HORIZON

INTERGENERATIONAL INTERPRETATION OF THE INTERNET OF THINGS

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Overview

This report investigates how different generations within a household interpret individual members' data generated by the Internet of Things (IoT). Adopting a mixed methods approach, we are interested in interpretations of the IoT by teenagers, their parents and grandparents, and how they understand and interact with the kinds of data that might be generated by IoT devices.

The first part of this document is a technical review that outlines the key existing and envisaged technologies that make up the IoT. It explores the definition and scope of the Internet of Things. Hardware, networking, intelligent objects and Human-Computer Interaction implications are all discussed in detail.

The second section focuses on the human perspective, looking at psychological and sociological issues relating to the interpretation of information generated by the IoT. Areas such as privacy, data ambiguity, ageism, and confirmation bias are explored.

The third section brings both aspects together, examining how technical and social aspects of the IoT interact in four specific application domains: energy monitoring, groceries and shopping, physical gaming, and sharing experiences. This section also presents three household scenarios developed to communicate and explore the complexities of integrating IoT technologies into family life.

The final section draws together all the findings and suggests future research.

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horizon
DIGITAL ECONOMY RESEARCH

Contents

Technology Review

This section describes the core technologies that combine to form a vision of the 'Internet of Things' (IoT). It begins by considering definitions of the concept from a technological perspective and goes on to explore the key technical issues involved in realising the IoT.

Definition

A large set of definitions of the IoT have been gathered together by the Postscapes website [1]. Through this it is clear that the IoT has been conceived of in diverse ways, with both broad and narrow definitions. For example, Fleisch [2] describes very simply that "*The basic idea of the IoT is that virtually every physical thing in this world can also become a computer that is connected to the Internet*". On the other hand, the European Research Cluster on the Internet of Things (IERC) states in more detail that the *"Internet of Things (IoT) enables the things/objects in our environment to be active participants, i.e., they share information with other stakeholders or members of the network; wired/wireless, often using the same Internet Protocol (IP) that connects the Internet. In this way the things/objects are capable of recognizing events and changes in their surroundings and are acting and reacting autonomously largely without human intervention in an appropriate way."* [3].

Writing from a business perspective, Haller et al define the IoT as "A world where physical objects are seamlessly integrated into the information network, and where the physical objects can become active participants in business processes. Services are available to interact with these 'smart objects' over the Internet, query their state and any information associated with them, taking into account security and privacy issues." [4].

Haller goes on to propose that the IoT should be conceptualised in terms of '*Entities of Interest',* from which state and attribute data can be drawn that is relevant from a user or application perspective. These entities are monitored and interacted with through embedded devices, or through devices that monitor the environment and can thus track the entity – which could for example be identified through a QRCode[2] or through image recognition. Though computational devices themselves might be entities of interest to some users (particularly those involved in developing or maintaining the system), they should be considered separate from the entities they monitor to avoid confusion [5]. Atzori et al see unique addressing systems for objects as being at the heart of IoT [6]. For Gigli and Koo, all IoT systems start with 'identity-related services' which either passively support identification by scanners or actively broadcast their identity to the surrounding area. Building on this, IoT services can aggregate information from multiple sources, collaborate with us by acting on our behalf with some level of autonomy, and in their fullest future incarnation, services could support ubiquitous monitoring and control of everything in the world [7].

The definitions discussed here and further ones available from [1] contain several core themes: computation in a wide range of objects, networking to share data and provide access, and in many cases 'smart' behaviour as a result of this combination. At a technological level, cars, homes, rivers, or crates of apples will still be distinguishable from the Internet itself, but devices that interact with

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[2] QR Code, abbreviated from Quick Response Code, is the trademark for a type of matrix barcode or two-dimensional code.

or are embedded in these things offer services such that this distinction is less relevant from a users' perspective. Blurring the distinction between computational devices and all entities is key to the IoT concept. Srivastava [8] states that the IoT represents the greatest level of technological convergence that we can currently imagine. Moving forward from user-generated content to 'thing-generated content' will produce a new level of planet-wide sensory awareness, with the goal of increasing our control over time and space [8]. Overall this leaves us without a single accepted standard definition of the IoT, so it is important to define the exact scope of this paper in terms of which of the myriad potential aspects of the IoT it will address.

Scope

The IoT concept is holistic and inevitably has fuzzy boundaries in relation to the technologies used. The integration of sensors, networking, and actuators into objects that did not previously feature computation is central, but most applications of this leverage utilise existing systems such as networks, services, data mining and visualisations. By definition IoT systems are tightly integrated with all kinds of pre-existing things, e.g. vehicles, passports, weather stations or trees. Such is this scope that discussions of IoTs sometimes veer off into broader territory; for example in a recent Financial Times article on IoT, it is reported that *"Alzheimer's sufferers could wear a small device they can press to summon help if they get lost"* [9]. Taken in isolation, this application seems to have little that would define it specifically as an IoT system, rather than as a device that could have existed prior to widespread use of the IoT concept. However, people and locations can also be considered as 'things' to which novel sensors and networking are being added, broadening the scope of the concept further.

Haller et al argue that "RFID, sensor networks, embedded systems etc. are just enabling technologies, and we will see the technologies change over the years" [4]. Rather than focusing on the detailed specifications of products, this review focuses on the character of the overarching technologies, concerns that will affect the direction of IoT development, and new systems emerging from the IoT concept. Many technologies that aim to support IoT applications – microcontrollers, sensors, beacons, wireless radio – are the same technologies used for decades in robotics. The Internet of Things appears to be founded on the conditions of: pervasiveness of broadband and mobile networks with effective services for data communication, storage and analysis; the progression of smaller microcontrollers at lower prices; the continuing development of low-power and passive methods of wireless communication, sensors; and advances in recognition technologies.

The IoT concept has clear overlaps with other concepts such as Ubiquitous Computing, Ambient Intelligence and Smart Environments. On the interpretation side, it is clear that data mining, analysis and information visualisation have large roles to play in supporting human interpretation of the massive raw data sets that will be generated by IoT systems. Despite the term being in use since 1999 [10], Gartner's 2011 'Hype Cycle' of emerging technologies describes IoT as relatively immature, yet to reach the 'peak of inflated expectations' according to their review. However many technologies considered deeply related to the IoT are in a more mature state, such as QR Codes and Location-Aware applications. Others such as Near-Field Communication and Augmented Reality are expected to mature before the general concept of IoT [11].

Broad surveys of IoT technologies already exist [6, 12], so whilst an overview of major technologies is provided here, there is greater focus on issues that relate to interpretation, such as the data that could be relevant and how it might be visualised or interacted with, and on four domains considered to provide interesting spaces for scenarios in relation to intergenerational interpretation.

In this review we focus on the ways in which we will view and interact with data collected from the IoT. Themes include supporting human interaction with massive data sets, interpretation of ambiguous data, links between IoT and information appliances or ambient displays, and web based and mobile applications to monitor or alert users. A further theme is monitoring and interpreting the 'active' component of IoT systems: effectively the IoT will require human interpretation of machine reasoning such that people are willing to adopt and able to understand system behaviour.

Underlying Hardware and Architectures

This section looks at the basic building blocks of the IoT, and some of the technical issues that are affecting the directions in which it develops. In 2010 Iera et al noted that *"The IoT paradigm's feasibility stems from the maturity level reached by several key technologies"* [13]. Their list of these contains RFID, wireless sensor networks, energy harvesting, web technologies such as XML and REST, and IPv6 as a necessary underlying transport infrastructure. In all these technologies they see scalability as a core element, allowing the network to keep growing and subsume an ever wider range of things across the world.

Making Objects Part of the IoT

Fundamentally the IoT requires diverse things to have a presence on a network through which some processes of data gathering or interaction can occur. At a technical level, Haller distinguishes 'Devices' from 'Things' – things being potential *entities of interest* to users and applications, while devices provide the means to access and interact with data. Whilst devices are also things, from the user perspective they are not necessarily of interest – though often their maintenance is to the bodies that manage them. Note that in this definition, purely passive (non tech) labels such as barcodes do not qualify as devices, but are seen as features of the entity of interest. A combination of devices may be embedded or attached to the entity of interest, or monitor the environment such that the state of the entity of interest becomes data (e.g. through RFiD interrogators, barcode scanners that monitor things passing through their reading fields, cameras etc.). Through networking these data become resources that can be accessed via services [5].

The vision that characterises the IoT is one where things are connected that we would not previously have considered relevant to computation or feasible to integrate with a network. This change in scope includes items that are already electronic, but not networked (e.g. appliances, lighting), things that are not by default networked or electronic, but to which these can be embedded (e.g. a door lock or a houseplant) and non-computational things that can be identified and monitored as they move through an environment (e.g. a package with barcode, a person recognised by facial recognition). Sensor networks can even bring this vision to things that have no solid form or are of great scale, such as rivers and mountains. Finally, there exists, and will further develop, an expanding class of new technologies designed based on the IoT vision itself, supporting interactions with the IoT and integrating it in to our lives. For example the Karotz [14] and Whereabouts

Clock [15] projects, described later.

RFID and QR codes are two technologies commonly used to make things part of the IoT. Both have mature forms but are increasingly being applied in new places. Whilst in some cases either could be used for the purpose of identifying an object and providing access to related services, the two technologies fulfil different requirements. QR codes are passive labels applied to items, whereas RFID tags are devices that can be used to share data wirelessly. Summing up the advantages of RFID over barcodes, Jiang et al include: not requiring line of sight to read, the ability to read multiple tags simultaneously, ability to use in a rugged environment, ability to carry more data, ability to be rewritten, and ability to use in combination with sensors to communicate environmental data [16]. Although the current surge in the use of QR codes is expected by some to be short lived and inadequate [17], many companies accept this as a current standard with valuable uses [18]. QR codes provide a more efficient way to connect data via a camera-equipped device to a physical object than typing in a URL. They are increasingly popular in advertising, almost cost free, require no power source of their own, and are usable over large distances if visible (e.g. on a large billboard). Whilst barcodes have been in use for decades, the recent proliferation of smartphones has rapidly increased their use in the general population [19]. QR codes are also widely used in augmented reality technologies (e.g. [20]). This emergence of a form of IoT into the mainstream has occurred because of a convergence of technologies into smartphone devices.

In contrast to barcodes, RFID tags are computational devices in their own right. They can be passive (without a battery, energised through receiving waves from scanners), battery assisted (using a battery boost when a scanner is detected passively) or active (using a battery constantly). Tags have been produced as small as 0.05×0.05mm [21]. The range at which tags can be recognised varies according to hardware, energy, and environment, but even some passive tags can be read from 20 metres or more [22]. In other deployments, scanning range is kept to a small defined area (e.g. entry card readers for buildings, or security gates in libraries or shops that activate if the tag on a product passes through without having been checked out or removed.

Supporting two-way communication over very short distances, Near Field Communication (NFC) is emerging as a further technology that may replace uses of QR codes and RFID in the future. The technology is already supporting payment through some Android smartphone models, with Apple expected to introduce it into its products in 2012. The short range of NFC makes it unsuitable for some applications so it is likely that a range of RFID technologies will remain in use. The current marketplace for low power, short range communications is diverse, other technologies emerging with potential for IoT applications include ZigBee, intended to be a less expensive alternative to Bluetooth. ZigBee is suited to applications requiring a low data rate, long battery life, and secure networking. Nodes can go from sleep to active in 30ms or less, making devices more responsive (wake up times for Bluetooth are typically around 3 seconds). Because ZigBee nodes can sleep most of the time but still be responsive, average power consumption can be lowered. A distinction is also made between end-devices that can be very small and use little power, connected to router and co-ordinator level devices that would allow a network of end-devices to operate effectively [23]. A further technology is DASH7. This is an open standard with the potential for multi-year battery life, encryption and a range of up to 2km [24].

