Visualization of Human Behavior data: the Quantified Self

Alessandro Marcengo, Telecom Italia, Italy
Amon Rapp, Computer Science Department - University of Torino, Italy

"Knowledge of the self is the mother of all knowledge. So it is incumbent on me to know my self, to know it completely, to know its minutiae, its characteristics, its subtleties, and its very atoms."
Khalil Gibran

ABSTRACT
Although in recent years the Quantified Self (QS) application domain is growing, are still palpable some fundamental problems that relegate the QS movement in a phase of low maturity. The first is a technological problem and specifically a lack of maturity in technologies for the collection, processing and data visualization. This is accompanied by a perhaps more fundamental problem of deficit, bias and lack of integration of aspects concerning the human side of the QS idea. The step that we tried to make in this chapter is to highlight aspects that could lead to a more robust approach in QS area. Primarily through a new approach in data visualization, secondly through a necessary management of complexity, both in technological terms and, for what concerns the human side of the whole issue, in theoretical terms. We have gone a little further stressing how the future directions of research could lead to significant impacts on both individual and social level.

1 INTRODUCTION
In this chapter our proposal is to outline some aspects of human behavior generated data in the light of a specific research branch, the so called Quantified Self (QS) area. We think that time has come to sketch current status and new directions in a field that even being explored for years, only recently, also thanks to some technological advances, is finding its practical application. We will analyze the first attempts to trace and represent human activity through the description of some experiments in this direction (e.g. LifeLog DARPA Project, MyLifeBits Microsoft Project, etc.). The chapter will then describe the most important application fields of QS, in order to draw a clear picture of the current situation and to give an overview of the most promising sectors in which this approach will be developed in the coming years.
In particular, we will describe the distinctive means to monitor and render human behavior and the applications aimed to persuade people to change their practices of everyday life, in areas related to health, mood and fitness but also with few references to sports, training, social networking, transportation, consumptions, emotions and communications.

The chapter will cover then two fundamental problems of the QS today, the technological problems and the theoretical problems both in terms of data visualization of large dataset and in terms of behaviour change theories that still make difficult to adopt a non-purely empirical QS approach. Will be then drawn the directions to handle these problems toward a more robust and credible QS scenario through new ways of representing data and new directions in the management of complexity, both on the technological side and on the human side of the topic. Then we will go further considering future directions of research with both individual and social impacts.

2 WHAT IS THE QUANTIFIED SELF

The QS is a school of thought which aims to use the increasingly invisible technology means in order to acquire and collect data on different aspects of the daily lives of people. These data can be "input" from the outside (such as the calories or the CO2 consumed), or they can be "states" (as the mood or the oxygen level in the blood) or parametric indicators of performance or activity (such as the kilometers run, the mail sent, or the mp3 heard). The purpose of collecting this data is the self-monitoring and the self-reflection oriented to some kind of change or improvement (behavioral, psychological, medical, etc.).

It is immediately evident how this approach, which we will analyze in more details in the following pages, raises a series of theoretical problems (for example, what are the foundations of human behaviour change?) but even before a series of technological issues. How can this data be collected (input)? With what kind of sensors? And above all, how this knowledge can be returned to the user (output)? With what kind of data visualization techniques? In this short arc, from doing an action (recorded by a sensor and stored by a database) to have the "image" of that action (displayed on a screen), there are about 200 years of research studies in different fields.

Just to do a little bit of history of this topic, the whole spectrum of toolset, application and technical approaches related to this type of thinking has taken different names over time. It can be found in literature as "Personal Informatics", "Personal analytics", "Self Tracking", "Living by Numbers", according to the focus on what has been emphasized by each definition.

Considering only the QS sunrise, the movement was founded in 2007 by the editors of "Wired" Gary Wolf and Kevin Kelly, with the purpose of creating collaboration between users and manufacturers involved in the development of self-knowledge through self-tracking technology. In 2008, the same Wolf and Kelly opened the site "quantifiedself.com". In 2010, Wolf spoke at TED Conference, and in May 2011 in Mountain View the movement held the first conference specifically on QS.

There are some basic points that define the QS movement: the data collection, the displaying of these data, and the cross linking of these data in order to discovery some possible correlations. The interest that is developing in these years around this current is also evidenced by the proliferation of gadgets that are appearing in trade shows such as CES (Consumer Electronic Association) or conference sponsors among which it is possible to find names such as Vodafone, Philips and Intel.

The whole issue seems to revolve around the question *"Who am I?"*. The supporters of the QS think that the answer lies in our daily activities and hence the need to quantify any behavior, taking photos of everything is eaten or drank, recording the distances covered, monitoring the pattern of REM/NREM sleep, noting the "mood of the day", storing the blood pressure and heart rate, and so on.

According to this fundamental question, is maybe necessary to underline what we mean by "Self" that perhaps is something too often left aside. The notion of "Self" has been a central aspect of many personality theories, including those of Sigmund Freud, Alfred Adler, Carl Jung, Carl Rogers, and Abraham H. Maslow. In Carl Jung's concept the self is a totality consisting of conscious and unconscious contents that dwarfs the ego in scope and intensity. The maturation of the self is the individuation process, which is the goal of any healthy personality. Many years later Rogers theorized that a person's self-concept determines his behaviour and his relation to the world, and that therapeutic improvement occurs only when the individual changes his own self-concept. Maslow's theory of self-actualization was based on a hierarchy of needs and emphasized the highest capacities or gratifications of a person. Nowadays a simple "common sense" definition of "Self" is *"one's identity, character, abilities, and attitudes,*

especially in relation to persons or things outside oneself or itself" (Definition of Self, 2012a), while amongst the more "academic" definitions we can find this kind of descriptions: *"The individual as the object of his own reflective consciousness; the man viewed by his own cognition as the subject of all his mental phenomena, the agent in his own activities, the subject of his own feelings, and the possessor of capacities and character; a person as a distinct individual; a being regarded as having personality"* (Definition of Self, 2012b).
The concept of "self" is central in all human history since the emergence of consciousness. The ability to reflect on oneself is central to each of us as human beings. The fundamental human question *"Who am I?"* is exactly the research of our "Self".

3 ROOTS OF QUANTIFIED SELF MOVEMENT

The idea to record the personal physical activity and psychological and emotional "states", through technology (spread sheet, digital pictures, etc.) has roots that can be traced to the mid-90s: the practice of lifelogging, "*a form of pervasive computing consisting of a unified digital record of the totality of an individual's experiences, captured multimodally through digital sensors and stored permanently as a personal multimedia archive*" (Dodge & Kitchin, 2007), is the one that comes closest to the idea of QS and finds in people like Steve Mann, professor at the University of Toronto, its precursors. Mann, a pioneer in the field of wearable devices, since 1994 decided to stream his daily life 24 hours a day. EyeTap (2012), the name of his project, consists of a wearable device allowing to store all that the user sees, making possible to record a complete photographic memory of everything happens to himself. Furthermore, EyeTap displays information to the user itself, altering the visual perception of the wearer and creating in this way a kind of augmented reality (Mann, 2004). In essence, users can "build" reality by altering the visual perception of the environment and the visual appearance of the sight by adding or modifying what they are seeing: this mediation of reality can be done in real time or in a following phase, going to retrieve what was recorded and applying to it the desired changes (Nack, 2005). Around the experience of Mann has developed, over the years, a community of lifeloggers (or globbers, as they call themselves) that aim to visually record everything that happens around them during their daily life: this community has reached the amount of 200 thousand units.
If EyeTap was one of the first individual projects designed to record all individual's perceptions on a digital media, "MyLifeBits" (Gemmell et al., 2006) was the first attempt, supported by the industry (Microsoft Company), to aspire to the complete recording of all the experiences of a human being. Conceived in 1998 as a tool to record daily life events, MyLifeBits aims to preserve the whole life of its creator: Gordon Bell. Bell decided to store in digital format everything with which he came into contact during his day: articles, CDs, letters, events, notes, sounds, conversations and photos. Bell, when began his experience of digitalization, still needed a human assistant to catalog and digitalize all the items flowing in his life. However, even all materials digitalized, Bell still not had the chance to use them due to the limitations of the software available at that time (Bell & Gemmell, 2007). MyLifeBits was designed to bring order and create links between the various data collected and stored by Bell, taking advantage of a metadata system in order to make possible the navigation in these huge amount of heterogeneous data. For instance the system is able to generate automatic links, by correlating the GPS location of Bell, continuously recorded throughout the day, with the time and date of a photo taken by the same Bell. Nevertheless, MyLifeBits records his telephone calls and the programs playing on his radio and television, automatically stores a copy of every Web page he visits and a transcript of every instant message he sends or receives. With the aid of a "SenseCam", a wearable device developed by Microsoft Research (Hodges et al., 2006) that automatically takes pictures when its sensors indicated that the user want to photograph, Bell preserves the image relating to the surrounding environments in which he moves, the people he meets, the significant moments of his life. In fact, Gordon Bell realized the pioneer idea of Vannevar Bush that since 1945, in his article "As We May Think" (Bush, 1945), envisioned a tool (the Memex – abbreviation for Memory Extender) able to store and catalog, using the microfilm technology, all the documents that an individual faces in the course of his life. The Memex should have been able to generate automatic annotation and create links between documents similarly to the process of

human associative memory. Today MyLifeBits is evolving towards a continuous connection with any kind of sensors, able to automatically generate data regarding the displacements of Bell, his health and his physiological parameters. However, the limit of the Bell's project is in his strong individual connotation because it was designed by and for its creator: a system tailored to the constant recording of Bell's daily life that had more the virtue of pointing the way, rather than to seek a large scale diffusion on consumer market.

"Total Recall", instead, is a Lifelog research project of the Internet Media Lab of the University of Southern California, that starts from a different perspective (Internet Multimedia Lab, 2004). The basic idea of this system is to increase the memory of people through the storing of experiences, events and knowledge relating to an individual or a multitude of individuals. Using a large amount of sensors, a microphone and a camera mounted on a pair of glasses or in a necklace, Total Recall aims to record the world from a personal point of view, allowing on demand to recover the data collected through customizable searching, analysis, and querying of this data. Total Recall was designed from the beginning to have a wide range of applications, all aimed at gathering information about an individual with the purpose of making evident data and elements that usually do not rise to his knowledge. For example, in the health care area, the system can monitor the daily diet of a diabetic person, reporting any risk situations or correlating these data with the visited environments by the same individual in order to identify specific allergies: the data, flowing continuously from the patient, can also help clinicians to fine tune the diagnosis and the treatments (Cheng et al. 2004).

