# 30

# INDEXICAL VISUALIZATION—THE DATA-LESS INFORMATION DISPLAY

*Dietmar Offenhuber and Orkan Telhan*

Contemporary cultures of ubiquitous computing have given rise to new way of interacting with digital information through embodied, ambient, contextual, performative means. Yet the way we visualize information still largely follows the logic of flat media. Data visualizations typically rely on symbolic languages found in charts, maps, or conceptual diagrams. Information graphics also frequently use abstractions of concrete objects, such as illustrations and assembly diagrams. In Charles Sanders Peirce's semiology, those two modes of representation would be referred to as symbolic and iconic signs. Information representations that transcend the established language of the flat display are rare and not always successful. We argue that the challenges of communicating embodied and ambient information call for utilizing a third category of signs from Peirce's semiology: the index—a sign that is linked to its object through a causal connection. In this chapter, we elaborate on the role of indexical signs in visualization and argue that indexical visualization deserves a vital place in today's computational design, visual communication, and rhetoric. Here, we present a series of examples to discuss the properties of indexicality and theorize it as a new design strategy that can inform the design process of today's material-based computation and synthetic biological design, which rely on the material organization of the sign and the conditions that encapsulate its meaning within its physical embodiment.

## Introduction

Visual representations of abstract data are ubiquitous in contemporary culture. Infographics, data visualizations, or visual narratives are representations designed with the intention to clarify, persuade, or educate. Much has been written about the relationship between their visual languages and their underlying objective—how to distinguish a comprehensible visualization from an obscure or a truthful map from a misleading one. The resulting canonizations of visual languages (Few 2012; Ware 2010) establish guidelines for the mapping data sources to the appropriate visual variables (Bertin 1983), which again can be manipulated through a set of operations (Schneiderman 1996). Attempts to develop a corresponding visual language for information embedded in the physical world are not always successful. Ambient displays mapping information to light, sound, or movement remain incomprehensible if the object and mapping are not known (Wisneski 1998). Contextual and location-referenced information is usually delivered within the narrow constraints of a smartphone display. In the domain of ubiquitous information, arbitrary symbolic languages are bound to fail without established visual conventions.

The disconnect between visual representations and the situation in which they are used also hint at the underlying issue of how data relate to the reality they supposedly describe. Instead of simply being a collection of given facts, a data set is the result of systematic observation and symbolic encoding. To account for this circumstance, Joanna Drucker proposes replacing the word 'data' with the active form 'capta' (taken) (Drucker 2011). If we understand 'data' as a collection of symbolically encoded observations, could we think of a display that conveys information—without the symbolic encoding of data—though its object itself?

Charles Sanders Peirce's theory of semiology distinguishes between three categories of signs—symbols, icons, and indices. Within the narrow boundaries of Information Visualization, only two of these categories, icons and symbols, are primarily utilized—charts, graphs, or the underlying data artifacts themselves are examples of symbolic representations, which use a visual language that is based on an arbitrary relationship between the sign and the object it stands for. Other than a shared convention, the number five and the symbol "5" have no direct relationship with each other. Architectural renderings, scientific illustrations, or assembly diagrams, on the other hand, are based on iconic signs. They can be decoded, because their representations resemble the objects they stand for.

Maps, diagrams, and most complex visual representations combine aspects of both resemblance and arbitrary conventions. However, this visual vocabulary has its limits, especially when we want to call attention to phenomena in the physical world around us—the realities of our living environment or the processes happening at the microscopic or molecular level. As a result, we treat most information as abstract, without considering the possibility that we could in fact observe their veracity directly with our senses. This requires that we take a step back from treating data as the literally 'given' and consider the processes of how they were coded and aggregated as observations of a physical phenomenon. Before latent fingerprints can be captured in digital form, they have to be made visible through physical particles, chemical or biological processes. Before a fragment of DNA can be coded, it has to be amplified by several orders of magnitude through Polymerase chain reaction (PCR). The fragments then are physically stained with coloring agents to become visible to the bare eyes with a technique known as gel electrophoresis.

The link between data and object is often lost within in the digital domain; however, it is also intentionally obscured. The popular model-view-controller (MVC) design pattern in computer science, for example, demands a clear separation between code modules that model the information from data, the visual display of the data and tasks that allow the users to act on the data (Gamma 1995). This abstraction offers obvious advantages, since it boosts the capacity to aggregate and process information. However, it can also diminish the awareness of a causal link between data and object, which may get manifested as a lack of critical scrutiny of the origins and qualities of the data, or on the contrary, a mistrust and outright dismissal due to its generation process.

We believe that there is a third possibility beyond symbolic and iconic representation that can fill this gap in our current data-centric worldview; a strategy for visualization that can be best described with Peirce's third family of signs, the indices. As Peirce notes, "The index is physically connected with its object; they make an organic pair, but the interpreting mind has nothing to do with this connection, except remarking it, after it is established" (Pierce, 9).

A simple example would be the representation of fire, which is commonly found on fire extinguishers or vehicles carrying inflammable substances: an abstracted, but nevertheless iconic representation resembling a flame. The word "fire" would correspond to a purely symbolic representation, consisting of a series of arbitrary symbols. An indexical sign, on the other hand, would be the smoke that rises from an actual flame. While the interpretation of the sign may still be subject to cultural conventions, its appearance is strictly determined by the material basis of the object that signals the meaning.

The concept of indexical signs is by no means a novelty and has played an important role in industrial design history, visible for example in the aerodynamic forms of the streamline modern. However, in contemporary digital culture, data are often treated as a 'raw material'—emphasizing their symbolic nature without considering their origin. Within information design and visualization, visual and numerical literacy call attention the internal validity of data sets, but cannot speak to the external connection with their objects. We think there are reasons why it might be worthwhile to explore the design space of indexical visualization. In the context of material-based computation, deep embedding of media into the environment, and design at the microscopic level, for example, the concept can be useful to call attention to the material basis of facts and hidden processes. They can turn us from being consumers of information to witnesses of an experiment. It can encourage careful observation and a critical curiosity for the ways information and knowledge can be linked to physical phenomena.

