What is the Internet of Things?

An ontological investigation

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Abstract

The Internet of Things is widely considered to be of major – and increasing – significance as a global socio-technical phenomenon. However, answering the question of what the Internet of Things *is* turns out to be surprisingly problematic. The problem is not the lack of an answer: indeed, the majority of writings on the Internet of Things seek to address this question in some manner. Rather, the problem is the range and diversity of answers that are proposed, leading to a troubling perplexity about how these answers might separately or collectively describe the Internet of Things. Resolving this perplexity is a highly pertinent challenge given the putative importance of the Internet of Things.

In addressing this challenge, I take an unreservedly ontological approach, building on recent ontological thinking in anthropology, Science and Technology Studies and philosophy. I first identify and summarise six influential philosophical schools of thought regarding the ontology of technology: Artefact-based Ontology, Technological Essentialism, Social constructivism, Relationism, Postphenomenology and Object-Oriented Ontology. I then use an inductive method to analyse a sample of Internet of Things literature, thus uncovering common categories of ontological claims about the Internet of Things. Twelve such categories are derived, revealing the Internet of Things to be referred to variously as a technological artefact, a trajectory, a force, an idea, a business opportunity, a contested term, a social actor, something threatened and threatening, a context of use, an enchanted world and a human endeavour. These ontological categories are then brought into dialogue with the philosophical ontologies of technology, identifying where the various categories accord with (or are in conflict with) the different philosophical ontologies.

Based on this analysis, I conclude that the Internet of Things, as reflected in the literature sample, is ontologically multiple, in the sense of having more than one way of being. The analysis also highlights limitations in how well any one of philosophical ontologies can account for the Internet of Things as it is described in the literature. In the final stage of my analysis, I consider the possibility that a single underlying ontology might be able to account for the observed ontological multiplicity of the Internet of Things. After reviewing each of the philosophical ontologies, I conclude that Object-Oriented Ontology – and in particular the theory of hyperobjects – provides the most useful underlying ontology.

Declaration

This is to certify that:

(i) the thesis comprises only my original work towards the PhD

(ii) due acknowledgement has been made in the text to all other material used; and

(iii) the thesis is fewer than 100,000 words in length, exclusive of tables, maps, bibliographies and appendices.

Signed,

Paul Siemers, 30 December 2020

Preface

The following is my own work. None of the chapters are published, or in the process of publication. Research for this thesis was undertaken during my PhD candidature, and has been funded through an Australian Government Research Training Program Scholarship.

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Firstly I offer my respects to the Wurundjeri people on whose land I lived and worked while conducting this research, and my gratitude to the nation of Australia which has offered me a safe and welcoming new home.

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1. Introduction

1.1. Context

The internet is undergoing a major expansion and transformation as the number of things connected to it comes to significantly exceed the number of humans. In 2015 a leading IT company predicted that there would be 50 billion things connected by 2020 (Cisco, 2015). In 2020, though exact figures are hard to come by, it is clear that many billions of devices are already in fact connected, with estimates ranging from around 10 billion (IoT Analytics, 2018) to as high as 31 billion (Cisco, 2019). The resulting 'Internet of Things' has been regularly rated as one of the leading technology trends affecting the world today (Gartner, 2015; Forrester, 2017). And the 'Internet of Things' (IoT) is described not only as a technology trend but as something with major social, economic, political and human implications (Howard, 2015; Manyika et al., 2015; Perkins, 2017). An excellent summary of the Internet of Things from an Australian perspective is provided by Fox et al. (2020) – published as this thesis was nearing completion.

Thus IoT appears in the literature as something important to be understood, something to be engaged with, and something to be built and shaped so that it serves the ends of society and humanity. One of the basic ways we have of understanding phenomena is to enquire into their ontology: to enquire into what they are, and into the nature of their being. A pragmatic first step in seeking to engage with IoT is thus to understand what we are dealing with, to ask the question: "What is the Internet of Things?" (For simplicity of reference, I shall for the remainder of the thesis, refer to "the Internet of Things" as "IoT".)

It may be objected at this point that our central concern should be with what the Internet of Things *does*—the role it plays in the world—rather than with what it *is*. There is however a close interplay between these questions—what a thing does is to some extent determined by what it is, and vice versa. Recent work in anthropology and Science and Technology Studies (referred to hereafter as STS) has demonstrated that ontology is a productive way to approach such questions. This will be discussed further in *Section 2.2:*

Ontology as a methodological tool below. Thus it is anticipated that an investigation into what IoT *is* will also cast some light on what IoT *does*. Such an investigation may indeed cast some light onto the relationship between *being* and *doing* (at least in the case of IoT). For the purposes of framing this research, it is sufficient to concede that both *being* and *doing* are important questions, and that this research is focused on the former while not being ignorant of the latter.

What then is the Internet of Things? Answering this question turns out to be surprisingly problematic, though the problem is not the lack of an answer. There are many answers—indeed the majority of writings on IoT seek to address this question in some manner. Rather, the problem is the great range and diversity of answers that are provided, leading to a troubling perplexity about how many of them can be true at the same time.

In an enquiry into the nature of IoT, a few of the characteristic answers encountered are the following:

The technical definition:

> Definition: The Internet of Things (IoT) is the network of dedicated physical objects (things) that contain embedded technology to sense or interact with their internal state or external environment. The IoT comprises an ecosystem that includes things, communications, applications and data analysis. (Tully et al., 2014, p. 6)

The articulation of a compelling vision:

> Bringing the digital magic of the Internet economy to the machines that run the world is the heady vision of the industrial Internet, or the industrial Internet of Things. (Lohr, 2015, p. 1)

Descriptions of sweeping changes to the way we live:

> The scope of IoT is enormous and will affect every aspect of all our lives. (Stankovic, 2014, p. 4)

Predictions of fundamental changes to society:

> The IoT is driving a pervasive digital presence throughout organizations that, when connected, will change the fabric of business and society. (Perkins, 2017, p. 4)

Projections of new political forms and forces:

> As an empire, the internet of things certainly has its enemies and rivals. (Howard, 2015, p. 151)

Promotion of opportunities for commerce and profit:

> The Internet of Things is a major opportunity for incumbent technology suppliers as well as for emerging players. (Manyika et al., 2015, p. 23)

Promises of benefits to humanity:

> The Internet of Things is beginning to demonstrate its potential to improve human health. (Manyika et al., 2015, p. 28)

And dystopian warnings:

> Although a dystopia is the worst-case scenario, the IoT could certainly exacerbate a range of undesirable situations. (Roman, Najera & Lopez, 2011, p. 54)

In the face of such diverse response, it is perhaps tempting to seek a simple resolution.

For example, perhaps IoT is *really* just the technical artefact, the "boxes and wires" (in which we may include software and data), and everything else is merely a consequence of this? On reflection, however, it can be seen how unconvincing this is. "Boxes and wires" may exist in a laboratory, but IoT exists out there in the world, inextricably tangled with things from pump stations to traffic lights to artificial hearts. Accounting for IoT as a discrete technical artefact (as "boxes and wires") cannot account for this entanglement of IoT's being with its worldly context. Besides which, it is hard to see how "boxes and wires" can, by themselves, effect social and economic change—which must ultimately implicate human agency. It seems that the Internet of Things must be inextricably entangled with the physical world and with human affairs—that this entanglement is necessary to the being of IoT.

Conversely, maybe IoT is *really* nothing more than the sum of its entanglements? This, however, leads to two apparent difficulties. Firstly, how are we to account for the fact that IoT is so widely regarded as something more than this, as something standing "behind" these entanglements (see for example the quotes above on the nature of IoT)? Secondly, if IoT is nothing more than its entanglements, how are we to explain IoT's ability to continually evolve by entering into *new* entanglements?

Or perhaps the IoT is *really* just the grand vision, and everything else is mere implementation? But this seems equally unsatisfactory. Part of what is meant by IoT is something real and tangible, thousands of projects, products on the shelves, billions of sensors. The grand vision could exist without any of this, but this would be a science-fiction concept (Skynet?) and not IoT.

It seems that any overly simplistic explanation must be subject to the kind of critique just given. The question "What is the Internet of Things?" thus proves to be challenging, and to require a searching ontological enquiry if we are to find a satisfactory answer. To undertake such an enquiry requires us to go beyond the usual bounds of IoT discourse and to engage with more fundamental philosophical questions. Such an inquiry is not only interesting, it is (as I shall argue below) also useful and important.

1.2. Aims, Scope and Significance

As a starting point for such an enquiry, it seems reasonable to grant that the Internet of Things is (at least in some respects) a technological phenomenon—if by this we mean no more than "a phenomenon which involves technology". Fortunately, ontological enquiry into the nature of technology and of technological phenomena is not a new endeavour. Interest in the nature of technological phenomena dates back to Aristotle (350BCEb), if not further. This interest was renewed during the Renaissance, notably in the works of Francis Bacon (Bacon, 2003). However, it was in the mid-20th century that it reached full expression in the writings of Mumford (2010), Heidegger (1977), Wiener (1961), Ellul (1980) and the Frankfurt school (Marcuse, 2002) (among others). Since that time there have been a number of distinctive (though related) approaches to the ontology of technology, including technological substantivism and determinism, social constructivism, Actor-Network Theory, postphenomenology and Object-Oriented Ontology. There has also been the continued articulation of a more artefact-centric ontology of technology, grounded in the engineering profession.

This enquiry will consider the nature of the Internet of Things through the lens of this long tradition of thinking about the nature of technology in general. There are three ways in which this will be a useful undertaking, which will make a meaningful contribution to our knowledge of both the Internet of Things and of technology more broadly:

Firstly, and as noted above, the Internet of Things is of such scale, and of such potential significance to human society, that understanding it better is a worthwhile project in itself. We may anticipate that a better understanding of a technological phenomenon such as IoT better equips us to shape its unfolding. For example, a better understanding of the Internet of Things will help to ensure that it enables greater human prosperity and human flourishing (rather than the reverse). Evans, Gruba & Zobel (2014, p. 87) note that, "[a] particular phenomenon can be studied in its own right"—which they term a "study"—"or to provide information on a broad range of similar phenomena"—which they term a "case study". As I have argued above, IoT is of sufficient significance to be studied in its own right, and so this thesis is primarily a study rather than a case study.

It may nevertheless be reasonably hypothesised that the Internet of Things has much in common with other large-scale technological phenomena, and more especially technological phenomena which are global, networked, and of broad application. Thus a better understanding of the ontology of IoT may provide a better understanding of the ontology of other technologies, which would in turn enable a better understanding of those technologies *in toto*. The value of an ontological examination is argued in *Section 2.2: Ontology as a methodological tool* below. Given the importance of technology in the current era, importance which brings with it significant opportunities and threats, any greater insight we can gain into technology is surely of value. It must nevertheless be stressed that the potential value of this thesis as a case study is secondary to its value as a study of the particular phenomenon of IoT.

Lastly, bringing theories regarding the ontology of technology into dialogue with a real-world example will, it may be hoped, provide fresh insight into these ontological theories – highlighting their areas of explanatory strength but also potentially demonstrating limitations, biases and blind-spots. Again, though significant, this value is supplementary to the thesis's primary contribution as a study of IoT.

1.3. Structure

This thesis is structured in the following way:

In *Chapter 2: Literature Review* I review three relevant bodies of literature: literature concerning ontological investigation as a method of enquiry, literature relating to the ontology of technology, and literature concerning IoT itself. Literature regarding ontological investigation is used to found the methodology employed in the rest of the thesis. The literature concerning IoT is briefly surveyed in the Literature Review, but a more detailed exploration of this class of literature is reserved for *Chapter 5: Data Analysis.*

Chapter 3: Ontologies of Technology examines the literature concerning the ontology of technology in more depth. From among the many currents of thought found in the literature relating to the ontology of technology, six broad philosophical perspectives are distilled. As the thesis progresses, these six philosophical perspectives on the ontology of technology are brought into dialogue with the literature concerning IoT.

The overall intent of the enquiry has already been indicated by asking "What is the Internet of Things?" I start *Chapter 4: Research Question, Methodology and Method* by refining this broad query into a well-defined research question, and by stating the contribution to be made by answering it. Next, I outline the approach to be adopted, relating this approach to various precedents. The chapter concludes with a more-detailed description of the method to be employed, with particular emphasis on the method for data sampling and analysis.

Chapter 5: Data Analysis begins with a quantitative and qualitative survey of the data sample. The major part of the chapter is then devoted to an inductive analysis of the way the ontology of technology is described in the sample texts. In particular, I argue that, in the texts sampled, the ontological references to IoT can be grouped into twelve broad but coherent empirical categories. The remainder of the chapter is devoted to a qualitative analysis of these categories, and a discussion of their relationship with one another.

In *Chapter 6: Ontological Investigation* the twelve categories of ontological reference identified in the IoT literature in *Chapter 5: Data Analysis* are brought into dialogue with the six philosophical perspectives on the ontology of technology described in *Chapter 2: Literature Review*. To commence, I reflect on the extent to which the ontological references found in the IoT texts allow us to attribute ontologies of IoT to these texts. I then compare the categories of ontological reference with the philosophical perspectives, and attempt to identify "resonances"—that is, instances where there is a demonstrable alignment between a category of ontological reference and a philosophical perspective. From this work, a pattern of resonances emerges, suggesting that IoT is ontologically multiple.

I then consider the possibility of an underlying ontology—that is, a deeper ontological structure which could account for this ontological multiplicity. Each of the six philosophical perspectives is evaluated as an underlying ontology. Three concepts from the literature—boundary objects, ontology-in-practice, and hyperobjects—are also considered as explanatory mechanisms. This section also provides the occasion to comment on the strengths and limitations of the philosophical perspectives, and the functions they perform.

In the final chapter (*Chapter 7: Conclusions and directions for future research)* I first revisit the key findings from Chapters 5 and 6. I then argue that, of the theories considered, Object-Oriented Ontology (and in particular the theory of hyperobjects) is best able to the meet the criteria for an underlying ontology, and can thus provide the most persuasive ontological account of IoT. To conclude the thesis I briefly explore key implications of this conclusion, identify some limitation of the current research, and suggest directions for future research.

2. Literature Review

The introductory chapter outlined the research project, and argued for its significance. To move forward with the project, it is first necessary to build a sound basis of theory through a critical review and analysis of the relevant literature.

In reviewing the literature, this chapter addresses three aims. Firstly, it situates the research within the existing literature, providing the necessary context to delineate the scope and significance of the research. Secondly, it identifies and reviews other efforts which have been made to explore similar questions. Finally, it considers what methods have been employed in such previous attempts, and weighs their relevance for the current study.

To meet these three aims, an overview will first be provided, explaining how this research lies at the intersection of three bodies of literature, namely:

(i) Literature relating to the use of ontology as an investigative tool
(ii) Literature concerning the ontology of technology
(iii) Literature relating specifically to IoT

The chapter will then consider the "ontology as method" literature in more detail, examining modern approaches to the use of ontology within STS and related disciplines. Next, the ontology of technology literature will be reviewed in more depth. An historical sketch of the history of the philosophy of technology will be used to identify and situate six approaches to the ontology of technology, which will be developed as an analytical framework in subsequent chapters. This will set the scene for an in-depth analysis of the IoT literature, which will be developed in the following chapters.

2.1. Overview

This thesis investigates the ontology of the Internet of Things and as yet no published body of literature exists on this topic. Nevertheless, there are three substantial bodies of literature which are proximate to it.

Firstly there is literature which is aligned to the current study in terms of approach; that is, literature which makes use of ontology as an investigative tool. The past few decades have seen a revival of interest in ontology across several of fields, including anthropology, STS and philosophy itself. In particular, ontology has been advanced as a theoretical tool for use in investigation of anthropological and sociotechnical phenomena. This literature is relevant to the current study because it provides methodological precedents.

Secondly, there is literature which examines a more general version of the problem under consideration—namely the general question of the ontology of technology. This literature has a long lineage, which can ultimately be traced back to Aristotle. It has grown in interest following the emergence of the philosophy of technology as a distinct discipline in the mid-twentieth century. The philosophy of technology has often proceeded from a strong ontological basis, whether overt or implicit. This literature provides the current study with ways of thinking and speaking about the ontology of technology in general, which form a frame for the investigation of the specific example of IoT.

The third corpus consists of the very extensive published literature on IoT. This may be further divided into three main sub-types. The academic literature alone includes more than 10,000 articles (Elsevier BV, 2017a). These are drawn mainly from the technical disciplines: computer science, engineering, mathematics and physics. However, there some are hundreds of articles drawn from other disciplines, including law, social science and various other humanities.

There is also large professional, commercial and "grey" literature, largely produced by and for practitioners in the many IoT-related fields (e.g., business professionals). Much of it is produced by advisory firms (e.g., Gartner, McKinsey, Deloitte) or by technology vendors (e.g., IBM, Cisco, Siemens).

Finally, there is the burgeoning popular literature on the topic of IoT, including books, newspaper and journal articles, websites and blogs. Much of this takes the form of general media sources (newspapers, magazines, blogs, etc.) commenting on IoT as a topic of popular interest.

As noted above, despite extensive coverage from other approaches, there is at present very little literature discussing IoT from a philosophical perspective. What does exist mostly takes the form of commentary on the ethical implications of IoT. No sustained analysis of IoT from an ontological standpoint has been identified.

One challenge faced by the current research project is the pragmatics of the analysis of such a large volume of texts, in order to make sense of the discourse as a whole. The proposed approach is to use textual analysis on sample sets of texts. Properly speaking then, the corpus of texts dealing with IoT is being treated as research data rather than as foundational literature *per se*. Further discussion of this corpus will thus be reserved for the next chapter.

2.2. Ontology as a methodological tool

As noted above, the first body of literature we shall examine is that which relates to the use of ontology as a methodological tool. The purpose of reviewing this literature is two-fold. Firstly, it will provide methodological precedents and guidelines for the current research. Secondly, it will demonstrate that the current research is part of a broader contemporary movement towards the use of ontological methods, and thus situate it within an ongoing intellectual discourse.

2.2.1. The Ontological Turn

As noted above, the last 20 years have seen a resurgence of interest in ontology across a number of fields, especially anthropology, STS and philosophy. This cross-disciplinary resurgence of interest in ontology may be described as the "ontological turn" (while noting that "ontological turn" has also been used to describe specific manifestations of this trend within anthropology) (Holbraad & Pedersen, 2017). This broad banner covers distinct but related trends of thought across the three disciplines (anthropology, STS, philosophy). Henare et al. (2007) describe this as a "quiet revolution" in anthropology underpinned by a shift in focus towards questions of ontology (Henare, Holbraad & Wastell, 2007, p. 19). Law (2004) stresses the vital importance of "ontological methodology" for method within social science research. Focusing on STS, he charts the growing importance of ontology since the 1980s, noting, for example, the influential work of Mol (2002) on medical ontology. In philosophy too, there has been a "recent surge of interest in properly ontological questions" (Bryant, Srnicek & Harman, 2011a, p. 4).

It is important at this point to note two different ways in which ontology is employed within the ontological turn. The first application of ontology is metaphysical; it takes the construction or uncovering of ontologies as its goal. These applications of ontology suggest "albeit often only implicitly, that a turn to ontology must involve participating in, or contributing to, the traditional philosophical project of building a metaphysical account of the basic constituents of existence" (Holbraad & Pedersen, 2017, p. 32).

The second application of ontology within the ontological turn is the methodological use of ontology as a means of elucidation: the deployment of ontology as an investigative tool to assist in the analysis, interpretation and understanding of whatever matter is under consideration. This methodological use of ontology need not have a metaphysical goal, that is, the use of ontology in a methodological fashion does not imply that the goal is to construct or recover ontolog(ies). Here ontology is used "not in the name of arriving at a better ontological image of what the world is 'really like', but rather as a matter of methodological expedience" (Holbraad & Pedersen, 2017, p. 32). It is *using* ontology rather than *doing* ontology. Because these two modalities of ontology—the metaphysical and the methodological—often occur in conjunction, it is helpful to keep the distinction in mind in order to avoid confusing their differing approaches and goals.

We shall now move to consider the forms taken by the ontological turn within each discipline. Given that ontology has its origins within the discipline of philosophy, philosophy will be taken as the point of departure.

2.2.2. The Ontological Turn in Philosophy

The recent ontological turn in philosophy is closely associated with the recent movement known as "speculative realism". The term speculative realism was coined for an event held at Goldsmiths College, London, in 2007, inspired by the publication of Quentin Meillassoux's book *After Finitude* (*Après la finitude*) (Bryant, Srnicek & Harman, 2011b). In *After Finitude,* Meillassoux criticises what he describes as a long tradition of "correlationism" within philosophy. For him, "correlationism consists in disqualifying the claim that it is possible to consider the realms of subjectivity and objectivity independently of one another" (Meillassoux, 2008, p. 13). In other words, correlationism is the view that we only have access to subjects and objects as they stand in relation to each other, never as they are in isolation from each other. Meillassoux argues that correlationism has impoverished contemporary philosophy:

> It could be that contemporary philosophers have lost the great outdoors, the absolute outside of pre-critical thinkers: that outside which was not relative to us, and which was given as indifferent to its own givenness to be what it is, existing in itself regardless of whether we are thinking of it or not; that outside which thought could explore with the legitimate feeling of being on foreign territory—of being entirely elsewhere. (Meillassoux, 2008, p. 17)

The speculative realist movement has flowered rapidly. It is one of the first philosophical movements to have been significantly shaped by online blogging and discussion (Bryant, Srnicek & Harman, 2011a) and has grown to include a sometimes bewildering diversity of views. This has led some to question the coherence and seriousness of the movement. Ray

Brassier—the actual inventor of the term “speculative realism”—has disavowed the movement altogether: “The ‘speculative realist movement’ exists only in the imaginations of a group of bloggers promoting an agenda for which I have no sympathy whatsoever” (Brassier, 2011, under "I am a nihilist because I still believe in truth").

Speculative realists are united in the first instance by what they reject: “The repetitive continental focus on texts, discourse, social practices, and human finitude”—all of which they see as reflecting an unjustified anthropocentrism. They are further united by the broad project of “turning once more toward reality itself” and understanding the “nature of reality independently of thought and of humanity more generally” (Bryant, Srnicek & Harman, 2011b, p. 3).

Under this broad banner, speculative realism brings together different branches of thought; and, of particular interest for the current research, a number of different approaches to ontology. For example, Meillassoux (2008) seeks to ground reality in the existence of a mathematical absolute. He argues that even correlationism requires knowledge of this absolute, and is incoherent without it. Iain Hamilton Grant (2011, p. 45) argues for a transcendental realism, with actual objects being grounded in a region of “pure productivity” which provides the “necessary anteriority for any and all objects”. Proponents of Object-Oriented Ontology—for example, Graham Harman—propose a “flat ontology”, granting equivalent ontological status to objects of all kinds and at all levels. This equivalence is extended to objects regardless of whether they are physical or conceptual.

It should be noted that no equivalent “turn to ontology” is discernible in reflections on technology itself, that is, in the philosophy of technology (Dusek, 2006; Franssen, Lokhorst & van de Poel, 2015; Reydon, 2020). The ontology of technology from a philosophical perspective in considered in some detail in *Chapter 3: Ontologies of Techology* below.

The ontological turn in philosophy means that there is now a significant—though by no means universal–move away from an exclusive focus on epistemology and the blanket rejection of metaphysics. The ontological approach of this thesis is thus not exceptional from a philosophical standpoint—it is part of broader re-awakening of interest in ontology.

In addition, the recent ontological turn in philosophy is relevant to the current thesis because it has opened up alternative possibilities for the ontology of technology. We shall return to

Object-Oriented Ontology in particular in a subsequent section as we consider possible ontologies of technology.

2.2.3. The Ontological Turn in Anthropology

The ontological turn in anthropology may be characterised by contrasting it with alternative methodological approaches. A distinction is drawn by Henare et al. (2007) between the alternatives of ontological and epistemological orientation within anthropological analysis. An epistemological orientation ascribes different perceptions of the world to differences in the observer, because the objective world is assumed to be the same for all observers. By accounting for differences in mental/cultural terms, epistemological methods are able to preserve a belief in a single material reality, which can be objectively described by natural science; in summary "matter (nature) just is what it is indifferently, mind (culture) can represent it in different ways" (Henare, Holbraad & Wastell, 2007, p. 9).

An ontological orientation, by contrast, is prepared to attribute differences in perception to differences present in the world itself. An ontological orientation, that is, concedes that the world may be different for different observers: it takes the observers' own ontological accounts seriously.

For example, consider Marcel Mauss's (1990) example of gift exchange in Maori society, discussed in his classic 1950 essay "The Gift". Mauss relates the Maori belief that personal goods (*taonga)* are possessed of a spiritual power (*hau*) relating to their owner. If the rules of reciprocal gift exchange are not properly observed, the *hau* may cause misfortune to fall upon the offender (Mauss, 1990). Later scholars question the ethnographic veracity of some aspects of Mauss's account (Sahlins, 1972).

Mauss's account is ontologically interesting because it challenges what we would regard as the normal boundary between people and things. According to Holbraad and Petersen, mainstream anthropological traditions seek to explain such ontological anomalies by "encasing them within generalizing theories about culture, society, human nature and so forth, or trying to explain them away with a good dose of common sense" (Holbraad & Pedersen, 2017, p. 2). For example, the *taonga/hau* may be explained as means for tracking value and ensuring fairness in exchange (Sahlins, 1972). The ontological approach, by contrast, does not prioritise the translation of *taonga*/*hau* into our own "common sense" ontology. Instead, it seeks to "run with" the reality of *taonga/hau* as given in order to understand how the Maori world is conceptualised (Holbraad & Pedersen, 2017).

According to Holbraad & Pedersen (2017) the ontological turn within anthropology includes three distinct approaches. The first of these they term *alternative ontology*. The alternative-ontology approach seeks to articulate an ontological alternative to what is taken by proponents of alternative ontology as the prevailing "Western" ontology. Proponents of alternative ontology criticise Western ontology for being rigidly dualist in the clear lines it draws between subject/object, mind/body, ideal/real etc. Such proponents argue that a non-dualist ontology is more inclusive than the dualist alternative in that it can express experiential dimensions of human experience which are obscured by dualism (Holbraad & Pedersen, 2017). In addition, advocates of alternative ontology argue for the moral superiority of non-dualism, associating dualism with the negative effects of Western hegemony. For example, de Castro (2015, p. 333) argues that Western ontology "turned out to have disastrous consequences when considered from its business end, i.e. as an imperialist, colonialist, ethnocidal and ecocidal 'mode of production'".

Holbraad and Pedersen term the second ontological approach within anthropology *deep ontologies*. The deep-ontologies approach argues that differences in ontology are deeply rooted causes of differences in culture and behaviour: "The idea that the human world comprises a deep level of ontological structures and dynamics which in turn informs a shallower ontological level of social formations and practices" (Holbraad & Pedersen, 2017, p. 60). For example, Scott (2007, p. 21) describes the study of "onto-praxis" as "the attempt to identify the deepest level of ontology operative in a given time and place, and to situate particular ideas, practices, and institutions with respect to the proper strata of ontology to which they give expression and on which they may impinge in transforming ways".

Finally, Holbraad & Pederson describe a third approach to ontology within anthropology, with which they themselves identify. Holbraad and Pederson do not furnish a specific term for their approach, but I shall term this approach *instrumental ontology*. Unlike deep ontologies or alternative ontology, "non-foundational ontology" does not set out to reveal fundamental ontological structures. Instead, ontology is used as a tool for investigation, for challenging assumptions in order to achieve greater insight. "Insofar as this way of doing anthropology is concerned with matters of metaphysics or 'ontology' in the philosophical sense of the word, it is so in the service of allowing the object of ethnographic analysis to have a transformative effect on the ontological assumptions the anthropologist brings to it (Holbraad & Pedersen, 2017, p. 68). Researchers are thus able to generate and employ ontologies as heuristics, without deeply committing to these ontologies (Pedersen, 2012).

The ontological turn within anthropology has been subject to robust criticism and debate (Laidlaw & Heywood, 2013). Critics of the ontological turn frequently take aim at its ontological foundations and commitments (Pedersen, 2012). Some of the critics suggest that the turn, far from opening up new freedom in ontological enquiry, commits its proponents in advance to a predefined meta-ontology. For example, Heywood (2012) argues that to take the ontological claims of different groups seriously commits the researcher in advance to "a meta-ontology in which 'many worlds' exist" (Heywood, 2012, p. 148).

At this point we should pause to consider what is meant by "meta-ontology". Hofweber (2014, S3.1) gives the philosophical definition of meta-ontology as "the study of what ontology is" and suggests that its scope is "saying what task it is that the discipline of ontology should aim to accomplish, if any, how the questions it aims to answer should be understood, and with what methodology they can be answered". He further notes that meta-ontology is strictly speaking not part of ontology, but that, "like most philosophical disciplines, ontology more broadly construed contains its own meta-study, and thus meta-ontology is part of ontology, more broadly construed". Within anthropological discourse, however, the use of the term meta-ontology is less narrowly defined. In anthropology, meta-ontology is commonly used to refer to any ontology which is not directly derived from the reports or observation of an interlocutor (see for example Heywood, 2012; Laidlaw & Heywood, 2013). Most frequently meta-ontology is used to refer to the ontological framework employed by a researcher, and the ontologies developed using this framework. The "many worlds" ontology described by Heywood (2012) is an example of such a theoretically derived framework. For the remainder of this section *meta-ontology* will be used in this second, anthropological sense.

Proponents of the ontological turn respond to critique of its meta-ontological foundations in various of ways, three of which are explored by Pedersen (2012). Firstly, they argue that any meta-ontology which is employed in investigation is not a deeply held dogma, but simply an exploratory device which may be used in a "playful" fashion. "The ontological turn has no covert meta-ontological ground, for its only 'ground' is precisely its radically contingent attitude expressed not only in its open-ended attitude to its object of study but also in its relative lack of commitment to the heuristic concepts that it creates and deploys" (Pedersen, 2012). This is similar to the approach described above as "non-foundational ontology".

Secondly, proponents of the ontological turn suggest that its underlying meta-ontological commitments are modest, and do not amount to a required belief in many worlds. An important example of this kind of meta-ontological commitment arises from two different senses in which the term "ontology" may be used. An ontology may either *describe a view* about what exists, or it may *advance a claim* about what exists (Laidlaw, 2012; Pedersen, 2012). Laidlaw (2012) accuses proponents of the turn of using these two senses in an inconsistent and interchangeable manner. Pedersen (2012) responds that "this seeming slippage from essence to theory/model is one of the greatest methodological advantages of the ontological turn". He argues that a meta-ontological acceptance of this slippage is in fact necessary to the ontological turn.

Pedersen then questions in turn, "does not the distinction between describing ontologies and making ontologies hinge on a tacit meta-ontology of its own?" This leads to the third defence made by champions of the ontological turn: to challenge the meta-ontogical assumptions of their opponents. Pedersen (2012) attacks these meta-ontological assumptions as "common nonsense": seemingly common-sense views which actually rest on implicit (and thus un-questioned) ontological assumptions.

The literature from the ontological turn in anthropology has been dealt with at some length because it provides useful theoretical foundations for the current research in several ways.

Firstly, it demonstrates that the use of ontology as the basis for an investigative method—though not uncontroversial—is thought to have significant explanatory power in empirical and not just theoretical settings. This is evidenced by a sizeable corpus of relevant research, which demonstrates that the current research is situated within a contemporary intellectual discourse of considerable breadth and promise.

Secondly, the literature from the ontological turn in anthropology clarifies the role of ontology in empirically grounded research. In particular, the extended theoretical debates referenced above make it clear that *using* ontology is not equivalent to *doing* ontology. In particular, it establishes that use of an ontological method does not commit one in advance to a particular "meta-ontology".

Finally, this body of literature underlines the importance of making the researcher's own ontological commitments explicit. If this is not done there is a danger of "smuggling in" implicit ontological assumptions which may determine the research's outcomes in advance.

2.2.4. The Ontological Turn in Science and Technology Studies (STS)

The ontological turn in anthropology is associated with a similar movement within STS: as observed by Holbraad and Pedersen (2017, p. 41), "the flow of inspiration between these two currents of thinking has been mutually rewarding and often productive". In particular, anthropologists often cite the work of Bruno Latour, certainly one of the most influential figures within STS.

In his 1991 classic *We have never been modern*, Latour takes aim at what he terms the "modern constitution", a rigid dualist ontology which sharply divides the world between things on the one hand, and humans on the other. Under this constitution, certain attributes are reserved for humans. In particular, only humans are to be regarded as capable of exercising true agency, with all the rights and obligations that this implies (Latour, 1991). Latour argues that this ontology misrepresents the world, suggesting that agency is much more widely distributed, being exercised by "hybrids" composed of both human and non-human actors.

Given Latour's formative influence on Actor-Network Theory (ANT), it is no exaggeration to say that ANT, and indeed much of modern STS research (e.g., Law, 2004; Mol, 2002), builds on the rejection of certain commonly held ontological assumptions. Further, it can be shown that ANT brings with it its own set of ontological assumptions. ANT emphasises not actors themselves, but the way they relate to each other (Dusek, 2006). The underlying ontology of ANT may thus be described as *relationism*: the view that a thing or object is fully revealed by relationships, and that it is these relations in which reality is ultimately grounded (Harman, 2009). The relationism of ANT is not merely an ontological position—it is first and foremost the basis for a methodology. Nevertheless, given the ontological approach of this research, it is the ontological ramifications of ANT's relationism which will be of most interest. The relationist ontology will be discussed further under *Section 3.4: Actor Network Theory and Relationism* below.

Despite these ontological underpinnings, an explicit focus on ontology as an element of method within STS is a relatively recent phenomenon. Woolgar & Lezaun (2013, p. 321) note that "there is in science and technology studies a perceptible new interest in matters of 'ontology'.

Until recently, the term 'ontology' had been sparingly used in the field. Now it appears to have acquired a new theoretical significance and lies at the centre of many programmes of empirical investigation."

The extent to which this might constitute a "turn", or indeed what such a turn might signify, is a matter of discussion and debate. For example, van Heur (2013) conclude that, while the use of ontological terminology in STS increased between 1998 and 2008, there is no strong evidence of a single, identifiable turn. Instead, they find evidence of several smaller and more localised shifts. They also note an increased citation of STS authors in neighbouring fields, concluding that "the discursive shift towards ontology in STS constitutes a successful "branding" strategy, contributing to the enhanced visibility of STS beyond its immediate borders" (van Heur, Leydesdorff & Wyatt, 2013, p. 357). An example of this can be seen in the frequent reference to STS authors within ontologically oriented anthropology texts (e.g., Holbraad & Pedersen, 2017).

The use of ontology within STS was pioneered by Annemarie Mol (2002) in her much-cited book, "The Body Multiple". In this influential work, Mol studies the ways in which diseases are diagnosed and treated in different departments of a Dutch hospital. She concludes that the same disease is ontologically different in different locations – for example, that atherosclerosis in the pathology laboratory is not the same thing as atherosclerosis in the doctor's surgery (Mol, 2002). Crucial to this argument is the metaphysical assumption that reality is not something passive which we discover, but is instead "enacted" by particular practices (Law, 2004). Thus different practices in different parts of the hospital do not simply create different perspectives on the same ontology, they enact different ontologies. As Law (2004, p. 55) emphasises, "We are not dealing with different and possibly flawed perspectives on the same object. Rather we are dealing with different objects produced in different method assemblages".

The idea that reality is "enacted" by practices or methods, rather than simply represented, effectively breaks down the binary distinction between ontology and epistemology. Woolgar & Lezaun (2013) suggest that problematizing the epistemology/ontology boundary has long formed part of the STS project, and that describing reality as "enacted" is an intensification of this trend, rather than a radical departure. They note that "enactment is one of a cluster of related terms used to adduce a form of scepticism about essentialism and about the notion that entities pre-exist our apprehension of them" (Woolgar & Lezaun, 2013, p. 324). By this account earlier concepts such as "social shaping" also seek to "expose the contingent bases of representation and thereby promote a sceptical view of the relation between representation and the world" (Woolgar & Lezaun, 2013, p. 324). "Enactment" is simply a more thorough-going and provocative approach to this task. Following this line of reasoning, the authors suggest that the turn to ontology within STS can best be understood, not as "a project to champion one or another version of ontology" but rather as another attempt to, "apply its [i.e., STS's] longstanding core slogan—'it could be otherwise'—this time to the realm of the ontological" (Woolgar & Lezaun, 2013, p. 324).

Pickering (2006a) argues that concepts in particular are intimately entangled with practice: "We should think of conceptual structures as themselves located in fields of agency, and of the transformation and extension of such structures as emerging in dialectics of resistance and accommodation within those fields, dialectics which, for short, I call the mangle of practice. . . . Metaphysics, like everything else, is subject to mangling in practice" (Pickering, 2006a, p. 251; ellipses added). These comments have a double relevance for this thesis. Firstly, they suggest how the construction and manipulation (the "mangling") of ontologies may form an integral part of the practice of IoT. Secondly, they suggest that the use of ontologies as an investigative tool within this thesis is part of the same overall field of practice.

In its overt intent, the use of ontology within STS is thus similar in spirit to what is described as "instrumental ontology" (see *Section 2.2.3: The Ontological Turn in Anthropology* above). As with instrumental ontology, ontology in STS is being used as an investigative tool, and without any deeply held ontological commitment on the part of the investigator. However, Holbraad & Pedersen (2017, p. 43) suggest that this ignores more fundamental ontological commitments within STS: "The characteristic methodological openness and conceptual reflexivity of much STS scholarship is often grounded on a specific image of the ontological constitution of the world, according to which the world is itself open and in a state of permanent reconstitution.… In such a case, however, what is presented as an essentially methodological, reflexive and constitutively disruptive ontological argument, ends up being pressed into the service of an authoritative metaphysical story about what the world is like, and how it works." This is closer to the "alternative ontology" approach discussed above (see *Section 2.2.3: The Ontological Turn in Anthropology* above).

The ontological turn in STS is important for the current study because it demonstrates that there is an influential school which takes the view that an investigative strategy founded in ontology is viable and produces useful results. In addition, the ontological turn in STS provides numerous case studies (e.g., Mol, 2002; Woolgar & Lezaun, 2013) which collectively outline a methodology which will inform the method to be adopted in the current research.

Having considered the literature relating to the use of ontology as a methodological tool, and the value of this approach, it is now possible to turn to the second body of literature mentioned above viz. the literature concerned with the ontology of technology.

2.3. Ontologies of technology: overview and survey

As noted above (see *Section 2.1: Overview*) philosophical reflection on technology has a long history. Much of this reflection is ontological, or has ontological implications, as will be shown. The canon includes dozens of major figures whose views are expressed with considerable nuance and complexity. Thus, one of the key challenges encountered in this research is the breadth of theoretical material available. To adequately consider more than two thousand years of reflection on the nature of technology within the space of a single thesis may seem an impossible task. The requirement is thus to summarise this tradition so as to provide a framework which is compact and coherent enough to be useful for the current study while remaining authentic to the philosophical tradition.

To provide such a framework requires summarisation and categorisation, which is an inherently imperfect and subjective task. To quote Foucault:

> This book first arose out of a passage in [Jorge Luis] Borges, out of the laughter that shattered, as I read the passage, all the familiar landmarks of my thought—our thought that bears the stamp of our age and our geography—breaking up all the ordered surfaces and all the planes with which we are accustomed to tame the wild profusion of existing things, and continuing long afterwards to disturb and threaten with collapse our age-old distinction between the Same and the Other. This passage quotes a "certain Chinese encyclopaedia" in which it is written that "animals are divided into: (a) belonging to the Emperor, (b) embalmed, (c) tame, (d) suckling pigs, (e) sirens, (f) fabulous, (g) stray dogs, (h) included in the present classification, (i) frenzied, (j) innumerable, (k) drawn with a very fine camelhair brush, (l) et cetera, (m) having just broken the water pitcher, (n) that from a long way off look like flies". In the wonderment of this taxonomy, the thing we apprehend in one great leap, the thing that, by means of the fable, is demonstrated as the exotic charm of another system of thought, is the limitation of our own, the stark impossibility of thinking *that*. (Foucault, 1970, p. xv)

We cannot hope for a final or perfect categorisation. We must rather aim for a categorisation which is as faithful as possible to the material under consideration while also being pragmatic, that is, of practical use to the investigation at hand.

In this research, to make the investigation manageable, consideration has been limited to six important schools of thought on the ontology of technology. These six schools of thought have been selected based on their prominence in the literature. I have taken the criteria for prominence to be that a school meet the following requirements:

- It is well-known to those versed in the discourse.
- It is regularly included in relevant anthologies.
- It has multiple and influential adherents.
- It is internally coherent, and has a well-established set of core tenets.
- It is distinguishable from the other schools in ways that make a difference.

While the schools considered are prominent in the literature they are by no means the only ones (for other positions see Section *2.3.2: A brief history of the ontology of technology* below). In addition, consideration has been focused on the mainstream positions, central tenets, and key proponents of each school.

This approach may open the thesis to criticism from proponents of theories (or proponents of variants of theories) who may, with some justification, feel that their views have been given inadequate consideration. I would respond in three ways:

Firstly, in framing research of this kind, it is frequently necessary to make pragmatic choices. In this case a choice had to be made between the number of schools of thought which could be considered, and the depth with which each of them could be treated. A similar compromise was necessary as to the number of individual thinkers whose ideas could be given a meaningful treatment within the scope of a single thesis.

Secondly, the approach taken seems preferable to the most obvious alternative of choosing an ontological position in advance and then making a sustained case for its applicability to IoT. The approach taken is, in principle, a logically sound weighing of alternative hypotheses. The alternative mentioned above would instead be circular, having the form: "If you first accept that all technological phenomena are beings of type A, I will demonstrate to you that IoT is a being of type A".

Finally, this thesis does not aspire to be the last word on the ontology of IoT. If a future researcher, by employing a different philosophical ontology (or a more nuanced version of one the ontologies considered) can provide a better account of the nature of IoT, then that is to be welcomed as advancing our collective understanding of the topic.

To commence, I shall consider what constitutes an ontology of technology, before providing a high-level historical account of the ontology of technology. This will provide the context for what I shall argue are the canonical ontological positions, each of which will be given a brief definition. The subsequent sections of this chapter will then take each of these canonical positions and discuss it in greater detail.

2.3.1. What is an ontology of technology?

Before considering the ontology of technology, we must consider what is meant by an "ontology of technology". I will commence by returning to the meaning of the term "ontology".

To avoid possible confusion, it is important to distinguish the philosophical sense of "ontology" from the way the term is used in computer science. According to Gruber (1993, p. 1999):

> An ontology is an explicit specification of a conceptualization. The term is borrowed from philosophy, where an ontology is a systematic account of Existence. For knowledge-based systems, what 'exists' is exactly that which can be represented. When the knowledge of a domain is represented in a declarative formalism, the set of objects that can be represented is called the universe of discourse. This set of objects, and the describable relationships among them, are reflected in the representational vocabulary with which a knowledge-based program represents knowledge. Thus, we can describe the ontology of a program by defining a set of representational terms.

Throughout this thesis "ontology" will be meant in the philosophical sense, unless the contrary is explicitly stated.

Philosophical ontology falls within the realm of metaphysics, that area of philosophical enquiry which "aims to be the most general investigation possible into the nature of reality" and also to "uncover what is ultimately real, frequently offering answers in sharp contrast to our everyday experience of the world" (Craig, 2016a). Ontology, in particular, is that part of metaphysics consisting of the "philosophical investigation of existence, or being. Such investigation may be directed towards the concept of being, asking what 'being' means, or what it is for something to exist; it may also (or instead) be concerned with the question 'what exists?', or 'what general sorts of thing are there?'" (Craig, 2016b).

It should be noted in passing that the boundaries of both metaphysics and ontology are subject to some dispute. For example, some authors limit ontology to the second of the two questions given above, defining it as "that part of metaphysics that explores the question of what things or sorts of things there are" (Macdonald, 2008, p. 15). While these definitional issues need not unduly delay us, they raise the valid question of the kind of ontology we are concerned with.

In this regard two distinctions made by Heidegger are useful. The first is the distinction between the ontical and the ontological "where the former is concerned with facts about entities and the latter is concerned with the meaning of Being, with how entities are intelligible as entities" (Wheeler, 2011, sec. 2.2.1). The second distinction, lying within the realm of the ontological, is between regional ontology, "concerned with the ontologies of particular domains, say biology or banking" and fundamental ontology, "concerned with the a priori, transcendental conditions that make possible particular modes of Being (i.e., particular regional ontologies)". For Heidegger, there is thus a hierarchy in which "the ontical presupposes the regional-ontological, which in turn presupposes the fundamental-ontological" (Wheeler, 2011, sec. 2.2.1). Thus, in philosophical terms, an "ontology of technology" is an example of regional ontology, providing something beyond the statement of surface facts about particular technologies but stopping short of accounting for the fundamental nature of being. This may be illustrated by the following examples (note that these are examples only, I am not supporting any of these three claims):

- To say that there were x billion IoT sensors world-wide in 2015 is to make an ontical claim, i.e., to state a fact about IoT.
- To say that IoT is essentially a technological artefact (comprised of technical components such as sensors) is to make a claim about the regional ontology of IoT.
- To say that all things, including IoT, have a temporal aspect, is to make a fundamental ontological claim.

For the remainder of this thesis, we shall be concerned primarily with ontics and with regional ontology, rather than with fundamental ontology. Thus references to "ontology" should be understood as referring to regional ontology, unless otherwise stated.

This adequately describes the "ontology" part of "ontology of technology". But what is meant by "technology"? Here caution is required. Clearly some definition is required in order to start the enquiry. However, if we define technology in overly ontological terms then we are guilty of begging the question by assuming the outcome of our enquiry in the framing of the question. For example, if we limit to technology to material artefacts, we will be committed in advance to a physicalist ontology of technology. Or again, if we define technology as being socially constructed, then an enquiry into the ontology of technology can lead only to a constructivist outcome. To avoid this, we will (1) take as general as possible a definition of technology, and (2) regard this definition as preliminary rather than definitive.

