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Data Sensification: Beyond Representation Modality, Toward Encoding Data in Experience

HOGAN Trevor [a]

[a] Human-Data Interaction Group, Cork Institute of Technology, Ireland
* Corresponding author e-mail: trevor.hogan@cit.ie
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Humans have represented data for thousands of years, yet the design process we use to encode data remains almost exclusively related to modalities such as visual, haptic, auditory, olfactory and gustatory. This paper proposes a novel approach to designing data representations, where we move beyond mapping data to a modality or combination of modalities and instead facilitate an understanding of the underlying data through people's overall experience of it. Based on a review of existing data representations that fall into this research area, but have not been discussed under one common term, this paper defines, for the first time, the term Data Sensification. Data Sensification is an emerging form of representation that encodes data in the behaviour, performance, affordances and resulting experience of a data representation. This research contributes to the on-going research on data representation beyond the visual paradigm as well as conceptualizing a new approach to representing data beyond representational modalities.

Data Sensification; Representational Modality; Design; Experience

Introduction

We live in a society where we are surrounded by various forms of data representations on a daily basis. The process of designing data representations is also practised across a broad spectrum of disciplines, including science (Nielson, Hagen & Müller 1997), human-computer interaction (cf. Hogan & Hornecker 2013), art (Viégas & Wattenberg, 2007), geography (Kraak & MacEachren, 2005), education (cf. He & Adar 2017), and the humanities (cf. Segel & Heer, 2010). While the design goals of data representations produced in these fields may vary, two things remain consistent: (1) the use of representational modalities to encode the data, and (2) the dependence on sense making - through the identification of patterns in the data representation to gain insight and generate meaning. This paper proposes an alternative approach by representing data beyond representational modalities and enabling people to generate data insight - not by seeking patterns - but instead through people's overall experience of the data representation.

The relationship between data representation and representational modality is extremely tight. Today, research fields and classes of data representation are delineated by their use of representational modality. The terminology used to describe these is also derived from the modality of choice. For instance, the research field that focuses on the visual modality is known as Information Visualisation (InfoVis). InfoVis is also the term commonly used to describe interactive computer systems that provide the user with external visual models of abstract data (Card, Mackinlay & Shneiderman, 1999).

While InfoVis is arguably the most prominent and active of all data related fields of research, the others are also identified by the modality that they focus on. For instance, Sonification is defined as "the use of non-speech audio to convey information" (Kramer, 1993). Here researchers study how data is represented through sound by mapping data values to audio variables such as pitch, volume, rhythm, loudness, and timbre. Whereas the study of data represented through the haptic modality is commonly known as Haptification (Paneels and Roberts, 2010) or Tactilization (Card, et al, 1999). This type of data representation has been applied successfully in diverse scenarios, such as a science museum to represent astronomical data (Hogan & Hornecker, 2013) and virtual surgery to provide feedback during simulations (Kaber & Zhang, 2011). Closely related to these, but moving in the direction of making data representations physically graspable, Zhao and Vande Moere introduced the notion of Data Sculpture which explores how physical embodiment can be used to analyse the connection between data and physical representations (Vande Moere, 2008; Zhao & Vande Moere, 2008). Following up on this research, Jansen and colleagues coined the term Physicalization as: "a physical artefact whose geometry or material properties encode data." (Jansen & Dragicevic, 2013, p.3228) and have established a framework for visualizations beyond the desktop paradigm (including Physicalization) to help describe, compare and critique non-screen based data representations (Jansen & Dragicevic, 2013). Data Physicalization is now an active research area, and a large number of projects exist that encode data in the physical and tactile properties of objects; in both static (cf. Stusak, Schwarz & Butz, 2015) and dynamic forms (cf. Taher, Jansen, Woodruff, Hardy, Hornbaek, & Alexander, 2017).

While the representational modalities discussed already have a relatively long historical tradition of investigation and practise (ranging from decades to hundreds of years), the remaining modalities (taste and smell) have received far less attention from the scientific and art and design community. This is mainly due to the innate technical difficulties in producing and controlling the output from these modalities. They also lack a commonly used neologism to describe the research and output associated with these modalities. Representing data through smell is still underexplored - however, there are some examples in the literature. For example, Dollars & Scents is an olfactory display that represents fluctuations in the stock market by releasing scents into the air, such as rose when the market is rising, and lemon when it is contracting (for more see Kaye, 2001). Much like olfactory, the information transmission capability of the gustatory sense is still largely unknown (Basdogan and Loftin, 2008). There are, however, some rare, but intriguing examples, including BeanCounter by Dan Maynes-Aminzade, who was one of the first to explore this space and introduce the concept of Edible User Interface (EUI) (Maynes-Aminzade, 2005). Another example that uses food to represent data is Data Cuisine. This initiative, led by data researcher and practicing artist, Moritz Stefaner, consists of workshops where the participants explore food as a means of data representation or as Stefaner refers to it – "edible diagrams" (Stefaner, 2014).