In this chapter, we discuss indexical visualization and design as an alternative approach to delivering information. In today's emerging design practices living and non-living matter can be manipulated at the molecular level. The agency and autonomy of bacteria, for example, can be repurposed for different applications as if they are machines or computers. We find it increasingly important to discuss alternative paradigms that can represent the design affordances of such artifacts and look at new ways to design the role of information for communicating their functions and behavior. We will start with discussion of examples that employ indexical representations and show how information can be conveyed without symbolic encoding. We will then feature a number of design principles that can be utilized for different indexical design applications and illustrate them with hypothetical cases. We are interested in questions such as: What are the representational strategies that constitute indexical visualizations? What are their potentials and limits concerning expression, argumentation, and rhetoric?

Indexical visualizations have been with us for a long time. A broad range of artifacts—analog instruments, notations systems, and representations—from art, design, science, and engineering embody different characteristics of indexicality. Often, the most common feature shared by these devices is the way they are designed to bear the effect that they are meant to communicate. Peirce gives a compelling example: " . . . an old-fashioned hygrometer is an index. For it is so contrived as to have a physical reaction with dryness and moisture in the air, so that the little man will come out if it is wet, and this would happen just the same if the use of the instrument should be entirely forgotten, so that it ceased actually to convey any information" (Pierce 1998, 163). Indexical signs often incorporate iconic and symbolic aspects, as in the case of photographic paper or the charts drawn by a seismograph. Our concern however is not taxonomic—our aim is to distinguish and identify design strategies to emphasize indexical qualities that can help making legible the connection between an object and its context. Indexical displays address the central demand of ubiquitous computing for situatedness rather than abstract universality in its representations and practices. Instead of offering a fixed mapping between data and representation, indexical design offers a framework for guiding observation. The main point is not to endorse physical information displays over digital ones, but to emphasize the importance of causality in constructing meaning. To this end, the task is to choose and configure the material of the display so that it can isolate and constrain the phenomenon of interest such that the effect on the display apparatus becomes legible. In a way, it can be stated that indexical design is the framing of meaning through the choice of constraints.

## Properties of Indexical Visualizations

Design choices for indexical visualizations can be illustrated through the mechanisms used in analog instruments for measurement. Using the example of a pressure gauge, Nelson Goodman describes the operations of semantic differentiation that are applied to translate the physical behavior of the device into a form of notation: from the analog signal into a visual trace (Goodman 1968, 157). While signal and trace are still causally linked, a semantic distance is introduced between gas pressure and the pen that produces the mark on paper. We are dealing with two different representations of gas pressure: first, the visual trace on paper produced by the pen moved by the pressure over multiple intermediary steps. But, second, one could argue that also the configuration of the instrument is a representation of the phenomenon, which it contains, embodies, constrains and reacts to. Based on these considerations, we can capture indexical visualization and design through a number of properties:

1. Indexical visualization represents an object through its own embodiment or its immediate impact on its environment.
2. Designing an indexical visualization means framing the underlying object in such a way that it becomes legible.
3. The framing happens by applying a set of constraints that act upon the object in such a way that only a specific aspect of the object is revealed and isolated from the object's other properties.
4. The indexical display remains linked with the underlying phenomenon through its visual or audible appearance. To some extent, its appearance is autonomous and not under the control of the designer.
5. Indexical visualization achieves its rhetorical strength by emphasizing this causal link, which allows it to achieve the status of evidence.
6. The specific configuration of constraints that act upon the object can be understood as the diagrammatic form of indexical visualization.

As an example, the physical configuration of the mercury thermometer (diagram) represents temperature (object) through the expansion of mercury (the object's material embodiment). This phenomenon is only legible because the mercury is constrained in a capillary glass tube, allowing it to expand only into one direction upon a change in temperature. Adding a corresponding spatial scale for comparison and quantification differentiates the amount of displacement further. At the same time, all other properties of the mercury are de-emphasized–its color, its weight, its unconstrained shape, and so forth. Compared to a digital thermometer with its multiple layers of sensing, abstraction, representation, and translation, the effect of temperature is rather 'directly' observed.

It is necessary to distinguish between the physical response of the thermometer, which is inevitable, and the act of communication, which may or may not happen. While the representation of temperature is direct or explicit, the reading or contextualization of it is still a learned experience shaped by convention. Furthermore, indices are often difficult to recognize and interpret. Michael Polanyi describes the example of a student learning to read x-ray images of lungs—an ability, for him, that cannot be acquired only by following explicit instructions but rather learned over time in a master—apprentice like relationship. Although the information on the x-ray is immediate and physically explicit, the interpretation of the subtleties of the visual imprint is a slow process. Indexical visualization therefore aims to increase the legibility of the index through external constraints (Polanyi, 106).

## Indexical Design and its Display

The manifestations of indexical representations can be diverse, depending on their context and medium. Nevertheless, we think that it is possible to describe the design space of indexical representations using a few parameters. In our understanding, a main criterion is the causal distance between the object and its representation. Is the causal chain of events between object and representation short and direct, or the result of many intermediary events? In most cases, a shorter, more immediate connection would be preferable.