In framing a similar question, Bijker (2010, p. 64) (acknowledging Mackenzie & Wacjman, 1999) states, "Technology comprises, first, artefacts and technical systems, second the knowledge about these and, third, the practices of handling these artefacts and systems."

Bijker's definition has the virtues of being succinct, consistent with the dictionary usage (OED Online, 2017) and not overtly committed to a particular ontology – it ranges across several It has the additional merit of having been used by a leading scholar for grounding a similar enquiry (Bijker, 2010). It is therefore proposed to adopt it here.

2.3.2. A brief history of the ontology of technology

Philosophical reflection on technology is as old as Western philosophy itself. The pre-Socratics speculated that technology had its origins in the imitation of nature. For example, Democritus (c. 460-c. 370 BCE) suggested that spinning was an imitation of the web-building of spiders, and weaving an imitation of the nest-building of swallows (Franssen, Lokhorst & van de Poel, 2015). However, it is Aristotle who makes the most influential early observations regarding the ontology of technology. In the "Physics" he advances the argument that there is a basic ontological distinction between natural and artificial kinds. He observes (following Antiphon) that if a bed is planted in the ground—and the rotting wood is able to sprout—what will sprout is not a bed but a tree. To Aristotle this suggests that the form of a tree is inherent within the wood, whereas the form of a bed has been imposed on the wood from outside. From this example, he argues that no artefact "has in itself the source of its own production" (Aristotle 350BCEb, II(1)). Thus an artefact (say a bed) has two distinct natures: its matter (wood) and its form (a bed). In contrast, the form and matter of a natural object (say a tree) are fundamentally conjoined (Aristotle 350BCEb).

To summarise Aristotle's position, technology consists of a class of physical objects (artefacts) which are ontologically different from other physical objects. In particular, artefacts are different from other physical things by virtue of having something "extra"—an artificial form which has been imposed on them from outside through the exercise of human agency. Because of the primacy which it accords to the ontology of artefacts, this tradition of enquiry may be broadly categorised as *artefact-based*. This is the first perspective on the ontology of technology which we shall recognise as paradigmatic, and which will be considered in greater detail in a following section. Artefact-based ontologies include physicalist views which privilege the physical artefact, as well as more nuanced positions which grant artefacts a "dual nature"—both physical and functional. Artefact-based ontology remains a topic of active interest today, and is an important area of enquiry within the analytic philosophy of technology (Franssen, Lokhorst & van de Poel, 2015).

Analytic philosophy of technology is similar in its themes and concerns to what Mitcham (1994) has termed "Engineering Philosophy of Technology". Mitcham makes a distinction between "Engineering Philosophy of Technology" (or "EPT") and "Humanities Philosophy of Technology" (or "HPT"). In his view, the former is concerned more directly with technology itself, the latter with the impact of technology on society (Franssen, Lokhorst & van de Poel, 2015). Mitcham characterises the Engineering Philosophy of Technology as an effort by technologists and engineers to articulate a technological philosophy, taking as their starting point the technological artefact and the engineering design process—an approach which he describes as working "from the inside out". By contrast, the Humanities Philosophy of Technology, having its starting point in the humanities, views the technological enterprise "from the outside in". The Humanities Philosophy of Technology thus gives greater attention to the social context of technology.

Concern with the impact of technology on society can be traced back at least as far as the Renaissance humanistic Francis Bacon, in the late 16th century. Bacon takes a very positive view of technological innovation as an enabler of social progress (Bacon, 2003). This interest in the social role of technology—whether benign or otherwise—was taken up by social theorists of the 19th century, for example, Karl Marx (1990), Friedrich Engels (1947) and Thorstein Veblen (1921). Such social theorists represent a diversity of viewpoints on technology—for example on the question of whether or not the effects of technological progress are uniformly positive. However, their shared interest in social theory refocused ontological interest in technology away from “technology as artefact” and towards “technology as social force”.

This theme is taken up in the 20th century by Lewis Mumford (2010) and, somewhat later, by a number of other prominent thinkers, including Martin Heidegger (1977), Jacques Ellul (1980), Herbert Marcuse (2002) and Langdon Winner (1977). In the works of these and similar writers, there is evidence of a growing disillusionment with technology. Technology is theorised as an independent and frequently hostile force, which exercises a powerful and frequently malign influence over human culture and society. This perspective is often termed *technological essentialism*: the view that technology is an entity having certain essential properties—such as developing independently from society and exercising a deterministic influence over society and culture (Bimber, 1994). Technological essentialism retains significant influence and resonance particularly in the popular imagination, and requires specific ontological commitments regarding the nature of technology, such as the existence of technology as a coherent entity. It will be the second of the six ontological viewpoints to be considered in greater detail below.

The next ontological viewpoint we shall consider explicitly opposes technological essentialism, particularly in its deterministic form. It arises from the theory of the Social Construction of Technology (SCOT). SCOT was pioneered by a group of scholars in the 1980s, with Trevor Pinch and Wiebe Bijker publishing a seminal article on the subject in 1984 (Bijker, 2010).

SCOT is part of a broader constructivist movement within the social sciences, which was strongly influenced by the work of Berger & Luckmann (1966). They originated the term “social construction” in their “treatise in the sociology of knowledge”—though the intellectual heritage of constructivism may ultimately be traced as far back as Vico, Hobbes and Kant (Dusek, 2006). Social constructivism may take both weaker and stronger forms. The weaker form makes the epistemological claim that society shapes our understanding of reality, and hence technology. The stronger (and more controversial) form makes the more overtly ontological claim that it is *reality itself* that is shaped by society: that there is no external reality which exists beyond society’s understanding of it (Dusek, 2006).

SCOT applies the constructivist critique to technology. As noted above, it rejects the essentialist view of technology as an independent entity which exercises an influence over the development of society. Reversing this perspective, it emphasises the controlling influence which society exerts over the development of technology, and over what kind of thing any given technology is taken to be. For example, Bijker sought to demonstrate that the modern bicycle is not simply the logical culmination of the bicycle's evolution, but is instead the contingent product of competing social forces. These forces not only shaped the technical design and development of the bicycle, but also shaped what kind of thing a bicycle was taken to be (Bijker, Hughes & Pinch, 1987).

The social constructivist critique remains important in shaping the contemporary narrative regarding the ontology of technology. *Social constructivism* will be the third ontological perspective which we will consider in more detail below.

The next ontology which we will consider arises from Actor-Network Theory (ANT). As noted above, ANT is a very important school within STS. ANT rejects the dualism implied by a fundamental ontological divide between humans and non-humans. In the ANT account, all actors are capable of exercising agency, regardless of whether they are human or non-human, or, for that matter, inorganic. For ANT the crucial concern is in fact not the nature of particular actors but the way these actants are drawn together into networks and alliances (Dusek, 2006).

The underlying ontology of ANT may thus be described as *relationism*: the view that a thing or object is fully revealed by relationships, and that it is these relations in which reality is ultimately grounded (Harman, 2009). Relationism is the fourth ontological paradigm which will be considered in greater detail below.

The next ontology we shall consider is of even more recent origin. It is part of the movement called "speculative realism", a term which was coined for an event held at Goldsmiths College, London in 2007 (Bryant, Srnicek & Harman, 2011b). Speculative realism includes various different branches of thought. They have in common the rejection of "the repetitive continental focus on texts, discourse, social practices, and human finitude" and a "turning once more toward reality itself". In particular, they seek to avoid anthropocentrism and understand the "nature of reality independently of thought and of humanity more generally" (Bryant, Srnicek & Harman, 2011b, p. 3).

Within the speculative realist tradition, I shall focus on *Object-Oriented Ontology*. Object-Oriented Ontology has engaged closely with ANT, and in particular with its ontological foundations. Graham Harman is perhaps the best-known proponent of Object-Oriented Ontology; the by-line of his well-known blog declares that "the centaur of classical metaphysics shall be mated with the cheetah of actor-network theory" (Harman, 2017). Harman rejects the relationist basis of ANT and argues instead for the essential but unknowable reality underlying objects. Object-Oriented Ontology articulates a flat ontology, according equal reality to objects at all scales. It resists efforts to explain things away either by reducing them to their parts, or by reducing them to being parts of some larger whole. It also asserts that objects are never fully revealed by their interactions, but retain an unknowable and inexhaustible core (Harman, 2010b).

The final viewpoint we shall consider is based on phenomenology, which aims to directly examine the structures of experience from a first-person perspective. Phenomenology does not fit neatly into the dialectical (and roughly chronological) narrative account given above. Indeed it is not overtly ontological, although many of its adherents would argue that it is foundational to ontology (Smith, 2018), as would many of its critics (e.g., Sparrow, 2014). Phenomenology was first systematically developed in the early twentieth century by Edmund Husserl. Building on Husserl's work, Martin Heidegger—Husserl's one-time protégé –further developed and applied the phenomenological approach in the investigation of technology. Heidegger argues that our notion of technology is deeply grounded in our everyday lived experience, of which technology forms an intrinsic part. Heidegger used this insight to develop an essentialist ontology of technology (as noted above). The phenomenological perspective has remained influential in our understanding of technology. It has been taken up by Don Ihde, and others, including Albert Borgmann, and used as the basis for a *post*-phenomenological account of technology. *Post-phenomenology* follows phenomenology in examining technology in terms of the ways in which it mediates human experience and practice. However, post-phenomenology differs from phenomenology in taking as its unit of analysis specific and concrete technologies, rather than technology-in-general (Verbeek, 2017). Post-phenomenology is the sixth and final philosophical perspective which I shall consider.

3. Ontologies of Technology

As indicated, we shall now expand our consideration of each of the six perspectives highlighted above, viz.:

(1) *Artefact-based ontology*: the ontological grounding of technology in physical artefacts—physical things with functional properties. First articulated by Aristotle, this remains the main approach to the ontology of technology within the analytic tradition, where it is combined with a concern for how artefacts are originated in the design process.

(2) *Technological essentialism*: the view that technology is an entity having certain essential properties: such as developing independently from society and exercising a deterministic influence over society and culture. This view is associated with thinkers such as Ellul, Winner, Heidegger and Mumford. It often takes a dystopian view of technology in general, though utopian or neutral essentialism is also possible.

(3) *Social constructivism*: the ontological theory that reality—and, in particular, technology—is above all a social construct. Technology is accounted for primarily in terms of social phenomena such as the social relations (e.g., the power relations) which it embodies. Constructivism was introduced into the study of technology through the SCOT (Social Construction of Technology) movement in the 1980s.

(4) *Relationism*: the theory that the reality of things is grounded in their relationships and effects. With respect to technology, relationism is associated with the well-established contemporary methodology of Actor-Network Theory (ANT), which was first formulated in the late 1980s.

(5) *Postphenomenology*: the perspective which grounds the ontology of technology in the structure of first-person experience. First developed by Heidegger, the phenomenology of technology has been explored and articulated by later thinkers like Don Ihde (Ihde, 2003) and Albert Borgmann (Borgmann, 1984).

(6) *Object-Oriented Ontology*: part of the broader speculative realist movement, which began in the mid-2000s. Speculative realism asserts that a speculative re-engagement with an underlying reality is possible, independent of the human viewpoint. Object-Oriented Ontology articulates a flat ontology, according equal reality to objects at all scales, asserting that objects are never fully revealed by their interactions, but retain an unknowable and inexhaustible core.

As noted above, these positions are not intended to provide a final and exhaustive catalogue of the possible ontologies of technology—a task which would be well beyond the scope of this thesis. Instead, the intention is to note the major landmarks in the ontology of technology, so that these may act as markers or signposts in exploring the ontology of IoT.

As explained above, this has meant that certain schools and thinkers have been excluded, or afforded only limited coverage. In, particular, we may note the following:

- Thinkers on technology who approach technology primarily from an economic point of view have not been treated separately. Such thinkers were prominent in the late-19th century and include for example Marx (1990), Engels (1947) and Veblen (1921). It may be argued that the views of such thinkers on the ontology of technology are largely covered in the discussion on essentialism.

- Though Heidegger's views on technology are discussed, limited space has been available to consider the extensive body of critical theory on technology. I would take such critical theorists to include members of the Frankfurt School as well as later thinkers within the same broad tradition such as Marcuse (2002), Arendt (1958), Habermas (1970) and Feenberg (2002). Coverage of these thinkers has only been undertaken within the broad rubric of technological substantavism.

- Feminist views on technology, notably those of Donna Haraway (1991) have not been treated separately. Although the feminist view of technology offers an original and coherent perspective on technology, this perspective is not based on an ontological standpoint distinct from the six discussed.

There are also many idiosyncratic individual thinkers whose views have not been taken fully into account. These include:

- Norbert Wiener's treatment of technology from a cybernetic standpoint (Wiener, 1961).

- Michel Foucault's forays into the description of technology, including, for example, his views on technology of the self (Foucault, 1991).

- Larry Hickman's pragmatist theory on technology, which builds on the philosophy of John Dewey (Hickman, 1990).

3.1. Artefact-based Ontology

As noted above (see *Section 2.3.1.: What is an ontology of technology?*) technology may be roughly considered to comprise three aspects viz. artefacts/systems, knowledge and practices. While any ontology of technology must account for each of these elements, the ontology we shall now consider takes as its point of departure artefacts and how they arise from the design process. It may thus usefully be described as "artefact-based ontology", which is suggested as being a more descriptive name than those found in the literature (which include "analytic philosophy of technology" and "engineering philosophy of technology").

It was Aristotle (see *Section 2.3.2.: A brief history of the ontology of technology*) who first brought attention to the ontological difference between artefacts and other physical things, noting in particular differences in the way in which they come into being (Aristotle 350BCEb). The metaphysical nature of artefacts remains a topic of active philosophical discussion (e.g., Houkes & Meijers, 2006; Houkes et al., 2011; Vaccari, 2013; Franssen et al., 2015) and is a key concern within the analytic philosophy of technology (Franssen, Lokhorst & van de Poel, 2015) but is much less salient in other areas of discourse (e.g., within the STS discourse).

In this section, I shall first examine Aristotle's ontology of artefacts. I will then discuss the origin and context of the analytic philosophy of technology in order to situate and explain the importance of artefact-oriented ontology. I will review the Dual Nature Program (DNP) which is a leading theory of the nature of artefacts, before examining some criticisms of DNP, and some alternative theories. Finally, I shall consider the relevance of artefact ontology to the current thesis.

3.1.1. Aristotle's Ontology of Artefacts

Aristotle hypothesised a fundamental difference between naturally occurring things and man-made artefacts. As summarised by Lokhorst & van de Poel:

> The former have their principles of generation and motion inside, whereas the latter, insofar as they are artefacts, are generated only by outward causes, namely human aims and forms in the human soul. Natural products (animals and their parts, plants, and the four elements) move, grow, change, and reproduce themselves by inner final causes; they are driven by purposes of nature. Artefacts, on the other hand, cannot reproduce themselves. Without human care and intervention, they vanish after some time by

> losing their artificial forms and decomposing into (natural) materials. (Franssen, Lokhorst & van de Poel, 2015)

In Aristotle's account, then, an artefact is distinguished by the fact that it bears the imprint of human intention. This idea remains at the heart of artefact ontology, as we shall see. Artefact-based ontology is most often encountered within a sub-realm of the philosophy of technology, namely the "Engineering Philosophy of Technology" or "EPT". Before proceeding with the examination of artefact ontology, the basis of EPT warrants some further explanation.

3.1.2. The Engineering Philosophy of Technology

Carl Mitcham (1994) famously drew the distinction between two quite distinct approaches to the philosophy of technology. The first, which he termed the Engineering Philosophy of Technology (or EPT) is the "attempt by technologists or engineers to elaborate a technological philosophy" (Mitcham, 1994, p. 17). The second, which he termed the Humanities Philosophy of Technology (or HPT) is the "effort by scholars from the humanities, especially philosophers, to take technology seriously as a theme for disciplined reflection" (Mitcham, 1994, p. 17). He noted that the "first tends to more pro-technology and analytic, the second somewhat more critical and interpretative" (Mitcham, 1994, p. 17). EPT has a long history, extending back at least to Mario Bunge's discussion of technology as applied science (Bunge, 1966).

Franssen et al. (2015) use the term "analytic philosophy of technology" to refer to an approach to the philosophy of technology similar to Mitcham's EPT. In their view, the analytic philosophy of technology is more directly concerned with the nature of technology itself, whereas HPT tends to focus on the relationship between technology and society. In particular, the analytic philosophy of technology focuses closely on the practices surrounding the creation of technology, broadly equivalent to the practice of engineering.

The development of the analytic philosophy of technology is associated with the so-called "empirical turn" in the philosophy of technology. A key milestone in this turn was the publication in 2000 of "The Empirical Turn in the Philosophy of Technology" (Kroes & Meijers, 2000). Proponents of this turn argue for an "engineering-oriented" approach contrasting this with earlier "society oriented" approaches (Brey, 2010). The empirical turn "focused primarily on the work of engineers. Accordingly, one of its principal messages was to urge a shift of focus to the design of technical artefacts, rather than their later career as constituents of use practices" (Franssen et al., 2016, p. 2).

Authors of the empirical turn accuse many earlier philosophers of technology of regarding Technology as a "black box", a single, monolithic, inescapable phenomenon: "[T]hese philosophers are almost all openly critical of technology: all things considered, they tend to have a negative judgment of the way technology has affected human society and culture, or at least they single out for consideration the negative effects of technology on human society and culture" (Franssen, Lokhorst & van de Poel, 2015).

This criticism gives rise to a further hallmark of the empirical approach; the move from a *normative/evaluative* approach to a more *descriptive* approach—"the focus should be on descriptive analysis with an aim of understanding modern technology and its inner organization rather than evaluating it or prescribing its direction" (Brey, 2010, p. 41).

In summary, then the analytic/empirical approach to the philosophy of technology focuses on a rigorous descriptive analysis of the practice of engineering, emphasising a close engagement with the technology itself, and the process of technological design. This contrasts, for example, with those approaches to the philosophy of technology which are more concerned with the nature of Technology in general, and with the social consequences of technological change. In terms of IoT, this focus would naturally lead philosophers of the analytical/approach towards closer engagement and alignment with certain parts of the IoT discourse. Specifically, it would lead to closer engagement with those parts of the discourse which are more oriented towards the practice of engineering, the process of design, and a detailed consideration of specific technologies.

The focus described above also gives rise to a distinctive set of investigative priorities, which I shall now explore in more depth, especially as they relate to ontology.

3.1.3. Artefacts and the Design Process

For the analytic approach, a central concern is the way artefacts are produced in the design process: "Technology is a practice focused on the creation of artefacts and, of increasing importance, artefact-based services. The design process, the structured process leading toward that goal, forms the core of the practice of technology" (Franssen, Lokhorst & van de Poel, 2015, sec. 2.3). However—given that this is an ontological investigation—what concerns us most directly here is not the process itself but the ontological implications of the process for artefacts.

In the analytic view, “an artefact may be defined as an object that has been intentionally made for some purpose” (Hilpinen, 2011, sec. 1). “Artefacts have a purpose or function: they are objects to be used for doing things and are characterized by a certain “for-ness”. It is this teleological element that sets technical artefacts apart from physical objects. In the design process, “the author’s intention ‘ties’ to an artefact a number of predicates which determine the intended character of the object. The existence and some of the properties of the artefact are dependent on its intended character” (Hilpinen, 2011, sec. 4). In this view, “the adequate description of artefacts must refer both to their status as tangible physical objects and to the intentions of the people engaged with them” (Franssen, Lokhorst & van de Poel, 2015, sec. 2.5). Attempts to provide such an explanation commonly ascribe to technical artefacts a “dual nature”—both physical and intentional. It is to this “dual nature” that I will now turn my attention.

3.1.4. The Dual Nature of Artefacts

According to the dual nature theory, technical artefacts are distinguished from other physical objects by their “purpose or function: they are objects to be used for doing things and are characterized by a certain ‘for-ness’ ” (Kroes & Meijers, 2006, p. 1). This teleological property is held to be distinct from the object’s physical properties, yet somehow tied together in the same artefact. Thus the artefact has two distinct nature, the physical and the intentional with “the notion of a function as a bridging concept that relates the physical and intentional domain” (Kroes & Meijers, 2006, p. 2). Specifically, functions must be understood, “against the background of use plans, goal-directed series of considered actions, including manipulations of one or more artefacts” (Houkes et al., 2011, p. 199). Use plans are the product of a process of design, communication, testing demonstration, etc., and the “consequent privileging of a set of possible use plans, leading to ascriptions of *proper functions*” (Houkes et al., 2011, p. 199).

This combination of two natures is analogous to the perennial philosophical dilemma of the mind–body problem “that has plagued philosophy for centuries” (Houkes & Meijers, 2006, p. 130). It is certainly similar in that no satisfactory account has yet been provided for how these two natures may be related. Houkes & Meijers (2006) consider several possible mechanisms to explain the dual nature relation. Their conclusion is that none of the mechanisms considered is able to account for the observed features of artefacts, suggesting that “artefacts need a tailor-made ontology; philosophers have left them in the cold for too long” (Houkes & Meijers, 2006, p. 130).

3.1.5. Criticisms of DNP

Given these difficulties, it is not surprising that various refinements and alternatives to dual nature theory have been put forward.

Vaesen (2011) suggests that a key problem lies with the over-reliance on function within dual nature theory. In Vaesen's view artefacts are not simple "function-bearers" but may also bear the stamp of various other kinds of intentionality. For example, an artefact's design may reflect considerations relating to ease of manufacture, or to ease of recycling, neither of which are directly related to function. Vaesen proposes that extending the concept of intention to capture such non-functional design considerations substantially improves the exploratory power of dual nature theory.

Schyfter (2009) raises more fundamental concerns about the role of function within dual nature theory. He suggests that dual nature accepts the notion of "function" too uncritically, and affords it unwarranted ontological priority. Specifically, he takes aim at the idea of normative "proper functions" based upon from use plans originating in the design process. He asserts that function must be decentred and deconstructed in order to reveal that functions are "generated by, rather than generative of, reference and use" (Schyfter, 2009, p. 15). In particular, he argues for the primacy of social institutions, stating that it is in consequence of social institutions that artefacts have functions. Thus Schyfter grants ontological priority to social institutions, describing function, ontology and normativity as phenomena which are all "products of the same social processes".

I would suggest that this solution—by describing artefacts as the product of ontologically prior social process—moves away from the artefact-centred ontologies which are the topic of this section, and toward the social constructivist views which are the topic of *Section 3.3: Social constructivism* below.

3.1.6. Relevance for this study

The analytic/empirical approach to the philosophy of technology—as exemplified in dual nature theory—provides a very distinctive take on the ontology of technology. It sharply highlights some aspects of technology, such as the functional nature of artefacts; the way technology arises in the design process. At the same time other aspects of technology, prominent in other schools of technological ontology, are backgrounded. For example, artefact ontology emphasises the role of the designer in the creation of technology, and thus plays down the ability of the users to shape technology. Other concerns, prominent elsewhere, are beyond the purview of the artefact-based ontology considered in this section. For example, artefact-based ontology gives limited space to the idea that technology may have substantial ethical content (this idea is considered in more depth in *Section 3.2: Technological Essentialism* below). Artefact-based ontology also gives limited consideration to the view that technology(ies) may exercise agency in their own right (an idea explored in *Section 3.4: Actor Network Theory and Relationism* below). Artefact-based ontology thus has a very distinctive voice, traces of which we can listen for as we review the IoT discourse.

3.2. Technological Essentialism

What then is meant by technological essentialism?

Thomson (2000, p. 430) observes that "the necessary criterion seems obvious; to be a technological essentialist, one needs to believe that technology has an essence."

This statement combines two claims:

(i) That there is something (a class) that can be called "technology" (as opposed to particular technologies or instances of technologies).

(ii) That this "technology" has an essence—essence being generally defined in philosophy as "the basic or primary element in the being of a thing; the thing's nature, or that without which it could not be what it is" (Blackburn, 2016).

Let us consider each of these two claims in turn.

Claim (i) is ontologically no more demanding than philosophical essentialism in general. It naturally calls to mind Platonic ideas, and suggests the existence of an "Idea" or "Form" of technology to which actual technologies approach. But to accept a class called technology does *not* ontologically commit one to the separate existence of "technology" as a Platonic Idea, because various nominalist accounts are equally defensible (van Inwagen & Sullivan, 2020). For example, the class "technology" could be defined by referring to certain properties that all technologies have in common, thus avoiding reference to a Platonic Idea of technology.

Claim (i) is required by *any* theory which intends to make claims about technology in general (that is, technology as a class). It is thus foundational to many positions in the philosophy of technology. However, as noted by Thomson (2000, p. 429), "A radical constructivist like Baudrillard or Latour might maintain that there is no technology, only particular technologies, and thus that all technological essentialisms are unsound (noting that Latour himself would justifiably reject the characterisation of his position as "radical constructivism" (Latour, 2003). Note also that scepticism towards technological essentialism need not preclude essentialism with respect to other classes (e.g., dogs, chairs).

The strength of claim (ii) depends on the essential properties being claimed for technology. On the one hand, a minimal set of essential properties would lead back to a neutral "dictionary" definition of technology as given in *Section 2.3.1: What is an ontology of technology?* above. For example, we could claim that the essential property of technology is just that it consists of artefacts, technical systems, and related knowledge and practices.

In contrast, consider Heidegger's statement regarding the essence of technology:

> The essence of technology is by no means anything technological. Thus we shall never experience our relationship to the essence of technology so long as we merely represent and pursue the technological, put up with it, or evade it. Everywhere we remain unfree and chained to technology, whether we passionately affirm or deny it. But we are delivered over to it in the worst possible way when we regard it as something neutral; for this conception of it, to which today we particularly like to pay homage, makes us utterly blind to the essence of technology. (Heidegger, 1977, p. 4)

By considering the essence of technology, Heidegger is intending to elucidate technology's fundamental nature in a way that the dictionary definition does not. Thus, in the philosophy of technology literature, "technological essentialism" is usually used to mean more than just "essentialism with respect to technology": it is used to characterise certain claims – particularly ambitious claims – about the nature of that essence (Thomson, 2000). In particular, it is often claimed that the essence of technology is such that technology determines social and cultural conditions ("technological determinism"), develops autonomously along a predetermined trajectory ("technological autonomy") and constrains our values and the way we see the world ("technological substantives") (Feenberg, 2003). The extent to which Heidegger subscribed to any of these views regarding the essence of technology is still a matter of debate (Thomson, 2000). Thus technological determinism, technological autonomy and technological substantivism each rely on an underlying adherence to technological essentialism, and may thus be considered different "flavours" of essentialism.

Note that to claim that technology is *essentially* deterministic (or autonomous or substantive) is not to claim that this is its *sole* defining property, and that anything deterministic is therefore technological (for example, the movement of the planets is deterministic but presumably not technological). Rather, determinism is being claimed as *one* of the essential properties of technology. Other essential properties would presumably include those which make up the "dictionary definition" of technology (e.g., "being human-made").

Let us consider each of technological determinism, technological autonomy and technological substantivism in turn, attempting to arrive at a clear and coherent understanding of each that is in line with general usage.

3.2.1. Technological determinism

Although *technological determinism* is a frequently used term, its use is inconsistent across the literature, and this is a frequent source of disagreement and debate (Bimber, 1994).

It is helpful to start from the definition of determinism as the view that "given the past, and the laws of nature, there is only one possible future" (van Inwagen, 1983, p. 65). From this starting point, technological determinism can be given at least three distinct interpretations, each of which may be found in the literature:

(a) That technology determines key aspects of society and culture; that technological conditions cause social and cultural conditions to arise (Dusek, 2006).
(b) That technological development is deterministic, i.e., that current technological conditions determine future technological development (Mitcham & Waelbers, 2009, p. 372).
(c) The conjunction of (a) and (b)the view that the current state of technological development determines both social conditions *and* the future development of technology (and thus determines future social conditions) (Feenberg, 2002).

Bimber (1994) refers to claims (a) to (c) collectively as "Nomological" or "law-like" determinism, and suggests that these are the only truly deterministic accounts of technology.

Bimber (1994) also identifies two additional senses in which the term "Technological determinism" is employed in the literature. The first is the use of determinism to describe a situation in which technological ideas of logic and productivity become the dominant norms of society, overriding all other values. Bimber refers to this as the "Normative" account of determinism; it will be discussed below under the heading of "Technological substantivism". The second is the use of determinism to refer to the fact that technology often has far-reaching and unforeseeable consequences, putting its ultimate effects beyond the practical control of social actors. Bimber refers to this as "Unintended Consequences" determinism.

We shall join Bimber by restricting our use of the term technological determinism to the so-called nomological cases, on the grounds that these are the only cases where determinism (as per Inwagen (1983)) is present. However, to be even more discriminating, we shall restrict its use to case (a) above, referring to case (b) by the more precise term *technological autonomy* (of which more below). (c) is then simply the conjunction of technological determinism and technological autonomy. The paradigmatic example of technological determinism in the sense of (a) is Lynn White's (1962) description of how the introduction of the stirrup into Western Europe led to the development of feudalism. Though widely regarded as mistaken, White's views remain influential: "White is both widely cited and paraphrased and yet thoroughly disproved . . . and somehow those two cognitively dissonant stances live in a state of truce" (Walton, 2019, p. 2).

In recent decades, strong forms of technological determinism have been strongly and repeatedly challenged in the literature (Dusek, 2006). The general form of this challenge is that technological determinism greatly oversimplifies the true dynamics of social and cultural change, to the extent that it has no value as an explanatory mechanism. In response, a weaker form of technological determinism has been advanced, which suggests only that technological conditions play an important enabling or restraining role in determining social and cultural conditions (Arnold, 2003). For example Schroeder (2018) prefers the term "technological shaping", arguing that technological change may guide and constrain social change without determining it.

3.2.2. Technological autonomy

As mentioned above, technological determinism (in our sense) is often associated with the related claim of *technological autonomy*. This is the claim that technology, and in particular the progression of technology, is beyond human control. This view is often associated with Langdon Winner and with Jacques Ellul, who summarises it thus: "An autonomous technology. This means that technology ultimately depends only on itself, it maps its own route, it is a prime and not a secondary factor" (Ellul, 1980, p. 125). The evolution of technology is thus an inevitable progression—the state of technology at time t determines the state of technology at time $t+1$. The version of technological autonomy usually encountered in the literature makes a weaker claim: that the evolutionary path of technology is determined only in a general way, but not in detail, in the sense that, for example, "iron ages" always occur after "bronze ages" (Mitcham & Waelbers, 2009, p. 376). A more restricted concept is Thomas Hughes' (1994) idea of *technological momentum*: roughly, that a degree of autonomy is acquired by mature, large-scale technological systems.

3.2.3. Technological substantivism

A third term is often met in the same neighbourhood: *technological substantivism*. Technological substantivism is the view that a specific set of cultural, social and moral outcomes are an inseparable element of modern technology; that technology "constitutes a new cultural system that restructures the entire social world as an object of control" (Feenberg, 2002, p. 6). Substantivists argue that our apprehension of the world is "enframed" by technology on a fundamental level. Trapped as we are within this frame (argue substantivists), technology is not simply a "means to an end", it also defines the ends that we pursue and our understanding of the world. This is similar to the "Normative" sense of determinism discussed above. Substantivism in this sense is familiar from the works of (for example) Heidegger, Ellul and Marcuse. Such substantivism takes an unwaveringly pessimistic view on the impact of modern technology on human life.

There is a kind of counter-point to this pessimistic view in technological utopianism, of the sort encountered in the works of Michael Zey (e.g., Zey, 2004) and Ray Kurzweil (e.g., Kurweil, 2005). Technological utopianism, like substantivism, takes modern technology to be the determining factor in a range of social and economic outcomes. Unlike substantivism, however, technological utopianism makes an overwhelmingly positive assessment of these impacts. While technological utopianism could be considered a kind of "optimistic substantivism" I will limit substantivism to its conventional meaning, and technological utopianism will be referred to as such.

Substantivism is thus a claim of a rather different sort than technological determinism and technological autonomy. It is not a general claim about the essence of technology applicable to any culture or epoch, but a more specific critique of the modern condition and the role which technology plays in that condition.

3.2.4. Relevance for this study

As discussed above, technological essentialism in its various forms was very influential during the mid-20th century. As we shall see below, the influence of technological essentialism in academic circles waned in the later years of the century. Nevertheless some aspects of technological essentialism—for example its highlighting of the dystopian potential of technology—retain influence on the popular imagination, as evidenced by dystopian films such as the popular “Terminator” series. It thus not unlikely that technological essentialism may have influenced in the IoT discourse. Key expressions of such an influence might be the tendency to essentialise IoT itself, and/or the tendency to see in IoT expression of a more general technological essence.

Of course, one must guard against the danger of reading such an interpretation into discourse. Being alert to such influences in the text must be balanced with being alert against being too hasty to see such influences where they do not, perhaps, exist. Consideration of essentialism must also make one conscious of another methodological danger: the danger of essentialising IoT. In other words, we cannot assume in the research that IoT has a singular “essence”—let alone a fixed or immutable essence. To do so would be to choose an ontological position in advance of the ontological analysis, that is, to beg the question of IoT’s ontology.

3.3. Social constructivism

This section will consider an approach to the ontology of technology, which provides a sharp contrast to the technological essentialism just discussed. Rather than seeing technology as an independent force with its own essential characteristics, social constructivism grounds technology firmly within the society in which it arises.

This section will describe the theory of Social Construction of Technology (SCOT), and its origins within the broader program of social constructivism. It will consider the ontological commitments and implications of constructivism, which are a subject of some debate. Next, two ontological constructs of particular interest for the investigation of emerging technologies will be discussed, viz. imaginaries and boundary objects. The section will conclude with a consideration of the relevance of constructivism for the current research project.

3.3.1. Social constructivism

Constructivism may be defined as defined as "the theory that knowledge is not something we acquire, but something we produce; that the objects in an area of enquiry are not there to be discovered, but are invented or constructed" (Mautner, 1996, p. 111). As noted above, constructivism is a broad intellectual tradition. Dusek (2006) traces its intellectual heritage as far back as Vico, Hobbes and Kant. For example, as early as 1710, Giambattista Vico advanced his well-known principle that "the true is precisely what is made" ("verum esse ipsum factum" [translation by Costelloe, 2016]), that is, that knowledge is constructed (Costelloe, 2016). Berger & Luckman (1966) were influential in introducing the idea of construction into the social sciences. Berger and Luckmann's (1966, p. 13) key thesis is that "that reality is socially constructed and that the sociology of knowledge must analyse the process in which this occurs".

In 1976 the Edinburgh-based scholar David Bloor and a group of collaborators (for example Harry Collins and Donald A. MacKenzie) formulated the so-called "Strong programme" in the Sociology of Scientific Knowledge (SSK). The Strong Programme introduced a constructivist approach to the study of scientific practices and knowledge. One of the key elements of the Strong Programme was an assumption of symmetry with respect to explanation: that the same kinds of causes should be used to account for successful theories, as are used to account for unsuccessful theories. This was a reaction against the tendency to ascribe unsuccessful theories to social causes, while arguing that successful theories arise not from social construction, but from a correct understanding of natural phenomena—that is, the fallacy of concluding that true theories are regarded as true because they are true (Sismondo, 2010).

In the following years, influenced by SSK, interest turned to the social construction of technology (Bijker, 2010). This is the development which concerns us most closely, and which we will now consider in more depth.

3.3.2. Social Construction of Technology

Research into the social construction of technology emerged as a coherent research program in the early 1980s. The SCOT (Social Construction of Technology) program formed around a group of scholars, most notably Wiebe Bijker and Trevor Pinch. Various other scholars, for example Douglas Mackenzie and Judy Wacjman, were also prominent in pioneering a constructivist analysis of technology (MacKenzie & Wajcman, 1998). An important milestone was the publication of "The Social Construction of Technological Systems: New Directions in the Sociology and History of Technology", a collection of the papers from a workshop held at University of Twente, The Netherlands, in 1984 (Bijker, Hughes & Pinch, 1987).

A fundamental precept for Bijker's study, and one which became foundational to SCOT, is the principle of symmetry. Just as the Strong Programme in SSK (as described above) argues that the successful and unsuccessful scientific theories must be described in the same terms, so SCOT argues that successful and unsuccessful technologies must be accorded a symmetrical explanation. Asymmetrical explanations—for example those which account for success in terms of technical superiority, and failure in terms of social causes—are to be avoided. The successful "working" of the technology is the thing to be explained, it cannot also be used as the explanation (Bijker, 1995; MacKenzie & Wajcman, 1999).

A paradigmatic case study within SCOT is Bijker's research into the development of the modern safety bicycle. Bijker challenges a linear account of the bicycle's evolution in which the "standard" modern bicycle inevitably triumphs due to its inherent technical superiority, being safer, more stable and more efficient than any of the alternative designs. Instead, Bijker considers in detail the proliferation of designs which flourished in the second half of the nineteenth century, and considers the reasons for their success or failure. He then uses this, and other examples, to develop a general framework to describe the evolution of technologies (Bijker, 1995; Sismondo, 2010).

Key concepts within this framework include:

- *Relevant social groups*: Important for this framework is the consideration of the different social groups involved with a technology. These social groupings are relevant for the social actors themselves, but are also useful in assisting the analysis. For example, in the development of the bicycle in the 1880s, young male sports enthusiasts—"young men of means and nerve" (Bijker, 1995, p. 49)—form a social group distinct from aspiring female cyclists.
- *Interpretive flexibility*: Interpretive flexibility is the concept that different social groups can place different interpretations on the "same" technology. For example, "high-wheeler" bicycles (such as the well-known "penny-farthing") were interpreted as "macho" or "daring" by young men, but as "unsafe" by women and older men (Bijker, 1995; Sismondo, 2010). Around the same time, a diversity of new forms of clothing were proposed in a bid

to make cycling "safe for women" e.g. by keeping long skirts out of the way of pedals (Jungnickel, 2018).

- *Closure*: The process by which an artefact reaches an agreed and comparatively stable form: "Closure in technology involves the stabilisation of an artefact and the 'disappearance' of problems" (Pinch & Bikjer, 1987, p. 44). In other words, the artefact—in this case the bicycle—ceases to be contentious and becomes an unproblematic feature of the technological landscape. Closure occurs when, "[c]onsensus among the different relevant social groups about the meaning of an artefact emerges and the 'pluralism of artefacts' diminishes" (Bijker, 1995, p. 86).

The basic framework articulated Bijker, Pinch and other continues to be influential, and to provide the theoretical foundation for an active program of empirical research. Recent examples include the application of SCOT to stormwater controls systems (Madsen et al., 2017) , offshore wind power farms (Shiau & Chuen-Yu, 2016), and—in a nod to Bijker's original case study—the recumbent bicycle (Wieser, 2017).

This is if of course by no means an exhaustive account of social constructivist views of technology. Given the ontological basis of this research, our primary interest in SCOT is to understand its ontological commitments.

3.3.3. Ontological foundations of constructivism

Bijker (2010) considers the question of whether SCOT requires a commitment to either a realist or idealist ontology, and concludes that SCOT is agnostic on this question. He then contends that, "all forms of SCOT are agnostic with respect to the ontological status of technology and the natural world: you need not take any ontological position as a researcher to use SCOT for studying technology, nor does SCOT have any bearings on the ontological status of technology" (Bijker, 2010, p. 74).

This may be true on the particular issue of realism vs idealism as defined by Bijker, but appears to overstate the general position: on examination, SCOT relies on certain ontological commitments regarding the nature of society and technology. SCOT is a theory of social construction, and in common with all such theories rests on claims of the type "X socially constructs Y" (Mallon, 2014). Thus SCOT is committed at least to the existence of social entities (X), technological entities (Y), and some relation of construction between X and Y. In the classic case studies of SCOT the social entities (X) are the "relevant social groups" and the technological entities (Y) are particular technologies such as the bicycles or light-bulbs (Bijker, 1995).

Haslanger (1995, p. 98) makes the following distinction between two primary forms of construction, causal and constitutive:

> *Causal construction*: Something is causally constructed iff [if and only if] social factors play a causal role in bringing it into existence or, to some substantial extent, in its being the way it is.
>
> *Constitutive construction*: Something is constitutively constructed iff [if and only if] in defining it we must make reference to social factors.

SCOT assumes that technology is both causally and constitutively constructed. Causal construction is implied by the generalised process which SCOT describes for the development of technology. This process, leading up to closure, is driven by the relevant social groups. However, the idea of interpretive flexibility (described above) also required constitutive construction: that the "meaning" of the technology—for example, what it means for something to be a bicycle—is itself socially constructed.

3.3.4. Criticisms of Constructivism

SCOT has been subject to a number of criticisms. In his influential paper "Upon opening the Black Box and finding it empty", Langdon Winner criticised SCOT on four grounds (Winner, 2004):

1. SCOT considers the social construction of technology, but largely ignores its social impacts or consequences.
2. The emphasis in SCOT on "relevant social groups" may understate the technological influence of marginalised or disenfranchised social groups.
3. SCOT's analysis of technology is usually silent on ethical issues. The doctrine of "interpretive flexibility" requires an even-handed treatment of different interpretations of the same technology. This can be problematic when some interpretations are morally inferior or even morally odious. Interpretive flexibility appears to require that these interpretations are in no way inferior to more morally compelling alternatives.
4. There is no consideration within SCOT of the "possibility that there may be dynamics evident in technological change beyond those revealed by studying the immediate

needs, interests, problems, and solutions of specific groups and social actors" (Winner, 2004, p. 370). Thus in rejecting technological determinism, SCOT tends to reject all ideas of technological essentialism—that is a deeper structure or dynamic to technology (e.g., a general progression from simpler to more complex technologies) which transcends particular instances.

A more fundamental criticism of social constructivism is that it accords too much importance to social factors, and too little to other—for example technical—factors. At the extreme, this can lead from constructivism to social determinism (Hughes, 1994; Lipartito, 2003; Jasanoff, 2004). This is linked to the ontological commitments of constructivism, as described above. In particular, the "X socially constructs Y" relation appears to (i) yield ontological primacy to X, and (ii) imply that X *determines* Y. In fact, neither (i) nor (ii) are necessary for the relation of construction to apply. Jasanoff (2004, p. 19) describes the dilemma thus: "Constructivism does not imply that social reality is ontologically prior to natural reality, nor that social factors alone determine the workings of nature; yet the rubric 'social construction' carries just such connotations". This criticism is used to motivate a more explicitly co-constructivist approach to the development of technology, in which technical and social considerations are given more even weighting (Lipartito, 2003; Jasanoff, 2004).

Having explored some of the basic precepts of constructivism, it is useful to consider two more specific concepts arising from a social constructivist critique of technology, namely boundary objects and social imaginaries. These are of particular relevance to this study as both concepts have been applied to the study of large-scale techno-social phenomena.

3.3.5. Boundary Objects

The idea of a boundary object was developed by Susan Leigh Star and Jim Griesemer in the late 1980s (Star & Griesemer, 1989), and is based on the social constructivist notion of interpretive flexibility, in terms of which a particular object may be interpreted differently by different social groups. Boundary objects are those objects which "both inhabit several intersecting social worlds and satisfy the informational requirements of each of them.… Boundary objects are objects which are both plastic enough to adapt to local needs and the constraints of the several parties employing them, yet robust enough to maintain a common identity across sites. They have different meanings in different social worlds but their structure is common enough to more than one world to make them recognizable, a means of translation" (Star & Griesemer, 1989, p. 393). For example, holiday-makers may see a topographical map as pointing out pleasant places to camp, while scientists see it pointing out animal habitats. However, to an external observer, the map involved may appear to be exactly the same. The map can thus function as a boundary and a means of communication between two groups with different understandings: "boundary objects are a sort of arrangement that allow different groups to work together without consensus" (Leigh Star, 2010, p. 602).

The dynamic involved in the maintenance of a boundary object may be summarised as follows (Leigh Star, 2010):

1. The object resides between different social groups, where it has a vaguer/less-structured form.
2. Particular social groups use the object, adapting it for specific local purposes by defining parts of it in more detail.
3. Groups are able to move between the more-specific local version of the object and the less-structured general version of the object.

The concept of boundary objects is widely used with STS research, including research into techno-social domains. For example, in e-health (electronic health) clinical simulation (the testing of information systems with clinicians in a realistic but controlled environment) has been studied as a boundary object (Jensen & Kushniruk, 2014). Similarly in e-government Information Systems (e.g., a forest-felling application processing system) have been analysed as boundary objects (Uppström & Lönn, 2017). Boundary objects have also been used to explore issues in the design of computer systems, including in interaction design (Foth et al., 2018; Light & Anderson, 2009).

3.3.6. Social Imaginaries

A second concept from constructivism that has potential application to IoT is that of the sociotechnical imaginary.

The idea of the sociotechnical imaginary builds on the more general notion of the social imaginary, described by Taylor (2003, p. 23) as "the ways people imagine their social existence, how they fit together with others, how things go on between them and their fellows, the expectations that are normally met, and the deeper normative notions and images that underlie these expectations". More specifically the idea of the sociotechnical imaginary references the concept of the techno-scientific imaginary developed in the anthology "Technoscientific imaginaries" (Marcus, 1995).

