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Internet of Things Request for Comment 2016 - Submission by Kayleen Manwaring, University of New South Wales Australia

There have been significant problems and inconsistencies with the definition of the Internet of Things and closely-related technologies over the last 20 years.

As a response to Questions 2 and 4 of the Notice for Request for Comment, I attach an article published by myself and my colleague Professor Roger Clarke in the international journal *Computer Law & Security Review* in October 2015 which sets out:

- Problems with, and limitations of, those definitions; and
- A framework to define and classify IoT and related technologies in order to assist with legal, business and policy development concerning these technologies.

Kind regards

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Computer Law & Security Review

Surfing the third wave of computing: A framework for research into eObjects

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ABSTRACT

During the last two decades, a "third wave of computing" has emerged: a move from a model of accessing the Internet and other internetworks almost exclusively via a desktop computer to alternative forms of distributed information technologies, such as smartphones, wearable computers, and sensors and microprocessors embedded in everyday objects. This paper undertakes a critical review of the literature that offers and discusses definitions of this "third wave". Not surprisingly in an area of innovation, definitions are evolving, overlapping and inconsistent. This paper analyses and consolidates the literature in order to identify the key aspects of this new phenomenon. We have coined the term "eObjects"[1] for the central element of the "third wave". The paper presents a framework for research into the technologies and their implications, distinguishing core from common attributes, and identifying categories of inter-device interaction. A subsequent paper will apply the research framework to legal research, with the intention of understanding areas in which litigation can be anticipated, and uncovering areas where the law may not adequately deal with emergent social and business practices.

1. Introduction

"In order to craft appropriate laws, both the technology and its uses must be well understood."[2]

For the last two decades, scholars, journalist and IT consultants have been presaging what has been labelled the "third wave of computing",[3] "a new age of embedded, intuitive computing in which our homes, cars, stores, farms, and factories have the ability to think, sense, understand, and respond to our needs".[4] The first wave comprised the introduction of mainframe computing, with a "many persons to one machine" model. The second wave of personal computing saw the development of one-to-one relationships between people and their computers. The third wave envisages a move from a model of

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[1] This term was suggested by Roger Clarke, as a shorthand descriptor of a model articulated by Kayleen Manwaring.

[2] Chris Reed, 'Taking Sides on Technology Neutrality' [2007] 4 SCRIPTed 263.

[3] Mark Weiser, 'Ubiquitous Computing' (1996) <http://www.ubiq.com/hypertext/weiser/UbiHome.html>.

[4] This reference to the "third wave" is distinct from (although the choice of terminology may well have been inspired by) the futurist Alvin Toffler's description of first, second and third wave societies in Alvin Toffler, *The Third Wave* (1st ed., Morrow 1980).

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people accessing internetworked computing services almost exclusively via a personal desktop computer to a "many people to many machines" model.[5] Advocates of the third wave predict the large scale development and use of alternative forms of distributed information technologies, of which early examples include smartphones, wearable computers and sensors and microprocessors embedded in everyday objects.[6]

One indication of the transition is mobile commerce, which is now part of the mainstream of e-commerce technologies, with applications for mobile entertainment, retail shopping, banking, stock trading and gambling all well-established, and on the rise.[7] The widespread use of computing devices embedded into buildings and everyday objects, formerly only a vision of a few computer scientists, is now emerging in the real world, with current commercial applications for home automation, energy management, healthcare and environmental monitoring, just to name a few.

These changes have led to different ways of doing business, different consumer experiences and different ways humans interact with computer systems. It has also led to a plethora of technical literature on aspects of the new model. Scholarship discussing possible effects is emerging in a number of areas. For example, examination of the effects on the legal landscape begins with Kang and Cuff[8] in 2005. However, the literature on impacts up to this point has usually failed to engage with the nature and features of the technology in a comprehensive way.[9] Much of this has been deliberate. In the field of law, for example, scholars have been approaching this question cautiously, feeling their way amongst discussions of technologies which are new, experimental and often merely visions of what "might be" rather than actual applications in commercial use.

However, to develop more meaningful scholarship in this particular area of technology regulation, there needs to be a good understanding of the character of the technology at issue.[10] Currently, even the cautious approach taken by legal scholars assumes two things: a consistency in the technological literature on definitions and terminology and a sufficient level of knowledge and understanding on the part of readers. The first assumption is unwarranted, and the second contentious. This paper presents a framework designed to aid in the identification and analysis of issues that might arise, such that research in the area can proceed with a better understanding of the technological issues.

A subsequent paper will apply this framework to the legal impacts, in order to analyse key technical and function innovations contained in the new model, and to thereby uncover areas where legal uncertainties may arise in relation to technological change brought about by developments in these areas.

It is essential to clarify what technology is being discussed. Koops, in his analysis of mapping research spaces within the discipline of technology regulation, argues that "[t]he questions raised by a certain development in technology depend very much on the character and level of abstraction of the technology at issue" (the "**technology type**").[11] Koops explains that questions of regulation will differ depending on whether a researcher is examining a concrete application of a certain technology, such as a fitness device, or more abstract notions such as information technology, or even technology, itself. A description of the characteristics of the "third wave" model is presented in Part 3 of this paper. However, it is also important to note at the outset that this description is the result of a deliberate choice to examine issues arising within a particular context. Various units of study exist, some of which are at differing levels of abstraction from one another, and others of which focus on particular features of the new model. For example, domotics (also known as home automation or "smart homes") has been a popular and rapidly developing unit of study for computer scientists, designers and health professionals.[12] Domotics envisages the use of computers remotely controlling appliances and systems in the home such as security systems, climate control systems, audio-visual devices, lights, window coverings, and garden devices. In addition, significant research has been done on technical, social

[5] Mark Weiser and John Seely Brown, 'The Coming Age of Calm Technology' (1996) <http://www.ubiq.com/hypertext/weiser/acmfuture2endnote.htm> accessed 26 February 2015.

[6] Weiser (n 3); Kalle Lyytinen and others, 'Surfing the Next Wave: Design and Implementation Challenges of Ubiquitous Computing' (2002) 30 Communications of the Association for Information Systems 695.

[7] Efraim Turban and others, *Electronic commerce 2012: a managerial and social networks perspective (Global Edition)* (Upper Saddle River: Pearson Education 2012), 277.

[8] Jerry Kang and Dana Cuff, 'Pervasive Computing: Embedding the Public Sphere' (2005) 62 Washington and Lee Law Review 93. Other key legal works include Kevin Werbach, 'Sensors and Sensibilities' (2007) 28 Cardozo L. Rev 2321; Rolf H. Weber and Romana Weber, *Internet of Things: Legal Perspectives* (Springer 2010); Mireille Hildebrandt and Bert-Jaap Koops, 'The Challenges of Ambient Law and Legal Protection in the Profiling Era' (2010) 73 Modern Law Review 428; Scott R. Peppet, 'Freedom of Contract in an Augmented Reality: The Case of Consumer Contracts' (2012) 59 UCLA Law Review 676; Joshua Fairfield, 'Mixed Reality: How the Laws of Virtual Worlds Govern Everyday Life' (2012) 27 Berkeley Technology Law Journal 55; Adam D. Thierer, 'The Internet of Things & Wearable Technology: Addressing Privacy & Security Concerns Without Derailing Innovation' (2015) 21 Richmond Journal of Law & Technology.

[9] With the notable exception of Anne Uteck, 'Reconceptualizing Spatial Privacy for the Internet of Everything' (PhD Thesis, University of Ottawa, 2013). However, Uteck's framework understandably focusses mainly on features of ubiquitous computing salient to her research on privacy, and therefore has some limitations for researchers looking at other issues.

[10] Mireille Hildebrandt, 'Chapter 9: Law at a Crossroads: Losing the Thread or Regaining Control? The collapse of distance in real-time computing' in Morag Goodwin, Bert-Jaap Koops and Ronald Leenes (eds), *Dimensions of Technology Regulation* (Wolf Legal Publishing 2010); Bert-Jaap Koops, 'Ten dimensions of technology regulation. Finding your bearings in the research space of an emerging discipline' in Morag Goodwin, Bert-Jaap Koops and Ronald Leenes (eds), *Dimensions of Technology Regulation* (Wolf Legal Publishing 2010).

[11] Koops (n 10), 212.

[12] M. Meulendijk and others, 'Am I in good care? Developing design principles for ambient intelligent domotics for elderly' (2011) 36 Inform Health Soc Care 75; M. M. Kohn and others, 'SMART CAMP: Environmental Sustainability Through Intelligent Automation Technologies' (24th IEEE International Conference on Advanced Information Networking and Applications, Perth, Australia, 20–23 April 2010); Rishabh Das and others, 'Security based Domotics' (2013) 10 Procedia Technology 942.

and legal implications relating to appliances,[13] wearables,[14] human ICT implants,[15] cyborgs,[16] augmented reality applications,[17] and artificial intelligence.[18] Researchers examining the new model described in this paper may find it helpful to draw on the literature of these subsets and intersecting spaces, with an awareness that the differences in attributes will most likely affect the nature of the legal problems that might arise.

Multiple variants of the new model that is the subject of this paper have been described by academic and industry commentators, but not with consistency. The variants have been described in different terms, and with somewhat different characteristics. However, despite these varying descriptions, "the important thing to note is that there is a trend towards taking technologies out of the office and away from being mere desktop computers in order to enhance previously non-computerised everyday situations".[19]

In more specific terms, the new model contemplates the widespread use of computer processors with data communications and data handling capabilities, embedded in a variety of objects from phones, to cars, to animals, to people. One important feature of the new model is that many of these objects were not previously capable of such communications and processes (**"enhanced objects"**). These enhanced objects may exist, operate and communicate in a fixed location, or with varying degrees of mobility. Importantly, mobile enhanced objects may be designed to be associated with human beings. They may be associated with an individual very closely (e.g. subcutaneous chips, or chips in prostheses), loosely or episodically (e.g. phones, wearables such as spectacles or items of clothing), or very loosely (e.g. cars[20]).

