



Actuation – Introduction

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While many physical data artifacts are either static or need to be updated manually to reflect changes in the data, this section covers physical data artifacts that can update themselves without human intervention. For example, Figure 1 shows a physical line chart whose shape can change with data, thanks to the presence of servo motors. Similarly, Figure 2 shows a map of Italy where the height of each region can be computer-controlled to encode particular data.

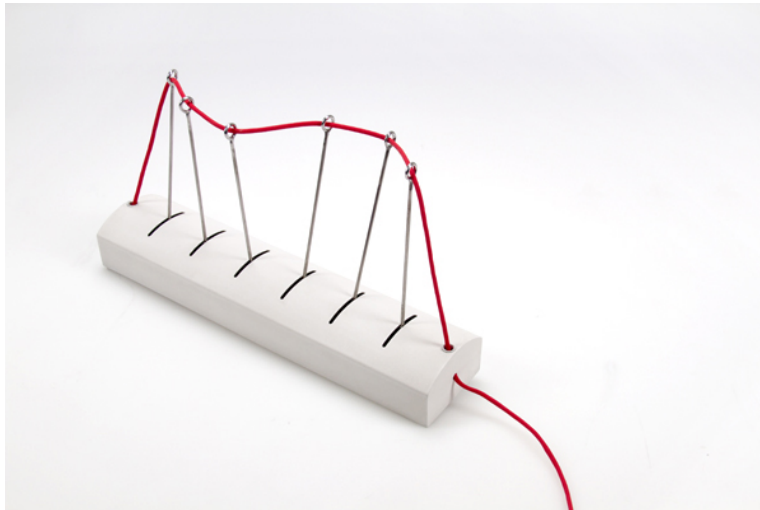


Figure 1 – A physical line chart consisting of a string whose shape is controlled by six servo motors. Source: <https://cargocollective.com/Pulse> (2012). Credit Jon McTaggart and Christian Ferrara. Permission pending.

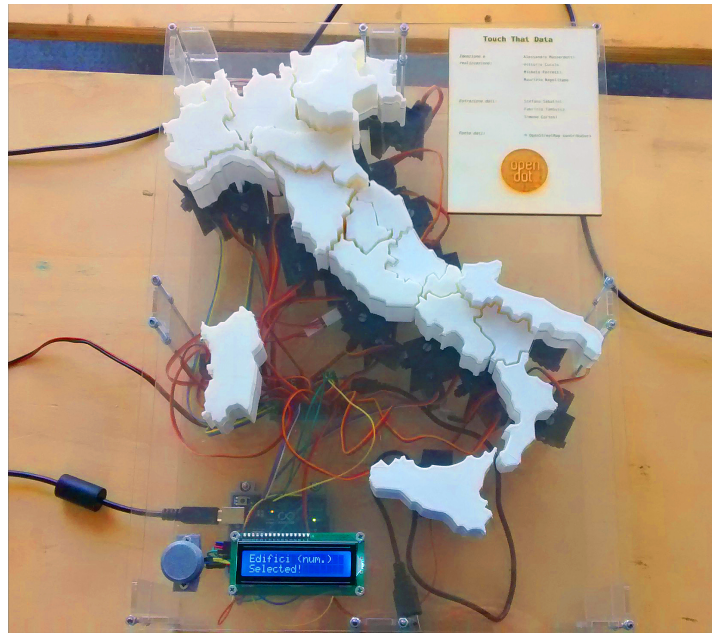


Figure 2 – A motorized map of Italy where the height of each region is computer-controlled. Source: <http://dataphys.org/list/actuated-prism-map-of-italy/> (2016). Credit Alessandro Masserdotti. Permission pending.

