9. Towards the Information Visualization of Connected Objects

by Massimo Botta, Giovanni Profeta
Scuola Universitaria Professionale della Svizzera Italiana (SUPSI)

9.1. Abstract

In the context of the Internet of things, the paper analyzes capabilities that connected objects are acquiring and the new emerging relationships with the environment and the human being, in order to provide a useful theoretical framework for their visualization. Nowadays every day objects are no longer disconnected elements from the digital world, but they can interoperate with each other by exchanging information through the network, showing capabilities that make objects able to sense themselves, perceive surrounding conditions and even predict their future conditions.

The new capabilities change the relationships between the object, the human being and the surrounding environment. These relationships are based on behaviors ranging from simple control actions to the articulation of multiple automatic actions that fulfill a specific user purpose.

By examining the way in which the hierarchy of knowledge – also known as DIKW hierarchy – evolves, we try to outline design implications for information visualization generated by new capabilities of connected objects.

9.2. Introduction

At CES 2015\(^1\), Eric Schmidt – executive chairman of Google – has led

\(^1\) CES (Consumer Electronics Show) is held every year in Las Vegas. It involves the major technologies companies in the world.
to the opening of a debate because of his statement: “The Internet will disappear”. His provocation does not refer to the fact that the Internet is becoming an obsolete tool, but to the fact that the traditional concept of the Internet is changing.

Today, in fact, the Internet is no longer a network consisting solely of computers, but it is becoming more pervasive, expanding to every day objects. This is happening thanks to the spread of multiple hardware technologies – such as sensors, actuators and miniaturized computers – and the development of better performing software technologies – such as non-relational databases for storing data and languages for processing big data.

As in a neural network, objects are able to sense the real world and to interoperate with each other in order to simplify, connect and enhance user lives. New connected objects capabilities modify both the common object proprieties and the relationships between them, the human being and the surrounding environment.

Thus, being able to analyze data and information generated by objects, through the use of graphical visualization, acquires particular importance. In this context, in fact, through visualization it is possible to describe complex phenomena that affect the objects and the human life and to understand the dynamics that govern them in order to undertake new design actions.

### 9.3. Connected Objects Capabilities

In an era where the Internet become more and more pervasive, objects – no longer closed element disconnected from the digital world – are able to autonomously interoperate with each other by exchanging information through the network. The definition of the Internet of Things (IoT) refers to the vision in which objects are able to observe, identify and understand the world. Within this vision, many definitions of connected objects exist. In some of them the focus is on functional and behavioral features that open

---

2 The Internet – understood as a worldwide network of computers – was publicly released in 1991 in the United States in order to provide a tool for exchanging information within the scientific community.

3 Big data is a term used to describe any voluminous amount of structured and unstructured data that has the potential to be mined for information. Big data can be described by the following characteristics: volume, variety, velocity, veracity.

4 Kevin Ashton, the co-founder of the Auto-ID Centre at the Massachusetts Institute of Technology (MIT), coined the term Internet of Things in 1999.
up new design scenarios.

The term Smart Things – for instance – refers to objects able to perform intelligent actions according to the context. Smart Things are physical objects with shape, texture, color, weight, temperature etc. But also with buttons or dials that trigger behavior and displays that communicate information (Kuniavsky 2010).

“Spime” – standing for space and time tracked objects – is instead a definition that compares objects with Internet entities. They are manufactured objects whose informational support is so rich that they are regarded as material instantiations of an immaterial system (Sterling 2005). In order to saving resources and reduce cognitive efforts, in a world of Spime, designers must design having in mind the techno-social interactions that unite people and objects.

The definition “things that think”, besides, refers to everyday objects that encapsulate capabilities to solve user problems (Gershenfeld 1999). These capabilities mainly affect the object state – in terms of configuration – and the communication among objects.

In this paper we would like to analyze objects capabilities within and through the network in order to provide a theoretical framework as a starting point for the articulation of information design elements useful for the visualization of connected objects.

In order to better understand objects capabilities we make an example of everyday life.

Let’s consider that the birthday of our friend will be in few weeks and we want to make a gift. Our friend lives in New York and he is very passionate of art. Thus, we decide to ship him a piece of art by using SenseAware, a shipment service that provides enhanced visibility during shipping, allowing users to take control of the supply chain. SenseAware consists in a small device that, placed in the shipment box, is able to track its position, temperature and other internal conditions, and to provide – as a service – information about shipment's environmental conditions.

We include the SenseAware device within the shipment box in order to avoid the gift get lost and to monitor any damages. During the shipment, we receive near real-time information about the box through a web application. When the package is delivered and our friend enjoy the gift,

5 Bruce Sterling argues that designers must to take into account two phenomena that in a world of Spime are in scarcity: cognitive load and opportunity costs. The first refers to the maintaining of the human brainpower. The second refers to the risk of losing human activities.

the service notifies us that the box was opened. If we want to donate fragile gifts to other our friends spread out in all around the world, SenseAware service would allow us to keep control of all shipments, to understand what are the best shipping companies and to take action before products are compromised.