The new capabilities of these objects may be used for a wide variety of data collection, processing and dissemination purposes, through interactions with processors entrenched in conventional computing devices or in other enhanced objects. Discussions of the new model often concentrate on the potential benefits to individuals and organisations, but also on possible detrimental effects, such as a loss of control over personal data or decision-making. It should also be noted that much of the technical literature concentrates on technological possibilities, or as yet uncommercialised technology currently only found in research laboratories. Whereas Part 1 introduced the overall themes of this paper, and the reasons for its existence, Part 2 of this paper proceeds with an outline of the literature on historical and current definitions of particular areas of the new model. Beginning with the development of ideas of "ubiquitous computing" in the early 1990s, Part 2 continues with a discussion of "pervasive computing", "mobile computing", "ambient intelligence", and the "Internet of Things", in order to provide a clear statement of the terminology and concepts behind the new model. This part also extracts from the literature some different ideas of the key dimensions or attributes of the new model. With considerable inconsistencies between existing analyses emerging, Part 3 reconciles these analyses into a research framework.

2. Definitions – historical and current

The new model "encompasses a wide range of disparate technological areas brought together by a common vision of computational resources deployed in real-time, real-world environments."[21] Examples of concrete applications currently in commercial use or in advanced stages of development include:

- electricity smart grid technology;[22]
- wearable electronics and other consumer devices;[23]
- healthcare products;[24]

[13] Computing devices whose full processing power is not made available to the end user, but is expressly constrained by the vendor to a small set of functionalities e.g. Microsoft Xbox, Apple iOS devices, Amazon Kindle ebooks. See e.g. Jonathan Zittrain, *The future of the internet and how to stop it* (Yale University Press 2008), particularly 101–126.

[14] For example, Steve Mann, 'Wearable Computing' in Mads Soegaard and Rikke Friis Dam (eds), *The Encyclopedia of Human-Computer Interaction* (2nd ed., The Interaction Design Foundation 2012) <https://www.interaction-design.org/encyclopedia/wearable_computing.html>.

[15] For example, Katina Michael and M. G. Michael (eds), *Uberveillance and the Social Implications of Microchip Implants: Emerging Technologies* (Information Science Reference 2014); Mark N. Gasson, Eleni Kosta and Diana M. Bowman, *Human ICT implants: technical, legal and ethical considerations* (Springer, 2012).

[16] Gowri Ramachandran, 'Against the right to bodily integrity: Of cyborgs and human rights' (2010) 87 Denver University Law Review 1; Roger Clarke, 'Cyborg Rights' (2011) 30 Technology and Society Magazine, IEEE 49.

[17] For example, Fairfield (n 8).

[18] For example, David C. Vladeck, 'Machines without Principals: Liability Rules and Artificial Intelligence;' (2014) 89 Washington Law Review 117.

[19] Katharina E. Kinder, 'Ubiquitous Computing in Industrial Workplaces: Cultural Logics and Theming in Use Contexts' (PhD thesis, Lancaster University 2009), 40.

[20] Although note levels of association may vary between individuals e.g. some people may have much stronger emotional associations with their cars than their mobile phones.

[21] Paul Dourish and Genevieve Bell, *Divining a digital future: mess and mythology in ubiquitous computing* (MIT Press 2011), 61.

[22] For example, the Smart Grid, Smart City trials in NSW – see https://ich.smartgridsmartcity.com.au/, and similar trials in the US (see http://www.smartgrid.gov/) and the EU (http://ses.jrc.ec.europa.eu/jrc-scientific-and-policy-report).

[23] For example, the Apple Watch, a wearable computer with smartphone-like functions (although currently somewhat limited and also dependent on proximity to a full-featured iPhone) – see https://www.apple.com/au/watch/. Other examples include fitness trackers such as FitBit, Nike Fuelband and Jawbone.

[24] For example, Scanadu Scout, which is a personal scanner in advanced development that tracks blood pressure, temperature, respiratory rate, oxygen saturation, heart rate and stress level by applying the device to the forehead for a short amount of time. See http://www.scanadu.com/scout.

- home[25] and industrial[26] automation applications;
- traffic applications;[27]
- smart and driverless cars and trucks;[28] and
- environmental monitoring.[29]

However, despite the fact that it is easy to point to current (and potential) examples, it is difficult to identify an accurate scope definition of this "new model" of computing. The terminology used by researchers, industry participants and governments is not fixed, and a number of different terms are frequently used. The most commonly used terms appear to be **ubiquitous computing**,[30] **pervasive computing**,[31] **ambient intelligence**,[32] and the **Internet of Things**.[33] Sometimes these terms are used interchangeably, other times they are used in different but overlapping contexts and with wider or narrower scopes of meaning.

This profusion and confusion of terms may be due to a number of reasons. Terminologies and descriptions in the literature appear to be contingent on a number of factors: they vary over geographical locations, and with individual researchers, and they change over time. In particular, terminology has often varied depending on the particular entity funding the research being discussed. Also, whereas many areas of information technology research have a significant and defined technical problem or problems to be solved, the research arenas of ubiquitous computing, pervasive computing and ambient intelligence have a far greater focus on the human (rather than technical) outcomes.[34] As a result, a great breadth of technology types and technical problems come under the research umbrella of these areas. This breadth makes almost any attempt at definition "messy", as Dourish and Bell characterise it.[35]

The purpose of this paper is to present the groundwork, to enable assessment of the capacity of existing law to deal with this new model of technology and its impacts on business and society. In order to come to a proper view of how the law does and should treat these emerging technologies, it is important to attempt to clear up at least some of the "messiness", clarify the fields of view of the various terms, and identify the characteristics that are of greatest relevance to their impacts, and to the way law interacts with the products, services and relationships that arise from the use of these technology types.

2.1. *Ubiquitous and pervasive computing*

2.1.1. *History*

In 1991 and years following, a computer science researcher, Mark Weiser, first articulated a vision of a world where the traditional computer would be replaced by tiny devices, distributed and embedded in items in the physical world, communicating and interoperating with each other with the benefit of new wireless communication technologies.[36] Weiser coined the term "ubiquitous computing" for this pattern of computing use.[37]

Ubiquitous computing has not yet been fully implemented in 2015 – or at least not in the way Weiser imagined it.[38] However, much of the technology he visualised exists either in research laboratories or has been fully commercialised, although with significant variations in business and consumer take-up. This has been facilitated by technological advances in:

> areas such as Internet technologies, mobile and distributed computing, handheld devices, computer hardware, wireless communication networks, embedded systems and computing, wireless sensor networks, software agents, human computer interfaces, and the like.[39]

Most attempts at a definition of the new model use Weiser's vision as a starting point, focusing "on potential benefits of

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[25] For example, Internet-enabled light, energy, security, entertainment, appliances, water – see Turban and others (n 7), 314–5. For example, LG has released an Internet-enabled and voice- and smartphone-activated refrigerator which manages expiry dates, creates shopping lists, and sends recipes to the householder (and their oven) – see http://www.lg.com/us/refrigerators/lg-LFX31995ST-french-3-door-refrigerator. In an additional example, a Brazilian company currently markets the SmartHydro, a bath which can be filled remotely by communication with a smartphone – http://www.ihouse.com.br/caracteristicas-da-smarthydro.php.

[26] For example, wireless sensor networking products such as SmartMesh WirelessHART – http://www.linear.com/products/smartmesh_wirelesshart.

[27] For example, traffic congestion reporting and automated decision-making services offered by inrix.com.

[28] For example, Daimler "Smart" brand cars, Google's driverless car, SARTRE self-driven road trains. See Turban and others (n 7), 315–6.

[29] Luís M. Oliveira and Joel J. Rodrigues, 'Wireless Sensor Networks: a Survey on Environmental Monitoring' (2011) 6 Journal of Communications 143.

[30] Mark Weiser, 'The Computer in the 21st Century' [1991] Scientific American 94. Ubiquitous computing is also commonly abbreviated to "ubicomp", the abbreviation appearing to have originated with Mark Weiser himself: the earliest reference I can find is to a penultimate draft of a paper published in *Scientific American* in 1991, available at http://www.ubiq.com/hypertext/weiser/SciAmDraft3.html (the term did not appear in the published article). This abbreviation has been used frequently since: most notably as the title of an Association of Computing Machinery's annual International Conference since 2001 – http://www.ubicomp.org/ubicomp2013/about.php.

[31] For example, Frank Adelstein and others, *Fundamentals of mobile and pervasive computing* (McGraw-Hill, 2005).

[32] Information Society and Technology Advisory Group, *Strategic orientations and priorities for IST in FP6* (Report, European Commission, June 2002, 2002).

[33] Neil Gershenfeld, Raffi Krikorian and Danny Cohen, 'The Internet of Things' [2004] Scientific American 76. Other terms are also used, such as "everyware", Adam Greenfield, *Everyware: the dawning age of ubiquitous computing* (New Riders, 2006), but the four listed are by far the dominant terms.

[34] Dourish and Bell (n 21), 61.

[35] Ibid.

[36] Weiser, 'The Computer in the 21st Century' (n 30); Mark Weiser, 'The World is not a Desktop' [1994] Interactions 7; Weiser and Brown (n 5), 2.

[37] Weiser, 'The Computer in the 21st Century' (n 30).

[38] Dourish and Bell (n 21), Ch 2.