All these attempts show how from the first half of the 90s the idea of recording the life of an individual and to return it back in some visual form was spreading in the world of industrial and academic research. Worth a note, however, "LifeLog" as the first government project aimed at monitoring and recording the lives of individuals with also potential military applications. LifeLog was a project developed by the Defense Advanced Research Projects Agency (DARPA) recognized as a system capable of collecting information on an individual, on its activities, its states and its relationship. The goal of LifeLog was to trace the entire life of an individual: his monetary transactions and his purchases, the contents of his phone calls, sent and received emails and messages, his movements (traced by a GPS signal), and even biomedical data related to his physical health (obtainable through specific wearable sensors). In the original concept the system could have been used in stand-alone mode as a sort of journal or recorder of individual memories, allowing the user to search and retrieve information and experiences related to his past in the form of images, sounds, videos. LifeLog Project was closed in 2004, due to privacy problems raised by the public opinion. However, during his short life it made the people imagine a future in which military commands would have been equipped with systems for continuous recording of their experiences, able to access their own data and to re-trace what happened to them (Allen, 2008).

All these early research efforts, trying to build applications for continuously tracking parameters about the whole human behavior, have found some obstacles in the availability, the complexity and the cost of the technology (O'hara et al., 2006) as well as in issues concerning ethics and privacy (Mayer-Schönberger, 2009). Only recently, technological advances in networks, sensors, search and storage seem to have changed this situation. How we will see, the birth of a number of academic projects and a considerable amount of commercial tools capable of tracking individual parameters of people's lives (then recomposing them in significant views) seems to make at least closer a credible QS scenario.

4 QUANTIFIED SELF PROMISES

Wolf in his famous speech at the TED (Wolf, 2010) opened his talk reciting a series of numbers. The time he woke up (6:10 am), his average beats per minute (61), his blood pressure (127/74), how many minutes of exercise he had (0), how many milligrams of caffeine he had been drinking (600), how many milliliters of alcohol (0) and such other numbers.

The statement Wolf pronounced was: *"If we want to act more effectively in the world, we have to get to know ourselves better."* This phrase, that actually at first glance seems to make sense, looks naïve to a more detailed analysis. Is not enough to know "things" (data) because this is able to produce some sort of change. This is a naïve thought that as we will see has its origin in partial or outdated psychological paradigms. What we now know for sure is that the human brain is not a “rational computer”, that given some data produces the "best" answer for that data. In a word, this rationalist model would work perhaps for Mr. Spock of Startrek (the rational, non-affective, vulcanian) but not for humans that are most dependent for their decisions by emotions, complex social cognition and even pre-cognitive processing that in data visualization drive the attentive focus.

Looking at the current QS scenario the impression is that this knowledge is shortly considered in favor of a “wow effect” or an aesthetic presentation. Hence the suspicion is that nowadays QS is not something oriented to build knowledge toward a purpose, but instead a way to collect data, like collecting butterflies, beer caps, etc. something that end in itself. The flavor is that QS supporters are more interested in collecting numbers, and putting them in some sort of neat filing cabinets (usually called infographics) than anything else. The risk is that the data do not help people to reach a personal goal, but their collection becomes a goal in itself, losing the big picture and the original motivations that should guide QS applications.

In fact, the interesting point of the whole QS movement is the ability to change something (for the better) in people’s lives. But often this discussion is simplified in this kind of statements: *"by seeing my data I have more information and this allows me to make better choices. Furthermore if the graph is nice I will like more to collect my data”.* In fact there are a number of mechanisms that govern the behavior change and them are numerous and complex. In the following sections we will see some key moments related to the study of human psychology seeing how some of these are used from time to time in QS application often without even realizing it.

Although Gary Wolf sometimes called the QS as *"the next step in human development"* stressing that having greater awareness of one’s data is a form of action against choice standardization imposed by TV, advertising, various media, etc., and a sort of re-appropriation of the individual self-determination, QS still looks like something very embryonic. In fact there are some fundamental problems yet to be solved. On the one hand some technological problems, but these are not of great concern, because the technological evolution is a fairly linear and predictable process. Those who appear the problems to be addressed in more deeper manner appear instead of a higher order, of theoretical order. The huge amount of data that can generate a QS scenario poses major challenge in the manipulation of this information and in the displaying of these data. It will be discussed in the next sections how far we are from having a knowledge applied to data visualization for large amounts of data and how we have to develop innovative solutions that take into account the ability of our brain to perceive data in a more natural way, as is done with the complexity of the natural world.

A second and even more profound problem is the lack of a true theory of behaviour change, or rather the existence of knowledge modules used in a more or less conscious way by QS applications but without an actual theoretical corpus that can be used by designers. There is therefore a theoretical problem that does not allow, besides some personal experiments in some application domain, to say which is the mechanism of operation that given some data should produce a change and consequently what should be considered in a QS application to produce a different personal behaviour.

In order to make more clearness, there will be in the next section a brief review of the elements that somehow seem to have a role in the QS as behaviour change engine and how these contribute to give a general impression of utility, though each has a different role in different application fields and for different people.

5 CURRENT APPLICATION FIELD OF QUANTIFIED SELF

Today there are more and more widespread applications and research projects related to the self tracking of people’s behavior. Regardless the particular application domain (e.g. health, fitness, mood, goals and time management) most of these tools can be outlined to tracking: a physiological state (e.g. body temperature, and breathing), a state of mind (e.g. thinking patterns , mood), a location (e.g. environment, travel), time (e.g. time intervals, performance time), people (people you are with, interactions). To collect these data, applications that spin around the QS movement may resort today to direct measurement (using wearable and/or environmental sensors), inference (using semantic reasoning and algorithms: some data can deduce or infer others) or self-reporting (requiring manual data entry). In this section we will review three of the domains in which the QS idea seemed to realize most successfully in recent years: health, mood and fitness.

5.1 Healthcare

There is a growing trend in consumer market to develop sensors and services that support self-tracking of data concerning health. At moment users can access a variety of services and applications that collect, analyze and display statistics about a diverse range of parameters and behaviors related to their health. Although there are studies that seek to correlate these parameters with each other or with the context in which these behaviors are produced (Bentley et al., 2012), typically these tools now detect a single parameter or health-related behavior of the individual, often relying on a device able to measure it, storing it on a website where the user can view changes over time and compare them with those of other users. These services are intended to improve the health condition of the patient and help him to live a more salubrious life by changing its behavior in a positive direction. Although it is more and more common trying to find new ways to influence current and future health behaviors (e.g. using "past-self" avatar able to "give birth" to the past behavior of a person, or improving self-efficacy of the patient's presenting "reminders of success" when a failure occurs (Ramirez & Hekler, 2012), or even more by using game mechanics related to the world of social media (HealthMonth, 2012)), the more common used methods today can be traced back to the display of data about current behaviors and the presentation of information about the progress towards a particular short or long term goal.

Most part of the services are not targeted to specific diseases but rather aim to facilitate the health reporting of individuals suffering from different disorders, trying, with the support of a social network, to facilitate the exchange of information between patients, providing disease progression, drug prescriptions and symptom tracking. The most famous is PatientsLikeMe (2012), founded in 2004, that today gathers more than 160 thousand registered patients: it allows to record the symptoms of their disease in order to find patients in similar conditions and to exchange information about the effectiveness of the treatments and the evolution of their medical symptoms. As well CureTogheter (2012) allows to compare the effectiveness of thousands of treatments to find the best solution for one’s own health needs and Health Tracking Network (2012) aims to get people to work together to monitor common illnesses and discover factors related to them, using a system of self-reporting and collecting information from third party tracking tools. HealthEngage (2012) instead appears as an aggregator of health data about individuals, able to trace the general condition of the patient, the medicine he has to take, his daily diet and any chronic disease he has, importing information from different free tools; HealthVault (2012), a Microsoft service, can arrange in one place all medical information relating to an individual, providing forms of data visualizations that should help patients to take more conscious decisions about their health; ReliefInsite (2012), finally, allows to track pain conditions and store them in a journal that can also serve the medical staff to reconstruct the patient's condition.

Related to this kind of services there are more specific applications that can monitor physiological trends and behaviors related to a specific chronic disease: DiaMedics (2012) DIALOG (2012) and SugarStats (2012) are all services that can monitor the health of a patient with diabetes, providing statistics, community support and collaborative sharing to motivate and improve health; while Asthmapolis (2012) uses a specific sensor to track spatially and temporally asthma attacks of a patient and the quantity of medicines he takes.

The use of specific sensors and dedicated devices is also implemented by applications that are able to track physiological parameters continuously throughout the day. Glasswing allows to measure non-invasively hemoglobin (2012). SenseWear (2012) as well as Fitbit (2012) and Zeo (2012) collect and analyze information related to physical activity performed by the patient and sleep behaviors: the tracker monitors how many times and for how long the patient wake up during the night providing information on the quantity and quality of sleep patterns. Other research projects, on the academic side, such as Lullaby (Kay et al. 2011) set more ambitious targets and, using a variety of different sensors (e.g. sensors for air quality, noise, RGB light, infrared camera) seek to integrate the monitoring of physiological parameters with the environmental factors that can affect the sleep of the patient. In the end, BAM Labs (2012) uses a non-intrusive system, called Touch-free Life Care (TLC), which, through an under-the-mattress biometric sensor, collects motion, heart and breathing rate without attaching anything to the body.

Taking advantage of a small but growing number of consumers who prefer to skip costs and delays of specialist medical consultations to order their laboratory tests, some companies have begun to offer services of medical lab tests, making it possible not only to order directly from their websites the desired analyzes, but also to keep track over time of the variations in the parameters analyzed, as the level of cholesterol or glucose in the blood. MyMedLab (2012) and Private MD Lab Services (2012) are two examples of services that are part of a more general trend that is bringing individuals to care for themselves health status, tracking, storing and managing their physiological parameters, in collaboration with health peers and in co-care with physicians. QS applications make it possible, and at the same time are a symptom of a change that is arising in the health care, toward a patient-driven health care characterized by *"having an increased level of information flow, transparency, customization, collaboration and patient choice and responsibility-taking, as well as quantitative, predictive and preventive aspects"* (Swan, 2009)

Finally, companies like 23andMe (2012) Pathway (2012), Knome (2012), Navigenics (2012) deCODEme (2012) have begun to offer tracking of DNA profiles to their clients: tracing the sequence of one million "snips" (snips are the current unit in personal genomics and are the part of the gene researchers have noticed that varies between individuals), these companies provide a series of numbers and letters that can be related to some aspects of their health and their genetic past. These genetic data can then be shared on network sites like Personal Genome Project (2012) or compared with the information contained in wikis as SNPedia (2012). As Gary Wolf noticed in his article Genomic Openness (Wolf, 2008) the field of Personal Genomics, or the ability to track data about their genes, is located at the edge of the field action of the QS. If the aim of the movement of the QS is the tracking of the physical and psychological “self” to make changes in behavior or take action to improve conditions (e.g. health) is not yet clear how knowledge of genome parts can lead to this result even if people like it. Melanie Swan from DIY Genomics (2012) advocates this strategy to develop a form of personalized preventive medicine (Swan, 2011)). The complexity in correlating these data with elements relating to personal health or personal phenotype makes to foresee that only an open sharing of raw genetic data and mass public collaboration could lead to some kind of knowledge advancement in the future.