A critical issue in this area is that increasing the smartness, range or capabilities of embedded computation increases energy costs. For instance, the energy required for a programmable integrated circuit can be 10-100 times that of a dedicated integrated circuit. Batteries are still cumbersome in producing many visions of smart networked objects, and whilst there are continuing developments in energy harvesting and management, these issues are likely to shape the approaches to IoT for some time to come [25, 26]. It is – for instance – a barrier to creating embedded technologies that can adapt to different networking or physical contexts, to embed actuators or active sensors into devices without creating situations where they will need to be regularly recharged, or to support complex on-chip processing of raw data that would reduce the network traffic produced by IoT enabled things.

Socio-Technical Considerations

On the socio-technical front a major issue in the development of an IoT is privacy. This is a holistic concern which needs to be tackled at several levels, but begins with the basic hardware used. Whereas it is generally clear that a barcode has been scanned, there are no standard means to offer the user any feedback or control over whether or not an RFID tag is detected by scanners. There has been exploratory work integrating awareness of scanning and control over whether the tag is locatable through custom chips, but this idea has yet to be widely adopted, and Marqardt et al note that in many of the cases where RFID is used, additional interaction overheads to ensure privacy would be problematic. Energy use and size would also increase to support user interaction. It is however clear that RFID chips can be designed differently depending on the context of use to support varied levels of privacy control [27].

In addition to privacy, there are concerns about the lack of effective security that these building blocks of the IoT provide. The proliferation of IoT technologies is a clear concern in that *"everyday objects become information security risks"* (US National Intelligence Council, from [6]). Despite its widespread use as a security mechanism, and even implanting chips into employees' bodies – intended as a new form of access control – hackers have claimed to easily clone RFID tags' ID codes, which can then be replicated into another tag to imitate the original [28]. Support for two-way communications means that NFC is more suited to activities such as monetary transactions that carry a clear security risk, but again, security overheads will increase energy and computational requirements.

In terms of achieving data collection or actions, there is a long history of developing sensors and actuators for robotics and in many cases work can be adapted from these for IoT use. These approaches have generally focused on replicating human senses and intelligence to allow robots to act effectively in the physical world and in concert with humans – something that many envisage IoT systems will need to achieve. Examples include robots that detect human speech in the presence of other auditory signals [29, 30], act as a mobile network of temperature sensors to inform search and rescue operations [30], or build dynamic understanding of their physical surroundings through cameras [31]. The addition of actuators to a device moves IoT even closer to being essentially a networked form of robotics. As with robotics, there is a DIY, hobbyist community supported by products such as the prototyping kit Arduino [32]. Since the IoT is likely to have such a pervasive influence, personalisation and end-user development are likely to remain important in its integration into our lives.

Connecting and Understanding Heterogeneous Objects

The number of objects connected to the Internet is already amazingly high. Cisco reported in 2008 that the number of things connected to the Internet exceeded the number of people on Earth, with the expectation that this will continue grow dramatically to a global network of hundreds of billions, if not trillions of networked things [33].

A key element to supporting this massive growth is the ability to provide addresses to a far greater number of objects. Whereas IPv4 only supported 4.3 billion addresses, IPv6 supports 340 undecillion addresses – 100 for every atom on earth [34]. While the adoption of IPv6 has backing from large tech corporations such as Cisco and Google [35], it has yet to become widely adopted in practice [36]. Transition from IPv4 is not without difficulties, but the pressure to adopt IPv6 is likely to increase as and when lack of address space becomes a problem. It may be however, that a large range of the technologies envisaged as forming the IoT could be achieved without making each object directly internet addressable. There are also overheads in supporting IP in limited power, space and computation situations such as on sensor nodes. However, the 6LoWPAN group have developed standards and specifications for the purpose of supporting IPv6 on such devices. Systems such as Zigbee do not support IPv6, and it may be that technologies of this type remain essential for small, ad-hoc networking where the overheads of working with IPv6 are not compatible with the constraints on the device. Akyildiz and Jornet (2010) suggest that nano technologies are unlikely to be able to connect to or be addressed directly to the Internet, but will be addressable only in local networks [37].

The concept of Object Memory appears practical to many IoT applications. The W3C Object Memory Modelling Incubator Group state that *"A digital object memory denotes a repository of digital data, which is linked with a physical artifact, and which is continuously enriched with data from entities that interact virtually or physically with the artifact. Technically seen, this repository may exist at the artifact itself, outside, or both. From a content point of view, it offers access to data about a history of events up to the current point of time."* [38]. Much of the work in this area has been inspired by US science fiction author Bruce Sterling, who imagined the notion of a 'Spime' - *"objects tracked through the entirety of their existence through both space and time"* [39]. This includes design documentation prior to an object being manufactured, a record of events during the objects' existence recorded from sensor data, and a digital existence after destruction that could allow the object to be understood or even regenerated in some form. Bleecker devolves the science fiction notion of Spime backwards to create the idea of a 'Blogject' as a more feasible 'ancestor' – an object that 'blogs', publishing information about itself [40].

Things Acting Smart Together

Visions of the IoT generally expect to use the increased availability of data and embedded networking technology to automate processes such as in efficient logistics or smart homes.

The ability for these devices to communicate and co-ordinate their actions effectively can be expected to be a focus for future research. For example, Corson et al. [41](argue that devices should have a ‘Wireless Sense’ that supports decentralised, proximity-aware networking. Through this, devices will be aware of others around them as they and the other device physically moves through an environment. This sense should operate autonomously and continuously, managing discovery, linking and recognition in a more advanced and secure way than current technologies like Bluetooth which can scan or make themselves ‘findable’. It could also support forms of Peer to Peer networking for faster, more efficient access to the Internet. [41]. Akyildiz and Jornet [37] discuss how nanotechnologies could be effectively networked, with ‘nano-routers’ connecting tiny nodes to interfaces and then on to Internet Gateways (either mobile devices or standard Wireless routers depending on location) [37].

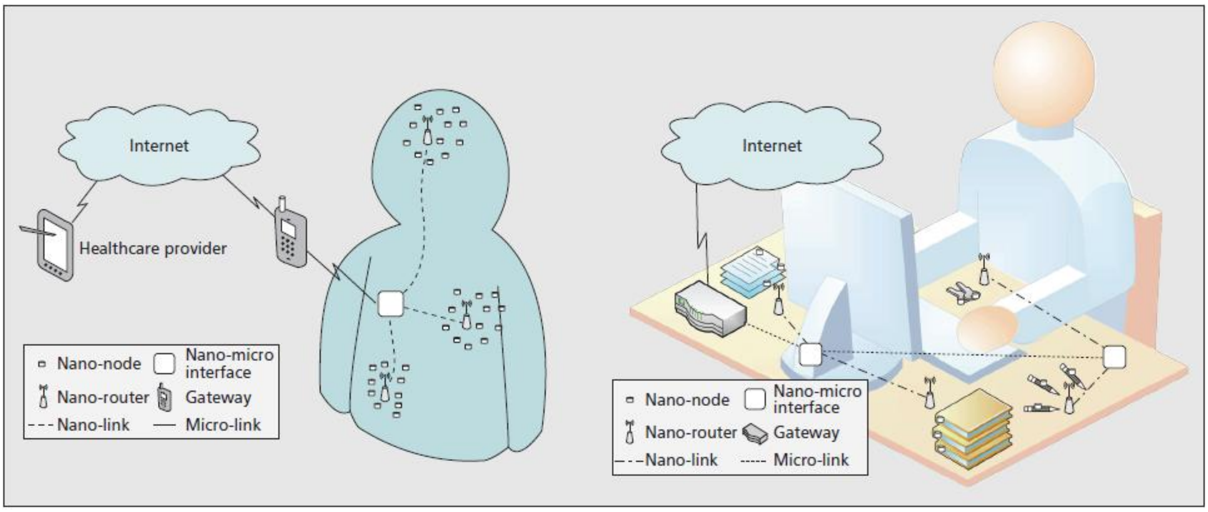


Figure 1: Network Architecture for the 'Internet of Nano-Things' from Akyildiz and Jornet [37]

At this point, research can become heavily connected to Agents and AI. Future visions of active systems that make objects and environments ‘smart’ are dependent on those agents forming effective understanding of peoples’ desires and intentions, along with peoples’ ability to understand the agents’ ‘intent’ and reasoning process. Grounding this survey in the basic components of the IoT, sensors and actuators are key components. Cook and Das define a ‘Smart Environment’ as *“one that is able to acquire and apply knowledge about the environment and its inhabitants in order to improve their experience in that environment”*. These environments comprise: Physical components – sensors, actuators and hardware interfaces. Communication components – sensor networks, software interfaces, routers. Information components – tools for prediction, data mining and modelling inhabitants using collected data. Finally, there are the Decision-Making components – rule engines and other tools for deciding on actions, which then occur through the communication and physical components [42].

Inhabitant modelling and acting on these models is a difficult and key challenge, particularly with multiple inhabitants. Mozers’ Adaptive House is one of a number of practical research projects that have investigated how collected data can produce predictive models that – for example – turn on lights and heating when inhabitants are expected to return home, or follow the patterns that a person used on a previous occasion – e.g. *‘last time they entered the room they switched this light on, so the next time they enter in the same way, it is done for them’* [43]. The iDorm project at Essex created a smart bedroom based on the standard design of student halls at the university. An inhabitant can control the rooms' fans, blinds, lights and heating via a personal digital assistant (PDA) while an agent builds rules and acts based on the inhabitants' behaviour and snapshots of the context when the behaviour occurred. In a trial with a person living in the room over 5½ days, the rules created by the agent stabilised mostly within 24 hours, and completely in 3½ days, which suggests that the person's routines in relation to these objects were then understood – or at least, that the person had stopped acting outside of the understood rules and was satisfied with the agents' decisions [44].

Where these approaches use machine-learning approaches that have a biological inspiration, such as neural networks, genetic algorithms and fuzzy logic, a further strand of work takes a 'biomimetic' approach, aiming to develop systems that adapt to changes in the environment in the same way as living organisms. This is discussed in relation to smart grids and city-level infrastructure, where data from weather stations or environmental sensors could be linked in to the logic controlling sewer systems, artificial wetlands or reservoirs to efficiently and ecologically manage the city as an organism [45].

Another phrase used in a similar way is Ambient Intelligence. This suggests *"Intelligent, user friendly interfaces"* connected to ubiquitous computing technologies. A connection is made with natural-user interfaces and a hybrid space between recognition by the computer of human activities and intentional human interaction aimed at a computer in the traditional sense [46].

Human Interactions with the IoT

As things become connected to the wider Internet, there is likely to be ever greater crossover between IoT and data from objects. A European Commission action plan suggested in 2009 that the *"interconnection of physical objects is expected to amplify the profound effects that large-scale networked communications are having on our society, gradually resulting in a genuine paradigm shift."* [47]. The way we interact with IoT data will begin as an extension of our current use of the Internet (e.g. through social media services or other websites to view and share data), but this may fundamentally change as innovations progress.