[39] Mohammad S. Obaidat, Mieso Denko and Isaac Woungang (eds), *Pervasive Computing and Networking* (John Wiley & Sons 2011), 3. Of particular interest for ubiquitous computing are the developments in radio frequency identification and near field communication (NFC) protocols.

widely distributed input and output devices–sensors, effectors, and displays that will be carried, worn, or embedded in the environment."[40]

Weiser's publications emerged from his research work as chief scientist at Xerox PARC, a research division of Xerox Corporation Ltd. In the early 1990s, however, a rival industrial vision emerged. IBM created a new research division which promoted research along the lines of leaving the desktop computer behind in order to develop opportunities in mobile and embedded computing[41], and developed an "architecture and marketing concept" that they labelled "pervasive computing".[42]

The two terms seemed to emerge as competing attempts from within two different organisations, Xerox PARC and IBM, both aimed at carving out a unique research space. However, from the beginning, there appeared to be a significant overlap in the two research foci of ubiquitous and pervasive computing. Want identified one major differentiation between the two research areas in the early 1990s: the emphasis by Xerox PARC on "calm" and "disappearing" technologies. This emphasis on invisible computing did not appear in IBM's early marketing efforts.[43]

In the next decade, some researchers explicitly attempted to differentiate the two terms. Despite IBM's common starting point with Xerox PARC in investigating opportunities in connected mobile and embedded computing,[44] in 2002 Lyytinen and Yoo distinguished the two as follows:

Type of computing	Level of mobility	Level of embeddedness
Pervasive computing	Low	High
Ubiquitous computing	High	High

They saw "the main challenges in ubiquitous computing originate[d] from integrating large-scale mobility with the pervasive computing functionality". In other words, design challenges arose out of the desire for computers to retrieve information from their environment through interaction with other computing systems and act "'intelligently' upon and within the environments in which we move".[45]

Therefore, a "smart office" containing sensors and actuators[46] which sense a person entering and turn on lights, adjust heating and activate displays would be a good example of *pervasive* computing, within the Lyytinen and Yoo definition. The Sensoria smart sock[47] would provide a better example of *ubiquitous* computing. The manufacturers have sewn a sensor chip into socks, which can communicate with a smartphone app. The sensor chip sends information about the wearer's running style to the smartphone app; the app itself sends alerts to the runner's mobile phone when, for example, the runner's tendency to heel strike exceeds acceptable levels.[48] This type of computing is both embedded and highly mobile.

However, both before and after Lyytinen and Yoo's article, commentators had a tendency to conflate the two concepts,[49] and the differences were disappearing. Singh, Puradkar and Lee in 2006 attempted to stop the convergence of the two definitions, stating that they were "conceptually different". However, even in their description of the two these authors co-opted the concept of **invisibility** into *pervasive* computing:[50] a concept that had been fundamental to the early descriptions of *ubiquitous* computing by Weiser.

It appears, however, that Singh, Puradkar and Lee were fighting a losing battle. From the mid-2000s or even earlier, most authors displayed a tendency to use both terms interchangeably or else acknowledge significant overlaps.[51] There are still those writing today who attempt to differentiate the two[52] but Want, writing in 2010, concluded that "any unique position described by either party has been slowly integrated into the shared vision and by the mid-2000s any publications that set out to describe this topic presented fundamentally the same

40 Jonathan Grudin, 'Group dynamics and ubiquitous computing' (2002) 45 Communications of the ACM 74, 74.

41 Roy Want, 'An Introduction to Ubiquitous Computing' in John Krumm (ed), *Ubiqutious Computing Fundamentals* (Chapman & Hall/CRC 2009), 11. The concepts of "calm" and "disappearing" computing were developed in, amongst others, Weiser, 'The Computer in the 21st Century' (n 30), 1; Weiser and Brown (n 5), 2; Mahadev Satyanarayanan, 'Pervasive computing: vision and challenges' (2001) 8 IEEE Personal Communications 10 (2001).

42 Sandhu Reema, 'Shifting paradigm from mobile to ubiquitous/pervasive computing' (2013) 2 COMPUSOFT: International Journal of Advanced Computer Technology 360, 360.

43 Want (n 41).

44 Ibid, 11.

45 Kalle Lyytinen and Youngjin Yoo, 'Issues and Challenges in Ubiquitous Computing' (2002) 45 Communications of the ACM 62, 64.

46 Devices which move things.

47 http://www.sensoriainc.com/.

48 Will Oremus, 'Smart socks may be the future of wearable technology' *Sydney Morning Herald* (30 November 2013) <http://www.smh.com.au/digital-life/digital-life-news/smart-socks-may-be-the-future-of-wearable-technology-20131130-2yihx.html>.

49 For example, Satyanarayanan (n 41), 1, "*ubiquitous computing*, now also called pervasive computing", also see D. Saha and A. Mukherjee, 'Pervasive computing: A paradigm for the 21st century' (2003) 36 Computer 25.

50 Sachin Singh, Sushil Puradkar and Yugyung Lee, 'Ubiquitous computing: connecting pervasive computing through semantic web' (2006) 4 Information Systems and e-Business Management 421, 422.

51 See, for example, Adelstein and others (n 31), 92, "Since the mid-1990s, ubiquitous computing has also been known as *pervasive computing*", George F. Coulouris and others, *Distributed systems: concepts and design* (Addison-Wesley (Pearson Education) 2012), 819, "Ubiquitous computing is also sometimes known as pervasive computing, and the two terms are usually taken to be synonymous", Stefan Poslad, *Ubiquitous computing: smart devices, environment and interaction* (John Wiley & Sons Ltd, 2009), "Ubiquitous computing, often also referred to as pervasive computing", xxv, Uwe Hansmann, *Pervasive computing: the mobile world* (2nd ed., Springer 2003), 1, " "*Everywhere at anytime*". . . This common slogan expresses in a nutshell the goal of Pervasive or Ubiquitous Computing".

52 For example, Rob Kitchin, *The Data Revolution: Big Data, Open Data, Data Infrastructures and Their Consequences* (Sage Publication Ltd, 2014). "If the mantra of pervasive computing is computation 'in everything', then the mantra of ubiquitous computing is computation 'in every place', with pervasive computing exhibiting processes of divergence (software being embedded into more and more devices) and ubiquitous computing exhibiting convergence (single digital devices undertaking more and more tasks)", citing Rob Kitchin and Martin Dodge, *Code/Space: Software and Everyday Life* (Matthew Fuller, Lev Manovitch and Noah Wardrip-Fruin, eds, MIT Press 2011).

position".[53] By this time, the number and diversity of actors involved in the field may well have meant that the convergence of the terms, considering their real similarities, was almost inevitable.[54]

2.1.2. *Properties of ubiquitous computing*

Weiser in 1991 identified the main properties of ubiquitous computing as computing which was **distributed**, **unobtrusive** and **context-aware**.[55] He also identified three form factors for potential ubiquitous computing devices, then being researched in the Xerox PARC laboratories: "tabs", "pads" and "boards".[56] Notably, modified versions of these form factors have become an intrinsic part of common technologies commercially available in 2015 (as smartphones, tablets and interactive whiteboards respectively), even though their usage is not quite as "ubiquitous" as Weiser might have hoped. In 2005, Endres, Butz and Macwilliams took a more expansive systems approach, and classified ubiquitous computing systems into three broad areas: augmented reality (virtual layer on a physical environment), intelligent environments (embedded sensors, actuators and/or processors), and distributed mobile systems (integrated multiple mobile devices).[57]

The most comprehensive framework proposed for ubiquitous computing was one developed by Stefan Poslad in 2009.[58] He identified a three-pronged framework for technical analysis and design of ubiquitous computing systems, called SmartDEI. Note that although Poslad called his book "Ubiquitous Computing", he made it clear that he included concepts of pervasive computing and ambient intelligence within that term.[59]

Poslad undertook a substantive literature review of authors who had identified a number of different types of classifications based on functional properties, types of devices, and types of systems.[60] From this review, he identified five "core internal properties" (and over 70 sub-properties) that ubiquitous computing devices and systems should manifest. He considered these core properties to be:

(1) **distributed** systems which are **networked** and **transparent** i.e. "acting as a single virtual system even although it is physically distributed"[61]. Poslad uses the term "transparency" consistently throughout his work to designate a desired design outcome of "hid[ing] the complexity of the distributed computing model from users"[62]. This is a problematic term: other writers use this term in relation to Weiser's idea of a "disappearing" or non-obtrusive computer,[63] which Poslad puts into his second category. From the perspective of the user, Poslad's use of "transparency" would probably be better phrased as "opaqueness" or a "black box" approach to design;
(2) the interaction between humans and computing devices/systems is **implicit**, or at least less obtrusive than conventional desktop computers. Poslad labelled the more extreme versions of this implicit human–computer interaction, or "iHCI".[64]
(3) computers are **context-aware** – of the physical environment, users and other computing systems;
(4) computers can operate **autonomously** (i.e. devices/systems can be "self-governing and are capable of their own independent decisions and actions"); and
(5) computers deal with multiple actions and interactions via "**intelligent**" decision making and interaction systems. Poslad indicates this concept "may entail some form of artificial intelligence".[65]

Because Poslad's framework provides a useful checklist of features found in "third wave" technologies, we have summarised his list of properties and sub-properties in Table 1.

Poslad concluded from his review that no one definition of ubiquitous computing was possible, and "rather there is a range of properties and types . . . which vary according to the application".[66] He proposed a fluid classification where "each individual property has its own domain of a more finely grained set of discrete values, rather than being seen as a property that is present or absent".[67] Therefore an individual system could display some but not all of the core properties strongly, and the remaining only weakly or perhaps not at all. From a definitional perspective, there are two significant problems with Poslad's classification of "core properties". The first is that many of the properties that he describes are not core at all. It seems he uses the term as indicating "possible" properties, rather than requiring these properties as part of a definition exercise. Also, when he attempts to define these core properties, the endpoints of the dimensions are not sufficiently described.

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53 Want (n 41), 11.
54 One significant indicator of convergence was the 2013 merger of the Association for Computing Machinery's two separate international conferences on pervasive and ubiquitous computing into one – UbiComp. See http://www.ubicomp.org/ubicomp2013/.
55 Weiser, 'The Computer in the 21st Century' (n 30).
56 Ibid, 98.
57 Christoph Endres, Andreas Butz and Asa MacWilliams, 'A survey of software infrastructures and frameworks for ubiquitous computing' (2005) 1 Mobile Information Systems 41, 42.
58 Senior Lecturer, School of Electronic Engineering and Computer Science, Queen Mary University of London.
59 Poslad (n 51), 18.
60 Ibid, 17–18.
61 Ibid (n 51), 19.
62 Ibid, 8.
63 D. J. Cook, J. C. Augusto and V. R. Jakkula, 'Ambient intelligence: Technologies, applications, and opportunities' (2009) 5 Pervasive and Mobile Computing 277, Coulouris and others (n 51), 10.
64 Poslad adopted the terminology from Albrecht Schmidt, 'Implicit human computer interaction through context' (2000) 4 Personal and Ubiquitous Computing 191, who further developed this in Albrecht Schmidt, 'Ubiquitous Computing – Computing in Context' (PhD thesis, Lancaster University 2002).
65 Poslad (n 51), 9. The first three of these are explicitly adapted from Weiser's work: the last two were additional proposals from Poslad.
66 Ibid, 35.
67 Ibid, 21.