5.2 Mood

Today, the mood tracking area is having increasing consideration. Applications and services related to this field are intended to help users to increase their awareness and understanding of all the factors that influence their “mood states” and their mental health. These applications, through different kind of visualizations, are able to track changes in mood over time and identify patterns and correlations with environmental and social factors, in order to facilitate the identification of variables that can affect the mental states of the person.

It is possible to find applications such as Track Your Happiness (2012) a research project of Mart Killingsworth at Harvard University: it allows you to draw the happiness of people asking them on a regular basis, via email or sms, what they are doing and how happy they feel at that time (through questions like: *“How happy are you right now?", "Do you want to do what you're doing?", "Do you have to do what you're doing?", "Where are you?", "Are you alone?"*). Reports inform the user about the changes in his happiness over time and what possible factors have had an influence on it. Happy Factor (2012) asks the user about their happiness by sending text messages: these data are recorded on a scale from 1 to 10 also associating them with some notes about activities carried out at that particular time. The application is then able to return in visual form history, average happiness for days, months and a frequency chart of words used in the notes from happiest to unhappiest. On the same mechanism is based

MoodPanda (2012): happiness rating on a 0-10 scale, and optionally adding a brief twitter-like comment on what's influencing the mood.
Other services instead, such Moodscope (2012) and MoodTracker (2012), aim to measure, track and share the mood not only onto the happiness dimension. The first, for instance, uses a simple card game for tracking daily mood, brings out what can have a positive or negative influence about it and allows to share data with a list of trusted friends who can support the person in order to improve his overall mood. Both applications are designed not only for the common people, but especially for those suffering from depression and bipolar disorder. Even FindingOptimism (2012) is a service that has the purpose of increasing the understanding of the factors that can affect the mental health of the individual, helping to identify the "triggers" that affect the patient, and the early warning signs of new episodes of mental disorder, favoring the filling of a wellness plan with detailed strategies for dealing with events related to his disorder. Less oriented to the therapeutic scope is Gotta Feeling (2012) that aims to track the emotions of the user with the purpose to share them on his social networks; it, however, uses a different model, asking the user to indicate what are the emotions he feels choosing from 10 different categories and connecting them to a more precise list of words that express the feeling: the reports keep track of all the registered feelings, places and people to whom they were linked.
Finally, some services use dedicated devices to track and return the overall mood of the user. This is the case of Rationalizer (2012) a kind of "emotional mirror" in which the user sees the intensity of his feelings, with the purpose of improving his financial decisions which should be less emotionally charged and more rationally founded. Rationalizer consists of two dedicated devices. The EmoBracelet measure the intensity of the user's emotion, in the form of arousal level, through a galvanic skin response sensor. The level of arousal is shown as a light pattern that is both on EmoBracelet both on the second device, the EmoBowl (a kind of light dish that displays different light patterns). The higher the level of arousal more intense will be the dynamic light pattern, larger the number of graphical elements of the pattern, greater their speed, the more intense their color. BodyMonitor (2012) instead is a research project of the Leibniz-Institut for Sozialwissenschaft, which, using a wearable armband, measures heart rate and skin conductance, to determine the emotional state of the user. In the end StressEraser (2012) is a portable biofeedback device designed with the aim of reducing the stress of the user synchronizing his heartbeat with his respiratory rate: the device displays heart rate variability on a graphical display, suggesting how to control breath using visual cues.

5.3 Fitness

Self-tracking wearable devices are increasingly used in the consumer market (especially in the fitness arena) to track calorie consumption and daily physical activity and to support self-awareness and healthy behaviors. These devices automatically recognize positive behaviors (such as walking) tracking changes over time: the underlay idea is that having always-available displays could be useful to increase the individual's awareness about individual physical activity level and this could be valuable particularly when people try to change their habits (Consolvo et al., 2008). In this sense, the fitness area is the one that most uses dedicated devices (or smartphones) able to track physical activity and physiological parameters to improve physical well-being. All these systems can monitor the entire daily physical activity or can be addressed to the tracking of some specific sports.
Nike + iPod Sport Kit (2012) is perhaps the today most widely used tracking system of physical activities in the consumer market, and consists of a suite of interconnected devices like Nike + running shoes, Nike + Sensor, iPod Nano, iPod touch, or iPhone. The Nike + sensors can be integrated into the Nike + shoes transmitting the frequency of your steps into the user Apple device, who can see time, distance, pace, and calories burned. The system also allows to load physical performances into the nikeplus.com site where stats regarding physical activity can be shared and compared with those of other users. On the same principles is based the Adidas service Micoach (2012) that through the SPEED_CELL™ is able to track running speed, distance run and heart rate providing real time digital coaching, interactive training and post-workout analysis of pace, distance and stride rate. Runkeeper (2012) instead uses the GPS built into

the iPhone of the user to track run, the distance, duration, speed and calories, preserving the history of run and showing progress and objectives.
Other service solutions are able to track more parameters and behaviors simultaneously correlating them. Jawbone UP System (2012) uses a wrist wearable motion detector interfaced with an iPhone application permitting to track daily physical activity and sleep behaviors, reminding to the user when it should make some exercise and waking him up at the right time. Even Fitbit (2012) is a device that can be worn throughout the day, allowing to track physical activity and sleep patterns. Once the data is collected, the user can view them on a website or mobile application. Fitbit has also been used by university research projects to identify unhealthy behaviors and intervene at the appropriate time to correct them. Fitbit+ uses Fitbit technology to identify sedentary moments in the day and prompt users to take walking breaks (Pina et al., 2012). BodyBugg (2012) uses a series of sensors such as an accelerometer, a skin-temperature sensor, a galvanic skin response sensor and a heat sensor to measure physical exercise in order to track how many calories the body has used during a physical activity. And it is right on eating behavior that many applications have been developed in the field of QS. They are capable of tracking daily weight changes and monitor the diet of the user. MyFitnessPal (2012) allows to keep track of daily diet by simply adding to the personal food journal the foods eaten during the day and available in the database of the system. The display of eating habits and calorie consumption, combined with the support of a social network of users, should provide motivation to adopt strategies to reduce body weight. Loseit (2012) and My Calorie Counter (2012) are based on the same principle of tracking the eating habits through self-reporting and viewing statistics that could make people more aware of how they behave every day. The Withings scales (2012) instead track daily weight, body mass index and fat mass index: the user smartphone can then display statistics showing significant changes during the time period selected.

6 QUANTIFIED SELF FUNDAMENTAL PROBLEMS

6.1 Technological limits for collection, processing and visualization of large dataset

At present the increasing miniaturization of electronic modules and processing power of microprocessors, the developments in sensor technologies, the new potentials offered by displays and micro-displays, the advances of mobile networks and the new models of dynamic data visualization focus to make large amounts of data accessible in a lesser amount of pixels and with littler attentional effort from the user.
On the data collection side nowadays the wearable computing, the body sensor networks, the RFID tags allow to gather information, in an automatic way, making possible to envision the opportunity of a constant monitoring of the individual behavior. The data collected by these technologies can today also be stored and structured (through semantic reasoning techniques) in almost tangible “knowledge”, manipulable and usable for different purposes. The appearance on the market of very large screen and highly innovative technologies, such as 3D printing, enable the exploration of new ways of viewing data and in some case the physical materialization of them.
Sensors available on the market today allow to monitor a variety of physical, biochemical and physiological parameters of the individuals as well as the environments in which they are moving at a very affordable price and with a very low power consumption. For example, from the perspective of physiological and biochemical parameters are increasingly spreading sensors for measuring heart rate, blood pressure, respiratory rate, temperature, muscle and brain activity (e.g. Shaltis et al. (2006) and Corbishley & Rodriguez-Villegas (2008)), while the development of flexible circuits insertable within tissues is allowing the integration of these sensors also in wearable device scenarios (Barbaro et al., 2010). In addition, accelerometers, gyroscopes and magnetometers integrated in wearable devices are now used to track the movements of people, and the data available from these sensors can be combined with information from other ambient sensors, such as motion sensors placed in a domestic environment, in order to determine, for instance, the type of activity performed by an individual (Bonato et al., 2012). All these sensors are often integrated in a sensor network that relies on modern wireless communication

networks. In recent years numerous standards are born for wireless communication networks that fulfill the requirements of miniaturization and low cost / low power consumption of transmitters and receivers. Not only the development of IEEE 802.15.4/ZigBee (ZigBee Alliance, 2012) and Bluetooth, but also of IEEE 802.15.4a standard based on ultra-wide-band (UWB) impulse radio made possible to foresee a set of sensor network applications with a high data rate (Zhang et al., 2009) easily deployable in many kind of environments. In addition, the need to transmit the data gathered from the sensors to a terminal that can process them, such as a mobile phone or a personal computer, can now be easily met by GSM or 3G communication mobile networks and soon by new LTE networks. The actual and future smartphones look like the ideal platform for applications that have to continuously monitor individual data. They have built-in large computing capacity and excellent graphic displays, are equipped with motion sensors, GPS systems capable of tracking the movements of individuals, and networking technologies, able to connect with the surrounding environment in order to become hubs for body area networks (BAN). Moreover, smartphones are always brought on by their users, eliminating the disadvantage of having to bring dedicated devices for recording specific daily activities and behaviors (Rawassizadeh et al., 2012).
On the data storage and processing side, the linear increasing in capacity, make now possible to store and process an amount of data just unthinkable few years ago. Today, one terabyte hard drive is available on the market at less than $ 100 and may contain all the written information we come in contact in the course of a lifetime (by mail, books, web pages). Twenty years from now, we will be able to buy at the same price 250 terabytes of storage sufficient to store ten thousand hours of video and tens of millions of photographs: a capacity able to meet the needs of recording of one hundred years of life (Bell & Gemmell, 2007). If the increasing miniaturization of digital media will continues to proceed according to Moore's Law, in 70 years will double around 47 times and in 2072 the physical space of storage needed to contain all the experiences of a lifetime will be the size of a grain of sand (Dix, 2002). In addition, all collected and stored data can now be structured semantically, using reasoning rules (possible to the increasing computational power of todays processors) to extract relevant information in response to complex queries. Ontologies and systems that can automatically annotate data with metadata can provide a structure to the information collected (e.g. Gruber (1995), Guarino (1998)) and also extract knowledge from large stores of unstructured data allowing the surfacing of relationships, patterns and connections. The extreme evolution of this approach permits to envision the possibility of retrieving links to specific items similarly to the retrieval mechanisms of human associative memory (O'Hara et al., 2006)
On the data visualization side technological advances are taking two opposite directions. On the one hand are increasingly available at a lesser cost very large screens capable of ensuring access to large amounts of data and allowing interaction with them quickly in order to gain understanding and take decisions faster; on the other hand there is a growing effort to find new ways to maximize the amount of information visible in a limited space, due to the growing popularity of smartphones and tablets as first choice devices for human behavior tracking applications (Few, 2009). Today are available many possible configurations of large displays. The Cave Automatic Virtual Environment (CAVEs™) is a projection-based display system (e.g. Mechdyne CAVETM Virtual Reality (2012)) with a resolution of 100 megapixels or higher. La Cueva Grande, is a five-sided slot with 33 projectors for a resolution of 43 megapixels (Canada et al., 2006) which surround the viewer with an immersive environment: they are commonly composed of four large wall displays arranged as a cube (Cruz-Neira et al., 1993). There are also monitor-based wall displays that combining the resolution of LCD monitors can get to reach a comprehensive resolution of hundreds megapixels (e.g. LambdaVision, a wall of 5 x 11 LCD panels with about 100 megapixels spread over a width of 5 meters (Renambot et al., 2012) and hyperwall composed by 49 LCD panels tiled in a 7x7 array (Sandstrom, 2003)): however, these configurations have the problem of not providing a continuous display, being interrupted by screen bezels (Thelen, 2010). There are then projector based systems that combines multiple computer projectors arranged in a grid in order to project on very large screens (e.g. the ten Sony SXRD 4K SRX-S110 projectors combined to create an image of approximately 88 Megapixels in ITC's Michigan Control Room (2012) and Visblock™ (2012)). The projectors resolution is increasing, as they are steady progress to optimize the calibration for example on color gamut matching, luminance matching and image blending. (Ni et al., 2006) Finally, are