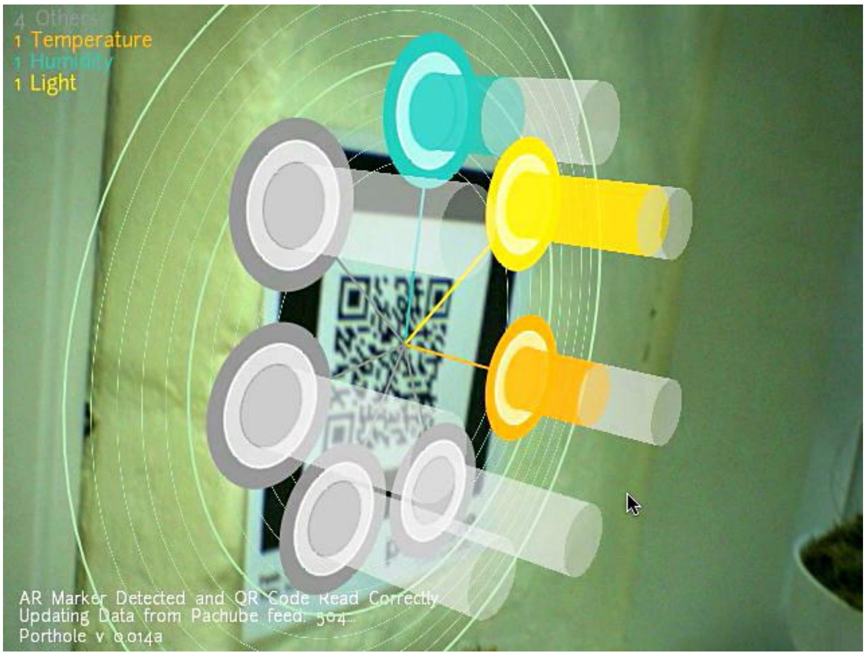
In relation to the 'smart' capabilities that Internet of Things enabled systems could achieve, a white paper from Les Institutes Carnot argues that active solutions must allow human awareness of the system state and allow users to understand the motivation behind actions, so that the system is not a black box. There is concern that users must remain in 'control' [26]. Many AI approaches are difficult to unpick or visualise such that people cannot understand system behaviour, and this tension may become more apparent as smart IoT technologies integrate closely and act in our daily lives.

The sharing and visualisation of data from the IoT is one of the most immediate ways in which the IoT is becoming apparent. Services such as Pachube [20] make it simple to stream data from network-enabled microcontrollers like the popular Arduino [32] board. This data – received from sensors attached to the Arduino or other devices – is then visualised on their website.

There has been little specific research to date on visualisation for the Internet of Things. The expected use of a wide range of heterogeneous data sets is likely to lead to similar issues as those faced by 'Linked Data' projects that bring together various public databases and aim to allow users to query and make use of this information together. Dadzie and Rowe describe a list of guidelines for the visualisation of Linked Data, including the need for generic (non domain-specific) browsers, intuitive search interfaces such as keyword and QandA style searches alongside more technical queries, and the ability to visualise trust in the different data sources [48].

Ghidini et al [49] have developed a visualisation framework specifically for the IoT called SNVis. Through this they suggest a range of design principles and challenges. They stress the importance of metadata for sensors and devices that can be used to ascertain the relevant visualisations for the different kinds of IoT data (e.g. location data goes on a map, daily temperature data on a time-based graph). They also stress the difficulty in communicating and presenting large data sets. Smaller screens and devices could not accurately represent large multifaceted data sets in full, and client/server side processing must be relative to the strengths of each such that the right data is available and can be manipulated without large delays. Aggregate values for intervals may be appropriate in some circumstances but not in others where it is the detail that is of interest. As part of SNVis, they developed an approach called 'Brush and Linking' that allows the same data point or area to be highlighted across multiple views where data sets are linked. Further challenges include the data from IoT objects often being a live stream so visualisations will need to be updated regularly, and also that data will often be poorly structured or pulled from different original structures as discussed in relation to Linked Data [49].

Physical things have a location relative to other things and to the environment as a whole. Virtual and Augmented representations are therefore likely to be developed as a useful way of understanding data in context. Kodym developed a system providing VR representations of sensors and objects in a mine, supporting decision making and crisis management [50]. A Pachube plugin under development shows other ways the data could be used: Porthole produces augmented reality visualisations of data mapped on to related points in the physical world using QR Codes and smartphones (see figure 2). This approach could be used to help users explore data from the physical world around them [20].



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AR Marker Detected and QR Code Read Correctly
Updating Data from Pachube feed: 504...
Porthole v 0.014a
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Figure 2: Porthole AR plugin for Pachube, showing data visualised on top of a QRCode in the environment.

Ishii et al [51] argue that ‘vision-driven design’ has been and will continue to be fundamental to major leaps in interfaces. This approach is similar to the way we have developed scenarios as part of creating this report (see section 3), but in their case a vision of ‘Radical Atoms’ is presented. This takes the progression of GUI and tangible user interfaces (TUIs) towards a further step where physical materials can be moulded and take forms in such a way that this becomes a new form of interface. They suggest that these dynamic physical materials need to do three things: Transform – change their physical shape in response to human or computer input, Conform – understand the constraints of their environment and how to transform safely in the current context, and Inform – make clear to users their affordances, given that their actual shape is dynamic, along with providing other information to users [51].

As with many other concepts, there is no distinct line between TUIs and IoT. Rather than contrasting them, it is interesting to consider how tangible interfaces could develop further when everyday objects are part of the IoT. Current systems often combine projectors or surface computing with tangibles (e.g. systems such as Microsoft Surface or Reactable recognise barcodes that can be attached to any suitable object, and can produce dynamic interfaces or respond in other ways when the item is placed, rotated or removed). Ishii notes that the *“success of TUIs is through a strong* *perceptual coupling between tangible and intangible (dynamic) representations"* [51].

Toys with new forms of embedded computation, networking or links between the physical and digital may be a particular area of innovation as demonstrated by Topobo – a 3D construction kit that resembles Lego with memory. Users combine the primitive parts and then record motions that are remembered and repeated by their design [52]. Shape-Memory Alloys were first developed in the 1930s that can remember a position when a current is passed through them (or they are heated). They have been used as a means of building small, low power robots and other actuators [53]. At a different end of this design space, augmented reality is being used to give physical toy figures an additional dimension. Mattel began this trend with toys for the film Avatar, where new content appeared on screen as an overlay when a figure was scanned by any webcam [54]. Skylanders: Spyros' Adventure is a game that unlocks characters on the computer in response to the presence of related physical toys [55]. Sifteo cubes are small blocks with 128x128 pixel LCD screens that use NFC to identify when they touch or where they are in relation to each other, supporting a range of games. The system uses a computer with USB dongle to play sound, perform computation and act as a router [56].

The Human Perspective

Despite the review of technologies relevant to the IoT in the previous sections, this report is primarily concerned not with the technologies themselves, but with how IoT technologies will impact our everyday lives. This section explores the myriad of psychological, sociological and ethical issues surrounding the intergenerational interpretation of the IoT.

Defining Generations

A logical starting point is to explore what we actually mean by the term 'generation'. Within a traditional nuclear family identifying a generation is easy: parents are a district generation from their children because of the simple fact that one is progeny and the other is progenitor. Similarly grandparents are defined by the fact they have created the parents who in turn created the children of the household. However, when studying multiple households or the community at large things become a little more complex. Generations could be defined by distance from a shared ancient ancestor, but doing so would be of limited use as the classification would change depending on the ancestor chosen and those defined by a generation would not necessarily have anything in common. For this reason generations have been re-defined in a number of ways in order be used as a method grouping individuals with similar roles, ages, life-experiences etc.

Generations can be considered simple in terms for age differences but as age is continuous any grouping would be arbitrary. A number of researchers suggest that generational differences are more fundamental than that.

Johnson and Johnson suggest that shared life changing events known as 'Generational Signposts' cause commonalities in general life outlook to different generations. For example; the Great Depressions, the World Wars and the September 11th 2001 attacks on the World Trade Center. Life Laws on the other hand are events that change the way we live, but take place early enough in our life such that we take them for granted. For example: mixed race schools, smoking in pubs, and women getting the vote. Using these concepts they define a Generation as: *"A group of individuals born and living contemporaneously who have common knowledge and experiences that affect their thoughts, attitudes, values, beliefs, and behaviours."* [57].

Some of the commonly defined generations based on this definition are:

Babyboomers: those born between 1946 and 1962 probably left secondary school before using a personal computer (PC). They are often referred to as idealists.

Generation X: born between 1963 and 1980, people in this generation may have seen a PC in Secondary school, especially those in 'elite education'. They are stereotypically defined by a tendency towards pragmatism and distrust of authority.

Millennials: born from 1981 to 2000, this generation is defined as having used computers from early in life.

Prensky takes this idea a step further and theorises that those born into the digital age have different language and even brain structures, due to the constant presence of interactive technology [58].

Salkowitz [59] provides the following commentary on generations:

> "The high-tech industry makes a conscious effort to associate its products with the excitement of youth in highly visible marketing campaigns. Younger people have been targeted as consumers since the 1980s, with messages promoting the benefits and downplaying the troublesome aspects of computers, software, devices, data services, high-speed connectivity, and literally thousands of specialized, highly complex products. The messages are keyed to generational sensibilities and reference cultural touchstones that have specific, emotionally resonant significance to younger customers. At the same time, media coverage of computers and the Internet — especially in newspaper features and TV newscasts disproportionally consumed and trusted by older audiences— often focuses in a sensationalistic way on the failures, risks, and problems of technology (e.g., viruses, identity theft, online sexual predators). It is no surprise that perceptions of technology can vary significantly among the generations."

However it's worth noting that these definitions are based on significant but geographical restricted events related to western cultures and thus are meaningless as a universal definition of generations.

Other researchers suggest a fuller understanding is gained by adopting the 'Lifespan Methodological Framework' that acknowledges the impact of age, cohort and historical period on generational differences [60-62].

In conclusion, it seems that the range of potential meanings for Generations means that the term is not particularly useful for communicating a specific concept. Instead this report will deal with the various aspects that make up the term, such as age and placement in family hierarchy.

Intergenerational Communication and Relationships

Family hierarchy can have a significant impact on how individuals communicate with each other. Williams [63] reviewed current research into communication and relationships between parents and adolescences. She comes to two important conclusions. Firstly that the main factors at work in terms of communication negotiations are three dialectical forces: autonomy versus connection, privacy versus open boundaries and individual versus intergroup. Secondly she concludes that "conceptualising parent-adolescent communication as dynamic and processural across the short and long term may be more useful than focusing on the parent as an agent or issuing recipes for successful communication with adolescents."

Furman and Buhrmester investigated how age (and sex) influence perceptions of networks of personal relationships in children and teenagers. It was show that parents are seen as the primary providers of support in younger children, but an even role between parents and same sex friends' support is established as children reach the middle of adolescence. They also found a peak in parent-child tensions during early to middle adolescence, due to differences in perceived conflict, influence and relative power [64].

Giles, Ryan and Anas studied perceptions of intergenerational communication by young, middle-aged and older Canadians. They found that people linked old age in targets with increased benevolence and decreased vitality. Older targets were also seen as less accommodating and more often avoided. Perhaps the most surprising is that they found that while all of these perception trends are more evident for younger correspondence, they are still present at a significant level in older adults [65].

Ng reviews social psychology literature relating to ageism and intergenerational relationships. He highlights the insufficiency of the categories "young" and "old" as a basis for research and proposes a focus on a more fine-grained approach to map out lifespan more fully [62]. This suggestion is already being realised as more and more research investigates the differences between the 'young-old' and the 'old-old' [66].

Parents may see these technologies as a tool to monitor child behaviour, in an attempt to reduce delinquency. While a range of previous studies have shown a direct link between parental knowledge of youths' activities and reduced delinquency [67], a more recent study by Stattin and Kerr [68] suggests that it is only self-disclosed information that is linked to reduced delinquency. This suggests that the application of IoT technologies to monitor youth activity will not help reduce delinquency, but will have an impact on privacy and potentially damage intergenerational relationships.

Perceptions of Age and Stereotypes

Core to this research area is the impact that the age of the actor has on the interpretation of data about them. Bengston states that:

"That our perceptions of others determine our behaviour towards them is one of the central premises of social science. That age represents an important parameter of social interaction is a central premise of life-cycle sociology and psychology. In popular culture today these two ideas are linked in public rhetoric and private anxiety about the 'generation gap.' This term suggests that persons perceive substantial differences in orientations between individuals of different age groups, and further than that these differences have behavioural consequences: competition, conflict, and coercion between age strata."[69].

Originally ageism was conceived as a way of describing negative stereotypes of the elderly [70], but it is much more broadly conceptualised as any form of prejudice or discrimination against or in favour of any age group [71].