Table 1 – Poslad's properties and sub-properties.[a]

Core properties	Sub-properties
Distributed	Universal, seamless, heterogeneous networked synchronised, coordinated open transparent, virtual mobile, nomadic
iHCI	Non-intrusive, hidden, invisible, calm computing tangible, natural anticipatory, speculative, pro-active affective, emotive user-aware post-human sense of presence, immersed, virtual, mediated reality
Context-aware	Sentient, unique, localised, situated adaptive, active context-aware person-aware, user-aware, personalised, tailored environment-aware, context-aware, physical context-aware ICT awareness
Autonomous	Automatic embedded, encapsulated, embodied resource-constrained untethered, amorphous autonomic, self-managing, self-star emergent, self-organising
Intelligent	Reactive, reflex model-based, rules/policy-based logic/reasoning goal-oriented, planned, pro-active utility-based, games theoretic learning, adaptive co-operative, collaborative, benevolence competitive, self-interested, antagonistic, adversarial orchestrator, choreographed, mediated task-sharing communal, shared meaning shared knowledge speech-act based, intentional, mentalistic emergent

[a] Table 1 is a consolidation of tables 1.1–1.5 in Poslad (n 51), 19.

The second part of Poslad's framework focussed on design architectures seen in ubiquitous computing systems. Poslad expanded on the previous ideas of Satyanarayanan[68] to identify three types of design architectures: "smart device", "smart environment", and "smart interaction". Smart devices in Poslad's framework take a range of forms, but are most often **multi-functional**, **personal** devices such as mobile phones, with a large amount of **explicit** interaction with humans, and between the device and other computers, but less so with the physical environment. Smart environments, by contrast, tend to contain **embedded** devices which are more limited in functionality,[69] but support higher levels of **implicit** human–computer interaction e.g. a door-opening system which opens a door automatically as a human approaches. They also tend to be more **public** than personal as they usually support interactions with many users.

Smart interaction systems were defined as a further step on from basic synchronous and asynchronous interactions between a sender and receiver, involving the use of both personal smart devices and smart environments. For example, Poslad's idea of smart interaction contemplated that a choice of action by a device (such as switching on a light, or rather a particular light in the room) will be dependent on sharing and processing information about user goals (e.g. whether or not the user is reading a book or watching a film).[70]

Poslad also viewed new model systems through a third lens, based on the type of **external interaction** inherent in ubiquitous computing systems. Poslad considered that there were three basic ubiquitous computing systems environments: the virtual (other ICT systems), the physical, and the human. The external interactions comprise human-to-computer, computer-to-physical world and computer-to-computer interactions, as well as combinations of these. For example, a human playing a game on a smartphone incorporates a human-to-computer interaction. Computer-to-computer interaction is required if the game is one with multiple remote players. Computer-to-physical world interaction will be required if the game contains augmented reality features, such as Niantic Labs' Ingress: this game is GPS-dependent, requiring users to be within a certain physical distance of physical landmarks in order to perform certain actions within the game.[71]

2.2. *Mobile computing*

Contemplating the use of a smartphone or other mobile device as part of a ubiquitous computing system brings an added complexity in defining the new model. This complexity results from the rise and dominance of mobile computing in the modern information technology landscape, most obviously

[68] Satyanarayanan (n 41).

[69] See the explanation of "appliances" in footnote 13. "Embedded" components can be embedded in parts of a physical or human environment, or be part of a larger ICT device. "Untethered" components are those that have some degree of physical freedom. These untethered components are likely to include micro electro mechanical systems (MEMS) devices, often referred to as "smart dust". Current MEMS products include automotive pressure sensors, airbag accelerometers and inkjet heads (although most growth is expected from MEMS technologies which are still early in the research and development stage). A. A. Berlin and K. J. Gabriel, 'Distributed MEMS: New challenges for computation' (1997) 4 IEEE Comput Sci Eng 12. Poslad, when discussing smart environments, concentrates on future possible uses of MEMS devices, such as a series of micro-sensors applied over surfaces, or diffused through other liquid or gaseous materials. For example, he raises the possibility that "smart paint" might be developed for transport infrastructure containing sensors which track traffic, wind and structural integrity. Poslad (n 51), 197.

[70] Poslad (n 51), 33. Note that this particular scenario has not yet been realised: and its utility will in all likelihood be limited by factors such as the need for human intention to produce some phenomenon that can actually be sensed by a machine.

[71] https://www.ingress.com. Niantic Labs is an internal department of Google.

demonstrated by the runaway commercial success of mobile phones with significant computer processing power. Mobile computing can be described as "the performance of computing tasks while the user is on the move, or visiting places other than their usual environment."[72]

The increasing use of smartphones and wireless tablets in developed and developing economies is one of the most obvious examples of the "third wave", or the move away from the desktop model. However, it is arguable that mobile computing is not confined to mobile phones and tablets. The concept could also cover areas such as wearable computing,[73] for example Internet-connected spectacles,[74] or computing which is implanted in humans or other animals such as a heart pacemaker.[75]

However, significant distinctions between mobile computing and Weiser's initial view of ubiquitous computing have previously been identified.[76] For one:

> [b]roadly speaking, mobile computing is concerned with exploiting the connectedness of devices that <u>move around</u> in the everyday physical world; ubiquitous computing is about exploring the increasing integration of computing devices <u>with</u> our everyday world.[77] (our underline)

Another important distinction arises from the nature of the interaction between device and user. Ubiquitous computing from the beginning contemplated a user model with many different computers (often with only one or two dedicated functions) interacting with many different users, or with different machines or devices. Mobile computing, on the other hand, currently operates closer to the desktop model: that is, a user interacts directly with one or two devices dedicated to her or him. Also, discussions of mobile computing usually assume a human's central involvement in the computing activity, while ubiquitous/pervasive computing does not confine itself in this way.

However, apart from these distinctions, mobile computing seems entrenched as part of the research space of ubiquitous/pervasive computing, as its features are usually discussed by computer scientists and other researchers as an essential part of ubiquitous computing concepts, whether as a subset or as a necessary adjunct.[78] Weiser himself in 1996 denied that ubiquitous computing was either a "superset or subset" of mobile computing,[79] but it is unlikely that this position can continue to be justified considering the technological and terminological changes since that time. For example, Weiser specifically rejected the idea of his vision of ubiquitous computing "liv[ing] on a personal device of any sort", but rather contemplated it existing "in the woodwork everywhere".[80] However, the "tabs" and "pads" prototypes he helped Xerox PARC develop have now been transformed into *personal* devices: smartphones and tablets. Of course the mobile infrastructure essential to the commercial success of these personal devices could be seen as indeed embedded in the "woodwork", admittedly not everywhere, but in very many places. Dourish and Bell in 2011 concluded that existing mobile computing is actually in its own way the current manifestation of Weiser's vision of ubiquitous computing, albeit messy, incomplete and using technologies that he had not anticipated.[81]

2.3. *Ambient intelligence*

2.3.1. *History*

The emergence of the term "ambient intelligence" came almost a decade after the development of ubiquitous and pervasive computing. It was first used in 1998 in a series of workshops commissioned by consumer electronics company Philips.[82] By 2009, the fundamental idea of "ambient intelligence" was defined as:

> by enriching an environment with technology (eg sensors and devices interconnected through a network), a system can be built . . . which senses features of the users and their environment, then reasons about the accumulated data, and finally selects actions to take that will benefit the users in the environment.[83]

Note that the idea of "benefits" in this definition was specifically related to "the users in the environment". The authors also identified loss of control, privacy and security concerns as possible disbenefits of these technologies.[84]

Philips spearheaded the corporate development of the concept, also developing links with industries and research universities, such as its collaboration with the MIT Oxygen project,[85] and its in-house development of a research laboratory to investigate scenarios for ambient intelligence, HomeLab.[86] The Philips workshops identified some particular characteristics of

72 Coulouris and others (n 51), 10.

73 For a discussion of the history of wearable computing, see Mann (n 14).

74 Such as Google Glass, Sony's Smart Eyeglass, and Toshiba Glass. The future of internet spectacles, at least in their availability to individual consumers, is uncertain. The most well-known of the products, Google Glass, had a limited public release on 15 April 2014, with a stated view to a full release in the US later in 2014. However, in January 2015 Google announced that the product would not be offered to consumers: however, it is still available to business customers, with applications in advanced development in the health science and aviation industries. See Paul Briden, 'Google Glass Review: Google Glass In Every Day Life' 11 April 2014 <http://www.knowyourmobile.com/google/google-glass/21388/google-glass-release-date-features-and-price-ray-ban-oakley-commit-future> and Gene Marks, 'How Google Saved Google Glass' Forbescom (2015) <http://www.forbes.com/sites/quickerbettertech/2015/02/02/how-google-saved-google-glass/> accessed 4 February 2015.

75 Poslad (n 51), 29.

76 Dourish and Bell (n 21), 117.

77 Coulouris and others (n 51), 818.

78 See e.g. Poslad (n 51); Adelstein and others (n 31); Coulouris and others (n 51); Dourish and Bell (n 21).

79 Weiser, 'Ubiquitous Computing' (n 3).

80 Ibid.

81 Dourish and Bell (n 21).

82 E. H. L. Aarts and José Luis Encarnação (eds), *True visions: the emergence of ambient intelligence* (Berlin: Springer-Verlag 2006), 6.

83 Cook, Augusto and Jakkula (n 63), 278.

84 Ibid, 286–7.

85 http://oxygen.lcs.mit.edu/Sponsors.html.

