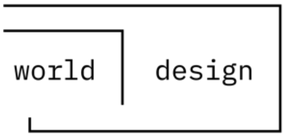
While feedback within machines, such as algorithms or graphics, are not spinning out of control, not creating a paradoxical reality by applying the recursion through the fabric of society, the paradoxical, complex state between true and false might be encountered. At the beginning of the 2020s, the social-media realities of *alternative facts*, *filter bubbles*, and *hashtag activisms* hint at a spiraling out of control into the realm of the paradoxical. The infinite scroll is a metaphor for infinity within the finite domain of computation. *The algorithmic, time-based, automated loops iterating the human mind might blur the boundaries of*

Aristotle's true and false logic into a state of complexity. Feedback can not only lead to self-regulation as a Gaussian normal distribution, but can also spiral outwards to the extremes of boundless power-law distributions. Feedback can lead not only to control but similarly to chaos. *Steering and collision belong together within the ever-elusive form of distinction.* The unmarked is continuously in question with the *re-entry* of humans into computation.

Screenshot from Twitter Donald J. Trump retweeting his own tweet.

The self-referentiality mathematics is afraid of is real on social media. Retweeting and re-entry into one's own creation.

World and Design



> *The algorithm shows us what it thinks we really want to see, as if in a strange kind of mirror that has become the new space of design.*
>
> — *Beatriz Colomina and Mark Wigley*[77]

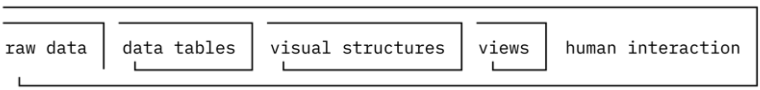
While distinctions have been underlying cultural formations since at least the invention of language, the *re-entry*, the feedback of procedural distinctions, reached a vastly different status in society through the rise of computational capacities. These automated realities create sameness, not difference. It is impossible to find a stone on the beach that is exactly like any other. It is impossible to live one day precisely like any other. *The world is ever-shifting;*

77 Ref.: Colomina, B. & Wigley, M., 2016. Are We Human?, p. 253

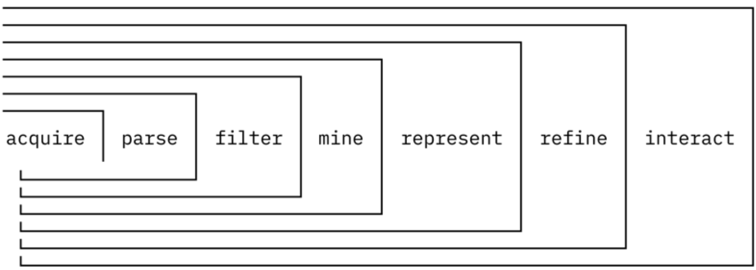
sameness is not intended in the world we inhabit. However, the reality computational design envisions only functions through self-similarity. Only because the social media timelines are based on the same constitutional framework at every re-load can they function at all. *The human-machine relationship is not only one of differentiation but is also built on iterative normalizing repetitions.*

Social media iterations do not reflect reality but function more like Bill Murray's daily awakenings in *Groundhog Day* from 1993. The eternally identical distinctions within the individual can choose between a small set of re-entries. Daft Punk's hit single *Around the World* from the 1997 debut studio album *Homework* consists of no other lyrics than 144 repetitions of the song title. The cultural mainstream on the early internet appears now to have been a preparation for the media realities of the 2010s.

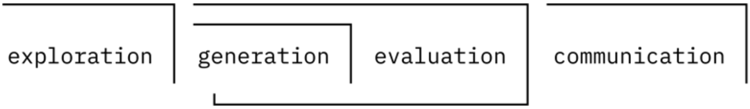
Design re-enters the world as a continuous iteration of identity and difference. Looking back at the chapter *Chain*, a collection of conceptualizations of visualization design processes, the common underlying concept behind the design processes are distinctions and re-entries. For example, I can graph Card et al.'s *Reference model for visualization* in the diagrammatic form of the calculus of design as:



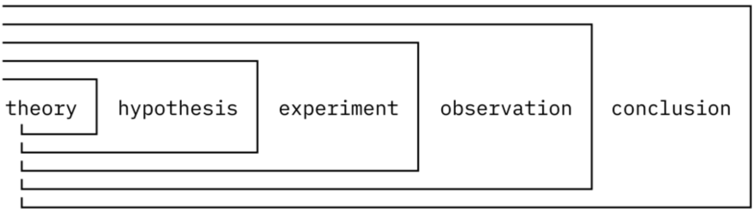
Ben Fry's seven-step process from the acquisition of data to the interaction within the visualization interface then looks like:



Similarly, I can represent design processes that do not specifically focus on visualization design as distinction and re-entry. An example is Nigel Cross' four-stage design process:[78]



The conceptualized pattern of the essence of design repeats itself. Only minor adjustments in terminology and re-entry patterns distinguish each of these models. The diagrammatic representation of the calculus of design can also represent scientific design processes, such as the THEOC model of the scientific method:



The calculus of design is a meta-theory for a general conceptualization of the design process. The distinction differentiates between various steps, and the *re-entry* represents the repetitiveness within the process. *The calculus of design renders the sameness of design process theories explicit, and by doing so allows these conceptions to be questioned.*

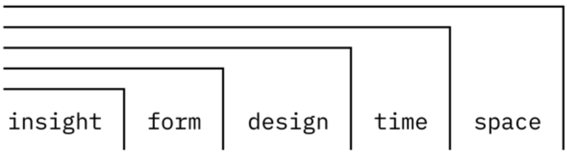
In the *calculus of design,* the distinction is always a separation of the marked from the unmarked. Crossing into the unmarked creates another unmarked space. The drawing of a distinction always separates the space; there is no sign without its negation, the *de*. Signs are negation operations, which I theorized as *de—sign*. Within the theory, the elusive can never be reached. Crossing from the marked to the unmarked is only possible with another distinction, creating another unmarked space, and thus another set of marked | unmarked relationships. Every difference establishes a boundary and excludes the unknown, collapsing

78 Ref.: Cross, N., 2007. Designerly Ways of Knowing, Springer Science & Business Media.

complexity through the distinction. Crossing into the unknown reveals something, but never everything. *Processes within the calculus of design are always elusive*. The uncertain is constantly inscribed within the distinct. The *calculus of design* is a display of its boundaries. Distinction and re-entry provide a specific worldview, which will never reveal its entirety, *a = not a*. The design process is and remains a *wicked problem*[79] that cannot be fully represented as orbs and arrows, as distinctions and re-entries. Neither true nor false are given, but rather complex iterations reflected through time.

[79] Ref.: Rittel, H.W.J. & Webber, M.M., 1972. Dilemmas in a General Theory of Planning

Insight



> *At the present moment we are constrained, in our reasoning processes, to do it the way it was done in Aristotle's day. The poet Blake might have had some insight into this, for in 1788 he wrote that 'reason, or the ratio of all we have already known, is not the same that it shall be when we know more.'*
>
> — *Spencer-Brown*[1]

To arrive at a novel conception of the interaction between design and insight, I will draw together the developing theory's various layers as examined here. The introduction chapter on *How to design a bar chart* exemplified the *calculus of design*; this final chapter will do the same but on the diagrammatic level of the design calculus. I will identify and interlink the various levels of the last four chapters to approach a novel notion of the structured and nested embeddedness of insights. Through this, I will get back to the question that drove my investigation:

How do data visualizations represent insights?

What kind of insights can data visualizations represent?

What is design's role within a process aimed at attaining insight?

If design is about creating structure, how does this affect insight?

How does organization influence what is known?

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1 Ref.: Spencer-Brown, G., 1969. Laws of Form First Edition, London: Allen & Unwin, p. xiii

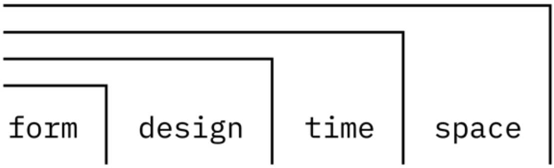
How do structure, organization, simplicity, and subjectivity relate to insight?

Calculus of Design

The first part's defining conclusion, the *conceptions of design for insight*, was that terms such as *insight*, *knowledge*, and *truth* are mentioned in bold statements and book titles but are rarely described or discussed in detail. Furthermore, the cited researchers and designers drew no relations between the process of design from data to graphic and the achievement of insights in any respect. Other terms, such as *efficiency* and *effectiveness*, came into focus instead. The predominant underlying narrative was one in which visualization design was imagined as a metaphorical refinery. Within this narrative, data was the crude oil, which the visualization turned into the fuel to obtain insights. The powerful postulation dominating applied visualization research is that insight already exists in the world, and the visualization of data is a method to make these insights visible.

The *calculus of design* radically questions this metaphor by predicating an alternative conception in which insight only exists within the form's marked space. The marked can only be perceived through the unmarked, by neglecting other possibilities. Insight is not given, but follows the command: *draw a distinction*. The distinction neglects the space as a consequence; *de–sign* is the operation of neglecting possibilities. The diagrammatic notation of the *calculus of design* offers an approach to render visible the layers and presumptions involved in the design operation.

The last four chapters in which I have articulated various layers of the *calculus of design* not only questioned the refinery metaphor, but revealed an alternative narrative. It is vital to clarify how profoundly the simple command, *draw a distinction*, changes one's embedding and interaction with the world. *Insights are not given, but are in correspondence with the operative act of drawing distinctions.* Insight is *de–signed* by drawing distinctions. The insight visualization design creates is not something given, but is instead dependent on a set of interlocked structures of meta-distinctions within which a designer draws. I have articulated one theoretical path called the *calculus of design* to bring the various interdependencies into perspective, namely: *form*, *design*, *space*, and *time*.[2]

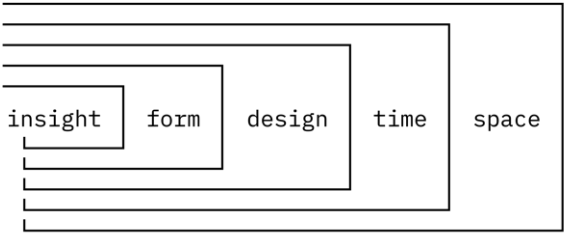


The chapter *Form* investigates the constituents of design as a calculus

consisting of the two-part step-by-step process of creating *crosses* of *distinction* and *indication*. The form is never given but is drawn by a *designer,* as I have concluded in the chapter *Design*. The form is only brought into existence by someone or something drawing a difference. Therefore, form is nested within the operation of design. The *design* of *form* is constituted by two additional crosses, each discussed in its own chapter: *Time* and *Space*.

These nested interdependent layers are the constituents of the interrelational notion of *insight* I have been working towards. Each layer corresponding to the last four chapters is not given but is instead narrated and by no means fixed. The layers re-enter each other, evolve in an iterative process over time until the distinctions become meaningless and new ones appear. As such, I draw five layers from *insight* to *space* as a nested set of crosses, each *re-entering* the other.

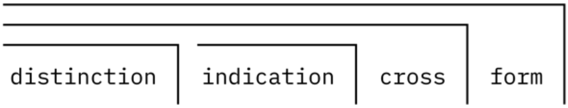
2 While the chapter *Space* is followed by the chapter *Time* within the diagrammatic representations of the layer, *time* is nested inside the *space*; due to the fundamental notion of space, it was essential for me to discuss this chapter before *time*. Within the diagrammatic representation, the notion of *space* as the contingency towards the *form* is so vast that it exists in layers above *time*.



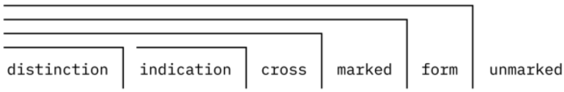
To apprehend the conception of insight within the theory, I will recapitulate the drawn meta-distinctions. The four layers *form*, *design*, *time*, and *space* conceptualized and exemplified the epistemological and operational layers of the design theory I am calling the *calculus of design*. In the following subchapters, I will contemplate the drawing of insights through the developed diagrammatic system of form and its two axioms of calling and crossing. The textual mediations accompany the diagrammatic notation system I have introduced in the chapter *form* to conceptualize an interdependent, nested conception of insight. The argumentation towards *insight* is primarily diagrammatic. The form of the cross becomes the means with which to understand the nature of insight in the context of design.

Form

At the center of the *calculus of design* lies *form*. It consists of distinct and indicated crosses, as articulated and summarized in the chapter with the same title. The distinction separates the space; the indication designates one of the two sides, marked or unmarked. The two operations are different but can only be drawn together. The vertical and horizontal lines of the cross represent the diagrammatic two-fold operation.



Each cross separates the space into marked and unmarked, signed and unsigned. The unmarked is always elusive. Crossing the form into the unobserved creates another unmarked space. This conception is not uncommon in design theory, as I have related the unmarked to design attributes of *ground*, *negative space,* or *ma*.[3]

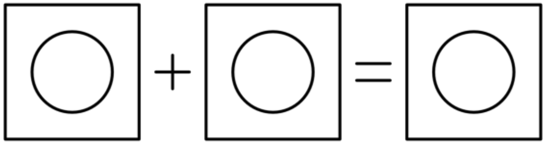


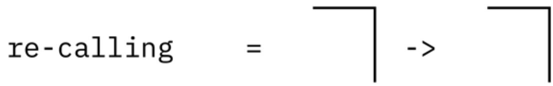
The form is a step-by-step procedure following the two axioms, resulting in *calling*, *re-calling*, and *crossing*.[4] *Calling* creates a new cross within the current cross. This operation distinguishes something within the distinction. A nested structure of distinctions becomes visible.

Re-calling does not change the form. The repetition of the same distinction without any difference equals the first distinction. Redrawing the same without a distinction does not create a difference.

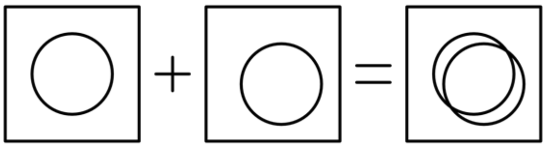
3 Chapter *Form*, subchapter *Characteristics of Design*: *Design Attributes*

4 Chapter *form*, subchapter *Operations of Design*: *Design Axioms*





Crossing is the operation from the indicated side of the cross towards the unmarked. The operation leaves the current distinction to draw another outside the current difference. The unmarked remains elusive, as crossing only creates a new cross outside of the set of crosses.