The study of data representation was once inextricably linked to the visualisation research community, but recent developments have offered opportunities to broaden the field of investigation to include the study of alternative representational modalities. As the medium used to encode data has moved from the printed page, over digital pixel, towards tangible objects, sonifications and other modalities, we have seen the research community fragment across the lines of modality. This paper proposes that we contemplate a new approach to data representation, where we don't encode the data in the properties and variables of modalities but instead we encode

data in our surroundings or the properties of everyday familiar objects. Humans have built up a familiarity with everyday objects and we intuitively understand how they work. The question then must be asked: can we harness this awareness and familiarity when representing data to enable people to generate data insight. HCI researchers have for some time now explored our surroundings as a means to communicate information. This area of research dates back to Weiser and Brown's work on defining ambient displays and calm technology as approaches to help ubiquitous computing applications enter our everyday life (Weiser & Brown, 1995). Ishii and Ullmer also explored the physical environment to present information when they coined the term ambient media as: information displays designed to present information in the periphery of the user's attention (Ishii & Ullmer, 1997). These concepts were subsequently adopted by the InfoVis community to address, for instance, the use of visualization in casual scenarios (Pousman, Stasko, & Mateas, 2007) and to explore the potential of information visualization in everyday life (Skog, Ljunglblad, & Holmquist, 2003; Willett, Jansen, & Dragicevic, 2017). This paper seeks to leverage this research by not only embedding data in our surroundings, but by moving beyond to embodying data in the properties of the objects that occupy our surroundings.

Hogan and Hornecker first discussed this notion in their exploration of the design space for multisensory data representation (Hogan and Hornecker, 2016). As part of this, they identified examples of data representations, which do not encode data in sensory modalities but instead in the experience people have with the representation. This paper seeks to extends Hogan and Hornecker's research by: (1) formalizing the notion of Data Sensification and defining it as a new class of data representation, (2) discussing current examples of Data Sensification and (3) pointing toward potential usage scenarios for Data Sensification, as well as the deign challenges that need to be addressed in the future.

Defining Data Sensification

The aim of this research is to classify data representations that fall outside the current list of categories, including: visualizations, sonifications, haptification, tactilization or olfactory and gustatory representations. There are, however, other types of representation that have already been defined, which do not ascribe to a specific modality, these are: Multisensory data representations (Hogan & Hornecker, 2017), Sensualization (Ogi and Hirose, 1996), Sensification (Tak & Toet, 2013), Perceptualization (Card, et al. 1999) or Cross/Multimodal displays (Hoggan, Crossan, Brewster, & Kaaresoja, 2009). However, in the context of this research these definitions pose difficulties, as they remain focused on modalities, or in these cases combinations of modalities as a means to facilitate data insight. There are types of data representations that have emerged over the years, which do not align themselves to representational modality, these include Information Aesthetics (Lau, & Vande Moere, 2007), Artistic Visualization (Viégas & Wattenberg, 2007), Data Art (Manovich, 2008) and Casual Visualization (Pousman, Stasko & Mateas, 2007). The focus of these is not on the modality used but on the aim, goals and target audience of the representation. These types of representation more closely align to the focus of this paper as they seek to: broaden the use of representation modality (cf. Vande Moere, 2008; Zhao & Vande Moere, 2008), widen the target audience (cf. Skog, Ljunglblad & Holmquist, 2003), and expose alternative data insight (cf. North, 2006; Cernea, Kerren & Ebert, 2011). While there are clear parallels with the later set of definitions, this papers proposes a formalisation of a new classification of data representation and in doing so we reappropriate the already used neologism Data Sensification to be redefined as follows:

> *"A class of data representation that has a clear intent to reveal insight by encoding data in the behaviour, functionality, performance, or affordance of an object and data insight is generated from the overall experience of the Sensification."*

At this point it should be noted that in proposing this definition of *Data Sensification* it is not meant as a replacement of the various definitions currently in use, nor is it meant to replace Tak and Toet's definition of *Sensification.* It is also not aimed at directing criticism at current approaches to the

design of data representation. Instead the goal here is to broaden the research agenda on data representation to include aspects beyond representational modality and toward data experience.