This concept of the sociotechnical imaginary was first used by Jasanoff & Kim (2009) who defined sociotechnical imaginaries to be "collectively imagined forms of social life and social order reflected in the design and fulfilment of ... scientific and/or technological projects." Jasanoff and Kim specifically discussed *national* sociotechnical imaginaries, but the role of the nation is not essential to the definition. According to Jasanoff and Kim, the sociotechnical imaginary is also a social imaginary in the sense that it reflects a shared sense of what would constitute a good (or bad) society. Sociotechnical imaginaries are also able to exercise agency: "in activating collective consciousness, imaginaries help create the political will or public resolve to attain them" (Jasanoff & Kim, 2009, p. 123). The concept of sociotechnical imaginaries has been used to investigate a range of phenomena, for example, electric vehicles (Wentland, 2016), smart cities (Haarstad, 2017), and smart grids (Engels & Münch, 2015). Foth et al. (2020) use the concept of the "urban imaginary" to describe how the future city is shaped across all dimensions including the political and the geographic. This is particularly pertinent in that one would expect IoT to be part of both the shaping process and the future shape.

In "The Internet Imaginaire", Patrice Flichy (2007) uses the concept of the "imaginaire" (cognate with "imaginary") to investigate the development of the internet. He observes that in large scale technical developments like the Internet "we encounter more than simply a project or a common intention; what we witness is a collective vision or imaginaire" (Flichy, 2007, p. 4), and argues that the development of the imaginaire is closely linked with that of the technology itself.

3.3.7. Relevance for this study

Social constructivism provides a clear vocabulary and approach for understanding the emergence of IoT, regarded as a sociotechnical system. Constructivism is primarily a method for the study of how technology is *made*. It investigates what technology represents for social actors, but does not engage directly with questions of what technology *is* (Bijker, 2010). Nevertheless, as we have seen above, constructivism rests on certain ontological commitments; though practitioners may hold these pragmatically (as being useful in practice) rather than dogmatically.

Social constructivism thus provides an ontological perspective and vocabulary for understanding the emergence of socio-technical phenomena such as IoT. For example, SCOT proposes a clear sequence of steps for the evolution of such phenomena (see *Section 3.3.2:*

Social Construction of Technology above). In particular, recent scholarship has proposed specific and well-defined kinds of objects—namely boundary objects and sociotechnical imaginaries—associated with sociotechnical phenomena such as IoT.

The next approach to be considered is Actor-Network Theory (ANT) and the relationist ontology with which it is associated.

3.4. Actor Network Theory and Relationism

Since its emergence in the late 1980s, Actor-Network Theory (ANT) has become enormously influential within STS. It has served as the basis for a very large number of studies and dominated the theoretical landscape of STS, indeed it "stands as the best known of STS's theoretical achievements so far" (Sismondo, 2010, p. 92).This section will briefly consider the origins and central tenets of ANT. The relationist ontological foundations of ANT will then be discussed, along with criticisms of these foundations. Finally, the possible relevance of ANT's ontology for this study will be evaluated.

3.4.1. Origins of ANT

Actor-Network Theory (ANT) was developed by Latour, Michel Callon, John Law and others from the late 1980s onwards. ANT arose at a similar time as social constructivism, and among a related group of scholars. For example, the important anthology "The Social Construction of Facts and Artefacts" (Bijker, Hughes & Pinch, 1987) includes works by key authors in both constructivism and ANT.

One of the principal breaks between ANT and constructivism arose on ontological grounds. Latour insisted that a fresh ontology was required to move STS forward (Latour, 1992). As noted above, in "We have never been modern" Latour rejected a sharp ontological distinction between social and natural actors, with agency being ascribed exclusively to the former. The ontological distinction rejected by Latour is, for example, embodied in the formula "X socially constructs Y" discussed above. Latour rejected the distinction between X and Y, arguing instead that agency is exercised by hybrids composed of multiple social (human) and natural (non-human) actors joined together in networks (Latour, 1991). Sociotechnical systems are examples of such hybrids—for example, a computer system includes programmers and users and well as servers, software and screens and a myriad of other human and non-human actors.

3.4.2. ANT and Ontological Symmetry

ANT follows Latour in rejecting the dualism implied by a fundamental ontological divide between humans and non-humans. In the ANT account, all actors (or in early ANT terminology "actants"), are capable of exercising agency, regardless of whether they are human or non-human, or, for that matter, inorganic (Dusek, 2006). For ANT the crucial concern is not the nature of particular actors (whether physical, artefactual, essential or socially constructed), but the way these actors are drawn together into networks and alliances.

As noted above, (see *Section 3.3.1: Social constructivism*) the so-called Strong Programme in the Sociology of Scientific Knowledge argues for an even-handed treatment in explaining successful and unsuccessful scientific theories, and SCOT adopted this principle in accounting for successful and unsuccessful technologies. ANT extends this principle of symmetry into ontology, arguing that an assumption of ontological symmetry—an assumption of the basic ontological equivalence of natural and social phenomena—is essential for the investigation of socio-technical phenomena. For example, in his influential study of the conservation of scallops of St. Brieuc, Michel Callon (1986) ascribes agency symmetrically to scallops, marine biologists and local fishermen.

Callon (1986, p. 3) suggests three principles relating to this symmetrical approach:

1. *Agnosticism*: adoption of a position of impartiality between actors, treating social claims as dispassionately as scientific or technical ones: "[n]o point of view is privileged and no interpretation is censored".

2. *Generalised symmetry*: the commitment to account for different perspectives (whether they be scientific, technological or social) in the same terms: "The goal is not only to explain conflicting viewpoints and arguments in a scientific or technological controversy in the same terms ... the rule which we must respect is not to change registers when we move from the technical to the social aspects of the problem studied".

3. *Free association*: a rejection of all definitive a priori distinctions between the natural and the social worlds: "Instead of imposing a pre-established grid of analysis upon these, the observer follows the actors in order to identify the manner in which these define and associate the different elements by which they build and explain their world, whether it be social or natural".

3.4.3. The Formation of Networks

Also interesting from an ontological perspective is the ANT account of how networks are formed. This is through a process of "translation", in which actors are brought together through the harmonisation of their interests in such a way that they can work in concert (Sismondo, 2010).

For example, Callon (1986) describes four "moments"—overlapping phases in the general process of translation:

1. *Problematization*: the definition of the nature of a problem by an actor in such a way as to define a set of entities along with their identities and relationships. In doing so, the actor defines "obligatory passage point(s)"—key topics, questions or purposes around which actors must converge.
2. *Interessement*: the devices used to impose and stabilise the roles defined in problematization onto a set of actors: "interessement helps corner the entities to be enrolled" (Callon, 1986, p. 204).
3. *Enrolment*: the series of "multilateral negotiations" which accompany the interessement devices, in order to successfully assemble the network: "interessement achieves enrolment if it is successful" (Callon, 1986, p. 206).
4. *Mobilization*: the previous phases have usually involved only "representatives" of large populations of actors. Mobilization is the process through which the representative power of these "spokesmen" is tested: ensuring that supposed spokesmen are properly representative and so extending the network over whole populations of actors.

The mobilisation of the network is not a single, definitive event—all such network are in a continual state of tension and change, requiring constant work and negotiation to maintain and adapt themselves (Callon, 1986; Law & Mol, 2001; Faik, Thompson & Walsham, 2013).

Although this model network formation remains influential, modifications to the model of have been proposed (e.g., Star & Griesemer, 1989). Nevertheless, some account of how a network is constructed or emerges remains of key concern to ANT. This appears particularly salient when attempting to understand an emergent phenomenon such as IoT.

3.4.4. ANT as relationist ontology

As discussed above, ANT builds on the rejection of certain commonly held ontological assumptions. ANT brings with it in its turn its own set of ontological assumptions. In the first place, ANT rejects any basic ontological distinction between natural and social actors. In its place, ANT introduces a “flat” ontology, with all manner of entities being accorded an equal ontological footing (Harman, 2016).

The underlying ontology of ANT may be summarised as “relational materialism” (Law, 1999). On the one hand, “ANT is a materialist theory. It reduces even the ‘social’ to the material, both inside and outside of science” (Sismondo, 2010, p. 82). Actors are thus “utterly concrete” (Harman, 2009, p. 19). On the other hand, it is strongly relational: actors are what they are only by virtue of their place in the network, by the ways they relate to each other (Dusek, 2006).

In summary then, an actor is (only) its relations. In his “Irreductions” Latour states that “everything happens only once, and at one place” (Latour, 1988, p. 169). He further rejects the idea of a “global” (as opposed to local) action, and of potential (as opposed to actual) properties or power (Latour, 1988). In his commentary on Latour, Harman (2009, pp. 17-19) summarises Latour’s position thus: actors “do not have an inner kernel or essence encrusted with trivial additional properties”; each actor is “always completely deployed in the world, fully implicated in the sum of its dealings at any given moment.… There is thus no underlying substance to give actors potentiality or durability”.

3.4.5. Relationship to other relationist ontologies

The underlying ontology of ANT has a number of similarities with process philosophy. Process philosophy opposes “substance metaphysics”, the dominant metaphysical theme in Western philosophy since Aristotle. Substance metaphysics is based on the assumption that underlying reality consists of sets of basic units (“substances”) which are fixed and enduring over time. By contrast, process philosophy holds that the underlying nature of being is dynamic, and that to understand reality we need to understand the processes of becoming rather than searching for immutable substances (Seibt, 2018). Leading figures in the process philosophy tradition include Henri Bergson, Samuel Alexander, and Alfred North Whitehead. Process philosophy also shares elements in common with the pragmatism of Charles Peirce, William James, John Dewey, and George Herbert Mead (Dusek, 2006).

Whitehead, in particular, is a direct philosophical ancestor of Latour. Whitehead asserts that "there are no brute, self-contained matters of fact, capable of being understood apart from interpretation as an element in a system" (Whitehead, 1929, p. 19). Thus for Whitehead, "the actual world is a manifold of prehensions, where a prehension is conceived as a concrete fact of relatedness" (Mays, 2014, p. 218). So for Whitehead, as for Latour, concrete relations are the ontological foundations of the world. Whitehead, however further asserts that underlying this reality are "eternal objects" and that these, "eternal objects, as in God's primordial nature, constitute the Platonic world of ideas" (Whitehead, 1929, p. 63). This appeal to God and eternal objects is not a prominent element of the philosophy of Latour or ANT (Harman, 2009).

3.4.6. Criticisms of relationism

As a longstanding and widely deployed methodology, ANT has been subject to criticisms on a number of grounds, ranging from its theoretical foundations to its efficacy in practice (Sismondo, 2010). In keeping with the ontological spirit of this enquiry, the focus will be on two metaphysical—rather than practical—criticisms.

Firstly, there is the concern raised by John Law in 1999. He acknowledges that ANT has been a very successful "machine for waging war on essential differences" which has "insisted on the performative character of relations and the objects constituted in those relations". However, he expresses misgivings that ANT has been successful, "to the point where its own topological assumptions have been naturalized" which has had the effect of 'homogenising' relations; that is, "of limiting the conditions of spatial and relational possibility" (Law, 1999, pp. 7-8). In other words, that ANT, founded on a critique of the ontological orthodoxy, has substituted an ontological orthodoxy of its own. In subsequent works, Law expands this criticism to argue for a more ontological approach to STS as a whole (Law, 2004)

Secondly, there is a more fundamental problem raised by Graham Harman. Harman attacks Latour's rejection of the idea of potential, noting that, "since Latour is committed to a model of actants fully deployed in alliances with nothing held in reserve, he cannot concede any slumbering potency lying in the things that is currently unexpressed [sic]" (Harman, 2009, p. 28). Harman notes the similarity between this position and that of the Megarians, who were famously criticised by Aristotle as follows:

> There are some who say, as the Megaric school does, that a thing *can* act only when it is acting, and when it is not acting it *cannot* act, e.g., that he who is not building cannot

> build, but only he who is building, when he is building; and so in all other cases. It is not hard to see the absurdities that attend this view.… For that which stands will always stand, and that which sits will always sit. (Aristotle 350 BCEa, IX:3)

Harman concludes that this failure to admit the reality of actors beyond their alliances, and the consequent inability to account for the ability of actors are to change, are severe enough to require the abandonment of relationist ontology. He argues—contra ANT—that objects, rather than relations, are the basic constituents of reality. Further—and again contra ANT—objects are not exhausted by their relations, but are always able to participate in new associations. This provides a way out of the Megarian conundrum. Harman's views are systematised in Object-Oriented Ontology, which will be discussed in the following section (Harman, 2009).

3.4.7. Relevance for this study

ANT is a methodology of great influence and longevity within STS. As discussed above, the ontological commitments of ANT have been both analysed and criticised in the literature. Based on a foundation of relational materialism, ANT makes positive ontological claims regarding the ontology of sociotechnical phenomena, and the process by which these phenomena arise.

In approaching IoT, ANT has a strong, almost seductive appeal. Firstly, IoT is an inherently networked, connected phenomenon. On the face of it, nothing could be more reasonable than to describe IoT as a network of actors, or to ascribe its emergence to the growing number of connected actors and their emerging alliances. This is particularly true given the very heterogeneous nature of the IoT actors; a heterogeneity which ANT anticipates and addresses. Secondly, the influence of ANT within STS is so pervasive as to make it almost invisible. The assumptions of ANT, rather than being explicit, have to some extent become "submerged": implicit in ways of analysis and thinking. An example is the assumption of symmetrical agency between human and non-human actors. In the experience of the author, this is sometimes held as an "article of faith" required for the successful practice of STS, rather than as a contestable hypothesis.

In summary, ANT displays significant potential for providing an ontological account of IoT, with a powerful and intuitively appealing ontological vocabulary which appears naturally fitted to the study of IoT. On the other hand, the methodological influence of ANT on the practice of STS requires the exercise of heightened vigilance against the danger of seeing only those constructs predicted by the method—a form of methodological confirmation bias. It should be noted, however, that although this thesis falls within the overall practice of STS, the method employed is not narrowly based on ANT. Thus, though the danger of methodological confirmation bias is real, it is not fatal to the study.

3.5. Postphenomenology

As discussed above, postphenomenology takes a different starting point from the other perspectives discussed so far; its point of departure for understanding technology is to understand how technology is experienced.

This section will discuss the origins of postphenomenology in phenomenology and the work of Heidegger. It will describe two forms of technological phenomenology. The broader form, which considers the phenomenology of technology as a whole, has already been mentioned above in the discussion of essentialism. This section will focus on the more specific form, which focuses on the phenomenology of specific technologies and technological experiences. In considering this, Ihde's perspectival model of technological experience will be considered, and the four modes of technological experience explained.

Next, the ontology of postphenomenology will be considered, and its relationship to similar ontological positions discussed. Various possible criticisms of postphenomenology will be then be weighed. The section will close with a discussion of the significance of postphenomenology for this research.

3.5.1. Phenomenology

Phenomenology may be described as the "study of structures of consciousness as experienced from the first-person point of view" (Smith, 2018) or, "the attempt to describe our experience directly, as it is, separately from its origins and development, independently of the causal explanations that historians, sociologists or psychologists might give" (Mautner, 1996).

The idea of examining consciousness directly is not new to philosophy, being found in both the Western and non-Western (e.g., Buddhist) traditions. As a distinct discipline, phenomenology came to prominence with the works of Edmund Husserl in the first decade of the twentieth century. Husserl's work was extended and altered in subsequent decades, most notably Sartre, Merleau-Ponty and Heidegger. Of these, it was Heidegger who was most concerned with the phenomenology of technology, and whose key ideas will now be considered.

3.5.2. Heidegger and the phenomenology of technology

Heidegger was a student of Husserl. However, his extension and development of phenomenology is so profound and far-reaching that it can overshadow the works of his former teacher.

Heidegger was a pioneer in two themes in the application of phenomenology to technology. The first of these is the use of phenomenology to develop a broad critique of technology and the technological attitude. This critique was originated by Heidegger (1977) in "The Question Concerning Technology" and has been discussed in *Section 3.2: Technological Essentialism* above. This approach has been extended and developed by, for example, Albert Borgmann, who has also used to it to examine particular technologies in the modern context. Borgmann stresses the difference between technological devices, which are merely means to an end, and "focal things and practices" which matter to people in their everyday lives (Borgmann, 1984; Introna, 2017). For example, fast food can be regarded as a mere device to relieve hunger, whereas a traditional family meal (which Borgmann cites as a focal practice) is intimately connected with the practices of food preparation and dining. Borgmann is concerned that technology may erode focal practices and thus impoverish the phenomenology of the lifeworld.

This section will focus on the second way in which phenomenology has been applied to technology, the use of phenomenology to explore the complexities and modalities of our interaction with technology. A key example of this approach is Heidegger's well-known discussion of the hammer in "Being and Time".

Firstly, Heidegger notes that our everyday experience of the world is shaped by "equipment": by things which have particular uses—chairs to sit on, doors to walk through and so on. Heidegger argues that our primordial experience of the world is the use of equipment, and that this precedes a theoretical understanding of objects. Heidegger then uses the example of the hammer to introduce some key ideas about our experience of technology. He notes that in everyday use of a hammer, it is not understood theoretically as an object with certain properties, but rather experienced directly as something useful. In this mode of experience, the hammer itself withdraws from view, and our experience is of the hammering. In this mode, the hammer is experienced as "ready-to-hand"—having the property of "handiness" or zuhandenheit.

Heidegger contrasts this with the way in which we would experience a hammer if we merely took it as an object for contemplation. In this case, the hammer would be experienced as a mere object which is “present-at-hand”. Finally, Heidegger discusses a third mode of encountering the hammer. If the hammer is not working properly, for example, if the handle is broken, the hammer itself obtrudes into our experience. However we do not experience it as simply present at hand; we experience it as “un-ready-to-hand”—not as phenomenologically transparent as a functioning hammer, but still having its being within the overall context of equipment (nails, wood, workshop etc.) Heidegger advances these differences as being fundamental to the structure of our experience (Heidegger, 1996; Wheeler, 2011).

3.5.3. Postphenomenology

Don Ihde and others have built on Heidegger’s phenomenology of the technological experience (as described above) to develop what they describe as postphenomenology. Postphenomenology shares with phenomenology a concern for direct experience—“it is inspired by the phenomenological focus on experience and concreteness” (Verbeek, 2017). However, postphenomenology follows the “empirical turn” in the philosophy of technology, rejecting generalisations regarding the nature of technology in favour of specific and detailed observations of specific cases (Verbeek, 2017): postphenomenology moves “away from a high altitude or transcendental perspective” and instead embraces “an appreciation of the multidimensionality of technologies as material cultures within a lifeworld” (Ihde, 2009, p. 22).

Ihde also argues that postphenomenology is indebted to pragmatism for enabling it to escape from the subject/object dualism which threatens to confine phenomenology to being a “subjective” philosophy. In broad terms, pragmatism avoids this problem by emphasising the importance of truths grasped through practice rather than through contemplation (Ihde, 2009).

3.5.4. Ihde and perspectivalism

One of the key achievements of postphenomenology has been Ihde’s clear articulation of four different modes in which technology may be experienced. These are:

1. *Embodiment relations*: Embodiment relations are those in which we enter into phenomenologically transparent relations with technology to enhance our perceptual ability. The technologies are phenomenologically “taken into” our body. We are not

aware of the technology itself, we are only aware of our enhanced perceptual abilities. Spectacles (or better still contact lenses) are a classic example of embodiment relations.

2. *Hermeneutic relations*: Hermeneutic relations arise when technology is used to provide us with information which we would not otherwise possess—for example, the speedometer on the dashboard of the car. Hermeneutic relations are not phenomenologically transparent. We are aware of the speedometer, and it does not directly engage with our sense of how fast the car is travelling. In a hermeneutic relation we technology to "read" the world, rather than to directly experience it.
3. *Alterity relations*: In embodiment and hermeneutic relations, technology references the world: in these relations, the role of technology is to moderate our experience of the world. In alterity relations, we engage with technology itself as "other", or at least "quasi-other". Toys are an example of this: a child engages directly with (say) a spinning top which does not reference the world beyond. The rise of digital technology underlies a growth in the importance of alterity relations. Engagement with autonomous digital agents provides an experience of technology as "other" whether a chatbot, an autonomous robot, or an automated video-game opponent.
4. *Background relations*: Background relations are the "invisible" relations we have with ambient and pervasive technologies in a technology-saturated world. For example, a thermostat moderates the temperature of the office, but we are not consciously aware of it unless or until it breaks or malfunctions. Such "background" technologies are similar to Heidegger's idea of "equipment": a constant background of technology which provides the necessary context for any technology which is "foregrounded" through use or malfunction.

(Ihde, 2003, 2009; Introna, 2017)

3.5.5. The ontology of postphenomenology

Ihde describes the ontology of postphenomenology as *interrelationist*, involving the "coconstitution of humans and their technologies", meaning that, "the human experiencer is to be found ontologically related to an environment or a world, but the interrelation is such that both are transformed within this relationality" (Ihde, 2009, pp. 23, 44). This position differs from the relationist position of ANT (see above) by making the human subject ontologically central. Pickering (2006b, p. 213)summarises Ihde's ontology as, "at the centre, the embodied human, immersed in a world that cannot be spoken of outside our experience of it, plus a set of representational instruments that efface our embodiment ... this centrality of the body itself constitutes an inescapable asymmetry between the human and the nonhuman in phenomenological enquiry”. This is a clear contrast to the relational symmetry advanced by ANT.

3.5.6. Criticisms of postphenomenology

Ihde’s postphenomenology has been criticised for paying too little attention to the phenomenon of Technology, that is, technology in general. In this, postphenomenology is a reaction against the substantivism of Heidegger, who takes a totalising, and pessimistic, view of Technology. Scharff (2006) argues that postphenomenology goes too far in this direction, eschewing global considerations of technology entirely, or consigning such global question to a different level from the specific, empirical phenomena which make up the subject matter of postphenomenology. He suggests that a global view of technology, whether positive or negative, is in fact inseparable from the phenomenology of technology: “In his eagerness to define his position against Heidegger, Ihde seems not to realize that he himself is displaying in his writings a sense of technoscientific existence that is just as “global” and “general” as Heidegger’s” (Scharff, 2006, p. 139). This may be linked to a more general criticism of phenomenology as being purely descriptive rather than prescriptive, and ignoring ethical questions (Ihde, 2006).

As observed above, the ontology of postphenomenology has been criticised as fundamentally asymmetrical and human-centred, which may be seen as a limitation (Pickering, 2006b). For example, Verbeek (2001, p. 130), himself a prominent postphenomenologist (Smith, 2015), has noted the apparent tension between Ihde’s concept of technological mediation and the “central thought” of phenomenology—that “the interrelation between subject and object always precedes the subject and the object themselves; the subject and object are constituted in their interrelation” (Verbeek 2001, p. 130). Verbeek concludes that this co-constitution is not incompatible with technological mediation if the latter is understood in properly phenomenological terms. He does, however, argue that a greater degree of symmetry between people and things is required in order to account for the moral content of things (Verbeek, 2006). He suggests that although things do not have moral agency, they are still part of the moral community by virtue of their power to shape human action and understanding.

3.5.7. Relevance for this study

The postphenomenological account of the mutual constitution of subjects and objects through technological mediation is invaluable in attempting to understand the human experience of a technologically saturated life-world. Indeed this is the only one of the perspectives considered which engages so directly with the human experience of technology. Given the putative potential impact of IoT on the lives of billions of people, the postphenomenological account is extremely relevant. For example, it may be asked what will IoT's main mode of mediation will be: embodiment, hermeneutic, alterity or background? Or rather, in what circumstances will each of these modes of mediation be most evident? And how will this understanding this modal experience of IoT inform our overall understanding of what IoT is? At a more fundamental level, postphenomenology asserts that the being of IoT is ontologically grounded in human experience. This is a strong claim, and one which may be brought into dialogue with the ontic claims about IoT to be found in the texts.

3.6. Object-Oriented Ontology

As discussed above (see *Section 2.2.2: The Ontological Turn in Philosophy*), Speculative Realism is a broad contemporary movement in metaphysics. Speculative realism argues for a philosophical re-engagement with external reality, while conceding that complete knowledge of this reality is ultimately impossible. In doing this, speculative realism is reacting against what it takes to be the anthropocentric and subjectivist bias of Western metaphysics since Kant.

Space does not permit consideration of all the authors and themes which make up Speculative Realism, nor is it required for the purposes of the thesis. Attention will therefore be focused on Object-Oriented Ontology, which is one of the more prominent strands of Speculative Realism and represents many of the defining themes that run through the speculative realist corpus. Besides its salience within Speculative Realism, Object-Oriented Ontology is recommended to this study by the fact that some Object-Oriented Ontology authors are directly engaged with contemporary technology. For example, Ian Bogost, a prominent Object-Oriented Ontology author, has a background in video-game design, and uses video games to comment on social issues (Bogost, 2011, 2012). Graham Harman, one of the main originators of Object-Oriented Ontology, also engages directly with some of the ontologies discussed in previous sections, notably the relationism of ANT and Heidegger's phenomenological analysis of tools and equipment (Harman, 2009).

3.6.1. An outline of Object-Oriented Ontology

Object-Oriented Ontology is based on a limited number of key tenets. These justify the status of Object-Oriented Ontology as a coherent ontological perspective. Chief among these tenets are:

(i) Rejection of anthropocentrism and correlationism

As noted above, the rejection of anthropocentrism and correlationism is one of the cornerstones of speculative realism in general. The articulation of this rejection by Quentin Meillassoux (2008) is one of the key foundational moments in the development of Speculative Realism. Object-Oriented Ontology follows this rejection, lamenting that Kant's "Copernican Revolution" led to an "anthropocentric unilateralization of the human-world relation to the detriment of the world"—given this "obsessive focus on the human-world relation or gap, it becomes impossible to investigate networks of objects because objects are reduced to that which is posited by human beings" (Bryant, 2010a).

(ii) Rejection of over- and under-mining

Object-Oriented Ontology argues for the essential reality of objects of every scale and type, from atoms and galaxies to football teams and fictional characters. Object-Oriented Ontology theorists argue that two tactics have been used within the Western philosophical tradition to deny or undercut the reality of objects.

The first of these tactics is *undermining*. Undermining uses reductionist logic to describe objects in terms of more basic constituents. Undermining is commonly encountered in the physical sciences. An exponent of undermining might, for example, argue that a chair is not an object in itself, as it "really nothing more" than a certain arrangement of atoms. In essence then, undermining is the reductionist claim that objects are simply the manifestations of a deeper underlying reality. At a fundamental level, undermining denies the very "chairness" of the chair. The existence of the chair as a chair is erased and is replaced by its constituents at many levels or on many scales, all the way down to sub-atomic particles.

Object-Oriented Ontology suggests that if objects are undermined it becomes difficult to account for emergent properties of objects, properties which attach to the object in itself rather than its constituent parts. For example, the fact that a particular chair is comfortable or uncomfortable is difficult to account for in terms of the way its atoms are arranged. An undermined ontology also has difficulty accounting for the continuity of an object despite changes to its constituent parts. Staying with the chair analogy, a chair can persist even if each of its individual components is replaced.

Overmining reduces objects not "downwards" towards underlying constituents but "upwards" towards its relations and effects. For example, ANT (see *Section 3.4.6: Criticisms of relationism*) describes actors as the sum total of their relations with other actors e.g., a chair is constituted as such by the fact that it was produced in a furniture factory, that people sit on it, that it is adjacent to a table and so on. To give another example, an idealist position might seek to overmine objects by describing them as nothing more than the ideas to which they give rise, for example, a chair might be understood as expression of bourgeois domesticity. In essence then, overmining is the claim that objects as such are an unnecessary surplus to our theories; that it is not necessary to subscribe to the material reality of objects in order to explain the world.

Object-Oriented Ontology rejects overmining, arguing that an overmined ontology has difficulty accounting for the ability of objects to change: to form new relations and to display new and different properties. An example of this criticism is Harman's rejection of ANT's claim that an actor is fully revealed by its relations at any time, on the grounds that this makes it difficult to account for how change occurs (see *Section 3.4: Actor-Network Theory and Relationism*).

Harman (2010a, 2016) argues that undermining and overmining tactics are often combined in an approach he terms "duomining". For example, scientific materialism undermines objects by reducing them downwards into atomic and sub-atomic particles. It then overmines these underlying constituents by arguing that they can be completely accounted for by a mathematical description of their properties.

(iii) Unknowability of objects

Following the rejection of under-, over- and duo-mining, Object-Oriented Ontology argues that objects have an "inner" reality that cannot be fully known. As expressed by Levi Bryant (2010b, under "Epistemology") "it is necessary to distinguish the being of objects from the manifestation of objects ... the proper being of the object is not its performance or manifestation, but the generative mechanism that serves as the condition under which these performances or manifestations are possible". Thus the being of objects is withdrawn from relations, and is ultimately unknowable—"there is always something of the object held in reserve" (Bryant, 2011, p. 271)—which gives the object its potential to change and to form new relations.

3.6.2. Varieties of Object-Oriented Ontology

A number of prominent thinkers within the Object-Oriented Ontology school have developed their own variations of the theory, though these agree on the metaphysical principles outlined above.

Levi Bryant, for example, terms his approach "onticology". He grounds this approach in what he calls the "Ontic Principle": that "that 'to be" is to make or produce a difference" or in other words "there is no difference that does not make a difference" (Bryant, 2011, p. 263). According to Bryant, two further principles follow from the Ontic Principle. The first of these is the Inhuman Principle which asserts that, "the differences that make a difference are not restricted to the domain of the human, the linguistic, the cultural, the sociological, or the semiotic.… The being of difference is, in no way, dependent on knowledge or consciousness" (Bryant, 2011, p. 267)—in other words, the human position with respect to being is in no way privileged. Bryant's third principle he terms the Ontological Principle. This principle states that because any entity which can make a difference is real, ontology is essentially flat in that no entity is "more real" than any other: "Insofar as the minimal criteria for being a being consists in making a difference, the number and variety of beings is infinitely multiplied.… Both quarks and the character of Half-Cock Jack in Neal Stephenson's Quicksilver both make differences, they both are, according to the Ontological Principle, real" (Bryant, 2011, p. 269). Although Bryant's approach is somewhat different to Harman's then, his conclusions are similar.

Ian Bogost argues for the need to move beyond general statements of Object-Oriented Ontology in order to examine specific examples of what it is like to be a non-human entity, a pursuit he terms "alien phenomenology". He seeks an "applied speculative realism" which would "embolden the actual philosophical treatment of actual material objects and their relations" by describing what is to "what it means that something in particular is for another thing that is" (Bogost, 2012, pp. 29-30).

Another influential development in the field of Object-Oriented Ontology has been Timothy Morton's development of the concept of hyperobjects. Hyperobjects are things "that are massively distributed in time and space relative to humans" (Morton, 2013a, p. 1). Morton gives a heterogeneous list of examples, including Styrofoam, global warming, industrial capitalism, the biosphere, a black hole, and the Solar System (Morton, 2013a).

According to Morton (2012), hyperobjects share five key properties:

1. Hyperobjects are viscous: “they stick to us and penetrate us” despite any attempt to withdraw from them (*viscosity*).
2. Hyperobjects are nonlocal: “they do not manifest at a specific time and place but rather are stretched out in such a way as to challenge the idea that a thing must occupy a specific place and time” (*nonlocality*).
3. Hyperobjects “have a temporality so different from current human ones that they force us to drop the idea of time as a neutral container” (*temporal undulation*).
4. Hyperobjects occupy more dimensions than the normal dimensions of space-time: this may make them seem to disappear and then reappear when viewed from a human perspective (*phasing*).
5. Hyperobjects “exist ‘interobjectively”, which is to say that they consist, of, yet are not reducible to, interactions between a large number of entities” (*interobjectivity*).

Morton argues that hyperobjects have already had a significant impact on the way in which humans exist in the world—indeed he argues that “the world”, as a background against which human events unfold, has already effectively ended (Morton, 2012).

Morton’s provocative and sometimes playful mode of description can make concept object of the hyperobject a difficult one to pin down. Nevertheless, given the massively distributed nature of IoT, there is some obvious potential resonance between IoT and the idea of the hyperobject. This will be explored further in following chapters.

3.6.3. Criticisms of Object-Oriented Ontology

Object-Oriented Ontology has been the target of several significant criticisms.

In “The Noumenon’s New Clothes” Peter Wolfendale accuses Object-Oriented Ontology of being a reversion to Kant, through the resurrection of his idea of the noumenon. By this account, Object-Oriented Ontology is a restoration of correlationism: “Harman essentially attempts to overcome the inconsistencies inherent within correlationism by sacrificing one of its core features—the prohibition on metaphysics—in order to construct a metaphysical prop whose purpose is nothing less than to bolster the rest of the calamitous edifice" (Wolfendale, 2012, p. 293). This view is supported by Slavoj Žižek in his review of "The Noumenon's New Clothes": "Object-Oriented Ontology is the last chapter in the interminable saga of the struggle between realism and transcendentalism. It attempts to undo the transcendental turn and resuscitate the precritical notion of reality in which humans are not subjects but one among many actants" (Žižek quoted by Urbanomic Media Ltd., 2014, under "The Noumenon's New Clothes").

As noted above, Object-Oriented Ontology reacts against the relationism of ANT, of which Whitehead's process philosophy is an ancestor. Shaviro (2011) argues that process philosophy, if correctly understood, is proof against Harman's criticisms of relationism. In particular, Shaviro argues that Whitehead's philosophy provides a dual-aspect account of things, which things being *both* actual entities and networks of relations. Harman (2011) responds that Whitehead's actual entities are ultimately reducible to their relations, or more exactly to a regress of their relations over time—leaving no place for actual entities beyond this web of relations.

3.6.4. Relevance for this study

Object-Oriented Ontology provides a comprehensive—if relatively new and controversial—approach to ontology. Among other things, it addresses weaknesses in the correlationalist and relationist positions. Unlike most of the other positions reviewed above (technological determinism, SCOT, postphenomenology, ANT), Object-Oriented Ontology is explicitly ontological, addressing head-on the metaphysical questions which other theories address only in passing or by implication. This makes it a useful tool in pursuing an ontological investigation, particularly given its clear and coherent viewpoint and terminology. On the other hand, Object-Oriented Ontology is a general ontology rather than a regional ontology of technology, which may limit its usefulness.

Several specific features of Object-Oriented Ontology make it alluring for the study of IoT. Firstly, Object-Oriented Ontology's rejection of anthropocentrism appears sympathetic to IoT's decentring of humans from the internet. Secondly, Object-Oriented Ontology explicitly focuses on complex and highly heterogeneous objects of the type that IoT is predicted to become – for example see the discussion of Morton's hyperobjects above.

3.7. Summary

This chapter has, as indicated at its commencement, addressed two key topics.

Firstly, it has explored the methodological foundations and precedents for the use of ontology as an investigative tool. The revival of interest in ontology within philosophy, anthropology and STS was described. Some of the main theoretical challenges to the methodological use of ontology were discussed, and addressed. It was concluded that an ontology-centred method was not only a viable but a promising approach to understanding IoT.

Secondly, six key approaches to the ontology of technology were considered. Each approach was described in terms of its origins, its key concepts and its applications. Common criticisms of each approach were also considered. The relevance of each approach for this study was also touched on.

The different philosophical ontologies of technology suggest different ontologies for IoT. In a very condensed form, these possible ontologies of IoT may be summarised as follows: An artefact-based perspective would suggest that IoT is a technical artefact, the outcome of engineering processes. An essentialist view would propose that IoT is a new expression of Technology, a force which lies outside society and possibly beyond human control. Conversely, the constructivist position would be that IoT is constructed by society, and shaped by the social imagination. In a postphenomenological account, the being of IoT must be located in the first instance in our direct experience. Relationism, meanwhile, would account for IoT as emerging from a complex network of interactions. Finally Object-Oriented Ontology would posit IoT as being a real object which we can, however, completely know.

It deserves to be re-emphasised that this analysis is not intended to be a comprehensive treatment of every philosophical position on the ontology of technology, an endeavour which would take many volumes. Neither is the analysis intended to be a fixed and rigid system classification into which data will be fitted in the manner of Procrustes. Instead, the purpose of surveying these ontological positions is to provide a provisional sketch map for the territory to be explored. The purpose of this map is to alert us to some of the ontological possibilities that we may encounter in the text. However, we should hold these possibilities in a relaxed way. We should not strain to see these ontologies—and risk seeing them when they are not there. Nor should we allow the existence of these ontological possibilities to blind us to the existence of others. We should not confuse the provisional sketch map with the territory.

It is now time to time to turn our attention to this territory—the voluminous and heterogeneous literature concerning IoT itself.

4. Research Question, Methodology and Method

In the Introduction I stated that the aim of my research was to enable a greater understanding of IoT by attempting to answer the question: "What is the Internet of Things?" With this aim in mind, the previous chapter reviewed the literature concerning ontology and the use of ontology in research. The next step is to define the research question in more detail, and then to describe the method to be employed in addressing it.

In this chapter, I will start by defining the research question of the thesis. I will then explain the contribution that answering this question will make to the field. Moving on to methodology, I will outline and justify the method to be used, considering both its strengths and its potential limitations. In the final part of this chapter, I will describe the method to be used in greater detail. This will prepare the ground for the data analysis which is the subject of the next chapter.

4.1. Research Question

In the Introduction I stated that the overall intent of this thesis is to address the question: "What is the Internet of Things?" This is, however, too general and imprecise a formulation to serve as a research question. In the first part of *Chapter 2: Literature Review*, the value of ontologically-based enquiry was explored, and it was demonstrated that this is a credible and widely accepted approach across a number of fields, and one which has yielded useful results. The second part of *Chapter 2: Literature Review* then showed that the ontology of technology is a topic with a long pedigree. It was also shown that a number of influential perspectives have dominated philosophical thinking regarding the ontology of technology, and six key philosophical perspectives on the ontology of technology were selected as being representative.

It has thus been established that an ontological approach is a promising way to investigate IoT. It has also been shown that such an investigation would be able to draw on a strong philosophical tradition regarding the ontology of technology. In making use of this philosophical tradition we must, however, steer between two extremes. On the one hand, to undervalue the philosophical tradition is to discount the insights developed by profound thinkers over a period of centuries. On the other hand, it would be counter-productive to accept the philosophical tradition without question as a Procrustean conceptual framework to be imposed on the data. This would be to pre-judge the results of the investigation, and would preclude the generation of any genuinely new insights.

In order to avoid both Scylla and Charybdis, my intention is to employ the philosophical ontologies of technology in an instrumental and heuristic way: I will use the philosophical ontologies of technology as an investigative tool, without committing to in advance to any one ontology. This will permit a reflexive interplay in the investigation between the ontologies derived from the philosophical literature and those read from the texts themselves.

Based on the foregoing, my research question can be more clearly stated as:

What does an ontological investigation of the Internet of Things, framed by prominent philosophical theories regarding the regional ontology of technology, reveal about the regional ontolog(ies) of the Internet of Things?

This question has a reflexive corollary, namely:

What does such an investigation reveal about the explanatory power of prominent philosophical technologies regarding the ontology of technology?

While not the primary focus of the thesis, the question will also be considered during the course of the investigation.

The contribution to be made by this thesis was described when the general area of enquiry was introduced (see *Section 1.2: Aims, Scope and Significance* above). To briefly restate this contribution, answering the research question will be valuable in three ways.

Firstly, as described in the introduction, it is widely anticipated that IoT will have a transformative impact on technology, society and the economy. Indeed, IoT is already of such a size and significance that it is, in its own right, a subject worth studying. Answering the research question will thus add value by improving our understanding of this important phenomenon. This will be the primary contribution of the thesis.

The benefit of taking a specifically ontological approach to such an investigation was described in *Section 2.2:*

Ontology as a methodological tool above. In particular, taking ontology as a matter for investigation – rather than as something out of scope or given in advance—has been shown to yield novel and useful insights into phenomena. For example, an ontological approach has yielded insights into the behaviour of phenomena, the way the phenomena evolve/unfold, the way they are enacted/encountered in practice, and the way they are understood and articulated by human protagonists (for example Mol, 2002).

Secondly, although IoT is unique in some ways, it seems reasonable to suggest that it shares many features with other large-scale technological phenomena—especially those which are global, networked, and multifunctional. This research may thus serve as a model for studies of other large-scale technological phenomena, which would test whether the conclusions of this study are of more general application. In other words, this thesis may serve as the basis for a case study which would improve our understanding of large-scale technological phenomena in general. It should be emphasised that this thesis is, in itself, a study of a particular case (that of IoT) rather than a case study. The value of the thesis as the potential basis for a case study is thus secondary to its primary contribution to the understanding of IoT.

Thirdly, understanding the ontology of technology is an important task given the importance of technology to contemporary society. By holding up a reflexive mirror to philosophical theories regarding the ontology of technology we can better understand the work that these theories can do, and the ways in which they can enhance or occlude our understanding of technology. Answering the research question will thus add value by improving our understanding of the theoretical ontology of technology. Again, this contribution is supplementary to the primary contribution of the research: improvement in our understanding of IoT.

4.2. Methodology

The intent of the current research is thus to investigate in more detail the nature of IoT, into what IoT is.

Conceived in these terms, the intent of the current enquiry is to look beyond the mere ontics of IoT, that is, the surface appearance captured by facts such as the number of devices connected, the ethical concerns expressed by lobby groups, the types of protocol used, the volume of IoT sales. By so doing, the objective is to uncover IoT's underlying regional ontology (or ontologies), that is, to account for IoT in terms of the nature of its being(s), and how it/they are intelligible as being(s). The current enquiry will not be directly concerned with fundamental ontology, though it may call upon fundamental ontology to provide a theoretical grounding for the enquiry.

The articulation of a regional ontology (or ontologies) to investigate socio-technical phenomena is a familiar method within the field of STS. For example, Mol's seminal work "The Body Multiple: Ontology in Medical Practice" explores the different ontologies enacted for the condition atherosclerosis in different disciplines and settings within a Dutch university hospital (Mol, 2002). Law (2004) draws upon this and numerous other examples to put ontology, and particularly contested or "messy" regional ontologies, at the heart of socio-technical enquiry.

This ontological approach has been adopted for the study of diverse areas including cybersecurity (Liebetrau & Christensen, 2021), drug policy (Lancaster & Rhodes, 2020), physiotherapy (Setchell et al., 2018), extremism (Dyboll, 2018), death (Hadders, 2009), the social impact of new media (Liu & Keane, 2020), milk production (Linn, 2019) and criminology (Lam, 2016). These, and other works from the STS canon, will provide a methodological precedent for the current project.

A key initial aim of the investigation will thus be to uncover and articulate the regional ontolog(ies) of IoT (the concept of regional ontology was introduced in *Section 2.3.1: What is an ontology of technology?* above). To articulate an ontology requires us to identify the things and types of things which are important to that ontology, as well as a description of their relationships and interactions. An ontology can also be characterised by the ontological status it accords to various entities, and by the way it accounts for agency and change. The context and situation of an ontology are also important features; we need to understand how it is enacted and used in practice, and to detail its adherents and opponents. An ontology may also be associated with the trajectory ascribed to it by its adherents, from origin myth ("where did it come from") to eschatology ("where will it end").

The proposed technique for investigating the regional ontolog(ies) is as follows:

The first step will be to review ontic references to IoT—that is, statements of fact about IoT—in relevant discourses. It is reasonable to anticipate that, for any regional ontology structure to be significant for IoT, it must have some impact on the communities of people concerned with IoT. It is thus likely that any salient regional ontology will leave traces in the discourses of these communities in the form of ontic claims about IoT. A review of these discourses is thus likely to be a reliable and fruitful way to find evidence of regional ontolog(ies). By contrast (say) relying on the philosophical intuition of the individual researcher would highlight the subjective ontological interests and concerns of the researcher, but these may have no importance for IoT as a whole. Similarly, studying IoT in a particular context (say a particular IoT project), would highlight the ontological interests and concerns salient to that context, but again these might be of limited significance for IoT overall.

It should be stressed that the ontology of IoT is not democratically determined. It is not determined by the most popular or common ontological claims made in the literature. The purpose of surveying the literature for ontic claims is not to "take a vote". The purpose is to reveal the widest range of ontological possibilities, which will then be subjected to philosophical analysis to draw conclusions about the ontolog(ies) of IoT.

Starting points for an investigation into the IoT discourse will be the academic, professional and popular literature on IoT, which contain ontic claims about the characteristics of IoT. It is not expected that regional ontologies will be described plainly and in full. Instead, as noted above, regional ontology(ies) must be excavated based on the evidence of ontic claims. An inductive analysis of the sampled texts will be undertaken to identify ontic claims about IoT in the texts. These ontic references may be explicit or implicit. Further work will then be done to compare and group these references, in order to understand the different ways in which the being of IoT is described in the sampled texts. Details of how this comparison and grouping will be done may be found in *Section 4.3.5: Analysis method* below. Groups of similar references will be referred to as "empirically derived ontological categories" (or simply "categories"). Note that no allusion to other philosophical uses of the term "category" is intended.

This research will differ from much of the STS mainstream in being strongly text-based; many STS projects also include a substantial element of practitioner interviews and direct observation. This textual approach is motivated by the scale and global reach of the IoT phenomenon; a text-based approach will allow for a wider and more representative analysis, though it will inevitably sacrifice some of the local richness of alternative approaches. It should be noted that to adopt text-based methods is not to assume that IoT's nature is discursive; the investigation must not prejudge IoT's ontological status (which is what is at stake in the investigation).

The second step in uncovering regional ontologies will be hermeneutic rather than empirical. It will consist of bringing the empirically derived ontological categories into dialogue with six established philosophical perspectives on technology.

The philosophical positions to be considered are those described in *Chapter 3: Ontologies of technology*, namely:

1. Artefact-based Ontology
2. Technological Essentialism
3. Social constructivism
4. Relationism
5. Postphenomenology
6. Object-Oriented Ontology

These positions will be referred to as "philosophical ontologies of technology" (or simply philosophical ontologies"). Limiting consideration to these six perspectives is a deliberate choice. The rationale for this choice is given in *Section 2.3: Ontologies of technology: overview and survey* above.

As noted above, my intention is to employ the philosophical ontologies of technology in an instrumental and heuristic way, employing them as an investigative tool, without committing in advance to any one of them upfront. This will enable me to create a reflexive engagement between the philosophical ontologies of technology and the empirically derived ontological categories drawn from the texts. By bringing these two bodies of knowledge into dialogue my intent is to gain fresh insight into both of IoT and the philosophical ontologies of technology.