Ageism has been described as containing two interconnected dimensions; first ageist ideology of stereotypes, beliefs and attitudes and secondly ageist behaviour that excludes or disadvantages certain ages groups relative to others [72]. However, more recent research suggests that even perceived age discrimination can have a negative effect on both individuals and the organisations they work with [73]. Further work on perceived age discrimination has shown that it related to general well-being in older adults, but not in any younger age groups. It is suggested that this is due to awareness of the fact that younger adults will at some stage leave the group associated with the discrimination, unlike older adults [74].

Neugarten, Moore and Lower argued that most people see others as having stronger opinions than their own about the importance of age appropriate behaviour. However this gap narrows significantly as people get older. This tells us that most people, especially the young, have a poor concept of how others judge age appropriate. This hypothesis implies that self-monitoring of age appropriate behaviour may be strongly influenced by incorrect perceptions of others' expectations [75].

There is a wide range of research exploring Ageism and perceptions of the old. Schmidt and Boland identified a range of 'trait clusters' that university students associate with the elderly. Their findings suggest that individuals (university students) associate both positive and negative traits with the elderly, as well as identifying how these trait descriptions cluster around specific stereotypical characteristics [76].

Positive trait clusters and exemplar underlying traits:

- John Wayne Conservative- tough, patriotic, doesn't like hand-outs
- Liberal Matriarch/Patriarch- lives life through their children, mellow
- Perfect Grandparent- capable, wise, useful
- Sage- intelligent, interesting

Negative trait clusters:

- Despondent- miserable, bored, hypercritical
- Mildly Impaired- sexually inactive, slow moving
- Vulnerable- poor, victim of crime, quiet
- Severely Impaired- dependant on family, sick, fragile
- Shrew/Curmudgeon- ill-tempered, bitter, demanding
- Recluse- suspicious of strangers easily upset
- Nosy Neighbour- frugal, busy-body
- Bag Lady/Vagrant- dirty, useless

This work highlights the complex stereotypes of the elderly. The range of personal activity information that internet of things applications make available may help change these limited and mostly negative stereotypes of the elderly.

However research in self-perception indicates that perceived age can be just as important as actual age as described by the adage 'You're only as old as you feel'. Montepare and Lachman provide evidence that subjective age or self-perception of age is positively correlated with both fear of aging and life satisfaction. Not only this, but this correlation is stronger than those between fear of aging and life satisfaction with actual age [77].

Social psychology research suggests that activated stereotypes affect quantitative task performance in both adults and children. This research shows that when individuals are made explicitly aware of a stereotype held about them, that it actually effects performance in tasks related to the stereotype. This effect has been show in children as low young as 5, although the complexities of social development mean that the direction of performance effects change with age [78, 79].

Recent research that considers the biological and psychosocial perspectives of ageism has resulted in the 'Bio-social-cognitive model of ageism' [80]. As Figure 3 illustrates, this model relates ageist practices and policies to impaired cognitive and social competences of older adults. This would lead to confirmation of the stereotype and could then feed into further practices and procedures.

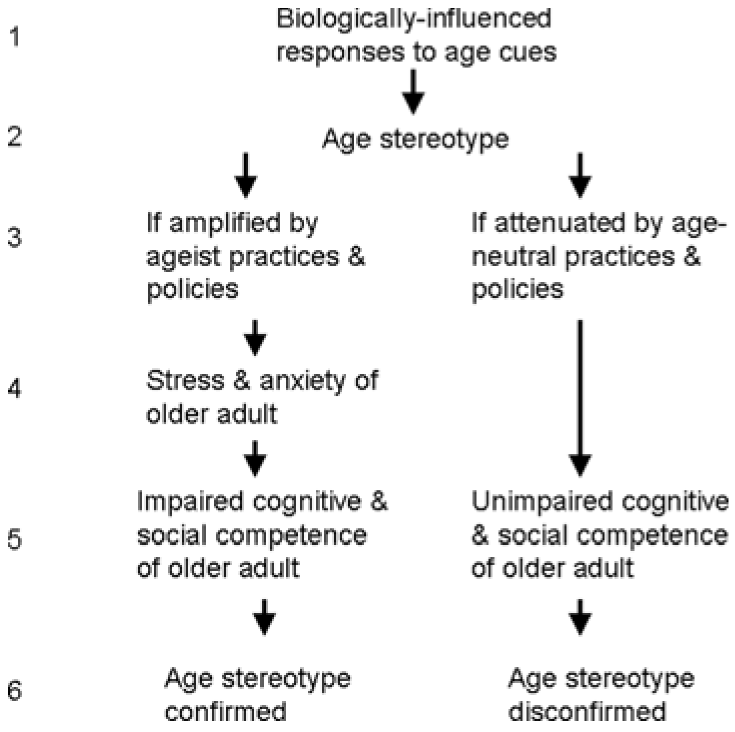


Figure 3: Bio-social cognitive model of ageism

Looking at the other end of the spectrum much less research has explored the presence and impact of ageism and age related perceptions of the young. While this issue has been repeatedly highlighted in the media [81, 82] research is generally domain specific with little in terms of generalizable findings [83]. This is perhaps related to the perception that for those discriminated against for youth it is only a temporary issues, as discussed earlier [74].

Age and Technology

Moving on to the implications of generation on technology interactions, we will first explore how age influences technology use. It is a commonly accepted belief that older people are slow to adapt to new technologies [84], but research in both human factors and psychology show that the reality is not that simple and suggest a more complex and nuanced view should be taken.

Research by Chung et al [85] used an extension of the Technology Acceptance Model [86] to investigate age effects on intent to participate with online communities (among non-users). They found Internet self-efficacy, perceived quality, perceived ease of use and behavioural intent were all significantly negatively correlated with age. This suggests that the tendency for some older users to be slow to adapt to technology is caused by lack of confidence and a critical view of the quality and accessibility of technology. When designing technologies that are aimed at all ages it is important to consider these underlying factors that could slow adoption by older users.

Many occupational psychology studies have explored how age affects technology acceptance and adaptation within the workplace [87]. One of the interesting findings in this area is that younger workers' technology usage is most strongly influenced by personal attitude, while older workers were more strongly influenced by subjective norms and perceived behavioural norms.

In the domain of teaching there is evidence that more experienced teachers are more likely to change the way they teach to allow for changing computer technology. Coupled with the strong link between age and experience this suggests that when it is seen as practical, older people can actually be quicker to adopt to new technologies [84].

Privacy

"Patterns of interaction in any social system are accompanied by counter-patterns of withdrawal…There exists a threshold beyond which social contract becomes irritating to all parties; therefor, some provision for removing oneself from interaction and observation must be built into every establishment"- B. Schwarts, 1968 [88]

Privacy is a highly researched area with hundreds of articles explored across many domains. In terms of understanding privacy in general, many models have been put forward. For example Carew and Stapleton [89] developed a highly detailed privacy framework for information systems development. However, the focus on technology means this model tells us little about the psychological and social implications of privacy, or lack of it.

A more human focused model of privacy has been developed by Pedersen [90]. On the basis of a number of pervious theoretical models [91, 92], he performed a range of studies identifying both the types of privacy that people use and the functions for which privacy is used [90, 93-95]. He identified five functions of privacy (Autonomy, Confiding, Rejuvenation, Contemplation and Creativity) and six types of privacy:

- Solitude: freedom from observation by others
- Reserve: no revealing personal aspects of oneself to other
- Isolation: being geographically removed from and freedom from observation by others
- Intimacy with family: being alone with family
- Intimacy with friends: being alone with friends

- Anonymity: being seen but not identified or identifiable by others

By asking participants to rate the extent to which each privacy need is fulfilled by each privacy function, a unique profile was identified for each type of privacy. In terms of IoT this research is very important as IoT data collected and presented to household members will restrict the potential for each type of privacy in different ways and in turn reduce the possibility for performing privacy functions to different extents.

For example an application that records and displays energy usage in the home may well preserve Anonymity privacy, but would probably impact solitude. Relating this to function would suggest a maximum impact in terms of opportunities for creativity and contemplation.

"Privacy is a fundamental human right [96], that continues to be violated by intrusive and unethical applications of technology in society and the workplace"- S. Baase, 2003[97]

Smith, Dinev, and Xu [98] reviewed 320 papers and 128 books in the area of information privacy, across various disciplines. They had two relevant major findings:

- A wealth of theoretical and descriptive development has been made, but relatively little empirical evident has been produced to back it up.

- Most of the research has focused on privacy concerns and more needs to be done to understand the antecedents to these concerns and the actual outcomes of holding these concerns.

Focusing on personal data, Graeff and Harmon explored the relationship between awareness of data that is collected, concerns about personal data privacy and Internet shopping behaviour. They found that despite universal concern about personal data privacy, awareness of how personal data is currently collected is generally low. They also discovered a significant inverse correlation between concern and reluctance to shop online [99].

Looking at a more specific example, evidence [100] suggests that users of Facebook tend to report high levels of concern about personal data privacy, but this is not strongly correlated with actual behaviour, i.e. many 'concerned' individuals reveal great amounts of personal information [100].

Soppera and Burbridge raise a range of privacy concerns in relation to the emergence of pervasive computing technologies that are embedded in to the fabric of everyday life. They first note that these devices will *"disappear so effectively that end users will lose awareness of the devices' presence or purpose"*, and in this case, they point out that if *"you cannot interact with the computer, how can you tell what data is collected, where the data is flowing to, and more importantly, what the consequences of your actions are?"*. To further explore these issues, they refer to principles that form the Organisation for Economic Co-operation and Development (OECD) privacy guidelines – a common basis for standards in 34 member countries around the world. Firstly, they argue that pervasive technologies disrupt the notion of *'personal'* data, as devices may collect volumes of data that is not directly related to any one person, but from which personal information can be ascertained through collation. Secondly, they note that guidelines on *data collection* suggest that this should be limited to appropriate situations where consent has been given, and for a specified purpose, but in pervasive systems, notifying and asking for consent could be difficult or impossible –

for example where a camera may recognise us and record our movements. Finally, the guidelines state that individuals should have the right to obtain data held about them. However pervasive technologies may mean there are many more hosts holding data about us, and less awareness or capability to identify whom these might be [101].

Looking at this issue from a different angle, the work of the philosopher-sociologist Bauman argues that European modernity itself is a bought at the cost of privacy. He states that modernity involves removing unknown and uncertainties via control over nature, rules, bureaucracy and categorisation; all in an attempt to remove personal insecurities. He goes on to identify the downsides of modernity such as a lack of freedom and fear/resentment of those that not known or controllable. If fully realised the Internet of Things could be a vivid example of Bauman's idea of modernity, giving us unprecedented knowledge about the location and actions of people and objects. Therefore it is important that we consider the downside we are warned of, constant observation by a cloud of sensors is bound to impact privacy and the huge amount of personal data collected also has serious security implications. However, Bauman suggests that the most insidious downside of modernity is the tendency to ostracize objects and people that do not fit into the controlled and known view of the world [102].

Ambiguity

In order for interpretation to be necessary, data must contain some form of ambiguity, wither in terms of accuracy, specificity, source or meaning.

Gaver, Beaver and Benford [103] propose that while mainstream HCI sees ambiguity as a purely negative element in design that causes frustration and inefficiency, it can be used a resource for designers to capture interest, increase engagement and encourage interpretation. They propose three core types of ambiguity. 'Ambiguity of Information' is found in the artefact itself, be it physical or digital. 'Ambiguity of Context' describes the sociocultural environment in which the artefact is experienced. Finally, 'Ambiguity of relationship' is more personal and describes how the individual evaluates and interprets the artefact.

Aoki and Woodruff [104] explore how the ambiguities inherent in the design of various communications technologies can be a useful feature in avoiding awkward social situations and saving face. Introducing existing and potential designs to users, they find that ambiguity supports multiple explanations for intentions, for example if a person is unresponsive to communication, a lack of context information means that a caller is open to multiple explanations (e.g. the person could be in a meeting or travelling) rather than assuming that they are being ignored [104]. In a similar way, IoT technologies could reduce the ambiguity in our knowledge of the actions of others, which could be problematic for personal relationships.