Possibilities are endless for physical data artifacts that support actuation. David Sweeney discusses the design of more complex mechanical charts in the Tenison Road Chart project ([Chapter X](#)). While many of these artifacts are meant to emulate classical charts, Figure 3 showcases a more artistic example where servo motors are used to deform a heart-looking latex object based on emotions inferred from a real-time sentiment analysis of blogs. In this book, Kim Sauvé and Steven Houben also discuss the design of LOOP, another example of non-conventional physical data representation employing servo motors ([Chapter X](#)). But data actuation does not necessarily have to rely on motors – in Figure 4, for example, the pressure of water jets varies in real-time according to the value of a currency, and in Figure 5, the concentration of ozone in plant enclosures varies according to the pollution level in different cities. As another example, Nik Hafermaas, Dan Goods, and Jamie Barlow discuss their installation named airFIELD, which employs liquid crystal to change the appearance of myriads of discs suspended in the air ([Chapter X](#)). Many other examples can be found online in the list of physical visualizations.¹

¹ <http://dataphys.org/list/categories/active-physical-visualization/>

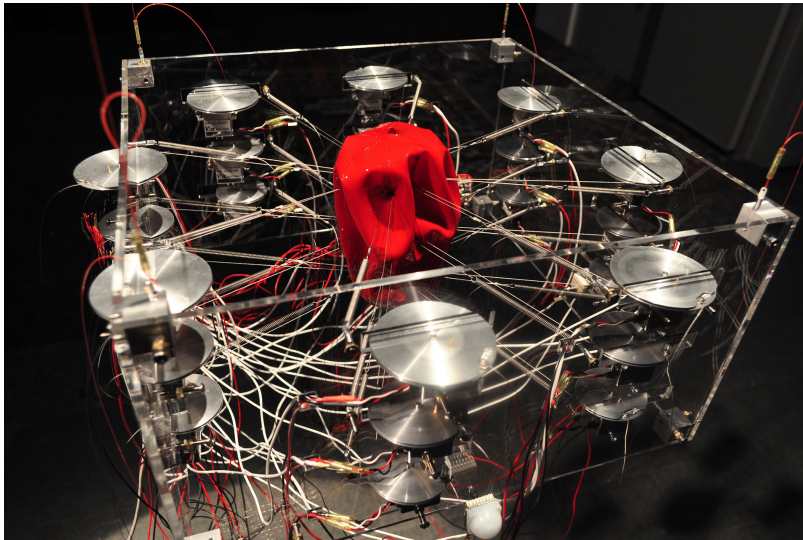


Figure 3 – An art installation where servo-motors control the shape of a heart-looking object depending on a real-time sentiment analysis of blogs. Source: <https://www.markuskison.de/kinetic.html> (2009). Credit Markus Kison. Permission pending.



Figure 4 – A fountain made of three water jets whose pressure is updated every five seconds according to the value of a currency. Source: <https://www.koert.com/work/datafountain/> (2004). Credit Koert van Mensvoort, Benjamin Voss, Charles Mignot, Rik Wesselink, Ronald Schipperen, Roy Damgrave, Koert van Mensvoort, Arian van Dorsten, and Jan Willem Nienhuis. Permission pending.



New York



Ottawa



Rom



Vienna

Figure 5 – An installation consisting of eight lettuces, each of which is enclosed in its own air-tight plexiglas box and represents a major city. The concentration of ozone in each box is controlled in real-time to reflect the current pollution level in the city. Source: https://www.researchgate.net/publication/345807023_Garden_of_Eden (2007). Credit Timm-Oliver Wilks, Thorsten Kiesl, and Harald Moser. Permission pending.

The designs shown in Figures 3 to 5 as well as those discussed in the [Chapter X](#) and [Chapter Y](#) are very expressive and effective at conveying their message, but they have the drawback of being highly specialized and thus hard to reuse. A designer who wishes to convey the same data differently or tell the story of an entirely different dataset needs to design and build a new device from scratch. The Italy map in Figure 2 is a bit more versatile because it can be used to convey arbitrary data about Italian regions, e.g., their population, gross domestic product, or proportion of people vaccinated against COVID-19. The device in Figure 1 is even more versatile because it can show any dataset that can be visualized as a simple line chart. However, it is far from being as versatile as a computer screen. If there was a computer screen that could only display line charts, most people would consider such a device as largely useless.