86 http://www.research.philips.com/technologies/projects/ami/background.html.

ambient intelligence, in particular, that the technology used would be **embedded**, **personalised**, **adaptive** and **anticipatory**.[87]

The idea – and the terminology – of ambient intelligence were given their most significant boost as a result of substantial investment by the European Union. In 1999, the EU's Information Society and Technology Advisory Group (ISTAG) created a workgroup on "Ambient Intelligence", and issued a series of reports over the next couple of years.[88] As a result of ISTAG's recommendations, ambient intelligence research formed a key part of the European Commission's Sixth Framework Programme for Research and Technological Development in the area of Information Society Technologies.[89] In its first report, ISTAG postulated four different scenarios concerning possible development in ambient intelligence technologies. One scenario described a woman who lived in a "smart house" where she could order food and other items via her refrigerator, and track her e-commerce activities via a mobile device. She could also access a car pool through her city infrastructure, which would also advise on traffic and also regulate the car's behaviour.[90]

2.3.2. *Characteristics of ambient intelligence*

It is noteworthy that, like the terms "ubiquitous" and "pervasive" computing, the term "ambient intelligence" emerged from a separate research organisation. The 2009 definition above makes clear the similarities between the scope of ambient intelligence and ubiquitous/pervasive computing research. However, unlike those terms, "ambient intelligence" has in many cases maintained a separate identity,[91] most likely due to its adoption by the EU in 2001, and consequential funding of research projects. It still remains a predominantly European term. The question remains: are there important differences?

Some scholars have proposed that the key distinguishing feature of ambient intelligence, when compared to ubiquitous or pervasive computing, is the assertion that the technologies need to be intelligent, in some sense of that word.[92] The very name assumes that ambient intelligence research concentrates on devices acting intelligently, but the term often seems to be used functionally, rather than engaging with existing complex and contested definitions[93] of artificial or synthetic "intelligence". In particular, the term "intelligence" is most often used in ambient intelligence literature as a synonym for making people's lives easier, which is difficult to justify as a defining factor. Undoubtedly technologies exist that can collect large amounts of data, use strong contextual models to recognise a problem that needs to be solved, and contain clever algorithms which can suggest solutions. Whether or not this is sufficient to be called "intelligent" is highly contested.[94] Aside from the outstanding question of whether technology can in fact ever approach human capabilities for flexibility, adaptability, tolerance and wisdom, an emphasis on intelligence alone as a **differentiating** factor is highly questionable considering the significance scholars have attributed to an "intelligent response" in ubiquitous and pervasive computing.[95]

A more sensible attempt at differentiation was made by ISTAG. It saw ambient intelligence as being "concerned less with basic technology than the use of the technology – by the individual, by business, and by the public sector."[96] This was supported recently by Sorrano and Botia, who proposed that:

> Ubiquitous Computing . . . is a vision for computer systems to merge the physical world and human and social environments . . . And Ambient Intelligence . . . is concerned with such kind of systems but it lays the emphasis on how they interact with people[97]

"Interactions with people" usually refers to interactions with devices that have significant and uniquely identifiable associations with individuals. Not surprisingly, ISTAG has anticipated the industrial base for ambient intelligence products as arising from consumer electronics companies, car and aeroplane manufacturers, and telecommunications companies, rather than from "general purpose" computer technology suppliers.[98]

It is clear that the research agendas overlap. However, research agendas attached to the name "ambient intelligence" are phrased in terms which are human-centred rather than technology-centred, and have a more energetic emphasis on artificial intelligence and context awareness, rather than contrasting ideas of "everywhereness" implied by the terms ubiquity and pervasiveness. In other words, ambient intelligence definitions tend to focus on the "ends" rather than the "means",

[87] Eli Zelkha and Brian Epstein, 'From Devices to "Ambient Intelligence": the Transformation of Consumer Electronics' Presentation slides circulated internally within Royal Philips Electronics, 24 June 1998 <http://www.epstein.org/brian/ambient_intelligence.htm>.

[88] Information Society and Technology Advisory Group, Scenarios for Ambient Intelligence in 2010 (Final Report, European Commission Community Research, 2001).

[89] European Commission, The Sixth Framework Program in Brief, December 2002 Edition <https://ec.europa.eu/research/fp6/pdf/fp6-in-brief_en.pdf>, 7.

[90] Information Society and Technology Advisory Group (n 88), 38–42.

[91] For example, with separate journals and conferences.

[92] E. Maeda and Y. Minami, 'Steps towards ambient intelligence' (2006) 4 NTT Technical Review, 51. See also Cook, Augusto and Jakkula (n 63), 279.

[93] A discussion of the complexity of the debate around definitions of artificial intelligence can be found at Roger Clarke, 'What drones inherit from their ancestors' (2014) 30 Computer Law & Security Review 247, section 2, 248–251.

[94] Ibid.

[95] See Lyytinen and Yoo (n 45). See also particularly Poslad (n 51), 18, who considered that ambient intelligence fit along a spectrum of types of ubiquitous computing, with an emphasis on autonomy, implicit human computer interaction, and intelligence; also Kenneth D. Pimple, 'Introduction: The Impacts, Benefits and Hazards of PICT' in Kenneth D. Pimple (ed), Emerging pervasive information and communication technologies (PICT): ethical challenges, opportunities and safeguards (Springer 2014), 2, "[a]mbient intelligence applies particularly to artificial intelligence (AI) devices, but AI capabilities are not excluded by the terms ubiquitous and pervasive".

[96] Information Society and Technology Advisory Group, Ambient Intelligence: from vision to reality (Report, European Commission, September 2003), 6.

[97] Emilio Serrano and Juan Botia, 'Validating ambient intelligence based ubiquitous computing systems by means of artificial societies' (2013) 222 Information Sciences 3, 3. See also David Wright and others (eds), Safeguards in a world of ambient intelligence, vol 1 (Springer 2008), xxi, who described the research emphasis as being "on greater user-friendliness, more efficient services support, user empowerment and support to human interactions".

[98] Information Society and Technology Advisory Group, Ambient Intelligence: from vision to reality (n 96), 3.

in contrast to the main area of concentration reflected in the ubiquitous/pervasive computing literature.

However, the emphasis in the ambient intelligence literature on interaction with, and benefits to, human users can obscure some key concerns. In the end, such systems will be built primarily by and for those corporate or government entities with the resources to do so. As a result, the intended beneficiaries of these systems will not necessarily be the individuals who "use" them: but may instead be companies or governments who wish to monitor their employees' or citizens' movements, or suppliers who want to target advertising of their products to people with a particular data profile. The reliance of ambient intelligence systems on data profiling – "the construction or inference of patterns by means of data mining and . . . the application of the ensuing profiles to people whose data match with them"[99] – gives rise to its own specific problems. Hildebrandt and Koops identified four categories of "vulnerabilities" that can arise from profiling: errors arising from "incorrect categorisation" (e.g. false positives and false negatives), loss of privacy and autonomy, the possibility of unfair discrimination and stigmatisation, and threats to due process."[100]

Other scholars have also expressed concern with the "rather too sunny view of our technological future" expressed by many people advocating the development of ambient intelligence technologies.[101] In particular, researchers funded by the European Commission spent 18 months in the mid-2000s developing the so-called "dark scenarios" to illustrate potential problems in areas such as privacy, security, identity protection, trust, loss of control, dependency, social exclusion, surveillance and spam.[102] These dark scenarios also help to illustrate a problem with terminology: we talk about individuals "using" these types of technologies, but in many cases it is more accurate to say that the technologies (or their controllers) "use" the individuals: for example to gather information about them, or to trigger actions based on their movements or preferences, but not providing any outcome desired by the individual, who may well be acted upon without his or her knowledge.

Philips researchers Zelkha and Epstein first proposed its defining characteristics in 1998 as **embedded**, **personalised**, **adaptive** and **anticipatory**.[103] By 2003, other Philips researchers (Aarts and Roovers) had added **context-aware** to that list.[104] In contrast, the ISTAG Report in the same year refused to identify any definitional characteristics, as ambient intelligence was to them an "emerging property".[105] However by this time, research into actual devices had developed to the extent that Aarts and Roovers could attempt to classify existing or potential devices on types of power dependence: autonomous devices (e.g. self-powered tags, sensors), portables (e.g. battery-powered mobile phones) and statics (e.g. home servers powered on mains electricity).[106]

In 2009, Cook, Augusto and Jakkula examined the most recent research by industry and academia. As a result, they expanded the definition of the main features of ambient intelligence technologies to include: **sensitivity**, **responsiveness**, **adaptiveness**, **transparency**, **ubiquity** and **intelligence**.[107] Another roughly concurrent attempt to define the key characteristics of ambient intelligence produced this list: complexity, a lack of boundaries, unpredictability, heterogeneity, incremental development and deployment and the ability to self-configure and adapt.[108]

2.4. *Internet of Things*

In spring 1998, at a similar time to the emergence of "ambient intelligence", Kevin Ashton presented to the multinational consumer goods corporate group Procter & Gamble an idea that the addition of RFID[109] and other sensor technologies to everyday objects could create an "Internet of Things".[110] The concept of an Internet of Things (also known as "**IoT**") has emerged as part of a model of the future direction for the Internet, in particular as a way to frame current developments in infrastructure and information management.