Data Sensifications Examples

To understand the issues raised by Data Sensifications, it is helpful to have a set of concrete examples in mind. The following provides descriptions of six projects that map data to properties beyond representational modalities. The aim here is not to provide an exhaustive analysis of the design space - such an undertaking is beyond the scope of this paper. Instead, this paper focuses on a selection of projects that highlight some of the central qualities of Data Sensifications.

The World's Best Spintop

The World's Best Spintop is an art piece created by Melanie Bossert[1], which consists of a number of 3D printed spinning tops, where the structure of each piece is a translation of political, environmental, health, education, quality of life and economic data from a specific country (Bossert, 2012).

Figure 1 The World's Best Spintop by Melanie Bossert circa 2012

Once the data for the country is collated, an algorithm generates the shape of a spin top. If a country performs 'poorly' the generated shape will be asymmetrical and the handle will be short, which results in the spinning top being difficult to set and maintain motion. However, if the data indicates that the country has performed 'well' the shape will be more symmetrical and the handle will be long enough to grasp (making it easy to set in motion). The data mapping procedure used, as well as three examples produced by the algorithm, are illustrated in Figure 2. The choice of using a spintop as a form of representation is highly significant as it reflects the various challenges countries face in order to balance what is needed to provide a high quality of life for its' people. Although the data is encoded in the physical properties of the spinning top (much like the other physicalizations mentioned already) the data cannot be fully interpreted and understood until the spintop is in motion, which means the data has been encoded in shape, behaviour, usability and experience of using the representation.

[1] See http://www.spintop.cc

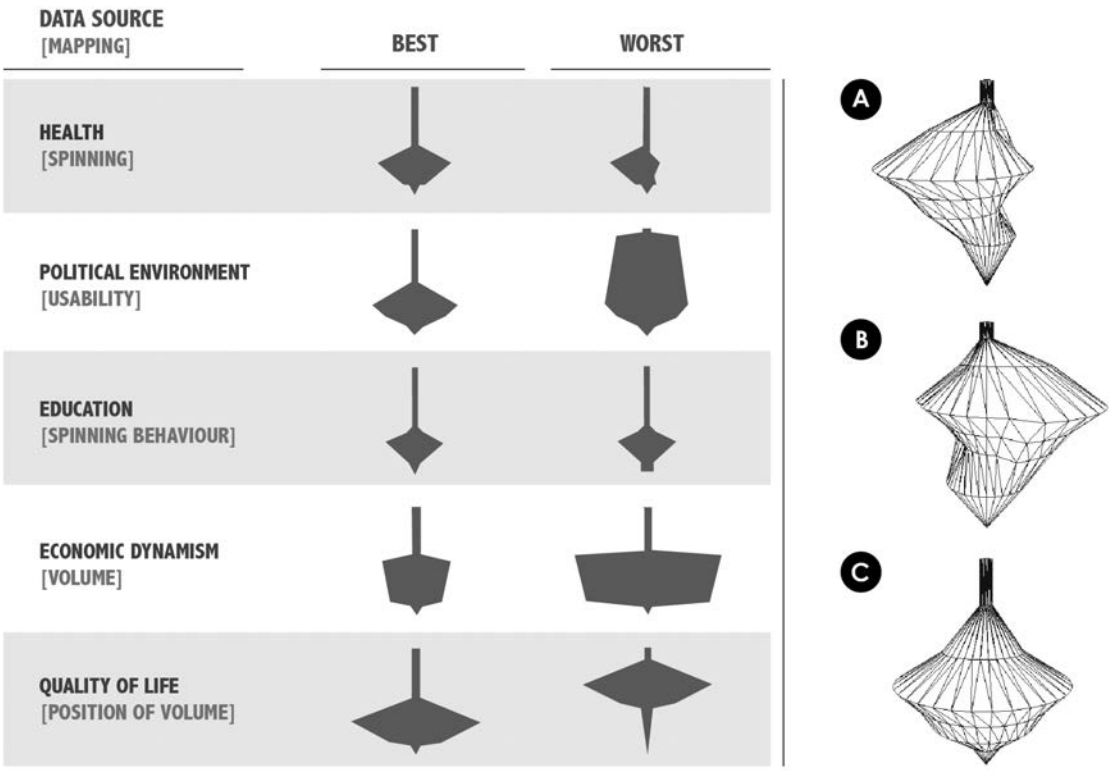

Figure 2 left: Algorithm used to generate the spinning top. Right: Examples of spinning tops produced by the algorithm (A) Zambia, (B) Burkina Faso, and (C) Ireland.