It is hypothesised that there will be some resonance between the philosophical ontologies and the empirically derived ontological categories—that is, certain philosophical ontologies are expected to be able to provide a convincing account of certain empirically derived ontological categories. For example, a category which described IoT as a physical artefact would be resonant with philosophical ontology which grounds the ontology of technology in physical artefacts; it would not be resonant with philosophical ontology which insists the ontology of technology is purely a social construction.

Given the "messiness" of practice (Law, 2004) this is not expected to be a neat and crisply bounded relationship. In addition, the empirical ontological categories cannot be assumed to be stable over time; they are likely to exhibit some degree of mutability, which may be framed by key events.

Based on methodological precedents (e.g., Law, 2004) it is expected that multiple distinct regional ontologies will emerge from this investigation, where a regional ontology consists of certain philosophical ontolog(ies) which correlate well with certain empirical ontological categor(ies). This should not prejudice other possibilities though, such as a single coherent regional ontology or multiple empirical ontological categories which cannot be mapped to any philosophical ontology.

In the expected case (i.e., where a number of alternative regional ontologies—as described in the previous paragraph—are revealed) the next task of the thesis will be to undertake a comparative analysis of the observed regional ontologies. For example, what kind of work do they perform in practice? What is their relative epistemic status?

At this point the analysis will move from describing and analysing the regional ontologies identified above, towards trying to provide a coherent overall account of these regional ontologies. This is a move from describing ontology towards doing ontology.

This part of the analysis will commence with an investigation into how the regional ontologies are interrelated. For example, Law (2004) describes a set of strategies that may be employed in practice to negotiate the use of multiple ontologies in practice. Some of these he describes as "perspectival", that is, intended to preserve the idea of a single reality behind the ontologies. Such methods include creating translations between the ontologies, or ordering them in a hierarchy. Other methods are non-perspectival, for example, the separation of the ontologies by barriers between communities or loci of practice, or the assumption that the different ontologies refer to distinct sets of objects.

From the literature on the philosophy of technology, three interesting approaches to dealing with ontological complexity and multiplicity were identified. Each approach would suggest a different interpretation of ontological multiplicity, as follows:

- Boundary Object theory: it is possible that IoT itself falls into the class of "boundary objects" described by Star & Griesemer (1989)—those objects which inhabit multiple intersecting social worlds, adapting to local needs while still maintaining a common identity across locales.
- Ontological emergence via praxis: It is possible that the ontologies of IoT are not pre-existing, but rather emerge as a result of praxis, with different forms of praxis resulting

in different IoT's, similar to the ontological multiplicity of arteriosclerosis shown by Mol (2002).

- Hyperobject theory: it is possible that IoT is a hyperobject of the sort described by Morton (2013) and that the ontological multiplicity of IoT reflects the complex and non-intuitive nature of this hyperobject.

Each of these possibilities will be considered in the analysis.

Much of the work done in the preceding sections will have been to regard IoT from different philosophical positions, and to consider how the resultant perspectives can enrich our understanding of this phenomenon. In summary: what can these philosophical positions reveal to us about IoT? We will then consider the reverse of this question: what can IoT reveal to us about these philosophical positions? How useful have they proved to be, and how cogent are their conclusions? What have they uncovered, and what have they obscured?

In summary, the proposed methodology builds on established theories and techniques in order to develop ontology as a critical lens for investigation of the emerging "Internet of Things". In doing so the proposed thesis will also cast light on the utility of ontology, and of different ontological theories and methods, for carrying out this kind of research.

This approach may be visualised as follows:

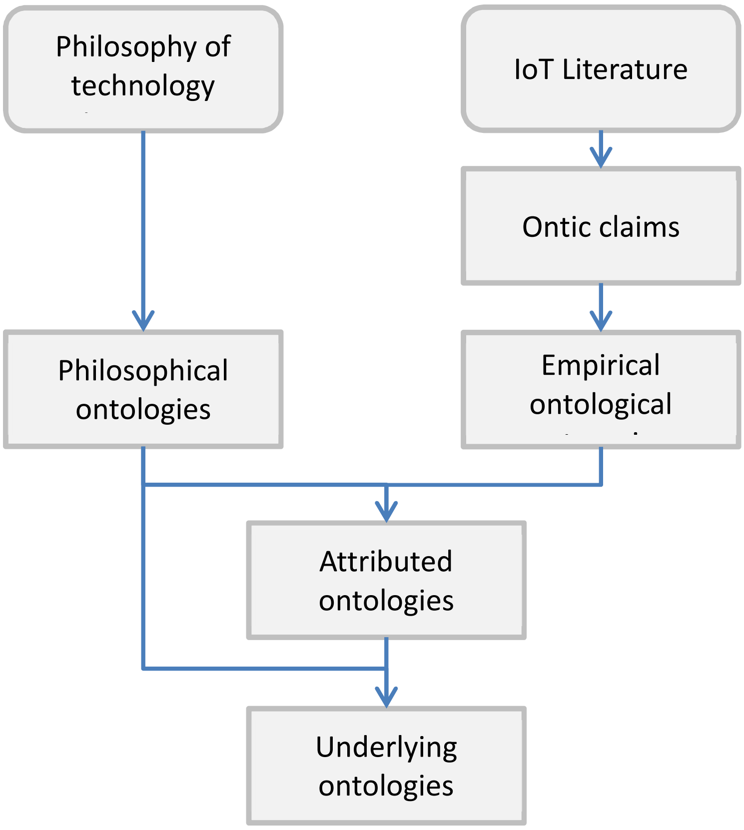


Figure 4-1 Graphical overview of approach

Before proceeding, it will be useful to clearly restate the terms which will be employed in the remainder of the thesis:

1. Philosophical ontology: a regional ontology of technology arising from a particular school of theory. In this thesis I will be concerned with the six philosophical ontologies outlined in *Chapter 3: Ontologies of Technology* above.

2. Ontic claim: a statement in the literature asserting a fact about IoT.

3. Empirically derived ontological category (or simply "category"): a grouping of similar or related ontic claims.

4. Attributed ontology: a regional ontology of IoT which may be attributed to a particular text (or corpus) on the basis of the category(ies) of ontic claims encountered in that text (or corpus).

5. Underlying ontology: a regional ontology of IoT which, if accepted, would provide a satisfactory account of various attributed ontologies.

It may also be useful to restate the three key moves which link these terms:

The first move is to group the ontic claims into empirically derived ontological categories. This move is intended to reveal the common assumptions about regional ontology which are entailed in the ontic claim.

The second move is to bring the empirically derived ontological categories into dialogue with the philosophical ontologies. This move is intended to allow us to attribute regional ontologies of IoT to the texts by identifying resonances between the categories, which reveal only rudimentary ontological assumptions, with the philosophical ontologies, which are full regional ontologies of technology.

The third move is to investigate what underlying ontologies could account for the attributed ontologies. Crucially, this a move from *using* ontology as a tool for investigation to *doing* ontology. Attributed ontologies are those which we may attribute to others; underlying ontologies are those which we may ourselves assert.

Having discussed and justified the overall approach to be taken to answering the research question, I will now turn to the details of the method to be employed.

4.3. Method

The first part of this chapter described the methodological foundations and approaches which form the basis for this research.

The current section deals in more concrete terms with the method employed, and particularly with the method of data analysis. In doing so, it describes and explains the data sources chosen, the way in which these sources were sampled, and the techniques used in analysing the sample texts. It then describes how the resultant analysis has been used to support the development of the thesis.

4.3.1. Data survey

The reasons for taking a literature-based approach, and the goals of analysing the IoT literature, were introduced in *Section 4.2: Methodology* above.

One of the challenges in employing a literature-based approach is the sheer scale of the IoT literature. For example, in November 2017, Amazon (a large online retailer) listed for sale 3,883 different books with the keyword "internet of things" (Amazon.com, 2017). At same time Scopus (a large academic citations index) returned 26,127 relevant documents (Elsevier

BV, 2017a) and the Google search engine returned 35,700,000 hits (Google.com, 2017). An exhaustive analysis is thus impossible.

A data strategy was thus sought which could provide meaningful insight across such an extensive and heterogeneous corpus. In order to support the goals of the thesis, the strategy needed to meet a number of criteria, notably:

(1) The strategy needed to provide sufficient breadth of coverage to enable the thesis to consider ontic claims about IoT across multiple contexts, geographies and time periods—not only IoT in a particular context, locale or moment.
(2) The strategy needed to provide sufficient depth of coverage to be able to reveal nuances and subtleties in ontic claims about IoT. Without such depth, the analysis would risk homogenising IoT, flattening out any differences leaving only the lowest constant common denominator.
(3) The strategy needed to be feasible and pragmatic, in order to be executed within a reasonable amount of time by a single researcher, and using freely available resources wherever possible.

A common means of classifying journal literature is into scholarly, trade and popular publications (Colorado State University Libraries, 2017; Rutgers University Libraries, 2017; University of Texas Libraries, 2017). According to this classification:

- *Scholarly publications* feature articles written by specialists in the field, particularly academics. They often use sophisticated and specialised vocabulary, and are usually peer-reviewed. These publications tend to be aimed at research and scholarship more than direct application, and thus the readership tends to be other researchers and scholars more than practitioners.
- *Trade or professional journals* contain articles written by people working within a particular field, or by journalists specialising in that field. These journals are not peer-reviewed, and often contain a mix of news, trends and opinions in addition to research. Articles in these journals often feature descriptions and analysis of designs and applications for a readership of practitioners.
- *Popular publications* are intended for a large and general audience. The intention is generally to entertain as well as to inform. The focus is on accessibility rather than rigour or precision; specialised or technical vocabulary is seldom employed. Articles

are typically written by journalists rather than by specialists (Colorado State University Libraries, 2017; Rutgers University Libraries, 2017; University of Texas Libraries, 2017).

These three classes of writing provide a fair summary of the IoT literature as it appears in periodicals. There are various other, non-periodical sources of IoT literature. Two significant examples are grey literature and online literature.

According to the so-called "Prague Definition", *grey literature*, "stands for manifold document types produced on all levels of government, academics, business and industry in print and electronic formats that are protected by intellectual property rights, of sufficient quality to be collected and preserved by library holdings or institutional repositories, but not controlled by commercial publishers, that is, where publishing is not the primary activity of the producing body" (Schöpfel, 2010, p. 24). In the IoT field, significant volumes of grey literature are being produced by technical practitioners—for example in the course of IoT projects, or in the context of industry conferences.

Secondly, there is a large of amount of *online literature* about IoT available via the internet, with a Google search for "Internet of things" or "IoT" returning more than 35 million results. Some of these results fall into one of the three classes mentioned above:

- *Scholarly publications*, such as electronic editions of scholarly journal
- *Trade or professional journals*, such as electronic editions of trade or professional journals, websites of industry and trade associations
- *Popular publications*, such as electronic editions of newspapers and magazines

However, there is also a substantial volume of self-published material originating in the blogosphere and other areas of social media (for example Facebook and Twitter). For example, a Google search for "Internet of things blog" returns some 78,000 results.

4.3.2. Data selection

Given the extent and variety of the published data available, extracting a useful sample corpus of texts requires some important choices to be made. These choices include:

- Choice of a *start date*, texts published *before* which will not be included in the sample.
- Choice of an *end date*, texts published after which will not be included in the sample.

- Choice of the *sources* to be included in the sample, and the relative proportions of texts to be included from each of these sources.
- Choice of the *search term* used to extract relevant texts from the sources.
- Choice of the *selection criteria* used to select sample texts from among the relevant texts.

These choices must be made in light of the criteria discussed in *Section 4.3.1: Data survey* above, that is, the chosen sampling must be feasible and pragmatic while providing sufficient breadth and depth.

The chosen *start date* for the sample is 1999, on the basis that this was the year when the term "internet of things" was first formulated, with the inventor generally agreed to be Kevin Ashton (Ashton, 2009; Gubbi et al., 2013). While this date has distinct virtue of being clear and definite, it may overlook thematic continuities between IoT and other, earlier terms (e.g., ubiquitous computing or "ubicomp"; see Gubbi et al., 2013).

The chosen *end date* for the sample is 2017. This is chosen on the pragmatic grounds that this is the last full year of publication available at the commencement of the data analysis in January 2018. Earlier cut-off points were contemplated, such as 2009, which would give a ten year period to analyse. However, given the rapid expansion of the IoT literature (as described in *Section 4.3.1: Data survey* above) it was considered desirable to include as much of this development as possible.

In terms of *sources*, it is proposed to select one representative source from each of three main classes of source described in *Section 4.3.1: Data survey*. The three proposed sources are as follows.

Scholarly publications are to be sourced from the Scopus online database. Scopus is published by Elsevier B.V., who describes it as, "the world's largest abstract and citation database of peer-reviewed research literature" with "over 22,000 titles from more than 5,000 international publishers" (Elsevier BV, 2017b). Scopus is generally regarded as one of the two most comprehensive academic databases, the other being Web of Science, owned by Thomson Reuters Corporation (Aghaei Chadegani et al., 2013). Comparisons of the two affirm that Scopus has broader recent coverage than Web of Science, but includes a greater proportion of more recent (post-1995) material (Aghaei Chadegani et al., 2013; Adriaanse & Rensleigh, 2011; Boston College Libraries, 2017). Given that this study will focus on the period commencing 1999, Scopus is thus the superior choice for my purposes.

Trade or professional publications will be represented by the publications of Gartner, Inc. Gartner describes itself as, “the world’s leading research and advisory company” claiming to have, “15,000 associates serving clients in 11,000 enterprises in 100 countries” (Gartner, 2018). Gartner’s dominant position in the technology advisory industry is confirmed by independent research (Pollock & Williams, 2016, under "The Expertise Ecosystem"):

> Gartner has outpaced its global competitors (Forrester and IDC) and a handful of smaller players like Ovum, Yankee Group. The success of the largest (now Big Three) IT industry analyst firms demonstrates the importance of economies of scale. Bigger firms can employ many analysts bringing a broad scope of knowledge which both rests upon and underpins their large client base with technology adopters. This also helps explain the dominance that the largest of these players, Gartner Inc. has achieved.… Gartner is today by far the largest of the analyst and research organizations (about 6 times the size of its nearest rival Forrester Research).

Popular publications will be represented by the online edition of the New York Times, which is the world’s most popular English-language online newspaper, based on commonly used rankings, such as Alexa and SimilarWeb, two of the leading traffic analysis sites commonly used to measure the popularity of websites (Agrawal, 2016). Neither Alexa nor SimilarWeb publish their ranking algorithm, however, both disclose that the ranking is based on a combination of page views and unique visitors, with some correction for data bias (Amazon.com, 2018; SimilarWeb, 2018). As of February 2018, the online New York Times is the top-ranked online English-language newspaper, according to the rankings provided by Alexa (Amazon.com, 2018) and SimilarWeb (SimilarWeb, 2018). While Alexa ranks the New York Times as the leading online newspaper, Alexa places it behind the Russian language Yandex and the Chinese-language Sina. According to SimilarWeb, the New York Times website averaged close to 400 million visits a month during the last six months of 2017 (SimilarWeb, 2018).

It is worth emphasizing that these sources do not exhaust the IoT literature, nor are they necessarily fully representative of it. For example, minority or local themes of discussion may not be reflected in sources selected based on global reach and authority. For this research, an exhaustive survey—which, as noted above, would be an unfeasible project—and is not required. It is not likely that significant empirical ontological categories of reference to IoT would be entirely absent from the sample, and the sample thus serves its purpose of pointing us towards candidate regional ontologies candidates.

It is sufficient for this research that the sources represent important areas of the IoT discourse. As already discussed, Scopus, Gartner and the New York Times occupy market-leading positions within the trade, scholarly and popular discourse respectively. The authority and readership of these three sources make them highly influential within their respective discourses. Thus articles drawn from these three sources can be fairly said to represent the most influential ideas and themes from each discourse. Thus drawing samples from Scopus, Gartner and the New York Times will allow conclusions to be advanced about the most influential ideas and themes relating to IoT, so long as these claims do not rely on assumptions of exhaustiveness or comprehensiveness.

The next step is to choose a suitable *search term* to extract relevant texts from the sources, For simplicity the term "Internet of Things" was chosen as best marking out the topic under consideration, there being no synonymous (or near synonymous) term in common use.

The final step in data selection is then the choice of the *selection criteria* which will be used to pick the final sample from the among the relevant texts. The intent of the selection criteria is to choose those texts which are most salient and influential within the discussion of IoT.

Before designing these criteria, an initial survey of the data sources was conducted in order to assess whether there were any salient features of these data sources which should be taken into account.

4.3.3. Data set overview

An initial review of the data sources described above reveals the scope and breadth of the underlying data set from which the samples are to be drawn:

Articles published per year																			
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
NY Times	1	2	1	-	3	1	1	3	2	-	1	8	10	10	20	80	56	78	32
Gartner	-	-	-	-	-	-	-	-	1	-	1	8	28	96	167	452	705	947	1,008
Scopus	-	-	-	-	3	4	10	17	21	50	90	395	831	1,279	1,823	2,778	4,146	7,216	9,949

Cumulative articles published																			
	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
New York T	1	3	4	4	7	8	9	12	14	14	15	23	33	43	63	143	199	277	309
Gartner	-	-	-	-	-	-	-	-	1	1	2	10	38	134	301	753	1,458	2,405	3,413
Scopus	-	-	-	-	3	7	17	34	55	105	195	590	1,421	2,700	4,523	7,301	11,447	18,663	28,612

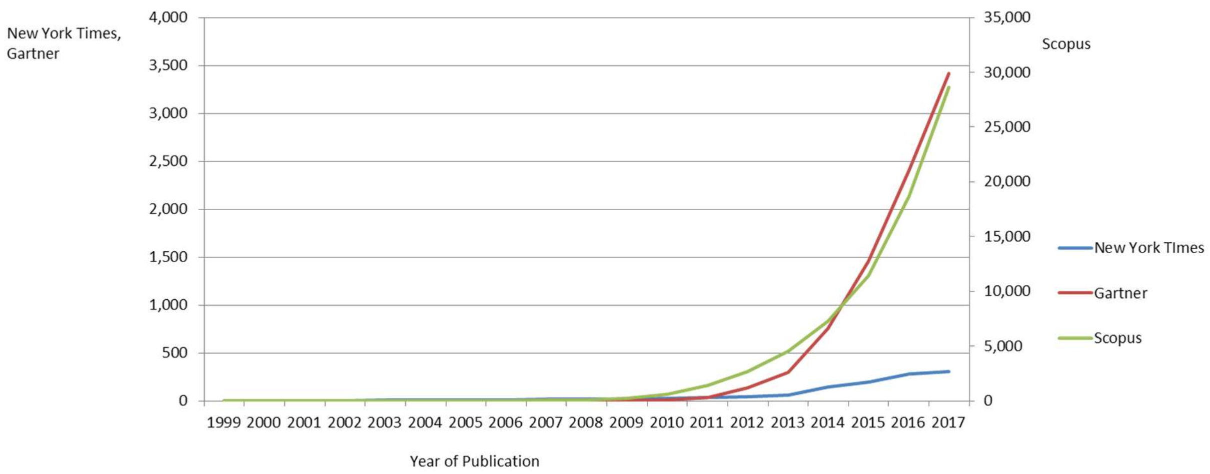


Figure 4-2 Rate of Publication of Articles on IoT

Source	2009 to 2014	2015 to 2017
New York Times	6x	0.4x (decline)
Gartner	452x	5x
Scopus	26x	4x

Table 4-3 Change in Annual Rate of Publication

Source	2009 to 2014	2015 to 2017
New York Times	34%	-26%
Gartner	177%	65%
Scopus	73%	58%

Table 4-4 Change in Annual Rate of Publication (average annual percentage change)

A per the tables above, the period under discussion may be divided into three fairly distinct phases:

(1) A long period of relatively slow growth from approximately 1999 to 2008. During this time the total number of articles published is low, and there is no pattern of consistent growth across the sources.

(2) A period of explosive growth from approximately 2009 to 2014. During this period the annual rate of publication rises sharply across all three sources.

(3) A period of sustained interest from 2015 to 2017. During this period the rate of publication in the New York Times declines, while the overall rate of publication across all sources continues to grow, but at a slower pace.

4.3.4. Data sampling method

In order to avoid introducing author bias into the sample, it was considered best to keep the data sampling criteria as simple and transparent as possible.

The simplest approach would be to choose the most influential articles from each source, based on some measure of article salience (e.g., number of citations, article relevance). This simple approach would not, however, take into account the rapid increase in the rate of publication of articles about IoT during the period 1999 to 2017. This increased rate of publication is presumably reflective of an increased level of interest in IoT. Ignoring this increase in both interest and rate of publication would tend to skew the sample towards the latter part of the period under consideration. For example, if 50 Gartner articles on IoT were selected based purely on salience, none of them would predate 2015 (search conducted in May 2015).

Based on the philosophical ontologies discussed in *Chapter 3: Ontologies of Technology* there is sufficient ground to doubt that ontological accounts of IoT in the literature would be fixed and immutable over time. For example, a social constructivist analysis would suggest that the nature of IoT would change as interpretive flexibility was replaced by consensus, stabilisation and closure (Bijker, 1995). Similarly, an ANT-based analysis would suggest that the reality of IoT is something that is constructed and maintained over time by agents in a network of practices (Law, 2004). To respect this possibility of change of time, it is proposed to take samples of texts from three distinct periods:

- 2011 and prior
- 2012 to 2014
- 2015 to 2017

There will thus be nine samples in all: three from each of the sources under consideration. This breaking of the period under consideration into three sub-periods will be sufficient to prevent articles from earlier years being swamped the volume of subsequent publications. From each of these periods, twenty articles will be chosen. Thus in total, there will be nine collections, each comprising 20 documents, making 180 documents in all. The size of the sample was decided on pragmatic grounds—it was based on the maximum number of documents which a single researcher could feasibly review within the period set for the PhD thesis.

For each of Gartner and the New York Times, articles will be selected based on relevance. Relevance is a score assigned to an article by the publishing organisation (Gartner, New York Times) based on how closely the article relates to the search term. Neither Gartner nor the New York Times publishes the algorithm used to calculate relevance, however, the most common method to assign relevance in text searches is to use some form of TFIDF ("Term Frequency—Inverse Document Frequency") score. Term Frequency is the frequency with which the search a term occurs in a particular document, and Inverse Document Frequency is the frequency of the search term in the entire corpus being searched. The TFIDF value for a document is highest if the search term occurs frequently in that document, but only rarely in the corpus as a whole. Search engines often apply modifications to the basic TFIDF score in order to better eliminate "noise" (e.g., by ignoring very common words) and better track relevance (Chen, 2017).

For articles from Scopus, articles will be selected based on citation score. This is a count of the number of citations which an article has attracted since 1996 (Elsevier BV, 2017a). Because the citation score tracks how often a given article has been referenced by subsequent researchers, it was considered to be a reliable indicator of the influence which that article has had on the research discourse.

The use of citation score as a measure of influence does have some limitations. For example, it would tend to under-state the influence of more recent publications, which had have insufficient time to attract significant numbers of citations. The division of the period under consideration into three sub-periods would mitigate, but not eliminate, this effect. In addition, citation score could well understate the influence of publications with a negative or dystopian view of IoT: mainstream IoT researchers may be reluctant to cite articles which do not promote the growth of "their" field.

4.3.5. Analysis method

As sketched in *Section 4.2: Methodology* above the first step in the ontological analysis will be:

(1) To identify the ontic references to IoT in the texts, and to group these into empirically derived ontological categories.

This description will be carried out by conducting a close reading of how the being of IoT is described in the texts. In particular, ontic references to IoT in the sampled texts will be coded and collected. During the process of gathering these references, similarities and themes will be identified. These will then be iteratively tested against the corpus of texts. The intent is to inductively identify a set of categories of ontological reference from the sampled texts, with each category corresponding to a kind of being that IoT is said to be. For example, there may be categories for IoT as an idea, IoT as a technological artefact, and so on.

There are inherent challenges and limitations to any categorisation, as was discussed above with reference to the philosophical ontologies (see *Section 2.3: Ontologies of technology: overview and survey*). As stated there, we cannot hope for a final or perfect categorisation. We must instead aim for a categorisation which is as faithful as possible to the material under consideration while also being of pragmatic value in pursuing the research question.

The method I have described above is thus empirical and inductive. I do not suggest that this method constitutes a strict implementation of the methods of Grounded Theory. I have, however, adopted some elements of technique from Grounded Theory where this was useful in adding structure to my method. In particular, I have adopted the steps of the Grounded Theory coding process (Charmaz, 2006) as follows:

(i) Initial coding: staying close to the data and being open to the ideas it contains.
(ii) Focused coding: iterative synthesis of codes, tested against the texts, to identify themes (these themes being the empirical categories mentioned above).
(iii) Theoretical coding: investigating the relationships between codes in order to build theoretical hypotheses.

One of the injunctions of Grounded Theory which I have adopted in my method is to guard against allowing preconceptions (theoretical or otherwise) to influence the coding process (Charmaz, 2006). To this end, I have avoided employing any ideas from the philosophical ontology of technology in the coding process. So far as possible I have set this literature entirely to one side while coding, and returned to it only at the conclusion of the coding process. I remain conscious that, by taking an explicitly ontological approach to the investigation, there was the risk of “ontologising”—of seeing references to ontology where none exist To avoid this tendency I have attempted to stay close to the texts in my coding, not introducing ontological references or connotations where these are not found in the sources themselves.

One of the characteristic challenges of using emergent and inductive coding is that it introduces an element of individual subjective judgement into the analysis. Choices must be made during the coding process, albeit that these choices are based on a thorough analysis and understanding of the options available, the selection criteria and the implications of selection. It is thus unlikely that any two researchers would arrive at precisely the same set of codes and categories even if starting from the same set of data. One method of improving the rigour of coding is for multiple researchers to code the material and for the codings to be compared. This is common in STEM research projects, particularly where the set of codes to be applied can be fixed in a "codebook" (see, for example, Berends & Johnston, 2005). For the current project, this approach would have been of limited utility, given that a code-set was not available prior to coding for implementation and then reliability checking. Instead, a significant part of the intellectual effort was the emergent development of the coding system and its ontological implications. The code-set was thus not an input to the method, but an output of the method. Further, it must be stressed that the main conclusions offered by this research are, based on the scope and goals of the project, more likely to depend on overall insights into the meaning of the texts than on the precise mechanics of coding and categorisation.

The next two steps in the analysis will be:

(2) To bring the empirically derived ontological categories into dialogue with the philosophical ontologies, in order to allow us to attribute regional ontologies of IoT to the texts.

(3) To investigate what underlying ontologies could account for the attributed ontologies.

Step (3) will also undertake a reflexive critique of the various philosophical positions on the ontology of technology, considering the relative utility of the different positions for different purposes, and what the different positions tend to reveal or obscure

Steps (2) and (3) have already been described in some detail in *Section 4.2: Methodology* above, and do not require any further commentary.

To conclude this chapter: I have now defined my research question, and justified the relevance and importance of this question. I have also outlined and justified the approach to be taken to investigating this question, and explained in some detail the method to be employed. In the next chapter, I will commence the selection and analysis of the sample data.

5. Data Analysis

The previous chapter proposed and justified a method to undertake an ontological analysis of the large corpus of IoT texts; this chapter reports on the outcomes of that analysis.

To begin with, a short survey analysis of the data sample is presented. The data sample contains a diversity of texts: these texts range from long academic treatises attempting a comprehensive description of IoT to popular articles on the IT market which reference IoT only in passing. The summary given in this section identifies the kinds of text contained in the sample, based on content and audience, and assesses how many of article of each type are found in the sample. The intent of this section is to give the reader a broad understanding of the sample.

As discussed in the method section, the primary approach used in the analysis was an inductive approach incorporating some Grounded Theory techniques and supported by the use of the Nvivo qualitative data analysis computer software package. An Nvivo report summarising the inductively derived coding structure has been attached as an appendix. Using this approach, ten main empirical categories were inductively developed. Each category tracks a different group or pattern of ontological references to IoT in the texts. The next section of this chapter describes how these categories were identified; this is followed by a full description of the categories themselves.

These categories are then analysed further. Their interrelationships, overlaps and conflicts are investigated; as are patterns and inconsistencies in their occurrence across the text sample. Finally, this chapter considers how the categories and their interrelationships may be used to uncover the ontology(ies) underlying the texts.

5.1. Data survey analysis

Section 4.3: Method (see above) described how a data sample of 180 texts was drawn from the IoT literature. This section presents a summary analysis of this data set. This is intended to provide an initial survey of the data—to provide a sense of the range of texts within the sample—preliminary to the more detailed exploration which follows in subsequent sections.

The 180 texts selected were grouped into fourteen broad types based on similarities in content, structure and approach. For each type of article, an assessment was made of the intended readership of the article by asking the question: “what type of reader would find this article interesting and/or useful”? The reason for considering article types and readership is to demonstrate that a diversity of articles with a diverse audience is represented in the sample. This is important because too homogeneous a sample might be suspected of having captured only a narrow slice of the IoT discourse.

For example, article readership is of interest given the possibility that similar readers might tend to share a similar standpoint on the ontology of IoT. For example, from a social-constructivist standpoint, similar readers might tend to belong to the same relevant social group, which would have a shared interest in the way IoT develops. They might then gravitate to the ontological interpretation of IoT which best serves this shared interest; for example, people whose primary engagement with technology is through making investment decisions might be expected to ontologically frame IoT as a set of competing or complementary investment choices. Thus if the articles in the sample were found to be directed at a single class of reader this might raise concerns that only a restricted set of ontologies would be reflected in the sample.

For the purpose of this analysis, four broad classes of reader were considered:

(1) General public: Readers with no special connection to IoT.
(2) Researchers: Researchers (academic but also based in government, industry, or civil society) engaged in researching IoT.
(3) Technology managers: Managers (typically in industry) involved in managing technology and making decisions related to technology (e.g., technology strategy or technology investments).
(4) Technical practitioners: Technical professionals engaged in the implementation of IoT.

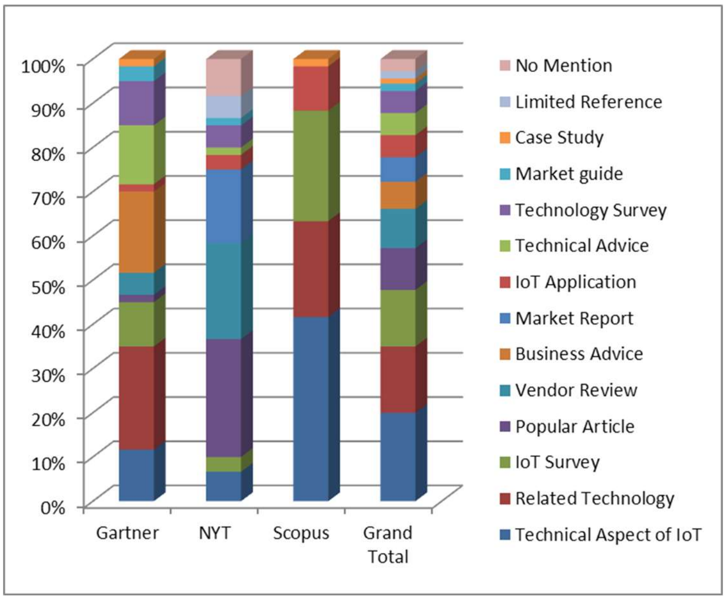
These types are not mutually exclusive—a minority of readers would fit into more than one of these types (the author, for example, is both a technology manager and an academic researcher).

Article Type	**Content**	**Primary audience**
IoT Survey	Survey of IoT in total, or of a broad aspect of IoT	Academic researchers Technology managers Technical practitioners
Technology Survey	Survey of various emerging technologies, including IoT	Technology managers

Popular Article	Article intended to introduce IoT (or some aspect of it) to a popular audience	General public
Technical Aspect of IoT	Article devoted to a particular technical aspect of IoT; e.g., IoT security	Academic researchers Technical practitioners
Related Technology	Article focused not on IoT but on an adjacent or related technology; e.g., cloud or AI	Academic researchers Technology managers Technical practitioners
Business Advice	Advice on the deployment of IoT within a business context	Technology managers
Technical Advice	Technical advice on the deployment of IoT	Technical practitioners
Vendor Review	Review of a particular IoT-related technology vendor	Technology managers General public
Market Report	Report on the stock market, with particular reference to one or more IoT vendors (includes, for example, reports on IoT-related mergers and acquisitions)	General public
Market guide	Guide to the IoT market (typically a survey of IoT vendors)	Technology managers
Case Study	Case study of a particular deployment of IoT	Technology managers
IoT Application	Description of a particular application of IoT; e.g., smart farming, e-health	Technology managers
Limited Reference	Article which contains only a passing reference to IoT	General public
No Mention*	Article which does not mention IoT	N/A

* There are five texts from the New York Times which contained no reference to IoT or any cognate term, despite appearing near in the search for “internet of things” by relevance. This is assumed to be due to an error in the relevance algorithm, which caused it to recommend a small percentage of irrelevant texts.

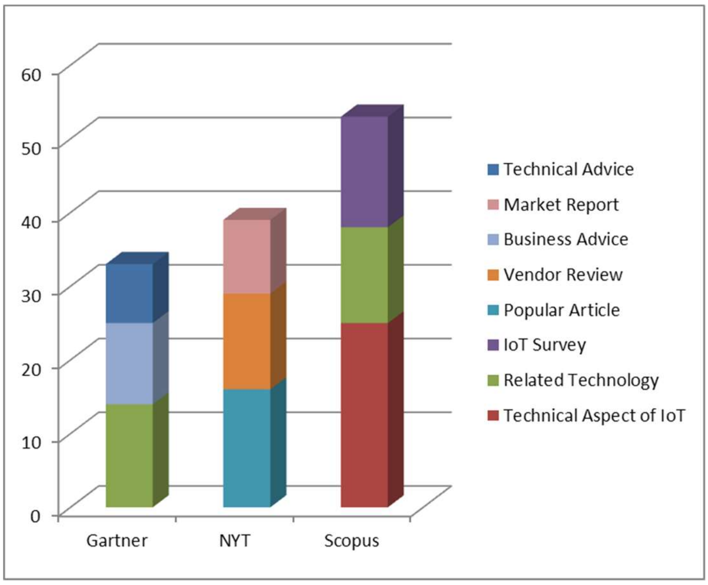
The distribution of articles between these types may be seen in the following graph and table. As noted above, the intent here is to assist with a general apprehension or a “landscape view” of the nature of the sample, rather than to attempt a sophisticated statistical analysis:



	Gartner	NYT	Scopus	Grand Total
Technical Aspect of IoT	7	4	25	36
Related Technology	14		13	27
IoT Survey	6	2	15	23
Popular Article	1	16		17
Vendor Review	3	13		16
Business Advice	11			11
Market Report		10		10
IoT Application	1	2	6	9
Technical Advice	8	1		9
Technology Survey	6	3		9
Market guide	2	1		3
Case Study	1		1	2
Limited Reference		3		3
No Mention		5		5
Grand Total	**60**	**60**	**60**	**180**

Figure 5-1 Distribution of article types by source

The top three article types per source are further analysed in the following table and graph.



	Gartner	NYT	Scopus
Technical Aspect of IoT			25
Related Technology	14		13
IoT Survey			15
Popular Article		16	
Vendor Review		13	
Business Advice	11		
Market Report		10	
Technical Advice	8		
Grand Total	**33**	**39**	**53**

Figure 5-2 Top 3 article types by source

The survey and categorisation of the texts presented above has provided some insight into the composition of the corpus of texts. This assists in a general understanding of the nature of the discourse, prior to more intensive analysis. In particular, this survey of the data demonstrates that the sample has captured a diversity of article types, directed at a variety of different audiences. With the preliminary survey complete, I will now discuss primary output of the text analysis: the empirically derived ontological categories.

5.2. Inside the Empirically Derived Ontological Categories

In this section, each of the categories derived from the texts is considered in significantly greater depth. Each concept is unpacked based on the way it occurs it the texts researched. The intention is to derive a richer understanding of the categories and how they are applied. In particular, variations and inconsistencies are investigated where these occur.

5.2.1. IoT as ARTEFACT

One of the most common ways in which IoT is described is as a technology, in the sense of an artefact, something tool-like, a human-made thing which serves a particular purpose (as defined by, for example, Hilpinen, 2011). In the coding of articles, this is the sense which was the subject of the largest number of individual codes. It was also the empirical ontological category referenced by the largest proportion of articles (41% of articles reviewed).

It must be emphasised that references to IoT as technological or "artefactual" do not reduce it to purely material existence. Firstly, significant aspects of IoT are conceptual rather than (or as well as) physical in there being—for example designs, standards, and architectures. Secondly, to regard IoT as an artefact requires IoT to have a function, and this function is not in itself physical, though it is imprinted on the physical artefact.

It may be argued that the "artefact view" of IoT is not only frequently encountered, it is also in some way the default or "common sense" understanding of IoT—that is, that the referent of "IoT" is generally considered to be an artefact of some kind. This contention is supported by the fact the definitions of IoT provided in the literature are often artefact oriented.

For example:

> The Internet of Things (IoT) is an emerging global Internet based information architecture facilitating the exchange of goods and services in global supply chain networks. (Weber 2010, p. 6)

> Today, a commonly accepted definition for IoT is "a dynamic global network infrastructure with self-configuring capabilities based on standard and interoperable communication protocols where physical and virtual 'Things' have identities, physical attributes, and virtual personalities and use intelligent interfaces, and are seamlessly

integrated into the information network." (Xu, He & Li, 2014, p. 2233)

Definition: The Internet of Things (IoT) is the network of dedicated physical objects (things) that contain embedded technology to sense or interact with their internal state or external environment. The IoT comprises an ecosystem that includes things, communications, applications and data analysis. (Tully et al., 2014, p. 6)

While there is no universal definition for the IoT, the core concept is that everyday objects can be equipped with identifying, sensing, networking and processing capabilities that will allow them to communicate with one another and with other devices and services over the Internet to achieve some useful objective. (Whitmore, Agarwal & Xu, 2015, p. 216)

This suggests that, when called upon to define IoT, it is "IoT as ARTEFACT" which is most salient to the author/s concerned. To the extent that a definition attempts to capture the essence of the thing defined, this also suggests that the essence of IoT is widely regarded as "artefactual"—IoT is at heart something technological, constructed to fulfil a purpose.

It should also be noted that the definitions given above—in common with the numerous others which appear in the literature reviewed—bear only a "family resemblance" (Wittgenstein, 2009) to each other. This can be clearly seen by reflecting on the unique features that define the artefact in each definition.

For example, according to the definitions, IoT:

- Is focused on the enablement of supply chain networks (Weber, 2010).
- Is self-configuring (Xu, He & Li, 2014).
- Is made up of dedicated physical objects (things) (Tully et al., 2014).
- Communicates over the internet (Whitmore, Agarwal & Xu, 2015).

However each of these elements is unique to that particular definition; it does not occur in any of the other three. In addition, none of these appear to be straightforward consequences of terms in any of the other definitions. For example, Xu et al. (2014) state that IoT is a "global network infrastructure", but it is not clear that this commensurate with Whitmore et al.'s (2015) requirement that the IoT should communicate over the internet. In fact, Xu et al.'s definition even hints that IoT is a network in its own right, rather than part of the Internet.

This suggests that, though "IoT as artefact" is a commonly held position, the nature of the artefact in question is not simple or straightforward.

In the literature reviewed, a common way of discussing and analysing the technological nature of IoT is to discuss its relations to other technologies and artefacts. In this discussion of IoT as artefact, IoT appears in at least four ways:

(1) As a technology in its own right, for example:

> Two of today's most hyped technologies are AI and IoT. Hardly a week goes by without some "breaking news" about either or both of them. (Hung & Austin, 2017, p. 3)

(2) As an assemblage of technologies, for example:

> The IoT is not about one technology, but rather *a combination of technologies* and techniques that can be combined to deliver greater value. (Ray & Ramamoorthy, 2018, p. 3)

(3) As a class (or type) of technologies, for example:

> Using a common framework for understanding disruptive trends provides EA practitioners with an approach to addressing the specific value that *Internet of Things (IoT) technologies* present to organizations. (Walker, 2014, p. 1)

(4) As part of some larger technological assemblage, for example:

> An emerging wave of Internet deployments, most notably the Internet of Things (IoTs), requires mobility support and geo-distribution in addition to location awareness and low latency. (Tully et al., 2014, p. 13)

This is not to claim that these uses are necessarily in opposition, but rather to draw attention to the richness of the technological ontology of IoT, which cannot easily be reduced to a simple unitary object.

In fact, a rather striking feature of the technological description of IoT is the way that it is made to form part of the wider equipment of IT, and described in terms of relationships with other technologies—relationships which include composition, difference, interaction, symbiosis, co-evolution and so on. One example of this is the hybridisation of IoT with other popular technologies, for example:

- Cloud Computing + IoT = CloudIoT (Botta et al., 2016)
- Social Networking + IoT = SIoT (Atzori et al., 2012)
- Consumer technology + IoT = CIoT (Palattella et al., 2016)
- Operational technology + IoT = IIoT (Palattella et al., 2016)

A number of articles which discuss IoT from a technological perspective attempt to produce reference architectures for IoT.

A reference architecture is a generic architecture that provides guidelines and options for making decisions in the development of more specific architectures and the implementation of solutions (Open Group, 2016). A reference architecture may be defined as "an authoritative source of information about a specific subject area that guides and constrains the instantiations of multiple architectures and solutions" (Office of the Assistant Secretary of Defense (US), 2010, p. 3). A reference architecture thus combines positive statements about a domain (to serve as "an authoritative source of information") with normative statements on that domain (in that it "guides and constrains").

The reference architectures found in the sample are depictions of the various technical components which much be assembled to produce an IoT solution. A reference architecture is abstracted—its intent is to form a schema within which the architecture of any IoT solution could be plotted. Such reference architectures are of ontological interest inasmuch as they constitute a conscious attempt to articulate an ontology (albeit a technology-centric ontology) of IoT. To avoid confusion, it should be noted that this is not an ontology in the way the term "ontology" is used in computer science, where it has the sense of "a description (like a formal specification of a program) of the concepts and relationships that can exist for an agent or a community of agents" (Gruber, 2001). The reference architectures found in the literature do not provide such a formal specification.

The literature sample examined contained 18 complete or partial reference architectures—if we assume a reference architecture to be any abstracted architectural depiction of a significant portion of IoT. As noted by Al-Fuqaha et al. (2015, p. 2349), "The ever increasing number of proposed architectures has not yet converged to a reference model". Implicit in this statement is the expectation that such a convergence can be anticipated over time—indeed that such a convergence is something to be desired, and that its non-emergence to date is a matter for regret. The picture is thus of a desire for a single, unified architecture, set against the reality of multiple architectures.

It is worth enquiring into the manner in which these architectures differ. In particular, we can attempt to discover whether these architectures are (i) in the nature of different views of the same object (a perspectival difference); or (ii) descriptions of different objects (an ontological difference). This is of course not a straightforward question and does not necessarily admit of a simple answer.

One way to commence such an investigation is to enquire whether the various architectures are congruent: whether they can in principle be reconciled with each other.
To pursue this line of enquiry, the following ten architecture models were compared:

- Hung & Austin (2017)
- Bandyopadhyay & Sen (2011)
- Gubbi et al. (2013)
- Xu et al. (2014)
- Perera et al. (2014)
- Atzori et al. (2012)
- Al-Fuqaha et al. (2015)
- Bonomi et al. (2012)
- Jing et al. (2014)
- Yan et al. (2014)

At the most basic level, these architectures share some similarities, emanating in the first instance from the conventions of architectural depiction. All the architectures describe IoT as consisting of layers, starting with objects (or in some cases sensors) at the bottom (or occasionally left). Beyond this, the heterogeneity of these various architectures is quite striking, starting from the point that the sources differ over whether there are three, four or five basic layers to IoT, and the fact that components given prominence in some accounts (e.g., middleware) are absent in others.

Some of these differences may be accounted for as "perspectival" given that the reference architectures examined differ significantly in what may, in general, be termed "perspective"—for example in scope, in area of focus, and in the level of abstraction. It is thus worth probing deeper to understand the commonalities and differences between these various architectures. To do this, the following grid was constructed. The rows are based on observations of the most salient features of a reference architecture. The similarities and differences between the architectures under consideration were then plotted against this grid.

Feature	Commonalities	Differences
Layers	All the architectures considered endeavour to describe IoT as a series of layers, though they do not explicitly reference a common formal layer model (e.g., Open Systems Interconnection (OSI) model; Microsoft, 2020). By convention, the "lowest" (the most basic or fundamental: typically physical) layers are shown at the bottom. Thus there is an upwards dependence of the layers, that is, each layer depends for its existence on the layer below it, but not vice versa. In the architectures reviewed, this lowest (and hence most fundamental) layer is taken to be objects and/or sensors.	There is a lack of consensus on the number of layers, and what the layers are. Various sources describe the number of "basic" layers as three (e.g., Gubbi et al., 2013), four (e.g., Bonomi et al., 2012) or five (e.g., Bandyopadhyay & Sen, 2011). There is also disagreement about whether IoT can be depicted as a simple vertical stack (e.g., Bandyopadhyay & Sen, 2011) or whether some more complex pattern of interlocking or parallel stacks is required (e.g., Atzori et al., 2010; Perera et al., 2014).
Components	There is some commonality in the components described between the different architectures, but there are only two components which occur in all the architectures considered. These common components are firstly sensors, usually shown as the bottom of the stack, and applications, usually shown as the top of the stack.	There is a diversity of components which occur in some, but not all, architectures. "Middleware" for example: • Is featured prominently in three of the architectures • Is approximately cognate with the "Services Layer" In one architecture • Is absent (or at least not salient) in the remainder of the architectures To take another example, consider the depiction of "actuators" as opposed to "sensors". To make the distinction clear, "actuators" are able to make some change to their physical environment (e.g., by opening and closing a valve), sensors by contrast are passive gatherers of information, although their outputs may cause some other activity (e.g., an alert may summon a technician). Actuators are shown clearly and explicitly in some architectures (e.g., Perera et al., 2014). In other architectures actuators are merely implied (e.g., under the title of smart objects Bonomi et al., 2012) or discussed in the notes the architecture. (e.g., Bandyopadhyay & Sen, 2011). In yet others (e.g., Xu et al., 2014; Yan et al., 2014) actuators appear to be entirely absent.