One definition of the Internet of Things is:

> . . .the general idea of things, especially everyday objects, that are readable, recognizable, locatable, addressable, and controllable via the Internet – whether via RFID, wireless LAN, wide-area network, or other means. . .[111]

However, the definition of the Internet of Things is the subject of debate. Even the use of the word "Internet" in this and other definitions incorporate a common misunderstanding. The technical definition of the "Internet" actually refers to a combination of computer networks using a particular set of communications protocols, most importantly the TCP/IP[112] protocols.[113] Many devices represented as examples of IoT, particularly those which communicate over very short distances, do not need (and often do not use) TCP/IP. For example, electronic door key applications, which lock and unlock doors in response to taps on a smartphone icon, may well communi-

[99] Hildebrandt and Koops, (n 8), 431.
[100] Ibid, 433–488.
[101] Michael Friedewald and others, The Brave New World of Ambient Intelligence: An Analysis of Scenarios Regarding Privacy, Identity and Security Issues (Springer 2006); see also Hildebrandt and Koops, (n 8), 433–488.
[102] See http://is.jrc.ec.europa.eu/pages/TFS/SWAMI.html and Wright and others (n 97).
[103] Zelkha and Epstein (n 87).
[104] E. Aarts and R. Roovers, 'IC design challenges for ambient intelligence' [2003] Proceedings of the Design, Automation and Test in Europe Conference and Exhibition 2. Aarts and Roovers used the term "contextual awareness", but "context-aware" has become much more common since this time.
[105] Information Society and Technology Advisory Group, Ambient Intelligence: from vision to reality (n 96), 3.
[106] Aarts and Roovers (n 104), 3.
[107] Cook, Augusto and Jakkula (n 63), 278–279.
[108] Wright and others (n 97).
[109] Radio-frequency identification.
[110] Kevin Ashton, 'That 'Internet of Things' Thing' RFID Journal (2009) <http://www.rfidjournal.com/articles/view?4986> accessed 26 February 2015.
[111] National Intelligence Council, Disruptive Technologies Global Trends 2025. Six Technologies with Potential Impacts on US Interests Out to 2025 (Conference Report, CR 2008-7, April 2008).
[112] Transmission Control Protocol and Internet Protocol.
[113] Roger Clarke, 'Origins and Nature of the Internet in Australia' (Xamax Consultancy Pty Ltd, 2004) <www.rogerclarke.com/II/OzI04.html> accessed 13 May 2015.

cate with the phone using simpler protocols over Bluetooth or infra-red channels.[114]

However, the "Internet of Things" is a widely accepted term in Europe and China. Although it is less widely used in the US, where other terms such as "smart object" are often preferred,[115] it seems to be gaining in popularity.[116] One common element among the various visions of an Internet of Things is the concept of a mass-scale networking infrastructure that supports "interdevice internetworking".[117] This concept envisages the "tagging" of physical objects with a unique identifier (often called an electronic product code or EPC). The tags can then be accessed (using automated identification and data collection technologies),[118] and information retrieved elsewhere via the Internet about the object: such as which object it is, who owns it, where it is physically, where it is in network space, where it has been and where it is going.[119]

Tagging of objects that are then scanned and tracked is hardly a recently-emerged functional concept – for example, as early as January 2005, the American multinational retail corporation Wal-Mart was requiring suppliers to apply RFID tags to its shipments.[120] However, what appears to be new about the Internet of Things is that it envisages that far more objects will have chips with communication capabilities embedded, to allow information relating to and/or collected by the physical object to be accessible via the Internet or a private network. This possibility is facilitated by the increasing deployment of IPv6, a network protocol dealing with address and control information that greatly expands the number of unique addresses available for Internet-connected devices (and their processes).[121]

The most common current use of Internet of Things is to "automate inventory, tracking and basic identification" of goods moving from one place to another.[122] However, technology development in the Internet of Things is in an early stage, and most uses beyond the above are currently not yet in full commercial production. Most of the existing installations of RFID and similar technologies are still communicating only within one enterprise or just with a limited number of partner enterprises: not really an Internet of Things, but rather an Intranet or Extranet of Things.[123] Even within consumer applications of the Internet of Things, most information is still not disseminated outside its capturing application,[124] at least not for the consumer's benefit. However, note that this technical limitation does not represent protection for consumer data. Many corporations that host consumer devices' associated web-based applications can and very probably will collect and disseminate data from these applications for marketing and profiling purposes.[125]

So how, then, does the Internet of Things fit in with concepts such as ubiquitous/pervasive computing and ambient intelligence? Some commentators consider them as equivalent terms.[126] However, others have a more limited view of the Internet of Things. Chaouchi describes the Internet of Things as "one step further on the path to ubiquitous computing".[127] More specifically, Weber and Weber have envisioned the Internet of Things as playing a significant role as a "backbone" or support infrastructure for these other forms of computing. In their view, a fully developed Internet of Things has the capacity to "enabl[e] smart environments to recognize and identify objects, and retrieve information from the Internet to facilitate their adaptive functionality".[128] Other envisioned usages, incorporating an increased use of sensor and actuator technologies, include:

> cars warning other cars of traffic jams, a cell phone reminding a person when it was last left next to the keys, a waste-bin inquiring its contents about their recyclability, or a medicine cabinet checking the storage life of the medications in it.[129]

The similarity of these scenarios to ubiquitous/pervasive computing and ambient intelligence scenarios is easy to see. It is not surprising that some commentators have attempted

114 For example, August Smart Lock. See Bonnie Cha, 'A Beginner's Guide to Understanding the Internet of Things' re/code (2015) <http://recode.net/2015/01/15/a-beginners-guide-to-understanding-the-internet-of-things/> accessed 15 January 2015.

115 Erin Anzelmo and others, 'The Internet of Things' (1st Berlin Symposium on Internet and Society, October 25–27, 2011), 4.

116 For example, the IEEE, which has a significant US membership and management, publishes the Internet of Things Journal and holds conferences on the Internet of Things.

117 Gershenfeld, Krikorian and Cohen (n 33), 78.

118 Like RFID, Near field communication and other sensor technologies. Stephan Haller, Stamatis Karnouskos and Christoph Schroth, 'The Internet of Things in an Enterprise Context' in John Domingue, Dieter Fensel and Paolo Traverso (eds), Future Internet – FIS 2008, vol 5468 (Springer 2009) <http://dx.doi.org/10.1007/978-3-642-00985-3_2>, 15.

119 Weber and Weber (n 8), 17.

120 Ian Poole, 'RFID History' (Radio-Electronics.com) <http://www.radio-electronics.com/info/wireless/radio-frequency-identification-rfid/development-history.php> accessed 20 February 2015. See also Mark Roberti, 'The History of RFID Technology' RFID Journal, 16 January 2005 <http://www.rfidjournal.com/articles/view?1338/> accessed 26 February 2015.

121 Haller, Karnouskos and Schroth (n 118), 21, who estimate that IPv6 could accommodate 2^{128} things.

122 European Commission, 'The Internet of Things' <http://ec.europa.eu/digital-agenda/en/internet-things> accessed 4 May 2015.

123 Dieter Uckelmann, Mark Harrison and Florian Michahelles, 'An Architectural Approach Towards the Future Internet of Things' in Dieter Uckelmann, Mark Harrison and Florian Michahelles (eds), Architecting the Internet of Things (Springer, 2011) <http://site.ebrary.com/lib/unsw/docDetail.action?docID=10461731>, 3.

124 Sarah Rotman Epps, 'There is no Internet of Things' Forbescom (2013) <http://www.forbes.com/sites/forrester/2013/10/17/there-is-no-internet-of-things/>.

125 For example, Fitbit's Australian privacy policy as at 30 December 2014 stated "De-identified data that does not identify you may be used to inform the health community about trends; for marketing and promotional use; or for sale to interested audiences" – https://www.fitbit.com/au/privacy.

126 For example, "Other terms for the Internet of Things include Internet-connected devices, smart connected devices, wireless sensor networks, machines and devices communicating wirelessly, *ubiquitous computing*, *ambient intelligence*, and smart matter" (our italics) Melanie Swan, 'Sensor Mania! The Internet of Things, Wearable Computing, Objective Metrics, and the Quantified Self 2.0' (2012) 1 Journal of Sensor and Actuator Networks 217, 218.

127 Hakima Chaouchi (ed) The Internet of Things: connecting objects to the web (John Wiley & Sons, 2010), xi.

128 Weber and Weber (n 8), 1.

129 Ibid, 1–2.

to conflate the idea of the Internet of Things and the other forms of computing discussed above. For example Santucci, presenting to the International Conference on Future Trends on the Internet, said "over the years Europe 'forgot' the term "Ambient Intelligence", which it had invented, and 'imported' and re-used the term "Internet of Things" ".[130]

However, the majority of the critical literature indicates that the definition of the Internet of Things, at least as it currently stands, is not "the same" as ambient intelligence or ubiquitous/pervasive computing. At the moment, at least, the Internet of Things is more accurately explained as a subset to these concepts, or as part of a technological path towards their implementation.[131] Of course, especially considering the history of the other terms and their convergence, it is not impossible that in time the increasing popularity of the term, especially in Europe and in China, may subsume the other definitions and incorporate their characteristics. It has certainly become the most popular of the terms in the public mind, as indicated in Fig. 1, which indicates the trends in the frequency with which the terms "ambient intelligence", "ubiquitous computing", "pervasive computing", and "Internet of Things" have been searched for using a leading search engine.

When considering the current definition, a major limiting factor is the insistence on a global communications and information-sharing network as an essential requirement. For example, Uckelmann, Harrison and Michahelles consider that the Internet of Things can currently be differentiated from ubiquitous/pervasive computing because the latter "does not imply the usage of objects nor does it require a global Internet infrastructure."[132] This distinction could apply equally well to ambient intelligence. For example, the ambient intelligence scenario of clothes made of smart materials that sense perspiration and adjust ventilation[133] does not require a connection to the Internet. Both ubiquitous/pervasive computing and ambient intelligence, as definitional terms, envisage a localised, globalised, (and potentially a universal), implementation: the "Internet of Things", at least in its present manifestation, is more confined. Localised silos of connected