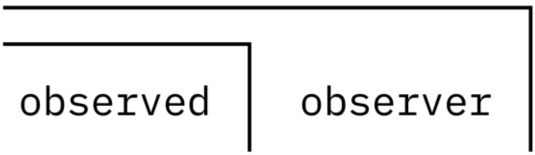
The operational possibilities of *calling*, *re-calling*, and *crossing* create a two-fold organization of the form: *within* and *next to*. The form's openness is crucial in understanding that in the *calculus of design* each step could also be different; the cross with its two lines of distinction and indication is always open towards other differences within and outside. There is no end to the combinatorial operation as long as space allows for further differentiation. What appears throughout this operation is a hierarchical structure of nested distinctions, a categorical branching system, persistently open to the unknown on each level by crossing the current set of differences.

Design

The conclusion I have developed from the individual chapters' arguments is that the creation of form, the operational, drawn, nested set of crosses consisting of distinction and indication, is the fundamental principle of what it means to *design*. As investigated and concluded in the chapter *Design,* the *calculus of design* operates on the radical command:

Draw a distinction

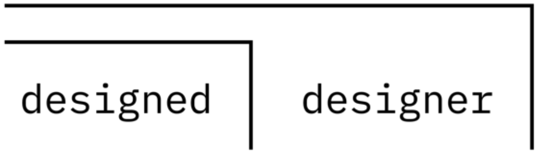
By drawing a distinction, form is designed. Design always includes the indication and thus the cross, the marked, and the unmarked. From the first distinction, the designer can draw further distinctions. The first distinction a priori to the unmarked space is the separation of *object* from *subject*. The observation is separated from the observer.



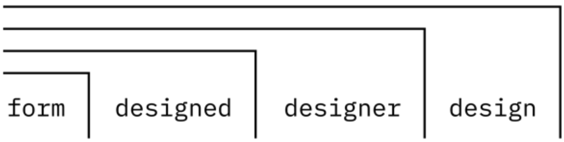
One fundamental argument I have developed in the subchapter *From Observer to Designer*[5] is that observation is not enough for the creation of form. I am proposing *design* as the actionable extension of observation. The *calculus of design* interprets design as *de—sign*, as designation, as marking and naming distinctions. Design is the drawing of distinctions in a world that does not hold differences in

5 Chapter: *design*

the first place; it needs the designator to turn the observed into the marked and distinguish it from the unmarked. The first distinction becomes one between the subject-object differentiation of designed and designer.



The initial distinction is the difference between distinguished and distinguisher, designed and designer. It is the first hierarchical set; a designer needs to distinguish herself from the design. The subject-object differentiation of designed and designer nested the callings from design to form.



Throughout the chapter *Design,* I am introducing a reinterpretation of the term *design*: I am separating the term into its linguistic compounds *de* and *sign*. The Latin prefix *de* is a word-forming element commonly meaning down, off, or away, but more importantly, it reverses a verb's action.[6]

De—sign is not a creation of signs, but their removal.

The cross separates the space into marked and unmarked. Design is about the removal of possibilities for signs for one specific cross within the form. *The design operation is not about what is created but about what is neglected.* I have exemplified the negative de—sign operation with the two cases of *graphic form* and *data form*.[7] Design operates within pre-defined structures; it is an act of disregarding

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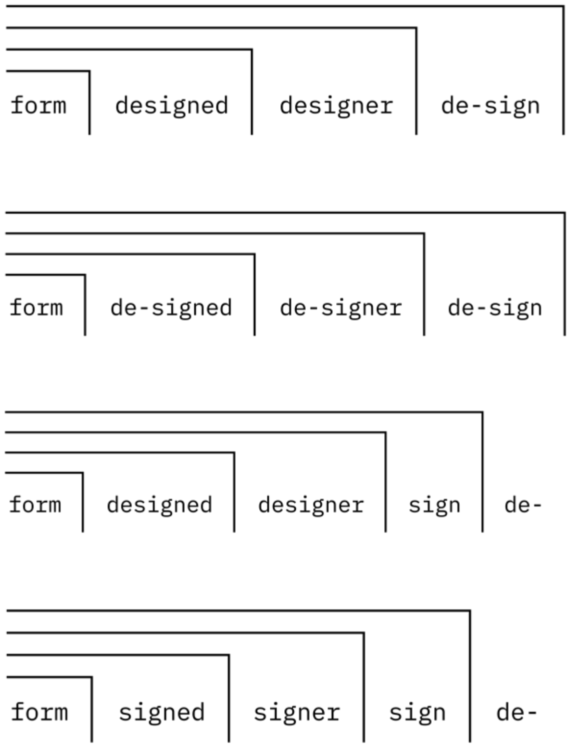
6 Ref.: Etymology Dictionary, de. etymonline.com. Available at: https://www.etymonline.com/word/de- Accessed October 26, 2020.

7 Chapter: *design*, subchapter: *Designing Distinctions*

possibilities for the form. The diagrammatic form of the *calculus of design* allows one to inquire, ask about, and question the neglected. The openness of the two-sided sign of the cross conceptualizes distinctions as an act that contains negativity by necessity. *Without neglect, design is impossible.* Design only exists because there is something to reject by choosing something else. Neglect becomes the basis of the reconceptualized notion of design.

I am rewriting design as *de–sign* to accentuate my interpretation of this negative design operation. The dash, the thought–line,[8] emphasizes the open compound between *de* and *sign*. The line itself is introduced into the term as a diagrammatic element. The insertion of the mark draws attention to the line of thought, the operative of the form. This readjustment leads to various operational reinterpretations of the form | design relationship within the diagrammatic notation of the *calculus of design*.

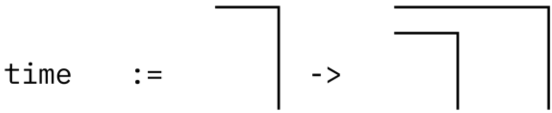
8 From the German *Gedankenstrich*. *Gedanken* = thought, *Strich* = line



The unmarked is the *de–* in *de–sign* while the *sign* is the marked rippling downwards to the *signer*, the *signed* resulting in *form*. The negativity of the *de–* represents the operational act from contingency to form. The command *draw a distinction* equals the removal of contingency towards the sign. Hence, *de–sign* only exists as a negative operation. The act of de–signing something collapses the space of possibilities the world contains. The focus on something is the rejection of something else.

Time

Time is what allows for the operative possibilities of the calculus. I defined the terminology *calculus* as a procedure by which one form is exchanged for another as a consequence of steps.[9] For this reason, I am calling the *calculus of design* an *operational design theory*. The sequential structure of drawing distinctions defines time within the theory. As I have derived and concluded in the chapter *Time*, time is the operative drawing of distinctions from one form to another. Therefore, design is a time-based process of neglect, of removing possibilities for the form.



Within this operational conception of time, the iteration of the cross is so essential that its symbol is extended by two additional lines, closing the two-sided cross into itself. As elaborated in the chapter *Time*, I am calling the re-iteration of the cross into itself or other distinctions the *re-entry*.

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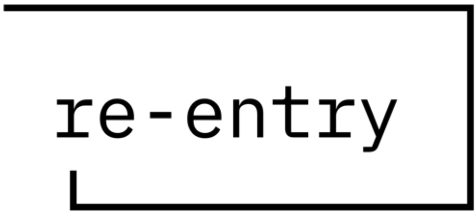
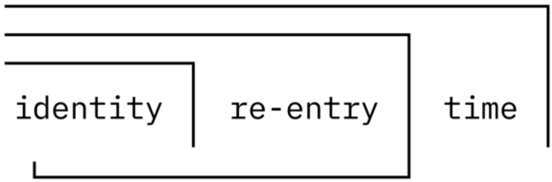
9 Chapter: *Form*, subchapter: *Calculus*

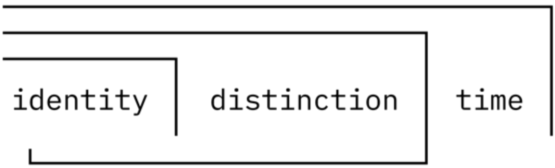


The *re-entry* notates automation as repetition, recursion, and self-reference within the *calculus of design*. A distinction re-enters itself or another set of differences. Time is the distinction that allows the re-entry of the form. By drawing the distinction that a difference equals a previously defined distinction, time emerges. *Time is an interplay of identity and difference; while something changes, it is the same within the distinction.* In the chapter *Time*, I am exemplifying this concept by not drawing a new distinction of a flying bird or a driving cyclist; by keeping its identity, the movement's change creates time. *While everything is in flow, identity generates time by fixing distinctions.*

Drawing distinctions is always operational; the re-entry's specificity is the repetition of differences. Repetition creates identity by iterating differentiations. The re-entry introduces sameness within the *calculus of design*. Identity emerges by re-calling a distinction even if the distinction varied in-between call and re-call. Time as the distinction within identity is crucial for computation. The foundational concept of the *loop* functions on the basis that `i = i + 1;`, the same `i` iterates over time. The foundations of mathematics and computer science diverge vastly at this point, the first excluding *paradoxes*, the second postulating *control*. For design as *de—sign*, the paradox is always contained within the interplay of marked and unmarked.



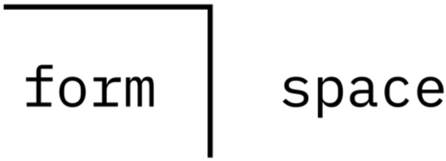
In my understanding of this theoretical concept, time and identity have a metaphysical relationship capable of creating paradoxes between distinction and identity. *Time emerges from a difference observed as identical while changing.* Changing a variable from `true` to `false` is a fundamental operation of a time-based function within computation. *Design re-enters the world as a continuous iteration of identity and difference.*



Space

The outermost distinction of the *calculus of design* is space. *Space is the pre-defined condition under which a de–signer draws distinctions.* As elaborated in the chapter *Space*, *contingency*, all possible operations drawing distinctions at a given point, pre-defines design. Without *contingency*, there is no possibility to act differently.

Design only exists if there is something to be excluded. Without the other, there would be no *de–sign*. Nothing could be drawn unmarked. A space without options, without the possibility to draw distinctions, is a non-designable space.



The starting point of *de—sign*, the *empty space*, is never empty but filled with presumptions from which the designer begins to draw distinctions.[10] A de–signer creates form by removing choices from space — the possibilities of space pre-define the form. I named this the *negativity of design*.[11]

While design spaces in the world are fuzzy and never fully definable, within the computational structures of the *algorithmic series*,[12] they must be unconditionally pre-defined. The nested structure of pre-definitions within computation is vast but finite. *Draw a distinction, but only one the system is designed for. Space pre-defines the form.* What differences are drawn, what becomes marked, and what stays unmarked within space needs the de–signer's motivation, without motive, no form.

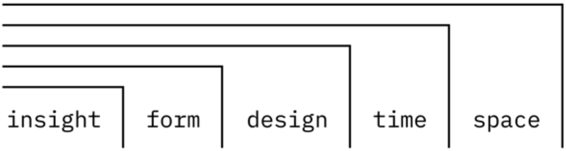
Operational, time-based, *distinctions* drawn by a *de–signer* are restricted by the boundaries of the *space* to create *form*. These are the distinct factors of the *calculus of design*. The chapter *Space* argues that the *calculus of design* as a drawing of distinctions is inevitably embedded within space, permitting for the operation in the first place. Rendering this space visible means observing the layers above the drawn distinctions. *Space restricts the freedom of the form into possible and impossible.*

10 Chapter: *Space*, subchapter: *Empty Spaces*

11 Chapter: *Space*, subchapter: *Negativity of Design*

12 Chapter: *Form*, Subchapter: *Design Evolutions*

Insight



This argument started in the first part, *Conceptions of Design for Insight*, with a collection of verbs used to describe visualization designs aimed at obtaining insight, knowledge, and truth. *Dig*, *explore*, *discover*, *find*, *gain*, *reveal*, *see*, *mine*, *uncover* were some of the terms used to discuss *data*, *visualization*, and *insight*.[13]

The *calculus of design* theory, method, and approach investigated the constitutional factors involved in drawing some *insight*. Through the conception of this approach, a different narrative emerged: *Insights are not discovered, gained, explored, revealed, or mined; they are operatively designed. Insights are designed by drawing distinctions in a culturally created infrastructure of nested embeddings. Insight is a design operation.*

One etymological reading of the term *insight* describes the term as *understanding from within*.[14] The relationship between design and insight in the *calculus of design* is not an understanding from within but rather a designed operation, transforming one form into another. Insight is not given but *de—signed*. The operational step-by-step calculus transforms one form into another by drawing distinctions.

To elucidate the interplay of design and insight, I am drawing a further conclusion and making it linguistically recognizable here — as a combination of concept and sign: I transform, just like design and *de—sign*, insight into *in—sight*, adding a line of thought and pause into the term. For a distinction to be *in—sight*, it needs to be *de—signed*. The contingent space of signs comes into view through operational distinctions. Insights are drawn through operative acts within the nested set of the *calculus of design*. *Insights are drawn in—sight.*

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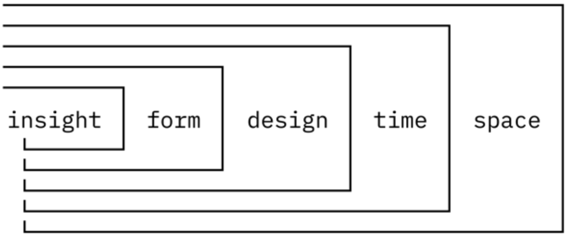
13 See chapter: *From Pattern to Insight*

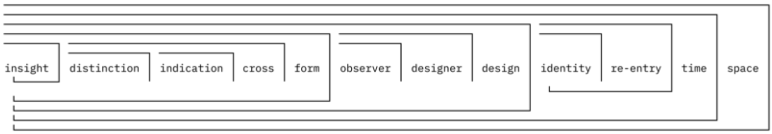
14 Ref.: Etymology Dictionary, 2018. insight (n.). etymonline.com. Available at: https://www.etymonline.com/word/insight Accessed March 24, 2021.