A second dimension is the semantic distance between the object and its representation. To what extent is the nature of the underlying phenomenon legible in the representation? Is the phenomenon translated into an arbitrary visual language or notation? While both dimensions, causal and semantic distance, are often linked, it does not necessarily have to be that way. The hygrometer in the shape of a weather house, with two figures that emerge from their respective doors because they are fixed on a disc that rotates with changing humidity, illustrates this difference. The chain of events is short and direct, yet the mechanism is hidden, and the representation allows no insight into this process, making it appear almost like a magical device. Again, a pure form of indexical visualization would involve a minimal amount of such symbolic mediation. These two parameters together span a space in which the indexical qualities of different examples can be compared. In this space, a representation with very short causal distance and a minimal amount of symbolic mediation would be indexical in the strong sense, a representation involving a long chain of causal events and a highly arbitrary representation will have very weak indexical qualities. The two parameters span up a two-dimensional space, in which the examples discussed in the following sections can be located.

## Analog vs. Digital Representations

Most traditional analog instruments for measurement, recording and displays are indexical to varying degrees; a sundial is arguably more than a mechanical clock. The installation *Meeting* by the artist James Turrell is probably one of the purest examples of an indexical display. The piece, originally installed in New York's PS1 institute, invites the visitors to observe the sky, framed by a square opening in the ceiling. This indirectly illuminated frame makes it possible to observe the subtle color changes of the sky in contrast to the matching illumination level of the surrounding ceiling (Adcock and Turrell 1990, 120). *Meeting* has the shortest possible causal distance between the object and its representation. At the same time, *Meeting* uses a short symbolic distance.

While digital representations that process input from the physical world can also produce deterministic and immediate outputs, as the causal link between input and output is obstructed through a mediation process, they can be considered indexical only in a weak sense. The separation of information from its original context, making information persistent and context interchangeable, offers a big advantage compared to analog technologies from a practical

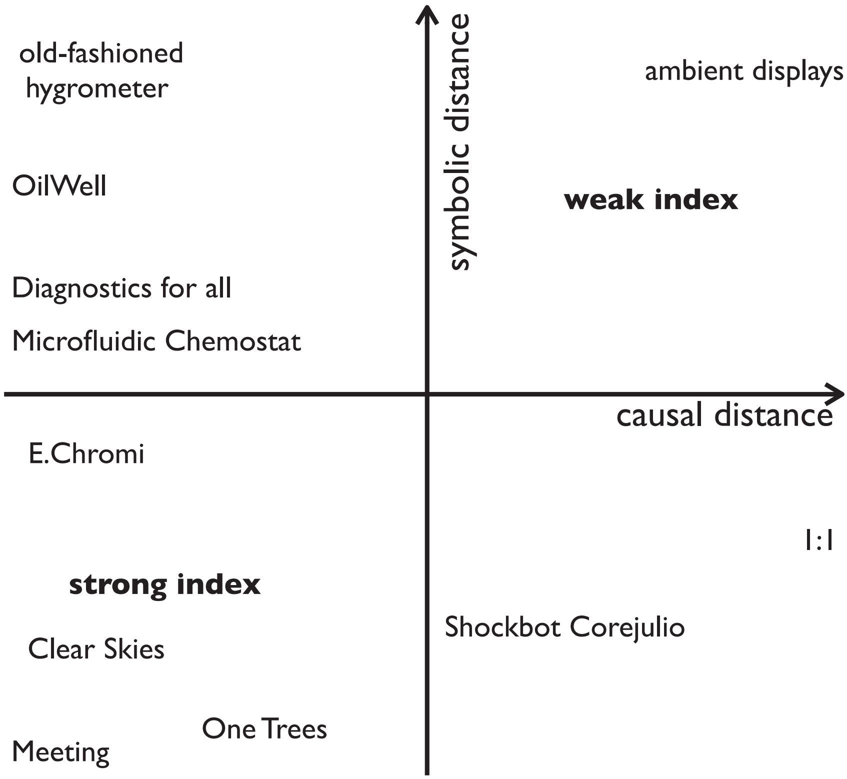


**FIGURE 30.1** The location of the discussed examples in the space spanned by causal and symbolic distance.

standpoint. However, this separation also means that the direct link to the original context will disappear or become arbitrary. Scholars studying the human factors of digital media, including Mark Weiser, John Seely Brown, and Hiroshi Ishii, have seen this arbitrariness as a disadvantage, and argued for emulating indexicality within the digital realm. Concepts such as *Calm Technology* and *Ambient Displays* are directly inspired by the indexical nature of analog instruments and the human capacity to constantly process a multitude of environmental cues without too much effort or with the background of attention (Weiser and Brown 1996; Wisneski 2008). In most cases, this indexical nature is used as a metaphor rather as the actual driver of the display. Ishii's *Tangible Media Group*, for example, demonstrated that the amount of network activity can be mapped to the rotation speed of pinwheels or similarly the temperature of water from a faucet can be represented with colored light illuminating the water stream. While in these examples indexical mappings were created between digital and physical phenomena, the research focus is on simplifying symbolic relationships, rather than eliminating translation and mediation. Although the causal distance between the object and its representation is undiminished, these visualizations intend to create the appearance of a direct and immediate causal connection. On the other hand, in terms of symbolic abstraction, ambient displays operate with entirely arbitrary mappings between input and output, sense and response pairings, making them essentially symbolic or iconic signs.

**FIGURE 30.2** Meeting (1986), James Turrell.

Other strategies in the digital realm try to minimize the level of symbolic abstraction rather than the causal distance between object and display. This can be achieved by establishing a clear structural correspondence between the object and its representation. The artist Lisa Jevbratt describes her project 1:1 from 1999 as an indexical visualization in which every single pixel of the display corresponds to a distinct entity—in this case a computer IP address (Jevbratt 2003). Unlike in most of our examples, here indexicality does not address the underlying physical substrate of computation, and remains in the symbolic realm by using an arbitrary mapping between a specific server on the network and a pixel on screen. However, by treating every pixel as a distinct marker with a direct correspondence to an object, the representation gains indexical qualities. In the same sense, treating a digital file as a raw stream of bytes and sending it directly to the sound device of a computer could be seen as an indexical representation within the digital realm.