Change Ringing

Change Ringing[2] is the collaborative artwork by artist Peter Shenai and composer Laurence Osborn (Shenai & Osborn, 2015). This piece comprises of a set of six bronze bells whose form is derived from graphic representations of climate data collected over the course of the twentieth century (see Fig. 3).

Figure 3 Change Ringing with permission from Peter Shenai circa 2015

Each bell represents a seventeen-year interval during this period and they are arranged in chronological order. Change Ringing is similar to 'The World's Best Spintop' in that the data is translated into the physical properties of the objects, however, the audience cannot fully interpret it until they hear the different sounds that emanate when the bells are played. There is also an aspect of performance in this piece, whereby the audience is encouraged to play the bells in chronological

[2] see http://www.change-ringing.co.uk/

order so that they can perceive the temporal nature of the dataset through a series of inharmonic spectra that communicate sonically the story of climate change during the twentieth century. The experience provided by this work is also extended beyond the interaction with the bells, as the sounds they produce are also used as a basis for a twenty-five minute composition, scored by Laurence Osborn for a string orchestra and the bells themselves[3]. Shenai and Osborn were deliberate in the choice of bells to communicate meaning from the data. As they see it, the bells are not merely a means to produce a sonic representation but are culturally significant objects that have been used throughout history in situations such as bringing communities together in the act of contemplating, religious and non-religious ritual, political processions and delineating the passing of time.

#Good vs. #Evil

#Good vs. #Evil[4] could be described as an automated data-driven racing game, which is controlled by social data scrapped from Twitter feeds (Castelli, 2016). This piece was created by Maxime Castelli at a workshop hosted by I&IC (Inhabiting and Interfacing the Clouds), a joint design research project that seeks to explore new approaches and uses of cloud computing (I&IC, 2014). This piece is comprised of a scalextric track and two model cars (see Fig. 4). Scalextric cars are traditionally controlled by a user with a remote handset. This handset allows the user to regulate the amount of electrical current going to a small motor in the car, which in turn controls the speed of the car. However, in #Good vs. #Evil the electrical current is controlled by a computer programme that counts the frequency of two hashtags on Twitter: #Good and #Evil. One of the cars is associated with #Good and the other with #Evil. At regular intervals the frequency of each hashtag is computed. The higher the frequency the more current is allowed to pass through, which results in the car increasing in speed. The result is a perpetual race between “good” and “evil” through their online hashtag iterations. Unlike the previous examples, data is not encoded in any physical properties nor is there any active interaction with the artefact. Instead the audience is invited to perceive the data as spectators at a car race. There is however an element of performance, but in this case it is conducted by the cars (or hashtags) competing against one another in a never ending game of good verses evil.

Figure 4 #Good vs. #Evil by Maxime Castelli circa 2016

[3] See more here: http://www.change-ringing.co.uk/really-composition
[4] See http://maximecastel.li/?/projects/TwitterRace/

My Life Don't Mean A Thing If It Ain't Got That Swing

While the previous example provided the audience with a performance to view, the goal of 'My Life Don't Mean A Thing If It Ain't Got That Swing' (see Fig. 5) is to provide people with an environment that requires significant levels of active participation to fully perceive the underlining data. This installation, which is comprised of a life-sized swing set, represents data related to the satisfaction levels of a country's population. The question asked of participants of the survey was: 'All things considered, how satisfied are you with your life as a whole these days?' (World Values Survey Association, 2015). Again, this could be conceived as a data representation that encodes data in physical and architectural properties i.e. the length of rope, the height and width of the seat. However the means by which people perceive the data go well beyond looking at and touching the representation. In this case the data is embodied in the levels of enjoyment and overall experience people have when swinging. The designers have accomplished this by mapping the data from a specific country to the elements of the swing, in so much as, if the data indicates that the population responded negatively to the survey question, the length of the swing will be short and the seat will be narrow, making the experience of swinging less appealing or exciting. However, positive responses result in providing people with a more comfortable and satisfying swing experience. This would enable people to map their understanding of the data to hedonistic responses such as pleasure, enjoyment, amusement or their counterparts. Moreover, the swing may also allow people to link the data to fun childhood memories, which is a difficult task to achieve with conventional data representations.