increasingly widespread in the consumer market stereoscopic displays that can display 3D images using special glasses or even autostereoscopic displays that eliminate the need to wear glasses to get the 3D visualization effect (e.g. AU Optronics prototype of autostereoscopic technology (Information Displays, 2012)). Although the costs of these devices are progressively going down, so that it is possible to imagine in the near future their massive spread, outside a research context, even in the consumer market (both for very large LCD monitor, and for autostereoscopic 3D display), commercial tools that aim to track the behavior of people and return back significant views are watching today mainly to the market of mobile devices to convey their services. The advent of high resolution micro-displays, such the 4" Retina Displays of Iphone5 (1136x640 resolution), or the 9.7" of the new iPad (with a resolution of 2048x1536), pushes the research towards new visualization solutions, such as interactive dashboards able to deal to the relative narrowness of the display surface of these devices.

The spread of human behaviors tracking applications on mobile devices poses today serious technical issues that are currently not fully resolved. The mobile devices, even if their ability to collect, process and display data is constantly increasing, suffer from both the small size of displays and the limited processing power, which limits the amount of data that can be managed locally and prevents the use of computationally expensive algorithms; the extreme segmentation of the smartphones and tablet market also rise the problem of the severe variability between different models in terms of performance and input peripherals (Burigat & Chittaro, 2007). Moreover, the mobile context introduces a number of problems in relation to fixed devices: on the one hand, the physical environment can affect the data visualization on the display (e.g. mobile devices can be used in different light condition that may vary from the bright light of the sun to the total darkness affecting so the perception of colors), on the other hand the mobility context makes it difficult to focus user attention on the device, because of the activities that are often performed at the same time that transform the use of the device in a secondary task (Chittaro, 2007).

However, other technological problems are shared by applications that rely both on fixed and mobile environment. One of the central issue is that often users and systems have to deal with digital data coming from various sources in heterogeneous forms and formats (Whittaker et al., 2012). In particular, this problem is related to the capacity of storing large amounts of information not only limited to textual data but also multimedial. Search and retrieval of textual information is now relatively simple, but other media present major problems about framing queries and organization of memory stores, and adding text annotations requires a great effort, often not covering the entire range of possible meanings that can convey an image or a sound: furthermore the future possibility to integrate new types of information (such as olfactory and haptic) poses new problems of integration between different “media” and how these heterogeneous information can be indexed, searched and retrieved (O’Hara et al., 2006). Last but non least, there is the central problem of how to handle this immense amount of information, because the possibility of capturing vast arrays of data is not yet balanced by the possibility of an efficient and really meaningful search, and this can overwhelm users in their effort to retrieving valuable information from large clusters of data (Abigail & Whittaker, 2010).

The technological problem as we have seen is quite relevant, even if the trend line makes it probable that this will have less and less importance in the future. What appear instead the most worrying aspects of the QS field are at a higher level. What is missing is some convincing positions about how to return people with sufficient clarity and sense the data they collect and how to structure a model of human behavior change that in front of these data makes possible to use them in the desired direction.

6.2 Theoretical Limits in Perception and Cognition

6.2.1 Data visualization

The data visualization is the way in which all the data collected are rendered and made available to the user. How the data “appear” is the first step that data make in the user brain, so it is important to consider all the studies on perception, reading charts, organization of complex data, because this first step is crucial in the pathway that data make into cognition. How data visualization is realized is able to modify and affect subsequent processing of the same data. The manner in which data are presented has a huge importance and is strongly influenced by the model of knowledge that is embraced: this is the reason why we will treat this aspect first and the cognition aspect later.

The first theoretical foundations that are available to help designers to organize information on a perceptive point of view are the Gestalt principles. The associationist psychology considered perception as the sum of more simple stimuli linked directly to the physiological substrate of the sensory systems. With the development and consolidation of Gestalt psychology, the center of the investigation on the perceptual processes passes from the previous elementaristic conception to a more complex notion of perception as result of interaction and global organization of various components. Gestalt, using a phenomenological approach to perception, canonizes a series of perceptual laws independent from external experience (hence not connected with learning processes) and present since birth.

These laws analyze the figural organization taking into account the separation of figure from background (by color, density, texture, contour). Wolfgang Köhler, the father of Gestalt psychology, suggested the following laws:

1. Law of superposition: the forms above are figures. In order to distinguish an overlap is necessary that there is evidence of depth.
2. Law of the occupied area. The separate zone which occupies minor extension tends to be seen as a figure, while the wider as background. This mechanism for the identification of objects in the background works even if the closure is incomplete.
3. Law of perceptual organization on the basis of common destiny. This mechanism of closeness is salient not only at the level of modification of the space, but also of time.

Further studies related to Gestalt psychology aimed to postulate general laws oriented to synthesize multiple items in a single global perception:

1. Simplicity or "good form" law which summarizes the whole logic of perception. Data are organized in the simplest and more consistent way possible, according to previous experiences.
2. Similarity law states that for elements arranged in a disorderly way, those who are similar tend to be perceived as a form, separated from the background. The perception of the figure is as strong as stronger the items similarity.
3. Continuity Law states that a perceptual unit emerge between the elements that offers the least number of irregularities or interruptions, being equal other features.

Other studies have instead explored the figural elements used for the perception of the third dimension. It is in fact linked to the motion perception. The main indicators are identified:

- the relative magnitude (the largest object is the closest)
- brightness
- the linear and aerial perspective

The laws of perception are considered innate because are not the result of learning, although it is demonstrated that there is a developmental progression in the development of perceptions. From the first months the baby is able to recognize colors and shapes (especially the human figure), but only later he acquires the "perceptual constancy", the ability to link a shape or figure already known, with a different one in which he recognizes characteristics of similarity (e.g. a statue associated with a person).

These laws are easily testable in everyday life and it is easy to have a direct evidence with optical effects. But they are only the basis of knowledge useful for improving the data visualization for human perception. Instead the purpose of data visualization as a discipline is to display parametric information essentially with a twofold perspective: on the one hand to better understand the data, on the other to extract evidence non-extractable otherwise. There are a lot of hidden meanings behind each set of data. To discover these meanings is necessary that the visualization choices of this data set are functional to the emergence of these meanings. When we say that “a picture is worth a thousand words” means just that that image is effective to convey with a single glance all the meaning hidden in a thousand words or a thousand numbers. But how to choose for the best visualization? Again we are dealing with a problem that has its basis in the theoretical research on perception and cognition, that is about how humans can see, filter, store, learn, retrieve complex content. But for the moment let's stop at the first step, we will see the basic theories of cognition in the following paragraphs. Speaking instead about perception we have already mentioned the fundamental Gestalt laws but what other theoretical elements we have to provide a good visualization to the users? Much of what is now the data visualization we owe to Descartes that in the 17th century invented the coordinate axes that in some extent are the first and most basic form of visualization of a set of two-dimensional data. In the modern sense the first significant contributions are due to William Playfair that as early as the 18th century began to develop almost all types of graphics that are still in use (bar charts, pie charts, etc.). There are no other significant contributions until the work *"Semiologie Graphique"* of Jacques Bertin in 1967 in which for the first time we found a complete reflection about the best ways to represent different kind of information. Then there is the fundamentals work of Tukey (1977), of Tufte (1983), and of Card et al. (1999), the most advanced in defining the best way of representation. Last but not least for a complete and comprehensive work on data visualization and its bases, see the work of Colin Ware - Visual Thinking for Design (2008). All the attention to the way we represent the data has only one purpose: that our eyes can distinguish good information and our brain can understand it. All this can be done simply running back on the results of 100 years of experimental psychology studies. Despite this knowledge has always been available, it has not been used very much. In the last 10-15 years it has been developed a number of products designed right to give meaning to data, but in fact simply based on covering data with shining graphic work with purely aesthetic value, not considering even some basic requirements that a good visualization must have to be considered a good one. We can resume them in few statement (Few, 2010). A good visualization:

- Must clearly indicate relationships
- Must represent quantities accurately
- Must make it possible to easily compare the quantities
- Must clearly show the ordering of values
- Must encourage people to use the information

These simple requirements inform us about the quality of visualization, and for example, show us how pie charts are not suitable for many types of data, or like sometimes the old bar charts are much more efficient. If a visualization does not meet these criteria is not suitable for that particular type of data.

The motivation to make better visualization is to make possible a primary processing already at the perceptual level, without having even turn on the cognitive processing level. It is a form of cognitive economy that allows us to already have all the information we need with fewer resources. The Gestalt laws mentioned at the beginning of paragraph are based right on this economical concept. But today there are interesting studies that come from the fields of neuroscience that provide material even more interesting (Guidano, 1983). The first research area is the pre-attentive visual processing. It is a sort of pre attentional processing that occurs before the data arrives at a consciousness level. It is made by particular neuronal structures able to perceive length orientation, but also by more complex properties such as shading, groupings and three-dimensional orientation.

The second broader research area is about the mechanisms that govern attention and memory. In particular for the attention, latest studies have shown that the attentional processes focus only on some parts of the scene. Also data visualization techniques should be able to govern their points of attentional salience organizing the data meant to be conveyed almost like a "real world" (Rensink, 2002). These aspects, together with the dynamic views required to manipulate large data sets (nowadays we are limited to organize levels starting from an overview, providing filtering and zooming features), introduce how the entire discipline of data visualization, specially if linked with QS large dataset, should become a discipline of data interaction rather than simple data visualization. In the next paragraphs we will see how storytelling in some extent represents a solution that includes both the aspect of interaction with the real world (fostering pre attentive elaboration), and the complexity of managing large amounts of data. Roambi (2012) a company specialized in data visualization is going in this direction with its latest product Roambi Flow that allows "to tell" data to the intended audience.