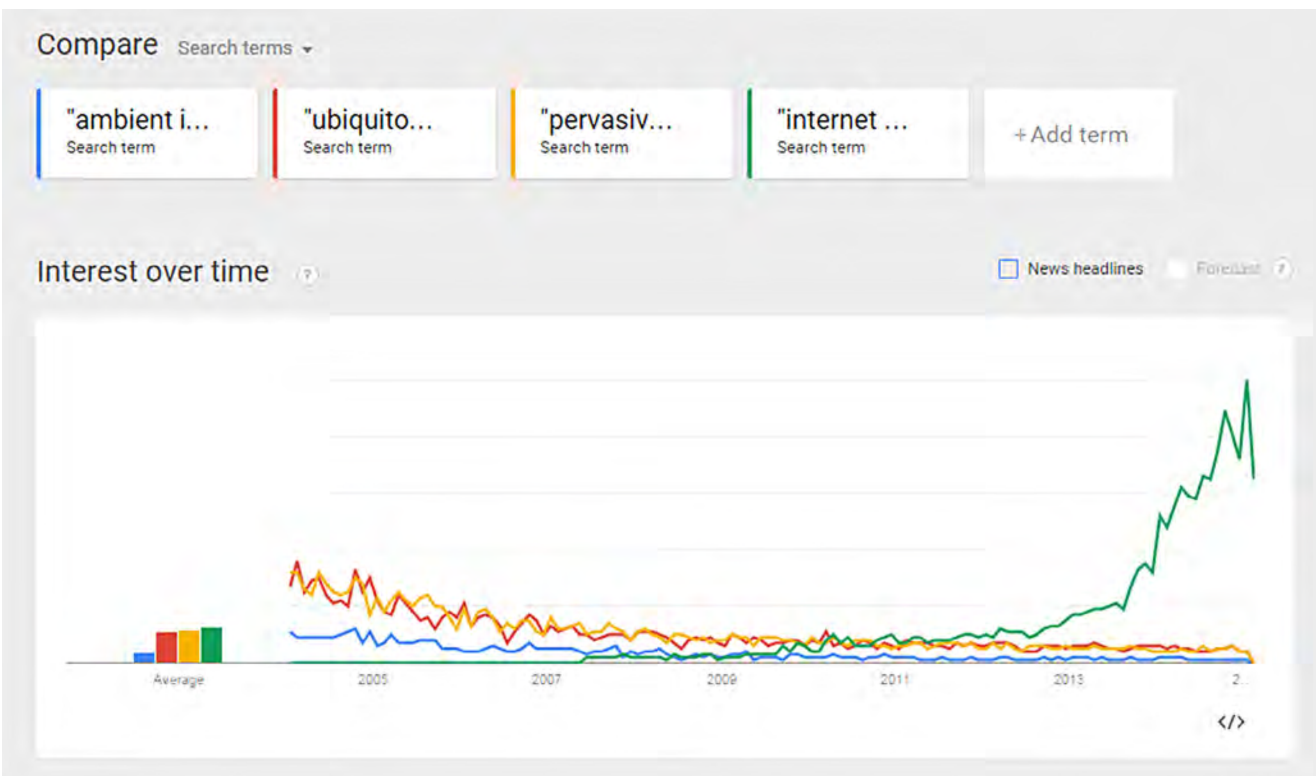

Fig. 1 – Popularity of search terms "ambient intelligence", "ubiquitous computing", "pervasive computing", "Internet of Things". Data Source: Google Trends (www.google.com/trends). In terms of content from all sources, a Google search run by the author of this paper on 1 December 2014 gave the following results: "Internet of Things" – about 15 800 000; "ubiquitous computing" 689 000; "pervasive computing" 651 000; "ambient intelligence" 438 000. However, a search on Google Scholar reveals that at least this subset of the academic literature reflects roughly opposite proportions.

130 Gerald Santucci, 'From Internet of Data to Internet of Things' (International Conference on Future Trends of the Internet, Luxembourg, 28 January 2009), 2–3.

131 Weber and Weber (n 8); also Chaouchi (n 127).

132 Uckelmann, Harrison and Michahelles (n 123), 5, citing Tomas Sanchez Lopez, Technical Blog, "What the Internet of Things is NOT"' 22 March 2010 <http://technicaltoplus.blogspot.com.au/2010/03/what-internet-of-things-is-not.html> . These authors do not expressly consider the possibility of a localised "Internet of Things".

133 Poslad (n 51), 426. Note that this scenario is provided in a book that is ostensibly about ubiquitous computing, not ambient intelligence.

things do currently exist, and are likely to exist in the future. However, as discussed above they are usually distinguished from IoT by using terms such as "intranet of Things".[134]

2.5. *Towards a framework*

Although this paper has identified some differences between these definitions, it cannot be said that any of these forms of computing have clear-cut boundaries separating them. It appears rather that mobile computing and the Internet of Things are best characterised as subsets of a broader type of computing, involving technological paths to achieving visions of ubiquitous computing or ambient intelligence. Discussions in the literature of broader visions of ubiquitous/pervasive computing and ambient intelligence do not usefully assist in identifying differences, as they routinely throw up similar forms of technology, just viewed through different dominant functional lenses: such as an emphasis on "everywhereness" for ubiquitous/pervasive computing, and "adaptability to humanness" for ambient intelligence. However, a map of the functional lenses creates a simplified but useful starting point. Fig. 2 presents such a map, summarising the relationship among the terms based on these functional lenses.

However, simple diagrams and express definitions are open to challenge, as they cannot accurately reflect the complexity of the new model, or inconsistencies within the literature. The model is better described through a framework that deals with key attributes, both technical and functional.

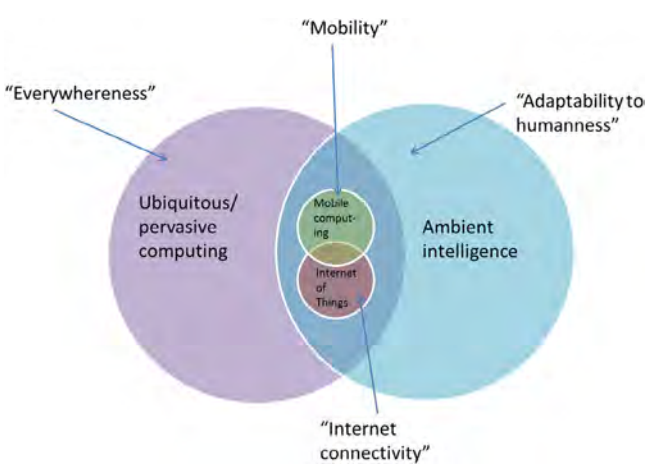

Fig. 2 – Dominant functional lenses of ubiquitous/pervasive computing, ambient intelligence, mobility and Internet of Things.

3. The research framework

3.1. *Construction: key attributes in the literature*

As set out in Part 2 above, scholars have made various attempts to describe the dimensions of this new form of computing. This paper distinguishes possible characterisations of technology within the new model in order to assist in understanding their impacts, and in particular in predicting where challenges might arise for existing regulatory frameworks. The framework is intended to provide guidance when researchers want to evaluate how existing or proposed legal, economic and/or policy models will work when confronted with the socio-technical change brought about by these technologies.

An initial identification of the key dimensions of this new model of computing makes sense as a first step in this analysis. A subsequent paper will take the next step of identifying how these characteristics, by themselves or in combination, differ from existing technologies in ways that might give rise to unique legal problems.

Before the first steps are taken, it is sensible to consider what term might be used to refer to the new model. The concept of "third wave" computing, although tenable, is somewhat too general to be fully useful. As the previous section has shown, no one of the major terms discussed for almost 20 years is satisfactory. As an alternative, we have adopted the term "eObject" to refer not to the model as a whole, but rather to the central element underlying the new model. The concept of "object" is general enough to include both natural things and artefacts, and encompasses living things such as humans and animals. The use of the "e" follows a tradition set by existing terms such as "e-commerce." However, its use here is intended to reflect a broader concept than that of electronic computing or use of the Internet. It describes objects as diverse as phones, walls, buildings, trees, animals and people that are enhanced through the embedment of computing power and communications capabilities.

Previous attempts to identify the characteristics of the variants of eObjects have tended to concentrate on two dimensions: core functional attributes and types of devices or systems. From the existing literature, the most commonly mentioned attributes of eObjects can be summarised as:

- increased device portability;[135]
- increased use of remote telecommunication services;[136]
- embedment of data-handling capabilities in objects or in environments not previously computerised;[137] and
- increased use of internetworking by devices which are partially or wholly autonomous from human users.[138]

Other important attributes of eObject devices and systems that also appear in the literature include:

- devices and systems that are designed to be invisible or unobtrusive to humans;[139]

[134] http://www.iot-a.eu/public.

[135] For example, Mahadev Satyanarayanan, 'Fundamental challenges in mobile computing' in principles of distributed computing: Proceedings of the fifteenth annual ACM symposium (ACM 1996).

[136] For example, Weiser, 'The Computer in the 21st Century' (n 30); Weiser, 'The World is not a Desktop' (n 36); Weiser and Brown (n 36), Poslad (n 51), 19.

[137] For example, Ashton (n 110), National Intelligence (n 111).

[138] For example, Pimple (n 95), 2, Poslad (n 51).

[139] For example, Weiser, 'The Computer in the 21st Century' (n 30), Singh, Puradkar and Lee (n 50), 422.

- devices capable of communication that are intended to populate all/many places, or to provide comprehensive coverage of a specific location;[140]
- humans interacting with many devices;[141]
- devices interacting with many other devices, over internetworks, often without human intervention;[142]
- mobility of the device and/or the human: therefore devices can be mobile, tethered or anywhere in-between;[143]
- devices and/or their interactions can be personalised to their human users;[144]
- devices are often volatile, in relation to their connections to the Internet and other internetworks, their resources and processing speed;[145]
- devices and systems are often more vulnerable to security issues than other types of information and communication technologies, due to both physical and technical design features;[146]
- devices are context-aware;[147]
- objects are capable of being uniquely identified;[148]
- objects are locatable in network space and in real space (geo-locatable);[149] and
- devices often have a significant dependence on external infrastructure, such as satellites or location APIs[150] (for location-tracking) and physical sites into which devices are integrated (such as bathroom shelves and bus shelters).[151]

3.2. *The framework*

The following working definition is adopted:

> An eObject is an object that is not inherently computerised, but into which has been embedded one or more computer processors with data-collection, data-handling and data communication capabilities

Due to the complexity of the model, however, this working definition does not give a complete view of the technologies encompassed within the third wave of computing.

In order to assist in a more detailed understanding of the technological landscape, we have formulated a framework which has 3 key dimensions: **core attributes** of the technology, the **interactions** between devices, systems and living things, and **other attributes** (attributes commonly but not always found in eObjects).

3.2.1. *Core attributes*

The core attributes of an eObject are elaborated in Table 2. These attributes are intended to be definitional: that is, a device or system that is missing one or more of them is not considered an "eObject".

eObjects are often not stand-alone objects, but may be nested within a larger object, or elements of a larger, distributed system. Many physical objects are combinations of other objects, and some or all of these combined objects can be eObjects. For example, a smart refrigerator may contain a number of eObjects: shelves which contain sensors to track products coming in and out via barcodes or RFID tags, an LCD screen with the capability to display notes and order new goods via the internet, and a door and walls containing sensors and actuators which track light, room temperature and door opening frequencies and adjust cooling temperature accordingly.[152]

This combination or "nesting" of eObjects is not limited to physical objects such as home appliances. Systems may be made up of a number of eObjects interacting with each other, living

Table 2 – An eObject's core attributes.