If we go beyond the symbolic domain of computation, the experience of technical failures in the underlying electronic circuits are probably closest to our understanding of indexical representations. Failures can reveal underlying properties of systems which are normally hidden. "Glitch" artists, who exploit the unintended artifacts of digital media formats, sometimes directly manipulating and destroying the underlying electronic hardware, often exploit this aspect. The installation 'Shockbot Corejulio' from the group 5voltcore is one such example, where a robotic device moves a steel brush over the circuits of the graphics board of the computer it is controlled by, triggering short circuits and occasional visual patterns created by the damaged electronics (Rebelo and Schroeder 2006).

In the natural sciences, especially in chemical and biological research, indexicality is the basis and necessary justification for almost all representation. The products of laboratories are discursive objects or *epistemic things*, as Rheinberger puts it, with the main purpose of providing material evidence for theoretical models (Rheinberger, 9). In scientific publications, symbolic representations in form of graphs or scatterplots are typically augmented by photographs or similar records of evidence. Sound is also frequently used to represent activity over time. Based on its perceptual qualities, sonic displays are inherently indexical rather, since sound usually indicates events in the physical world and is a potent medium for communicating causal relationships (Hogg and Vickers 2006). In Hubel and Wiesel's classic neuroscience experiment, the researchers mapped visual neurons guided by the audible bursts created by an electrode, which was used to capture the activity of a single neuron in the visual cortex of a cat (Hubel 1959).

In diagnostic tests or chemical analysis, the symbolic distance is very short, since the representation follows the dictate of the material properties of the involved substances. However, with the emergence of new frontiers in biochemical design, such as synthetic biology, it becomes important to assess the ways the supposedly rigid, unmediated, and immediate connection between material and what it stands for can be manipulated purposefully. The design of the behavior of a chemical or biological marker—when engineered at the level of a single-cell organism introduces new parameters to the design of indexical living matter. The organism, as a living design, has the ability to manipulate its own interpretation. It can grow, change, mutate, and eventually deviate from its designer's intentions. Bacteria, for example, exercise different preferences based on their environmental conditions. The availability of certain chemicals or the presence of other organisms around can influence their behavior. So when bacteria is designed to respond to a chemical marker, say produce a visual outcome in response to the presence of a particular molecule in its environment, the accuracy, precision, and the repeatability of that chemical sign can show great variability based on the way organism exercises its agency throughout its life. Thus when the bacteria respond to the chemical phenomena and become their own indexical representation, the response can be immediate and direct and yet not entirely predictable. However, such index is inherently different from a simple analog design; as for example, the way the lead molecule in the thermometer responds to changes in temperature. The living organism can inherently exercise its own autonomy and introduce a level of indeterminacy to the overall design. On the other hand the intent behind such indexical design can also be the actual manipulation and regulation of this autonomy so that it can turn into a legible source of information.

## Examples

In the examples presented below, design operates at different resolutions: as pixels, genes, molecules, or atoms. In reference to Rheinberger's notion of epistemic things, we could refer to these units as *signthings*. As already noted, signthings can exercise different levels of agency and autonomy depending on their medium. Regardless of the scale on which signthings operate, it is important to note that the interpretation context—the framing of the meaning—always takes place at the macro level. Any state-, color-, or shape-transition at the microscopic level has to result in a visible effect that enables quantification, ordering, enumeration, and interpretation. Therefore, indexical displays are resolution-independent, making their intrinsic properties legible to an external observer.

In Natalie Jeremijenko's *One Trees* public art installation, a hundred trees, cloned from a single source were planted across the Bay Area. The artist intended to emphasize the effect of spatial variations in air quality and microclimatic conditions on the genetically identical trees. Since the external conditions cause every tree to develop in a different way, *One Trees* is an indexical visualization, not only showing but also bearing the effects of changing environmental forces and interactions with urban life (Whitelaw, 98). In the related project *Clear Skies*, Jeremijeno designs disposable dust protection masks to measure the particulate pollution Bay Area bikers are exposed to during their commute. To read the amount of dust that has accumulated in the mask, a grey color gradient is printed on the masks matching the different degrees of discoloration and hence pollution.

All of these signs, the state vegetation, the visible deposits of air pollution, are present in the environment and can be read as implicit cues by trained observers. The interventions by the designer emphasize these cues and provide a rubric for their interpretation, to translate them into explicit data points.

Beyond art projects, indexical displays can be found in research environment as well as in objects of everyday life. They rely on physical, biological, and chemical mechanism and combine biological, diagnostic, and therapeutic functions with information design. Personal pregnancy, HIV, and cholesterol tests use indexical representations designed to be understood by a broad population. By using synthetic or natural markers that respond to chemical or biological phenomena, such tests capture causality through material change—indicate presence of factors, change, quantity, or frequency through visual feedback.

Diagnostic For All, a non-profit enterprise, utilizes material-level interaction both for registering medical symptoms and for providing visual feedback for advanced diagnosis (Plate 30.1). In this design, biological reagents stored on traces or wells patterned onto chemically treated paper respond to the body fluids of the patients to detect liver complications. Upon contact with a patient, the paper device registers change by color and quantifies the phenomena through a scale printed onto the device. As the device primarily aims patients in developing countries with limited access to professional facilities, it is designed to register the embody the colorimetric output until it can be studied further by an expert in a remote location who can provide further diagnosis through a digital image of the paper.