After this theoretical analysis on data visualization let's move on to what are the theoretical foundations of behaviour change theory that implicitly (sometimes without awareness) are used by many applications of QS.

6.2.2 Behavior Change Theories

As mentioned previously, one of the fundamental problems of QS is that it does not have a well-structured and well-established theoretical basis. QS is nowadays mostly a series of experiences more or less significant where, an application, in a certain domain, worked at a certain time for someone in particular. Basically it is not a generalizable or falsifiable approach according to scientific criteria (Popper & Eccles, 1977). It is a pragmatic and empirical approach which carries with it the limitation of not progressing beyond few single anecdotal cases and takes the risk of disappearing or becoming irrelevant. On the other hand, today's technology makes QS look very modern, but in a variety of fields the habit of data recording in order to find relationships between variables and to drive changes it's quite an old idea, at least dating back to the birth of the industrial age. In the medical, financial, industrial fields since decades it is custom to fill graphs and spreadsheets, and also on a personal level in many biographies is possible to find peculiar a way to organize self-knowledge through manual annotation of notes an tables and filling of summary sheets.

The most innovative aspect is perhaps, more than anything else, that QS, taking advantage of new technological devices, frees the individual from the burden to personally record every data. But there is another aspect of substantive novelty. As long as you remain in the domain of financial or political science the change process driven by new knowledge emerged by data seems easier to implement according to a rationalistic model. When we move in the domain of personal and individual change, things get complicated. What are the rules that govern the individual change? Are they so clear? Can we put them in a structured system that can predictably drive the change? In part yes and in part not yet. The various paradigms that have developed over 20th century and are still evolving thanks to the neurosciences have precisely tried to answer these questions. Some pieces of knowledge are now part of these simplified change theories that are implicitly implemented (often misused and distorted) within many QS applications. In the following lines there is a brief summary of the paradigms borrowed by this "naïve change theory".

6.2.2.1 Behaviorism and the positive/negative reinforcement

Who has tried to do fitness with the Nintendo Wii Fit will have noticed that by according to his performance the system will critique you if the performance is poor or on the contrary praise you if it is positive. The system simply seeks to introduce a positive or negative reinforcement providing paradigm derived from behaviorism. Behaviorism was originally developed by psychologist John Watson at the beginning of the twentieth century, based on the assumption that explicit behavior is the only unit of analysis to be studied scientifically by psychology, because it is directly observable by the researcher. The mind is thus seen as a black box, a black box whose inner workings are unknowable and, in some respects, irrelevant: what really matters for behaviorists is to have a thorough understanding of empirical and experimental relationships between certain types of stimuli (environment) and certain types of responses (behavior). Within this broad approach, emphasis is placed on particular aspects. One of the major assumptions is the mechanism of the conditioning, according to which the repeated association of a stimulus, said neutral stimulus, with a response that is not directly related to it, will ensure that, after a period of time, such stimulus will follow the conditioned response. The famous experiment of Pavlov's dog that everyone knows makes reference to this type of mechanism.

Skinner with his writings "The Behavior of Organisms" (1938) and "Science and Human Behavior" (1953) laid the foundation for the discovery of the laws and of the most important paradigms of matter, giving rise to a new way of conceiving the causes and enabling thus to enlarge significantly the possibilities to influence the observable behavior. His great merit is in fact to have found that human behavior is predictable and controllable through an appropriate management of two classes of stimuli from the physical environment: "antecedent" stimuli that the body receives before implementing a behavior and "result" stimuli that the body receives immediately after the behavior has been put in place. After the discoveries of Skinner, a growing number of researchers have progressively developed many

techniques for behavioral change in almost all areas of application and, from the mid-seventies, even within organizations and in the specific field of work safety.
In North America, the birthplace of the QS, this behaviorist perspective strongly permeates the environment especially in the common sense psychology. In terms of QS, this paradigm was translated using positive or negative reinforcement depending on the behavior to drive. An example is the badge gaining, the collection of awards, such as elements of positive reinforcement (e.g. Foursquare, Nike +) or, conversely, the blame, the criticism, etc. if the behavior is not consistent with the purposes of the application. This mechanism is well documented but, as the same latest generation behaviorists have stressed, is not rigidly determined. There are in fact a number of intervening variables that change or at least modulate the Stimulus-Response (S-R) arc. For example, it is necessary for the user to perceive correctly the reinforcement, to understand it, to weight it, to check if is relevant for him and so on. In the case of Nike +, the praise that arrives from the system or by the community can have a totally different weight for two different people, or even for the same person at different times of his life or even of his day.
Recognizing excessive simplicity and rigidity of the behaviorist paradigm, some behavioral psychologists, called "neo behaviorists", proposed some corrective premises (the so-called "intervening variables of the SR process") opening the way for further development of cognitive psychology. The evident role of internal and external variables in determining the behavior demonstrated by many experiments paved the way for at least two other types of theoretical contributions to the behaviour change topic: cognitivism introducing the internals variables and social psychology introducing the externals variables influencing behavior.

6.2.2.2 Cognitivism the role of mind

At a QS meetup a speaker explain: *"I use the Nike + app on my iPhone. I find it motivates me to run more, try and run faster than previous PB's and Generally lets me check up on myself for further improvements. Couple this with Their website of the same name and I now have a 24week plan for running a marathon. Good times"* (Guardian, 2010). Some athletes or coaches (in various sports) have been doing things like this for decades: keeping daily written notes on workouts, feelings before and after, bodyweight, body temperature, sleep, nutrition, techniques used etc. using then that data for statistical analysis. This is a classic example of self-monitoring model deriving from early cognitivist model of feedback engine (TOTE) as we will see below.
Cognitivism is sometimes considered an evolution of behaviorism because it introduces more complexity in the S-R arc recovering the concept of mind (the black-box originally excluded by behaviorism). Cognitivist focus is on the mind as an intermediate element between the behavior and purely neurophysiological brain activity. The mind operations are metaphorically compared to that of a software that processes information (input) coming from the outside, giving in return information (output) in the form of knowledge representation and semantic and cognitive networks. Perception, learning, reasoning, problem solving, memory, attention, language, and emotions are mental processes studied by cognitive psychology (Neisser, 1967). In the early cognitivist models, processing was conceived as a process that occurs in subsequent stages, finished one step the "system" move to the next, and so on. In the '70s were presented new models that put in evidence both the possibility of feedback of a processing stage to the previous ones, and the possibility to activate operations of the next stage without previous ones had already processed their information.
Another important aspect was the emphasis on specific objectives targeted by mental processes. The behavior was now conceived as a series of acts guided by cognitive processes for the solution of a problem, with constant adjustments to ensure the best solution. The notion of "feedback", developed by cybernetics became central in this conception of behavior directed toward a goal. The experimental psychologist of language G. Miller with his works brought to a real turning point in the representation of behavior: the behavior was seen now as the product of a data-processing system, driven by the development of a plan helpful to solve a problem, in certain sense like a computer (Miller et al., 1960). In this new model the behavior was therefore not an epiphenomenon of a reflex arc (sensory input,

processing, motor output), but the result of a process of continuous retroactive monitoring of the behavior plan according to the TOTE unit (test, operate, test, exit). The final act (exit) does not follow directly to a sensory input or a motor command, but it is the result of previous environmental conditions verification (test), intermediate operations (operate) and new tests (test). In the feedback model is expected that to complete a specific goal there are some verification stages and then an exit from the plan (if the goal is reached) or new operations (if the goal is not reached). This model is also implicitly widely used in QS application. The concept is that if there is a goal that the application advocates, it is possible through constant quantification (test) show to the user how far away he is from and so drive him to focus and continue the action (operate) toward the goal or stop it when the same goal is reached (exit).

The concept of the mind as a computer based on feedback engine underlies many QS applications and in a certain extent is also one of their main limitations. Knowing how far from a goal we are is certainly informative in itself; however it is not enough to motivate a behavior in a generalizable way (for instance the fact that I know what my sleep patterns are, hardly makes me change the time that I go to bed). There are other variables that can intervene: for instance external social variables.

6.2.2.3 Social Psychology: the role of external variables

Many applications of QS refer to a social and interpersonal dimension both in agonistic terms, the cases in which there is a gaming dimension and for example the most virtuous climb a rank (many applications of energy savings are based on this example) and in cooperative terms, where many people work together to obtain an objective valuable for all (for instance in many healthcare QS applications).

Social psychologists typically explain human behavior in terms of interaction between mental states and social situations. In the famous heuristic formula of Kurt Lewin (1951) behavior (C) is seen as a function (F) of the interaction between the person (P) and the environment (A). "Social" is an interdisciplinary domain that bridges the gap between psychology and sociology. During the years immediately following the Second World War, there was frequent collaboration between psychologists and sociologists. In recent years, the two disciplines are increasingly specialized and isolated from each other, with sociologists focusing on "macro variables" (social structure). Nevertheless, sociological approaches to social psychology remain an important counterpart to psychological research in this area. Cognitive strategies are influenced by our relationships with others, our expectations on their reactions, from belonging to a group or another, membership of which brings us to the definition of who we are and our social identity. In particular, the group is a unit with its overall social identity, which determines what each member expects from others in terms of behaviors. This social identity is then linked to the social identity of the group members. Our identity is, in fact, largely a function of our belonging to different social groups.

7 TOWARD A MORE ROBUST APPROACH IN QUANTIFIED SELF

7.1 New model of data Visualization - Telling Stories

In recent years, much research has focused on the role that storytelling can play in data visualization. Often are also been highlighted the great similarities that a good data visualization has with the ability to tell engaging stories through images. Since 2001, Gershon & Page (2001) predicted that the technology could have used different genres and media to convey information in a story-like manner. However, since what makes data visualization different from other types of visual storytelling is the complexity of the content that needs to be communicated (Wojtkowski & Wojtkowski, 2002), to effectively use storytelling are necessary skills like those familiar to movie directors, beyond a technical expert’s knowledge of computer engineering and computer science (Gershon & Page, 2001). At present applications that attempted to implement narrative elements within data visualization scope are very few (e.g Heer et al. (2008), Eccles et al. (2007)). Moreover, since none of these seems to go beyond the incorporation of some superficial narrative mechanisms in the flow of data visualization, also the researches carried out appear to be limited to the enumeration of stylistic and narrative mechanics, but decontextualized from their original media. Edward Segel and Jeffrey Heer (2008), for example, analyzing several case studies of narrative visualizations, identify three divisions of features (genres, visual narrative tactics, and narrative structures) that can be considered patterns for narrative visualization. Genres identify established visual structures that can be used to communicate data, such as comic strips, slide shows, and film / video / animation; visual narrative tactics are instead visual devices that assist and facilitate the narrative; while narrative structures are mechanisms that assist the narrative. Nevertheless, the analogy with stories seems to be hard. As Zach Gemignani (2012) underlines many of the key elements of the stories are not present in data visualization: characters, a plot, a beginning and an end. On the other hand data visualizations have characteristics that are missing from the traditional storytelling. As interactive means data visualizations allow users to explore in an active and dynamic way the data to find insights by themselves. For these reasons Gemignani notes that the data visualization today has nothing to do with telling a story more than with accompanying the audience in a guided conversation.