All the distinct layers are furthermore not independent from one another but continually re-enter each other. *The only constant is flux — the always changing renegotiation of the layered conceptions of embeddings aimed at achieving insight.* The *calculus of design* sheds light on a continuous redrawing of the various layers. The investigated theory is only one possible path I have de–signed by removing the contingency of possibilities of design theories.



The calculus of design does not claim that there is no outside, no world, beyond the distinction. There is a *realwelt*. However, naming it is collapsing the real into form, and thus creating marked and unmarked. Yet, to interact with the world we are adding distinctions that we cannot subtract. The operational act of *de—sign* is constantly submerged in the underlying *realwelt*. Using the terminology of *realwelt,* I have already drawn a distinction, drawn a sign, created the unmarked, and thus removed myself from the actuality through the sign. *Insights are not random; there is something past the form, but to encounter this something the cultural setting of data, visualization, interfaces, computation, and language all operate on the act of drawing and re-entering distinctions.* The vast distinctions of technology, culture, and natural phenomena merge and contract within the operation of drawing distinctions. Once having moved out of these extensive categories, their distinctions are not valid anymore.

The chapter *Form* introduced four *design evolutions*: the *unique*, the *craft series*, the *industrial series*, and, my addition, the *algorithmic series*. Each iteration can be read as an intensification towards the sign and away from the undefinable, from the unique, in which everything is dissimilar, towards the algorithmic, defined by almost infinite re-entries of signs through data. Through each evolution, the *calculus of design* approach has gained significance. The serialization of the sign within computation is the ultimate intensification of design as a step-by-step operation from one form to another. *The vast infrastructures of nested differences are drawn distinctions of how someone or something encounters reality. Insight only exists as a* *set of conceptions within the realm of computation, data, and visualization as designed distinctions.* As I have concluded in the chapter *Space*, *design as de–sign is the act of deciding for something and against everything else.* The difference is not given in the world, but rather created, *de—signed*. One etymological root of the term *compute* is to prune, *to cut away unnecessary parts*.[15] Computation cuts, separates, distinguishes form in order to operate. Within computation, *de–sign is the operational drawing of differences.* The step-by-step sequence draws forms of distinction, indication, and re-entry. Here, I am graphing the most significant callings, re-callings, and crossings of the *calculus of design* as:



The above diagram contains the most significant nested layers of the *calculus of design* approach that I have elaborated on throughout the last four chapters. It is the meta-diagram of the embeddings of computational design aimed at obtaining insight. The unmarked always remains in question and thus the diagram is not a guideline but a set to deconstruct, to operate against. The *calculus of design* offers an approach to discuss and notate the operation of *de–sign*, to draw something *in–sight*. Throughout the next section, I will explain the importance of mapping the artificial to come up with an epistemological design theory.

From efficiency to deficiency

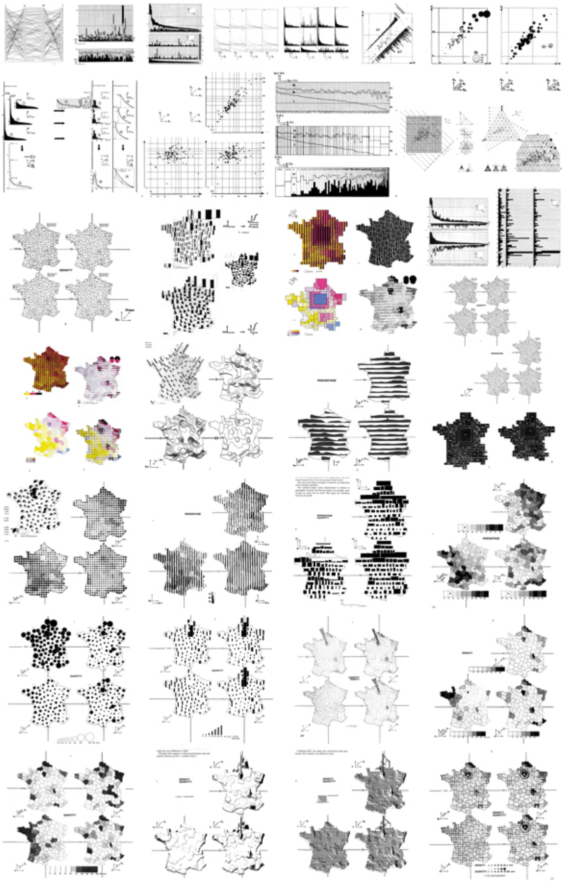
The theories and practices highlighted in the chapters of the first section, *Conceptions of Design for Insight,* contained a powerful design narrative. Sometimes subliminal, sometimes clearly stated, the objective of visualization design is efficiency and effectiveness. The design operation from data to a graphic is

15 Ref.: Etymology Dictionary, 2018. compute | Origin and meaning of compute by Online Etymology Dictionary. etymonline.com. Available at: https://www.etymonline.com/word/compute Accessed July 14, 2018.

imagined as an optimization problem aimed at obtaining the quickest and most accurate human understanding of data. Over the last century, visualization design has followed a modernist agenda, first articulated by Jaques Bertin, motivated by efficiency. In this subchapter, and against the background of the *calculus of design* approach, I will question and deconstruct the concepts of efficiency and effectiveness. I will showcase how efficiency can lead to unwanted outcomes and, more importantly, miss the entirety of what it means to design in the first place.

Rather than asking about efficiency and effectiveness, I will postulate another hypothesis that design can strive towards, namely *deficiency*. The *calculus of design* is an approach to the re-calling, questioning, of any particular distinction. *The calculus of design prompts the question of what is missing from a current perspective.* Where does the deficiency lie? I will elaborate on this argument with the help of two examples. First, a refresher on the origins of efficiency within visualization design, this time theorized and applied through the *calculus of design,* and the second one a narration of a set of design iterations that operates outside of efficiency as a possible design principle.

Efficiency

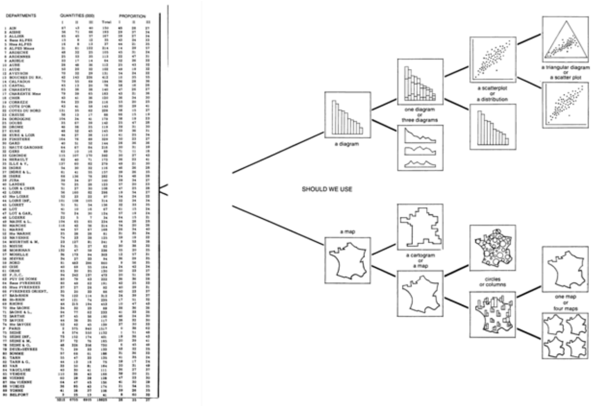


Collection of all graphics Bertin drew from one dataset about the workforce in france.

In the chapter *Raster*, I collected the graphics that Jaques Bertin drew over 35 pages using one dataset about France's workforce.[16] As a consequence of the

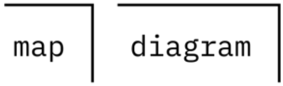
[16] Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press.

calculus of design approach, I can discuss and theorize Bertin's efforts from a novel perspective: The operation from data to visual is a combinatorial drawing of distinctions and re-entries of data onto graphical symbols — the design operation calling, re-calling, and crossing. The result is a branching nested set of differences. Bertin himself was aware of the branching process and created a diagram of the first four layers of drawn distinctions.

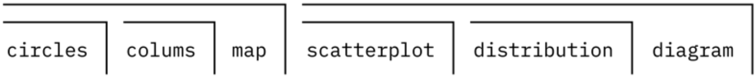


Jaques Bertin: The basic graphic problem, p. 100 - 101

On the left, the data table used to create the graphics. On the right, a sketch suggesting how to think about the different combinatorial possibilities. Bertin's first drawn distinction is one between the map and the diagram. Calling this distinction the *first* only applies under the conception of the form. Crossing the form into the unobserved leads to the vast array of already distinguished differences, from the country France, the selected dataset, the choice to use data as a method, or the decision to use paper as a medium. The *first* is always a question of what is observed and what remains unobserved within the observation. The *space* is seldom called in question within visualization design, but is always present.



My interpretation is that the process Bertin draws is one of differentiation between drawn distinctions, a nested set of crosses. *Visualization design becomes the drawing of differences with graphic symbols that re-enter data.* From one line representing France's contours, Bertin adds rectangles and circles, manipulates the outline, and multiplies it. *I approach design as a play of differentiation, while visualization design does so from data to drawing in—sight.*



I want to repeat Bertin's conclusion from this process, as it is something deeply entrenched in visualization design:

> *We have just examined a hundred graphics in terms of the correspondence between components and graphic variables. Some of the graphics are 'good,' others 'worse,' others simply 'bad.' But these opinions are purely subjective. We need only submit a dozen maps for evaluation by a group of readers in order to discover that each person will have a different opinion, based most often on considerations of an aesthetic nature. It is important, therefore, to define a precise, measurable criterion which we can use to class constructions, determine the best one for a given case, and explain why readers prefer different constructions. We will call this criterion 'efficiency.'*
>
> — *Jacques Bertin*[17]

Bertin motivates the contingency to act differently, with one goal: *efficiency.* As brought to light in the chapter *Conceptions of Design for Insight,* efficiency from data to graphic is one of the most articulated motives in visualization design. The contingency, possibilities of choice, *space* allowing one to design within it from data to graphic with all its branches, is drawn in the meta-distinction between efficiency and inefficiency.

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17 Ref.: Bertin, J. & Berg, W.J., 2011. Semiology of Graphics, Esri Press, p. 139

efficiency | inefficiency

From this perspective, I will discuss one example of how drawing distinctions influences insight and how efficiency cannot guide such processes.

Deficiency

The research article *The migration map trap. On the invasion arrows in the cartography of migration* by Henk van Houtum and Rodrigo Bueno Lacy examines mappings of undocumented migration, their historical influences, and prospects.[18] The author's mindset regarding the topic is captured in statements such as the following:

> *They are not merely a reflection of power but power itself: visual statements and narratives about the political topics they picture or, in other words, visual discourses. Their production is 'controlled, selected, organised, and redistributed' by procedures of exclusion that establish what is reasonable, true and acceptable to say – or depict – and what is not.*
>
> *— Henk van Houtum and Rodrigo Bueno Lacy* [19,20]

The *procedures of exclusion* map well onto the *calculus of design* approach and its argument of a *negative design operation*. One year after the publication of the scientific article, in 2020, van Houtum together with the news website *The Correspondent* created a series of changes to an official map of illegal border crossings by the European Border and Coast Guard Agency, also known as Frontex.[21]

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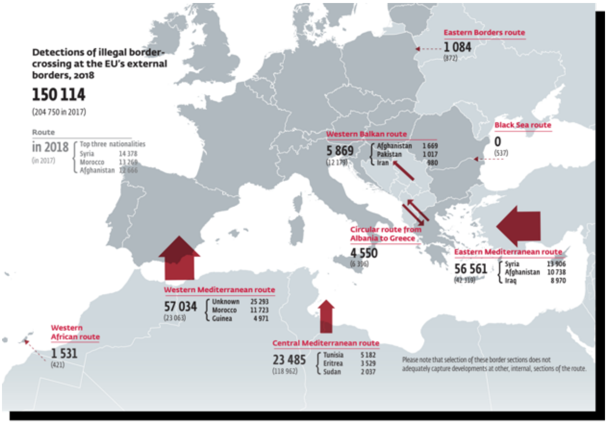
18 Ref.: van Houtum, H. & Bueno Lacy, R., 2020. The migration map trap. On the invasion arrows in the cartography of migration. Mobilities, 15(2), pp.196–219.

19 Ref.: van Houtum, H. & Bueno Lacy, R., 2020. The migration map trap. On the invasion arrows in the cartography of migration. Mobilities, 15(2), pp.196–219.

20 The authors reference within this quote *Foucault, M. 1981. L'Ordre du Discours. Paris: Gallimard., 52–53*

21 Ref.: Vermeulen, M., de Korte, L. & van Houtum, H., 2020. How maps in the media make



The article's changes to the Frontex map are illuminating examples regarding the procedures of the *calculus of design* approach. I will diagrammatically showcase through this example how drawing distinctions influences observation and how *efficiency* cannot function as a design motive. The authors first abstract the Frontex map into the standard layout of their website. They remove particular distinctions from the graphic — for example, the crossings from Morocco to the Canary Islands.

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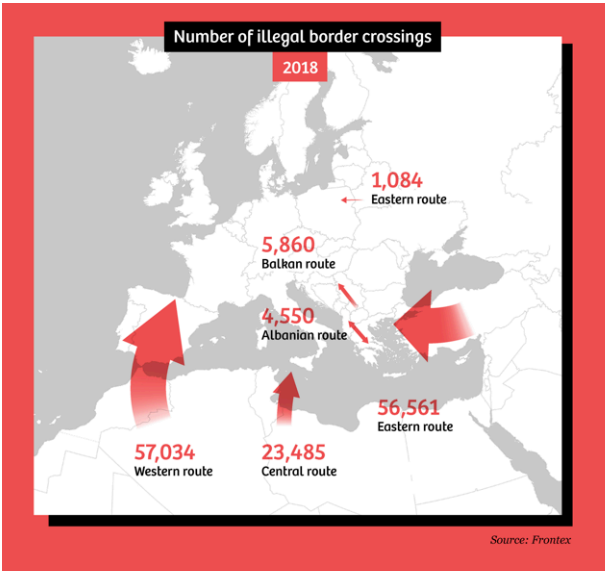
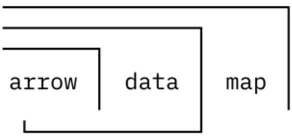
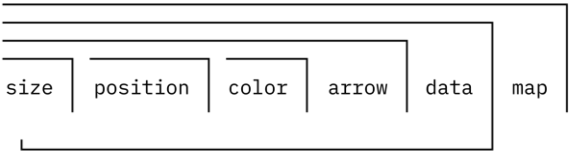
us more negative about migrants. thecorrespondent.com. Available at: https://thecorrespondent.com/664/how-maps-in-the-media-make-us-more-negative-about-migrants/738023272448-bac255ba Accessed February 26, 2021.