The design of synthetic biomarkers for diagnostic purposes is also a research direction in synthetic biology, a field that is concerned with designing living systems with engineering methods (Drew 2005). Plate 30.2 shows *E.Chromi*, a synthetic biology project in which bacteria are engineered to detect particular chemical signatures within the human gut flora. By incorporating color-making genes into the genome of Escherichia coli (E. coli), designers can turn the organism into a biosensor, which can respond to different disease patterns. As E. coli senses the chemicals, it can synthesize the proteins that will allow it induce a color-change in its physical embodiment. As E. coli with different color markings exit the body, they leave their traces on the human manure and provide the user with a visualization of their medical condition.

Synthetic biology is ultimately concerned with building living systems that function like biological circuits or computational hardware. It focuses on designing the biological equivalents of switches, logic gates, transistors, oscillators, and other kinds of devices, feedback, and decision-making systems that can execute complex computational instructions. Like the color-changing E.coli example, these designs exhibit indexical behavior and represent their functions or the outcomes of their functions visually in their material embodiment. Bacteria and other single-cell organisms can be synthesized with custom genomes, which can function like computational hardware that can sense, respond, and deliver not only information but also bio-molecular payload, compressing the difference between a sign and its material embodiment in the biological context.

Microfluidic systems—dealing with the control and manipulation of fluids at a micro-scale—are an important tool of synthetic biology (Plate 30.3). Like advanced thermometers, which provide both the biological context and the physical framing—and site—of the biological activity, microfluids can be implemented in different materials such as paper, glass, ceramics, or silicones, and can be designed to exhibit characteristics known from electro-mechanical and computational systems (Whitesides 2006). Microfluidic systems can be used to regulate the flow, mixing, and dissemination of chemicals—organic and inorganic fluidic matter—through micro channels. These "Lab-on-chips" are also highly informative systems, which can provide information regarding material-level interaction through visual patterning, measurement, and spatialization techniques embedded within the design of the system. 2D and 3D Bio-arrays, for example, are popular experiment design tools that allow the automatic study biomolecular differentiation through comparative analysis.

Micro or mili-capillary environments can also be designed as consumer artifacts that can expand their use beyond medical devices. *The Oilwell* by Orkan Telhan (Plate 30.4) is the prototype of a personal biosynthesis machine—a microbial perfumery—that incubates bacteria, which can exhibit different colors and smells based on the design of their genomes. The *Oilwell* features a clear silicon housing that functions as an indexical display. Here, the bacteria grown in a mix of nutritious media and mineral oil are pumped from an incubator towards a heating element through capillary channels. As bacteria go through their certain growth phase, they respond to the inhibiting compounds in the media; change color and indicate to the outside viewer that they are ready to emit smell. This process can be observed in real-time with plain sight like a thermometer. When bacteria is ready, the users can activate the pumps such that they can get pushed towards the end of the housing, where they get dropped onto a heating element and made to evaporate like a traditional oil lamp. While genetically modified bacteria are inevitably killed at the end of the process, the system provides a measure of safety for not letting the genetically modified organisms leave their confined environment. The *Oilwell* uses indexical design both as a functional and aesthetic element. Here, the bacteria can be made to grow a number of different smells—such as citrus, mint green, or banana odor—in a randomized fashion. Each smell can be visualized by a particular color marker—such as amber indicating banana, green citrus, and so on—and therefore be observed from outside before the bacteria is channeled to the pump. As bacteria go through different cycles of smell production, the users can determine when exactly to activate the smell based on its indicator color. Here, while the mapping of color to a particular smell could be left to a preference or an arbitrary mapping, the way bacteria signals the smell production to the audience is an indexical process. The integration of indexical designs to aesthetic and symbolic artifacts offer a new design space that can incorporate elements of biochemical design with the rich history of product design that is rooted in constructing meaningful experiences through the cultural and historical meaning of the artifacts. As a perfume bottle, *Oilwell* intends to combine the different design cultures of product design with biochemical design and pay close attention to different stages of creating a user experience from the form of the perfumery to the way its content can communicate its fabrication process to its user. Being currently a novel category, artifacts with living designs, require a different visual language that inevitably extend the ways we design experience and meaning without relying on information produced in symbolic or iconic ways.

For most applications of desktop and mobile computing, the symbolic domain is sufficient to represent and act on information. However, when computation is embedded in the physical world and carried through living organisms or chemical processes, we need to extend our understanding of computation beyond paradigms dominated by computational media and information design. Biochemical processes such as DNA assembly, protein synthesis, or bacterial transformation can be computationally modeled, viewed, and controlled inside a living organism without creating any symbols and information. As users, we can visually observe the process, give input, and act on the outcomes through markers that are physically coupled to the processes. Symbol-free computation allows us to act directly on the physical matter, avoid the intermediary representations, and minimize the distance between cause and effect.

While pure indexical displays offer a wide variety of affordances from biosynthesis to cellular or subcellular imaging and live visualizations, hybrid formats that integrate some form of symbolic abstraction (the second axis) into indexical design, offer another promising area of research. Hybrid visualization paradigms offer ways to map indexical information onto the symbolic domain and allow computation to take different roles in the symbolic or physical domain. A citizen-science project could, for example, use cameras to observe the change in the environment through a variety of organisms such moss, lichens, or algae which respond to PH, humidity, Co2 levels, and so on by a physical change in their appearances[1]. By digitally characterizing the effects of these bioindicators through cameras and sensors, it would be possible to device systems that can record changes over time and computationally monitor habitats through their own ecologies. In addition to designing feedback loops between indexical and symbolic systems, hybrid modalities can also be used to correlate calculated information and indexical observation to increase the reliability to symbolic processes. By registering the state of living phenomena (i.e. texture, color, etc.) through symbolic means, it becomes possible to observe phenomena beyond the life cycles of living systems or the limited durability of physical phenomena. The symbolic processes produce information that can be preserved indefinitely hence make hybrid systems really viable solutions.