The example described above shows how new capabilities of connected objects – within the context of the Internet of Things – enhance human life by saving resources and by providing significant insights for decision-making. The more connected objects are involved in the user everyday life, the more they can act as active partners.

Capabilities of connected objects seem to create new relations and support new experiences between the human being, everyday life objects and the surrounding world. The following list tries to summarize and describe these new capabilities.

**Perceiving surrounding conditions** is the capability to experience the world by quantifying it. Surrounding conditions include the physical environment and what affect its quite state – such as the user or other living beings as well as other objects.

Environmental sensors make objects able to gather data in order to identify and track the characteristics of the context where they are placed.

**Detecting the time and the space position** – both in the real space and within the network – is a fundamental capability for the integration within the Internet. The position recognition and the univocal identity, in fact, allow the object to be recognized and to be reached through the network. Thanks to this capability, objects can be precisely tracked through space and time through out their earthly sojourn (Sterling 2005).

**Remembering object and surrounding conditions** at a point of time in the past refers to the capability to keep record of what happen in the object life. Despite memory about the past may be limited, object information storage need to maintain a degree of information about past conditions. This capability allows object to work not just in reaction to what is happening in the moment, but what also was experienced before (Kuniavsky 2010).

**Predicting future conditions** refers to the capability to analyze past conditions and make a forecast about possible future conditions. Due to the uncertainty of the future, the capability to predict future conditions in a reliable manner requires a large dataset of previous conditions and high

---

7 Environmental sensors are electronic devices able to transform physical stimuli into digital signals.
computational performances. This capability allows objects to make reasonable choices about the present in order to optimize resources and to avoid possible issues.

**Sensing object conditions** refers to the capability to sense sensory stimuli coming from parts of the object. Stimuli felt – that can relate both internal and external parts of the objects – are strictly related to the closer surroundings such as the pressure on the surface, the light exposition, the state of charge etc. Objects that sense their own physical conditions have the potential to make the user aware of any malfunction and to provide him tips for prevention and maintenance. The capability to sense internal conditions is particularly needed for objects exposed to stress conditions. In fact, through these capabilities, it is possible to push the object to its technological and mechanical limits.

The communication between the object, the environment and the user (**communicating information**) takes place through physical stimuli coming from digital and tangibles interfaces. Objects provided with the capability to communicate essentially act as information systems: objects gather information coming from environmental conditions or flowing through the network, elaborate it and then share information with the user.

**Exchanging information** is the capability to share information with other objects connected to the network and to get information from it. This capability is based on the fact that objects must have a common language that allows them to interpret the information exchanged meaningfully and accurately in order to get useful results.

By exchanging information, objects become gateways to the network. They can both make tangible Internet contents and send to Internet information generated from tangible actions.

The capacity to **perform tangible actions** consists in acting in a way that has an affect on the physical world. Despite connected objects can be primarily conceived as information elements, they can affect their surroundings by changing their own physical conditions and by modifying the state of other objects.

Objects capability to **perform autonomous actions** refers to acts that take place without human intervention and according to the surroundings circumstances. Objects can act autonomously thanks to the ability to reason on current and past conditions. Mainly because of this capability connected objects reduce user cognitive effort by avoiding repetitive or annoying actions.

The term **interoperability** refers to the objects capability to work together in order to reach a common goal. Connected objects that interoperate with each other act in a way that facilitate multiple aspects of
user life, optimize resources within the network and prevent any problem before it happen.

Interoperability requires common practices and standards. Although objects can have very different technologies and information processing, a standardized information schema can make them able to obtain a global interoperability (Friedmann and Floerkemeier 2010).

9.4. Relationships Between the Object, the Network, and the Human Being

Within the Internet of Things the development of the new object capabilities is changing the relationships between objects, the Internet and human beings. With the term relationship we intend the articulation of interactions between entities able to influence each other. Unlike the recent past – when objects cannot connect to the Internet – nowadays interdependence connections within the Internet of Things are becoming more and more strict.

As we argue in the previous list, the capabilities of connected objects are essentially based on the gathering, the exchange and the analysis of information coming from inside and outside the network. The information is the raw material that generates hierarchical relationships between connected objects and the context.

The interactions hierarchy – that is strictly related to the presence of one or more capabilities – goes from very basic objects behaviors that slightly affect each other and the user to meaningful actions that address a specific user purpose.

In the context described above, the connection and communication between objects, the human being and the network generates four basic relationships: tagging, linking, tutoring and networking.

Tagging refers to relationships in which connected objects track living beings or other non-connected objects. In this relationship connected objects detect positions and the state of other “things” in order to remotely control them. Connected objects have a passive role within the network; they just have the function to reveal third part conditions and movements.

The linking relationship merges the physical with the digital world. Objects able to link tangible things with digital contents allow users to interact and share information with each other by remote. Despite objects can have a physical function, they are primarily conceived as access point to information coming from the network (Còrdoba et al. 2011).
Two main categories of linking relationships exist: Internet-to-world relationship and world-to-internet relationship. The first one consists of objects that perform actions according to information coming from the Internet. The second one consists of objects that gather physical stimuli – coming from users and the physical world – and communicate information to the Internet. In both the two categories the act to sense and to behave can take place almost simultaneously.