However, the QS field seems to offer new opportunities for the use of storytelling in data visualization. Visualizing human behavior is in a certain extent to put in the center of the visualization the subject as individual. Finding new ways to make alive these data, to make them meaningful in the eyes of the person they belong to, seems to be the real challenge that QS must face. In this sense a huge importance can gain one of the key elements of storytelling, the character, through which the story takes a perspective and a point of view. Aggregating data about personal behavior in the form of a fictional character can be seen as a way to give sense, in two ways, as meaning and as direction. The direction is firstly temporal from the past to the future, and through the overcoming of continuous testing and objectives, key elements in narratological theory (e.g. Greimas (1987), Propp (1927)), sets in motion a narrative development that can really bring, no more superficially, but essentially, data visualization to a new level closer to the storytelling. From this point of view today video games seem the more suitable media narrative forms from which to take inspiration for the creation of new ways to display behavioral data. Video games in fact have managed to create a form of interactive narrative where hypertext narrative had failed, managing to involve deeply the audience while leaving the user the power to influence the story told. Although not leaving a completely open narrative, which, as noted by Jesse Schell in his book (2008), is difficult to achieve both in technical and design terms, as well as difficult to use, video games, especially in the form of MMORPGs (Massively Multiplayer Online Role-Playing Games), leave broad room for their users to build the mirror of themselves in dynamic ways. Growing his own virtual avatar on different form and sizes depending on the choices made, users can, within these worlds, see themselves from different perspectives in a logic that encourage reflection about the actions taken, the objectives achieved, and the changes that they have produced on own subjectivity and identity. From these media products, therefore, the QS can draw on design strategies, tactics, forms of representation and temporal evolution, that in the near future could revolutionize the display of human behavior data.

7.2 Manage complexity in technology and people

We can understand the management of complexity in both directions, one more technological and one more human. Let's see them separately.

7.2.1 Technological Side

What today is missing is a platform that integrates all the data a person collect during his daily activities, a complete, adequate, integrated, picture of the individual. Nowadays there are only a small amount of recorder that manage certain parameters to render them in different and separate applications. In this sense, the technological complexity that QS will have to face in the future years is the tracking of many different kind of data and the integration of them in meaningful visualizations. In a certain sense is the rediscovery of the original ambitions of Lifelogging depicted in the first paragraphs but on a massive and more pervasive seamless plan. We could call it the "ultimate lifelogging scenario".

Some examples in this sense already exist: for instance Capzels (2012) uses social storytelling to allow users to create chronological slideshows containing photos, videos and slide decks located on a timeline.

LifeLapse (2012) is an iPhone app that lets you take a photo every 30 seconds tying your iPhone to the neck. The preserved images can then be seen one by one or mounted in a video that evokes the recorded life experience. If in these two applications build from scratch the lifelogging experience require an active intervention by the user to continuously record his life experience, other applications such as your.flowingdata (2012) and Daytum (2012) exploit the popular micro-blogging site Twitter as input mechanism to trace the daily life of users. Daytum allows you to collect, categorize and communicate your everyday data through the storage and display of personal statistics related to the daily events, providing various forms of statistical display, as pie charts, bar charts, timelines, etc. Your.flowingdata captures the lives of users using data from Twitter. Following @YFD on Twitter the user can begin to record his experiences simply sending a tweet to @YFD. Data about what the user eats, sees and more generally experiences are recorded by the system in order to be displayed on the application site. Display modes range from timelines to charts, also integrating experimental visualizations that allow the user to find cross-correlations between data, to explore durations between a start and stop actions and to use calendar visualizations, which displays the frequency of an action on a given day through the intensity of color (Yau & Hansen, 2010).
However, lifelogging systems are still suffering some difficulties to spread on the consumer market and it seems quite far away the possibility to see in the next future an application that can be used by all users to really record all aspects of a person's life, as it was hoped by the first pioneering research projects of the lifeloggers. Although the miniaturization of sensors and chips, such as audio recorders and cameras, makes possible now to integrate them into common smartphones, these applications seem destined to remain for some time prerogative of academic research projects. This is partly due the excessive involvement of the user that is necessary today (through self-reporting or manual annotation of recorded media) in order to record all the experiences of his life. Research projects try also to address another technological problem: how to cope with the difficulties of recovering significant data in the enormous amount of information that can be recorded in an extensive lifelogging scenario. For instance Poyozo is an automatic journal able to generate summaries and statistics displays from heterogeneous activity data, integrating this information into a calendar trying to create a meaningful narrative life for the user (Moore et al., 2010). Or like in an interesting research project of the Aizu University, trying to overcome the problem of information overload storing only the significant highlights of a lifetime, without requiring active intervention by the user. This system automatically saves significant events for a group of people if their emotional arousal (detected by an heart rate monitor and compared through a peer-to-peer network) exceeds a certain threshold (Gyorbiro et al., 2010).

7.2.2 Human Side

Another level of complexity that we must address is that about the complexity that drives behaviors (Guidano, 1987). We have to accept that human action is not simply driven by rationality but also from infinite variables that affect the final behavior. We all know that is not enough just to look at the weight on the balance (awareness) to make us want to do more sport or eating less. We have to take into account the human complexity. An attempt in this direction is carried out by the second cognitivism which introduces greater complexity compared to the first theoretical assumptions. This development suggests how the reading of the “reality”, the “world”, is in fact very personal and can lead to different meaning depending on who is “reading”. There is a shift from a realistic/objective paradigm to a subjective one. Human behavior becomes so the result of an articulated and variously structured cognitive process of information processing.
The most recent results on the analysis of cognitive processes, focus these dynamics in the social and interpersonal contexts in which the thought develops. This approach based on cognitivism, defined as social cognitive theory, studies the interaction between cognition and social context. Great importance in this theoretical core is attributed to the reflections of Albert Bandura (1986) about cognitive-emotional processes, that see these processes express themselves through behaviors. There is essentially a complete re-evaluation of interpersonal and emotional components as human action drivers.

Let's consider just one the many examples of QS interpreted as "augmented awareness". Asthmapolis (2012) links sensors attached to the inhalers used by patients with asthma to smartphones. These sensors gather data on where and when they are used. Recording this information helps patients identify the triggers that make their conditions worse. The concept seems simple: more data lead to greater awareness and make possible the anticipation. In fact, looking at this example the impression is that the driver of who decides to rely on Asthmapolis is more emotional, driven by the concern, the fear and the attempt to gain control on this. One of the main fear mastery strategies is to seek information to improve or prevent damage to ourselves, or even to prevent the stress of uncertainty. It is what is called in psychology coping strategy: looking frantically for information, for new data. Collecting personal information is an effective coping strategy that manage the emotional stress of the disease. The real driver of those who use this form of QS is not the rational data collection in order to develop more knowledge, at least not only that, there is also (and maybe is even more crucial) in the application adoption, the coping strategy to decrease in a certain extent the fear given by their disease condition. Fear is not instead what guides those who collect their own fitness data: in this case the motivational mechanism underlying the emotional matrix will be linked rather to the positive emotions related to competitive motivational systems. In this sense we speak about taking into account the human complexity, to really address the full spectrum of human behaviour drivers.

8 FUTURE RESEARCH DIRECTIONS

Future research directions should start from what is stated in the preceding paragraph, a different management of technological and human complexity and new ways to address this complexity keeping in mind that the real and final purpose of the QS is the personal and social improvements.

8.1 Individual impact

Let's consider this example. A QS supporter claims to have lost 20 kg of his 100 by either writing the word "lethargic" or "energised" on a flash card at 3pm every day for 18 months, depending on how he felt: *"I gradually noticed that my perception of some foods shifted from thinking they were delicious to starting to feel their heaviness and the effects they were going to have on me. The act of paying greater attention has an effect on your behaviour"* (Guardian, 2011). What we see in this example again is not an example of augmented awareness; it is rather a gradual reorganization of the "Self", through the focusing on the connection between behavior and the mood, the emotional component ("lethargic" or "energised") linked to the behavior (food consumption) (Damasio, 1999). The effect of this focusing is well known as instrument of change in psychology and therapy under different names and has its theoretical bases in Cognitive Behavioral Therapy (CBT) and even more in the post rationalist paradigm. The studies that have helped to define the post-rationalist paradigm have pointed out that it is not possible to have a unique idea of an objective reality. Echoing comments made by Ricoeur (1992) and Morin (2003) the reality is quite captured through a reading that is in large part subjective and in which are critical, even more than the rational, the emotional and affective components. The reality is then reconstructed on the basis of emotional and cognitive tools available to the person at some point of his life cycle. The focus is so shifted from what is valid or common for all individuals to subjective experience.

As Guidano (1991) evidenced the varied and changeable flow of experience inbound is compared with the pre-existing mental configurations that act as frames of reference. Any knowledge of external reality, as well as data from the QS, trigger subjective mode of experience, from which are then extracted the personal knowledge and the vision of the world. There is thus a dialogic dimension of continuous mutual influence between the "Self" and the narration of incoming data that continuously restructure the same "Self". This means that the data that I collect and how they are presented to me, on the one hand will be seen in a different way depending on the current emotional and cognitive configuration but on other hand will also contribute to define it. So we are in a scenario where the data really have a role in building the "Self" and the personal identity (Guidano & Liotti, 1987). This is especially true if we speak about data that reflect our mental activity in terms of thought, action and emotional aspects. There are already some examples in this regard. DreamBoard (2012) is a platform that collects dreams and renders a graphic story of dream activities, quantifying characters, mood, recurring figures, etc. Because the dream, as many studies proved, is a mental activity among the others (Fosshage, 1997) this kind of restitution contributes to develops new meanings to some cognitive restructuring and actual construction “self”. This is a greater self-knowledge but not in the trivial terms of knowing more “things” in a quantitative way, but instead to know more in the terms expressed by Gibran in the sentence quoted at the beginning of the chapter, in a qualitative way.