As we present a multitude of approaches to extend information processing and visualization in ubiquitous computing to the indexical domain, advocate for hybrid models, it also becomes important to list the limits of indexicality.

## The Limits of Staging Indices

The opportunities for indexical design, as illustrated by the examples above, are bound to certain limits. With its emphasis on causal relationships between material conditions, the difficulties in physically framing a phenomenon, and the challenges in making the phenomenon legible, the practice of indexical visualization operates in a tight space. It is applicable only to a small fraction of possible visualization tasks and problems. Beyond the challenges that have been already discussed in the earlier sections, we want to mention four other challenges to that pertain to the design of indexical visualizations.

## Distortion

While the behavior of indexical displays is determined by the underlying physical processes, its appearance can nevertheless be distorted and exaggerated. In the thermometer, for example, the ratio between the dimensions of the capillary tube and the expansion rate of mercury would be an important criterion that will determine how much the element will spread in space. As the adjustment of this ratio will yield different amounts of spread along the axis, it will inherently determine how much visible difference can be indexed from temperature's effect onto the metal.

The interpretation of indexical displays relies on the context, which introduces a second possibility for manipulation. The marks on the scale placed next to the thermometer can be wrongly spaced, or not correspond to the actual behavior of the material, which might show linear or nonlinear characteristics. While many of these distortions could be resolved through repeated observation of the display under various conditions, it should not be ignored that the design of indexical displays includes a rhetoric element—of staging the object in the most effective way.

## Ambiguity

The framing in indexical visualizations is a matter of explicating implicit and ambiguous information. Since the interpretation of physical traces and phenomena requires some level of expert knowledge, an effective representation for non-experts usually means a reduction of ambiguity. At the same time, this disambiguation can increase the causal distance between the phenomenon and the representation. To be convincing as "evidence," indexical visualizations require the presence of some amount of implicit information and ambiguity to be able to construct the basis of interpretation. Ambiguity is a necessary trade-off for the sake of minimizing the causal distance to the object. On the other hand, ambiguity can call attention to the physical properties of the object, offer additional cues, and therefore make the representation more believable—just as artifacts in analog media are an important means for verifying the authenticity of a document.

## Ephemerality

Indexical displays change over time and often leave little trace of previous states. Either due to their physical characteristics or the way they are framed, it is often not possible to preserve their appearance over a longer time or create records of their previous states. If inscriptions are created, as in the case of a seismograph, the encoded information often does not have the same universally legible quality. The persuasive power of indexical displays is tightly coupled to their ephemerality. They are performative and show mechanisms and causalities rather than produce data. However, as visualizations, they do not afford the permanence characteristic of other representations: They require observation and interpretation, therefore the information they convey might not be the same for different observers. At the same time, the display is often locked into a specific context. As information displays, indexical visualizations do not offer the advantage of what Bruno Latour called "immutable mobiles:" representations of information that are both stable and mobile and therefore allow operations that go beyond the representations immediate context (Latour 1987).

## Agency and Autonomy

A leather shoe can be bearer of the physical marks on its surface, and thus record the history of its users permanently, whereas the skin tissue of a cow will not be able to do this. As the live tissue will constantly renew itself, it may, on the other hand, show the effects of immediate causes—such as the change of color in an area when the tissue experienced a physical impact. Indexical visualizations that are designed from state-changing materials, biological or living materials introduce new kinds of opportunities and limits to representation. Agency is at the expense of ephemerality but introduces an ability to actively respond to change. Agency is also a source of active reframing, in which the design can change both its physical and material framing and the interpretation contexts at the same time.

The intent behind the manipulation, engineering, and programming of living matter also introduces different degrees and kinds of agency to indexical design. The autonomy exercised by single-cell organisms, for example, brings an inherent underspecificity to the overall design, subjecting it to operate at higher margins of uncertainty yet with the benefits of microbial intelligence. In a designed context, E. coli would be as a signthing, which would be expected to act, react, communicate, and live its own being. It will make decisions and bear the consequences of its own actions. However, in the meantime, it will be read as an index. Its responses to phenomena will be manifested as biological change and become legible under different interpretations that will frame it so.

## Conclusion

Indexical strategies of visualization do not foreclose the act of interpretation. Instead of delivering quantifiable messages, they offer a framework for observation. In this chapter, we described a few principles for information design involving representations that highlight indexical properties, rather than employing iconic or symbolic visual languages. Since an indexical sign is a direct and necessary result of an underlying process, its appearance can only be indirectly manipulated by the designer. Design intervention therefore happens by applying a set of constraints that are aimed at making the underlying phenomenon legible. As long as the representation remains recognizable as a causal effect of the indicated phenomenon, the display becomes a persuasive demonstration of evidence. We intended to revise the place of the index among the palette available to the information designer, and identified and discussed a series of parameters—such as causal and symbolic distance—to assess different levels of indexicality. While the field of indexical design and visualization has not been thoroughly investigated, there have been individual attempts to capture indexical properties in visual designs. Our goal was to survey a series of examples that qualify as indexical visualizations as we describe them, and distill certain attributes and guidelines to design and interpret new kinds of indexical systems. While indexical representations currently occupy a somewhat marginal role in design, we expect that with the emergence of fields such as synthetic biology or microfluidic applications, they will become important in the near future. As we advance in our abilities to engineer molecular level responses to materials and use the agency of biological systems for specific design-making capabilities, we witness an increasing possibility to design visualizations that can compress the space between representation, translation, and mediation through the immediacy of cause-effect and input-output relationships.

Peirce's semiotic model provides a good backdrop to theorize new kinds of designs that can represent phenomena through themselves; exercise a different level of agency that lies outside the traditional visualization conventions that is built through icons and symbols. Under the category of the index, we described a new category of signs—signthings—that can utilize their physical embodiment—living and non-living nature—to exercise such agency. We believe that, as they find new places in the visual rhetoric, new types of indexical designs and visualizations will establish their own reading habits and interpretation conventions and fundamentally challenge our former experiences with signs and signifying systems.