Alternatively, 'Confirmation Bias' may mean that ambiguous data is misinterpreted to support existing stereotypes and biases. Originally studied in philosophy, this theory suggests the tendency for people to bias the information they receive in one way or another, so that it confirms beliefs that are already considered or held [105]. This phenomenon can be presented in a number of ways:

- Restricting attention to information that supports a favoured hypothesis [106]

- Preferential treatment of evidence supporting existing beliefs [107]
- Looking only or primarily for positive cases [108]
- Overweighting positive confirmatory instances [109]
- Seeing only what one is looking for [110]

Social Ambivalence

Another related concept is that of 'Ambivalence'. The range of positive and negative potential of the IoT already highlighted in this report, suggests that ambivalence could be an important concept in understanding this area. Hillcoat-Nallétamby and Philips [111] explore the social implications of ambivalence. They first note the lack of research in this area by contemporary sociologists, due to its association with psychoanalysis and a history of research ignoring the sociological aspects. They go on to describe social ambivalence as "a manifestation of contradictions which stem from social actors' transactional engagement with others". Conceived in this way social ambivalence is both transient and cannot be reduced meaningfully to the level of an individual experience. Issues such as privacy and potential confirmation of stereotypes paired up against the obvious potential for economic and health advantages mean that social ambivalence towards IoT applications is almost inevitable and is an area that requires further exploration [111].

Event Segmentation

Another interesting, although not as obviously related area of research is Event Segmentation. Recent years have seen a number of cognitive psychology studies explore how people segment on-going activity into distinct events [112-115, 116]. Work in this area has shown that event segmentation is both automatic and that event boundary judgements are reasonable consistent between different viewers of the events [116]. It has also been found that there is a direct collation between inconsistent event segmentation and poor memory of said event [113], and that both of these variables are related to age [112]. These findings suggest that in old age there is degradation in our ability to segment events and that this is a factor that impacts memory formation and recall. This series of work has important implications for intergenerational interpretation as it suggest that underlying cognitive differences may affect how older people segment and in turn interpreted activity data.

Application Areas

This section of the report explores four specific application areas within the IoT. Within each area the technological state of the art and challenges for future research are discussed. Three scenarios are also presented to communicate some of the potential interpretation issues that these technologies may give rise too.

Energy Control

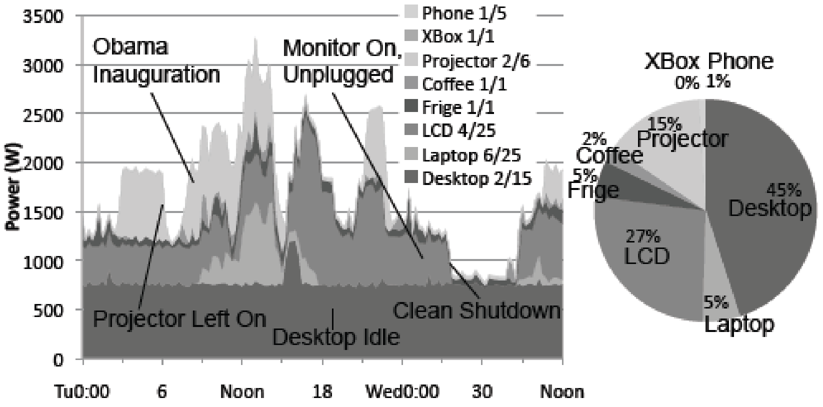


Figure 4: Energy Usage by Appliance Type Visualisation. From [117]

Although devices for energy monitoring in the home are already becoming mainstream, most households currently lack fine grained, real-time understanding of their energy use, and lack control over their appliances at a distance or via a centralised interface to complement this such as that shown in Figure 4. Infrastructure and cost-effective technologies for greater control are entering the market, and it can be expected that monitoring the use of specific appliances and being able to control those appliances from a distance will become common in the near future [117].

Jiang et al describe the development and testing of a wireless network for monitoring and control of appliances of the kind that may soon become commonplace. Wireless systems can integrate on top of the current electrical circuit in a building, providing simple switches and real-time data on each appliance. They expect the data to be applied to increase personal accountability for energy use, to audit buildings for inefficient appliances and activities, as part of a wider smart home approach that uses sensors to identify lack of occupancy and acts accordingly, or to act in response to price increases at peak times – limiting use of appliances deemed unnecessary if the cost is too high [117]. Chen and Helal suggest that in a vision of IoT where devices are aware of each other and their environment, alerts or constraints could be imposed on the operation of devices such that risks to safety or undesirable combinations are mitigated. For example operating a heater and air conditioner simultaneously, or using an electric radio in the vicinity of a bath full of water [118].

While devices can be added to plug sockets that support monitoring and control of appliances, home lighting is a more complex challenge. One potential way of adding individual lights to the IoT is through IP-based light bulbs. NXP plan to integrate low-cost wireless networking in to lights, thus mitigating the need to overhaul circuits in the home, and using materials costing less than $1 per unit [119].

People Power is a company developing an open source platform for connecting any appliance to the

Internet and interacting with it through a smartphone app or via the web. The platform includes a social networking feature to compare energy use with others. Although the current version only offers basic house-wide energy monitoring, the developers are working towards architecture to integrate control and monitoring for any individual appliance, with energy saving recommendations and rule-based control using a cloud-based analytics engine. The company aim to work with manufacturers to integrate control chips into new appliances, and also into multi-plug power strips [120, 121]. People Power suggest that real-time energy monitoring will produce a fundamentally different user experience to receiving a monthly bill, resulting in energy conservation becoming a "game you are paid to play" [30, 31].

Qbus is another company integrating energy monitoring hardware with novel control interfaces for smartphones and situated touchscreen computers. Their EQOmmand software uses a floor plan visualisation, representing the locations and status of controlled devices, and integrates cameras and other sensors for remote monitoring. The system also offers time-based visualisations and users can set up presets to turn lights and appliances to required states at specified times, and room-based alarms can be set up – e.g. flashing the lights in a room to alert occupants [122].

Figure 5: Qbus EQOmmand Home Control Software [122]

Data on power usage might be primarily collected for the purposes of energy monitoring and conservation, but it is clear that it offers a window into the current activities and longer-term habits of those in a monitored location. Although services such as People Power generally make it clear that usage data remains private to the user, even in this case data could support inferences about other household members' activities, such as whether individual rooms are occupied, how much television or computer use occurs, or the time someone goes to bed or gets up. Publically available home energy data streams on Pachube appear to support this already (see Figure 5) [122]. Without effective design and understanding of security from users, IoT data could be used for illicit purposes in a similar way to status updates in social media, from which burglars can identify empty properties [123]. Beyond this, energy data – passively collected without a persons' knowledge or consent – could support detailed surveillance both in the moment and over extended periods of time.

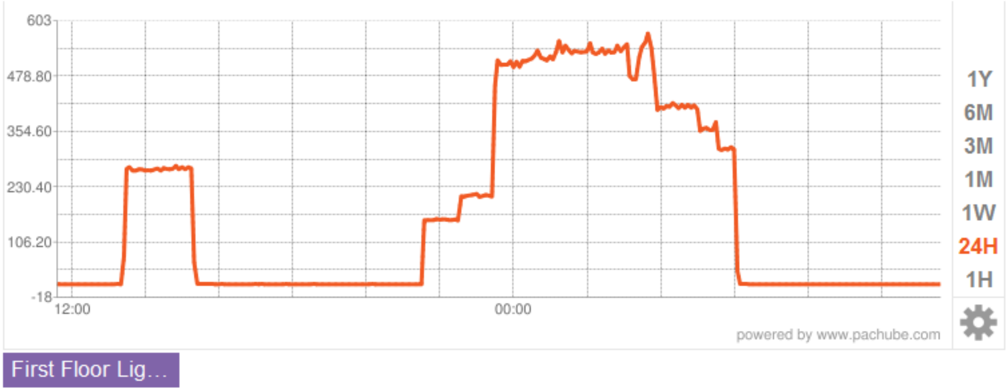
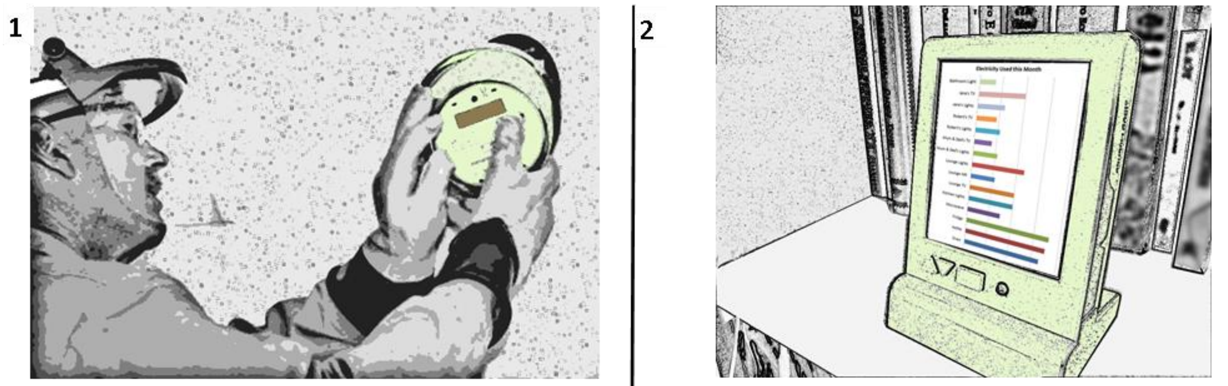


Figure 6: Example Pachube visualisation of home lighting data could suggest occupation and sleep times

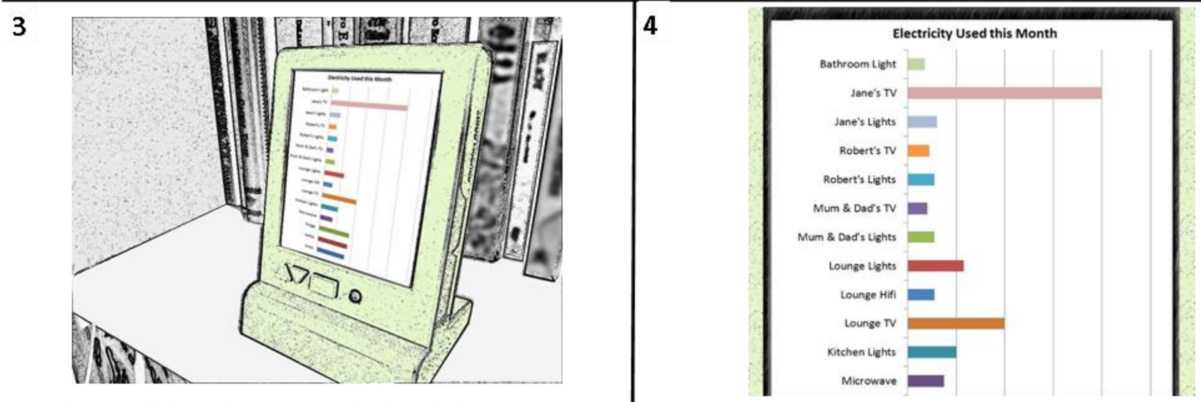
Scenario 1: Energy Micro-Management

The UK government is currently installing smart metres in every household in the country; this multi-billion pound project will enable households, government and energy providers' access to live and historical precise energy use data [124]. This scenario takes the concept of energy monitoring a step further, exploring how monitoring energy use on the level of individual appliances could influence family dynamics and the personal issues that could arise. Members of the household will be able to access energy use and thus infer frequency of use for both shared and non-shared appliances. In practice this data will invariably be used not only to monitor energy use by also movements and activities of household members.



1) The Jones family are having a new electricity metering system installed.

2) The system records electricity use data for each appliance in the home. Use in the past month is shown on a display.



3) A month later, they return to look at their energy use.

4) The meter shows that their daughter Jane's television set is responsible for a large proportion of the family's energy use.