8.2 Social impacts

On a social level again an example is the social dimension of the management of our data and the return of favorable options. It is possible in this case to extend the QS concept, toward Quantified family, Quantified cities, Quantified country. We can take for example the case of our travel habits, consumption trends, all the personal health or needs that we express individually and that nowadays are totally disconnected from others individuality. The aggregate use of this data for statistical analysis in order to provide solutions based on these analyzes would be essential in order to optimize, in a social sense, many of the resources that are now wasted. Of course, this opens a hot topic for QS: privacy and ethical issues. In fact, the described scenario is already happening partly for our consumption behaviors: all our “Consumption Self” is already recorded by third parties, not for social purposes but for profiling and customization to encourage further consumption.
It should therefore paid much attention to this type of use of information even when it is done for social purposes. An example of this was a research project of UCLA (2011) who built a stress app for young mothers oriented at personalized health care based on a phone's GPS system,. The purpose of the research was noble, to develop a pilot program based on Android smartphones technology to monitor assess, and treat participants. The device was able (thanks to the accelerometer on board) to track the location and the movement in detail. All these data clearly started to become an issue so as to include the use of a "personal data vaults" a digital lock box run by a third-party intermediary. Beside the privacy issue some QS companies are already going in this “social” direction. For instance Zeo databases now contains more than 400,000 nights of sleep. Cure Toghether is the site where thousands of patients can post and compare their own symptoms and treatments for more than 500 diseases. For example thanks to the posting on CureTogheter the aggregation of the data showed that people who have had vertigo in association with migraine had four times more likely to have side effects using the Imitrex (a medicine for migraine) than those who did not had vertigo. It is obvious that the critics of this approach point out that all the intervening variables does not make this data reliable, making this exchange of the same value of a chat bar and not a form of medical research. However, it remains the great value of the enormous amount of data collected.

9 CONCLUSION

In this chapter we set ourselves the aim of defining the growing movement of QS in the light of the two words that compose the name itself. In fact, we have seen how under other names a similar technological ambition was seen at least since the mid 90’s. Many are the experimental projects that have sought to rely on technology to quantify the “Self”, or at least the human behavior in the world. This original ambition was declined in the last years according to various purposes some of which still unclear, unrealistic or naïve. Although many are the application domains of QS (we outlined in paragraph 5 those related to healthcare, mood management, and fitness), are still palpable some fundamental problems that relegate the QS movement in a phase of low maturity. The first is a technological problem and specifically a lack of maturity in technologies for the collection, processing and data rendering. This is accompanied by a perhaps more fundamental problem of deficit, bias and lack of integration of aspects concerning the human side of the QS idea. There are in fact some theoretical aspects that still to be understood about how to render meaningfully the representation of the large amounts of data that an integrated QS scenario produces (despite some theoretical elements are already available but often not applied in favor of the banality of a simple "wow effect"). But there are also and above some theoretical limits on the most fundamentals goals of QS: change, improvement, transformation. Just the difficulty in having an effective theory of human behaviour change, that is now fragmented between modules from behaviorism, from cognitivism, from social psychology theories, makes the deployments of QS application so unexpectedly ineffective, unsatisfactory or irrelevant. The step that we tried to make in this chapter is to highlight aspects that could lead to a more robust approach in QS area. Primarily through modes of data representation, taking into account the limitations and potential of human pre-attentional processing, identifying in studies on storytelling approach a possible way to reach a new form of QS data visualization. Secondly, through a necessary management of complexity, both in terms of technology (toward "ultimate lifelogging" scenarios that integrate and create value between different data of areas today addressed vertically) both in theoretical terms for what concerns the human side of the whole issue (thereby integrating social and emotional components in an all-embracing theory of human behavior change). We have gone a little further stressing how the future directions of research could lead to significant impacts on both individual and social level. On the one hand by configuring the QS as a tool to support the personal constant construction of the individual "Self" (a kind of mirror in constant communication with our identity) and on the other driving the aggregation of QS data at a sufficient level to be able to extract knowledge and new social services propositions based on statistical analyzes (for instance in Healthcare, Mobility, Energy sector). In conclusion are necessary some considerations about the possible risks that QS scenarios can generate especially considering its possible massive use. The privacy risks combined with ethical issues related to social control scenarios lead up to a glimpse of dystopia in which in the name of a "superior" aggregate knowledge the individual is excluded from any kind of the decisions, even minimal, concerning him.

10 REFERENCES

23andMe (2012) Retrieved September 27, 2012, from https://www.23andme.com/]

Abigail, S. & Whittaker, S. (2010). Beyond total capture: a constructive critique of lifelogging. *Communications of the ACM* 53(5), 70-77

Adidas service Micoach (2012) Retrieved September 27, 2012, from http://www.adidas.com/us/micoach/

Allen, A. L. (2008) Dredging-up the Past: Lifelogging, Memory and Surveillance. *University of Chicago Law Review*, 75(1), 47-74

Asthmapolis (2012) Retrieved September 27, 2012, from http://asthmapolis.com/

BAM Labs (2012) Retrieved September 27, 2012, from http://bamlabs.com/product/

Bandura, A. (1986). *Social Foundations of Thought and Action*. Englewood Cliffs, NJ: Prentice-Hall.

Barbaro M. et al. (2010) Active devices based on organic semiconductors for wearable applications. *IEEE Transactions on Information Technology in Biomedicine 2010*, Vol. 14, No. 3, 758-766

Bell, G. & Gemmell, J. (2007) A Digital Life. *Scientific American Magazine*, February 18, 2007.

Bentley, F. et al. (2012) Personal Health Mashups: Mining significant observation from wellbeing data and context. In Proceedings of *CHI2012 Workshop on Personal Informatics in Practice: Improving Quality of Life Through Data*.

BodyBugg (2012) Retrieved September 27, 2012, from http://www.bodybugg.com/

BodyMonitor (2012) Retrieved September 27, 2012, from http://bodymonitor.de

Bonato, P. et al. (2012) A review of wearable sensors and systems with application in rehabilitation. *Journal of NeuroEngineering and Rehabilitation* 2012, 9:21

Burigat, S. & Chittaro, L. (2007) Geographic Data Visualization on Mobile Devices for User's Navigation and Decision Support Activities. In: Belussi A. et al. (eds.), Spatial Data on the Web - Modeling and Management, Berlin: Springer, July 2007

Bush, V. (1945) As We May Think. *The Atlantic Monthly*, vol. 176, no. 1, 101-108

Canada, C et al. (2006) La Cueva Grande: a 43-Megapixel Immersive System. In Proceedings of *Virtual Reality Conference 2006*

Card, S. K., (eds.) (1999). *Readings in Information Visualization: Using Vision to Think*. San Francisco, CA: Morgan Kaufmann

Capzels (2012) Retrieved September 27, 2012, from http://www.capzles.com/

Cheng, W. C., et al. (2004). Total recall: Are privacy changes inevitable? In Proceedings of CARPE 2004 First ACM Workshop on Continuous Archival and Retrieval of Personal Experiences. New York, NY: ACM

Chittaro L. (2006) Visualizing Information on Mobile Devices, *IEEE Computer*, Vol. 39, No. 3, 34-39

Colin, W. (2008). *Visual Thinking: for Design*. San Francisco, CA: Morgan Kaufmann

Consolvo S. et al. (2008) Flowers or a Robot Army? Encouraging Awareness & Activity with Personal, Mobile Displays. In Proceedings of the 10th International Conference on Ubiquitous Computing: UbiComp 08 54-63.

Corbishley P. & Rodriguez-Villegas E (2008) Breathing detection: towards a miniaturized, wearable, battery-operated monitoring system. *IEEE Transactions on Biomedical Engineering 2008*, Vol. 55, No. 1, 196-204.

Cruz-Neira, C. et al. (1993) Surround-screen projection-based virtual reality: The design and implementation of the cave. In Proceedings of *ACM SIGGRAPH* 1993

CureTogheter (2012) Retrieved September 27, 2012, from http://curetogether.com/

Damasio A. R. (1999) *The feeling of what happens: body and emotion in the making of consciousness*. London, UK: Harcourt Inc.

Daytum (2012) Retrieved September 27, 2012, from http://www.daytum.com/

deCODEme (2012) Retrieved September 27, 2012, from http://www.decodeme.com/

Definition of Self (2012a) Retrieved September 27, 2012, from http://www.yourdictionary.com/self-definition

Definition of Self (2012b) Retrieved September 27, 2012, from http://en.academic.ru/dic.nsf/cide/156773/Self

DiaMedics (2012) Retrieved September 27, 2012, from http://www.martoon.com/Diamedic/Diamedic/Overview.html

DIALOG (2012) Retrieved September 27, 2012, from http://4thmainhealth.com/

Dix, A. (2002) The ultimate interface and the sums of life*? Interfaces* 50, 16

DIY Genomics (2012) Retrieved September 27, 2012, from http://diygenomics.org/

Dodge, M. & Kitchin, R. (2007). Outlines of a World Coming into Existence: Pervasive Computing and the Ethics of Forgetting, *Environment & Planning B: Planning & Design*, 24, 431-445

DreamBoard (2012) Retrieved September 27, 2012, from http://www.dreamborad.com

Eccles, R. et al. (2007). Stories in geotime. In *IEEE Symposium on Visual Analytics Science and Technology*, 2007.

EyeTap (2012) Retrieved September 27, 2012, from http://eyetap.org/

Few, S. (2009) Data visualization past, present and future. *Innovation in Action Series*. 2009

Few, S. (2010). Data Visualization for Human Perception. In: Mads, S. & Friis D. R. (eds.). *Encyclopedia of Human-Computer Interaction*. Aarhus, Denmark: The Interaction Design Foundation. Retrieved September 27, 2012, from http://www.interaction-design.org/encyclopedia/data_visualization_for_human_perception.html

FindingOptimism (2012) Retrieved September 27, 2012, from http://www.findingoptimism.com/

Fitbit (2012) Retrieved September 27, 2012, from http://www.fitbit.com/

Fosshage, J. L. (1997). The organizing functions of dream mentation. *Contemporary Psychoanalysis*, Vol 33(3), Jul 1997, 429-458

Gemignani, Z. (2012) Retrieved September 27, 2012, from http://www.juiceanalytics.com/writing/data-visualization-as-storytelling-a-stretched-analogy/

Gemmell, J. et al. MyLifeBits (2006) A Personal Database for Everything. In *Communications of the ACM*, Vol. 49, No. 1, 88-95

Gershon, N. D. & Page, W. (2001). What storytelling can do for information visualization. *Communications of the ACM*. New York, NY: 44(8): 31-37

Glasswing (2012) Retrieved September 27, 2012, from http://www.orsense.com/product.php?ID=38

Happy Factor (2012) Retrieved September 27, 2012, from Http://howhappy.dreamhosters.com/

Gotta Feeling (2012) Retrieved September 27, 2012, from http://gottafeeling.com/

Greimas, A.-J. (1987). *On Meaning: Selected Writings in Semiotic Theory*. University of Minnesota Press.

Gruber, T.R. (1995) Toward principles for the design of ontologies used for knowledge sharing? *International Journal of Human Computer Studies* 43 (5-6) 907-928

Guardian (2010) Retrieved September 27, 2012, from http://www.guardian.co.uk/science/2011/dec/02/psychology-human-biology?newsfeed=true

Guarino, N. (1998), Formal Ontology in Information Systems. In Proceedings of FOIS '98. Amsterdam, IOS Press, 3-15

Guidano, V.F. & Liotti, G. *Cognitive processes and emotional disorders*. New York, NY: Guilford

Guidano, V.F. (1987) Complexity of the Self. New York, NY: Guilford.

Guidano, V.F. (1991) The self in process. New York, NY: Guilford.