Boundaries	An architecture will usually show the entity of interest (in this case IoT) in the context of related entities with which the entity of interest interacts. There are some common elements which lie within IoT in the various architectures under consideration. For example, at lower levels of the stack, there is general agreement that the sensor layer (variously defined) is part of IoT. Towards the top of the stack, there is consensus in the sources reviewed that the component which makes IoT data and/or capabilities available for use is part of IoT.	There a several noteworthy differences in the way the boundaries of IoT are drawn between the various sources. Firstly, at the lowest level of the architecture, there are some sources which make the "things" themselves—as opposed to the sensors/actuators embedded in those things—explicitly part of IoT (e.g., (c) and (d) in Al-Fuqaha et al. (2015), Bonomi et al. (2012). Equally there are architectures which exclude physical things from IoT with varying degrees of specificity (e.g., Xu et al., 2014; Perera et al., 2014). Secondly, the sources differ as to where the "top" of IoT lies. Some sources (e.g., Perera et al., 2014 and arguably Hung & Austin, 2017) exclude applications from IoT. Most sources (e.g., Bandyopadhyay & Sen 2011; Gubbi et al., 2013: Atzori et al., 2012) regard applications as the top level of IoT architecture stack. A few however such as Yan et al. (2014) and arguably (d) in Al-Fuqaha et al. (2015) extend the stack upwards, including users (in the case of Yan, Zhang and Vasilakos, 2014) and business (in the case of Al-Fuqaha et al., 2015)

As noted above, architectures include both positive and normative statements. It follows that the observed differences between reference architectures may be as much concerned with different views about *what should be* as with different views about *what is.*

Another important aspect of "IoT as Technology" is the role of technical standards. The design process is often viewed as fundamental to the development of technology (Franssen, Lokhorst & van de Poel, 2015). Standards are an important value when making design decisions, acting as a constraint on design choice (Newberry, 2016). In particular, standards may form part of regulatory frameworks which "may be seen as a kind of reified morality" which "lays down prescriptions for right action in rules".

Standards are a frequently referenced topic in the literature reviewed. A number of themes are common in the discussion of standards. These may be summarised as follows.

(1) There are a large number of standards available at present with diverse origins, which standards overlap and compete with each other, for example, Zanella et al. (2014); Ray & Ramamoorthy (2018).

(2) Standardisation will be a key factor in the future success (however defined) of IoT, for example, Xu et al. (2014); Judah & Moran (2017).

(3) Standardisation is thus something, in the words of Shakespeare, "devoutly to be wished", despite the anticipated difficulty of the undertaking, for example, Gerschenfeld et al. (2004); Lohr (2013).

General claims of this sort are frequently accompanied by lists of standards, along with arguments supporting or opposing their validity. As might be anticipated given points (1) to (3) above, these lists vary widely in the standards referenced. No article claims to provide a comprehensive index of relevant standards, but Al-Fuqaha et al. (2015), for example, lists more than 50.

Much like reference architectures, standards can play both a positive and a normative role. In either case, standards are something ontological—either advancing a *positive* claim about the way the world is, or a *normative* claim about the way it should be (or, for the standard's true-believer, will be). Thus the clash of opposing standards shows in clear relief the tension between competing versions of current and future ontology, accompanied by a common desire for unity.

In summary then, the widespread consensus that IoT is a "technology" reveals many areas of ambiguity and dispute. For example, there is dispute regarding:

- What (if anything) is the "essential" technological feature of IoT.
- Whether IoT is a technology in its own right, a type of technology, an assemblage of technologies, or part of a larger technological assemblage.
- What makes up the architecture of IoT.
- What standards define IoT.

It is not that there is an area of solid consensus, surrounded by a penumbra of dispute. The disputes are so pervasive as to suggest that, even when regarded simply as a technological artefact, the ontology of IoT is multiple.

5.2.2. IoT as TRAJECTORY

In speaking of IoT as a trajectory, we are using "trajectory" not in its literal sense of "the path followed by a projectile flying or an object moving under the action of given force" but in the figurative sense derived therefrom, as in "the rapid upward trajectory of Rich's career" (OED Online, 2019d).

The references to IoT as trajectory claim that having a trajectory is a key feature of IoT, that "trajectori-ness" is an important part of IoT's way of being. They do not claim that IoT is *only* a trajectory. Thus the formulation "IoT *is* a trajectory" is not satisfactory, as it implies that IoT is only a trajectory. However "IoT *has* a trajectory" is also misleading, as it suggests that IoT is something apart from its trajectory, that IoT could not have a trajectory and still be IoT. I will thus avoid both these formulations.

The concept of IoT as trajectory brings together those codes describing IoT as a process of change or a process of becoming. These codes share the feature of describing IoT with respect to temporal change, sometimes expressed by analogy with spatial movement.

Accounts of IoT's trajectory are dominated by ideas of speed and acceleration—for example of IoT accelerating (Fenn & Hung, 2014) or gaining momentum, of the explosive growth number of connected devices (Jones, 2014).

It is difficult to find dissenting voices to this narrative of growth and momentum, at least within the corpus studied. Of the 180 documents reviewed, only Palatella (2016, p. 522) strikes a clear note of caution (and disappointment): "The number of connected "things" in the Internet of Things is not meeting the predictions made a few years back. In general, the IoT rollout lags behind in terms of what market research has predicted. This is really surprising to many since there is no doubt that instrumenting the planet with IoT capabilities would yield significant operational savings and/or financial gains."

Analogies with organic growth are also common: IoT is in its infancy (Xu, He & Li, 2014) (Shelby & Bormann, 2009) or even embryonic (Hung & Austin, 2017). Even more commonly, IoT has left its infancy (Jin et al., 2014) and is rapidly evolving (Nuttall et al., 2017). Note here the disagreement between contemporaneous sources—in 2014 IoT is seen by contemporaneous sources as "in its infancy" and "having left its infancy"; three years later it is both "embryonic" and "rapidly evolving".

While this concept seems to imply that IoT has an essence which is undergoing some kind of process, this essence is elided by the diversity of transformations which this essence is undergoing. What essence is it that is being preserved through birth, acceleration, explosive growth and rapid evolution? It is tempting to read these references as identifying IoT with the vividly drawn processes of change rather than with the elided essence.

Plotting IoT as a trajectory leads naturally to questions of where this trajectory started—its point of departure—and where it might end. Multiple and various origins are proposed for IoT. Some find its origins coincident with the origins of “ambient intelligence” and “ubiquitous computing” (“ubicomp”) (e.g., Zorzi et al*.,* 2010; Miorandi et al*.,* 2012). Others see IoT as the logical evolution of Wireless Sensor Networks (WSNs) (e.g., Mainetti et al., 2014; Islam et al., 2015) Radio Frequency Identification (RFID) technologies (e.g., Welbourne et al. 2009; Kortuem et al. 2010) or some combination of these (Palattella et al., 2016). Those focusing on the Industrial Internet of Things (IIOT)—the application of IoT to industry—see IoT as arising in a natural way from the progress of industrial automation (Sheporm lby & Bormann, 2009; Lohr, 2015). Finally, there are many who see the origin of IoT in the internet, describing as the next stage in the overall trajectory of the Internet (e.g., Mahoney & Hung 2011; Fenn & Hung 2011; Freeland 2011). The appeal to origins is not as simplistic as this analysis might suggest. Some sources reference multiple points of origin, and link these to disparate categories of IoT (of which more later). For example, Atzori et al*.* (2010) distinguish between “Thing-oriented” visions of IoT, grounded in WSN’s, RFID and related protocols, and “Internet-oriented” visions of IoT, grounded in the development of internet protocols (they also identify a unifying third category of “Semantic-oriented” visions).

A notable claim is that it is that through these processes of transformation IoT is “becoming a reality”. This is usually used to mean that IoT is moving from being a concept or vision to being a “tangible reality” (e.g., Prentice 2011), that is, the “actualization of the IoT concept into the real world” (Atzori, Iera & Morabito, 2010, p. 2790). The exact nature of this “realised” or “actualised” IoT is not straightforward. Certainly, it goes beyond mere *physical* presence. Several sources refer to the vision being realised into a *paradigm*—a “well engineered, commercially viable technological paradigm” (Miorandi et al., 2012, p. 1502) or a “paradigm that will improve many aspects of daily life” (Roman, Najera & Lopez, 2011, p. 57).

This notion of realisation raises questions about the nature and timing of realisation—When will it occur? Will it be sudden or gradual? How can we judge whether it has occurred, whether IoT has been "realised"?

There is little consensus on these questions in the literature, as may be illustrated using the following quotes from the New York Times illustrate:

> The concept has been around for years, sometimes called the Internet of Things or the Industrial Internet. Yet it takes time for the economics and engineering to catch up with the predictions. And that moment is upon us. (Lohr, 2011, p. 1)
>
> The exact timing of when the Internet of Things ... will be upon us is still to be determined. (Bilton, 2014b, p. 2)
>
> The vision of the so-called internet of things ... has been years ahead of reality. But that gap is closing fast. (Lohr, 2016, p. 1)

It is hard to account for this variance in terms of disagreement on the actual state of play with respect to IoT progress, as this is primarily described in terms of ontic facts about IoT—such as the number of devices connected, the value of the IoT market, the progress of IoT initiatives. Instead, the observed variance in views about the "nearness" of IoT is most convincingly explained by a lack of clarity on what an "actualised" IoT would be, that is, on clear criteria on which to judge whether actualisation has been achieved.

For example, compare the following statements:

(1) "By 2020, the installed base of the IoT will exceed 26 billion units worldwide and will consist of a very diverse range of smart objects and equipment" (Jones, 2014, p. 1); "Gartner estimates a cumulative base of 20 billion units installed by 2020 and $400 billion in professional services revenue" (Velosa, 2017, p. 4).

(2) "The IoT is still in formative stages and not yet been realized.… The IoT is still in a conceptual state and the field is very dynamic at this point.… The challenges facing the emergence of the IoT are numerous. They are both technical and social" (Whitmore, Agarwal & Xu, 2015, p. 265).

While (1) suggests that the realisation of IoT is a matter of a growth in endpoints, (2) assumes that other tests must be met, that numerous and technical and social challenges must be overcome. It is by no means clear that (2) is a pre-requisite for (1), that is, that quantitative growth cannot continue along its current trajectory without (for example) the resolution of social concerns. In such a case, there would be disagreement between (1) and (2) as to whether IoT had been "realised".

5.2.3. IoT as FORCE

The next aspect of IoT to be considered is IoT as a force—with force used here in the sense of a "thing regarded as exerting power or influence" (OED Online, 2019a). This manifestation of IoT is deeply involved with IoT as technological artefact, yet quite distinct from it. In particular, as shall be described, "IoT as FORCE" entails IoT exerting agency of a form quite removed from the mechanistic cause and effect that might normally be associated with technological artefacts.

This kind of agency is exhibited in the most unambiguous manner when IoT is described as a "transformational" or "driving" force, for example:

> A formidable new technology infrastructure—the Internet of Things—is emerging with the potential to push much of economic life to near zero marginal cost over the course of the next two decades. (Rifkin, 2014, p. 1)

> The IoT is driving a pervasive digital presence throughout organizations that, when connected, will change the fabric of business and society. (Perkins, 2017, p. 4)

> Mass adoption is shifting the IoT into a powerful force for business transformation. (Tully et al., 2014, p. 1)

There are clear parallels here with the ideas a technological determinism discussed in the Literature Review (see *Section 3.2: Technological Essentialism* above). As mentioned previously, the intention here will be discussed and analyse what is found in the texts under review. In the next chapter, these texts will be brought in dialogue with the wider literature on the ontology of technology.

A somewhat different form of agency is encountered when IoT is represented as an imperative which motivates the development of new technologies, that is, when IoT is represented as exercising "pull" rather than "push" agency. For example:

> The IoT demands a wide range of new technologies, many of which will take the enterprise into unfamiliar territory and demand new skills. (Jones, 2017, p. 1)

In particular, as in the example above, IoT is seen as *requiring* new technologies, skills etc. for its realisation:

> The IoT vision will require substantial advances in a number of ICT fields. (Miorandi et al., 2012, p. 1499)

In its requirement for new technologies, IoT is regarded as being able to mobilise not only the technologies themselves, but also to motivate the human and organisational resources to develop them:

> Several industrial, standardization and research bodies are currently involved in the activity of development of solutions to fulfill the technological requirements of IoT. (Bandyopadhyay & Sen, 2011, p. 50)

Thus, when used in the imperative sense, IoT is not such much a technology as a source of requirements for technologies; technologies which must be developed and mobilised in order to realise the vision of IoT. Indeed, in this imperative sense, IoT manifests as a series of technological challenges—challenges which the technological community are summoned to overcome.

A number of significant survey articles are devoted to cataloguing these challenges and mustering the resources of the technological community towards their resolution.

For example, the seminal paper Atzori et al. (2010) identifies the following “open issues”:

- Standardization
- Addressing and networking issues
- Security
- Privacy

Borgia (2014), meanwhile, lists the following challenges:

- Network architecture and system design
- Addressing and naming

- Objects' mobility
- M2M communications
- Flexible GWs
- Device management
- Data management
- Traffic characterization
- Security

In summary, then, multiple of sources account for IoT in agential terms. In these terms, IoT is made manifest in technological artefacts but has an essence which precedes these artefacts and helps bring them into being.

5.2.4. IoT as IDEA

"IoT as IDEA" indicates those occasions when IoT is referred to as an "idea"—that is, something which is based in the mind(s) of people. This may be contrasted with occasions on which IoT is characterised as being based in material reality.

It is then useful to enquire what sort of idea IoT is considered to be. Specifically, we shall enquire into the use of three terms: "concept", "vision" and "paradigm". These may be regarded as examples of "in vivo" codes. In the terminology of Grounded Theory, an "in vivo" code is derived from a term used by the participants in a discourse. The term carries a particular meaning for the participants, which is assumed by them to be generally shared (Charmaz, 2006, p. 55), and is picked-up by the in vivo code.

Firstly, IoT is often referred to as a "concept" (e.g., Mahoney & Hung 2011, Lohr 2011). "Concept" is a broad term. In the common view, it is roughly equivalent to "abstract idea" (OED Online, 2018); in philosophical terms, it may be defined as "the constituents of thoughts" (Margolis and Laurence, 2017). There is a rich literature concerning the nature of concepts—the kind of things that concepts are—and specifically the ontology of concepts (example e.g., Margolis and Laurence, 2017). The use of concepts as a tool in techno-scientific practice has also been explored (see for example Pickering (2006). The purpose of this section, however, is to explore how “IoT as concept” appears in the literature sample. Deeper ontological investigation is left to the next chapter.

Secondly, IoT is commonly referred to as a vision (e.g., Green, 2014; Atzori et al., 2010; Lohr, 2016), which we may consider as a particular type of idea—“specifically a mental image of what the future will or could be like” (OED Online, 2019e). Given that a concept is an “abstract idea” which may or may not be accompanied by a specific mental representation, a vision might then be regarded as a specific type of concept.

Thirdly, IoT is frequently referred to as a “paradigm”. The intended meaning is presumably along the lines of “a worldview underlying the theories and methodology of a particular scientific subject” (OED Online, 2019b). Based on this definition, a paradigm may, (like a vision), be understood as a particular type of concept. The use of the term “paradigm” is also likely to refer to the influential works of Thomas Kuhn in the study of scientific revolutions. It is not easy to summarise what Kuhn meant by “paradigm”—Masterman (1970) for example, has identified 21 different sense of the term in his works. She concludes, however, that for Kuhn a paradigm must ultimately be “a concrete ‘picture” used analogically”—a “way of seeing” (Masterman, 1970, p. 76).

As noted above (see *Section 5.2.2: IoT as TRAJECTORY*) some sources regard “paradigm” as being an evolutionary step forward from “mere” concept. Thus Miorandi et al. (2012, p. 1502) for example, speak of “the research challenges that need to be addressed in order to turn the Internet-of-Things from a concept into a well-engineered, commercially viable technological paradigm.”

It should be noted that the terms above are not necessarily used with great precision in the texts. For example, consider the opening paragraph of Atzori et al. (2010, p. 2787; italics added):

> The Internet of Things (IoT) is a novel *paradigm* that is rapidly gaining ground in the scenario of modern wireless telecommunications. The basic *idea* of this *concept* is the pervasive presence around us of a variety of things or objects—such as Radio-Frequency IDentification (RFID) tags, sensors, actuators, mobile phones, etc.—which, through unique addressing schemes, are able to interact with each other and cooperate with their neighbours to reach common goals.

Here “paradigm”, “idea” and “concept” are roughly co-joined—IoT is a paradigm grounded on a concept based on an idea. In addition, the “basic idea” as expressed seems so bound to material reality as to make it concrete rather than abstract in nature.

Consider also the following two definitions of IoT, both from Gartner:

> The Internet of Things is a concept that describes how the Internet will expand as physical items such as consumer devices and physical assets are connected to the Internet. The vision and concept have existed for years; however, there has been acceleration in the number and types of things that are being connected (Fenn & Hung (2011, p. 4).
>
> Definition: The Internet of Things (IoT) is the network of dedicated physical objects (things) that contain embedded technology to sense or interact with their internal state or external environment. The IoT comprises an ecosystem that includes things, communications, applications and data analysis.
>
> Additional Explanation: Conceptually, the IoT is an ecosystem that integrates things with applications and services to achieve a benefit of some kind. Uses are extremely varied and range from smart waste bins on city streets to connected toys for young children. Tully et al. (2014, p. 4)

The first definition, in common with that of Atzori et al., defines IoT as *essentially* a concept. In the second definition, IoT has become essentially a material network, which can, however, be conceptualised as an ecosystem. This clearly relates to the theme—discussed in *Section 5.2.2: IoT as TRAJECTORY* above—of IoT being transformed from a concept into some form of material reality.

Another way in which “IoT as IDEA” interacts with the external world is through the attraction that it exercises. Thus the IoT vision is described as a “heady” (Neuman & Butters, 2017), “compelling” (Kortuem et al., 2010, p. 44) or a “dream” (Roman, Najera & Lopez, 2011, p. 2267). In fact, it might be argued that the notion of “vision” implies “something to be striven towards”. Thus IoT is not simply an abstract idea but also an object of desire.

In considering “IoT as IDEA” it is useful to ask who holds this idea, or subscribes to this vision. Most sources avoid this issue, referring simply to “the concept of IoT” or “the vision of IoT” as though to a Platonic Idea. This impression of universality is reinforced by accounts of the concept of IoT as a being having existed for a long but vaguely specified time (e.g., of "not being new" (Picker, Scott & Soble, 2016, p. 261), of "having existed for years" (Vance, 2010; Fenn & Hung, 2011, p. 4). However this impression of a timeless and impersonal existence is belied by accounts of the lively disputes surrounding the vision of IoT, for example:

> Differences, sometimes substantial, in the IoT visions raise from the fact that stakeholders, business alliances, research and standardization bodies start approaching the issue from either an "Internet oriented" or a "Things oriented" perspective, depending on their specific interests, finalities and backgrounds. Atzori et al. (2010, p. 2788)

These accounts make it clear that concepts and visions are strongly grounded in particular individuals or groups.

In summary then, "IoT as IDEA" is a common kind of ontic claim about IoT. On occasion "IoT as IDEA"—is put forward as the essential element of IoT, that is, IoT is described as being essentially conceptual rather than material. The exact nature of the idea which constitutes IoT is less clear—it is variously a paradigm, concept, vision or dream. Certainly "IoT as IDEA" does not exist in isolation, it influences IoT's development in the world through the attraction which it exercises.

5.2.5. IoT as BUSINESS OPPORTUNITY

The heading of 'IoT as BUSINESS OPPORTUNITY" is used to group references to IoT which describe it in business or commercial terms. These references speak of IoT mainly from the perspective of its impact on an individual business enterprise. The emphasis is often on the opportunity which IoT represents to business enterprise: "Organizations with a unique plan of action that specifically addresses IoT capabilities dramatically increase their competitive advantage by identifying business transformation opportunities" (Walker, 2014, p. 13;see also Miorandi et al., 2012; Al-Fuqaha et al., 2015). There is also mention of the risk posed to enterprises which do not seize this opportunity—"Those failing to plan and deploy for a world where the IoT is as prevalent as the internet and smartphones stand to lose out, perhaps catastrophically" (Velosa, 2017, p. 2).

The implication here is that the context of IoT defines its being—being located within business structures and processes, it adopts the ontology of its surroundings, and is itself a business construct. This is a form of relational ontology, with the being of IoT arising from its relations with other entities.

The place of IoT within the business context is distinguished by breadth and diversity rather consensus. At a high-level, the opportunity presented by IoT to enterprises is described as two-fold.

Firstly, IoT can be used to be more efficient or effective within the scope of their current operations—for example by improving supply chain efficiency and transparency, improving asset utilisation and maintenance, and enabling the remote monitoring and control of operations (Velosa, 2017; Liu, 2017).

Secondly, IoT can enable organisations to create or adopt new business models. There is an extensive literature on the exact definition of "business model". Magretta's (2002) review of the available definitions concluded that broadly speaking, business models are "stories that explain how enterprises work. A good business model answers Peter Drucker's age-old questions: 'Who is the customer? And what does the customer value?' It also answers the fundamental questions every manager must ask: How do we make money in this business? What is the underlying economic logic that explains how we can deliver value to customers at an appropriate cost?"

IoT can enable new business models in several different ways. Firstly, it can be used to create products which were not previously feasible, such as (to give three illustrative examples):

(1) Smart vehicles: vehicles incorporating sensor and actuators constantly connected to the internet. This connection would make possible a range of in-car services, such parking guidance (e.g., helping drivers to locate vacant parking places), fault diagnosis (e.g., automatics monitoring of key engine performance indicators) and infotainment (e.g., providing information relevant to the driver's location and interests). Smart vehicles also offer the potential of fully automated driving, or advance driver assistance (e.g., collision detection) (Velosa et al., 2014).
(2) Smart home devices: the use of sensors and actuators in common household settings to improve lifestyle and efficiency. This includes, for example, smart lighting to provide light when required (e.g., based on motion or time-based triggers). Another example is the use of sensors to efficiently regulate home temperature (e.g., by raising and lowering blinds based on weather forecasts (Al-Fuqaha et al., 2015).

(3) Remotely monitored medical devices: the use of sensors to monitor vital signs and key indicators (e.g., blood pressure, blood sugar and pulse). Remote medical monitoring can also take the form of sensors embedded in medical implants (e.g., artificial organs) (Borgia, 2014).

IoT can enable markedly different ways of developing or delivering existing products. This can include the transformation of areas such as manufacturing, supply chain and logistics. For example, in the area of agriculture, IoT could allow producers to disintermediate major supermarket chains and supply products directly to consumers (Bandyopadhyay & Sen, 2011).

References to "IoT as BUSINESS OPPORTUNITY" have a distinctive language when compared to other references to IoT. It may be argued that these differences have an ontological character. Firstly, "IoT as BUSINESS OPPORTUNITY" tends to "flatten" the description of IoT into business language. This renders some features of IoT—specifically those of importance to a business audience – more salient, which de-emphasising others. This may indicate that "business" references to IoT are part of a distinct discourse with a distinct ontology—in Foucault's sense of discourses as "systems of thought composed of ideas, attitudes, courses of action, beliefs and practices that systematically construct the subjects and the worlds of which they speak" (Lessa, 2006, p. 284).

For example, IoT may be described as:

(1) A source (or type) of investment opportunities which need to be evaluated in terms of ROI (return on investment) or some other metric (Lee & Lee, 2015; Palattella et al., 2016).
(2) An arena for business competition: "the future market is the IoT, where capital investments are focused and where it is essential to be present and make great effort not to be left behind" (Borgia, 2014, p. 3).
(3) An enabler of new business models, as discussed above (Whitmore, Agarwal & Xu, 2015).

IoT thus occurs in a diversity of guises within the business context—a source of efficiency, enabler of new business models, type of investment, and field of competition.

The common factor in these examples is that IoT has been appropriated into the world of business management, where it plays a part as another commercial factor or possibility to be taken into account. One distinctive aspect of IoT in this context is its location within time. In these examples, IoT figures not as a realised artefact nor as an abstract future vision but as a present potentiality.

In summary, “IoT as BUSINESS OPPORTUNITY” is IoT as it exists in the context of the business enterprise. Consider the statement “From production line and warehousing to retail delivery and store shelving, the IoT is transforming business processes by providing more accurate and real-time visibility into the flow of materials and products” (Lee & Lee, 2015, p. 431). IoT here is ontologically both transformative and commercial and changes the enterprise not just in technological terms but also in terms of business process, analytics, decision-making, and (presumably) skills, organisational structures, and culture.

5.2.6. IoT as CONTESTED TERM

Most references to IoT carry the assumption that the term “IoT” refers to a more-or-less stable external referent, with “referent” having the vernacular sense of, “the thing in the world that a word or phrase denotes or stands for” (OED Online, 2019c).

This is true even of occasions where certain aspects of IoT are recognised as being in dispute. For example, an article which discusses competing standards for IoT may nevertheless regard IoT as an identifiable “thing in the world”. Similarly, adherence to a stable referent is compatible with a belief that this reference is subject to emergence, expansion and change. For example, an acknowledgement that the number of devices connected to IoT is rapidly expanding need call into question the fundamental nature of IoT (or indeed the idea that it possesses a “fundamental nature”).

On the other, a minority of references IoT make no such assumption of a stable referent. Such references instead take the view that IoT referent is illusory or deeply contested. This view may be expressed explicitly or implied from the way the term “IoT” is used. These references (i.e., those which do not assume IoT as a fixed referent) form the basis for the category “IoT as CONTESTED TERM”.

A useful way to identify references to “IoT as CONTESTED TERM” is by the use of inverted commas around the term “IoT”. This may be a neutral usage, serving simply to designate IoT as a comparative neologism, as this is a common use of inverted commas (McDowell, 2019). On the other hand, inverted commas (or quotation marks) are, “often used to alert readers that a term is used in a nonstandard (or slang), ironic, or other special sense. Such scare quotes imply ‘This is not my term’ or ‘This is not how the term is usually applied’” (University of

Chicago Press, 2003, p. 293). This may also be indicated by the use of adjectives such as "so-called" as in, for example, "The so-called Internet of Things, its proponents argue, offers many benefits" (Markoff, 2016). Scepticism may also be conveyed the attribution of the term IoT to a specific speaker or group:

> Prime Minister Wen Jiabao committed China to creating an "Internet of things." (Barboza & Markoff, 2011)

> For many years now, Silicon Valley has hyped a concept known as the Internet of Things. (Vance, 2010)

A small number of texts engage more explicitly with the contested or uncertain nature of IoT. Some of these texts acknowledge that the concept of IoT is relatively "fuzzy" or unformed, for example:

> Manifold definitions of Internet of Things traceable within the research community testify to the strong interest in the IoT issue and to the vivacity of the debates on it. By browsing the literature, an interested reader might experience a real difficulty in understanding what IoT really means, which basic ideas stand behind this concept, and which social, economical and technical implications the full deployment of IoT will have. (Atzori, Iera & Morabito, 2010, p. 2788)

There is an interesting tension here between the implicit assumption that IoT "really means" something, and the acknowledgement that this "real something" is rather hard to fathom.

Other texts go further in attributing this difficulty in defining IoT to the competing interests of the parties involved:

> The growing interest that scientific research as well as marketing and sales strategies raises onto the IoT paradigm has the inevitable consequence that there is not a clear and unambiguous definition of IoT. This is mainly due to the different underlying visions with which standards organizations and research centers, enterprises and various alliances (each one with a different background and driven by specific interests and purposes) look at this paradigm. (Borgia, 2014, p. 3)

This idea of IoT as a contested space is also brought to life by comparisons of IoT to an unoccupied physical space:

> As the IoT hype continues to build to a boiling point, we see a land grab in the IoT. (Velosa et al., 2014, p. 9)

> The Internet of Things (IoT) arena as of today resembles the "Wild West" of a couple of centuries ago. It is a vast, mostly unexplored territory, without clear borders, where all current technologies can play a role, and where ad hoc solutions are often the norm. (Zorzi et al., 2010, p. 44)

The metaphor of an IoT as a "wild frontier" serves here to dramatise its unsettled and contested status.

In summary then: the texts considered differ in the degree of stability which they attribute to the IoT referent. It is common-place to acknowledge that IoT is subject to emergence and change, and that some aspects of it are disputed or unresolved. A minority of sources, however, go further. These sources question the very existence of the IoT referent, or cast it as deeply divided or contested.

5.2.7. IoT as SOCIAL ACTOR

"IoT as SOCIAL ACTOR" groups those references that characterise IoT as having agency in the social realm, that is, as something that has social effects. I take the claim of such agency as a claim about a distinct feature of IoT's ontology. The use of the term "actor" here has the ordinary sense of "one that acts", and is not intended to specifically reference Actor-Network Theory (see, for example, Sismondo, 2010) or any other theoretical system. As mentioned earlier, the next chapter will bring the categories described here into dialogue with the previously articulated theoretical positions on the ontology of technology.

This is a fairly common mode of reference in the texts considered. For example, in talking about IoT, Tim O'Reilly (quoted in Hardy, 2015) says: "I worry about real disruption. The social kind, with massive discontents". Atzori et al. (2010) note that IoT is included by the US National Intelligence Council in its list of six "Disruptive Civil Technologies".

One way in which the social effects of IoT are discussed by referencing its projected economic impact (given that economic activity is a fundamental part of society):

> A formidable new technology infrastructure—the Internet of Things—is emerging with the potential to push much of economic life to near zero marginal cost over the course of the next two decades. (Rifkin, 2014)

> The McKinsey Global Institute has identified twelve technologies that, by 2025, will have massive, economically disruptive impact, driving profound changes in many dimensions: in citizens' lives, in business and across the global economy. Specifically, four technologies fall within CPS [Cyber Physical Systems]: (i) automation of knowledge work, (ii) Internet of Things, (iii) advanced robotics, and (iv) autonomous/near-autonomous vehicles. Among them, the Internet of Things (IoT), with an estimated value of 36 trillion of dollars, is considered the CPS paradigm with the highest economic impact. (Atzori et al., 2012)

There are also more radical claims about the social consequences of IoT. For example, Phillip N. Howard, the author of "Pax Technica", sees in IoT the foundations of a New World Order:

> Just as Smith's "invisible hand" alluded to the unobservable market forces that lead to equilibrium in a free market, so Howard's Pax Technica ... evokes the cumulative stabilizing effect of the tens of billions of connected devices forming the Internet of Things (IoT). There is, simply put, too much connection in the world today to allow space for outright destruction, even emanating from Trump. Implicit in this theory is a radical reordering of the nature of power. Pax Romana, Pax Britannica and Pax Americana depended on the military might of sovereign governments. Pax Technica shifts the source of stability to what Howard calls an "empire of connected things." National authorities are less influential than supranational connected platforms and the private corporations behind them. (Cohen, 2017)

This is a radical claim as it positions IoT as a direct social actor on a global scale. More common are statements which attribute social change to IoT in a more indirect manner. The implicit causal logic is along the lines (see, for example, Jing et al., 2014):

(1) IoT will be applied in various use contexts.
(2) Change in these use contexts will result in lifestyle changes.
(3) These lifestyle changes will result in a broader social changes.

For example:

(1) IoT will enable autonomous vehicles.
(2) As autonomous vehicles become widely available, individual car ownership will decline.

(3) Decline in individual car ownership will cause broad social change (for example, all the societal infrastructure, rituals, roles etc. related to widespread car ownership, such as car dealerships, petrol stations, driving tests, taxi drivers, drunk driving, urban planning) will be transformed.

This example is more explicit than those found in the literature surveyed. More typical is a tendency to gesture towards social change without attempting to predict it in any detail. For example, impact at the “lifestyle” level:

> What the lifestyles would be is anyone’s guess. It would be fair to say that we cannot predict how lives will change. We did not predict the Internet, the Web, social networking, Facebook, Twitter, millions of apps for smartphones, etc., and these have all qualitatively changed societies’ lifestyle. (Stankovic, 2014, p. 8)

References to social change are often accompanied by expressions of concern about the direction and desirability of this change, along the lines of: “Although a dystopia is the worst-case scenario, the IoT could certainly exacerbate a range of undesirable situations” (Roman, Najera & Lopez, 2011, p. 54).

These concerns are also expressed in the desire for IoT to be constrained by a social construct in the form of a legal and/or governance framework (e.g., Roman et al., 2011; Whitmore et al., 2015, p. 26). Two areas of focus usually proposed for such frameworks are security and privacy (e.g., Weber, 2010, p. 30; Bajaj, 2014).

IoT is seen as creating new security risks because a widespread network of devices will present an attractive target for those seeking to gain unauthorised access to computer networks. In addition, the control that IoT devices could exercise over powerful machines and processes (e.g., self-driving cars, water treatment plants) would greatly increase the potential impact of such attacks (Lohr, 2016; Roman et al., 2011). Thus IoT is seen as a potential avenue for social harm; an avenue which may be blocked by the use of appropriate social controls.

IoT is also viewed as increasing privacy risks because of the huge quantity of data which IoT could potentially gather. There is a concern that, if unregulated, this data could be used to exercise an unacceptable level of social surveillance and control (Roman, Najera & Lopez, 2011). As in the discussion above, IoT is viewed as potentially harmful for society; and requiring a commensurate social response.

From an ontological perspective, the reference to IoT as posing a social threat (to security and privacy) and requiring social restraint (through regulation and legislation) confirm the status of IoT as a powerful social actor.

A further way in which this social presence of IoT manifests in the sources is through accounts of potential social resistance to IoT (Atzori et al. 2010, p. 2801; Bilton, 2014b; Bilton, 2014a). This is generally discussed at the level of resistance by individual consumers—a "failure to adopt" IoT. For example, Lee Rainie of Pew Research is quoted in Bilton (2014b) as saying: "There is a reference in our report to consumer willingness to embrace these things. If they seem too powerful and know too much about us, consumers aren't going to want to adopt these products." As LeHong (2011, p. 4) puts it "Even though consumers could order food from a refrigerator, doesn't mean that they will."

Taken on the wider scale, these social factors are seen by some as presenting a significant challenge to the emergence of IoT (Atzori, Iera & Morabito, 2010). As Raskino & LeHong (2011, p. 2) note, "While many very powerful business and consumer IoT application ideas have been discussed and written about in the last decade, disappointingly few have been implemented."

In summary then, the texts considered contain significant reference to IoT as a social actor. IoT is seen as exercising a form of social agency, and conversely being susceptible to social control and social resistance. The exact nature and mechanism of this social agency is not made very clear or explicit, and varies significantly between references. By comparison, the account of IoT as a technical artefact (for example) absorbs much more attention and is elaborated in meticulous detail. Nevertheless, IoT's social presence is an important aspect of its ontology as described in the sources. This does not mean that any texts claim that IoT's being is *exclusively* social. However, any ontological account of IoT which does not account for this social dimension would be incomplete.

5.2.8. IoT as THREAT(ENED)

The literature surveyed contains numerous references to IoT which associate IoT with threat in some manner. There is considerable variation in the kind of threat envisaged, and the relationship between IoT and this threat. This section will explore these variations.

Many of the threat-related references to IoT concern security and/or privacy (e.g., Tan & Wang, 2010; Xu et al., 2014; Al-Fuqaha et al., 2015).

The *security* threat is viewed by most sources as an extension of the cybersecurity concerns familiar from the internet, that is, that parts or regions of IoT may be subject to malign attacks from hostile actors. Authors speculate that IoT may “spark novel and ingenious malicious models” (Roman, Najera & Lopez, 2011, p. 51). In addition, methods used to secure the internet may prove ineffective for IoT. For example, IoT devices may not be powerful enough to run the security software which would be considered standard in the context of the internet (Whitmore et al., 2015; Sicari et al., 2015). Also, many IoT devices are, of necessity, deployed in unsecured locations, for example, a flood level sensor needs to be deployed in the area which is subject to flooding. This means that IoT devices cannot rely on physical security to the same extent as traditional computers (Kortuem et al., 2010; Whitmore et al., 2015; Razzaque et al., 2016). In summary, the IoT security threat is akin to current cybersecurity concerns, while differing significantly in its particular characteristics.

The *privacy* threat related to IoT is the risk that sensitive data (for example, data concerning personal health) may be released or accessed without permission, whether deliberately or accidentally. As with security, this is viewed an extension of the existing privacy risk posed by the internet (Jing et al., 2014; Tan & Wang, 2010).

In discussions of threat, security and privacy are frequently phrased as technical properties: desirable technical qualities without with IoT will not be successful. It is in this context that IoT can be spoken of “having” or “not having” privacy or security. For example:

> Security and privacy is always one of the most concerned issues by the public [sic]. There is a need to have a technically sound solution to guarantee security and privacy of the customers in order to have a widespread adoption of the Internet of Things. (Tan & Wang, 2010, p. 380)

Accounting for security and privacy as technical qualities may obscure some more fundamental questions associated with the notion of “threat”. Two of these more fundamental questions will now be considered:

Firstly, there is the question of the relationship between IoT and the putative threat. On the one hand, IoT may be threatened by malicious actors, by hackers seeking to gain unauthorised access and control. On the other hand, IoT itself can be threatening—for example threatening to privacy. Thus IoT can be both threat and threatened. One scenario in which these two aspects may come together is where unauthorised access is gained to devices, and then those devices are subverted, turned against their owners e.g., by using them to spy on their owners. In the first step, IoT is threatened by malicious external actors. In the second step, IoT itself becomes a threat to device owners.

A second (and related) question relating to threat is the ethical standing of IoT. The literature reviewed reflects two different assumptions about this ethical standing. These different ethical assumptions reflect different ontological assumptions about IoT:

(i) In much of the literature there is an assumption that IoT is essentially beneficial (e.g., Borgia, 2014; Hardy, 2015a), that is, that IoT is beneficial "by design" and is thus beneficial when used for legitimate purposes (those purposes intended by its designers). This assumption that IoT is essentially beneficial is compatible with the view that the benefit of IoT may be compromised by the actions of criminal actors, such as hackers (e.g., Lohr, 2016; Markoff, 2016). Ontologically, the claim that IoT is essentially beneficial requires that IoT has an essence (i.e., it requires technological essentialism with respect to IoT; see Thomson, 2000). The claim that IoT is essentially beneficial also requires that IoT can cause social benefits (i.e., it requires technological determinism (Dusek, 2006) with respect IoT in the sense that IoT can cause certain social conditions to arise).

(ii) A second perspective is that IoT is a neutral technology, neither harmful nor beneficial in itself. It is then incumbent on ethical actors to use IoT for ethical purposes, and to thwart or restrain the efforts of the malicious. Such sources discuss the benefits of IoT, but balance this with consideration of the downsides, especially of surveillance (Green, 2014; Bilton, 2014b; Bilton, 2014a). Ontologically, the claim that IoT is "neutral" requires an instrumentalist understanding of technology, meaning that technology, "has no preference as between the various possible uses to which it can be put" (Feenberg, 2003, p. 5).

None of the resources reviewed supported a third possible position: that IoT is ethically negative in an essential way, that is, that the ethical problems presented by IoT emerge from—and are inextricable from—IoT itself, rather from the extrinsic motivations of actors. This view would embody a dystopian version of technological determinism, that is, that IoT (or technology in general) is bound to cause negative social consequences. This could include the substantivist view that IoT (or modern technology in general) leads inevitably to a technologically enframed understanding of the world, resulting in negative ethical and social outcomes. Versions of determinist and substantivist thinking are associated with writers such as Ellul, Winner, Heidegger and Mumford (see *Section 3.2: Technological Essentialism* above)—they would seem not to have had a significant effect on the literature surveyed.

In summary then, the notion of threat is a common feature of the IoT discourse. Closer examination reveals different views on the relationship of IoT vis-à-vis this threat, and on whether IoT is, at heart, ethically good or ethically neutral. These different views suggest the existence of different beliefs about the ontology of IoT.

5.2.9. IoT as CONTEXT OF USE

"IoT as CONTEXT OF USE" refers to those references which discuss IoT in terms of specific situations of use. Some common contexts of use for IoT were already discussed under "IoT as BUSINESS OPPORTUNITY" above.

"IoT as CONTEXT OF USE" is a very common mode of reference, with most articles in the sample making some reference to a set of use contexts to help define and/or explain what IoT is. A number of articles also attempt to provide a comprehensive view of the high-level domains of application. Five such views are compared in the following table:

Atzori et al. (2010)	Bandyopadhyay & Sen (2011)	Borgia (2014)	Whitmore et al. (2015)	Al-Fuqaha et al. (2015)
• Transport & logistics ○ Logistics ○ Assisted driving ○ Mobile ticketing ○ Environment monitoring ○ Augmented maps • Healthcare ○ Tracking ○ Identification, authentication ○ Data collection ○ Sensing • Smart environments ○ Comfortable homes/offices ○ Industrial plants	• Aerospace and Aviation Industry • Automotive Industry • Telecommuni-cations Industry • Medical and Healthcare Industry • Independent Living • Pharmaceutica l Industry	• Industrial domain ○ Logistic and product lifetime management ○ Agriculture and breeding ○ Industrial processes • Smart city domain ○ Smart mobility and smart tourism ○ Smart grid	• Smart infrastructure (includes Smart home, Smart buildings, Smart city) • Healthcare • Supply chains/ logistics • Social applications	• Smart home • Smart buildings • Transportation • Industrial automation • Smart healthcare • Smart grids • Smart city

◦ Smart museum and gym • Personal and social ◦ Social networking ◦ Historical queries ◦ Losses ◦ Thefts • Futuristic ◦ Robotic taxi ◦ City information model ◦ Augmented games room	• Retail, Logistics and Supply Chain Management • Manufacturing Industry • Process Industry • Environment Monitoring • Transportation Industry • Media, Entertainment Industry • Insurance Industry • Agriculture and Breeding • Recycling	◦ Smart home/building ◦ Public safety and environmental monitoring • Health well-being domain ◦ Medical and healthcare ◦ Independent living		

Comparison between the lists is possible if some allowance is made for the difference of nomenclature and granularity. Such comparison reveals that there is significant commonality between these lists, with few items unique to a particular list, but even fewer appearing in all lists, as may be seen from the following table:

Items which occur on all lists	Items which occur on more than one list, but not on all	Items which occur on only one list
• Smart healthcare	• Smart home • Smart buildings • Transportation • Industrial automation • Smart grids • Smart city • Personal applications • Social applications • Media & Entertainment • Logistics • Agriculture and Breeding • Environment Monitoring	• Aerospace and Aviation • Telecommunications • Insurance • Recycling

From the perspective of the frequent references in the literature sample to IoT's application domains, these application domains are an important, even essential, aspect of the ontology of IoT. In other words, IoT would not exist in anything like its current form if it did not have a set of identifiable domains of application. It should be noted that these application domains are primarily areas of *potential* rather than *realised* implementation. It can thus be said that, from the standpoint of the sources considered in this section, potential domains of application are key constituents of IoT.

At the same time, none of the sources reviewed argue that the meaning of IoT is *exhausted* by its potential domains of application. If IoT was exhausted by its domains of applications this would, among other things, exclude the discovery of new application domains. Thus, on this reading, domains of application are necessary but not sufficient for the existence of IoT.

It may further be argued that IoT's character is partly determined by *which* application domains are most significant. This may be demonstrated with a hypothetical example. All the sources above list health-care as a domain of significant potential for IoT. None of them reference any military potential for IoT. Imagine the reverse of this situation, that is, that IoT had major potential in the military sphere, but none in the field of health-care—let us call this Harmful IoT. This would seem to constitute a significant shift in the being of IoT, that is, it would seem that Harmful IoT would be, in important respects, a different thing from IoT as we now understand it—not just the same thing applied differently.

As observed above, the application domains articulated by different sources have commonalities, but also significant differences. Following the logic articulated above, this indicates some consensus as to the character of IoT, but also areas of significant difference.

5.2.10. IoT as ENCHANTED WORLD

The category "IoT as ENCHANTED WORLD" groups those references which account for IoT as a transformation of the world into one populated by intelligent objects which respond to our needs and desires: "'a better world for human beings', where objects around us know what we like, what we want, and what we need and act accordingly without explicit instructions" (Perera et al., 2014, p. 416). This vision fits into the long tradition of technological utopianism, prominent in the 19th and early 20th century, but still present in popular thought (Ellul, 1980; Arnold, 2003).

References in the literature frequently cite examples drawn from everyday convenience:

> You could imagine one sock emailing the other to say it fell behind the dryer, your car would know when your carburettor is acting up and automatically set up an appointment with your mechanic to fix the issue, or the buttons on your shirt could be heart monitors that notify your doctor if you're not feeling well. (Bilton, 2014b)

> Cutlery and condiments that monitor your eating habits, an umbrella that tells you when it's going to rain, a trash can that orders food, a table that displays your Facebook photos. (Green, 2014)

> The report [Pew Research Report on IoT] is a cornucopia of delights about how our toothbrush will email our dentist, how the toilet paper dispenser will know when to order a new roll from Amazon, how our alarm clock will start our coffee maker minutes before we get up. (Bilton, 2014a)

The word "enchanted" is taken from the term "enchanted objects" used by David Rose of MIT Media Labs, and references the similarity of this conception of a world of "magical" objects to that found in children's literature (such as J.K. Rowling's popular "Harry Potter" series) (Green, 2014).