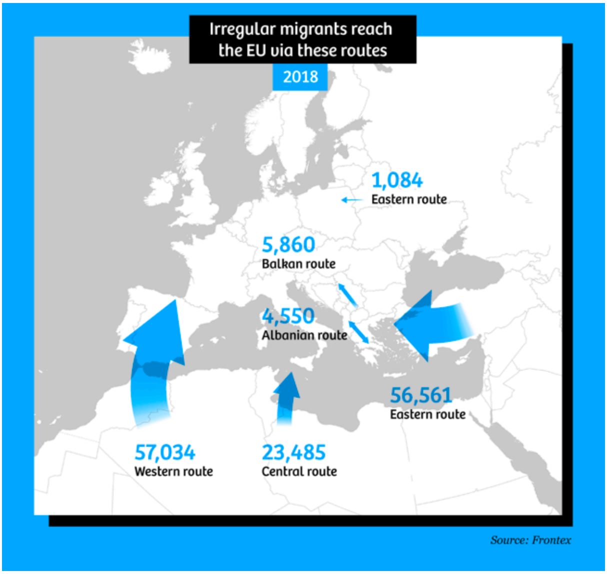
To emphasize the function of distinction in this paradigmatic example, I am abstracting the visualization here within the diagrammatic notation of the *calculus of design*, creating a meta-visualization of the design process the article develops. The first graph makes three significant drawn distinctions, the map, the arrows, and the data. The data is re-entered into the map through the arrow.



The diagrammatic notation of the form makes visible the operation of the *de—signed* distinctions. Calling, crossing, and re-entering the form is not only a theoretical procedure but a practical reflection of *de—sign* through the diagrammatic notation of the *calculus of design*. The arrow contains further distinctions, such as size, position, and color. Distinctions are always collapsed complexities, drawn differences between distinctions and against others.



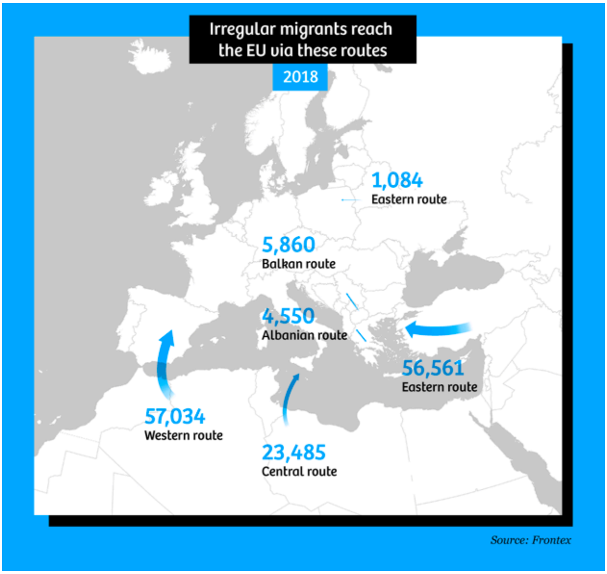
I am interpreting the authors' work as a reflection and re-operation on various levels of drawn distinctions. The first operation changes the color of the arrows from red to blue.[22] The article comments that red is a color of danger, which makes the map look alarming.



In the second operation, the arrows' size is changed as the authors write *the arrows are larger than most European countries. The width of the arrow lines makes it look like it involves huge numbers of migrants.* Both color mapping and arrow scaling are never given, but only designed distinctions without any correspondence or relationship. There is no pre-definition to these distinctions. Asking for the most efficient reading of the graphic cannot cope with what is at stake. It might even be

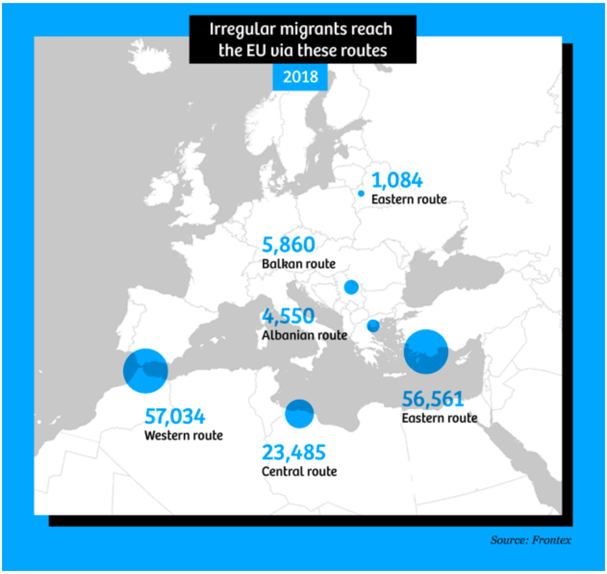
22 Also the title is changed, but I will focus on the graphic elements.

that the original design decisions are based on a notion of efficiency without acknowledging the drawing's implications.



The first two changes redrew distinctions of the arrow. The broad red arrows would most probably be preferable if efficiency alone guided the distinctions drawn. The example shows how flawed design can become under the motive of efficiency.

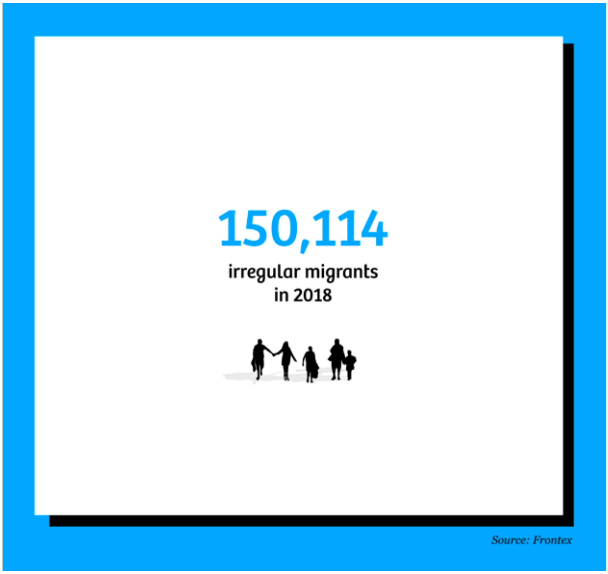
The next operation exchanges the distinction of the arrow itself. The article states that *arrows are reminiscent of battle maps: it looks as if Europe is under attack.* Furthermore, I would like to highlight what is represented here by the width of an arrow or the circle's radius. Drawing distinctions is always an operation of exclusion, abstraction, and simplification. There is no mark without the unmarked.



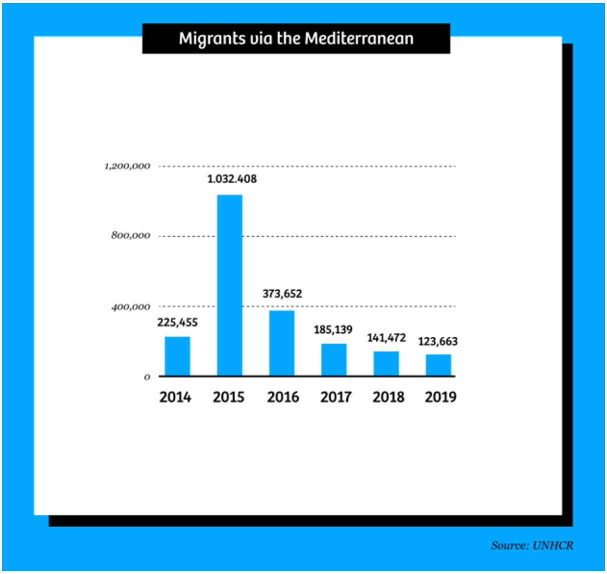
In this specific example, one symbol represents thousands of individual lives, complex, rich, and often sad entanglements in the world. Re-entering the distinction of 57,034 irregular migrants via the western route into the radius of a circle is immensely abstract. It is one distinction containing vast amounts of suffering and tragedy. The *calculus of design* approach reveals how the seemingly empty space is distinct as a consequence of step-by-step procedures. *What is drawn and what is left out holds consequences far beyond the question of efficiency; the design operation is not about what is created but about what is neglected.* The arrow Frontex applied to the data in its mappings is drawn into question.

The next operation of the newspaper article questions the outermost distinction of the map itself. What other forms can visualize the data?

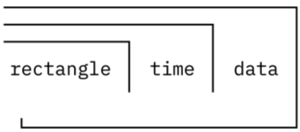
The distinctions in the data are reduced to the total number of irregular migrants in 2018. Human lives are distinct in one number, their sum.



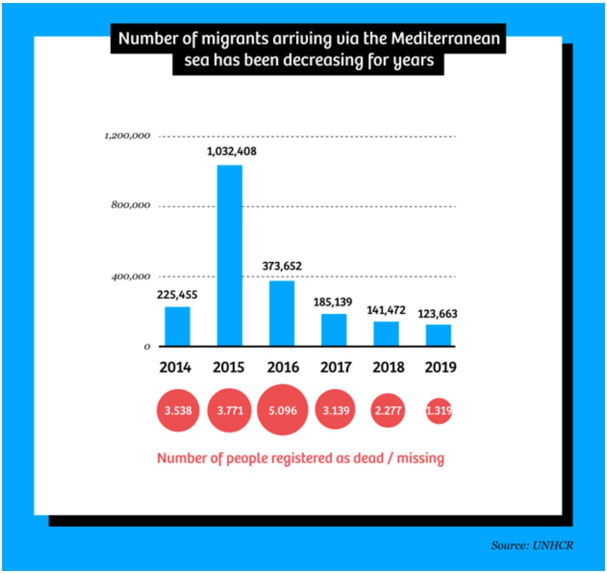
The authors redraw a novel set of differences onto the last unchanged distinction from collapsing distinctions — the data itself. The migration data from 2018 is extended and compared to similar surveys conducted from 2014 to 2019. This data is re-entered through the symbol of the rectangle, and each data point ordered along the horizontal axis.



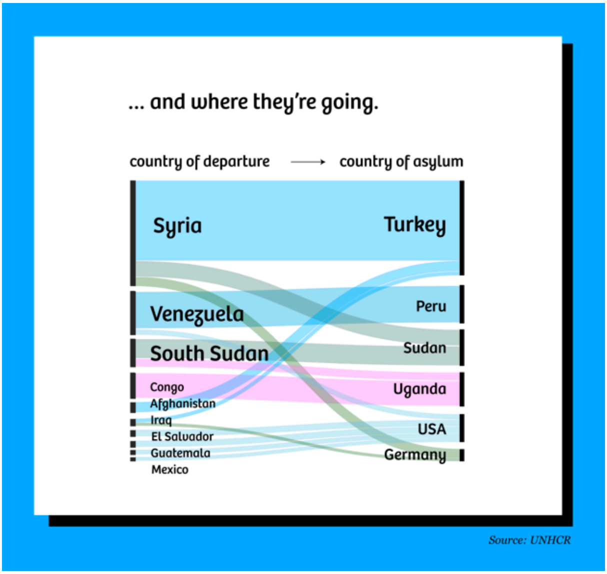
This operation changing from conglomerates of geographic movements towards Europe to comparisons of sums over the years changes perspective. The view shifts from Frontex's *invasion* map to the sound decline of irregular migration from 2015 onwards. *Drawing and re-drawing distinctions, the operation of form, the change in perspective: This is how insight is designed.*



The authors add another data difference in the next operation. Circles iterate the number of individuals registered as dead or missing. The distinction between rectangle and data is crossed to draw another dataset, another set of differences into the relation through the form of the circle.

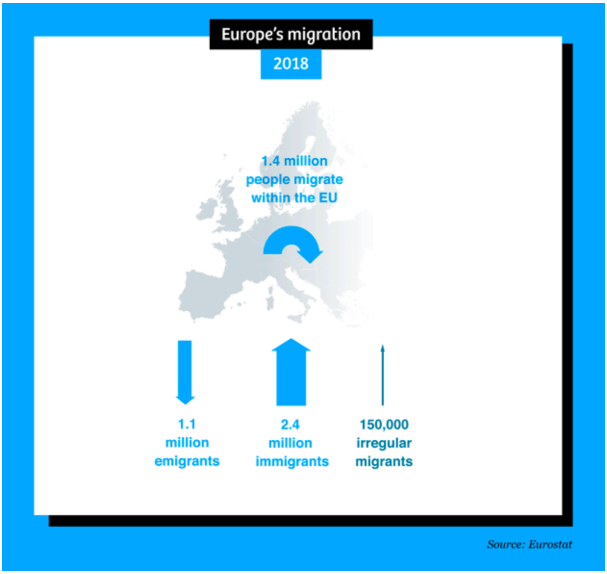


Furthermore, the authors change the perspective from Europe and the incoming irregular migrants to a view of their countries of origin and countries of asylum.



The graph altogether changes the perspective from the Frontex map. From the ten countries with the most asylum seekers, very few proceeded to Europe in 2018. Again, this picture draws few differences for a vast and complex entanglement of the geopolitics of Syria, Turkey, the European Union, and other cultural drawn distinctions. The form of the *calculus of design* always contains the unmarked, the unobserved. The article's final graphic performs another operation, changing from only observing irregular migrants to comparing these to emigrants, immigrants, and migration within Europe. By drawing the distinction of irregular migration next to other forms of human movement, scales between the various differentiations become visible. From the mathematically derived *calculus of design,* the examination of the article *How maps in the media make us more negative about migrants* is shown as an inquiry into marked and unmarked, observed and unobserved. Each change in the drawing of distinctions changes the observer's understanding.

Within the operations, the motive of efficiency is not only unsatisfactory but moreover not suitable to motivate the drawn distinctions. *Questioning, reflecting on what has been rendered visible, what has been left out, what marked, and what unmarked is not computable from the motivation of efficiency. The unmarked is excluded from the motive of efficiency; in contrast, it becomes the nucleus of deficiency.* The *calculus of design* is my contribution to making the *de—sign* process visible. The unmarked always comes into question by mapping the marked in the form of crosses from data to graphic.