Gyorbiro, N. et al. (2010) Collaborative Capturing of Significant Life Memories? In Proceedings of *CHI 2010 Workshop - Know Thyself: Monitoring and Reflecting on Facets of One's Life*

HealthEngage (2012) Retrieved September 27, 2012, from http://www.healthengage.com/

HealthMonth (2012) Retrieved September 27, 2012, from http://healthmonth.com

Health Tracking (2012) Retrieved September 27, 2012, from Network http://www.healthtracking.net/

HealthVault (2012) Retrieved September 27, 2012, from http://www.microsoft.com/en-gb/healthvault/default.aspx

Heer, J. et al. (2008) Graphical histories for visualization: Supporting analysis, communication, and evaluation. *IEEE Transactions on Visualization and Computer Graphics*, 14(6) 1189-1196.

Hodges, S. et al. (2006) L. SenseCam: a Retrospective Memory Aid. In Proceedings of UBICOMP 2006, 81 - 90

Information Display: Display Week (2012) *Review Issue* July/August 2012 Vol. 28

Information Management System. Retrieved September 27, 2012, from http://bourbon.usc.edu/iml/recall/

Internet Multimedia Lab at the University of Southern California, (2004). Total Recall: a Personal

ITC's Michigan Control Room (2012) Retrieved September 27, 2012, from http:/ / pro.sony.com / bbsccms / assets / files / micro / sxrd / articles / ITC_IGI_SXRD_CASE_STUDY.pdf

Jawbone UP System (2012) Retrieved September 27, 2012, from http://jawbone.com/up

Kay M. et al. (2011) Lulaby: Environmental Sensing for Sleep Self-Improvement. In Proceedings of *CHI2011 Workshop on Personal Informatics*

Knome (2012) Retrieved September 27, 2012, from http://www.knome.com/

Lewin, K. (1951). *Field theory in social science; selected theoretical papers*. Cartwright D. (ed.). New York, NY: Harper & Row.

LifeLapse (2012) Retrieved September 27, 2012, from http://www.lifelapse.com/

Loseit (2012) Retrieved September 27, 2012, from http://www.loseit.com/

Mann, S. (2004) Continuous Lifelong Capture of Personal Experiences with EyeTap. In Proceedings of *1st ACM Workshop on Continuous Archival and Retrieval of Personal Experiences*, ACM Press, 1-21

Mayer- Schönberger, V. (2009) *Delete: The Virtue of Forgetting in the Digital Age*. Princeton: Princeton University Press.

Mechdyne Retrieved September 27, 2012, from http://www.mechdyne.com/cave.aspx

Miller, G. A. et al. (1960). *Plans and the structure of behavior*. New York, NY: Holt, Rhinehart, & Winston.

MoodPanda (2012) Retrieved September 27, 2012, from http://MoodPanda.com/

Moodscope (2012) Retrieved September 27, 2012, from http://www.moodscope.com/login

MoodTracker (2012) Retrieved September 27, 2012, from https://www.moodtracker.com/

Morin, E. (2003). *La Méthode: L'humanité de l'humanité - l'identité humaine* (t. 5), Paris, France: Le Seuil, Nouvelle Èdition, coll. Points

My Calorie Counter (2012) Retrieved September 27, 2012, from http://my-calorie-counter.com/calorie_counter.asp

MyFitnessPal (2012) Retrieved September 27, 2012, from http://www.myfitnesspal.com/

MyMedLab (2012) Retrieved September 27, 2012, from https://www.mymedlab.com/

Moore, B. et al. (2010). Assisted Self Reflection: Combining Lifetracking, Sensemaking, & Personal Information Management, In Proceedings of *CHI 2010 Workshop - Know Thyself: Monitoring and Reflecting on Facets of One's Life*

Nack, F. (2005) You Must Remember This, IEEE Multimedia Vol 12, No. 1, pp. 4 – 7

Navigenics (2012) Retrieved September 27, 2012, from http: / / www.navigenics.com/

Neisser, U. (1967) *Cognitive Psychology*. New York, NY: Appleton-Century-Crofts.

Ni, T. et al. (2006) A Survey of Large High-Resolution Display Technologies, Techniques, and Applications. In Proceedings of the IEEE conference on Virtual Reality 2006

Nike + iPod Sport Kit (2012) Retrieved September 27, 2012, from http://www.apple.com/ipod/nike/

O'Hara, K et al. (2006). Memories for life: a review of the science and technology. *Journal of the Royal Society Interface*, 3, 351-365

Pathway (2012) Retrieved September 27, 2012, from https://www.pathway.com/

PatientsLikeMe (2012) Retrieved September 27, 2012, from http://www.patientslikeme.com/

Personal Genome Project (2012) Retrieved September 27, 2012, from http://www.personalgenomes.org

Pina, L.R et al. (2012) Fitbit+: A behavior-based intervention system to reduce sedentary behavior In

Popper, K. R. & Eccles, J. C. (1977). *The self and the brain*. London, UK: Springer International

Proceedings of Pervasive Computing Technologies for Healthcare (PervasiveHealth) 2012

Private MD Lab Services (2012) Retrieved September 27, 2012, from https://www.mymedlab.com/

Propp, V. (1927). *Morphology of the Folktale*. Trans., Laurence Scott. 2nd ed. Austin, TX: University of Texas Press, 1968

Ramirez, E. R. & Hekler, E. (2012) Digital Histories for Future Health. In Proceedings of *CHI2012 Workshop on Personal Informatics in Practice: Improving Quality of Life Through Data*

Rationalizer (2012) Retrieved September 27, 2012, from http://www.mirrorofemotions.com/

Rawassizadeh, R. et al. (2012) UbiqLog: A Generic Mobile Phone based Life-Log Framework. *Personal and Ubiquitous Computing, 2012* London, UK: Springer.

ReliefInsite (2012) Retrieved September 27, 2012, from http://www.reliefinsite.com/

Renambot, L. et al. (2012) Lambdavision: Building a 100 megapixel display. Retrieved September 27, 2012, from www.evl.uic.edu/cavern/sage/pubs/LambdaVision-light.pdf.

Rensink, R.A. (2002). Internal vs. external information in visual perception. In Proceedings of the *Second International Symposium on Smart Graphics*. Smart Graphics 2 63-70

Ricoeur, P. (1992) *Oneself as Another*, Chicago, IL: University of Chicago Press.

Roambi (2012) Retrieved September 27, 2012, from http://www.roambi.com

Runkeeper (2012) Retrieved September 27, 2012, from http://runkeeper.com/

Sandstrom, T. et al. (2003) The hyperwall. In Proceedings of the *Conference on Coordinated and Multiple Views in Exploratory Visualizations* 2003.

Segel & E. Heer, J. (2010) Narrative Visualization: Telling Stories with Data. IEEE Transactions on Visualization and Computer Graphics 16(6): 1139-1148.

SenseWear (2012) Retrieved September 27, 2012, from http://sensewear.bodymedia.com/

Shaltis P.A. et al. (2006) Wearable, cuff-less PPG-based blood pressure monitor with novel height sensor. In Proceedings of *IEEE Enineering in Medicine and Biology Society 2006*

Schell, J. (2008). *The Art of Game Design: A book of Lenses*. Burlington, MA: Elsevier

Skinner, B.F. (1938) *The behavior of organisms: An experimental analysis*. New York, NY: Appleton-Century.

Skinner, B.F. (1953) *Science and human behavior*. New York, NY: Macmillan.

SNPedia (2012) Retrieved September 27, 2012, from http://www.snpedia.com/index.php / SNPedia

StressEraser (2012) Retrieved September 27, 2012, from [http://www.stresseraser.com

SugarStats (2012) Retrieved September 27, 2012, from https://sugarstats.com/

Swan, M. (2009): Emerging Patient-Driven Health Care Models: An Examination of Health Social

Networks, Consumer Personalized Medicine and Quantified Self- Tracking, *International Journal of Environmental Research and Public Health*, 6(2), 492-525

Swan, M. (2011) Genomic self-hacking http://quantifiedself.com/2011/11/melanie-swan-on-genomic-self-hacking/

Thelen, S. (2010) Advanced Visualization and Interaction Techniques for Large High-Resolution Displays. In Ariane Middel et al. (eds.), Visualization of Large and Unstructured Data Sets - Applications in Geospatial Planning, Modeling and Engineering (IRTG 1131 Workshop), VLUDS 2010, Volume 19 of OASICS, 73-81

Track Your Happiness (2012) Retrieved September 27, 2012, from http://www.trackyourhappiness.org/

Visblock™ (2012) Retrieved September 27, 2012, from http://www.visbox.com/visblock.html. Last accessed accessed September 18, 2012]

Tufte, E. R. (1983). *The Visual Display of Quantitative Information*. Cheshire, CT: Graphics Press

Tukey, J. W. (1977). *Exploratory Data Analysis*. Addison-Wesley

UCLA (2011) Retrieved September 27, 2012, from http://www.cens.ucla.edu/pub/ParticipatoryOpenMhealth-Apple-DE080711.pdf

Whittaker, S. et al. (2012). Socio-technical lifelogging: Deriving design principles for a future proof digital past. *Human-Computer Interaction*, 27, 37–62

Withings scales (2012) Retrieved September 27, 2012, from http://www.withings.com/

Wolf, G. (2008) Genomic Openness Retrieved September 27, 2012, from http://quantifiedself.com/2008/01/genomic-openness/

Wojtkowski, W. & Wojtkowski, W. G. (2002) Storytelling: its role in information visualization. In Proceedings of *European Systems Science Congress*.

Wolf, G. (2010) Ted Talk, Retrieved September 27, 2012, from http://www.ted.com/talks/gary_wolf_the_quantified_self.html

Yau, N. and Hansen, M. your.flowingdata: Personal Data Collection via Twitter. In Proceedings of *CHI 2010 Workshop - Know Thyself: Monitoring and Reflecting on Facets of One's Life*

Your.flowingdata (2012) Retrieved September 27, 2012, from http://your.flowingdata.com/

Zeo (2012) Retrieved September 27, 2012, from http://www.myzeo.com/sleep/

Zhang J. et al. (2009): UWB systems for wireless sensor networks. In Proceedings of the *IEEE 2009*, Vol. 97, No. 2, 313-331

ZigBee Alliance. (2012). Retrieved September 27, 2012, from Http://www.zigbee.org.

11 KEY TERMS & DEFINITIONS

Lifelog: the practice of digital recording of the totality of an individual's experiences.

Personal Informatics: it is another way to call the Quantified Self, a class of tools that support people to collect personal information for the aim of self-monitoring.

Gestalt: it means "form", and in gestalt psychology it means that perception is a result of interaction and global organization of various components, emphasizing that the whole is greater than the sum of its part.

Reinforcement: it is a term in the behaviorist paradigm for a process of strengthening the probability of a specific response.

Massively Multiplayer Online Role-Playing Games: it is a class of role-playing video games in which a huge number of users play together in a shared virtual world.