Figure 5 My Life Don't Mean A Thing If It Ain't Got That Swing by Polly O'Flynn, James Pockson and Peter Shenai circa 2015

Waste Production

Waste Production[5] is a data representation created by Nadeem Haidary as part of the In-Formed series (Haidary, 2009). This piece consists of an elegantly designed refuse bin whose form changes depending on the weight of the garbage it contains (see Fig. 6). As it fills up the top-half of the bin bends over, making it less inviting and giving you a visual cue as to how much trash you are throwing away. While the data (weight of garbage) is encoded in the shape of the object (bin), much like other data physicalizations, what makes this piece unique is how Haidary has connected the data mapping to the functionality of the bin. When it is empty it functions much like any other conventional bin by

[5] See http://www.nadeemhaidary.com/informed/

enabling easy access to the inner chamber. However, as the bin is filled its shape changes, resulting in its functionality becoming impeded. Ultimately it reaches a point when there is no longer access to the internal chamber. This is an example of encoding the data into functionality and overall experience of using the artefact.

Figure 6 Waste Production by Nadeem Haidary circa 2009

Drowning Over the Decades

Drowning Over the Decades[6] is an interactive art installation created by Cathy O'Donovan (O'Donovan, 2016). This piece represents data related to the amount of people in Ireland who have died from drowning in each decade from 1916 to 2016. The data, which was captured from the Central Statistics Office of Ireland[7], is mapped to the amount of water contained in each wine glass (one millilitre per death) and each glass represents a decade of data. Similar to *Change Ringing* the choice of metaphor is highly significant in this work. Although the symbolism of bells in Change Ringing is somewhat oblique, in this piece there is an obvious relationship between the data (deaths by drowning) and the use of water as a representational variable.

Figure 7 Drowning Over the Decades by Cathy O'Donovan circa 2016

[6] See https://vimeo.com/165565652
[7] See http://www.cso.ie

While the data can be perceived by viewing the amount of water in each glass, the installation offers a more unique perspective of the data by playing the piece like a glass harp. The glass harp is type of musical instrument that was first invented by Richard Pockrich in the 18th Century. Sounds are created when energy is applied to the glass and the physical properties of the glass start to resonate. Energy is applied by rubbing wet fingers along the each of the glass, which causes the glass to vibrate at its natural frequency. Different tones are obtained by varying the amount of water in each glass. *Drowning Over the Decades* could be considered a multisensory data representation, as it encodes data in visible, physical and sonic properties. However, its performative aspect extends its representational properties beyond the modalities in use, towards a piece that is required to be used and experienced in order to fully interpret the underlining data.

The proceeding sections describe six exemplary *Data Sensifications*, in the following sections the paper addresses related design issues and challenges that need to be met into the future.

Designing Data Sensifications

Before exploring the design approach of *Data Sensification* it is important to describe some of the issues that currently confront designers of data representation.

Issues with Representational Modality

As alluded to already, the current and traditional approach to designing data representations typically involves deciding which attributes of the data should be mapped to each sense. As such, designers must consider how to best represent the given data to provide users with insight by mapping data attributes to modality properties such as colour (visual), volume (physical), frequency (auditory), sweetness (taste), and fragrance (olfactory) or a combination of the previous. In doing so the designer should be aware how the Gestalt principles of perception play an important role in helping people identify patterns and relationships in the representation. For example, by assigning specific colours, shapes, textures, and sounds to different variables in a data set, it is possible to quickly identify groups of information and patterns represented by similar variables. There are, however, known difficulties with this approach. For instance, with respect to the human visual system, research has shown that it is inherently band limited and suffers from perceptual and change blindness (Mancero, Wong, & Amaldi, 2007), as well as occlusion, crowding and clutter (Van der Burg, Olivers, Bronkhorst & Theeuwes, 2009). Researchers have attempted to overcome some of these concerns by increasing bandwidth of information transfer through the use multisensory data representations (cf. Sarter, 2006). This paper seeks to sidestep these issues completely by not focusing on representational modality as a means to transfer information, but instead on facilitating the generation of data insight through the overall experience of the data representation.

Design Process

The process of designing data representations has remained relatively stable for many years. It involves first collecting and processing the data, which may involve methods such as data mining and filtering. The next stage involves mapping the data to an appropriate sensory variable, such as, for instance, mapping to colour, volume, sound frequency, sweetness or fragrance. The final stage involves presenting the representation, in whatever manner chosen, to the user so that he/she can easily interpret the data. This is typically an iterative process of analysis, design and use.