There have been efforts at trying to design highly versatile physical displays which date back from the late 1990s and originate in large part from the Tangible Media Group at the MIT MediaLab. At the time, several research projects have demonstrated so-called *tabletop tangible user interfaces* that involved manipulating and rearranging physical objects on a table instead of operating a keyboard and a mouse. However, because computers were unable to move those objects, the range of applications and features (such as saving and restoring work) that could be supported was limited. This issue was addressed with

electromagnet-based designs allowing tangible objects to rearrange themselves without human assistance (Figure 6). These designs later inspired robot-based systems such as the Zoids system by Mathieu Le Goc and colleagues ([Chapter X](#)). Because all such systems can freely arrange multiple objects on a surface, they can be used to create physical versions of charts that represent data using collections of dots on a plane, such as two-dimensional scatterplots. Meanwhile, the third dimension is within reach, with experimental systems already capable of positioning physical objects in mid-air (Figure 7).

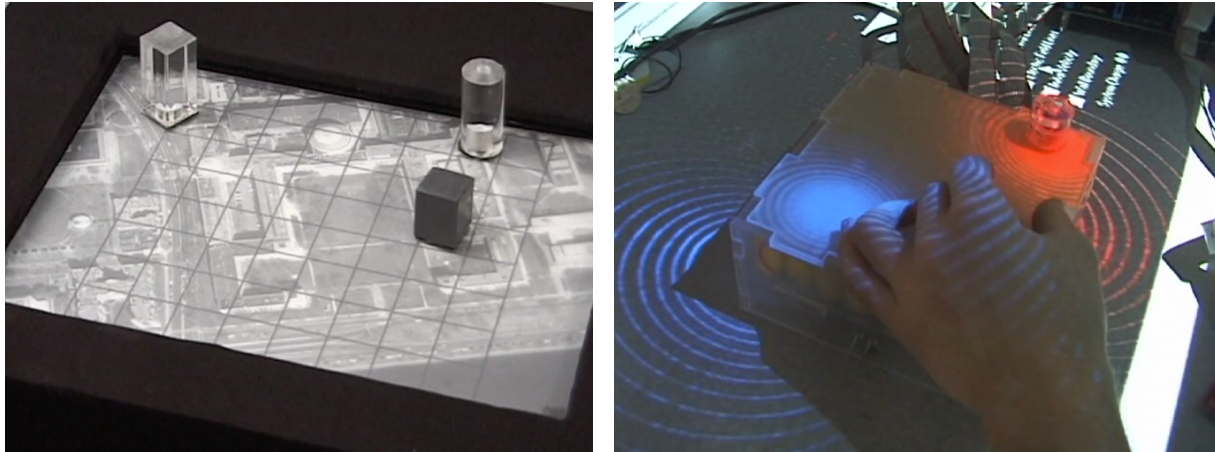


Figure 6 – Early prototypes of actuated tangible user interfaces. While the PSyBench (left image) moves objects with an electromagnet placed on a 2-axis positioning mechanism under the surface, the Actuated Workbench (right image) does so using an array of electromagnets. Sources: PSyBench <https://tangible.media.mit.edu/project/psybench/> (1998). Credit Scott Brave, Colyn Bulthaupt, and Hiroshi Ishii. Actuated Workbench: <https://tangible.media.mit.edu/project/actuated-workbench/> (2002). Credit Gian Pangaro, Dan Maynes-Aminzade, and Hiroshi Ishii. Permissions pending.



Figure 7 – Recent research prototypes that can position physical objects in three-dimensional space. BitDrones (left image) uses rotors, while the Floating Charts device (right image) uses acoustic levitation. Sources: BitDrones <http://www.humanmedialab.org/blog/bitdrones> (2015). Credit Calvin Rubens, Sean Braley, Antonio Gomes, Daniel Goc, Xujing Zhang, Juan-Pablo Carrascal, and Roel Vertegaal. Floating Charts <https://www.youtube.com/watch?v=3-Tjcz16rXU> (2016). Credit Themis Omirou, Asier Marzo Perez, Sriram Subramanian, and Anne Roudaut. Permissions pending.

In parallel with developments in computer-controlled positioning of physical objects, research on new user interfaces has explored so-called *shape displays*, physical devices whose shape can be controlled by a computer. Perhaps the most common approach is assembling an array of motorized pins, which can be used to create physical versions of 3D bar charts and 3D surfaces (see Figure 8-left). Pin-based shape displays have also been used by artists to create kinetic art installations (see Figure 8-right). Jason Alexander and his colleagues have designed and studied a tabletop pin-based shape display specifically designed for data exploration ([Chapter X](#)).