In the tutoring relationships objects perform action or provide suggestions to the human being according to perceived circumstances. The purpose of this relationship is to optimize user efforts and to prevent contingent problems. Despite objects are mostly listening, they take decisions and act when needed. Reasoning processes drive their actions according to information gathered by their surroundings and the objects network.

Networking refers to relationships in which objects interoperate with one another by exchanging and elaborating information through the Internet. Interoperating objects are strongly active and the experience – intended as the storage and the analysis of both previous and current conditions – can drive their actions.

9.5. Visualizing Connected Objects

New capabilities acquired by connected objects, resulting in the development of new relationships between them and the surrounding world, open up new design scenarios for visualizing information generated by objects.

In order to understand emerging characteristics in the visualization of connected objects, we take as reference the DIKW hierarchy\(^8\), a theoretical model representing structural connections between data, information, knowledge and wisdom\(^9\).

According to the DIKW hierarchy, information comes from data\(^10\) that are endowed with meaning and purpose (Ackoff 1989). Both data and

---

\(^8\) In information research, DIKW hierarchy is also known as knowledge hierarchy and information hierarchy. It is commonly represented as a pyramid with data in the bottom and the wisdom in the top.

\(^9\) The origin of the concept recall the poem “The Rock” by T.S. Eliot (1934) and the song “Packard Goose” by Frank Zappa (1979) Since 1980s, the DIKW (Data, Information, Knowledge, Wisdom) hierarchy is part of the information science language.

\(^10\) Data are discrete, objective facts or observations, which are unorganized and unprocessed.
information are piecemeal and partial. Due to their atomized nature they can be generated without direct human interpretation (Zeleny 1987). Information connected by a pattern provides a high level of predictability and constitutes the knowledge. Knowledge is the understanding of facts. It is involved in the process in which people answer to no-easy question by discernment and produces wisdom. Wisdom refers to the ability to think and act in order to increase value and effectiveness.

In the context of the connected objects, raw data are essentially sets of values of quantitative and qualitative variables generated by sensors. It can be associated with other metadata in order to provide a context to them. The raw data come from three distinct domains: the object, the human being and the world. Their qualities depend on many factors. Among these there are the extension, the types of connections between entities and the peculiarities of the instruments for data collection.

Due to the capability to describe reality and characteristics of objects in a rigorous and objective way, raw data has a great informative potential that can be communicated through visualization.

The information consists of data interpreted in order to understand patterns that are hidden in them. Pattern refers to the articulation of behaviors that occur in the object. Information visualization highlights aspects that denote the concentration of activities in a given situation — among others there are activity peaks, multiple occurrences and clusters of actions.

The term knowledge refers to the structuring of information for understanding relationships between objects. Visualizing this complex interactions — mediated by object behaviors — requires the consideration of the actions performed by objects, of the interaction frequency, of the level of involvement — intended as the typology and the quantity of performed actions — and of the trigger events.

Within visualization the presence of objective information — in quantities suitable for the human understanding11 — provides to the user the essential basis for the development of knowledge12.

Finally, the wisdom is the stratification of knowledge for understanding the ecosystem of connected objects. Wisdom allows people to have a full understanding of dynamics and characteristics that govern complex systems

---

11 The excessive amount of information generates information overload. Information overload refers to the difficulty in understanding and decision-making of the user. It is due to the excess of information that should be processed.

12 The process of knowledge acquisition — performed by human being — is mediated by past experience and the socio-cultural context.
in order to facilitate strategic decision making for their optimization and upgrading.

At this level of the DIKW hierarchy, the inference arises. Inference refers to the capability of objects to derive logical conclusions from known data and, consequently, to act according to surrounding conditions. Visualizing inference would allow understand – with a greater level of detail – the trend of an ecosystem. Furthermore it would allow understand how objects learn from their own mistakes, to identify trigger events within the system and to highlight the quality of the relationships established between objects, the environment and human being.

In more general terms and in ascending order, at a first level graphical visualization would allow to monitor an ecosystem – by taking into account data coming from the objects – synthesizing the phenomena and maximizing clarity.

At a second level visualization would allow analyse an ecosystem, by highlighting insights and significant details.

Lastly, at a third level visualization would allow to facilitate decision-making for system optimization. It would therefore highlight possible areas of intervention by combining the simplicity of the visualization with the need of understanding.

Visualizing all these aspects will allow designers and engineers, on one hand, to improve technologies determining object capabilities, on the other hand, to have a useful interpretative framework to support decisions about potential effects that will take place in the near future.

In order to reach high levels of knowledge and wisdom, allowing to improve complex systems of connected objects\(^\text{13}\), it will be increasingly necessary to have visualization that respond truthfully to the requirement above.

Due to the fact that visualization is a synthetic representation of reality, it cannot be fully comprehensive of the phenomena that take place in a world of connected objects. However, the rapid increase of available data suggests that in the near future it will be possible to have visualization more and more exhaustive for the comprehension of networks, allowing the human being to take necessary actions to improve their living conditions.

---

\(^{13}\) Among complex systems of connected objects there are: the network of postal shipments, the production chain of industries and all the constitutive infrastructure of smart grids.
References