This world of "enchanted objects" is a vision of the future, thus "IoT as ENCHANTED WORLD" is a specific subcategory of the more general "IoT as IDEA" discussed in an earlier section.

An analogous reference to the enchanted world in more technical terms is the description of IoT as an "Internet of smart objects" (Kortuem et al., 2010, p. 45). This view is associated with a "thing-oriented" vision of IoT, which places the emphasis on the things which are connected in IoT. This "thing-oriented" vision may be contrasted with an "internet-oriented vision" which emphasises the network which connects the things (Atzori, Iera & Morabito, 2010). Thing-orientation privileges the edge of the network (which is where the things reside) over the centre: "The design direction will be for more autonomous, independent edges that communicate occasionally with a central core, rather than depending on the core for real-time computing" (Bittman, 2017, p. 11).

It is now germane to consider what a smart object is, and what the criteria are for smartness.

A starting point for this is the notion of the "spime" first coined by Bruce Sterling (Sterling, 2004) which has developed alongside that of IoT. A spime (the word is a combination of “space” and “time”) may be defined as “an object that can be tracked through space and time throughout its lifetime and that will be sustainable, enhanceable, and uniquely identifiable” (Atzori, Iera & Morabito, 2010, p. 2789). A spime includes several of the criteria required for an object to participate in IoT (trackability, unique identifiability) but being a spime does not in itself guarantee “smartness”.

Atzori et al. (2010) attempts to define levels of “smartness”, and makes the distinction between:

(i) A passive object, which cannot take any action on its own, but may trigger action when it is “read”, such as a product coded with an RFID chip.
(ii) A responder object, which can perform a limited range of actions based on particular input, such as a light which can be turned on remotely.
(iii) An autonomous object which can perform a large range of different actions, based not only on input but also on context, such as a complex piece of industrial machinery.

“IoT as ENCHANTED WORLD” relies heavily on this last class, that is, autonomous objects, as in the following prediction:

> Things will evolve from being programmatic executioners of simple tasks. Instead, they will become more intelligent, adaptable and able to choose from multiple options. Finally, they will become fully autonomous and able to decide and take actions independent of humans. (Davies et al., 2017, p. 3)

Autonomous objects are generally envisioned as working not in isolation, but in collaboration with other smart objects: “As intelligent things proliferate, we expect a shift from stand-alone intelligent things to a collaborative intelligent things model” (Walker, Jones & Wallin, 2016, p. 3). An environment of collaborating smart objects is similar to what was generally described—before the rise of the term “IoT”—as “ambient intelligence” or “ubiquitous computing” (“ubicomp”):

> IoT shares a number of characteristics with ambient intelligence. In Ambient Intelligence (AmI), environments rich in sensing/computing/actuation capabilities are designed so to respond in an intelligent way to the presence of users, thereby supporting them in carrying out specific tasks. Ambient intelligence builds upon the ubiquitous computing concept, loosely defined as the embedding of computational devices into the environment. Ubiquitous computing provides therefore the distributed infrastructure

> necessary to enable the development of AmI applications. (Miorandi et al., 2012, p. 1500)

When expanded to the global scale, this collection of smart objects results in what has been ambitiously termed “the sensor-aware planetary computer” (Lohr, 2011), the world as smart object (Hardy, 2016), or a “smartworld” (Stankovic, 2014).

“IoT as ENCHANTED WORLD” has three interesting, and inter-related, ontological consequences. These are:

(1) Things will act more like people.
(2) People will function as elements of IoT.
(3) IoT will elide the ontological distinction between people and things.

Each of these ideas will now be explored in more detail:

(1) Things will act more like people.

A number of articles argue that, as things increase in complexity and autonomy, they will be imbued with human-like properties. Interestingly, the focus here tends to be on the complexity and autonomy of individual things, rather than on the emergent intelligence arising from networks of connected things. For example, a European Commission vision for IoT includes the claim that “things having identities and virtual personalities” (Atzori, Iera & Morabito, 2010, p. 2789). Green (2014) describes things on IoT as “mechanical deputies, running the systems in our homes, our cars and our cities in ever more efficient ways, so we don’t have to”. Borgia (2014, p. 25) suggests that “objects may have a social consciousness and may exhibit social behaviours allowing them to build their own social network of objects”.

Davies et al. (2017, p. 1) argues that we should prepare for “a world where customers, citizens and workers are not necessarily human.” This account is then expanded to consider the different roles which things might perform—from customers to public servants, to citizen ambassadors, to colleagues and employees. One example will suffice:

> A mechanical colleague: Technology assumes the role of an employee (robot, virtual assistant [VA], etc.) and as such is exposed to ‘life’, including abuse or situations that compromise performance—for example, a robotic forklift that is able to change its own battery. (Davies, Scheibenreif & Mullen, 2017, p. 15)

Neuman & Butters (2017) explore the philosophical consequences of this anthropomorphism in more depth, arguing that IoT is in some ways analogous to the animism of ancient Andean cultures: “We now live in a world where objects once again have life. We can talk to them and they can answer back, as is the case with Alexa and Siri and their digital kin.” Further, they argue that, “Inherent in the idea that objects have life is the more subversive concept that they also have desires; feel hate and love; seek revenge; and have the capacity to act on their own.”

(2) People will function as elements of IoT.

Other sources suggest that people will be increasingly immersed in IoT: “Humans will often be the [sic] integral parts of the IoT system” (Stankovic, 2014, p. 4). This is part of a vision in which, “humans will be completely immersed in the world of technology, leading to the so-called Immersed human” (Borgia, 2014, p. 2). One cited example of this is the so-called “citizen sensor” where a community of people use mobile phones to take pictures of issues with urban infrastructure (e.g., potholes, graffiti), effectively operating as IoT sensors for local authorities (Ganti et al., 2011; Jin et al., 2014). A further example from outside the sample is that of a “human-machine reconcile mechanism” where humans and machines participate on an equal footing in a blockchain to provide food chain traceability (Cao et al., 2021).

(3) IoT will elide the ontological distinction between people and things.

The combination of things acting more like people, and people functioning as elements of IoT may result in a breaking down of the ontological distinction between people and things, as discussed in several of the sources examined. This elision arises from the way IoT breaks down the “in principle” distinction between people and things: IoT allows a variety of things and people to interact “in any combination” (Sicari et al., 2015, p. 146). This means that IoT and social networks are not very far removed from each other (Atzori, Iera & Morabito, 2010). Davies et al. (2017, p. 2) takes a more radical version of this, arguing that:

> As our digital society matures, the virtual and physical worlds continue to merge. Increasingly, everyone and everything will be connected. This “digital connectivism” doesn't position things in the service of people, or people in the service of things. It instead describes the role of people and things as "agents" in an ecosystem where we do not differentiate between the two.

This symmetrical treatment of people and things is as interacting entities is reminiscent of both cybernetics and ANT (Wiener, 1961; Latour, 1991).

To summarise: “IoT as ENCHANTED WORLD” is a commonly encountered vision for IoT, which falls within the long tradition of technological utopianism. The “fairy tale” appeal of this vision belies its underlying nuances and complexities. Few sources in the sample engage with these complexities, and even fewer with the underlying philosophical questions which they occasion.

Although “IoT as ENCHANTED WORLD” was commonly encountered in the sample, the opposing vision (i.e., IoT as dystopian nightmare) was not. Dystopian views of IoT – for example as a tool for mass surveillance – certainly occur elsewhere in the literature (e.g. Mann et al., 2020; Zuboff, 2018; Mattern, 2021). The fact that such dystopian references do not occur in the sample may reflect a sampling bias against articles reflecting negative views towards IoT (see *Section 4.3.4 Data sampling method* above). Equally, it may simply reflect the fact that dystopian views are not very influential in the mainstream IoT literature.

5.2.11. IoT as HUMAN ENDEAVOUR

“IoT as HUMAN ENDEAVOUR” is used to label references to IoT as an activity undertaken by people and groups of people. These references frame IoT as something to be done or achieved, as a “movement” (LeHong, 2011). These references privilege human agency in a way that others (for example “IoT as FORCE” or “IoT as FORCE” do not. The ontological implications of this privileging will be explored in the next chapter.

Based on the literature reviewed, this endeavour takes place at many different scales, notably:

- *Individuals*: Some sources stress this individual dimension, emphasising the potential impact of individual inventors, “tinkerers”, and “makers”. A further democratisation of IoT is predicted as easier-to-use tools enable broader participation in the development of IoT (Basiliere & Tully, 2014; Vance, 2010; Raskino & LeHong, 2011). A related sort of reference is the description of Kevin Ashton as the “conceptual father” of IoT (and not just the person who first coined the term). For example:

> The term was coined by Kevin Ashton, one of the founders of the original Auto-ID Center at MIT, who introduced it in 1999 during a presentation held at Procter & Gamble (P&G). He imagined a world where Internet is connected to the physical world through ubiquitous sensors and a platform based on real-time feedbacks, which have a huge potential to enhance comfort, security and control of our lives. Borgia (2014, p. 3)

- *Projects*: The project is frequently referenced as the main unit of IoT effort, especially within the context of an enterprise. For example:

> Most organizations that have adopted or plan to adopt IoT before the end of 2018 are focused on implementing either internal IoT projects (14%) or both internal and external IoT projects (82%), with very few electing to implement an external IoT project only (4%). Nuttall et al. (2017, p. 1)

Here the assumption is that IoT is something that enterprises can adopt, and this adoption is achieved through the execution of projects. The projects spoken of in these references are local initiatives, which only loosely linked to each other. Such projects are distinct from larger, co-ordinated initiatives, such as the national initiatives described below.

- *Enterprises*: As seen in the quote above, another commonly cited "unit of endeavour" is the enterprise—which includes both business enterprises and similar organisations (e.g., government agencies, not-for-profit organisations; see, for example, Basiliere & Tully, 2014; LeHong, 2011; Mahoney & Hung, 2011). The notion of IoT as an opportunity for enterprises was discussed under the heading of "IoT as BUSINESS OPPORTUNITY" above. The difference between that discussion and the present one is that here IoT is regarded not as an opportunity which may be pursued but rather as something which an enterprise can "do" (e.g., by doing IoT projects). In this latter sense, IoT is a human construct—in this case, a human artefact (an IoT project) constructed by an enterprise. These two senses in which an enterprise may engage IoT are complementary rather than mutually exclusive.
- *Associations*: Associations are also referenced as being active in the overall IoT endeavour. Those discussed include standards bodies, industry associations and research groups. These may be at a national or international level (Borgia, 2014; Xu et al., 2014; Gubbi et al., 2013).
- *Nations*: Lastly, whole nations and national blocs (e.g., the EU) are referenced as taking part in the IoT, usually via major investments in IoT initiatives, or through the industry or standards associations (e.g., Perera et al., 2014; Islam et al., 2015; Sicari et al., 2015). Examples of these include Japan's u-Japan and i-Japan initiatives, intended to embed IoT in all areas of daily life in Japan (Xu, He & Li, 2014).

Most references to IoT as a human project privilege certain actors who are portrayed as the "motive force" behind IoT. As discussed in "IoT as SOCIAL ACTOR" (above) the role of the populace at large tends to be restricted to that of onlookers, consumers, or resistors. Thus references to IoT as a human endeavour are ultimately about the empowered people and groups who are engaged at many different levels in projects of construction.

IoT as ultimately constituting a *single global project* is not referenced in the literature considered. It is nevertheless an appealing idea that the multiple levels and initiatives described above form part of a unifying whole. Such a unifying whole would place IoT in the larger narrative of grand technological projects dating back to the railroad and the telegraph (as described in the introduction to Smith & Marx, 1994). This idea takes us beyond the strict analysis of the data, and I will therefore leave its exploration for the following chapter.

5.2.12. IoT as EXPERIENCE

References to "IoT as EXPERIENCE" ground IoT in direct human experience; they address the phenomenology of IoT and in so doing position the ontology of IoT as being phenomenological. This is in distinction to "IoT as ENCHANTED WORLD" references, which take as their point of departure the "magical" technology itself rather than its grounding inexperience. Of the 12 categories derived from the literature, this is the one least commonly encountered. It is encountered only in a handful of cases, and always as a passingly reference rather than as the main theme of articles. Nevertheless, these reflect a perspective quite different to those above, and were hence felt to merit separate mention.

Several sources suggest IoT will have a major impact on the lifeworld—the lived experience—of the majority of people, both in a domestic and work setting—"the scope of IoT is enormous and will affect every aspect of all our lives" (Stankovic, 2014, p. 4); IoT will be "a seamless piece of the daily digital fabric of people's lives" (Quain, 2016). Discussions of what this impact will be are frustratingly elusive. For example, discussions of the applications of IoT (see *Section 5.2.9: IoT as Context of Use* above) tend to focus on how the use contexts will work from a functional perspective, rather than on the phenomenological dimensions of the use contexts.

Nevertheless there appears to be some dichotomy in the sources as to the phenomenological character of IoT.

On the one hand, the "enchanted world" view of IoT (see above) implies immersion in a rich and strange new phenomenology, reminiscent of fairy tales, where our life is increasingly run by “mechanical deputies” (Green, 2014) which are ever-present in the foreground of our daily experience.

On the other hand, a few sources suggest that IoT will be hidden (Gubbi et al., 2013), that IoT features will be “inherently integrated into the environment, so that their presence will be pervasive but invisible” (Zorzi et al., 2010, p. 47) and that as a consequence IoT will “disappear from the consciousness of the user” (Gubbi et al., 2013, p. 1645). As a result of this “disappearing” IoT would not be experienced directly, but only indirectly.

On the face of it, these two accounts of the phenomenology of IoT stand in contrast to each other. To resolve this apparent tension would require reference to a more sophisticated account of the phenomenology of technology (e.g., a Heideggerian phenomenology of technology). Discussion of this possibility is reserved for the next chapter.

In summary then, references to “IoT as EXPERIENCE” are sparse within the sampled text. Nevertheless, there is an apparent disagreement as to the extent to which IoT will be present in the foreground of our experience.

5.2.13. Other possible categories

As already described, the categories above were derived using inductive methods informed by Grounded Theory. While the categories are thus firmly rooted in the texts, they did not emerge “fully formed”—hermeneutic effort was required to extract and shape them. In this process, some codes were found which did not adhere to categories, or which—while related—did not adhere sufficiently to each other to allow coherent categories to be derived. Such cases included references to IoT as millions, billions or even trillions of things (e.g., Stankovic, 2014; Atzori et al., 2010; Roman et al., 2011). This is a very common figure of speech employed in the literature. Ultimately, however, this was considered to be a trope rather than a category in its own right.

5.2.14. Summary of categories

The empirical ontological categories discussed in the preceding sections may be summarised as follows:

IoT as ARTEFACT IoT is a technical artefact, or assemblage of technologies. It incorporates both material elements (e.g., sensors) and design/functional elements (e.g., standards, architectural descriptions). It occupies an intermediate place between concept and implementation. It is also part of a menagerie of related technologies, all existing in dialogue and tension with each other, and (at least partly) because of each other.
IoT as TRAJECTORY IoT is kinetic, a process, something which changes over time. It can start, accelerate, gain momentum, or slow down, lose traction etc. IoT could be this change itself, or something which undergoes this change.
IoT as FORCE IoT is part of a (deterministic? autonomous?) force called "Technology". This force has agency of its own, it can cause events and impact on objects and other forces. It stands outside society.
IoT as IDEA IoT is a non-physical object, a concept/paradigm/vision. It is not clear where this vision resides, or how it arose. It has existed for some time, and is widely—even universally—held. It can be single or multiple, very general or highly specific.
IoT as BUSINESS OPPORTUNITY IoT is a field for commercial competition and profit. It represents a competitive opportunity for some organisations and a threat for others. Commercial enterprises attempt to control and dominate it through the tools of products, mergers, lobbying etc.
IoT as CONTESTED TERM IoT lacks ontological essence, it is a mere term, "so-called" IoT. It is nothing new, a collage of existing ideas, technologies etc. Various players attempt to shape IoT by gaining control of this narrative, by redefining IoT to their own advantage.
IoT as SOCIAL ACTOR IoT is a social actor, exercising agency in the social world. It changes society in both positive and negative ways. On the one had it creates economic benefits, on the other, it threatens jobs. Other social actors interact with it in various ways, opposing it, accepting it, promoting it and seeking to regulate it.
IoT as THREAT IoT constitutes a threat in some way, especially from a privacy or security perspective. This is because IoT itself it at risk of subversion (e.g., by malicious corporations or hackers).
IoT as CONTEXT OF USE IoT is the transformation of some familiar lifeworld context—the car, the farm, the kitchen—through the introduction of IoT technology.
IoT as ENCHANTED WORLD

IoT is a transformation of the lifeworld in general, by the appearance of intelligent/autonomous/social things which can occupy formerly human roles as citizens, friends etc. This can extend to the world itself being intelligent.
IoT as HUMAN ENDEAVOUR IoT is a vast human project, involving human/social organisations such as national bodies, standards organisations, inventors, projects and so on.
IoT as EXPERIENCE IoT transforms the way we experience the everyday world.

Figure 5-3 Summary of empirical ontological categories

5.3. Considering the categories

Before proceeding with further analysis of the categories, it will be worthwhile to reflect on the status of the categories in themselves. In particular, for the discussion below to be useful and informative, it needs to be asserted that the categories are not arbitrarily imposed on the data, that is, that they track something real in the discourse itself. If this were not the case, then the categories are created by the category-system itself, and the analysis of categories will provide no insight into the discourse.

To claim that the categories have epistemological utility is not, of course, to claim that this is the only set of categories which could be derived from the data. As noted in *Section 2.3: Ontologies of technology: overview and survey* above, categorisation is inherently inexact and problematic. For example, categories could have been grouped together or divided up further—that is, clumped or split in different ways—for example, "IoT as IDEA" could have been divided further into "IoT as Concept", "IoT as Vision" and "IoT as Paradigm".

Although not the only possible set of categories, it is nevertheless argued that the categories track some real structure within the discourses, because they were derived from the discourses using an inductive method informed by Grounded Theory. In particular, the category set was not based on any pre-existing or pre-conceived taxonomy. The inductive method was applied without reference to ontological theory, and in particular without reference to the six philosophical ontologies developed in *Chapter 2: Literature Review*. Any theory-laden judgements or conclusion theory-laden assumptions, have either been suspended or explicitly identified as such.

Having discussed and justified the utility of the categories, subsequent sections will now present a quantitative analysis based on the categories, and consider the relationship between them.

5.4. Quantitative survey of categories

The investigation being undertaken is essentially qualitative rather than quantitative in nature. Given that, as noted above, some level of considered judgement was inevitably involved in the development of the categories above (e.g., in deciding whether to clump or split categories), the use of these categories as basis for advanced statistical analysis would be theoretically questionable and of uncertain value.

Nevertheless, a simple quantitative survey will assist in understanding the relationship between the categories and the sources.

Firstly, consider the number of categories referenced by each article:

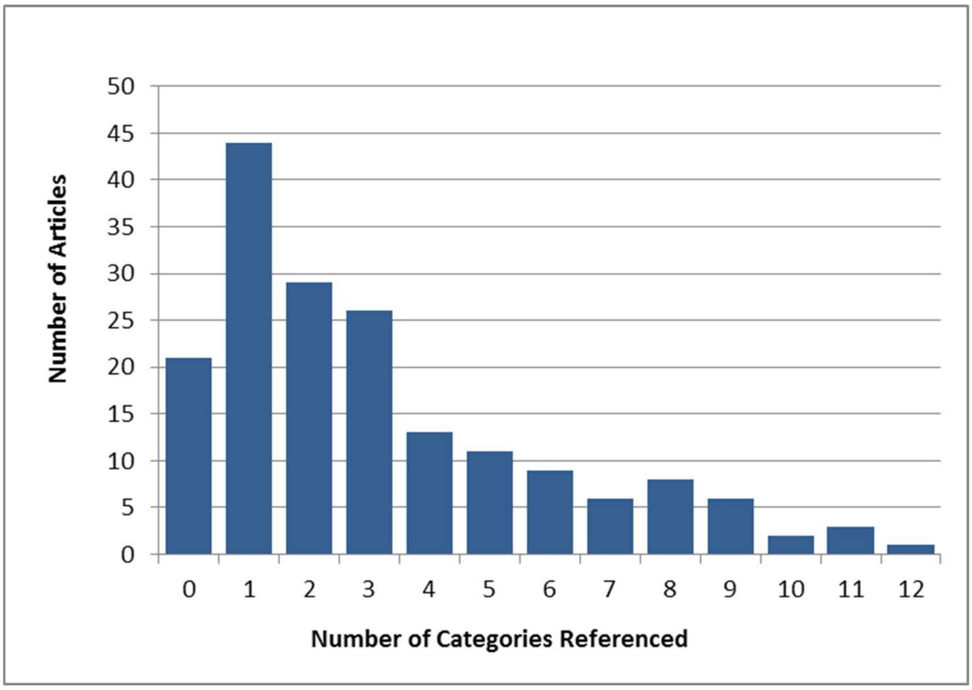


Figure 5-4 Number of Categories referenced per article

From Figure 5-4 it can be seen that the majority of articles (63%, or 114 out of 180) reference more than one category. A significant minority (11%, or 20 out of 180) reference 8 or more categories. Authors thus frequently reference multiple categories within the course of a single text. This demonstrates that the categories are not commonly regarded as mutually exclusive, or at odds with one another.

It is also useful to consider the way category references occur across different periods and different source-types:

	Category	Gartner	New York Times	Scopus
1	IoT as ARTEFACT	23	9	43
2	IoT as TRAJECTORY	24	13	30
3	IoT as FORCE	16	8	41
4	IoT as IDEA	14	11	30
5	IoT as BUSINESS OPPORTUNITY	23	13	17
6	IoT as CONTESTED TERM	16	20	14
7	IoT as SOCIAL ACTOR	12	14	23
8	IoT as THREAT(ENED)	6	13	23
9	IoT as CONTEXT OF USE	5	0	30
10	IoT as ENCHANTED WORLD	5	9	16
11	IoT as HUMAN ENDEAVOUR	12	2	14
12	IoT as EXPERIENCE	3	3	11

Table 5-5 Number of articles referencing a given category (by source type)

	Category	2011	2012 to 2014	2015 to 2017
1	IoT as ARTEFACT	19	32	24
2	IoT as TRAJECTORY	23	24	20
3	IoT as FORCE	17	22	26
4	IoT as IDEA	22	17	16
5	IoT as BUSINESS OPPORTUNITY	9	19	25
6	IoT as CONTESTED TERM	16	20	14
7	IoT as SOCIAL ACTOR	14	16	19
8	IoT as THREAT(ENED)	13	13	16
9	IoT as CONTEXT OF USE	10	14	11
10	IoT as ENCHANTED WORLD	10	11	9
11	IoT as HUMAN ENDEAVOUR	6	8	14
12	IoT as EXPERIENCE	7	4	6

Table 5-6 Number of articles referencing a given category (by date of publication)

Table 5-5 and Table 5-6 demonstrate that categories occur fairly evenly across time periods and source types. Thus for any source and time period, a multiplicity of categories are present in the discourse. Indeed this is true even for the majority of individual articles. It is thus pertinent to discuss the relationships between categories, and how this is negotiated by authors.

5.5. Relationships between categories

The section above considered each category in isolation. In this section, the focus is instead on the relationships between categories—on their boundaries and overlaps, on their causal and other connections.

5.5.1. Category relationships

An initial question may concern the relative independence of the categories: does occurrence of the categories vary independently across the selected documents, are some categories always (or generally) found together, or are some categories never (or almost never) found together?

	1 : IoT as ARTEFACT	2 : IoT as TRAJECTORY	3 : IoT as FORCE	4 : IoT as IDEA	5 : IoT as BUSINESS OPPORTUNITY	6 : IoT as CONTESTED TERM	7 : IoT as SOCIAL ACTOR	8 : IoT as THREAT(ENED)	9 : IoT as CONTEXT OF USE	10 : IoT as ENCHANTED WORLD	11 : IoT as HUMAN ENDEAVOUR	12 : IoT as EXPERIENCE
1 : IoT as ARTEFACT	75	9	11	7	3	4	4	4	2	4	2	2
2 : IoT as TRAJECTORY	9	67	10	9	5	5	6	0	1	6	2	3
3 : IoT as FORCE	11	10	65	5	5	4	10	10	2	2	2	1
4 : IoT as IDEA	7	9	5	55	2	5	2	0	0	3	0	3
5 : IoT as BUSINESS OPPORTUNITY	3	5	5	2	53	2	5	0	1	0	3	4
6 : IoT as CONTESTED TERM	4	5	4	5	2	50	3	1	0	1	2	1
7 : IoT as SOCIAL ACTOR	4	6	10	2	5	3	49	5	2	0	3	4
8 : IoT as THREAT(ENED)	4	0	10	0	0	1	5	42	1	1	0	0
9 : IoT as CONTEXT OF USE	2	1	2	0	1	0	2	1	35	0	0	0
10 : IoT as ENCHANTED WORLD	4	6	2	3	0	1	0	1	0	30	0	2
11 : IoT as HUMAN ENDEAVOUR	2	2	2	0	3	2	3	0	0	0	28	0
12 : IoT as EXPERIENCE	2	3	1	3	4	1	4	0	0	2	0	17

Figure 5-7 Number of documents coding a combination of categories (Red indicates more documents, blue indicates fewer)

Figure 5-7 demonstrates that there are no categories which invariably occur together. This suggests that categories are relatively independent of each other; thus, for example, no category is a subset of another category, no category is a direct corollary of another category.

	1 : IoT as ARTEFACT	2 : IoT as TRAJECTORY	3 : IoT as FORCE	4 : IoT as IDEA	5 : IoT as BUSINESS OPPORTUNITY	6 : IoT as CONTESTED TERM	7 : IoT as SOCIAL ACTOR	8 : IoT as THREAT(ENED)	9 : IoT as CONTEXT OF USE	10 : IoT as ENCHANTED WORLD	11 : IoT as HUMAN ENDEAVOUR	12 : IoT as EXPERIENCE
1 : IoT as ARTEFACT	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
2 : IoT as TRAJECTORY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes
3 : IoT as FORCE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
4 : IoT as IDEA	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes
5 : IoT as BUSINESS OPPORTUNITY	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	No	Yes	Yes
6 : IoT as CONTESTED TERM	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes
7 : IoT as SOCIAL ACTOR	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
8 : IoT as THREAT(ENED)	Yes	No	Yes	No	No	Yes	Yes	Yes	Yes	Yes	No	No
9 : IoT as CONTEXT OF USE	Yes	Yes	Yes	No	Yes	No	Yes	Yes	Yes	No	No	No
10 : IoT as ENCHANTED WORLD	Yes	Yes	Yes	Yes	No	Yes	No	Yes	No	Yes	No	Yes
11 : IoT as HUMAN ENDEAVOUR	Yes	Yes	Yes	No	Yes	Yes	Yes	No	No	No	Yes	No
12 : IoT as EXPERIENCE	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	Yes	No	Yes

Figure 5-8 Are there documents which contain references to a given pair of categories? (Red indicates "Yes", blue indicates "No")

According to Figure 5-8, 57 out of 72 (or 79.2%) of possible combinations of categories are found within documents in the sample. This suggests that the great majority of category-combinations are seen as compatible by at least some authors.

Thus from Figure 5-4, Figure 5-7 and Figure 5-8 we can conclude that:

(1) Most of the documents sampled reference more than one category.
(2) These categories are not dependent on each other.
(3) Most possible combinations of categories occur in at least one document.

It is thus salient to enquire how combinations of categories are negotiated within individual documents.

5.6. Negotiating multiple categories

In understanding how multiple categories are articulated within a single article it is appropriate to start with those articles which reference a multiplicity of categories: it is here that we would expect the challenge of negotiating between categories to be most acute. As observed above, a substantial minority of documents reference a large number of categories—for example, 11% of articles (20 out of 180) reference eight or more categories.

It should be noted that the ontic claims made are not generally exclusive claims. The claims are of the form "IoT is an X" or "X is an important aspect of IoT". They are not of the form "IoT is *only* an X" or "X is *the only* important aspect of IoT". The empirically derived ontological categories are thus also non-exclusive, which makes the challenge of negotiating multiple categories more feasible.

In the literature surveyed, a common method of dealing with multiple categories is simply conjunction—listing the different categories without much comment on their interconnection. Thus, for example, a number of papers are structured in sections, with each section addressing a different aspect of IoT. These aspects often map onto categories in a fairly direct manner. For example, Bandyopadhyay & Sen (2011, p. 50) describe the structure of their paper as follows (insertions in angle brackets identify the category(ies) most relevant to each section; see also similar summaries in Atzori et al., 2010, Al-Fuqaha et al., 2015):

> Section 2 presents the vision of IoT <IDEA>. Section 3 discusses a generic layered architectural framework for IoT and various issues involved in different layers <ARTEFACT>. Section 4 presents the key technologies involved in IoT <ARTEFACT>. Section 5 presents some specific applications of IoT in various industry verticals <CONTEXT OF USE>. Section 6 identifies some of the challenges in deploying the concept of IoT in the real world <TRAJECTORY, HUMAN ENDEAVOUR>. Section 7 presents future research areas in the domain of IoT, and Section 8 concludes the paper. (Bandyopadhyay & Sen, 2011, p. 50)

> Section 2 introduces the concepts at the basis of the IoT paradigm and the different visions expressed over the years by different bodies <IDEA>. Section 3 is devoted to the presentation of the key technologies involved in IoT <ARTEFACT>. Section 4 explores the impact of IoT on the economy and on the society by providing an overview of the potential IoT applications <SOCIAL ACTOR, CONTEXT OF USE>. In Section

5 we analyse the IoT requirements, focusing also on those specific features needed to support the IoT traffic <FORCE>, while Section 6 identifies the major milestones and challenges for the IoT deployment in the real world <TRAJECTORY>. In Section 7, we give an overview of the growing number of initiatives connected with the IoT domain <HUMAN ENDEAVOUR>, while in Section 8 we provide a brief summary of other emerging aspects that revolve around the IoT world. Finally, Section 9 concludes the paper. (Borgia, 2014, p. 3)

These summaries do not add greatly to our understanding of what IoT is, except to say that it is that which participates in multiple categories. Thus, for example, from Borgia (2014, p. 3) we can conclude that:

- IoT is a paradigm and there are different visions for IoT.
- IoT involves a number of key technologies.
- IoT will impact on society and the economy.
- IoT has a number of potential applications.
- IoT is a source of requirements.
- IoT confronts challenges and will achieve milestones.
- IoT is the domain of a growing number of initiatives.

This summary does not, however, say anything about the relationship of these properties—except that they are related by being properties of IoT. Further, this summary does not provide any simple resolution to the overarching ontological question concerning IoT. It merely asserts that IoT is the sort of being which has the listed attributes.

It is also useful to consider instances where a single passage references multiple of categories in a descriptive rather than enumerative fashion, and enquire whether these passages cast any further light on the putative relationship between categories.

For example, we may consider the following extract from Islam et al. (2015, p. 1):

> The Internet of Things (IoT) is a concept <IDEA> reflecting a connected set of anyone, anything, anytime, anyplace, any service, and any network. The IoT is a megatrend <TRAJECTORY> in next-generation technologies that can impact the whole business spectrum and can be thought of as the interconnection of uniquely identifiable smart objects and devices within today's internet infrastructure <ARTEFACT> with extended

> benefits. Benefits typically include the advanced connectivity of these devices, systems, and services that goes beyond machine-to-machine (M2M) scenarios [1]. Therefore, introducing automation is conceivable in nearly every field. The IoT provides appropriate solutions <CONTEXT OF USE> for a wide range of applications such as smart cities, traffic congestion, waste management, structural health, security, emergency services, logistics, retails, industrial control, and health care. (Islam et al., 2015, p. 1; category references added in angle brackets)

Here, multiple categories are treated in a discursive manner, rather than being merely listed manner. Nevertheless, little is said about the way the categories are related. More interesting in this respect is the following passage from Atzori et al. (2010, p. 2787). A very similar passage may also be found in Bandyopadhyay & Sen (2011):

> Unquestionably, the main strength <FORCE> of the IoT idea <IDEA> is the high impact <FORCE> it will have on several aspects of everyday-life and behaviour of potential users <EXPERIENCE>. From the point of view of a private user, the most obvious effects of the IoT introduction will be visible in both working and domestic fields. In this context, domotics, assisted living, e-health, enhanced learning <CONTEXT OF USE> are only a few examples of possible application scenarios in which the new paradigm <IDEA> will play a leading role in the near future. Similarly, from the perspective of business users, the most apparent consequences will be equally visible in fields such as, automation and industrial manufacturing, logistics, business/process management, intelligent transportation of people and goods <CONTEXT OF USE>. By starting from the considerations above, it should not be surprising that IoT is included by the US National Intelligence Council in the list of six “Disruptive Civil Technologies” <ARTEFACT> with potential impacts on US national power [2] <SOCIAL ACTOR>. NIC foresees that “by 2025 Internet nodes may reside in everyday things – food packages, furniture, paper documents, and more”. It highlights future opportunities that will arise, starting from the idea that “popular demand combined with technology advances could drive widespread diffusion of an Internet of Things (IoT) <TRAJECTORY> that could, like the present Internet, contribute invaluably to economic development” <BUSINESS OPPORTUNITY>. The possible threats deriving from a widespread adoption of such a technology are also stressed <THREAT>. Indeed, it is emphasized that “to the extent that everyday objects become information security risks, the IoT could distribute those risks far more widely

than the Internet has to date." (Atzori et al., 2010, p. 2787; category references added in angle brackets)

In this dense paragraph, no fewer than eight categories are referenced in close proximity to each other. On a casual reading, this bringing together of categories appears to be accomplished in a reasonably coherent manner. However, it is argued that a closer reading reveals that a degree of forcing, imprecision and elision is required to navigate the tension between the different categories.

Some of the techniques employed to navigate this tension may be seen more clearly by considering the following sentence from the passage, "Unquestionably, the main strength of the IoT idea is the high impact it will have on several aspects of everyday-life and behaviour of potential users". At first glance, this claim appears unremarkable. On closer consideration, the claim that an idea has the strength to have a high impact on everyday-life is somewhat surprising. Firstly, the assertion that this is unquestionable must surely be incorrect, given that it is a contingent claim about the future. Secondly, the question of the mechanism by which this impact will occur is unclear. The statement claims that there will be "*high* impact on *several* aspects of *everyday-life* and *behaviour of potential users*". This implies that impact is reasonably well understood in terms of the degree of impact ("high"), the scope of impact ("several aspects") and the areas impacted ("everyday-life and behaviour of potential users"). However, presumably, an idea must be mediated through some social and technological process in order to impact everyday life. Any such mechanism would necessarily be complex, and its outcomes uncertain. Any discussion of this mechanism would involve the authors with the ontological complexity and contingency of IoT. Thus these questions are avoided, leaving the deceptively simple [idea → everyday world] relationship which may be presented as unquestionable.

Next, we may compare the later sentence (quoted favourably from the US National Intelligence Council) that "popular demand combined with technology advances could drive widespread diffusion of an Internet of Things (IoT) that could, like the present Internet, contribute invaluably to economic development" (Atzori et al., 2010, p. 2787). Here the relationship between the various elements is different. IoT is no longer an idea which impacts on the everyday life of users. Instead, it is user demand (coupled with technological advances) which will drive the development of IoT. What constitutes IoT in this later context is not specified. The reference to "diffusion of an Internet of Things" (italics added) suggests that perhaps it is to be understood as a technological artefact which will exist in the future. It is suggested that the scale of this technological artefact (which constitutes IoT) will be driven by "pull-factors" emanating from the population. Given that a commonly referenced characteristic of IoT is its large scale, IoT, in this case, is a technological artefact brought into existence in some unspecified way by popular human will.

As a final example, consider that "IoT is included by the US National Intelligence Council in the list of six 'Disruptive Civil Technologies' with potential impacts on US national power" (Atzori et al., 2010, p. 2787). Here IoT is positioned as a "technology" by being placed on a list of technologies. However, for IoT to be able to (potentially) impact the national power of the United States, it must be something more than a mere technological artefact. It must have sufficient agency be able to interact with, and influence other actors important for US national security—US national security agencies, weapons systems, foreign governments, ideologies opposed to the US etc. IoT is not then, merely hardware and software. Phrased in the language of ANT, IoT is an actor in the national security network (understood in terms of ANT).

We may summarise the ontological content of the three examples above as:

- IoT is an idea which will impact several aspects of everyday life.
- User demand and technological advancement will drive the diffusion of an IoT—this diffusion is necessary to provide the scale which is a defining characteristic of IoT.
- IoT is a technological actor which may impact US national power.

It may be possible to combine these statements in a way which preserves the ontological unity of IoT. However a way to achieve this is not clear from the passage, and would seem to require further ontological "work". This demonstrates the tension between different ways of referring to IoT, and that these tensions are not only found between authors or discourses but may also be found within the scope of a single passage. This analysis also shows the way in which these difficulties may be "smoothed over" in a text through some combination of forcing and imprecision.

Some sources do acknowledge these tensions, albeit without definitive resolution. For example:

> Within such perspective, the term 'Internet-of-Things' (IoT) <CONTESTED TERM> is broadly used to refer to both: (i) the resulting global network interconnecting smart objects by means of extended Internet technologies <ARTEFACT> , (ii) the set of supporting technologies necessary to realize such a vision (including, e.g., RFIDs,

> sensor/actuators, machine-to-machine communication devices <ARTEFACT–assemblage of technologies>, etc.) and (iii) the ensemble of applications and services <CONTEXT OF USE> leveraging such technologies to open new business and market opportunities <BUSINESS OPPORTUNITY> [2,3]. In this survey article, we aim at providing a holistic perspective on the Internet-of-Things concept <IDEA> and development <TRAJECTORY>, including a critical revision of application fields, enabling technologies and research challenges. (Miorandi et al., 2012, p. 1498; category references added in angle brackets)

In this extract some of the ontological difficulties relating to IoT are acknowledged. The proposed resolution is to take an "holistic perspective"—presumably to position these different perspectives as elements of a broader understanding of IoT. However, it is suggested that to arrive at a clearer understanding of IoT these tensions must be addressed directly. It is not enough to put these categories together in additive way—the relationships between them must be investigated, understood and (if possible) resolved.

5.7. Summary

This section will summarise what has been learnt from the preceding data analysis, and provide a link to the ontological analysis which follows.

The sample of 180 articles chosen has provided a rich source of ontic claims about IoT, containing over 1,000 separate references to IoT. Drawn from three sources (Gartner, Scopus and the New York Times), the documents were found to be quite diverse in content and audience, being divisible into fourteen broad types of article, and directed towards four different audiences.

Using an inductive method, references to IoT were grouped into twelve empirically derived categories. Each category represents a more-or-less distinct regional ontology of IoT; though some of these regional ontologies are partial and fragmentary. The categories were found be largely independent of each other (i.e., no category is a subset of, or directly dependent on, another category). The categories were also found to be common across the various sources, and the various types of article. The categories were also found to persist over time. Most categories were, however, found to be capable of further sub-division. For example, a given set of references might concur that IoT is an idea, but differ as to whether it is better understood as a vision, concept or paradigm.

It was found that categories frequently occur together. Most possible combinations of categories are found, and most articles contain references to more than one category. This suggests that a single category does not, in itself, exhaust a typical author's understanding of the ontology of IoT. For example, most authors would not agree that IoT is only a technological artefact, or only a vision, or only a business opportunity. To understand the ontology of IoT as represented in the literature we must thus investigate sets of related categories.

As noted in the previous section, the literature does not give a clear and explicit account of the relationships between categories. Still less does the literature provide guidance on how we may move from a set of related categories to an ontology for IoT. To attempt this movement will require further hermeneutic effort, which will be the task of the next chapter. In particular, the categories described in the current chapter will be brought into dialogue with the ontologies of technology which were described in the literature review. As outlined in the introduction, the intent of this dialogue is to provide greater insight into the ontology of IoT, and also to enable reflection on the ontological theories themselves.

6. Ontological Investigation

The intent of this chapter is to progress the ontological investigation of IoT, enquiring more deeply into both putative and possible regional ontolog(ies) of IoT. To do this, two previously developed themes will be brought into dialogue—the philosophical ontologies on technology discussed in *Chapter 2: Literature Review* and the empirically derived ontological categories of IoT derived from the texts in *Chapter 4: Methodology*.

Chapter 4: Methodology derived a number of empirical ontological categories, each reflecting a regional ontology—or a fragment of a regional ontology—of IoT. *Chapter 4: Methodology* also analysed the relationships between these categories. From these categories, and relationships between categories, we can begin to articulate the regional ontolog(ies) of IT However, the ontologies thus derived are not very theoretically rich or fully featured. The main aim of the texts reviewed is not ontological, it is (for example) to provide entertainment, give practical business advice, or report the results of a project. Ontological references are thus often terse or tangential, and allow us only to sketch the outlines of an ontology. Thus, for example, a newspaper reference to IoT as a vision makes an ontological claim but does not provide an account of the way a vision might function in shaping IoT over time.

In *Chapter 2: Literature Review*, on the other hand, various philosophical approaches to the ontology of technology were investigated. These philosophical approaches give a rich theoretical account of the ontology of technology. These philosophies also attribute implications, fields, impacts, power, dynamics and so on, but they do not speak specifically of IoT; instead, they speak of Technology in general, or of specific technologies other than IoT

By bringing the specificity of the attributed ontologies of IoT (from *Chapter 4: Methodology*) into dialogue with the richer but more generalised ontologies of technology (from *Chapter 2: Literature Review*), it is possible to describe the implications of the attributed ontologies of IoT—implications which are inherent in the attributed ontologies, but which are only revealed by examining IoT using the theoretical framework provided by philosophical ontologies of technology. This analysis will, symmetrically, consider the extent to which the philosophical ontologies on technology have the capacity to account for the attributed ontologies of IoT in the texts. Such a symmetrical move will enable both the attributed ontologies of IoT and the theoretical landscapes of technologies to be critiqued using the empirical work of the thesis.

The next step in the analysis will move beyond individual ontologies and perspectives to consider attributed ontologies and philosophically derived ontologies *en bloc*. The attributed ontologies as a group will be considered in the light of the philosophical ontologies. The possibility of combining different philosophical ontologies will also be considered. The intent will be to arrive at a theoretically informed understanding of what the attributed ontolog(ies) of IoT reveal about IoT as a being (or beings). As in the preceding analysis, the intent will be to combine the specificity of the attributed ontologies with the explanatory power of the philosophical ontologies. Considering attributed ontologies and philosophical ontologies in groups rather than individually will allow a more complete and nuanced picture of the possible regional ontolog(ies) of IoT to be developed.

Once again, the intent will be to conduct a symmetrical analysis. After considering what the philosophical ontologies reveal about the possible regional ontolog(ies) of IoT, the efficacy and explanatory reach of each of the philosophical ontologies will also be considered.

This chapter will be structured in the following way:

(1) Firstly, I will consider the move from the categories of ontological reference developed above (see *Chapter 5: Data Analysis*) to attributed ontologies. Attributed ontologies are derived from the empirical categories of ontological reference which were identified in *Chapter 4: Methodology*. However, this derivation is not completely self-explanatory, but rather requires a measure of deduction and synthesis. This section will make some general remarks about attributed ontologies, and then explain the required deduction/synthesis process, and the limits of what it can achieve. At this point, the primary unit of analysis will be the individual text and its attribution of ontology to IoT.

(2) I will then consider the attributed ontologies of IoT in light of the six philosophical ontologies of technology developed in *Chapter 2: Literature Review*. The extent to which the attributed ontologies can be accounted for in terms of the various philosophical ontologies will be analysed, and resonances between particular attributed ontologies and particular philosophical ontologies will be highlighted. I will also consider how these resonances can help us to better understand the implications of the attributed ontologies of IoT. The explanatory reach and power of each of the philosophical ontologies will be considered in terms of its ability to provide insight into the empirical data.

(3) Next, I will explore the relationship between the attributed ontologies and the philosophical ontologies in total. In particular, I will ask whether it is possible for there to be underlying ontolog(ies) of IoT – ontolog(ies) more fundamental than the attributed ontologies and which are capable of explaining the attributed ontolog(ies). I will consider the criteria that such underlying ontolog(ies) would have to fulfil, and what work underlying ontolog(ies) would do. I will then investigate to what extent the philosophical ontologies can furnish such underlying ontolog(ies). From this discussion, three plausible candidates will emerge as to the nature of IoT's underlying ontolog(ies).

    (i) IoT is a socio-technical imaginary—a collectively held vision of the future to be attained through technological advancement (for full definition see *Section 3.3.6: Social Imaginaries* above).

    (ii) The ontology of IoT is irreducibly multiple and fragmented, and emerges performatively from a network of relations.

    (iii) IoT is the kind of complex object envisioned in Object-Oriented Ontology—and in particular is a hyperobject.

(4) As in section (3), I will then undertake an analysis symmetric to that of the previous section. In this case, the explanatory reach and power of each of the philosophical ontologies will be considered in terms of its ability to provide insight into the question of underlying ontolog(ies).

(5) Finally, I will review and summarise the finding of this chapter, and move towards the conclusions and directions for future study which will the final chapter of the thesis.

6.1. Attributed ontologies

An attributed ontology is the set of ontological beliefs which we may reasonably take to be expressed in a particular text. It is preferable here to refer to text rather than author(s) in order to avoid the complex question of authorial intent. Unfortunately, as noted above, such ontological commitments are rarely expressed clearly and in full—instead, some level of hermeneutic effort is required to recover them.