There is no single motive from which to operate from contingency to form safely. The mapping of and thus reflection on drawn distinctions, the operations through the nested sets of differences is the de—sign towards in—sight. *Mapping the form, reflecting on the marked and unmarked states, allows de–sign to come into view, to become in–sight. The quest for efficiency leads towards one perspective of insight, but reflecting on deficiencies, re-entering the unmarked, leads towards multiplicity.*

The Operation of Exclusion

The questions around design are too fundamental for the motive of efficiency. The choice of a specific set of distinctions against all other possible forms renders visible the de—signer's conscious and unconscious intentions towards the form. Efficiency in this respect only articulates a narrow motive for working with the form. What is rendered visible, what is left out, cannot be determined by questions of efficiency; it operates beyond efficient decodings of graphic representation.

Reducing design to efficiency, to legibility, is a misconception of the agency design has concerning the world. Design as the act of drawing distinctions into the world reveals how reality can be encountered. There is not one existing state of reality but rather the continuous operation of contingency in designers drawing distinctions. The *real* continuously collapses into the marked by neglecting the unmarked. Neither efficiency nor legibility could answer questions on what to mark and, in so doing, leave unmarked. Efficiency underestimates design in sometimes dangerous ways. From the perspective of the *calculus of design*, I am interpreting deficiency as a motivation to question the drawing of distinctions continuously, being aware that marking by necessity unmarks. *De—sign as an operation of exclusion.*

The diagrammatic reflection of the *calculus of design* maps the marked and thus questions the unmarked. The approach goes beyond a theorization of design and its relationship to insights. By mapping, the de—sign operations towards drawing in—sight, the *calculus of design* offers a mode to reflect on the drawn distinctions visually. The example of mapping migration is one application, one applicable reflection to the nested layers within design. The approach allows an alternative perspective on computation, data, interfaces, and these structures' design. Every nested layer from data, algorithm, to graphic display is designed.

The *calculus of design* theorizes and diagrammatically applies how drawing distinctions design form our understanding and interaction with the world. Within statistical analysis research, the coastline paradox[23], the Simpson's paradox[24,25], the modifiable areal unit problem[26] are exemplifications of questions on how design influences the observed. Political systems are using the possibilities of drawing distinctions under the term gerrymandering.[27] Cartographer Bill Rankin overlaid 100 maps distinguishing the region *Midwest* within the USA.[28,29]

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23 Ref.: Richardson, L.F., Ashford, O.M. & Drazin, P.G., 1993. The Collected Papers of Lewis Fry Richardson: Volume 1, CUP Archive.

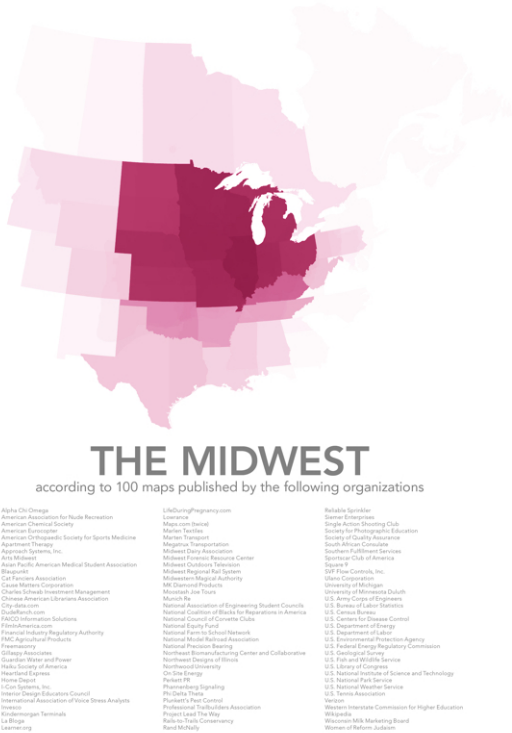
24 Ref.: Schneps, L. & Colmez, C., 2013. Math on Trial, Basic Books (AZ).

25 Ref.: Alipourfard, N., Fennell, P.G. & Lerman, K., 2018. Can you Trust the Trend: Discovering Simpson's Paradoxes in Social Data. arXiv.org, cs.CY.

26 Ref.: Pietrzak, M.B., 2014. The Modifiable Areal Unit Problem - Analysis of Correlation and Regression, Institute of Economic Research.

27 Ref.: Eilperin, J., 2006. The Gerrymander That Ate America. slate.com. Available at: https://slate.com/news-and-politics/2006/04/this-is-the-only-way-to-fix-congress.html Accessed February 26, 2021.

28 Ref.: Rankin, B., 2013. The Midwest. radicalcartography.net. Available at: http://



Drawing distinctions goes beyond the conception of *bias*; it is not something one could get rid of. *The theory is that the best we can do is become reflexive about the interaction between design and insight. The calculus of design draws one path towards an awareness of the operations one draws in-place to separate the world towards making sense of it.*

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www.radicalcartography.net/index.html?midwest Accessed February 26, 2021.

29 Lena V. Groeger collected various examples in her ProPublica article *When the Designer Shows Up In the Design*.

Ref.: Groeger, L.V., 2017. When the Designer Shows Up In the Design. propublica.org. Available at: https://www.propublica.org/article/when-the-designer-shows-up-in-the-design Accessed February 26, 2021.

Prospects of de–singing form

The *calculus of design* renders visible an alternative relationship between design and insight. The thesis is that *insights are not discovered, gained, explored, revealed, or mined, but are operatively designed*. *To understand what insights are, we have to map the processes leading towards them. The process, structures, and perspective the designer is embedded in and operates from need to be rendered into focus.* The diagrammatic notation of the *calculus of design* draws out the layers of the design operation. It is an approach towards visualizing the step-by-step procedures of design. A visualization about the process of creating visualizations, a meta-diagram towards drawing in—sight: distinction, indication, and re-entry are never given but always created, meaning: only by observing and re-designing the *how*, the operational distinctions, insight comes into sight. The *calculus of design* allows the re-entry of design onto itself. A self–reflective design includes what is excluded, always keeping in mind what is not designed, not distinguished. The *calculus of design* provides a minimal set of two axioms of *calling* and *crossing* to draw form. Simultaneously the notion of design through this minimal set of general principles renders vast. In the terminology of Slavoj Zizek : *... the very birth of humanity out of design.*[30]

From the results of my examination of *form*, *design*, *time*, *space* and in conclusion *insight* a vastly different relation between *data*, *visualization* and *insight* renders visible. *Insight is no longer found by mining, discovering, or distilling. It is a reflexive form-bound process of distinction and identity. Social co-existence creates structures that allow for furthermore differentiations.* From the seed, which distincts soil and sun for growth, to a global sensing system detecting global warming. *It is not how the world is, but how we make sense of the world.*[31] The calculus of design enables mapping of the underlying distinctions drawn of splicing. Designed contingency allows for further differentiation. *Form* exists as reductions of the *space* by a *designer* over *time*. *Insight is the result of this self-abstraction from reality.*

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30 Ref.: Zizek, S., 2006. Design as an Ideological State-Apparatus. ico-d.org. Available at: https://www.ico-d.org/connect/features/post/236.php Accessed February 26, 2021.

31 Ref.: Kentridge, W., 2014. William Kentridge: How we make sense of the world. Louisiana Channel. Available at: https://vimeo.com/107688864.

The three operations calling, re-calling, and crossing, create relational structures that render in—sight, into sight, in the first place. *Insight is a chain of operations, not a given but an interrelation. Design is the operation of drawing form; the reflection of form draws in—sight. This operational loop is a gradual re-designing of the understanding of the world we are embedded in. We are constantly on the edge of something else.*

Prospects

Before ending my journey through the *calculus of design,* I want to provide a brief outlook on future developments and investigations that intrigue me. The approach I have developed throughout this dissertation is less of a result and more a starting point to re-conceptualize and draw together media theory and design application. By questioning the crosses of the form and the spaces a form is embedded in, computational processes are deconstructed. I want to name three vital paths briefly: a *de—sign pedagogy*, the *limits of the calculus of design*, and its *more comprehensive application*.

One question I am currently starting to imagine negotiates the idea of a design pedagogy based on this approach: How would a design education look like based on the *calculus of design*? The various design fields, like graphic design, product design, architecture, and interface design, would certainly not be the guiding principles of the approach. Design from the *calculus of design* is more than what the various design sub-disciplines cover. *Design is a relational operation within a pre-defined structure of mediations drawn towards the world.* A design education based on this fundamental principle would follow the deconstruction of given distinctions and a re-iteration and re-imagination of current systems. A pedagogy based on this approach would be based on investigating seemingly given systems and exploring alternative paths to re-imagine these systems. A significant change within a design pedagogy based on the *calculus of design* would be a perspective on the media environments that the designed distinctions neglect. *Media theory and design practices would not be two separate entities, but imagined together.* The drawing of form depends on the mediated spaces of possibility collapsed through the *de—sign* process.

The computational calculus of calling, crossing, and reflecting draws into relation and into question various other research fields: One particularly intriguing branch this approach calls into focus is a reversal of the scholarly area of *digital humanities.* A standard definition of *digital humanities* is founded on the introduction of computing, digital tools, and methods in research areas of the humanities.[1] To me, the reversal seems much more needed: to apply humanistic modes of inquiry to computing, digital tools, and methods. The *calculus of design* offers one approach towards a reflexive usage of computation through the questions arising from the command *draw a distinction*. What are the structures a design is embedded within, and how do these structures influence the possibility space of the form? Current design fields are structured around specific sets of software spaces; a *de—sign* pedagogy would introduce a reflexive critique of these spaces, investigate alternatives, and map the *resolution* of spaces.

The entire conception of the *calculus of design* is based on a rigid structure of interdependencies of *next to* and *within*. The *unmarked* questions these linkages, but only drawing another distinction can re-enter the unobserved within the design calculus. A question I want to investigate in the future is: *Is there an act of design beyond the distinction?* Are there other imaginations beyond the separation of space by the form? The dissertation and all its exemplifications have shown how well the calculus of design conceptualizes the computational sign-based design process. I am intrigued about the cases in which the approach would fail and render its limitations visible. The *calculus of design* investigates the negative operation of drawing distinctions, of *de—signing*. This sign-based, iconographic perspective highlights the computational procedures within which a designer draws distinctions.

One excluded perspective is the undefinable, the affective correspondence, within the nested structure of the form. Seeing and interacting with a visualization is not only a rational but simultaneously an emotional exchange. Within the software/hardware configurations of computations, *de—sign* is an act of operating from space to form. Being shocked, engaged, disturbed, or entertained is nothing the current approach brings into perspective. The *calculus of design* approach conceptualizes a fundamental framework of the design process and its relation towards insights. The focus lies on the process of design and not its reception. On the human argumentation level, the emotional response, the affective layer, I cannot make statements based on the current approach. The superstructure of distinctions in which any visualization is embedded is only *form* within the system. Above the iconographic, the *form* is much more than a set of nested re-entering structures. I argue in the chapter *Design*: *The reflection of the drawn distinctions of a specific operative form leads to the question of motive. The calculus*

1 Ref.: Burdick, A. et al., 2012. Digital Humanities, MIT Press.

of design does not state a rationale in the first place but asks for it. Rather than claiming a text should be as legible as possible, the algorithm as fast as possible, the question of what is motivating a particular set of distinctions draws into focus. The approach opens up the question of motive without stating a specific one.[2]

The conceptualization, theory, approach, and diagrammatic method of the *calculus of design* cannot only be applied to visualization design. Similarly, a designer can reflect on creating a poster, house, or chair as nested sets of drawn distinctions. Furthermore, areas that do not necessarily fall into the categorization of design can be graphed by the nested crosses within form. I am chiefly envisioning the *de—sign* of datasets, databases, software structures, algorithms, and further scientific and political operations and systems. Any drawn distinction within a mediated space is an act of *de—sign*. But, what would this more expansive scope mean in relationship to insight? Is there a relationship between these otherwise diverging categorizations and the way we comprehend the world? What is in sight is always a collapsed complexity, a de—signed operation towards the world. I would be intrigued to apply this conception far beyond the scope of visualization design.

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2 In chapter *Design,* I intruduce various current design motives within data visualization.

Bibliography

Ackoff, R., *1989.* From Data to Wisdom. Journal of Applied Systems Analysis

Aicher, O., *2015.* The World as Design, John Wiley & Sons

Aicher, O., *2015.* die welt als entwurf, John Wiley & Sons

Albrecht, K. & Battles, M., *2020.* Their Names. Their Names. Available at: https://theirnames.org/ Accessed April 12, 2021

Albrecht, K., *2017.* Artificial Senses. Available at: https://artificial-senses.kimalbrecht.com/ Accessed February 19, 2020

Albrecht, K., *2019.* Distinction Machine. Available at: http://distinctionmachine.kimalbrecht.com/ Accessed February 19, 2020

Albrecht, K., *2020.* Hypercam. kimalbrecht.com. Available at: https://hypercam.kimalbrecht.com/ Accessed April 12, 2021

Albrecht, K., *2020.* Watching Machines. kimalbrecht.com. Available at: https://watching-machines.kimalbrecht.com/ Accessed April 12, 2021

Alexander, C., *1964.* Notes on the Synthesis of Form, Harvard University Press.

Alipourfard, N., Fennell, P.G. & Lerman, K., *2018.* Can you Trust the Trend: Discovering Simpson's Paradoxes in Social Data. arXiv.org, cs.CY.

Anderson, M., Meyer, B. & Olivier, P., *2011.* Diagrammatic Representation and Reasoning M. Anderson, B. Meyer, & P. Olivier, eds., London: Springer Science & Business Media.

Andrews, R.J., *2019.* Info We Trust, John Wiley & Sons.

Arndt, J. & Haenel, C., *2012.* Pi - Unleashed, Berlin, Heidelberg: Springer Science & Business Media.

Asimov, M., *1976.* Introduction to Design

BMIA., *2016.* “MAN transFORMS: The Documents” Hans Hollein in the new space created by Petra Blaisse. bmiaa.com. Available at: https://www.bmiaa.com/man-transforms-the-documents-hans-hollein-in-the-new-space-created-by-petra-blaisse/(#) Accessed October 26, 2020

Baang., *2015.* A Cybernetic Loop, wikipedia.org. Available at: https://en.wikipedia.org/wiki/Cybernetics#/media/File:Cybernetics.jpg.