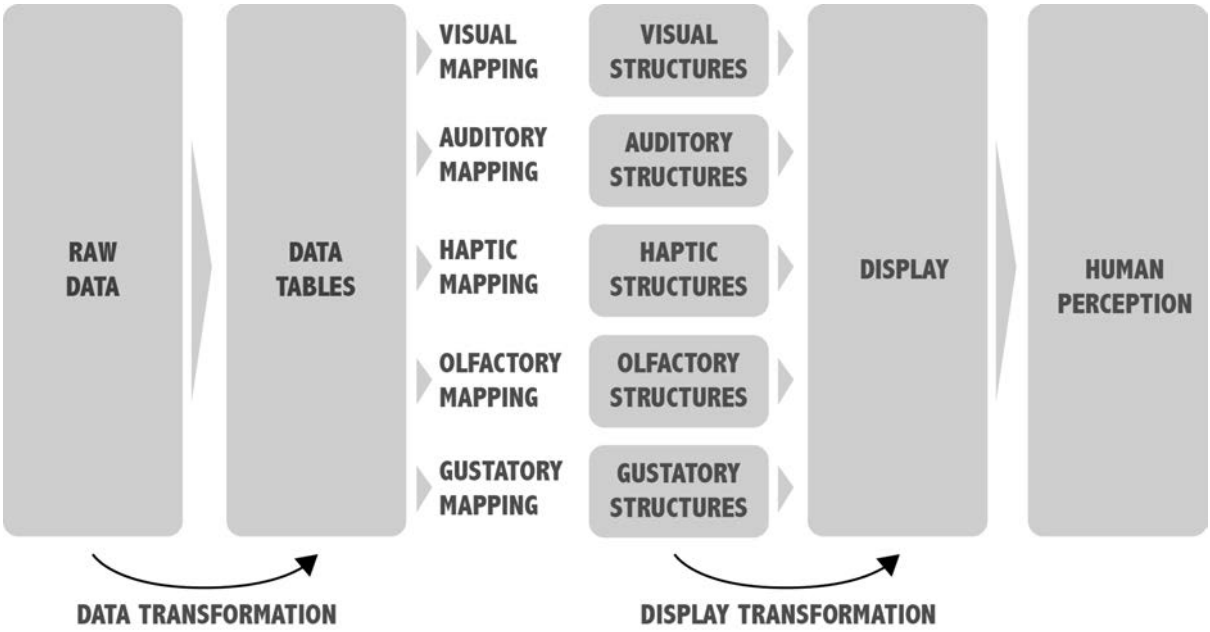

Table 1 Card and Mackinlay's Visualization Process Model (Card, Mackinlay & Shneiderman, 1999) extended to include all sensory modalities.

Card and colleagues published one of the first formalisations of this process and coined the term 'Visualization Process' (Card, Mackinlay & Shneiderman, 1999). The Visualization Process maps 'Raw Data' to 'Data Tables' to 'Visual Structures' and finally 'Displays' into 'Views'. This process has been extended in Table 1 to account for the other modalities.

Data Sensification

There are two clear distinctions between the design of typical data representation and that of *Data Sensifications*. Firstly, the role of representational modality in *Data Sensification* is given less prominence. In fact, the choice of modality is of little concern to the designer as the data is not transmitted through representational modalities but through the overall experience people have with the representation. One could argue that the role of representational modality has been replaced by the use of metaphors in *Data Sensifications.* As can be seen in the examples, metaphors and semiotics play a significant role in the transmission of insight. Metaphors are often used as a starting point in designing information displays by only allowing the user to take advantage of existing cognitive models but also "ecologically-developed perceptual skills" (Nesbitt, 2001). This paper argues the heightening the use of metaphors for the design of *Data Sensification* to a point where the metaphor becomes the central aspect of the data representation. For example, if we look at *The World's Best Spintop* (Fig. 1) the notion of a country attempting to balance the social, economic and political conditions of its population is engrained into the difficulties we have controlling a spinning top, especially when its form has been dented. The same could be said for the *My Life Don't Mean A Thing If It Ain't Got That Swing.* Here, data related to the quality of life, is embedded into the functionality of the swing, meaning that the user embodies the data through his/her levels of enjoyment. Peter Shenai, one of the creators of this swing installation, talks about this approach to data representation as allowing him to push the interactive medium to its limits, up to and including the point of malfunction, as the malfunction or breakdown of the artefact, in this case a swing, serves as a reminder to the user that the data has been skewed strongly in one direction (Shenai, 2015).