It might be argued that texts need not take an ontological stance on IoT, that is, that there are texts to which no ontology can reasonably be attributed. Against this, however, it may be observed that ontological commitment to IoT is commonplace in the literature (see *Section 5.2.6: IoT as CONTESTED TERM* above). Almost without exception the sources reviewed refer to IoT as something real, something existing in the world. IoT is something with properties, actual or emergent; IoT is something tangible, or something in the process of becoming tangible; IoT exists beyond particular projects, technologies, vendors, or texts. Most often this takes the simple form "The Internet of Things is ..." In a minority of sources, IoT is described as an element of language rather than a thing, as a sign rather than a referent. For example, it may be called a "neologism" or a "buzzword". In these cases, however, this is done in such a way as to make it clear that it is a sign which ***has*** a real referent.

Despite this widespread ontological commitment to IoT, there is seldom any overt discussion of the ontology of IoT. For example, there is no overt discussion of whether IoT is a vision or a physical network, or how these two could be related. Instead of being the matter at issue for the texts, the ontology of IoT provides a background or substrate for the texts.

The preceding paragraphs have described attributed ontologies, and argued for their relevance to the texts. It is now worth recapitulating the conclusions of *Chapter 5: Data Analysis*, which provide the basic evidence for the nature of the attributed ontologies:

- From the texts analysed, twelve categories of ontological reference to IoT were identified, each category representing a distinct point of view as to the nature of IoT. As a reminder, these categories were:
    - IoT as ARTEFACT
    - IoT as TRAJECTORY
    - IoT as FORCE
    - IoT as IDEA
    - IoT as BUSINESS OPPORTUNITY
    - IoT as CONTESTED TERM
    - IoT as SOCIAL ACTOR
    - IoT as THREAT(ENED)
    - IoT as CONTEXT OF USE
    - IoT as ENCHANTED WORLD
    - IoT as HUMAN ENDEAVOUR
    - IoT as EXPERIENCE

1. Categories frequently occur together, with most articles containing references to multiple categories, and most possible combinations of categories. Thus a single grounded category does not usually exhaust the range of a text's ontological references.
2. In most cases, texts do not clearly articulate the relationship between categories. Generally, when multiple categories occur, they are conjoined in a merely additive way.

Thus, working only from the evidence in the texts, the best conclusion that we can venture is that the attributed ontology in a text is the combination of those categories to which it refers. For example, if a given text refers to IoT as a concept, a technology and a business opportunity, then for that text IoT is merely that: a concept AND a technology AND a business opportunity. This is certainly a possibility, and one which should not instantly be dismissed. However, from an ontological perspective, this possibility is rather unsatisfying as it says nothing about how IoT is these different things, or how these things are related. It also limits our understanding of these things (concept, technology, business opportunity) to the rather limited evidence provided by the texts.

To give an (imperfect) analogy—we if we observe a butterfly at two different times we can conclude that it *is* both its larval form (the caterpillar) and its adult form (the adult butterfly). But to say that it simply *is* these two things leaves something out of the account. This gap may be filled by reference to a wider theory of the lifecycle of insects. Reference to such a theory will allow us to understand that the caterpillar transforms into the adult butterfly via the pupal stage. It will also enable us to grasp the relative functions of these different developmental stages. Y.

In an analogous way, I will now attempt to place ontological observations from the texts into the context of a wider ontological understanding of technology (as developed in *Chapter 2: Literature Review*). The intent is to provide a richer account of the attributed ontologies of IoT encountered, and how the different categories which make up these ontologies may be related.

6.2. Applying theoretical perspectives to attributed ontologies

I will now discuss the categories and attributed ontologies developed in *Chapter 5: Data Analysis* and the previous section, in the light of the philosophical ontologies of technology discussed in *Chapter 3: Ontologies of Technology.*

The main questions to be considered are:

- What resonances (or, alternatively, conflicts) are there between the attributed ontologies and the philosophical ontologies?
- Where resonances occur, does this constitute causality or correlation (i.e., was the attributed ontology arrived at independently of the theory (correlation) or was it informed by the theory (causality))?
- Which philosophical ontologies resonate most with the attributed ontologies found in the texts, and which not at all?
- How do these resonances and/or conflicts improve our understanding of the categories themselves, or the relationship between them?

In the interests of transparency, several potential challenges to this analysis should be called out and (as far as possible) addressed:

- As noted above, the texts considered are not ontological treatises. Ontological references are often fleeting or fragmentary. In looking for ontological references there is a danger of over-interpretation, of ontologising, of finding more than is actually there. To avoid this tendency, care has been taking to stay as close to the texts themselves as possible—for example, to rely on the actual words encountered in the texts rather than risk re-stating them in (unintentionally) more ontological terms.
- There is the inherent risk of conducting two levels of inference: firstly using inference to attribute an ontology to a given example of literature, and secondly inferring a relation between the attributed ontology and a philosophical perspective. Either of these steps may be subject to challenge as misinterpretations. To guard against such misinterpretation and maintain rigour in the analysis, inferences have been made as transparent and explicit as possible (without making the discussion unreadable or unnecessarily prolix).

There is also a possibility of circularity in the analysis. Because the researcher was aware of the philosophical ontologies before conducting the data analysis, there is a danger that the philosophical ontologies were "read into" the texts when identifying the categories, only to be read back out when comparing categories and philosophical ontologies. To mitigate this risk, categories were identified using a structured method, based on close analysis of the texts, and limiting the requirement for subjective interpretation. In addition, the philosophical ontologies were not employed in the initial discussion and description of the categories (*Chapter 5: Data Analysis*).

Another comment on method is required at this point. As already stated, the intent is to work between attributed ontologies and philosophical ontologies. However, as noted, attributed ontologies comprise combinations of categories. The possible number of such combinations is very large: $\sum_{n=1}^{12} \frac{12!}{n!(12-n!)} = 4095.$ Though the number of combinations actually present is considerably smaller than this, it is still too large to be a workable basis for analysis. Thus, for pragmatic reasons, I shall use categories rather than using attributed ontologies as the main unit of analysis.

Having considered these challenges, and discussed how they have been addressed, I will now move on to consider the relationship between attributed ontologies and philosophical ontologies.

Reflection suggests that a given category may have a range of relationships with a given philosophical perspective. It may be hypothesised that this relationship might vary from strong resonance to strong conflict, along the following lines:

1. *Highly resonant*: There are strong correspondences between the category and philosophical perspective. If the category plays a significant role within a text it strongly suggests that the text's attributed ontology is aligned with the philosophical perspective.
2. *Resonant*: There are some correspondences between the category and philosophical perspective. If the category occurs within a text it may suggest that the text's attributed ontology is aligned with the philosophical perspective.
3. *Neutral (underdetermined)*: The category and the philosophical perspective do not bear much relationship to each other. Occurrence of the category in a text does not provide any meaningful evidence as to whether its attributed ontology would be aligned with the philosophical perspective.
4. *Dissonant*: There are some conflicts or contradictions between the category and philosophical perspective. If the category occurs within a text it may suggest that the text's attributed ontology is not aligned with the philosophical perspective.
5. *Highly dissonant*: There are strong conflicts or contradictions between the category and philosophical perspective. If the category occurs within a text it strongly suggests that the text's attributed ontology is not aligned with the philosophical perspective.

The relationship between categories and philosophical ontologies will be explored in the following discussion, and then the findings summarised in a table. The first approach will be to work from the perspective of the philosophical ontologies, seeking instances of resonance and/or opposition.

6.2.1. Artefact-centricity

Perhaps the most striking resonance is between the category of "IoT as ARTEFACT" and the perspective which I have termed "Artefact-based Ontology" (see *Chapter 3: Ontologies of Technology*). This resonance results from the fact that both "IoT as ARTEFACT" and "Artefact-based Ontology" make the technological artefact (in this case IoT) the being of primary concern. Both accounts place the artefact itself very much in the foreground, regarding other beings (for example users) as secondary adjuncts to the artefact itself.

As noted above, Artefact-based Ontology is not naively physicalist. Indeed one of its core concerns is to explain the dual nature of artefacts—both physical and functional. This strain of thought is also prominent in the references to "IoT as ARTEFACT". Much of the description of "IoT as ARTEFACT" is devoted not to physical artefacts (e.g., implemented hardware, or actual instances of software); it is instead devoted to standards and architectures. These standards and architectures outline the functional structure of IoT: it is by conformance with these standards and architectures that technical artefacts take on the functions which make them part of IoT. Artefact-based Ontology here enriches our understanding of IoT as artefact by providing a more sophisticated account of the relationship between an artefact's physical and functional natures, and the role played by standards , protocols and the like in assigning function to the artefact in the design process (see *Section 3.1.3.1.3: Artefacts and the Design Process* above.

"IoT as ARTEFACT" the most common category of reference in the literature surveyed. At the same time, Artefact-based Ontology is only one of the six philosophical ontologies to emerge from an engineering rather than humanities perspective. I would suggest that this is not a coincidence. With the preponderance of the literature forming part of the technical discourse—written by and for those in the technological disciplines—it is perhaps not surprising that an engineering-based ontology is pervasive.

In the discussion of Artefact-based Ontology two areas not emphasised by this perspective were noted (see *Section 3.1: Artefact-based Ontology* above):

(i) It pays only limited attention to ethical concerns.
(ii) It emphasises the agency of the designer compared to the agency of other groups.

I have argued above that the artefact-oriented perspective is possibly the most pervasive perspective encountered in the IoT texts sampled. One might thus expect to frequently encounter limitations (i) and (ii) when reviewing the texts. This hypothesis may be tested by reference to the texts:

With respect to (i), it is certainly true that most discussion of prima facie ethical issues such as privacy, security, and trust takes place in technical terms (see *Section: 5.2.8 IoT as THREAT(ENED)* above). Privacy and security are framed as desirable technical attribute of the artefact rather than as ethical prima concerns. When more fundamental ethical questions are addressed, this is generally done en passant in the form of assumptions, rather than being the topic of extended discussion.

With respect to (ii) it has been noted above (see *Section 5.2.11: IoT as HUMAN ENDEAVOUR* above) that most references to IoT as a human activity focus on privileged classes of actors—whether individuals, projects, enterprises, associations or nations—that are depicted as designing and building IoT. Certain actors who are portrayed as the "motive force" behind IoT. As discussed in "IoT as SOCIAL ACTOR" (see *Section 5.2.7: IoT as SOCIAL ACTOR* above) the populace at large tends to be described as largely passive, or acting only within certain well-defined roles: onlookers, consumers, resistors.

6.2.2. Essentialism

The second nexus of resonance is to be found between the category "IoT as FORCE" and the philosophical perspectives which I have collectively termed technological essentialism. This resonance was noted when "IoT as FORCE" was discussed (see *Section 5.2.3: IoT as FORCE* above). For IoT to be a force which can exercise widespread agency, this quality of forcefulness—of being able to demand and drive change—must be an essential aspect of IoT. This strong claim about the essential nature of IoT firmly links "IoT as FORCE" with technological essentialism.

There is also resonance between essentialism and "IoT as TRAJECTORY". "IoT as TRAJECTORY" places IoT on a "natural" arc of development starting with the internet and/or ubicomp. This category resonates with essentialism because it describes IoT as persisting over a long duration despite significant changes to various IoT—for example its scale and the uses to which it is put—a view which requires that IoT is characterised by an essence of some sort.

A further resonance may be observed between essentialism and a third category: "IoT as SOCIAL ACTOR"—in particular those references in which technology is described as being a driving force behind social change (e.g., Perkins, 2017). Such references resonate with essentialism in that they require that IoT has some consistent essence and that IoT is able to determine social outcomes.

It is then useful to enquire to what extent the essentialism encountered in the literature conforms with one of the "flavours" of essentialism discussed in *Chapter 2: Literature Review* viz. technological determinism, technological autonomy, and technological substantivism.

Of these three, it is technological determinism—in the sense that technological conditions cause social and cultural conditions to arise (Dusek, 2006)—which is most commonly encountered, with clear appeals to technological determinism being found in the category of "IoT as SOCIAL ACTOR" (see *Section 5.2.7: IoT as SOCIAL ACTOR* above. The IoT literature tends to portray IoT as primarily beneficial (see *Section: 5.2.8 IoT as THREAT(ENED)* above); thus the IoT literature is aligned with a techno-utopian rather than techno-dystopian variety of essentialism.

Evidence for technological autonomy is provided by the references to "IoT as TRAJECTORY". In these references, IoT follows a logical developmental trajectory from origins in earlier technologies (ubicomp, Internet) towards globally connected future (see *Section 5.2.2: IoT as TRAJECTORY* above*).* This sense that technology "follows its own path"—that its evolution is caused by technical factors and not its social context—is the central tenet of technological autonomy (see *Section 3.2.2: Technological autonomy* above).

Notably lacking from the literature surveyed is technological substantivism, the view that modern technology leads inevitably to a technologically enframed understanding of the world, with dystopian consequences. As noted in *Section: 5.2.8 IoT as THREAT(ENED)* (above) the social consequences of IoT as foreseen as mainly beneficial or, at worst, ambiguous.

Reference to the philosophical ontologies has here assisted understanding of the attributed ontology of "IoT as FORCE", enabling it to be understood as essentialist, determinist and autonomous, but not substantivist.

6.2.3. Social Constructivism

As discussed above, the category of "IoT as IDEA" is widespread in the literature, with "idea" meaning variously vision, concept and/or paradigm (see *Section 5.2.4: IoT as IDEA* above). This reference to IoT as a collective conception of the future resonates with the notion of the "technoscientific imaginary" or "imaginaire" developed in *Chapter 4: Methodology*. For example, the description of IoT as "a vision in which the Internet extends into our everyday lives through a wireless network of uniquely identifiable objects" (Welbourne et al., 2009, p. 48) matches well with the definition of a "technoscientific imaginary" as "collectively imagined forms of social life and social order reflected in the design and fulfilment of ... scientific and/or technological projects" (Jasanoff & Kim, 2009, p. 120).

The technological "idea" is also important to the artefact-oriented perspective, in the sense of the intentional character of a given artefact, the "the author's intention" in making it (Hilpinen, 2011). However, "IoT as IDEA" goes beyond the intent of a particular individual or group, and beyond artefact design, to the imagination of a future world. "IoT as IDEA" thus exceeds the narrow bounds of intentional character, and is closer in meaning to the broader notion of technoscientific imaginary.

The concept of the imaginary also echoes another category: "IoT as SOCIAL ACTOR". It will be recalled that this category identifies references to IoT's ability to exercise social agency. As described in *Chapter 2: Literature Review*, technoscientific imaginaries are able to stimulate the collective mind, and thereby mobilise the collective will to attain the imaginary. The attribution of social agency to IoT in the literature is more wide-ranging than this mobilisation of will to achieve IoT. For example, IoT's social agency is described as being able to drive large scale social, political and economic changes which are not necessarily entailed in "the achievement of IoT" (unless it is argued the IoT imaginary entails these social, political and economic changes). Nevertheless, the theory of the imaginary is helpful in that it provides a plausible mechanism by which IoT is able to exercise social agency at all.

There is also an apparent sympathy between other strands of social constructivist thought and another category viz. "IoT as HUMAN ENDEAVOUR". This sympathy arises from the way that both social constructivism and "IoT as HUMAN ENDEAVOUR" privilege the exercise of human agency. "IoT as HUMAN ENDEAVOUR" does not, however, fully embody the insights of constructivism because it focuses on a limited number of engaged social groups, such as projects, enterprises and nations, while downplaying others, such as activist groups and consumers.

There is a second sense in which "IoT as HUMAN ENDEAVOUR" entails only a limited form of constructivism. In *Section 3.3: Social constructivism*, two types of constructivism were discussed—causal and constitutive. "IoT as HUMAN ENDEAVOUR" implies causal constructivism, that is, that social factors play a role in bringing IoT into being, and making it the way it is. "IoT as HUMAN ENDEAVOUR" does not, however, require constitutive constructivism, that is, that the very meaning of IoT is socially constructed.

Finally, there is a resonance between social constructivism and the category of "IoT as FORCE". Social constructivism articulates a clear evolutionary path for technology toward stabilisation and closure (see *Section 3.3.2: Social Construction of Technology* above). "IoT as FORCE" describes IoT as growing and evolving in the process of "becoming real". However, the resonance here is rather weak as the IoT literature does not mention typical constructivist concepts such as interpretative flexibility, stabilisation, and closure; nor does the IoT literature account for the evolution of IoT in terms of the interests of relevant social groups.

6.2.4. Postphenomenology

There is a direct resonance between phenomenology and the category of "IoT as EXPERIENCE": both phenomenology and "IoT as EXPERIENCE" ground the being of technology in direct human experience.

As noted in *Chapter 4: Methodology*, phenomenological references in the literature include references to the "disappearance of IoT", which are reminiscent of Heidegger's notion of technology's "withdrawal", and of Ihde's analysis of technology's mediating role in our experience of the world (see *Section 3.5: Postphenomenology* above). There are, however, only a small number of such references to "disappearance" in the literature.

More numerous are references to IoT as an element of the "lifeworld", of lived human experience. Where these references refer explicitly to the experiential dimension of IoT they were grouped under "IoT as EXPERIENCE". The category of "IoT as Enchanted Reality" also has some resonance with the phenomenological perspective on technology because of their shared interest in the technological transformation of everyday life. This resonance is, however, somewhat shallow: "IoT as Enchanted Reality" tends to focus on intelligent things as objects rather than as aspects of experience.

6.2.5. Relationism

According to the category "IoT as ENCHANTED WORLD", IoT will give rise to a seemingly magical world populated by everyday objects which can interact as if they had minds of their own. This focus on the interactivity between people and things makes "IoT as ENCHANTED WORLD" resonant with the ideas of relationism. In particular, "IoT as ENCHANTED WORLD" tends to erase the ontological distinction between people and things. This ontological flattening into a single class of "actors" is certainly reminiscent of ANT. "IoT as ENCHANTED WORLD" also entails some assumption of the primacy of relations over essence. From the perspective of "IoT as ENCHANTED WORLD", an intelligent object is one which can display intelligence in its relations with other things/people; it is not a question of whether the object is innately intelligent. Thus the emphasis is on relations rather than essences.

In a similar way, "IoT as SOCIAL ACTOR" flattens the ontological distinction between technological and social actors in an ANT-like manner. IoT is seen as exercising social agency by means of its interaction with other social actors (e.g., the economy, US global power) and encountering resistance in interactions with others (e.g., unwilling consumers). IoT is thus shaped by its relations with other social actors.

The strength of the resonance between "IoT and Enchanted World" should not, however, be overstated. The similarities outlined in the paragraph above have been derived hermeneutically, through interpretation of the texts. It is not clear whether it would be recognised by the authors of the relevant texts. In addition, none of the texts considered employs the distinctive ontological vocabulary of ANT—the language of actors, networks, and interessement—which would indicate a more direct influence of relationism on the IoT literature.

6.2.6. Object-Oriented Ontology

None of the categories of reference derived from the texts has an explicit resonance with Object-Oriented Ontology. As will be seen below, Object-Oriented Ontology may nevertheless be useful in making sense of the ontology of IoT.

6.2.7. Non-Ontology

The category of "IoT as CONTESTED TERM" cannot be said to resonate with one of the six philosophical ontologies in particular. However, two possible accounts of its resonance with the perspective in general may be given. Firstly, it might be considered a rejection of ontological accounts of IoT in general, that is, a rejection of the notion that IoT has an ontology which may be described. There is, however, no direct evidence from the texts to support this view. Secondly, it may be considered an acknowledgement that there is no single, authoritative ontology which can encapsulate IoT in its entirety to the satisfaction of all. Here there is directly supporting evidence from the texts: several references speak of the contested nature of IoT, the existence of multiple competing visions, and the competition that exists to dominate this "wild frontier".

6.2.8. Non-Resonant Categories

Having worked through the six philosophical ontologies identified in *Chapter 2: Literature Review*, it is interesting to note that there are a few categories without any particular resonance with the philosophical ontologies:

- IoT as BUSINESS OPPORTUNITY
- IoT as THREAT(ENED)
- IoT as CONTEXT OF USE

These categories could of course be explained in terms of one or more of the philosophical ontologies. For example, it could be suggested that "IoT as BUSINESS OPPORTUNITY" is a way of understanding the deployment of IoT (as *technological artefact*) in the world of business. It also could be argued that "IoT as BUSINESS OPPORTUNITY" in an expression of the *technological essence* of IoT, reflecting the way IoT enframes the world as a Heideggerian "standing reserve", as an opportunity to be consumed. Equally, it could be suggested that "IoT as BUSINESS OPPORTUNITY" reflects one of the mechanisms by which IoT (as *social construction*) is being shaped.

However, the risk here is that by employing a preconceived ontological perspective the category is not such much being explained, as being explained away. This goes against a basic tenet of the ontological method: to take the ontologies of our interlocutors seriously (see, for example, Viveiros de Castro et al., 2014). From the analysis of the literature (see *Chapter 4: Methodology* above) it is clear that when authors describe IoT "as a business opportunity", this is, in general, the primary mode of being which they assign to IoT. They apprehend IoT first and foremost *as a business opportunity*. Presumably "IoT is a business opportunity" is not shorthand for (for example) "IoT is a technical artefact which may be used by businesses to create differential capabilities and this may create a business opportunity". Or at least, such convoluted translation of one ontological perspective into another is not encountered in the literature.

6.2.9. Summary

We can summarise the findings of the discussion above in the following table, with “A” indicating a higher degree of resonance, and “a” indicating a weaker degree of resonance.

	Artefact-based ontology	Technological essentialism	Social constructivism	Relationism	Postphenomenology	Object-Oriented Ontology Object-Oriented Ontology
IoT as ARTEFACT	**A**					
IoT as TRAJECTORY		A	a			
IoT as FORCE		**A**				
IoT as IDEA			**A**			
IoT as BUSINESS OPPORTUNITY						
IoT as CONTESTED TERM						
IoT as SOCIAL ACTOR		A	a	a		
IoT as THREAT						
IoT as USE CASE						
IoT as ENCHANTED WORLD				a	a	
IoT as HUMAN ENDEAVOUR			a			
IoT as EXPERIENCE					**A**	

Table 6-1 Correlation between empirical categories and philosophical ontologies

Some useful insights can be derived from the observed pattern of resonance.

Firstly, the philosophical ontologies cannot neatly or comprehensively account for the empirically derived ontological categories. There is an element of messiness and incompleteness. This is heartening from a methodological perspective. Too clean and neat a mapping might suggest that the philosophical ontologies had had an undue influence on the construction of the categories: that the philosophical ontologies had been “read into” the texts under analysis, and then “read out” again. The unevenness of the mapping also indicated that the philosophical ontologies have not had much direct influence on the authors of the texts. If there had been a stronger direct influence—if the authors of the texts were (for example) avowed social constructivists, ANT practitioners or essentialists—stronger and more explicit linkages between categories and philosophical ontologies might have been anticipated.

On the other hand, there is some observable resonance between philosophical ontologies and categories. This is also encouraging in that it suggests the project is not futile—that there is some connection between the categories and the philosophical ontologies, and that this connection can fruitfully be studied. In a number of cases above, a reference to a philosophical perspective has generated additional insight into the categories derived from the texts. For example:

- Reference to the philosophical perspective of essentialism helped to more accurately pinpoint the type of essentialism encountered in the texts, that is, that the prevailing theme in the texts is technological determinism and technological autonomy rather than technological substantivism.
- Reference to the philosophical perspective of artefact-based ontology predicted two limitations of this ontological approach—namely a somewhat limited interest in ethical concerns and an emphasis of the agency of the user—which could then be confirmed by reference to the texts.
- The philosophical notion of the socio-technical imaginary helped to inform a more sophisticated understanding of “IoT as IDEA”, and to suggest a mechanism by which an idea could exercise social agency.

It can further be noted that the categories are not neatly or comprehensively explained by a single ontological perspective. Five of the six philosophical ontologies resonate with the categories, with four of them having a strong resonance with a category. This means that it is not possible to give a convincing ontological account of the texts studied by relying on only a single ontological perspective. Ontological explanation of the texts requires reference to multiple ontological theories. In other words, IoT, as encountered in the corpus of texts, is ontologically multiple.

Furthermore, individual texts often contain a variety of categories not contain only a single category (see *Chapter 5: Data Analysis*). Thus multiple philosophical ontologies are required to account for views expressed even in a single text. In other words, IoT is ontologically multiple not only for the corpus as a whole, but also for individual texts.

Finally, it may be noted that no overt dissonance between categories and philosophical ontologies was discovered (as described in *Section 6.2: Applying theoretical perspectives to attributed ontologies* above, dissonance occurs when there are conflicts or contradictions between a category and a philosophical perspective). This is because the empirically derived ontological categories are founded on positive ontic claims along the lines of "IoT is an X" (where X is a type of being). Claims of the form "IoT is only an X" or "IoT is not a Y" are seldom encountered in the literature (where Y is a different type of being). Now say a philosophical ontology (P) can account well for IoT as an X, but cannot account well for IoT as a Y. We can then say that P and the claim that IoT is a Y do not resonate. However, there is no overt contradiction or conflict, and hence no dissonance—but rather an absence of resonance. Thus the figure above displays a pattern of resonance and the absence of resonance, rather than a pattern of resonance and dissonance.

6.2.10. Analysis

In summary then, what can be said about the ontology of IoT as appears in the texts, considered in the light of various philosophical positions?

To reiterate a conclusion from *Chapter 4: Methodology*, IoT is generally regarded in the texts as a being which can be defined and discussed. Its attributes can be identified, and true claims can be made about it. In other words, IoT is generally viewed in an ontological light.

However, IoT is multiple in two different ways:

Firstly, there are differences at the ontic level, at the level of concrete facts about IoT. At this level, many aspects of IoT are contested: Is IoT a vision, a concept or a paradigm? How fast will the number of IoT devices grow? What are the foundational standards which define IoT?

How many architectural layers does IoT have? On these and similar questions, the literature furnishes a range of divergent views.

Secondly, there are differences about what kind of being IoT is—whether it is an imaginary, a technological artefact, a transformational force, or a change to our lifeworld. These differences were already noted in *Chapter 5: Data Analysis*. However, the discussion in this chapter has demonstrated that these differences cannot be resolved by reference to philosophical views on the ontology of technology. In other words, these differences are not merely a feature of the categories which were inductively derived in *Chapter 5: Data Analysis*—instead, they arise from more fundamental differences as to the nature of technology. These differences regarding the ontology of IoT may be described as being at the level of "regional ontology", that is, differences as to the ontology of a particular subject. In Heideggerian terms, they may be understood as being intermediate between ontic differences (differences as to particular facts) and ontological differences (differences as to the nature of being itself) (Wheeler, 2011). To give an example: Ontic multiplicity is evidenced by the different attributes imputed to IoT, for example, the different architectural layering models imputed to IoT (see *Section 5.2.1: IoT as ARTEFACT*). Regional ontological multiplicity is evidenced by the different kinds of being attributed to IoT, of which a technological artefact with a layered architecture is only one.

As outlined in *Chapter 4: Methodology*, the literature approaches these two levels of difference in different ways. Ontic differences are a frequent topic of discussion. Attempts are made to summarise these differences and then to find a synthesis or consensus which will reconcile them. To give two illustrative examples:

Atzori et al. (2010) attempt to group the various visions for IoT as "thing"-oriented, "internet"-oriented and "semantic"-oriented:

- "Thing"-oriented visions anchor IoT in the growing intelligence of things, starting with the ability of RFID-enabled things to uniquely identify themselves.
- "Internet"-oriented visions position IoT as an extension to the use of existing internet concepts and protocols.
- "Semantic"-oriented visions emphasis the need to name billions of things, and to be able to relate them to each other, and consequently stress the key role to be played by semantic technologies.

These different visions are then reconciled in a Venn diagram, showing how these visions can be conceptualised as part of the overall IoT "paradigm".

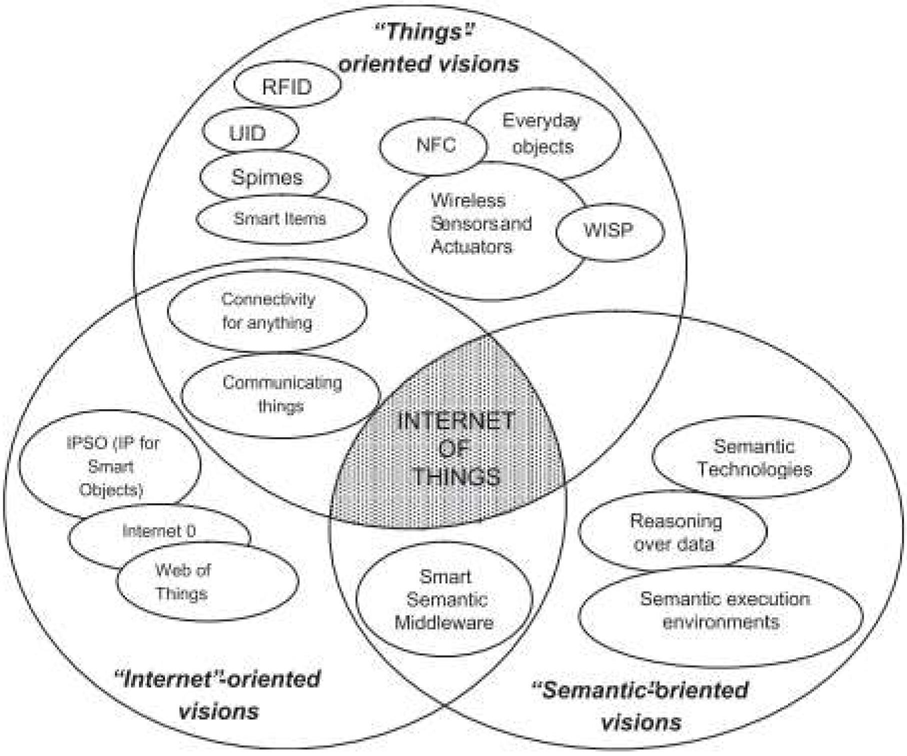


Figure 6-2 "Internet of Things" paradigm as a result of the convergence of different visions (Atzori et al., 2010)

Note that Figure 6-2 and Table 6-3 are given only as exhibits of the *kind* of constructs encountered in the texts. An understanding of the specific technical terminology and acronyms employed is not needed.

Sicari et al. (2015) explore and synthesise different approaches to IoT security, privacy and trust, by highlighting similarities and divergences, gaps and overlaps. For example, nine major European IoT security projects are compared via a table. This table provides a schematic view of how these initiatives could be harmonised and reconciled.

	Butler	EBBITS	Hydra	uTRUSTit	iCore	HACMS	NSF	FIRE	EUJapan
Authentication	x			x	x	x	x	x	
Confidentiality	x	x	x		x	x	x	x	x
Access Control	x	x		x	x	x	x	x	
Privacy	x				x		x	x	x
Trust				x	x		x		
Enforcement									
Middleware		x	x		x				
Mobile	x						x		

Table 6-3 Contribution of ongoing European projects on IoT security (Sicari et al., 2015)

Thus the management and reconciliation of ontic multiplicity is a common theme in the literature. The position with respect to the multiplicity of regional ontology is rather different. As was noted in the conclusion to *Chapter 5: Data Analysis*, the discussion of the relationship between categories is rather oblique: multiple categories are usually simply co-joined in a list. Little attention is given to reconciling and harmonising categories (as is done for ontic differences). Furthermore, in this chapter, the resonance between categories and philosophical ontologies has been demonstrated. Thus the relationship between co-joined categories cannot be resolved by reference to the philosophical ontologies. For example: to co-join "IoT as IDEA" and "IoT as technological artefact" is to co-join a social constructivist and an artefact-centric understanding of IoT.

Thus, whereas ontic multiplicity is seen as a matter for resolution, regional ontological multiplicity appears to be widely assumed. In fact, it can be said there is a fairly catholic approach to regional ontology. As an example of how this manifests: claims of ontological exclusivity—claims along the lines that IoT is an idea and *not* a technological artefact—are not encountered. It can be added that, in the literature, IoT is accepted not only as ontologically multiple, but also as changeable and emerging—IoT is frequently described as being in a process of becoming (e.g., see *Section 5.2.2: IoT as TRAJECTORY* above).

In summary then, from a reading of the texts, IoT emerges as ontologically multiple in a sense that goes beyond mere ontic disputes. I will now consider what this means for our understanding of the ontology of IoT. Must ontological multiplicity be accepted, and if so, what are the implications for how we understand IoT? Or is ontological multiplicity only an appearance, beyond which lies a more fundamental unity? These questions will be considered in the next section.

6.3. Underlying ontologies

In *Chapter 2: Literature Review* the point was made that ontology may either *describe a view* about what exists, or it may *advance a claim* about what exists (Laidlaw, 2012; Pedersen, 2012)—though it was noted that there made be "slippage" between these two modalities. Up to this point, ontology has been employed in a descriptive manner to describe the views encountered in the texts, and in an instrumental manner to investigate and analyse them. I will now move from a descriptive/instrumental use of ontology to a more direct consideration of ontological claims. The question at issue is no longer "What is the perspective of the texts on the ontology of IoT?" It is now: "Based on the claims made in the texts, what *is* the ontology of IoT?"

It appears that there are three plausible answers which may be given to this question:

(1) It may be argued that the premise of the question is incorrect, that is, that IoT has no ontological basis. For example, it could be suggested that IoT is purely a linguistic construct, and has no existence beyond the discourse.

(2) It may be argued that ontology appears multiple, but can, in fact, be understood as a whole by reference to a deeper ontological structure on which different texts (and indeed different parts of the same texts) have a different perspective.

(3) It may be accepted that the ontology of IoT is irreducibly multiple, and give an account of how such multiple ontologies could function.

Option (1) entails a rejection of the utility of the ontological mode of investigation, at least with respect to IoT. By taking an ontological approach to this investigation, I have chosen not to pursue this line of enquiry. The reasons for taking an ontological approach were laid out in *Chapter 3: Ontologies of Technology*. Based on an analysis of the texts, additional justification for an ontological approach may also be stated. As noted above, the vast majority of texts state or assume an ontology for IoT. Thus to argue that IoT is fundamentally "non-ontological" is to go against the testimony of the witnesses—to risk, in the words of de Castro (2015) not taking our interlocutors seriously.

The remainder of this section will consider Option (2)—that the apparent multiplicity of the ontology of IoT in fact masks a deeper ontological unity, or at least a deeper ontological structure which renders IoT intelligible. Option (3)—that IoT Is irreducibly multiple—will be considered in the following section.

I shall proceed by:

1. Clarifying the role of, and requirements for, an underlying ontology.
2. Reviewing the candidates for an underlying ontology—including the six philosophical ontologies described in *Chapter 2: Literature Review*.
3. Discussing each of the most promising candidates in greater detail.

6.3.1. Underlying ontology: role, requirements, candidates

I shall now consider the role played by an underlying ontology, and the requirements it must fulfil in order to play this role effectively.

To begin, it is necessary to clarify what is meant by "underlying ontology". I shall use the term to describe an ontology which is not directly found in the texts, but which provides a convincing account of the ontologies found in the texts. The notion of an underlying ontology relies on the assumption that the true ontology of IoT may not be apparent to participants in IoT (for example the authors of the texts) but may nevertheless provide a convincing explanation for the ontological commitments found in the texts.

This is well illustrated by the Jain parable of the blind men and the elephant (subsequently adopted into both Hindu and Buddhist teachings):

> Once upon a time, there lived six blind men in a village. One day the villagers told them, "Hey, there is an elephant in the village today".
>
> They had no idea what an elephant is. They decided, "Even though we would not be able to see it, let us go and feel it anyway". All of them went where the elephant was. Every one of them touched the elephant.
>
> "Hey, the elephant is a pillar", said the first man who touched his leg.
>
> "Oh, no! it is like a rope", said the second man who touched the tail.
>
> "Oh, no! it is like a thick branch of a tree", said the third man who touched the trunk of the elephant.
>
> "It is like a big hand fan", said the fourth man who touched the ear of the elephant.
>
> "It is like a huge wall", said the fifth man who touched the belly of the elephant.
>
> "It is like a solid pipe", Said the sixth man who touched the tusk of the elephant.
>
> They began to argue about the elephant and every one of them insisted that he was right. It looked like they were getting agitated. A wise man was passing by and he saw this. He stopped and asked them, "What is the matter?" They said, "We cannot agree to what the elephant is like". Each one of them told what he thought the elephant was like. The wise man calmly explained to them, "All of you are right. The reason every one of you

> is telling it differently because each one of you touched the different part of the elephant. So, actually the elephant has all those features what you all said”.
>
> “Oh!” everyone said. There was no more fight. They felt happy that they were all right. (Jain Global Resource Centre, 2019, under "Jain Stories")

The elephant is not apparent to the blind men, but the existence of an elephant provides a convincing and unified account of the ontologies that they have individually constructed. Unfortunately, there is no guarantee that the analogy works for the ontology of IoT—that any “elephant” exists. Certainly, there is no wise man to whom it is revealed in its entirety—we can only grope towards it, trying to assemble a picture from the accounts of the (other) blind men.

There are certain criteria which an underlying ontology would need to fulfil, certain kinds of work which it must be capable of performing:

- Firstly, it must be an ontology—it must form a coherent and convincing ontology of its own.
- Secondly, it must account for the observed ontologies: it must explain how IoT is what it is said to be in the texts. In doing this it needs to take seriously the ontological possibilities suggested by the claims in the texts: these cannot simple be discounted or “explained away”. In particular, it should explain how the ontological perspectives of the protagonists are experienced as ontological—rather than (for example) assuming mendacity or credulity on the part of the observers. This imperative to take observers seriously when they talk about ontology is fundamental to the methodological use of ontology—see *Section 2.2:*
- *Ontology as a* methodological tool above.
- Thirdly, it must be preferable (e.g., simpler, more plausible, or with greater explanatory power) than simply accepting all the individual perspectives collectively.

The most obvious candidates for the role of underlying ontology are the six philosophical ontologies developed earlier. Being well-developed ontologies, these will at least meet the first of the criteria described above. This is a non-trivial criterion. The six philosophical ontologies were distilled from a broad survey of the history of thought about technology. It can thus be argued that they represent six of the best developed and most widely accepted ontologies of technology available to us. There is thus good reason to believe that an underlying ontology of IoT (if there is such a thing) will be found somewhere among these philosophical ontologies.

Before proceeding, it will be useful to consider what it means for an underlying ontology to account for ontological perspectives *as ontological.*

6.3.2. Accounting for ontological perspectives

The question to be considered is: “if IoT is actually an A, how can this account for the fact that the texts consider it to be an X?” for example, “if IoT is actually an ARTEFACT, how can we account for the fact that the texts consider it to be an IDEA?”

This account can be rendered in two different ways.

The first approach addresses the causal question of how the ontological perspective occurs: if an ontological perspective involves things which are not part of the underlying ontology, how is it that these things come to arise?

Such an explanation may take one of the following forms (note that in these examples “the thing” is the ontological view to be explained, e.g., “IoT as an IDEA”. In the following discussion the capitalised terms (BASIC, EPIPHENOMENON etc.) will be used to reference these various kinds of explanation):

- The thing is seen as a basic foundational element of the ontology of IoT (e.g., in a scientific worldview—hydrogen fusion is an essential element of the sun) (BASIC).
- The thing is accounted for as a “side effect” of the truly basic ontological elements (e.g., in a scientific worldview—photosynthesis or eclipses are not part of the sun, they are an effect of the sun) (EPIPHENOMENON).
- The thing is viewed not as ontologically “real” but as a way in which the real ontology of IoT is perceived or understood (e.g., in a scientific worldview—sunbathing is not part of the sun, it is a way in which the sun is experienced) (PERCEPTION).
- The thing does not form part of the ontology of IoT, because it does not really exist, that is, it is mistaken or illusory (e.g., in a scientific worldview—a crocodile eating the sun during eclipses does not really happen—this is a mistaken belief) (ILLUSION).

The other approach is to investigate *why* the texts invoke these things as ontological; why these things are reified. Such explanations can be framed in terms of the strategies and motivations of the texts—employing a particular ontology can be a strategy employed in pursuit of a goal.

For example, ideas can do things which artefacts cannot, such as change and spread with great rapidity. For IoT to be an idea may thus useful for a protagonist's interests in shaping or diffusing IoT.

The discussion above has outlined the role and nature of an underlying ontology, and the work that such an ontology must do. The following sections will explore the potential of the philosophical ontologies to function as underlying ontologies for IoT.

6.4. IoT as Artefact

This section will discuss the potential of an artefact-oriented ontology to function as an underlying ontology for IoT.

As observed above, an artefact-based ontology resonates strongly with one of the most pervasive categories encountered in the texts—namely "IoT as ARTEFACT". In fact, as noted previously, this category is so widely encountered that it can be plausibly described as "the common-sense view" of IoT. Unsurprisingly, artefact-based ontology can thus provide a very satisfying explanation of IoT *to the extent that it is grasped as an artefact.* This includes not only the physical aspects of IoT but also functional elements such as standards and designs.

However, "IoT as ARTEFACT" is the only category with which artefact-based ontology strongly resonates. Accounting for the other categories in terms of artefact-based ontology is much more challenging. Such an accounting might be attempted along the following lines.

"IoT as TRAJECTORY" and "IoT as FORCE" are PERCEPTIONS which have been reified. As the artefact grows and evolves it may appear to be following a trajectory, or the expression of a force or essence. This is, however, only a reified perception. The actual IoT is the presently existing artefact.

"IoT as IDEA" is a real aspect of IoT but only to the extent that takes the form of designs which are imprinted onto the artefact as functions. Functional intent is a real aspect of the artefact, as real as its physical nature (at least according to the "Dual Nature" versions of artefact-oriented ontology). The same cannot, however, be said for more general visions of IoT. These are speculations about the future nature of IoT, they do not constitute part of IoT itself.

Similarly, "IoT as HUMAN ENDEAVOUR" is a real aspect of IoT up to a point. In particular, the work of those designing and building IoT is closely bound to the reality of the artefact—it is they who furnish the functional intent which is imprinted onto IoT. The same cannot be said for the broader group of IoT stakeholders—those who read about it in the newspaper or resist its implementation at their place of work. These people stand outside IoT and react to it, while designers and engineers are in effect part of it.

“IoT as USE CASE” is an interesting challenge for the artefact-based ontology. In sense “IoT as USE CASE” represents encounters along the edge of the artefact. A use case is an instance of IoT being applied in the world. Each use case is dependent on the participation of IoT in the use case. For example, in a use case where asset condition is being monitored (say sewerage pipes are being monitored for corrosion) the use case cannot work without the involvement of IoT sensors, networks, and data aggregation. However, for IoT to be a technological artefact, the entire use case assemblage (which includes people, ideas, locations and many other actors) cannot be part of IoT. Thus, in artefact-based ontology, a boundary must be drawn between those parts of the use case which are part of IoT, and those which are not. In the case given above, for example, perhaps the corrosion monitors are part of IoT, but the sewerage pipes are not. Thus the use case is an EPIPHENOMENON of IoT. There appears, however, to be an element of arbitrariness to the drawing of this boundary. For example, in the case of an IoT-enabled autonomous vehicle crammed with thousands of sensors and actuators, it seems difficult to credit that the sensors and actuators are all part of IoT, yet the car (with which they are so intimately entangled) is not.

Viewed through an artefact-oriented lens, “IoT as BUSINESS OPPORTUNITY” appears to be the adoption of IoT to address a particular class of use case: namely, use cases which occur in the world of business. As for the example of “IoT as USE CASE” then, the business opportunities in question rely on the use of IoT technology, but are not themselves part of IoT.

From an artefact-oriented perspective, other categories appear to even more remote from IoT’s character as a technological artefact.

“IoT as EXPERIENCE” and “IoT as ENCHANTED WORLD” are, from the artefact-based viewpoint, descriptions of how the individual user might encounter IoT, particularly in a future state in which it is pervasively deployed. These experiences are contingent on the existence of IoT, but do not form part of its fundamental ontology, and are hence EPIPHENOMENA.

Similarly, “IoT as SOCIAL ACTOR” and “IoT as THREAT”, from the artefact-based viewpoint, describe how IoT is encountered by social. The progressive growth and adoption of IoT will create threats and opportunities to which society will respond—for example, the opportunity of better medical care, or the threat of cyber-attacks. These threats and opportunities, and the social responses to them, are caused by the development IoT. They are not, however, an integral *part* of IoT, and so again are EPIPHENOMENA.

Finally, "IoT as CONTESTED TERM", takes on the appearance, from an artefact-based perspective, as mere controversy about the definition of IoT. From the perspective of technology-builder this controversy is unhelpful, and can best be resolved by tackling the problem of definitions in a systematic, rigorous and co-ordinated manner.

In summary then, artefact-based ontology is very successful in accounting for the most commonly encountered category—"IoT as ARTEFACT". Artefact-based ontology can also provide a limited account of some of the categories which can be more easily linked to "IoT as ARTEFACT", such as "IoT as IDEA" and "IoT as HUMAN ENDEAVOUR".

Artefact-based ontology has, however, difficulty accounting for other aspects of IoT, such as "IoT as USE CASE", "IoT as ENCHANTED WORLD". As far as I can make out, artefact-based ontology can account for these categories by describing them as mere side-effects (epiphenomena) or perceptions of the "actual" IoT (i.e., the artefact). It appears problematic for an underlying ontology to take either of these approaches:

- To describe a category as a mere perception (rather than something ontological in its own right) is to discount the ontic claims of those texts for which the category is important for the ontology of IoT.
- To describe a category as an epiphenomenon of IoT is to imply that that category is not an essential part of IoT. However, the categories which artefact-based ontology must treat in this way appear to be central to the conception of IoT. For example, it is hard to conceive of an IoT which is not realised in multiple use cases, and which does not represent a very significant business opportunity. It is thus difficult to accept an account of IoT in which the categories of "IoT as USE CASE" and "IoT as BUSINESS OPPORTUNITY" are not "really" part of IoT, but merely side-effects of it.