Baecker, D., *1993.* Probleme der Form, Frankfurt am Main: Suhrkamp, p.46

Baecker, D., *1993a.* Kalkül der Form, Frankfurt am Main: Suhrkamp.

Baecker, D., *1993b.* Probleme der Form, Frankfurt am Main: Suhrkamp.

Baecker, D., *2002.* Wozu Systeme? Berlin: Kulturverlag Kadmos.

Baecker, D., *2007.* Form und Formen der Kommunikation, Frankfurt am Main: Suhrkamp.

Baecker, D., *2013.* Beobachter unter sich, Frankfurt am Main: Suhrkamp.

Baecker, D., *2014.* Kulturkalkül, Berlin: Merve.

Baecker, D., *2015.* Designvertrauen. Merkur, pp.89–97.

Baecker, D., *2015.* Working the Form: George Spencer-Brown and the Mark of Distinction. Mousse Magazine.

Baecker, D., *2017.* Mindful Design in the Humanities.

Baecker, D., *2018.* 4.0, Leipzig: Merve.

Baecker, D., *2018.* Why Catjects? catjects.wordpress.com. Available at: https://catjects.files.wordpress.com/2018/01/whycatjects3.pdf(#) *Accessed September 4, 2020*.

Baecker, D., *2019.* Intelligenz, künstlich und komplex, Lwipzig: Merve.

Barabási, A.-L. & Yan, G., *2015.* Spectrum of Controlling and Observing Complex Networks. pp.1–18.

Barabási, A.-L., *2005.* The origin of bursts and heavy tails in human dynamics. arXiv.org, cond-mat.stat-mech(7), pp.207–211.

Barabási, A.-L., *2012.* Graph theory and basic terminology Learning the language. barabasilab.neu.edu. Available at: http://barabasilab.neu.edu/courses/phys5116/content/Class2_NetSci_2012/02_Class_2012_Graphs.pdf Accessed April 19, 2014

Bateson, G., *1972.* Form, Substance and Difference. In Steps to an Ecology of Mind. University of Chicago Press.

Bauer, M. & Ernst, C., *2015.* Diagrammatik, transcript Verlag.

Bechmann, G. & Stehr, N., *2002.* The legacy of Niklas Luhmann. Society, 39(2), pp.67–75.

Belsey, C., *2013.* Poststrukturalismus, Stuttgart: Reclam Sachbuch.

Benacerraf, P. & Putnam, H., *1984.* Philosophy of Mathematics, Cambridge University Press.

Benkler, Y., *2000.* From consumers to users: Shifting the deeper structures of regulation toward sustainable commons and user access. Federal Communications Law Journal 52.

Berners-Lee, T. & Fischetti, M., *2008.* Weaving the Web

Bernstein, W.Z. et al., *2015.* Mutually Coordinated Visualization of Product and Supply Chain Metadata for Sustainable Design. Journal of Mechanical Design, 137(12), p.090301.

Bertin, J. & Berg, W.J., *2011.* Semiology of Graphics, Esri Press, p. 100-101

Bihanic, D., *2014.* New Challenges for Data Design, Springer.

Boehm, G., *1995.* Was ist ein Bild?

Bogen, S., *2005.* Schattenriss und Sonnenuhr: Überlegungen zu einer kunsthistorischen Diagrammatik. Zeitschrift für Kunstgeschichte.

Bojanova, I., The Digital Revolution: What's on the Horizon? IT Professional, 16(1), pp.8–12.

Borges, J.L., *1972.* A Universal History of Infamy, Argentina: Editorial Tor.

Bostock, M., *2014.* Design is a Search Problem, Available at: https://www.youtube.com/watch?v=fThhbt23SGM(https://www.youtube.com/watch?v=fThhbt23SGM)

Bounford, T., *2000.* Digital Diagrams, Watson-Guptill.

Braden, R., *1989.* Requirements for internet hosts--communication layers.

Brand, S. ed., *1969.* Spring. Whole Earth Catalog.

Brand, S., *1969.* Whole Earth Catalog S. Brand, ed., Menlo Park: Portola Institute, Inc. Available at: http://www.westdenhaag.nl/information/publications/Alphabetum/Laws_of_Form/Alphabetum_III_V8_ONLINE.pdf.

Brand, S., *1971.* The Last Whole Earth Catalog, Available at: https://archive.org/stream/B-001-013-719#mode/2up(#).

Bratton, B.H., *2016.* The Stack, MIT Press.

Bredekamp, H., Dünkel, V. & Schneider, B., *2015.* The Technical Image, University of Chicago Press.

Bredekamp, H., Schneider, B. & Dünkel, V., *2008.* Das Technische Bild, Walter de Gruyter.

Bridle, J., *2018.* New Dark Age, Verso.

Burdick, A. et al., *2012.* Digital Humanities, MIT Press.

Bush, R., *1985.* T.S. Eliot, Oxford University Press, USA.

Börner, K. & Polley, D.E., *2014.* Visual Insights, MIT Press.

Börner, K., *2015.* Atlas of Knowledge, MIT Press.

Börner, K., Bueckle, A. & Ginda, M., *2019.* Data visualization literacy: Definitions, conceptual frameworks, exercises, and assessments. National Academy of Sciences, 116(6), pp.1857–1864.

Cairo, A., *2012.* The Functional Art, New Riders.

Cairo, A., *2016.* The Truthful Art, New Riders.

Card, S.K., Mackinlay, J.D. & Shneiderman, B., *1999.* Readings in Information Visualization, Morgan Kaufmann.

Carrier, M., *2006.* Wissenschaftstheorie, Hamburg: Junius.

Carroll, L., *1876.* The Hunting of the Snark

Chang, R. et al., *2009.* Defining Insight for Visual Analytics. ieeexplore.ieee.org.

Chen, C. & Song, M., *2017.* Representing Scientific Knowledge, Cham: Springer.

Chen, C., *2002.* Information visualization.

Chen, C., *2003.* Mapping Scientific Frontiers, Springer Science & Business Media.

Chen, C., *2010.* Information visualization. Wiley Interdisciplinary Reviews: Computational Statistics, 2(4), pp.387–403.

Chun, W.H.K., *2005.* Control and Freedom, MIT Press.

Chun, W.H.K., *2016.* Updating to Remain the Same, MIT Press.

Cichold, I., *1925.* Programm der Konstruktivisten. Elementare Typographie.

Clarke, K.C. & Teague, P.D., *1998.* Cartographic symbolization of uncertainty. ACSM Annual Conference.

Cleveland, W.S. & McGill, R., *1984.* Graphical Perception and Graphical Methods for Analyzing Scientific Data, American Association for the Advancement of Science.

Colomina, B. & Wigley, M., *2016.* Are We Human?

Cook, K.A. & Thomas, J.J., *2005.* Illuminating the Path: The Research and Development Agenda for Visual Analytics, IEEE Computer Society, Los Alamitos, CA, United States(US).

Coy, W. et al., *2013.* Sichtweisen der Informatik W. Coy et al., eds., Wiesbaden: Springer-Verlag.

Cross, N., *2007.* Designerly Ways of Knowing, Springer Science & Business Media.

Daston, L. & Galison, P., *2010.* Objectivity, New York: Zone Books.

Der Begriff der Gestaltung, Klee, P. in Schneider, M., *2014.* Information über Gestalt, Birkhäuser.

Derrida, J., *1978.* Writing and Difference, University of Chicago Press.

Descartes, R., *1954.* The Geometry of René Descartes, Courier Corporation.

Descartes, R., La Géométrie, 1637.

Designation Agentur Münche., *2019.* Why does no-one understand my data visualization?

de la Torre Arenas, I., *2016.* The process of graphic journalism for breaking news… behance.net. Available at: https://www.behance.net/gallery/37259457/The-process-of-graphic-journalism-for-breaking-news Accessed December 17, 2019

Distelmeyer, J., *2017.* Machtzeichen, Bertz + Fischer.

Distelmeyer, J., *2018.* Drawing Connections – How Interfaces Matter. F. Hadler, A. Soiné, & D. Irrgang, eds. Interface Critique Journal, Vol. 1, pp.1–11.

Distelmeyer, J., *2020.* Interface II. Zur Programmatik leitender Prozesse der ‚digitalen Gegenwart'. In Wovon sprechen wir, wenn wir von Digitalisierung sprechen? Frankfurt am Main: CompaRe, pp. 59–73.

Distelmeyer, J., *2020.* Kontrollieren – (Inter-)Aktivitäten in, mit und von Computerspielen. In Videospiele als didaktische Herausforderung, p. 88-90

Distelmeyer, J., *2021.* Kritik der Digitalität, Wiesbaden: Springer VS.

Dragicevic, P., *2012.* 1968 – Jacques Bertin's Reorderable Matrices. dataphys.org. Available at: http://dataphys.org/list/bertins-reorderable-matrices/ Accessed January 10, 2020

Drucker, J., *2014.* Graphesis, Harvard University Press .

Druckrey, T., *1999.* Ars Electronica, MIT Press, p. 203.

Dubberly, H., *2004.* How do you design?

Dürsteler, J.C. & Engelhardt, Y., *2007.* InfoVis Diagram. infovis-wiki.net. Available at: https://infovis-wiki.net/wiki/2007-02-15:_New_issue_of_Inf@Vis!_(infovis.net)_on_%22InfoVis_Diagram%22_available Accessed December 17, 2019

D'Ignazio, C. & Klein, L., *2019.* Data Feminism, MIT Press Open.

Eilperin, J., *2006.* The Gerrymander That Ate America. slate.com. Available at: https://slate.com/news-and-politics/2006/04/this-is-the-only-way-to-fix-congress.html Accessed February 26, 2021

Electronic Maps to Assist Public Scienc., *2012.* EMAPS » Design process. emapsproject.com. Available at: http://www.emapsproject.com/blog/archives/1397 Accessed December 17, 2019

Eliot, T.S., *2015.* The Poems of T. S. Eliot Volume II, Faber & Faber.

Engelhardt, Y., *2002.* The Language of Graphics, Yuri Engelhardt.

Enzensberger, H.M., *1997.* Baukasten zu einer Theorie der Medien.

Etymology Dictionar., *2018.* compute | Origin and meaning of compute by Online Etymology Dictionary. etymonline.com. Available at: https://www.etymonline.com/word/compute Accessed July 14, 2018

Etymology Dictionar., *2018.* cybernetics (n.). etymonline.com. Available at: https://www.etymonline.com/word/cybernetics Accessed December 2, 2020

Etymology Dictionar., *2018.* insight (n.). etymonline.com. Available at: https://www.etymonline.com/word/insight Accessed March 24, 2021

Etymology Dictionary, de. etymonline.com. Available at: https://www.etymonline.com/word/de- Accessed October 26, 2020

Farocki, H., *2003.* Eye/Machine III, Auge/Maschine III

Figueroa, A., *2019.* Data Demystified—DIKW model. Available at: https://towardsdatascience.com/rootstrap-dikw-model-32cef9ae6dfb Accessed January 9, 2020

Fletcher, A., *2001.* The Art of Looking Sideways, Phaidon, p.370

Flusser, V., *1997.* Für eine Philosophie der Fotografie, European Photography.

Foerster, Von, H. & Glasersfeld, von, E., *2007.* Wie wir uns erfinden 5 ed., Carl-Auer.

Foerster, Von, H., *1993.* KybernEthik, Merve Verlag.

Foerster, Von, H., *2003.* Cybernetics of Cybernetics. In Understanding Understanding. New York: Springer, New York, NY, pp. 283–286.

Foucault, M., *1980.* The Confession of the Flesh C. Gordon, ed. PowerKnowledge Selected Interviews and Other Writings.

Foucault, M., *1983.* This is not a Pipe, University of California Press.

Foucault, M., *2012.* The Archaeology of Knowledge, London and New York: Routledge.

Friedrich Kluge, Etymologisches Wörterbuch der deutschen Sprache, 2002.

Frutiger, A., *1989.* Signs and Symbols, New York: Van Nostrand Reinhold.

Fry, B., *2004.* computational information design.

Fry, B., distellamap. benfry.com. Available at: http://benfry.com/distellamap/ Accessed May 30, 2018

Galison, P., *2006.* Images scatter into data, data gather into images, Images: A Reader.

Galloway, A.R., *2006.* Protocol, MIT Press.

Geiger, A., Hennecke, S. & Kempf, C., *2005.* Spielarten des Organischen in Architektur, Design und Kunst.

Gilbert, E.W., *1958.* Pioneer Maps of Health and Disease in England. The Geographical Journal, 124(2), p.172 -183.

Greitzer, F., *2011.* Defining a Framework for Visual Analytics. vacommunity.org. Available at: http://www.vacommunity.org/article28 Accessed December 11, 2019

Grimm, R.E., *1973.* The Autobiography of Leonardo Pisano. Fibonacci Quarterly, pp.99–104.

Groeger, L.V., *2017.* When the Designer Shows Up In the Design. propublica.org. Available at: https://www.propublica.org/article/when-the-designer-shows-up-in-the-design Accessed February 26, 2021

Grosskurth, A. & Godfrey, M.W., *2005.* A reference architecture for web browsers. On pp. 661–664.

Gödel, K., *1929.* Über die Vollständigkeit des Logikkalküls. University of Vienna.

Hacking, I., *2014.* Why Is There Philosophy of Mathematics At All? Cambridge University Press.

Haraway, D., *1988.* Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. Feminist Studies, 14.

Harding, S.G., *1998.* Is Science Multicultural? Indiana University Press.

Harper, D., *2020.* observe. etymonline.com. Available at: https://www.etymonline.com/word/observe

Harper, D., *2021.* algebra (n.). etymonline.com. Available at: https://www.etymonline.com/word/algebra#etymonline_v_8140 Accessed February 16, 2021

Harper, D., *2021.* arithmetic (n.). etymonline.com. Available at: https://www.etymonline.com/word/arithmetic#etymonline_v_16998 Accessed February 16, 2021

Harper, D., gain | Search Online Etymology Dictionary. etymonline.com. Available at: https://www.etymonline.com/search?q=gain Accessed January 23, 2020

Heath, T.L., *2015.* The Thirteen Books of Euclid's Elements, Cambridge University Press.