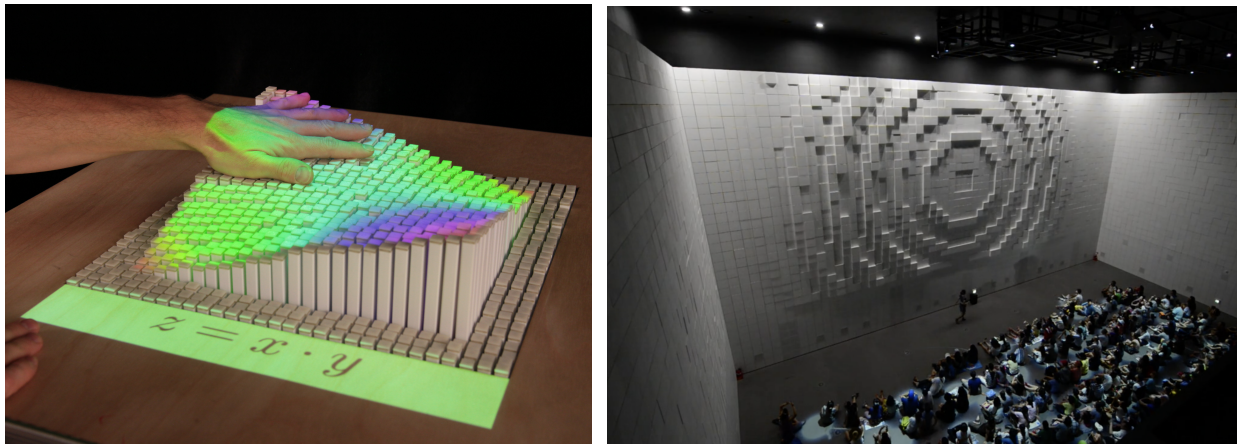


Figure 8 – Two examples of shape displays. inFORM (on the left) is a tabletop interactive shape display made of 900 motorized pins (30 x 30), while Hyper-Matrix (on the right) is a large-scale wall-mounted shape display used as a kinetic art installation. Sources: inFORM <https://tangible.media.mit.edu/project/inform/> (2013). Credit: Daniel Leithinger, Sean Follmer, and Hiroshi Ishii. Hyper-Matrix <http://jonpasang.com/index.php/works/hyper-matrix-2012/> (2012). Credit: Jinyo Mok, Earl Park, Jinwook Yeo, Sangwook Yoo, and Sookyun Yang. Permissions pending.

All physical display designs we have seen so far focus on controlling the geometry (arrangement or shape) of physical entities, but geometry is only one way data can be conveyed physically. A range of material and perceptual properties (e.g., weight, texture, stiffness, reflectivity, temperature, smell, taste) can be used to encode information physically, and can be in principle "actuated" to reflect changing data. However, controlling such material properties is often not trivial, and little research has been done in this area.

Much of the research on versatile physical displays takes inspiration from a vision of the future broadly referred to as *programmable matter*, according to which physical displays will exist that can adopt any shape, color and material properties. This vision is far from reach but is increasingly present in popular culture (for example, the 2013 movie *Man of Steel* or the 2021 TV Series *Foundation*), and is being pursued in several disciplines such as physics, robotics, and computer science. The prospect of such a technology is probably as disturbing as it is exciting, as conveyed by this 1965 quote from the famous computer scientist Ivan Sutherland:

The ultimate display would, of course, be a room within which the computer can control the existence of matter. A chair displayed in such a room would be good enough to sit in. Handcuffs displayed in such a room would be confining, and a bullet displayed in such a room would be fatal. With appropriate programming such a display could literally be the Wonderland into which Alice walked.²

Although the safety and ethics of programmable matter will be important to consider, such a technology will be an unprecedented creative tool in the hands of infographic designers, data journalists, educators and data artists. Not only will it allow them to re-create all the data artifacts we have discussed, it will also allow them to create radically new types of interactive data experiences that are beyond our current imagination.

² <http://worrydream.com/refs/Sutherland%20-%20The%20Ultimate%20Display.pdf>