Figure 7 Example Energy Micro-Management Storyboard

Figure 7 shows a storyboard developed to communicate this scenario. A newly installed energy monitor records and displays energy use on an appliance-by-appliance basis. In this example the daughters TV is show to have used a large amount of energy. While this data only means exactly that more energy has been used by this appliance, it could be (mis)interpreted in a number of ways:

- A fault in the monitor or TV
- Excessive use of the TV
- Poor energy efficiency of the TV
- Failure to turn off the TV due to negligence or ignorance
- Multiple householders using the daughters TV

The research reviewed earlier in this report would suggests that factors such as age, relative position in the family hierarchy and confirmation bias could all influence how this data is responded to my members of the household. However, the implications of the scenario go beyond the reaction to specific data. This type of object specific data will also impact how individuals interact with the objects that are attached to this system, as they are aware that use is always being recorded.

Research into consumers' behaviour in terms of analyse energy use suggest that they already access a wide variety of information sources including bills, comparisons with neighbours, weather considerations and the utility meter itself [125]. While it is encouraging to see the level of interest consumers are already paying to energy usage, the research also suggests that a lack of knowledge and/or analytical abilities means that customers often make poor decisions based on the data they collect. While the IoT will definitely offer more and more information sources it will not necessarily help customers interpret, analyse or act upon the data appropriately. This scenario will be used to explore a range of issues that could result from unrelenting collection of energy use data of the finest detail.

Groceries and Shopping

Grocery supply chains are a domain at the forefront of IoT solutions from the farm or factory, through to purchase, storage and use, and on to recycling and waste disposal. For example, Wal-Mart has worked since 2005 to encourage all of its major suppliers to RFID tag shipments, and has also trialled tagging of individual products in stores. Whilst this has met some resistance from suppliers (it is not clear that there are efficiency savings for them) and consumer groups (privacy concerns), the program continues to evolve [126, 127]. Metro AG – the world fourth largest retail group – launched a 'Future Store Initiative' in 2003, which also included a roll out of RFID on pallets and trials with using the same technology on the sales floor [128]. SAP have also developed a 'Future Retail Center', showcasing solutions that combine improved navigation and information for consumers with accurate traceability and visibility of stock.

It is clear that Wal-Mart, Metro AG and SAP see efficiency savings as the key business driver for these IoT technologies, but also that customer experiences can be improved and product quality ensured. The concept of Object Memory is particularly relevant where items are fragile or perishable, as it can support the collection and use of data to show whether the item has been kept within acceptable temperature limits, or is still fresh. FedEx already offer a 'SenseAware' service – which provides real time access to data including temperature, exposure to light and tampering for packages. This information could be integrated at the point of sale, providing assurance to customers or offering discounts if product quality has been partially compromised.

Despite the extensive interest shown in IoT solutions, and money spent on trials and implementations, Luckett finds barriers that make individual-level tagging for many items far from a foregone conclusion, predicting in 2006 that tagging in the following 5-10 years was unlikely due to perceivable benefits being less than the cost of tagging and infrastructure, except for high value items. In addition, there has been evidence of a negative reaction to these technologies. This has taken the form of activism in response to trials of RFID tagging – including the group CASPIAN (Consumers against Supermarket Privacy Invasion and Numbering), who set up a boycott of Gillette when they trialled RFID in razor packaging [129]. In 2003, Duce [130] ran focus group sessions with consumers, and interviews with 'opinion formers' such as academics, journalists and advocacy groups. She found widespread evidence of negative attitudes to aspects of RFID tagging in the supply chain across the UK, Germany, France, Japan and the USA. In particular, consumers were concerned about embedding tags in clothing, the monitoring of purchase patterns, increased susceptibility to theft through awareness of the items on a person, and health issues (e.g. chips as a potential cause of tumours) [130]. Whilst these concerns are likely to remain an issue for the acceptance of many forms of IoT, it is also interesting to note that supermarket loyalty cards have become an accepted part of shopping, even though – as CASPIAN founder Katherine Albrecht argues

- they allow companies to monitor grocery purchasing patterns and use this data in potentially invasive ways – for example personalising prices, or sharing data with healthcare organisations or law enforcement. However, even in 2002, 60% of US grocers required some form of loyalty card for shoppers to get discounts. Given the right incentives, people often appear to overlook their concerns with these kinds of technologies [131].

Kroner et al suggest three classes of interaction that need to be supported in the use of memory-equipped objects. These are ***Choosing*** an object based on its memory (e.g. compare the carbon footprint of similar products, or look at reviews and statistics for the product). ***Using*** an object (e.g. pay per use models can be supported, suggest mistakes in cooking or improvements based on previous data and feedback such as cooking time in this oven, how much of a certain ingredient was added and resulting satisfaction). Finally, ***Observing*** interactions use the object as a container or access mechanism for information about the surrounding environment (e.g. understanding where the product came from, or the wider context in which it is being sold) [132].

IoT technologies could radically change the in-store shopping and checkout experience, with IBM envisaging customers and their purchases simply being RFID scanned on exit and charged appropriately. They have also demonstrated ‘Breadcrumbs’, an initial version of a smartphone application that allows users to gather information about products from the web based on their barcodes. If products can be uniquely identified in the future, it is assumed that information such as product age, shelf life, other purchasers in the location, and the ability to check for counterfeiting would be available whilst shopping through this class of application. Other smartphone shopping apps such as GroceryIQ combine list making functionality with barcode scanning, generate lists based on supermarket aisles, and provide coupons on related goods as an incentive to users. The EU funded Experiential Living Lab for the Internet of Things (ELLIOT) project sees a ‘personal information terminal’ being key to intelligent shopping and payment. Again this is envisaged as a tablet-type device that recognises products and locations in the store, providing product information, recommendations and guiding customers to products of interest. A current technology providing supermarket shoppers with self-scanning, product information and quick checkout is the Motorola MC17 consumer shopping terminal, found in UK and US supermarkets (see Figure 8).

Figure 8: Motorola MC17 Consumer Shopping Terminal. Photo: Ben+Sam (CC)

If groceries become commonly tagged prior to sale, and privacy concerns can be allayed, it seems only a small step to continue to track items through this mechanism as they enter the home, kitchen, fridge, or waste bin, and then begin to make use of this data. A range of research prototype kitchens have been developed under the assumption that food and other items will be tagged and can therefore be sensed as they are used in the home. Within these environments novel applications such as the Semantic Cookbook are possible – supporting the capture and playback of recipes based on interpretation of data from cameras, appliances and implements. The Ambient Kitchen installed at Newcastle University embeds RFID tag readers in kitchen work surfaces and uses floor pressure sensors, accelerometers in utensils and cupboard doors and cameras. It provides information via situated displays and is designed for use without a keyboard or mouse. The same is true of the kitchen in Microsoft's Future Home, which uses voice recognition for commands, and to recognise groceries placed on the surfaces. The system also projects information directly on to kitchen surfaces, supporting novel, natural interactions like showing how large to cut a piece of dough directly on the surface (see Figure 10).

Figure 10: Kitchen Display in Microsoft Future Home

Commercially, the concept of 'Internet-enabled' refrigerators has been taken up by several manufacturers included LG and Samsung. However to date this has mainly focused on integrating existing computational systems into a new information appliance – taking the fridge to be a point in the home where access to social media, information such as recipes and virtual 'post it' notes can be accessed through a touchscreen. An interface for manual food management has been included (see Figure 11), and it is expected that this will lead in to an automated system when the underlying infrastructure makes this feasible.

Figure 11: LG Thinq Food Management System

It is also possible to monitor and support interactions with groceries by embedding technology more deeply into containers. For example GlowCaps are enhanced lids for prescription medicines that recognise when a bottle has been opened, and can communicate this information to the wider world. The caps themselves can glow as a reminder to take the medicine, and additional dedicated wireless lights can provide salient reminders from a distance – whilst also linking GlowCaps to the Cloud. This allows emails and reports to be produced for doctors, pharmacies and patients, so that a new prescription can be delivered as required, and patient memory is augmented. Similar technologies could be applied in different containers to support memory of how and when groceries are used, providing this data to the household.

The monitoring of food in the home, combined with the growth in online grocery shopping, offers opportunities to design for more intelligent management of household grocery shopping and reflection on the eating habits of self and others. The visualisation of food consumption has been explored by designer Lauren Manning, using a personal data set created over two years (see Figure 12).