Heer, J., *2018.* Constructing Charts and Graphs. In Revisiting Cybernetic Serendipity. Washington.

Hegel, G.W.F., *1807.* Phänomenologie des Geistes, Bamberg und Würzburg.

Heider, F., *2005.* Ding und Medium, Kulturverlag Kadmos.

Heyman, D. et al., Visual Variables. axismaps.com. Available at: https://www.axismaps.com/guide/general/visual-variables/ Accessed December 7, 2019

Hilbert, D., *1996.* Axiomatic thought. In From Kant to Hilbert. Oxford: Oxford University Press, pp. 1114–1115.

Hirdina, H., *2005.* Design. In Ästhetische Grundbegriffe.

Hofstadter, D.R., *1979.* Godel, Escher, Bach, Basic Books.

Hofstadter, D.R., *2007.* I Am a Strange Loop, Hachette UK.

Hollein, H., *1974.* MANtransFORMS. hollein.com. Available at: https://www.hollein.com/ger/Schriften/Texte/MANtransFORMS Accessed October 26, 2020

Holmes, N., *1993.* The Best in Diagrammatic Graphics, Rotovision/Quarto.

Huron, S., *2014.* Constructive Visualization : A token-based paradigm allowing to assemble dynamic visual representation for non-experts.

IBM Cloud Garage, Data and analytics for insights and visualization. ibm.com. Available at: https://www.ibm.com/cloud/garage/architectures/dataAnalyticsArchitecture/ Accessed March 14, 2019

Intg., *2007.* Simple feedback model. AB < 0 for negative feedback, wikipedia.org. Available at: https://en.wikipedia.org/wiki/Cybernetics#/media/File:Ideal_feedback_model.svg.

Jacobs, F., *2014.* Agloe: How a Completely Made Up New York Town Became Real. bigthink.com. Available at: http://bigthink.com/strange-maps/643-agloe-the-paper-town-stronger-than-fiction

Jayatilleke, K.N., *1967.* The Logic of Four Alternatives. Philosophy East and Wes., *17.* pp.69–83.

Jones, J.C., *1963.* Conference on Design Methods.

Jones, J.C., *1992.* Design Methods, John Wiley & Sons.

Jones, J.C., *1970.* The State of the Art in Design Methods,

Joseph, G.G., *2011.* The Crest of the Peacock, Princeton University Press.

Jung, E.C. & Sato, K., *2006.* Context-Sensitive Visualization for User-Centered Information System and Product Design.

Jung, M., *2014.* Wilhelm Dilthey, Hamburg: Junius.

Kant, I., *1956.* Kritik der reinen Vernunft, AA IV 92

Kauffman, L.H., *2001.* Reformulating the Map Color Theorem. arXiv.org, math.CO. Available at: http://arxiv.org/abs/math/0112266v2 Accessed February 16, 2021

Kauffman, L.H., *2001.* The Mathematics of Charles Sanders Peirce. Cybernetics and Human Knowin., *8.* pp.79–110.

Kauffman, L.H., *2006.* Laws of Form - An Exploration in Mathematics and Foundations, Available at: https://homepages.math.uic.edu/

Kauffman, L.H., *2019.* The Semiotics of Laws of Form. Available at: https://www.researchgate.net/publication/331672992_The_Semiotics_of_Laws_of_Form

Keim, D. et al., *2008.* Visual Analytics: Definition, Process, and Challenges. In Information Visualization. Lecture Notes in Computer Science. Berlin, Heidelberg: Springer, Berlin, Heidelberg, pp. 154–175.

Kellner, H. & Heuberger, F., *1988.* Zur Rationalität der Postmoderne und ihrer Träger in Kultur und Alltag. Soziale Welt, (6), pp.325–337.

Kelly, K., *2010.* What Technology Wants, Penguin.

Kemp, W., *1974.* Disegno. In Marburger Jahrbuch für Kunstwissenschaft. Beiträge zur Geschichte des Begriffs zwischen 1547 und 1607. pp. 219–240. Available at: https://www.jstor.org/stable/1348597.

Kentridge, W., *2014.* William Kentridge: How we make sense of the world. Louisiana Channel. Available at: https://vimeo.com/107688864.

Kirk, A., *2018a.* Data Visualisation - A Game of Decisions with Andy Kirk, Available at: https://www.youtube.com/watch?v=GVkXbQOzKNs

Kirk, A., *2018b.* Data Visualisation: A Game of Decisions. In Sage webinar.

Kirk, A., *2019.* Data Visualisation, SAGE.

Kittler, F., *2007.* Die Endlichkeit der Algorithmen | transmediale. transmediale.de.

Klee, P., *2014.* Der Begriff der Gestaltung. In Information über Gestalt. Braunschweig/Wiesbaden: Birkhäuser.

Kleinman, Z., *2019.* Emma Haruka Iwao smashes pi world record with Google help. BBC. Available at: https://www.bbc.com/news/technology-47524760.

Klinke, H., *2014.* Art Theory as Visual Epistemology, Cambridge Scholars Publishing.

Kluge, F., *2019.* Etymologisches Wörterbuch der deutschen Sprache A. Schirmer, ed., Walter de Gruyter GmbH & Co KG.

Korzybski, A., *1958.* Science and Sanity, Institute of GS.

Kosack, S. et al., *2018.* Functional structures of US state governments. National Academy of Sciences, 115(46), pp.11748–11753.

Kosslyn, S.M., *1994.* Elements of Graph Design, W H Freeman & Company.

Kowalski, R., *1979.* Algorithm = logic + control. Communications of the ACM, 22(7), pp.424–436.

Krassanakis, V. & Vassilopoulou, V., *2018.* Introducing a data-driven approach towards the identification of grid cell size threshold (CST) for spatial data visualization: An application on marine spatial planning (MSP). Journal of Urban and Environmental Engineering, (12).

Krygier, J. & Wood, D., *2011.* Making Maps, Guilford Press.

Krygier, J.B., Geography 353 Cartography and Visualization.

Krämer, S., *1998.* Form als Vollzug oder: Was gewinnen wir mit Niklas Luhmanns Unterscheidung von Medium und Form?

Krämer, S., *2009a.* Epistemology of the Line. Studies in Diagrammatology and Diagram Praxis.

Krämer, S., *2009b.* Operative Bildlichkeit. In Logik des Bildlichen. Von der ‚Grammatologie' zu einer ‚Diagrammatologie'? Reflexionen über erkennendes ‚Sehen'. pp. 94–122.

Krämer, S., *2016.* Figuration, Anschauung, Erkenntnis, Suhrkamp Verlag.

Krämer, S., *2020.* Cultural history of digitisation. Making Sense of the Digital Society. Available at: https://www.hiig.de/en/events/sybille-kraemer-cultural-history-of-digitisation/.

Latour, B. & Weibel, P., *2002.* Iconoclash: Beyond the Image Wars in Science, Religion and Art. Cambridge.

Latour, B., *2008.* A Cautious Prometheus?

Lau, F., *2015.* Die Form der Paradoxie, Carl-Auer Verlag.

Leary, T., *1991.* The Cyberpunk: the individual as reality pilot. In Storming the Reality Studio. Duke University Press.

Lima, M., *2011.* Information Visualization Framework. visualcomplexity.com. Available at: http://www.visualcomplexity.com/vc/blog/?p=1076 Accessed December 17, 2019

Liu, Z. & Stasko, J.T., *2010.* Mental Models, Visual Reasoning and Interaction in Information Visualization: A Top-down Perspective. ieeexplore.ieee.org.

Lohse, G.L. et al., *1994.* A classification of visual representations. Communications of the ACM, 37(12), pp.36–49.

Loukissas, Y.A., *2019.* All Data Are Local, MIT Press.

Lovell, S., *2011.* Dieter Rams: As Little Design as Possible, Phaidon Press.

Luhmann, N. & Kieserling, A., *2002.* Die Politik der Gesellschaft, Frankfurt am Main: Suhrkamp.

Luhmann, N., *1970.* Soziologische Aufklärung 1, Wiesbaden: VS Verlag für Sozialwissenschaften.

Luhmann, N., *1987.* Soziale Systeme, Frankfurt am Main: Suhrkamp.

Luhmann, N., *1992.* Die Wissenschaft der Gesellschaft, Frankfurt am Main: Suhrkamp.

Luhmann, N., *1995.* Das Recht der Gesellschaft, Frankfurt am Main: Suhrkamp.

Luhmann, N., *1995.* Die Kunst der Gesellschaft, Frankfurt am Main: Suhrkamp.

Luhmann, N., *1998.* Die Gesellschaft der Gesellschaft, Suhrkamp.

Luhmann, N., *2000.* Die Religion der Gesellschaft, Frankfurt am Main: Suhrkamp.

Luhmann, N., *2006.* System as Difference. Organization, 13(1), p.37–57.

Luhmann, N., *2009.* Die Realität der Massenmedien, Springer-Verlag.

Luhmann, N., *2011a.* Das Medium der Kunst. In Niklas Luhmann Aufsätze und Reden. Reclam.

Luhmann, N., *2011b.* Erkenntnis als Konstruktion. In Jahraus, ed. Niklas Luhmann Aufsätze und Reden.

Lupi, G., *2016.* How Accurat's Giorgia Lupi Approaches Data-Viz Design. Available at: https://www.tableau.com/about/blog/2016/3/drawing-and-data-visualizations-tool-allow-connections-be-made-51060 Accessed February 27, 2019

MDN contributor., *2021.* Paths. developer.mozilla.org. Available at: https://developer.mozilla.org/en-US/docs/Web/SVG/Tutorial/Paths Accessed March 3, 2021

MacEachren, A.M., *2001.* An evolving cognitive-semiotic approach to geographic visualization and knowledge construction. Information Design Journal, 10(1), pp.26–36.

Mackinlay, J., *1986.* Automating the design of graphical presentations of relational information. ACM Transactions on Graphics (TOG), 5(2), pp.110–141.

Maeda, J., *2012.* How art, technology and design inform creative leaders. TEDGlobal. Available at: https://www.ted.com/talks/john_maeda_how_art_technology_and_design_inform_creative_leaders

Magritte, R. & Torczyner, H., *1977.* Magritte, ideas and images.

Magritte, R., *1929.* La Trahison des images.

Manovich, L., *2001.* The Language of New Media, MIT Press.

March, L., *1984.* The Logic of Design. In Developments of Design Methodology. New York: John Wiley.

Mareis, C., *2014a.* Design als Wissenskultur, transcript Verlag.

Mareis, C., *2014b.* Theorien des Designs, Junius.

Masud, L. et al., *2010.* From data to knowledge-visualizations as transformation processes within the data-information-knowledge continuum. ieeexplore.ieee.org.

Mazur, B., *2018.* Axiomatic Reasoning, Harvard University. Available at: http://people.math.harvard.edu/

McCandless, D., *2010.* The beauty of data visualization. TED.

McCandless, D., *2012.* Information is Beautiful, Collins Publishers.

McCandless, D., *2014.* Knowledge is Beautiful, HarperCollins.

McCandless, D., About — Information is Beautiful. informationisbeautiful.net. Available at: https://informationisbeautiful.net/about/ Accessed 2019.

McLuhan, M., *1965.* The Future of Man in the Electric Age. Min.: 7:00 Available at: http://www.marshallmcluhanspeaks.com/interview/1965-the-future-of-man-in-the-electric-age/

Meirelles, I., *2013.* Design for Information, Rockport Publishers.

Mersch, D., *2006a.* Mediale Paradoxa. Zum Verhältnis von Kunst und Medien. Sic et Non. zeitschrift fur philosophie und kultur, pp.1–18.

Mersch, D., *2006b.* Medientheorien zur Einführung, Hamburg: Junius.

Mersch, D., *2011.* Aspects of Visual Epistemology: On the “Logic” of the Iconic.

Mersch, D., *2013.* Ordo ab chao - Order from Noise.

Meurer, B. & Vincon, H., *1990.* Industrielle Ästhetik, Anabas-Verlag.

Meyer, H., bauen H. Meyer, ed. bauhaus. Zeitschrift für Gestaltun., *4.* Available at: https://monoskop.org/images/c/c8/Bauhaus_2-4_1928.pdf.

Minard, C.J., *1869.* Carte figurative des pertes successives en hommes de l'Armée Française dans la campagne de Russie 1812–1813,

Moholy-Nagy, L., *1929.* von material zu architektur.

Munzner, T., *2009.* A Nested Model for Visualization Design and Validation. IEEE Transactions on Visualization and Computer Graphics, 15(6), pp.921–928.

Munzner, T., *2014.* Visualization Analysis and Design, CRC Press.

Murray, S., *2013.* Interactive Data Visualization for the Web, O'Reilly Media, Inc.

Murray, S., *2014.* The Keys to a Successful Data Design Process with Scott Murray, (https://www.youtube.com/watch?v=ZMB_6OeCEP8)

Murray, S., *2014.* data-vis-process. github.com. Available at: https://github.com/alignedleft/data-vis-process Accessed January 9, 2020

Muthesius, H., *1909.* Kultur und Kunst, Jena: Eugen Diederichs.

Müller, B., *2017.* Design in Four Revolutions. medium.com. Available at: https://medium.com/@borism/design-in-four-revolutions-fb0f01a806d2 Accessed February 16, 2021

Münker, S. & Roesler, A., *2008.* Was ist ein Medium? Suhrkamp.

Nagel, J., *2014.* Knowledge, Oxford: Oxford University Press.

Nake, F., *2001.* Vilém Flusser und Max Bense des Pixels angesichtig werdend. In Fotografie denken. Eine Überlegung am Rande der Computergrafik. pp. 169–182. Available at: https://archive.compart.uni-bremen.de/2006/agis-website/ARCHIV/Publikationen/FlusserBense.pdf.

Niedderer, K., *2007.* Mapping the meaning of knowledge in design research.