The other difference relates to the process followed when designing *Data Sensifications*. Once the role of representational modality has been removed from the design process we need to rethink and reformulate the current approach ('Visualization Process'). This paper proposes an extension of Card et al's 'Visualization Process' by replacing the sensory mapping of structures to data values, with the

mapping of metaphorical attributes to data values (see Table 2). To help understand the proposed representation process of Data Sensification let's use this to understand how one of our examples has been created. The 'raw data' used for *The World's Best Spintop* was collected from sources such as the World Bank, WHO and CIA amongst others. Once the 'raw data' is collected it is parsed into 'data tables' and sorted for each country. The next step involves formulating a 'metaphor' to carry the data representation. While we do not have any insight into this design decision, it can be surmised that the spinning top metaphor is a significant aspect to this piece. Haidary mapped the functional attributes of the spinning top (i.e. volume, symmetry, usability etc.) to different data values. The next stage of process involves Haidary 'displaying' the representation by 3D printing a collection of spinning tops that represent each of the countries data. The *Data Sensification* is then presented to the audience who interprets the data by attempting to set the spintops in motion.

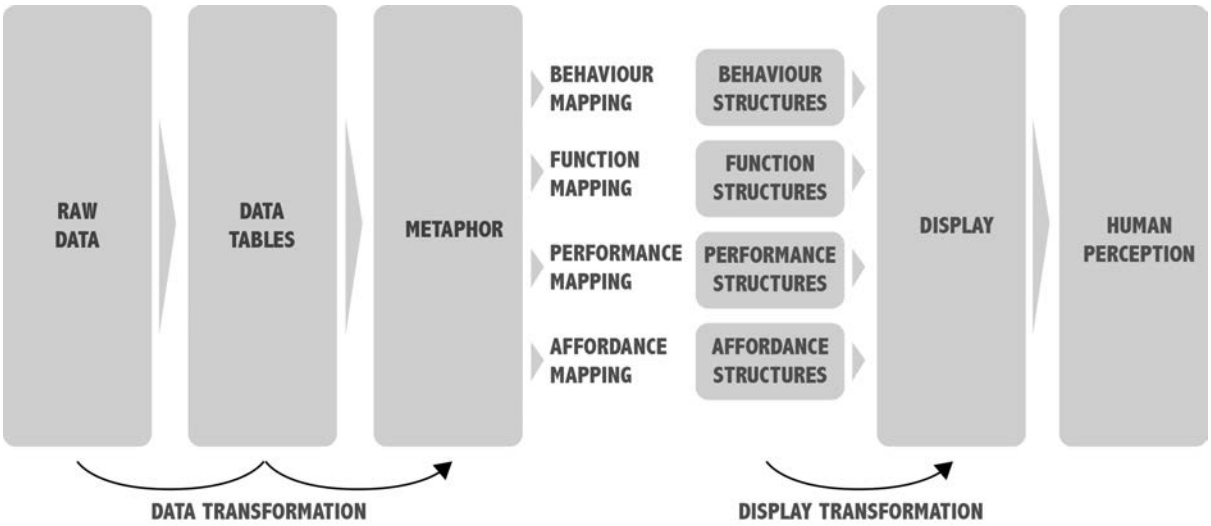

Table 2 The Representation Process of Data Sensifications, an adaption of Card, Mackinlay & Shneiderman's 'Visualization Process' (1999).

Discussion and Future Directions

The study and practise of *Data Sensification* is only in its infancy, and although there are only a few examples available, the exploration of these has raised a number of questions. These include: what are the potential usage scenarios for *Data Sensifications*? What are the key design challenges for *Data Sensifications?* And, how do *Data Sensifications* affect people's user-experience of data representation? The following paragraphs present a first step in addressing these questions, which is followed by a more personal perspective on the future direction of *Data Sensification.*

What are the potential usage scenarios for Data Sensifications?

Five of the six examples discussed in this paper are situated in the field Data Art (Manovich, 2008), with one exception (*Waste Production*, see Fig. 6), which is situated in the field of product design. While the current usage scenario for *Data Sensification* is very narrow, one alternative explored here is: *Data Sensifications for childhood learning*. Research has shown the use of information visualizations in the classroom can be a positive pedagogical tool (Gwozdz-lukawska, Janiga, & Guncaga, 2015) - however, they can also cause cognitive challenges for children (Schneider, 1996). The main difficulties arise when presenting children with complicated visual presentations. An alternative, and less complex approach, is to represent data through visual metaphors. This approach has been proven to be a positive addition to the classroom (Leslie & Waguespack, 1989; Gu, Koh, Chen & Duh, 2010). Leveraging on this research, we can surmise the use of metaphors - beyond the visual paradigm - may also have positive impact on childhood pedagogy. A vision of this may involve embodying data in the properties of objects that are meaningful and familiar to children, such as games and toys. These could then be used as tools for learning in the classroom for

subjects such as science, math and engineering. *Data Sensification* for childhood learning is but one example of a possible usage scenario, and further research is needed to explore other possibilities.