## Acknowledgements

We thank Gerhard Dirmoser for his insightful feedback and criticism.

## Note

1 http://nature.com/scitable/knowledge/library/bioindicators-using-organisms-to-measure-environmental-impacts-16821310

## References

Adcock, Craig E., and James Turrell. 1990. *The Art of Light and Space*. Berkeley: University of California Press.

Bertin, Jacques. 1983. *Semiology of Graphics: Diagrams, Networks, Maps*. Madison, Wisconsin: University of Wisconsin Press.

Brown, John Seely, and Mark Weiser. 1996. "Designing Calm Technology." *PowerGrid Journal* 1 (1): 75–85.

Endy, Drew. 2005. "Foundations for Engineering Biology." *Nature* 438 (7067): 449–453.

Drucker, Johanna. 2011. "Humanities Approaches to Graphical Display." *Digital Humanities Quarterly* 5 (1). http://digitalhumanities.org/dhq/vol/5/1/000091/000091.html. (Accessed 08 22, 2014).

Few, Stephen. 2012. *Show Me the Numbers: Designing Tables and Graphs to Enlighten*, Second edition. Burlingame, CA: Analytics Press.

Gamma, Erich, John Vlissides, Ralph Johnson, and Richard Helm. 1995. *Design Patterns: Elements of Reusable Object-Oriented Software*. Reading, MA: Addison-Wesley.

Goodman, Nelson. 1968. *Languages of Art: An Approach to a Theory of Symbols*. Indianapolis: Bobbs-Merrill.

Hogg, Bennett, and Paul Vickers. 2006. "Sonification Abstraite/Sonification Concrete: An 'Æsthetic Perspective Space' for Classifying Auditory Displays in the Ars Musica Domain." *International Conference on Auditory Display (ICAD2006), London, UK.*

Hubel, David H. 1959. "Single Unit Activity in Striate Cortex of Unrestrained Cats." *The Journal of Physiology* 147 (2): 226–238.

Jevbratt, Lisa. 2003. "Coding the Infome: Writing Abstract Reality." *Dichtung Digital* 29 (3).

Latour, Bruno. 1987. *Science in Action: How to Follow Scientists and Engineers through Society*. Cambridge, MA: Harvard University Press

Peirce, Charles Sanders, Nathan Houser, and Christian J. W. Kloesel. 1998. *The Essential Peirce: Selected Philosophical Writings, 1893–1913*. Indiana: Indiana University Press.

Polanyi, Michael. 1998. *Personal Knowledge: Towards a Post-Critical Philosophy*. London: CRC Press.

Rebelo, Pedro, and Franziska Schroeder. 2006. "Performing the Order: The Messiness of Play." *Performance Research* 11 (1): 3–8.

Rheinberger, Hans-Jörg. 1997. *Toward a History of Epistemic Things: Synthesizing Proteins in the Test Tube.* Redwood City, CA: Stanford University Press.

Shneiderman, Ben. 1996. "The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations," In *Visual Languages, 1996. Proceedings, IEEE Symposium on*, 1996, 336–43, http://ieeexplore.ieee.org/xpls/abs_all.jsp?arnumber=545307.

Ware, Colin. 2010. *Visual Thinking: For Design*. San Francisco: Morgan Kaufmann.

Whitelaw, Mitchell. *Metacreation: Art and Artificial Life*. Cambridge, Mass: MIT Press

Whitesides, George M. 2006. "The Origins and the Future of Microfluidics." *Nature* 442 (7101) (July 27): 368–373

Wisneski, Craig et al. 1998. "Ambient Displays: Turning Architectural Space into an Interface between People and Digital Information." *Proceedings of the First International Workshop on Cooperative Buildings, Integrating Information, Organization, and Architecture*: 22–32.