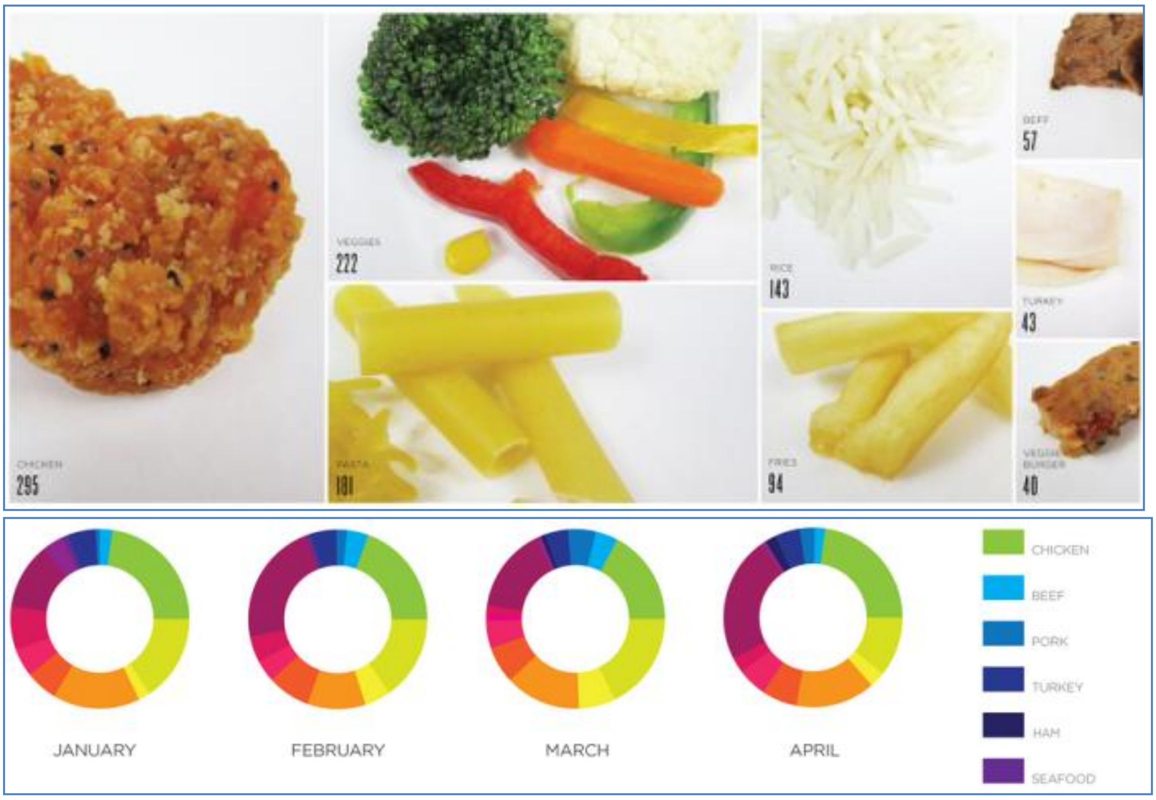


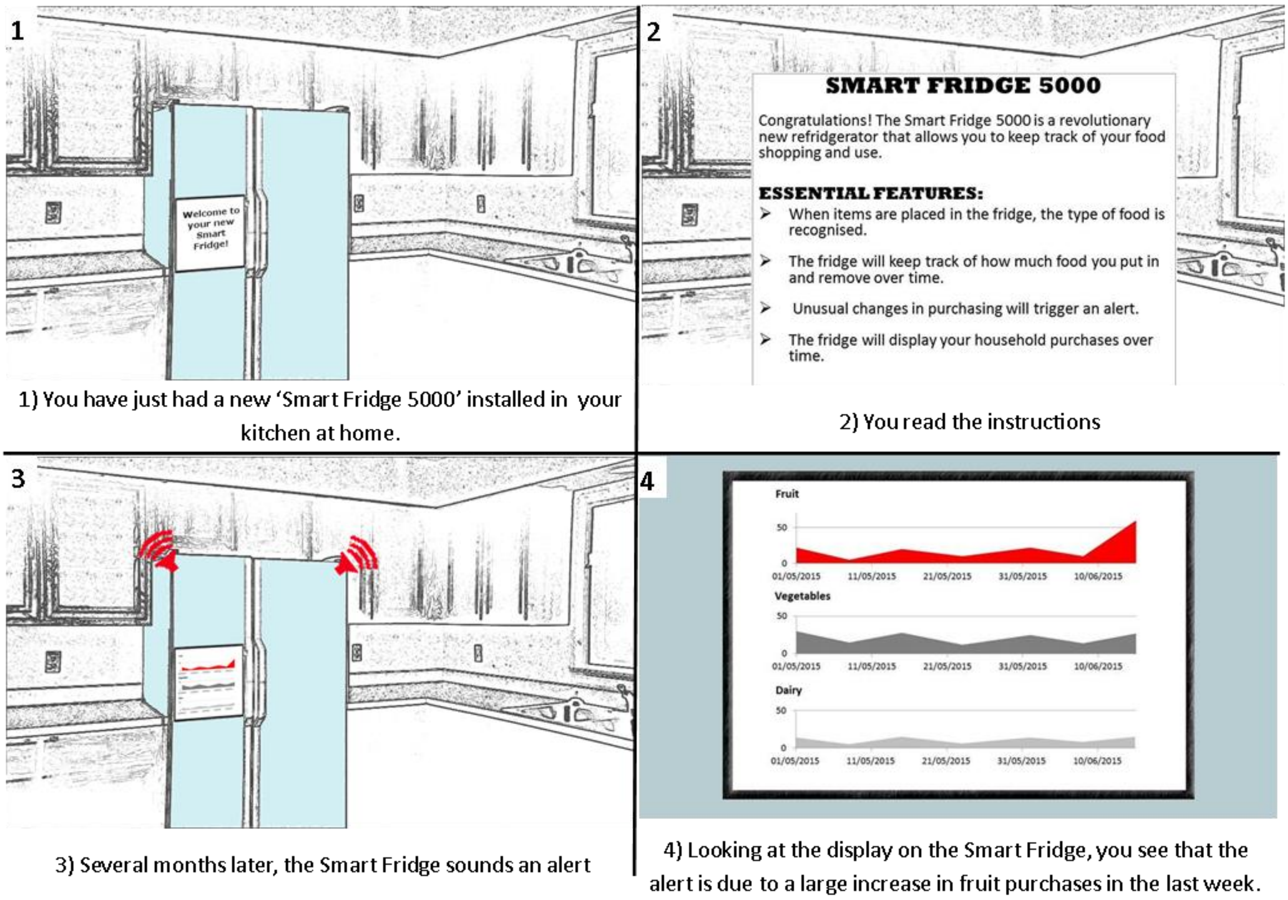
Figure 12: Visualisations of Personal Food Consumption. Lauren Manning (CC)

Taking a wider global perspective on the interpretation and use of this data, economic, environmental and social benefits can be envisioned. For example GlowCaps markets its approach as behavioural economics – translating the savings made by someone taking their medicine to schedule, into economic incentives. A project to track which homes are recycling waste attached RFID tags to new recycling bins, and expected to increase the productivity of the recycling program through this measure. Given that RFID tags are increasingly likely to be included in individual products, even richer data on the materials being recycled could soon be gathered. The BinCam system again seeks to change behaviour through collection of photographic data on each item deposited, and currently uses human recognition of the objects to guide reflection on waste. IoT technologies could support social awareness of the objects owned by neighbours and friends, facilitating the potential for efficient use and sharing of resources. Internet infrastructures for sharing large items like cars are already emerging (e.g. Buzzcar), and other systems such as Freecycle have matured to support the reuse of unwanted goods. Building on this, Jansen describes the idea of an IoT platform to encourage neighbours to trust each other and share groceries and other belongings [133].

Scenario 2: Food Control

The ability to monitor foodstuffs in the house brings with it a myriad of potential applications. Food wastage, unhealthy eating habits and expensive behaviours can all be identified and linked to the individuals responsible. This scenario focuses on the impact of the detailed information that these systems could produce on household relationships.

'Smart Fridge 5000' is theoretical warning system connected to a variety of tags and sensors that ally it to monitor food purchase, consumption and storage in the home. Users can set up any number of alerts that sound to identify unwanted food behaviour. For example it can warn you if you're not eating enough protein, if the family shopping bill is rising drastically or if food is going to spoil soon.



SMART FRIDGE 5000

Congratulations! The Smart Fridge 5000 is a revolutionary new refridgerator that allows you to keep track of your food shopping and use.

ESSENTIAL FEATURES:

- When items are placed in the fridge, the type of food is recognised.
- The fridge will keep track of how much food you put in and remove over time.
- Unusual changes in purchasing will trigger an alert.
- The fridge will display your household purchases over time.

1) You have just had a new 'Smart Fridge 5000' installed in your kitchen at home.

2) You read the instructions

3) Several months later, the Smart Fridge sounds an alert

4) Looking at the display on the Smart Fridge, you see that the alert is due to a large increase in fruit purchases in the last week.

Figure 13 Example Food Control Storyboard

Figure 13 shows a specific example were 'Smart Fridge 5000' has detected an increase in the household purchases of fruit. This information could be interpreted in a number of ways, each potentially causing very different behaviour in the household.

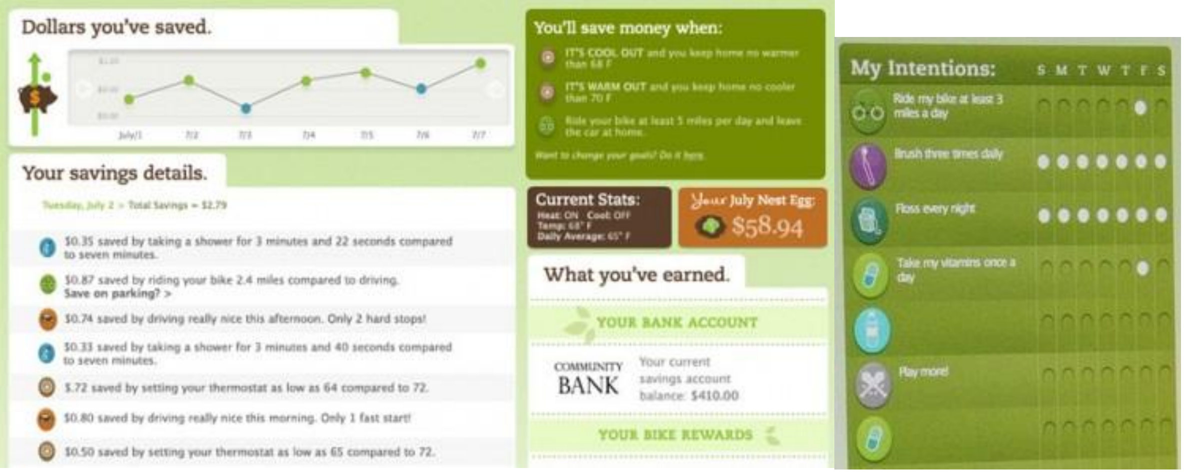
- The household as a whole has been buying too much fruit.
- A specific individual has been buying too much fruit.
- The household as a whole has been eating more healthily.
- A specific individual has been eating more healthily.

- The household as a whole has been eating too much recently.

Physical Gaming

Games that involved greater physical interaction than pressing buttons and moving a joystick originated in arcades, as gaming moved in to the home and on to mobile devices. Physical games eventually followed suit through hardware such as EyeToy, Wii and Kinect. Taking games outside of traditional settings has produced a design space in which IoT technologies could be key. Whereas current physical games generally revolve around tracking human movement directly, technologies could soon be used to gamify many aspects of our lives by tracking our interactions with a range of objects.

The Greengoose system – launching in January 2012 – exemplifies this approach. The manufacturers claim to have specialised sensors for over 100 different activities in development, from measuring how long a Frisbee can be kept in the air, to brushing teeth and checking that the toilet seat has been closed. The sensors are packaged as small stickers to attach to everyday objects, and communicate with a base station plugged in to a home router with a 250ft+ range [99]. The company states that the system will let us “have more fun doing everyday things” and allow us to “feel closer to those important to you” by seeing others’ activities.



$0.35 saved by taking a shower for 3 minutes and 22 seconds compared to seven minutes.

$0.87 saved by riding your bike 2.4 miles compared to driving. Save on parking? >

$0.74 saved by driving really nice this afternoon. Only 2 hard stops!

$0.33 saved by taking a shower for 3 minutes and 40 seconds compared to seven minutes.

$.72 saved by setting your thermostat as low as 64 compared to 72.

$0.80 saved by driving really nice this morning. Only 1 fast start!

$0.50 saved by setting your thermostat as low as 65 compared to 72.

Figure 14: GreenGoose Beta Interface: Money Saving and Goal Setting

As Figure 14 shows, saving money and improving wellbeing are seen as incentives in Greengoose. It is also expected that insurance and healthcare companies could be interested in using the data generated by these systems [134]. It is clear that the IoT could lead to much more extensive monitoring of our health, using sensors in a range of objects that come in to close contact with us such as clothes, combs, razors, chairs and earphones to continuously assess our health and wellbeing [135]. A plethora of sites including me-trics.com and beeminder.com have been set up to support personal goal setting and tracking, incited in part by the adoption of Internet-enabled smartphones that allow people to continually input data regardless of their location [136].

A mobile IoT vision of physical gaming sees buildings as features in games, using GPS to track players. In Foursquare users gain badges and can become Mayor of a property by checking in when they reach the physical location. Now boasting over a million players, MyTown extends this gaming aspect towards a physical version of Monopoly, where players can ‘buy’ locations and collect rent on them. Commercial opportunities to make use of these games as forms of marketing appear to be particularly effective: Volvo and HandM have both perceived MyTown to be a successful part of marketing campaigns, providing incentives for users to check in at their stores. In the future, mobile devices could feature a range of rich object recognition technologies, from NFC to 3D cameras that support Kinect-style recognition of movements in the surrounding environment [137].

Gamification of the world and of peoples’ lives is currently seen as a major area for innovation. Since there are certain identifiable models through which games can influence behaviour, tapping in to desires such as progression and status, it has been argued that a generic ‘game layer’ can be placed on top of the world. This has been seen as analogous to the way that Facebook provides a generic ‘social layer’ to life regardless of who you are and who you interact with [138]. SCVNGR describe their gamification platform as simply: *“Go places. Do challenges. Earn points and unlock rewards! (Think free coffee!)”* [139]. IoT technologies support new ways of passively monitoring progress towards completing challenges. Gamification combined with the IoT offers the possibility to guide or encourage behavioural change through novel reward structures and opportunities for accurate in depth monitoring. Since the success of Farmville and similar games, social networking is now understood as an important because playing and competing with *real world* friends brings a greater sense of reality and therefore emotional engagement. Virtual currencies and goods from games are now traded with a real world value measured in billions of US dollars. Closer integration between games and the real world is therefore expected to be an on-going trend with IoT technologies at the heart of the next evolution [140].

Sharing Experiences

Using IoT technologies to share in the experiences of others is a perhaps a wider design space than the previous scenarios. Various types and combinations of things, data, visualisations and devices could be used to facilitate this, with the potential for varied practical, social and emotional benefits. It is clear that the IoT as envisaged will produce large amounts of heterogeneous data that could be linked to an individual and to the relationships between individuals. These data could be used to provide additional links in close relationships, or identify those with a related experience – watching the same film or visiting the same places – and bring them together as participants in novel sharing activities.