Nigan Bayazit. “Investigating Design: A Review of Forty Years of Design Research.” English. In: dx.doi.org 20.1 (Mar. 2006).

Norman, D., *2013.* The Design of Everyday Things, Hachette UK.

Norman, D.A., *1986.* Cognitive Engineering. In User Centred System Design. Lawrence Erlbaum Association.

Norman, D.A., *1993.* Things that Make Us Smart, Basic Books.

Norman, D.A., *2010.* Living with Complexity, MIT Press.

Norris, K.W., *1963.* The Morphological Approach to Engineering Design. Conference on Design Methods.

North, C., *2006.* Toward measuring visualization insight. ieeexplore.ieee.org.

Okasha, S., *2002.* Philosophy of Science, Oxford: Oxford University Press.

Oxford Dictionaries, morphology | Definition of morphology in English by Oxford Dictionaries. oxforddictionaries.com. Available at: https://en.oxforddictionaries.com/definition/morphology Accessed March 22, 2019

Papanek, V., *1971.* Design for the Real World

Patterson, R.E. et al., *2014.* A human cognition framework for information visualization. Computers & Graphic., *42.* pp.42–58.

Peirce, C.S., *1933.* A Boolean Algebra with One Constant. In C. Hartshorne & P. Weiss, eds. Collected Papers of Charles Sanders Peirce, Volume The Simplest Mathematics.

Peirce, C.S., *1974.* Collected Papers of Charles Sanders Peirce, Harvard University Press.

Pietrzak, M.B., *2014.* The Modifiable Areal Unit Problem - Analysis of Correlation and Regression, Institute of Economic Research.

Plat., *1943.* Plato's The Republic, New York: :Books, Inc, 514a–520a

Playfair, W., *1786.* The Commercial and Political Atlas.

Plumpe, M., *2014.* Systemtheoretische und konstruktivistische Medientheorien. In J. Schröter, ed. Handbuch Medienwissenschaft.

Postel, J., *1981.* Internet Protocol. Available at: https://tools.ietf.org/html/rfc791.

Postman, N. (2006). Media Ecology Education. Explorations in Media Ecology, 5(1), 5–14. doi:10.1386/eme.5.1.5_1

Postman, N., *1998.* Five Things We Need to Know About Technological Change. The New Technologies and the Human Person Communicating the Faith in the New Millennium. Available at: https://student.cs.uwaterloo.ca/

Priest, G., *2014.* Beyond true and false E. Lake, ed. aeon.co. Available at: https://aeon.co/essays/the-logic-of-buddhist-philosophy-goes-beyond-simple-truth Accessed December 2, 2020

Priest, G., *2014.* Beyond true and false. aeon.co. Available at: https://aeon.co/essays/the-logic-of-buddhist-philosophy-goes-beyond-simple-truth Accessed March 2, 2021

Quian Quiroga, R., *2012.* Borges and Memory, MIT Press. Loc. 2131-2136

Ralph Johnson, Erich Gamma, John Vlissides, and Richard Helm. Design Patterns. English. Elements of Reusable Object- Oriented Software. Addison-Wesley, 1995.

Rankin, B., *2013.* The Midwest. radicalcartography.net. Available at: http://www.radicalcartography.net/index.html?midwest Accessed February 26, 2021

Rao, V.R., *2018.* From data to knowledge. ibm.com. Available at: https://www.ibm.com/developerworks/library/ba-data-becomes-knowledge-1/index.html Accessed March 14, 2019

Rendgen, S., *2018.* The Minard System, Chronicle Books.

Rendgen, S., *2019.* The History of Information Graphics, Taschen.

Resnikoff, H.L., *2012.* The Illusion of Reality, New York, NY: Springer Science & Business Media.

Rheinberger, H.-J., *2007.* Historische Epistemologie, Hamburg: Junius.

Richards, C.J., *1984.* Diagrammatics, Royal College of Art.

Richardson, L. F., *1961.* The problem of contiguity: An appendix to Statistic of Deadly Quarrels in Richardson, L.F., Ashford, O.M. & Drazin, P.G., *1993.* The Collected Papers of Lewis Fry Richardson: Volume 1, CUP Archive.

Richardson, L.F., Ashford, O.M. & Drazin, P.G., *1993.* The Collected Papers of Lewis Fry Richardson: Volume 1, CUP Archive.

Rifkin, J., *2004.* The End of Work, Tarcher.

Rifkin, J., *2011.* The Third Industrial Revolution, St. Martin's Press.

Ritchey, T., *2002.* General Morphological Analysis. swemorph.com

Rittel, H.W.J. & Webber, M.M., *1972.* Dilemmas in a General Theory of Planning

Robinson, A.C., *2013.* Highlighting in Geovisualization. Cartography and Geographic Information Science, 38(4), pp.373–383.

Rodighiero, D. & Romele, A., *2020.* The Hermeneutic Circle of Data Visualization: the Case Study of the Affinity Map. Techné: Research in Philosophy and Technology, 24(2).

Rogers, H., *1987.* Theory of Recursive Functions and Effective Computability, Cambridge: MIT Press.

Roose, K., *2020.* Welcome to the "Rabbit Hole." New York Times. Available at: https://www.nytimes.com/2020/04/16/technology/rabbit-hole-podcast-kevin-roose.html.

Rorty, R., *1992.* The Linguistic Turn, University of Chicago Press.

Rosling, H., *2006.* The best stats you've ever seen. ted.com. Available at: https://www.ted.com/talks/hans_rosling_the_best_stats_you_ve_ever_seen.

Rosling, H., Rönnlund, A.R. & Rosling, O., *2018.* Factfulness, Flatiron Books.

Ross, S.D., *2004.* Aristotle, Routledge.

Rost, L.C., *2016.* One Chart, Twelve Charting Libraries. lisacharlotterost.de. Available at: https://lisacharlotterost.de/2016/05/17/one-chart-code/ Accessed October 26, 2020

Rost, L.C., *2016.* One Chart, Twelve Tools. lisacharlotterost.de. Available at: https://lisacharlotterost.de/2016/05/17/one-chart-tools/ Accessed October 26, 2020

Rost, L.C., *2017.* What Questions to Ask When Creating Charts. blog.datawrapper.de. Available at: https://blog.datawrapper.de/better-charts/index.html Accessed December 17, 2019

Rost, L.C., *2018.* One Chart, Nine Tools – Revisited. lisacharlotterost.de. Available at: https://lisacharlotterost.de/datavistools-revisited Accessed October 26, 2020

Rowley, J., *2007.* The wisdom hierarchy: representations of the DIKW hierarchy. Journal of Information Science, 33(2), pp.163–180.

Rubin, E., *1915.* Synsoplevede figurer, studier i psykologisk analyse. København og Kristiania: Nordisk forlag.

Rushkoff, D., *2010.* Program or be Programmed, OR Books.

Russell, B., *1980.* Correspondence with Frege. In Gottlob Frege: Philosophical and Mathematical Correspondence. University of Chicago Press.

Russell, B., *1996.* The Principles of Mathematics, New York: W. W. Norton & Company.

SAS Institut., *2019.* Data Visualization: What it is and why it matters. sas.com. Available at: https://www.sas.com/en_sa/insights/big-data/data-visualization.html Accessed March 1, 2019.

Sacha, D. et al., *2014.* Knowledge Generation Model for Visual Analytics. Visualization and Computer Graphics, IEEE Transactions on, 20(12), pp.1604–1613.

Sava, A., *2019.* Operating systems default serif fonts. fontsarena.com. Available at: https://fontsarena.com/blog/operating-systems-default-serif-fonts/ Accessed March 3, 2021

Schneider, B., *2016.* Burning worlds of cartography: a critical approach to climate cosmograms of the Anthropocene. Geo: Geography and Environment, 3(2), pp.e00027–15.

Schneider, B., Ernst, C. & Wöpking, J., *2016.* Diagrammatik-Reader, Walter de Gruyter

Schneps, L. & Colmez, C., *2013.* Math on Trial, Basic Books (AZ).

Schnädelbach, H., *2002.* Erkenntnistheorie, Hamburg: Junius.

Schröter, J., *2014.* Handbuch Medienwissenschaft, Springer-Verlag.

Schönwälder, T., Wille, K. & Hölscher, T., *2013.* George Spencer Brown, Springer-Verlag.

Sedley, D., *2003.* Plato's Cratylus, assets.cambridge.org.

Sedlmair, M., Meyer, M. & Munzner, T., *2012.* Design Study Methodology: Reflections from the Trenches and the Stacks. IEEE Transactions on Visualization and Computer Graphics, 18(12), pp.2431–2440.

Shannon, C.E., *1948.* A Mathematical Theory of Communication. The Bell System Technical Journa., *27.* pp.379–423.

Simon, F.B., *2017.* Einführung in die Systemtheorie und Konstruktivismus, Heidelberg: Carl-Auer Verlag.

Simon, H.A., *1996.* The Sciences of the Artificial, MIT Press.

Snow, C.P. & Collini, S., *2012.* The Two Cultures, Cambridge University Press.

Sparkes, M., *2014.* Facebook sex changes: which one of 50 genders are you? The Telegraph. Available at: https://www.telegraph.co.uk/technology/facebook/10637968/Facebook-sex-changes-which-one-of-50-genders-are-you.html.

Spear, M.E., *1969.* Practical charting techniques, McGraw-Hill Companies.

Spencer-Brown, G., *1969.* Laws of Form, First Edition, London: Allen & Unwin.

Spencer-Brown, G., *1973.* AUM Conference Transcript Session One to Four. AUM Conference.

Spencer-Brown, G., *1973.* AUM Conference Transcript Session One. AUM Conference. Available: https://web.archive.org/web/20060821204917/http://lawsofform.org/aum/session1.html(https://web.archive.org/web/20060821204917/http://lawsofform.org/aum/session1.html)

Spencer-Brown, G., *1973.* AUM Conference Transcript Session Two. AUM Conference. Available at: https://web.archive.org/web/20060821185718/http://lawsofform.org/aum/session2.html(#)

Spencer-Brown, G., *1997.* Laws of Form German Language edition, Bohmeier Verlag.

Spencer-Brown, G., Vita. lawsofform.org. Available at: https://web.archive.org/web/20040611164702/http://www.lawsofform.org/gsb/vita.html Accessed February 11, 2021

Stefaner, M., Truth & Beauty - Data visualization. truth-and-beauty.net. Available at: https://truth-and-beauty.net/ Accessed February 28, 2019

Stevenson, A. & Lindberg, C.A., *2010.* New Oxford American Dictionary 3rd Edition, Oxford University Press.

Stevenson, A., *2010.* Oxford Dictionary of English, Oxford University Press.

Städtke, K., *2005.* Form. In Ästhetische Grundbegriffe. J. B. Metzler Verlag.

Sullivan, Louis H., *1896.* The Tall Office Building Artistically Considered

Taylor, R.S., *1986.* Value-added Processes in Information Systems, Norwood, N.J. : Ablex Publishing Corporation.

Tilmans, W., *2017.* Lichtjahre. Zeit Magazi., *23.* Available at: https://www.zeit.de/zeit-magazin/2017/23/wolfgang-tilmans-fotograf-kuenstler/seite-2.

Tufte, E.R., *1983.* The Visual Display of Quantitative Information, Graphics Press.

Tufte, E.R., *1997.* Visual Explanations, Graphics Press USA.

Tukey, J.W., *1977.* Exploratory Data Analysis, Pearson College Division.

Tydecks, W., *2019.* A commentary on Laws of Form from Spencer-Brown. tydecks.info. Available at: http://www.tydecks.info/online/themen_e_spencer_brown_logik.html Accessed December 2, 2020

Utrilla, P. et al., *2009.* A palaeolithic map from 13,660 calBP: engraved stone blocks from the Late Magdalenian in Abauntz Cave (Navarra, Spain). Journal of human evolutio., *57.* pp.99–111.

van Houtum, H. & Bueno Lacy, R., *2020.* The migration map trap. On the invasion arrows in the cartography of migration. Mobilities, 15(2), pp.196–219.

Van Leeuwen, T., *2005.* Introducing Social Semiotics, Psychology Press.

Vermeulen, M., de Korte, L. & van Houtum, H., *2020.* How maps in the media make us more negative about migrants. thecorrespondent.com. Available at: https://thecorrespondent.com/664/how-maps-in-the-media-make-us-more-negative-about-migrants/738023272448-bac255ba Accessed February 26, 2021

Virchow, R., *1877.* Die Freiheit der Wissenschaft im modernen Staat

Vyrgioti, P., *2016.* Data Visualization: From Information to Wisdom. blog.sas.com. Available at: https://blogs.sas.com/content/brightdata/2016/08/01/data-visualization-from-information-to-wisdom/ Accessed March 14, 2019

Ware, C., *2010.* Visual Thinking, Elsevier.

Ware, C., *2013.* Information Visualization, Elsevier.

Wiederkehr, B., Benjamin Wiederkehr's Master Thesis - Visualization Design Process. master.benjaminwiederkehr.com. Available at: http://master.benjaminwiederkehr.com/journal/design-process Accessed February 27, 2019

Wiener, N., *1948.* Cybernetics Or Control and Communication in the Animal and the Machine, MIT Press.

Wiener, N., *1988.* The Human Use Of Human Beings, Hachette UK.

Wittgenstein, L., *1922.* Tractatus Logico-philosophicus.

Wong, P.C. et al., Visual Analytics. IEEE Computer Graphics.

Wurman, R.S., *1990.* Information Anxiety, Bantam Books.

Wurman, R.S., *1997.* Information Architects, Graphis Incorporated.

Yantis, S., *2001.* Visual Perception, Psychology Press.

Yau, N., *2016.* Shorten the Visualization Path Back to Reality. flowingdata.com. Available at: https://flowingdata.com/2016/09/14/shorten-the-visualization-path-back-to-reality/ Accessed December 17, 2019

Zizek, S., *2006.* Design as an Ideological State-Apparatus. ico-d.org. Available at: https://www.ico-d.org/connect/features/post/236.php Accessed February 26, 2021

Zuboff, S., *2019.* The Age of Surveillance Capitalism. pp.1–717.

Zwicky, F., *1948.* Morphological Astronomy. The Observatory, 68(845).