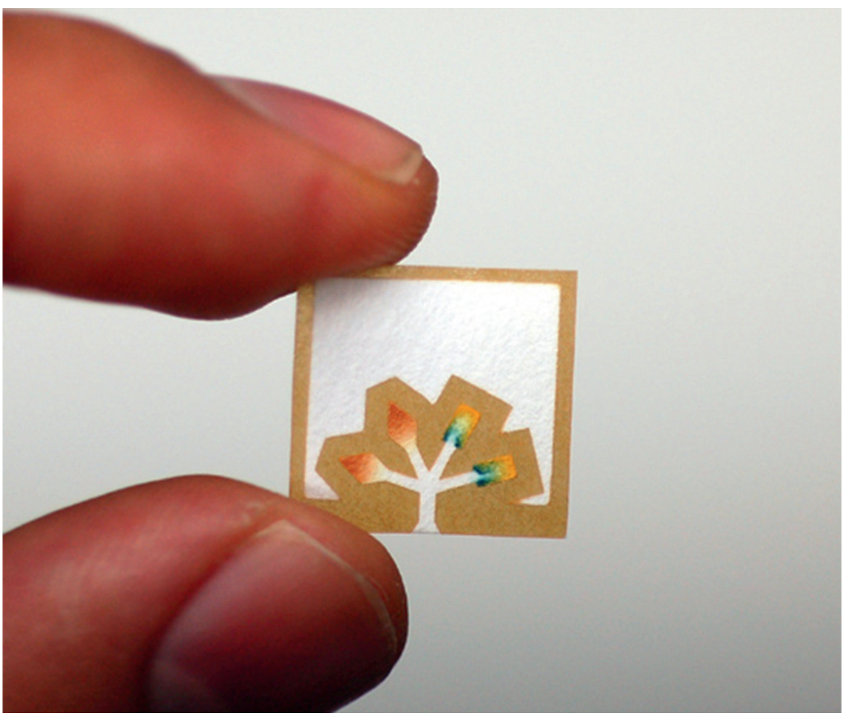

**PLATE 30.1** A diagnostic paper-chip by Diagnostics For All

**PLATE 30.2** Scatalog —a fictional catalog of human manure stained with genetically engineered E. coli

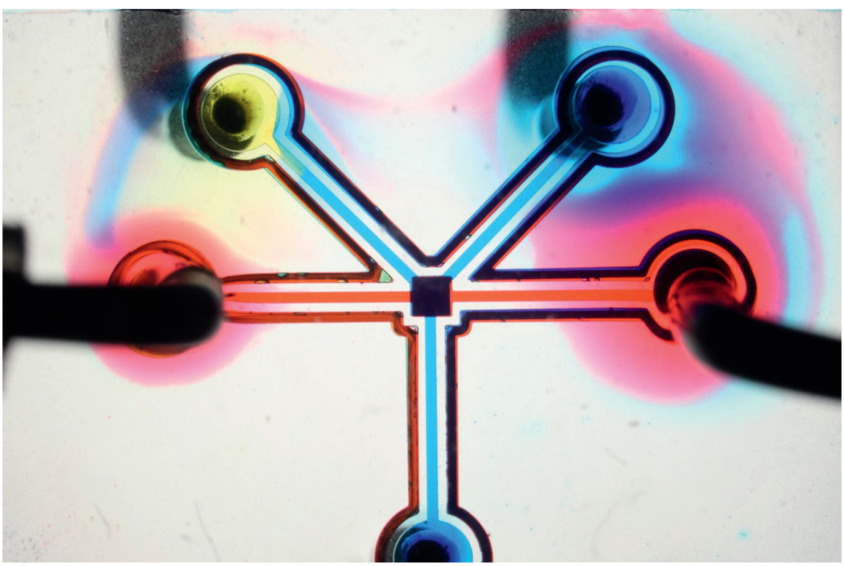

**PLATE 30.3** Microfluidic system

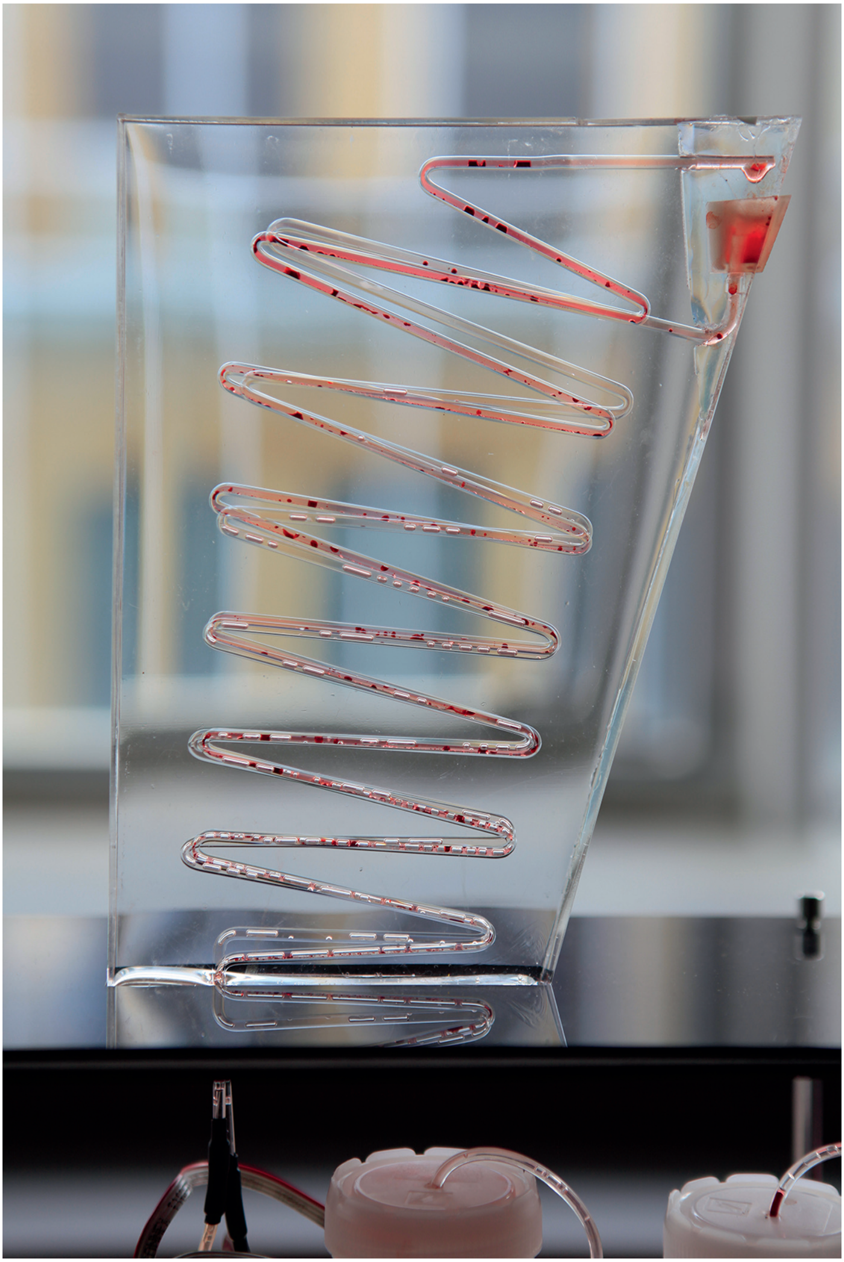

**PLATE 30.4** The Oilwell. Prototype for a microbial perfumery that incorporates an indexical display