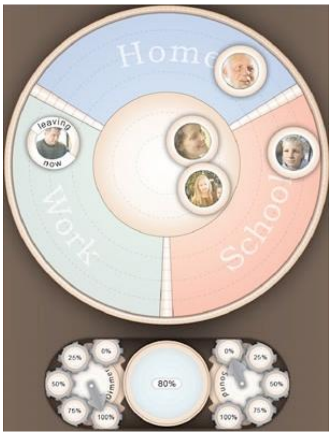


Figure 15: Whereabouts Clock

Given the IoT focus on physical objects, the sharing practices generated by innovations are likely to involve data about objects that previously had no computation or network connection, or data collected through these objects (e.g. their environment or use). Finally, objects themselves could be replicated and shared through 3D printing, or novel internet-enabled objects can be designed specifically as conduits for sharing. Sharing could be initiated by individuals, similar to making a phone call or posting on a social networking site, individuals could allow others to monitor data passively collected about them, or a system could trigger a sharing event based on certain criteria.

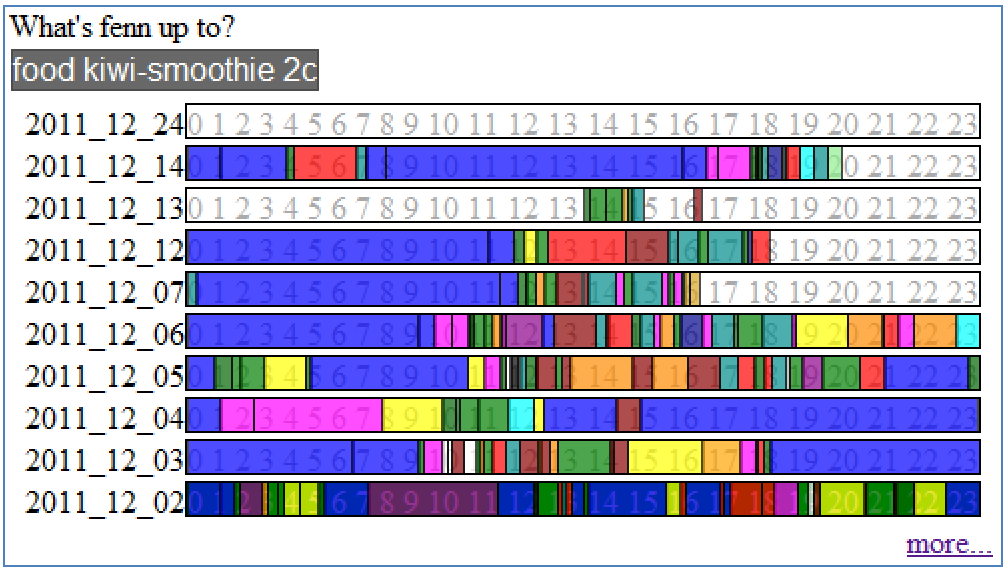
Exploring the sharing of location information, Brown et al describe the development and evaluation of the Whereabouts Clock – an example of a novel Internet-enabled object for sharing current experiences. In this case, a coarse-grained location – “WORK”, “HOME” or “SCHOOL” – is displayed in the home, based on GPS data. The findings suggest that whilst this information was useful, but should be augmented by more detailed information beyond geography. The authors also suggest that new devices for smart homes should allow families to continue “doing the work of ‘being a family’”, but make them smarter in doing this, rather than automating or taking tasks out of their hands [15].

Using a far wider data set of user locations, CitySense is a new mobile application that aims to guide people to nightlife by identifying ‘tribes’ with similar interests and the locations that they are currently clustering around in real time. The system aims to learn to identify these groups and answer the question "where is everybody like me right now?", even if the user visits a different city [141].

New forms of information appliance like the Whereabouts Clock are emerging as part of the IoT vision. These smart objects aim to better integrate technologies like RFID and sensors into our lives for awareness and sharing purposes. For example Karotz is an ‘Intelligent Internet Companion’ that includes image, voice and RFID recognition, packaged to look like a cute toy / ornament. As well as reading out email or Twitter feeds, Karotz allows a family member to swipe a personal tag, at which point a photo will be taken and an email or text will be delivered to alert others that the person has arrived. The webcam can also be monitored from a distance at other times, and users can change the colour of a light on the device or have it read a message to communicate with those in the room [14].

Figure 16: Karotz Internet Companion with tags

Richer data sets about individuals are being collected and shared through ‘Life Logging’ and ‘Quantified Self’ activities. These may give a sense of data that can be collected automatically from a range of IoT technologies in the future, and could be used as the basis for sharing of experience. For example Ben Lipkowitz has published and discussed over 5 years of data mapping in great detail everything he does each day (see Figure 17) [142].



What's fenn up to?

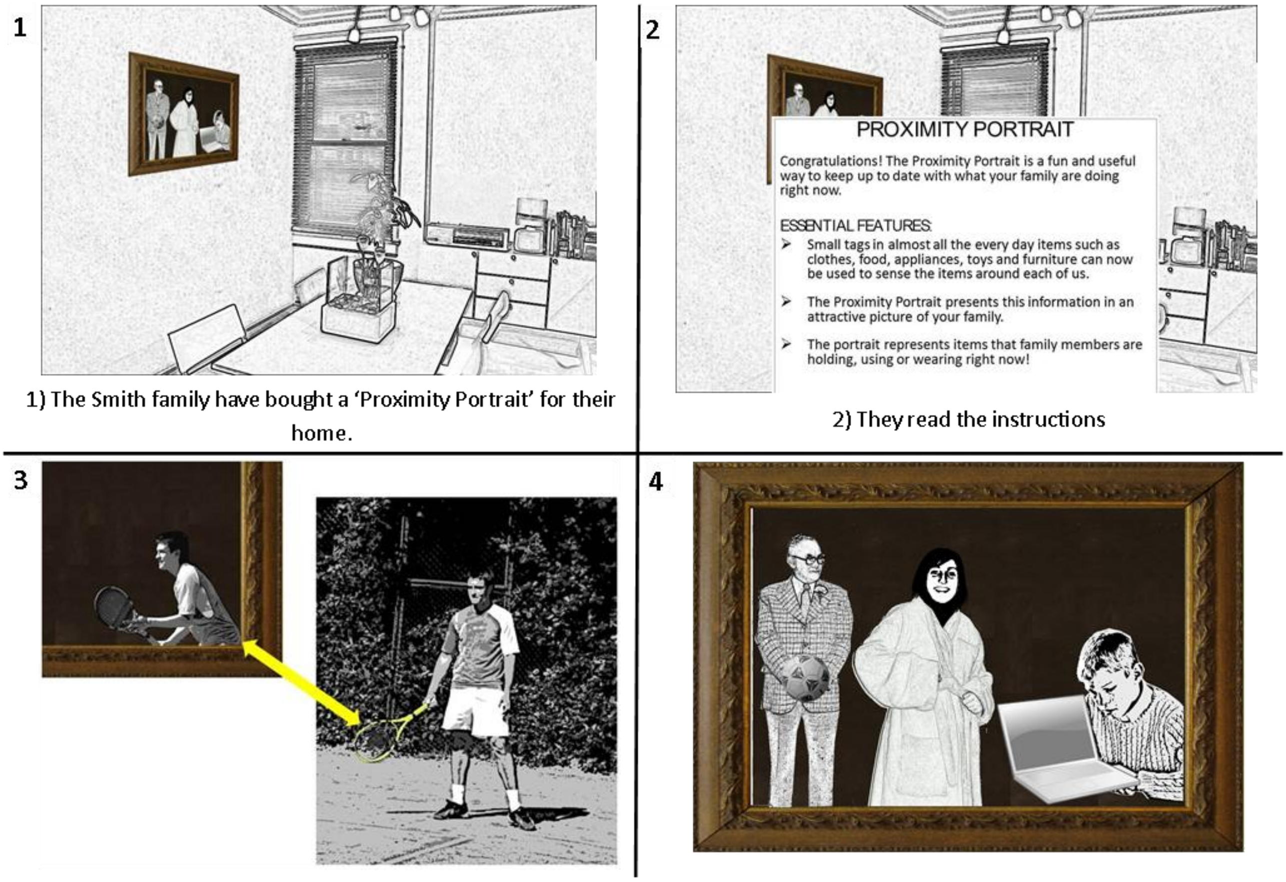
food kiwi-smoothie 2c

Figure 17: Life log visualisation by Ben Lipkowitz. Categories include Sleep = Dark Blue, Reading = Purple, Internet Use = Red, Eating = Green. From [142].

Objects themselves can often form important mementos or records of experiences, and the integration of such objects in to an IoT could lead to highly novel interactions. The 'Tales of Things' project provides a platform to add information to any object tagged by a QR code. For example, members of the public and celebrities were invited to include a short video clip with items they donated to a charity shop [143]. A similar approach could be considered for family heirlooms, with other data such as location and proximity to family members collected and combined in to an Object Memory. Taking an alternative approach, the Storybeads project developed a tangible interface for oral storytelling traditions in South Africa. A bead with embedded RFID chip is placed on top of a recording box – the 'Storyteller', which begins an audio recording process for the person to capture a story. The bead can then be given to others and the recording replayed when it is placed back on the Storyteller [144]. Essentially both these projects both aim to attach virtual information to physical objects that are already meaningful. In contrast, the MemoryStone project created a new smart object allowing individuals to collect and take responsibility for a mixture of personal and clinical information during pregnancy. Recorded information can then be viewed through a television or computer [145].

Scenario 3: Proximity Portrait

The scenario is conceived as a display in the home that visualises objects in close proximity to each member of a household or family at any given time. For instance it could depict the clothes they were wearing, and show if they were driving a car, reading a book or playing a computer game. As with standard portraits, the Proximity Portrait supports a view into the past with particular relevance for family or household members. Visualisations can be shown to change over an extended time period, enabling members of the household to explore questions like – how did the clothes we wear evolve? What we were doing on the same day last year? What were the most common objects around us each month?



1) The Smith family have bought a 'Proximity Portrait' for their home.

PROXIMITY PORTRAIT

Congratulations! The Proximity Portrait is a fun and useful way to keep up to date with what your family are doing right now.

ESSENTIAL FEATURES:

- Small tags in almost all the every day items such as clothes, food, appliances, toys and furniture can now be used to sense the items around each of us.
- The Proximity Portrait presents this information in an attractive picture of your family.
- The portrait represents items that family members are holding, using or wearing right now!

2) They read the instructions

Figure 18 Example Proximity Portrait Storyboard

Figure 18 shows how the 'Proximity Portrait' to glimpse into the lives of their fellow household members. Naturally this type of technology has implications beyond simply sharing experiences, it could be used to track family members activities, reminisce about events in the past or simply used as a method of communication. Thus, this application can influence and be influenced by bias, social hierarchy, family dynamics, privacy and security.

Conclusions

From a technical standpoint, it is clear that the IoT is no longer a vision of the future, but a technology that is beginning to infiltrate our lives. Computer games and stock management are perhaps the two areas where this is most obvious. However, despite the growing commercialisation of IoT technologies it is clear that its massive potential to improve people's lives is far from realised. While the precursor technologies already exist, the low cost consumables and infrastructure investment necessary to implement a fully integrated and internationally networked IoT has not yet been realised [28, 127].

However, it is important that we understand more than the technical implications of the IoT. The explosion of personal data collected and brings with it a range of personal, social and political issues that cannot be ignored.

This review explored how different generations will interpret the data produced by the IoT. The literature shows that this area is an area that is far from clear. Psychological issues such as privacy, stereotypes, intergenerational communication and even event segmentation may play a role, but it is also important to consider complex multi-disciplinary factors like technology acceptance, social ambivalence and personal data privacy.

While it may be possible to draw some inferences from research in these fields, the complexity of the interaction between social, psychological and technological factors mean that focused research is needed to understand how individuals will understand and reach to the data produced by internet of things applications.

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