Attribute	Description
Object	Is a physical object, which may be natural or an artefact, of any size, and inert or living
Computer	Contains one or more general-purpose programmable computers, sufficiently miniaturised
Embedded	One or more computers are physically embedded in the object (as distinct from being socially, culturally or metaphorically embedded)
Data-collection	Contains one or more sensors that can collect or generate data. Note that sensors are a core attribute, while **actuators** are not: an ability to act in a physical manner on the environment is **common** in eObjects, but not **essential** (other than the ability to communicate data).
Data-handling	Includes a capability to process data.
Data communication	Can communicate with other nodes inside the same object, or with other objects[a]

[a] Poslad (n 51), 426, postulates the development of "clothes [that] could sense human skin and reconfigure itself to offer more ventilation if it senses the skin is sweating".

[140] For example, Weiser, 'The Computer in the 21st Century' (n 30), Lyytinen and Yoo (n 45).
[141] For example, Weiser and Brown (n 5).
[142] Poslad (n 51), 9.
[143] For example, Lyytinen and Yoo (n 45).
[144] For example, Zelkha and Epstein (n 87).
[145] For example, Satyanarayanan, 'Pervasive computing: vision and challenges' (n 41), Satyanarayanan, 'Fundamental challenges in mobile computing' (n 136), Coulouris and others (n 51), 817.
[146] For example, small portable devices such as fitness trackers and mobile phones are more susceptible to physical theft or damage. There is also some evidence emerging that many eObjects are inherently more vulnerable to security breaches. For example, Satyanarayanan, 'Pervasive computing: vision and challenges' (n 41), Cook, Augusto and Jakkula (n 63), 286–7.
[147] For example, Aarts and Roovers (n 104).
[148] For example, Haller, Karnouskos and Schroth (n 118), 15.
[149] National Intelligence Council (n 111).
[150] Application Program Interface.
[151] For example, Gershenfeld, Krikorian and Cohen (n 33), 78.
[152] See e.g. http://www.yourhome.gov.au/energy/smart-meters-displays-and-appliances; http://au.panasonic.com.au/News+and+views/News/2012/June/Panasonic+ECONAVI+Refrigerators.

things and/or the physical world, even though the system itself may not be an eObject. For example, a home automation system may use:

- embedded processors in its air conditioning, lights, locks, curtains and power supply;
- the owner's smartphone and its applications; and
- a security company's computing and communications devices.

3.2.2. *Interactions*

Interactions among the various types of eObjects and systems represent the second key dimension within the framework. eObjects can interact with living things, the physical world, each other, and other computing devices and systems. These interactions can be technical, physical or social. One reason why interactions are important to distinguish is that, when researching the efficacy of existing regulatory frameworks, the types of interactions may affect relationships between consumers, businesses and governments involved with the technologies. Some examples of interactions relevant to legal, economic and policy research include:

- Interactions with living things: eObjects may have a number of different types of interactions with living things. For example, an eObject may accept input from, or measure something about, a person, animal or plant. If it contains an actuator, it may also act upon that living entity in a physical way. A simple example is a Fitbit fitness device which counts steps taken, and then vibrates to let the user know when a target goal has been achieved.[153] A more complex example is cyborgisation, where legal and policy problems have already been identified, particularly where the implantation that transforms a person into an eObject is involuntary.[154]
- Interactions with other eObjects or systems: eObjects may have interactions with other eObjects or systems which are permanent, or temporary. Many of the eObjects in a smart home will have permanent interactions between them, as they are in fixed locations and are initially designed to work together. A temporary interaction might occur where the processing or communication capabilities of an eObject are co-opted by a system into whose proximity the eObject has been brought. For example, iBeacon devices installed in shops interact with passing mobile phones to trigger

Table 3 – eObjects' other attributes (in alphabetical order).

Attributes	Limits
Active capacity	An eObject may be able to perform acts which have an impact on the physical world, through the use of different types of actuators (devices which move things)
Adaptability	An eObject may adapt or be responsive to context (e.g. physical environment) and/or an individual (often referred to as "context-awareness")
Addressability	An eObject may have, at any given moment, an address that is unique, and that is at least potentially knowable (e.g. IP address, cell address, geo-coordinates)
Associability with living beings	An eObject may have degrees of personal association (either physical, emotional or based on a legal relationship) with particular individual humans and/or groups. These can range from family cars, to phones, to jewellery, to chips implanted in the human body. Associations may also exist with animals or plants (e.g. tracking movement or propagation of endangered populations).
Autonomy	An eObject may be fully autonomous, or have some degree of autonomy from human users or systems of which they form a part. The decision-making capabilities of eObjects may exhibit varying degrees of sophistication.[a]
Dependency	An eObject may depend on remote services and/or infrastructure
Geo-locatability	Any particular eObject, or all eObjects in a system, may be locatable in universal physical space or some bounded physical space
Human computer interaction (HCI)	An eObject, or a system that has eObjects as elements, may be "used" by obvious or explicit interaction (e.g. mobile phones), or by implicit human computer interaction (iHCI) where the eObject interface is unobtrusive or invisible
Identifiability	An eObject may have one or more identifiers each of which may be unique, and each of which may be at least potentially knowable (e.g. International Mobile Equipment Identity (IMEI) number for mobile phone handsets, International Mobile Subscriber Identity (IMSI) number for GSM SIM cards, Media Access Control (MAC) address for a network interface card)
Network locatability	Any particular eObject, or all eObjects in a system, may be locatable in universal network space or some bounded network space[b]
Mobility	An eObject may be operational while moving within a physical space, when used by a person on the move or acting autonomously. A system that has eObjects as elements may maintain services to people while they are on the move, or autonomous operations, within some bounded physical space, by utilising multiple eObjects or successive eObjects encountered by any of its elements while on the move.[c]
Operational, economic and social impact	An eObject's features and performance may be beneficial to some parties and detrimental to others

(*continued on next page*)

[153] www.fitbit.com.

[154] Clarke, 'Cyborg Rights' (n 16).

Table 3 – (continued)

Attributes	Limits
Portability	An eObject may be fixed in place, somewhat limited in movement by cables and connectors (i.e. tethered) or fully portable. Note that this is a subtly different concept from that of mobility: a mobile eObject can operate while on the move, whereas one which is merely portable can be moved from one physical place to another, but cannot operate while in transit.
Prevalence	A category of eObjects, or a system that uses eObjects to perform some function, may be in many places ("pervasive"), or in all places ("ubiquitous")
Use pattern	A person may have, or may use, one particular eObject or multiple eObjects, and may do so only once, with varying frequencies, or continuously.
Volatility	Due to its form factor, an eObject may have variable connectivity, restricted energy, limited storage capacity and slow or intermittent processing capabilities
Vulnerability	An eObject may be more or less vulnerable to security breaches, theft, and physical damage or destruction

[a] Many authors have classified the decision-making aspects of this attribute as an "intelligent" response. We have avoided the use of the term "intelligent" for the reasons discussed in Section 2.3.1 and footnote 93.
[b] Although note that "devices can appear and disappear on the network intermittently, either to save energy or because they are on the move", Neil Gershenfeld and JP Vasseur, 'As Objects Go Online; The Promise (and Pitfalls) of the Internet of Things' (2014) 93 Foreign Affairs 60, 65–66.
[c] Mobility and portability are often conflated in the literature. However, some authors have acknowledged the difference between the two concepts while still using the umbrella term "mobility". See e.g. Uteck (n 9), 34. To better acknowledge the difference between the two concepts, we have used two different terms.

notifications of discounts, or allow for wireless payment.[155] This interaction may lead to the creation of a contractual relationship and/or a duty of care.

3.2.3. *Other attributes*

The third of the key dimensions in the framework is concerned with eObjects' other attributes, which are presented in Table 3. Even though they fall outside of the core definition, they are included within the framework because their existence, inter-relationships, and even the frequency with which they appear can help define various sub-sets within the eObject model. In addition, examination of these common attributes can lead to more specific and detailed analysis of problems that might arise in relation to an eObject. For example, those interested in researching the protection of location information (from either a legal or strategic business perspective) would be particularly interested in objects or systems that are **vulnerable**, **identifiable** and **geo-locatable**.

4. Conclusion

This paper has examined the current literature on the "third wave of computing", in order to better define and understand it for the purposes of the conduct of research, particularly research relating to the impact it may have on existing legal rules and frameworks. The literature, not surprisingly for an area of significant innovation, does not presently contain a clear description of this "third wave", but rather a number of terminologies and definitions that are evolving, overlapping and inconsistent.

The paper has proposed the notion of an 'eObject'. The core properties of an eObject consist of the embedment in objects of computers with data-collection, data-handling and data communication capabilities. Further, the paper recognises that there are many other properties of relevance to these types of technologies, and a variety of interactions among them.

The identification of core and other properties provides a depth of appreciation of the nature of eObjects. Legal scholars have already begun preliminary research in this area, but the research to date appears to have lacked a comprehensive and consistent view of the technology under discussion. This paper has proposed a framework within which researchers are able to analyse the features in depth, with a particular focus on the examination of legal problems that might arise from particular aspects of socio-technological change brought about by eObjects.

The research framework presented above provides a foundation for analysing the implications of the "third wave" from legal, business strategy and public policy perspectives. A subsequent paper will examine socio-technological change brought about by the key innovations of eObjects, particularly in relation to possible effects on consumers (both individual and enterprise), and on manufacturers and distributors of these technologies. The paper will show how the framework enables analyses to be undertaken of particular contexts, showing how the attributes and interactions may give rise to increased litigation. It also offers the prospect of novel fact scenarios for judges to consider, and supports consideration as to whether special rules may need to be created to deal with uses and abuses of these new technologies.

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[155] http://blog.pointrlabs.com/beacons-everything-you-need-to-know/.

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