What are the design challenges for Data Sensifications?

Unlike other research domains that focus on data representation, *Data Sensification* has no established design principles. Other fields, such as InfoVis, have a rich tradition of investigating design principles, which can be traced back to Jacques Bertin's seminal work on visual variables published in 1967 (Bertin, 1967/1983). Bertin identified seven visual variables (position, size, value, texture, colour, orientation and shape) and presented a set of rules - which are still in use today - for their appropriate use in data visualizations. Research has continued over the years to validate these (cf. Cleveland and McGill, 1986) as well as to extend them to apply to other domains (*computer graphics*: MacEachren, 1995; *InfoVis*: Carpendale, 2003) and modalities (*sound*: Krygier, 1994; *tactile*: Vasconcellos, 1995; *physical*: Jansen and Hornbæk, 2016). There has also been research on formulating guidelines for the design process of visualizations. Card and colleagues proposed an iterative process of analysis, design and use, which they describe as a 'Visualisation Process' that maps 'raw data' to 'views' (Card, Mackinlay & Shneiderman, 1999). Nesbitt sought to extend Card et al's work to account for the design of multisensory data representations. This paper proposes to extend Card et al's visualization for the design of *Data Sensification*, but further research is needed to validate this. In particular, this process suggests replacing the focus on mapping data to representational modality with the use of metaphors to facilitate data insight. Questions remain on how we can provide specific design guidelines on this in order to make the process understandable and repeatable. Further research is also needed to explore strategies that will allow this mapping process to be clear for the user.

How do Data Sensifications affect the user-experience?

Analysing examples of *Data Sensification* show a range of human interaction, from swinging, over spinning, to musical composition. Also, the type of data insight designers seek to facilitate varies from awareness over intrigue to curiosity. Apart from some rare exceptions (cf. Hogan & Hornecker, 2016) this form of interaction and data insight is seldom facilitated in current data representation. This relatively new approach to data representation opens up challenges that have rarely been addressed in other forms of data representation. Key to this is the approach we take to evaluating the success of current and future *Data Sensification*, which needs to reflect their purpose and goals. This also mirrors the challenges being met by third-wave HCI researchers (cf. Bødker, 2006; Bardzell & Bardzell, 2011). In relation to the InfoVis, Chen and Czerwinski have also stressed the need for improved methods in areas such as task analysis, usability evaluation and usage analysis (Chen & Czerwinski, 2000). However, apart from some rare examples (cf. Hogan, Hinrichs, Hornecker, 2016), the vast majority of prior research in this area evaluates the usability of data representations based on traditional measures such as efficiency and effectiveness. It is recognized that there is an inherent difficulty in measuring non-traditional qualities facilitated by data representations such as awareness, intrigue and curiosity - however, the HCI has a rich history in evaluating such properties (cf. Hassenzahl & Tractinsky, 2006; Wright & McCarthy, 2008). The evaluation of *Data Sensification*s can leverage the research and methods developed in HCI for the evaluation of *Data Sensification*s that have a similar intent: to evoke hedonic responses from their users/audience.

A Final Remark

This paper introduced and explored a novel form of data representation and termed it *Data Sensification.* As part of this, a definition was applied that formalises *Data Sensification* as a class of data representation that has a clear intent to reveal insight by encoding data in the behaviour, functionality, performance, or affordance of an object and data insight is generated from the overall experience of the Sensification. Based on this definition six example *Data Sensifications* were identified and described, which led to a discussion on design issues and challenges that need to be addressed in future research.

The aim of this paper is not to act as a definite guide to *Data Sensification*, nor is it meant to be treated as an exhaustive design space analysis. The field is too young for these. Instead it is hoped this paper is read as a call to design and wider communities to draw their attention to an emerging trend in data representation. It should be acknowledged there are many questions that were not fully resolved in this paper, but, arguably, this is to be expected as the topic under discussion is only emerging and there is little research available. The aim of this paper was never to resolve all questions; instead it was to present a range of questions that need to be addressed into the future and also to trigger conversations within the community.

The future holds many exciting opportunities for researchers and designers who work with data analysis and representation and it is hoped that *Data Sensification* will add another layer to the challenges we face with designing the data representations of the future.

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About the Author:

Trevor Hogan is a lecturer at CIT, Ireland, in the Human-Data Interaction Group. He received his PhD from the Bauhaus-Universität Weimar, Germany. The aim of his research is to better understand how embodiment influences people's experience of data representation.