It was noted above that it may be fruitful to investigate not only *how* a given philosophical ontology might account for categories, but also *why* that approach might be taken, that is, what work a given ontological approach might perform. The discussion above has attempted to address the first of these questions for artefact-based ontology—I will now turn my attention to the second.

The utility of the artefact-oriented approach can be seen on several grounds.

Firstly, this ontological approach brooks very little ambiguity. By understanding the development of IoT as the building of an artefact, we dispense with the need to grapple with the difficult and subtle issues relating to ethics, society and imaginaries. Instead, we need deal only with the "hard" technological facts. Questions of perception and understanding become secondary—IoT is realised as a something objective existing in the world. Practical technical questions are pushed to the foreground. Ontic disputes may arise – for example regarding the technical standards to which IoT should adhere. The artefact-oriented approach provides a rational way of settling such disputes, not in terms of competing interests but in terms of rational pursuit of the technically best standards, that is, those which will best facilitate the development of the IoT artefact. Even if such methods fail, such ontic questions will ultimately be resolved by the evolution of IoT—the question will become not, "Which standards *should* IoT embody?" but "Which standards *does* IoT embody?" Thus artefact-based ontology is of practical value to those whose concern is the technical construction of IoT—it serves as conceptual scaffolding for this project.

Artefact-based ontology has a second appeal to this community. As noted previously, this approach tends to privilege the involvement of designers and engineers. For example, it regards these groups as more properly part of IoT than is society in general. Thus, design ideas for IoT are part of IoT in a way that popular notions about IoT are not. In this way, artefact-based ontology appeals to technical stakeholders—designer, engineers—because it increases their influence and agency: puts them in the "driver's seat" of IoT. By making IoT something technical, artefact-based ontology increases the power and leverage of technical stakeholders and hence is likely to appeal to precisely those stakeholders.

6.5. IoT as Technological Essence

This section will consider the viability of technological essentialism as an underlying ontology for IoT.

As discussed in *Section 3.2: Technological Essentialism*, I take technological essentialism to mean some combination of three separate but interconnected claims:

(i) That technology determines social and cultural conditions ("technological determinism").
(ii) That technology develops autonomously along a predetermined trajectory ("technological autonomy").
(iii) That technology constrains our values and the way we see the world ("technological substantivism").

As noted above in *Section 6.2.2: Essentialism*:

(i) Evidence was found in the texts for a belief in technological determinism.
(ii) The evidence for a belief technological autonomy was limited and ambiguous.
(iii) No evidence was found for a belief in technological substantivism. Indeed, the texts generally portrayed the social and economic changes driven by the IoT in a favourable light. This is closer to the technological utopianism of Zey and Kurzweil (Zey, 2004; Kurweil, 2005) than to substantivism in its usual (pessimistic) sense.

As also noted in *Section 6.2.2: Essentialism*, essentialist ontology resonates strongly with the categories of "IoT as TRAJECTORY", "IoT as FORCE" and "IoT as SOCIAL ACTOR". An underlying essentialism would provide a coherent account of these categories.

"IoT as IDEA" can be accommodated within an essentialist ontological frame by regarding it ("IoT as IDEA") as expressing the "essential idea" of IoT—that is, as a description of the essence of IoT. As previously described (see *Section 5.2.4: IoT as IDEA* above) some references within this category do indeed describe the essence of IoT as being something conceptual (rather than, say, physical or social). This accommodation does, however, present certain difficulties. References with the category of "IoT as IDEA" often describe the "idea of IoT" as something teleological, as a goal to be realised though the deployment of technology. By contrast, essentialism is not, generally speaking, teleological. Essentialism (and particularly technological autonomy) regards technology and society as progressing in a more-or-less pre-determined manner, but not in pursuit of a known future goal. It is driven more by "push" factors than "pull" factors. The push factors (according to prominent essentialists such as Ellul) are calculative rationalism, instrumentalism, empiricism and the like.

Essentialism is less convincing when dealing with the other categories identified in *Chapter 4: Methodology*:

Essentialism can account for the technical specifics of “IoT as ARTEFACT” only as expressions of a more general technological essence, whether this is the essence of (T)echnology as a whole, or the essence of IoT. De-emphasising the specifics in favour of more general explanations lays essentialism open to the charge of over-simplification (see *Section 3.2: Technological Essentialism* above). To borrow an idea from Object-Oriented Ontology, essentialism risks “overmining” IoT: not addressing IoT as it is, but instead reducing it “upwards” into its relations and effects (see *Section 3.6: Object-Oriented Ontology* above).

Essentialism would seem to require a similar approach to two further categories, viz. “IoT as USE CASE” and “IoT as BUSINESS OPPORTUNITY”. The details of particular use cases and business opportunities are not essential to the nature of IoT. An essentialist account would, therefore, tend to de-emphasise such details in favour of more “essential” characteristics. Once again, the risk in this approach is that categories regarded as ontological in the texts are “overmined”, de-reified in order to fit in with a priori ontological assumptions.

Generally, essentialism would not be able to account well for the category of “IoT as EXPERIENCE”. This could be regarded as an epiphenomenon, not properly part of IoT itself. An exception is the technological essentialism of Heidegger, which regards the particular phenomenological character of technology as a “clearing” to be its essence. (A “clearing” is a “region of Being in which things are revealed as mattering in some specific way or another”; Wheeler, 2011).

Essentialism’s usefulness in accounting for the category of “IoT as THREAT(ENED)” is somewhat mixed. This category can be well accounted for to the extent that the nature of IoT as being threat(ened) as be explained in a general way as part of IoT’s essence. When, however, this category takes the form of more specific and technical threat characteristics, essentialism is of limited assistance in accounting for these specifics.

Similar limitations occur in trying to fit “IoT as ENCHANTED WORLD” to an underlying essentialism. Essentialism can provide some account of the overall impact of IoT in transforming the everyday world (given that essentialism depicts IoT as a transformative force), but is less helpful in providing a nuanced account of the variegated features of such a world.

“IoT as HUMAN ENDEAVOUR” is not a category which essentialism can readily elucidate; indeed there is a degree of dissonance (opposition) between them. While “IoT as HUMAN ENDEAVOUR” emphasises the importance of human agency in the development of IoT, essentialism tends to stress the agency exercised by Technology itself. An essentialist account would, it seems, need to explain human agency as being an expression of an underlying Technological agency.

Finally, essentialism could best account for "IoT as CONTESTED TERM" not as a feature of IoT itself, but as a reflection of the human attempts to come to linguistic grips with the emerging technological phenomenon.

In summary, essentialism can be of significant service as an underlying ontology of IoT. It is able to provide a coherent basis for a number of categories beyond those few with which it has a strong resonance. Unsurprisingly, the distinguishing character of essentialist ontology of IoT which emerges from the discussion above is its tendency to essentialise, to speak of things in terms of their essences. This makes essentialism more powerful when dealing with the general character of things than when dealing with their specifics. After all, while it seems that one could plausibly investigate the "essential character" of IoT, the essential character of a particular standard or use case would necessarily be of very narrow interest.

I will now move from the question of what an essentialist ontology of IoT might look like to the question of why such an ontology might be employed, and what work it might do.

The totalising, "overmining" tendencies of essentialist ontology make it very apt for certain purposes. In particular, such an ontology enables IoT to be grasped as a whole, to be dealt with as a single thing. It was noted above (see *Section 5.2.1: IoT as Artefact*) that artefact-based ontology also produces a kind of unity: over time multiple planned or conjectured artefacts are replaced by a single physically instantiated artefact. However, the instantiated artefact, though unitary, may be so complex that it may be impossible to apprehend in its entirety. This is especially true for artefacts of the scale and heterogeneity ascribed to IoT.

By contrast, to grasp the essential identity of IoT does not require one to grapple with the near-infinite complications of IoT's efflorescence into the world. By implication, the essence of IoT is simpler than IoT's many forms, though it lies behind these forms and is productive of them. In addition, while IoT as artefact will only evolve over time, the essence of IoT is already present to be understood and/or shaped.

An essentialist approach thus enables the ascription of fundamental and non-transient attributes to IoT—attributes which will be true regardless of time and place (though they might not yet be fully revealed). Thus if the essence of IoT is to be powerful, formidable and evasive (see

Section 3.2: Technological Essentialism) this is presumably already so, even though it might not yet be fully manifested. The essentialist approach therefore facilitates such universalising claims. One context where this is efficacious is in evoking a response to IoT as a whole. For example, essentialist ontology enables an emotional response to IoT as a whole, whether this is fear of the consequences of IoT, resignation to IoT's inevitability, or desire for IoT's benefits.

The non-transient nature of essential traits makes essentialism effective in tracing the path of IoT over time. Thus, for example, essentialism makes it possible to trace the continuity between pre-IoT concepts (e.g., ubicomp), IoT in its emerging state, and the ultimate, "realised" IoT, by ascribing to them a shared and defining essence.

Thus essentialism may play an effective instrumental role if deployed as an underlying ontology for IoT, despite its difficulty in accounting for IoT's more specific features.

6.6. IoT as Social Construction

This section will consider the usefulness of social constructivism as a foundational ontology for IoT. The analysis will build on the account of social constructivism given above (see *Section 3.3: Social constructivism*). In particular, the concepts of imaginaries and boundary objects will be considered as tools for exploring the nature of IoT.

As outlined *Section 6.2.3: Social Constructivism* above, social constructivism resonates strongly with the category of "IoT as IDEA". Social constructivism also has a (more limited) resonance with "IoT as SOCIAL ACTOR", "IoT as HUMAN ENDEAVOUR" and "IoT as TRAJECTORY". How well then can social constructivism act as a general ontological basis for IoT?

In a sense, social constructivism is able to account for all categories in a common manner, that is, as social constructions. This certainly appears to be a convincing claim with respect to the constitutive construction of the categories (remembering that "something is constitutively constructed if in defining it we must make reference to social factors"—Haslanger 1995, p. 98). From "IoT as THREAT(ENED)" to "IoT as FORCE" to "IoT as EXPERIENCE" none of the categories can be adequately explained without reference to their social context. For example, in "IoT as THREAT(ENED)", IoT is a threat to certain relevant social groups (e.g., auto workers) and is threatened by other (e.g., hackers).

The category which at first glance seems least dependent on social factors for its definition is "IoT as TECHNOLOGICAL ARTEFACT"—which seeks to define IoT primarily in technical terms. However, the SCOT program in the 1980s demonstrated the decisive social contribution to the definition of similar technical artefacts (see *Section 3.3.2: Social Construction of Technology* above).

The question of the causal construction of the categories appears more problematic (remembering that "something is causally constructed if social factors play a causal role in bringing it into existence or, to some substantial extent, in its being the way it is"; Haslanger 1995, p. 98).

The categories of "IoT as FORCE", "IoT as TRAJECTORY", and "IoT as SOCIAL ACTOR"—precisely those categories which are most resonant with technological essentialism—present a particular challenge to the notion of causal construction. Fundamental to these categories is technological determinism, that is, the claim of a causal role for IoT in driving change, including social change (see *Section 6.5: IoT as Technological Essence* above). It is difficult to square this claim of a causal role for IoT with any strong claim of social causation.

It is of course possible to account for these categories ("IoT as FORCE", "IoT as TRAJECTORY", and "IoT as SOCIAL ACTOR") in strict constructivist terms by arguing that they *seem* causal in their own right, but are *actually* socially caused, that is, that these categories are merely PERCEPTIONS (see *Section 6.3.2: Accounting for ontological perspectives* above). This, however, fails the test given above (see *Section 6.3.1: Underlying ontology: role, requirements, candidates*) that an underlying ontology needs to take the ontological perspectives of the texts seriously, without discounting perspectives or explaining them away. In the language of Object-Oriented Ontology, accounting for essentialist ontological claims as socially constructed is "undermining" (see *Section 3.6: Object-Oriented Ontology* above): accounting for one kind of thing as an emergent expression of a more fundamental reality composed of things of quite a different type.

One way to avoid this difficulty (i.e., the incompatibility of essentialist and constructivist ontological claims) is to appeal to a more nuanced form of socio-technical co-constitution, which allows for both society and technology to play a causal role (see above *Section 3.3.4: Criticisms of Constructivism* above). This is, however, not an entirely satisfactory strategy.

Firstly, it requires a dilution in the social constructivist ontology which this section is evaluating as an ontological basis for IoT. Secondly, it does not do full justice to the strength of the causal claims for technological determinism which are found in references to “IoT as FORCE”, “IoT as TRAJECTORY”, and “IoT as SOCIAL ACTOR”. It is thus a compromise which is not fully satisfactory from either a constructivist or essentialist standpoint.

Another category which represents a challenge to any strong view of social causation is that of “IoT as TECHNOLOGICAL ARTEFACT”. As acknowledged above, SCOT demonstrated that technological artefacts are socially constructed in a constitutive sense. However causal construction is rather a different matter. There are some aspects of the artefact which are difficult to account for simply as the result of social causes, and which appear to be directly constrained by the physicality of the artefact. For example, the protocols used for wireless transmission in IoT are constrained by the realities of battery life, bandwidth availability and the maximum transmission distance of different frequencies. Once again there appear to be two ways out of this dilemma. Firstly, one may seek to “undermine” the technological artefact by arguing that it is the outcome of a more fundamental constructivist ontology. This would presumably be the position of those aligned with the so-called Strong Programme initiated by David Bloor and others (Sismondo, 2010). Secondly one may move to a more nuanced co-constructivist position, arguing that society and the artefact co-construct each other. Once again neither of these positions seems completely satisfactory, as neither of them fully accounts for “IoT as TECHNOLOGICAL ARTEFACT” as an ontological category.

As noted above, a concept from the constructivist literature which appears to have particular promise in making sense of IoT is that of the boundary object (see *Section 3.3.5: Boundary Objects* above). In particular, the boundary object offers an explanation for how there can be a fundamental unity underlying multiple versions of the same object – which is similar to the project on which we are here embarked. The usefulness of the boundary object concepts in making sense of IoT will now be considered:

A boundary object resides at the intersection of different social worlds, each social world belonging to a different social group. The boundary object is nevertheless able to satisfy the informational requirements of each social group, and so to function in each social world. This is possible because boundary objects exist in different “versions”—a more generalised version which is shared between the social groups, and more detailed versions particular to each social group (Star & Griesemer 1989; see *Section 3.3.5: Boundary Objects* for further description).

The thesis thus far has highlighted the existence of different accounts of IoT. These accounts were described as different categories of ontological reference in *Chapter 4: Methodology* (see *Section 5.2: Inside the Empirically Derived Ontological Categories* above). The categories were then shown to resonate with different philosophical ontologies of technology (see *Section 6.2: Applying theoretical perspectives to attributed ontologies* above). It is thus reasonable to ask whether IoT is a boundary object, and whether these different accounts correspond to the different "versions" which a boundary object would have when encountered in different social spaces. For example, do the different categories appear only in different social spaces, and is there a weakly structured version of IoT which is independent of social space?

On initial consideration, this conjecture has some appeal. It could be hypothesised that each category of reference yields a different detailed version of IoT. Under this hypothesis, there would then be a number of detailed versions of IoT, each corresponding with a social space. Thus, depending on the social space where it is encountered, IoT would be:

- a TRAJECTORY
- a TECHNOLOGICAL ARTEFACT
- a FORCE
- an IDEA
- a BUSINESS OPPORTUNITY
- a CONTESTED TERM
- a SOCIAL ACTOR
- a THREAT (or something THREATENED)
- a series of USE CASES
- an ENCHANTED WORLD
- a HUMAN ENDEAVOUR
- an EXPERIENCE

The boundary object relies on the existence of different social groups, each group having its own version of the boundary object. In boundary object theory these groups have different ontological and epistemological commitments, and do not necessarily correspond with social groups identified via other means. Nevertheless, a correspondence of versions of IoT with social groups identified via other means would provide corroborating evidence for IoT's role as a boundary object.

It was suggested earlier (see *Section 5.1: Data survey analysis* above) that the readership of the texts would be drawn primarily from among four social groups—the general public, researchers, technology managers, and technology practitioners—with each group being primarily interested in certain types of articles, which are concentrated in particular sources. Thus, for example, the general public might be expected to be particularly interested in popular articles about IoT, which are often found in the New York Times. Researchers, on the other hand, might be expected to be comparatively more interested in articles on specific technical aspects of IoT, which are more often found in the academic literature. Technology managers, meanwhile, could be presumed to be more interested in practical technical guidance, such as is more typically found in Gartner. If different categories were associated with different sources (and hence social groups) this would (as mentioned) provide corroborating evidence for IoT's role as a boundary object. In fact, however, the categories do not strongly correlate with the sources—all the categories occur across all the sources (see *Section 5.4: Quantitative survey of categories* above). This does not mean that IoT is not a boundary object—but if it is, the relevant social groups are not those identified previously.

The generalised occurrence of the categories across the texts, often entangled with each other in a single passage, also suggests that, if IoT *is* a boundary object, the categories do not track the different versions of the boundary object. That is to say: it does not seem possible to divide up the texts into territories corresponding with social groups in such a way that the version of IoT found in each territory contains only a limited and distinctive set of categories. It is possible instead that the "generalised" version of the boundary object contains all the categories of reference. Different "specialised" versions are then distinguished by which categories are articulated in greater depth. In this scenario, "everyone's" IoT is a FORCE, an IDEA, a TECHNOLOGICAL ARTEFACT, a USE CASE, a BUSINESS OPPORTUNITY and so on. However, in some versions, the technical aspects of IoT are articulated in great depth, while the other categories remain undeveloped, a passing reference in a text's introduction. In other texts, it is the various use cases and applications of IoT which are emphasised, while the technical aspects appear only in simplified terms. The difference between different versions of IoT would thus be represented not by which categories occur in texts, but which categories are emphasised. This distinction would not be detected by the method employed (see *Section 4.3: Method*) above, which does not distinguish between a simple reference to a category and a lengthy and detailed exposition of that category.

“IoT as boundary object” is an intuitively appealing explanation for the way in IoT functions across multiple sources, audiences and article type, allowing communication and co-operation between groups with differing different ontological and epistemological commitments. It accounts for how IoT can be represented in strikingly different contexts – such as a popular article in the New York Times, a business advisory in Gartner, and a lengthy piece of technical analysis in an academic journal—while at the same time retaining an underlying unity as a topic of discourse. This explanation does not, however, a key aspect of IoT’s being: it does not address the fact that IoT is encountered as ontological multiple not only when considered across multiple discourses, but even within a single discourse. Within even a single paragraph, IoT may be described as a compound of multiple categories, resonating with multiple diverse ontological theories. Take, for example, the passages analysed in *Section*

Negotiating multiple categories above, in which up to seven categories are referenced within a single passage.

There is a second way in which the account which the theory of boundary objects can render of the ontology of IoT is somewhat less than satisfactory. As a constructivist theory, an explanation in terms of boundary objects is ultimately grounded in the social: the attributes of the boundary object are ultimately social constructions. This is less than satisfactory in the sense that it undermines those attributes of the IoT boundary object which claim a non-social origin. For example, if one of the IoT boundary object’s attributes is to be a force, then to explain the boundary object itself as a social construction, is ultimately to undermine its force-like nature. For a constructivist, it is satisfactory to say (following boundary object theory) that IoT is a force in certain territories by virtue of the ontological commitments of a certain social group. This, however, is unlikely to satisfy those protagonists for whom IoT is essentially and always a force.

I will now consider the question of the utility of a constructivist ontology for IoT: why it might be employed, and what it might be used to accomplish.

As noted above, a key feature of the constructivist account is interpretive flexibility—that social groups may differ in their interpretation of the same technological object. Opening this space for ambiguity allows different possibilities for IoT to be considered and discussed, without the need for immediate closure and resolution. This is in contrast to an artefact-based ontology (see *6.4: IoT as Artefact* above) which assumes that the competing views about IoT ultimately “cash out” in a single physical and functional artefact, that is, that at a given point in time there only *is* one IoT. This is the case even the artefact is fragmented or regionalised, that is, different in different places, such as in different countries, industries or organisations.

The constructivist account also permits the outcome of IoT to be indeterminate – a constructivist ontology of IoT is compatible with IoT becoming an important global phenomenon or receding into insignificance. This is in contrast, for example, with the assumptions required for an essentialist ontology of IoT (see *Section 6.5: IoT as Technological Essence* above). An essentialist account must assume that IoT has an essence (even if this is identical with the essence of Technology) and that this essence has certain characteristics, e.g., powerfulness, pervasiveness. Thus the essentialist account assumes a degree of "pre-destination"—that IoT will follow a pre-ordained trajectory.

Constructivist ontology is thus most useful in helping to articulate the ambiguities, contingencies and emerging possibilities of IoT. By articulating IoT as something contingent and available to be shaped, the constructivist ontology creates opportunities for the protagonist to influence and shape IoT, in a way that is not possible for protagonists of artefact-based or essentialist ontologies.

On the other hand, constructivist ontology is less efficacious when grappling with the mass of hard technical detail associated with IoT. For example, a constructivist platform can explain debates about architectural layering models for IoT (see *Section 5.2.1: IoT as ARTEFACT* IoT as) but is of limited use when attempting to enter into those debates. Equally, constructivist ontology is of limited assistance when attempting to draw totalising conclusions about the nature and direction of IoT as a whole. Indeed constructivist ontology tends to undercut any such claims by associating them with particular social groups and rejecting universal claims in the name of interpretive flexibility.

6.7. IoT as Phenomenon

In this section, I will consider to what extent postphenomenology is able to provide a viable underlying ontology for IoT.

The category with which the phenomenological account of IoT most resonates is "IoT as EXPERIENCE" (*Section 6.2.4 above: Postphenomenology* above), and this is the least common category (see *Section 5.2: Inside the Empirically Derived Ontological Categories* above).

When postphenomenology was introduced (*Section 3.5: Postphenomenology*) it was distinguished from classic phenomenology—and in particular the essentialist phenomenology of Heidegger (which arguably lies closer to essentialism than to postphenomenology). Most references to "IoT as EXPERIENCE" are not sufficiently clear or detailed enough to advise on this distinction: they could equally well point to either a phenomenological or postphenomenological perspective.

Postphenomenology is also somewhat resonant with "IOT as ENCHANTED WORLD". After all, "IoT as ENCHANTED WORLD" refers to a particular kind of technologically-mediated experience—the experience of the world as being populated with seemingly magical beings,

"IoT as EXPERIENCE" and "IOT as ENCHANTED WORLD" are the only two categories which resonated with postphenomenology, in the sense of being aligned with, and easily accounted for by, postphenomenology. Postphenomenology thus has only a limited resonance with the categories drawn from the texts. How well then can postphenomenology serve as an underlying ontology for IoT? Postphenomenology takes as fundamental the experiential interrelation between humans and technology, holding that humans and technology are co-constitutive of each other and of the world (Ihde, 2009). Thus for postphenomenology to function as the underlying ontology of IoT, postphenomenology must presumably account for the categories in terms of how they arise from this co-constitution.

As outlined in *Section 3.5: Postphenomenology* above, Ihde (2003; 2009) has described four different modalities of human-technology relations: embodiment relations, hermeneutic relations, alterity relations and background relations.

In relating the categories to these modalities of relation, two levels of relation need to be taken into account. The first of these is the relation that exists between the text itself (the authorial perspective) and IoT. The second is the relation that the text posits to exist between people and IoT.

It seems that the first of these (the text → IoT relation) must necessarily be one of alterity. By making an ontological reference to IoT in a text the text is necessarily positing IoT as an "other". It must be noted that these references are not the type of alterity relation most frequently cited. More commonly, the examples given of alterity relations are relations with video games and robotic toys which absorb the attention without referencing the world beyond (e.g., Selinger, 2006; Introna, 2017). Nevertheless, textual references to IoT as an ontological entity have, “the form I-technology-[world], indicating that the world withdraws into the background and technology emerges as a focal entity” (Introna, 2017). It thus seems reasonable to conclude that they are alterity relations.

The exception is the category of “IoT as CONTESTED TERM”: References in the category of “IoT as CONTESTED TERM” do not commit to the existence of IoT, and may thus do not constitute relations to IoT.

The fact that all most all textual references fit within the single modality of alterity is itself a useful comment on the method employed in this thesis. It highlights that a text-based investigation of IoT cannot exhaust the topic because it is limited to exploring a single mode of relation to IoT—that of describing IoT as other. In practice, people will relate to IoT in a richer and more diverse set of ways (e.g., by designing it or by using it, by enjoying its benefits or by losing their employment because of it). To fully grasp the ontology of IoT would require additional investigation of these modes of relation.

What then can be said about the second class of relations mentioned above, that is, the relation that the text posits to exist between people and IoT?

Once again, most of the categories identified engage with IoT as “other”, and thus fall under the broad heading of alterity relations: relations is which technology is experienced as, “a being that is otherwise, different from me, technology-as-other” (Introna, 2017).

I take the following categories to fit unambiguously into the category of alterity:

- IoT as TRAJECTORY
- IoT as ARTEFACT
- IoT as FORCE
- IoT as IDEA
- IoT as SOCIAL ACTOR
- IoT as THREAT
- IoT as HUMAN ENDEAVOUR
- IoT as BUSINESS OPPORTUNITY

In each of these categories, people and society are described as encountering IoT as “other”. Take, for example, “IoT as FORCE”. In this category, IoT is described as an impersonal force, with an independent existence. Thus references in this category describe people’s relation to

IoT as having "the form I-technology-[world], indicating that the world withdraws into the background and technology emerges as a focal entity" (Introna, 2017, sec. 2.4), and are thus alterity relations.

However, not all the relations described by the categories are alterity relations:

- "IoT as CONTESTED TERM", as explained above, does not acknowledge IoT as existing beyond the text, and does not, therefore, posit any relation to exist between people and IoT in the world beyond the text.
- In the category of "IoT as EXPERIENCE" (as noted in *Section 5.2.12: IoT as EXPERIENCE* above) two different sorts of experience are suggested. The first is that IoT will recede into the background of experience. This would fit the into Ihde's grouping of *background* relations. In background relations technology plays a (potentially powerful) role in shaping the world of experience, but is not, "is not directly implicated in a conscious process of engagement on the part of the human actor" (Introna, 2017). Other references to "IoT as EXPERIENCE", however, suggest that IoT will be prominent in everyday experience as digital agents taking a leading role in helping us order and run our lives. These references have much in common with "IoT as ENCHANTED WORLD" which I will now explore.
- In the category of "IoT as ENCHANTED WORLD", IoT becomes a foreground feature of day-to-day experience, as everyday objects acquire seemingly magical properties. As noted in *Section 5.2.10: IoT as ENCHANTED WORLD* above, most of these references focus on autonomous objects—objects which are able to act independently, and in a seemingly intelligent manner. Engagement with such objects will be engagement with IoT as "other" and will consequently fit the description of alterity relations. However, "IoT as ENCHANTED WORLD" includes other forms of relations too:
    - Some of the things described in this category are designed primarily to convey information about the world, rather than to act independently. For example, there is the umbrella the handle of which lights up when rain is forecast (Green, 2014). These things engage people in *hermeneutic* relations, in which "the technology functions as an immediate referent to something beyond itself" (Introna, 2017). In the example of the umbrella, what is encountered or grasped

is not the changed colour of the umbrella handle, but the onset of inclement weather to which it points.

  - "IoT as ENCHANTED WORLD" also includes examples of people's experience being subsumed into IoT: a vision in which, "humans will be completely immersed in the world of technology, leading to the so-called Immersed human" (Borgia, 2014, p. 2). I take such relations to be examples of what Ihde termed *embodiment* relations, in which "technology is taken as the very medium of subjective perceptual experience of the world" (Introna, 2017). Take, for example, the case described in *Section 5.2.10: IoT as ENCHANTED WORLD* above in which a community of people use mobile phones to take pictures of issues with urban infrastructure (e.g., potholes, graffiti), effectively operating as IoT sensors for local authorities. In this case, the subjective experience is (presumably) one of immersion in IoT, of being a component of IoT.

- In the category of "IoT as USE CASE", examples can also be found of people engaging in background, embodiment, hermeneutic and alterity relations with IoT. For instance, the examples described in the paragraphs above (the paragraphs dealing with "IoT as EXPERIENCE" and "IoT as ENCHANTED WORLD") may also be found in references to "IoT as USE CASE". The difference is that when these are referred to in the context of "IoT as USE CASE" the focus is *how* these outcomes were achieved (e.g., how the "alerting umbrella" was designed and built) whereas in the context of "IoT as EXPERIENCE" and "IoT as ENCHANTED WORLD" the focus is on how these are experienced (e.g., what it is like—or would be like—to own an alerting umbrella).

In summary, even the simplified version of postphenomenology considered here offers a conceptual framework which can give an account of the various categories of ontological reference to IoT found in the texts. Indeed, postphenomenology is able to provide significant insights into the experiential relations formed with IoT, and how these may be classed, grouped and understood.

There is, however, a limitation to the account which postphenomenology provides of the categories of ontological reference. This limitation is that postphenomenology does not account for these categories as ontological in themselves. For example, in the texts, references of the category "IoT as ARTEFACT" refer to IoT as a technological artefact. Such references are congruent with artefact-based ontology, which regards technological artefacts as ontologically basic. Postphenomenology, however, regards the technological artefact as a product of alterity relations, relations which precede and co-constitute the observer and the technological artefact. This example may be repeated for most other categories. Indeed, only those categories resonant with postphenomenology—"IoT as EXPERIENCE" and "IoT as ENCHANTED WORLD"—appear capable of ontological self-sufficiency when viewed from the perspective of postphenomenology. The other categories all emerge only from more basic co-constitutive relations between observer and technology. In Object-Oriented Ontology terms this is described as "undermining" (see *Section 3.6: Object-Oriented Ontology* above): regarding a thing as an emergent expression of a more fundamental reality: in this case, a fundamental reality composed of observer/technology/world relations of various types.

6.8. IoT as System of Relations

In this section I will consider the viability of relationist underlying ontology for IoT. In particular, I will reflect on the applicability of Annemarie Mol's theory of multiple ontologies as developed in "The Body Multiple" (Mol, 2002) .

As previously discussed (see *Section 6.2.5: Relationism* above) relationist ontology has only a limited resonance with the categories derived in *Chapter 4: Methodology*. In particular, relationist ontology has some resonance with:

- "IoT as ENCHANTED WORLD", in which IoT will be realised in an apparently magical world filled with intelligent objects.
- "IoT as SOCIAL ACTOR" in which IoT is seen as exercising social agency, shaping and being shaped by other social actors.

Both these resonances may be described as hermeneutic rather than direct: the references in question do not overtly espouse relationism, the resonance is rendered visible only through interpretation (Mol, 2002).

What are the implications of this limited resonance with the texts themselves for the viability of relationism as a unifying ontology for IoT? On my reading, this lack of resonance can be an advantage as well as a weakness: by not being strongly aligned (resonant) with any particular categories, the relationist account also avoids strong dissonance (see *Section 6.2: Applying theoretical perspectives to attributed ontologies* above) with any categories. This is in contrast with the artefact-oriented, constructivist, essentialist and postphenomenological accounts, where strong resonance with some categories is offset by dissonance with others. For example:

(1) The ease with which essentialism accounts for IoT as a single unified force or trajectory is offset by its limitations in accounting for the complicated topology of IoT use cases. In this case, strength in dealing with the general is correlated with a comparative lack of facility in dealing with the particular.
(2) Constructivism's strength in explaining the complexities of "IoT as IDEA" is offset by the comparative difficulty it experiences in fully accounting for "IoT as ARTEFACT". In this case, strength in dealing with the conceptual is correlated with a comparative lack of facility in dealing with the concrete.

Relationism can account for all the categories in a consistent manner, as emergent patterns in a system of relations. This can be achieved by describing IoT as an Actor-Network, and positioning the categories as a partial list of the heterogeneous actors in this network. Thus the actors in this network will include IoT as:

- a TRAJECTORY
- a TECHNOLOGICAL ARTEFACT
- a FORCE
- an IDEA
- a BUSINESS OPPORTUNITY
- a CONTESTED TERM
- a SOCIAL ACTOR
- a THREAT (or something THREATENED)
- a series of USE CASES
- an ENCHANTED WORLD
- a HUMAN ENDEAVOUR
- an EXPERIENCE

In such an ontology, the categories are not isolated from each other, nor are they irreconcilable. Instead, they are locked together in a state of dynamic tension in which they are defined by the relations that they form with each other and with other actors. Work is required to build and maintain this network—this is the kind of work undertaken by the texts (and, indeed, by this thesis). The kind of tensions described in the paragraphs above—tensions between the general and the particular, tensions between the conceptual and concrete—animate this network and inform its ongoing growth and development. None of the individual actors is the "real" IoT. Instead, IoT is the totality of the actors and the network which defines them and in which they act.

In many ways this is a compelling account of IoT, explaining as it does how ontologically heterogeneous categories can co-exist, interact and evolve over time. It also explains how conflicts and tensions between categories is not problematic but fundamental to the existence of the network and hence of IoT.

There are, however, limitations to the persuasiveness of this account at an ontological level.

In particular, there is the difficulty common to the ontologies already considered, that is, artefact-orientation, essentialism, constructivism and postphenomenology: the fact that their ability to account for ontologically heterogeneous beings relies on their ability to render these beings ontologically homogenous. In Object-Oriented Ontological terms, this is process is described as undermining and/or overmining. Thus, for example, constructivism (see *Section 6.6: IoT as Social Construction* above) can account for any being so long as it is first accepted that all these beings are social constructions. This criticism of ANT's tendency to homogenise ontologies is acknowledged by STS practitioners (e.g., Law) and has been discussed in *Section 3.4.6: Criticisms of relationism* above.

ANT is quite subtle in this regard as ANT networks are accepted as ontologically diverse; bringing together social, technological, conceptual, textual and other actors on a level ontological playing field. However, there is a price to be paid for admission to this game, and that price is to accept that actors are fully revealed by their relations—actors may not retain a "hidden essence" of any kind (see *Section 3.4.6: Criticisms of relationism* above).

This requirement (for things to be defined by their relations) is problematic in two ways. Firstly, it involves an element of reductionism (or in Object-Oriented Ontology terms, undermining): there is a concern that categories are not present in ANT in their ontological form, but only in the "translated" form of systems of relations. This raises the (by now familiar) concern that the claims of the texts are not being taken entirely seriously, for example, that there is not really any essence underlying "IoT as FORCE", but only a conjunction of relations which give the impression of essence. Secondly, ANT's reliance on an ontology of relations exposes it to criticisms regarding the limitations of such an ontology, as discussed in *Section 3.4.6:*

Criticisms of relationism above. In particular, it has difficulty in accounting for the way actors are able to reveal new properties, and enter into new relationships. This is a significant difficulty when dealing with a phenomenon as protean as IoT.

There has, as previously discussed, been a significant interest in ontology within the STS discipline in the last 20 years (see *Section 2.2.4: The Ontological Turn in Science and Technology Studies (STS)* above). Central to this interest is the idea that objects are not discovered, but are enacted in practice. This idea has two important consequences. Firstly, it means that objects are created by practice, they do not pre-exist it. Secondly, it means that different kinds of practice—different "method assemblages"—will tend to create different objects. The relationship between these different objects is a complex one. To quote from Annemarie Mol's influential "The Body Multiple":

> Ontology-in-practice is multiple. Objects that are enacted cannot be aligned from small to big, from simple to complex. Their relations are the intricate ones that we find between practices. Instead of being piled up in a pyramid, they rather relate like the pages in a sketch book. Each new page may yield a different image, made with a different technique and in as far as a scale is recognizable, it may again, each time, be a different one. There is no fixed point of comparison. (Mol, 2002, p. 155)

To what extent are the ideas of "ontology-in-practice" relevant to the current thesis? The method employed in my investigation of IoT is rather different to that of Mol, and indeed to that of much "mainstream" of STS research (for discussion of the choice of method, see *Chapter 4: Research Question, Methodology and Method* above). In particular, the choice of a text-based investigation denies the researcher the intimate knowledge of local practices which are central to Mol's research. For this reason, the current project is less attuned (less attuned, that is, than a more practice-based investigation) to detect different objects generated by different local practices. Nevertheless, as laid out in *Chapter 5: Data Analysis* above, different objects—or at least different ontological features suggestive of different objects—have been encountered.

Ontology-in-practice suggests that different objects may arise through different practices. As noted already, this method of this thesis is based in textual analysis rather than the study of praxis. However, these texts must, of course, be created within the context of praxis; indeed the creation of texts is itself a form of praxis. In addition, different kinds of text arise from different kinds of practice: a New York Times article originates in the praxis of reportage, a

Gartner article originates in the praxis of business consulting, and an academic article originates in the praxis of academic research. Ontology-in-practice would suggest that these different forms of praxis might well enact "different IoTs".

It is certainly true that the "flavour" of IoT is different between different kinds of text. That is to say that the sense or impression of IoT one gets from a short popular piece (e.g., Green, 2014) is different to that which one gets from a lengthy academic survey of IoT (e.g., Atzori et al., 2010) which is different again from that which emerges from a business survey of emerging trends (e.g., Jones, 2017) or from an in-depth discussion of particular technical components and standards (Yan, Zhang & Vasilakos, 2014). However, when considered at the level of ontology, the striking feature is the commonality of categories across periods and sources (see *Section 5.4: Quantitative survey of categories* above, a similar point was made in *Section 6.6: IoT as Social Construction*). This suggests that the ontological complexity or multiplicity characteristic of IoT is largely independent of the kind of praxis employed—or, at least, is enacted by multiple forms of practice. This is, nevertheless, consistent with the idea that different aspects of this ontological multiplicity are more fully articulated or enacted in different forms of praxis. It would, then, be this difference in articulation which accounts for the different "flavours" of IoT described above, rather than the existence of multiple of ontologically distinct IoT's.

To put this in terms of Mol's "sketchbook" analogy above: while the sketches are indeed different, a few key features – the red front door, the old pine tree, the moss-covered bench—occur together in sketch after sketch. Or, in terms of the Jain story of the elephant (see *Section 6.3.1: Underlying ontology: role, requirements, candidates* above): instead of reporting one feature each, each of the blind men reports that the elephant is like a pillar, a rope and a tree branch all at the same time.

In summary then, ontology-in-practice is useful in dealing with the multiplicity of IoT, but cannot provide a convincing account of certain core aspects of multiplicity. In addition, because of its grounding in relationism, ontology-in-practice can be presumed to inherit the ontological weaknesses of relationism outlined above:

(1) The tendency to explain all beings as arising from an ontologically homogenous base of relations (described in this case, as the relations arising within praxis).
(2) The difficulty in explaining how things are able to change and enter into new relations.

The relationist account of IoT was not found to be much used in the literature reviewed; in fact, none of the texts considered employed an explicitly relationist account of IoT. This is in contrast to the ontologies already discussed in this chapter—artefact-oriented, constructivist, essentialist and postphenomenological—which were all, to varying extents, explicitly employed. One could hypothesise that the "even-handed" approach of relationism—which avoids privileging any one particular actor, point of view, or version of events—is of limited utility for those working within the overall IoT "project"; it is more like to employed by those studying IoT "from the outside".

A final observation is that this thesis also constitutes praxis of a sort, albeit not of the localised sort most commonly studied by STS. Thus, from an ontology-in-practice standpoint, the ontolog(ies) of IoT as discussed in this and preceding chapters are not pre-existing objects which have been discovered, but rather objects which have been contracted by my praxis. The same is true of the ontolog(ies) of arteriosclerosis studied/constructed by Mol. This places fresh emphasis on the importance of taking our interlocutors seriously—trying, as far as possible, to account for their ontologies in their terms rather than translating them into ours.

6.9. IoT as Inexhaustible Object

In this section I will consider the extent to which Object-Oriented Ontology can provide an underlying ontology for IoT. Compared to the philosophical ontologies which have already been considered, there are two particular challenges to doing this.

Firstly, there are no obvious resonances between Object-Oriented Ontology and the texts under consideration. Object-Oriented Ontology is not referenced explicitly, nor were implicit references discovered. This makes building an ontological foundation for IoT out of Object-Oriented Ontology an inherently speculative project. The speculative nature of the project does not make it invalid—indeed it is consistent with the speculative realism from which Object-Oriented Ontology springs—but it does suggest that caution is required to avoid straying too far from the evidence of the texts.

Secondly, Object-Oriented Ontology is a general ontology rather than a regional ontology of technology (see *3.6: Object-Oriented Ontology* above). All the philosophical ontologies considered up to this point have been either specifically directed towards technology (artefact-based ontology, technological essentialism) or have had substantial bodies of literature devoted to applying them to technology (SCOT in the case of constructivism, ANT (and much of STS) in the case of relationism, postphenomenology in the case of phenomenology). While Object-Oriented Ontology authors have displayed significant interest in technology, (see, for example, Bogost 2012) there is no established literature or discipline relating Object-Oriented Ontology to technology on the scale of SCOT, ANT or postphenomenology. The absence of such an established body of knowledge or practice again means that significant interpretative effort is required to understand IoT in terms of Object-Oriented Ontology.

These two challenges have suggested that conceiving an Object-Oriented Ontology-based underlying ontology for IoT is necessarily a speculative undertaking. I will thus commence by considering what form such an ontology could take. In doing this, it is worth considering three key tenets of Object-Oriented Ontology as discussed in Section *3.6.1: An outline of* above, and their implications for an ontology of IoT:

(i) Rejection of anthropocentrism and correlationism

Object-Oriented Ontology accepts the reality of the external world, and does not privilege the human perspective above any other point of view (Bryant, 2010a). As a consequence, an Object-Oriented Ontology-based ontology of IoT would accept IoT as a real being external to human experience, and would not seek to ground IoT in human experience. It would not privilege the human-centred relations (e.g., relations between human and things) above non-human relations (e.g., relations between things and things).

(ii) Rejection of over and undermining

Object-Oriented Ontology argues for the reality of objects of every scale and type, from atoms and galaxies to football teams and fictional characters. Further, Object-Oriented Ontology suggests that all ontology is "flat"—that all objects at all levels are equally real. An Object-Oriented Ontology-based ontology of IoT would thus accord equal reality to the multiple levels and scales of IoT (Harman, 2016).

(iii) Unknowability of objects

Object-Oriented Ontology argues that objects are not exhausted by their relations: that they have an "inner" reality that cannot be fully known (Bryant, 2011). Thus an Object-Oriented Ontology-based IoT would always elude our full knowledge: it would have an inexhaustible inner essence which would enable IoT to continually evolve, displaying new properties and entering into new relations.

Point (ii) requires some further discussion. I take Object-Oriented Ontology's tolerance of ontological diversity to be sufficient to admit the different IoT's described in the categories of reference identified in *Chapter 4: Methodology*. Thus within an Object-Oriented Ontology-based ontology there could an "IoT as ARTEFACT", an "IoT as ESSENCE" and "IoT as IDEA" and so on. Or, to take ontological unification a stage further, IoT could be a single (though complex and baffling) object which is simultaneously a technological artefact, a force, an idea, a business opportunity, a contested term, a social actor, something both threatening and threatened, something manifested in many contexts of use, a human endeavour and an experience. Indeed Object-Oriented Ontology would suggest that IoT is capable of an inexhaustible multiplicity of manifestations. In terms of philosophical ontologies, such an object could be (inter alia) an artefact, an essence, a social construct, a phenomenon, and a system of relations.

The flexible nature of Object-Oriented Ontology is thus very accommodating, allowing the different categories and perspectives can be reconciled into a single object, albeit a complex and mysterious one. Indeed this mysteriousness is not specific to this particular object, but is a feature of Object-Oriented Ontology in general, which requires us to concede the essential unknowability of objects.

One advantage of an Object-Oriented Ontology explanation for IoT is thus its acceptance of ontological diversity and heterogeneity. Conversely, Object-Oriented Ontology is difficult to reconcile with a claim of ontological exclusivity. For example, it is hard to reconcile an Object-Oriented Ontology-based ontology for IoT with the claim that IoT is, ultimately, *only* an artefact, an idea, an experience, an essence or a system of relations. Such an object—for example, an IoT which is *only* an artefact—are not incompatible with Object-Oriented Ontology. Object-Oriented Ontology rejects essentialism on the grounds that essentialism claims some "ultimate" knowledge of a an object—ultimate knowledge which would contradict Object-Oriented Ontology's view of objects as being ultimately unknowable (Morton, 2013b). However, such ontologically homogenous versions of IoT are, , not required in an underlying ontology for IoT because claims of ontological exclusivity are not encountered in the texts themselves As noted above (see *Section 6.2: Applying theoretical perspectives to attributed* ontologies) ontic claims in the texts are generally of the form "IoT is an X" rather than "IoT is *only* an X" or "IoT is *not* a Y" (where X and Y are types of being). Instead, claims of ontological exclusivity are introduced by the various philosophical ontologies which tend to stress a particular ontological feature as being foundational (see *Section 6.2.1: Artefact-centricity* to *Section 6.2.5: Relationism* above).

A possible further criticism of the Object-Oriented Ontology position is that of "ontological exoticism"—of introducing a kind of being which is not found anywhere in the texts themselves. Occam's Razor suggests that such a procedure should be avoided *wherever possible*. This is, however, no barrier to introducing such new elements when, without them, a satisfactory explanation of the observed phenomena cannot be given. To build on the Jain story of the elephant given above (see *Section 6.3.1: Underlying ontology: role, requirements, candidates*) the elephant is something different (and extends beyond) the features encountered by each of the blind men. By contrast, an explanation seeking to found the elephant's being only in the observed features—perhaps by explaining that the elephant is really ultimately made up only of trunks which can seem like legs or ears when rigid or flattened (or when touched In a certain way)—would be less convincing.

As previously discussed (see *Section 3.6.2: Varieties of* above) Timothy Morton (2013) has used Object-Oriented Ontology as a basis to describe a class of beings he terms "hyperobjects"—"genuine nonhuman objects that are not simply the products of a human gaze" (Morton, 2013a, p. 199) and which are, "massively distributed in time and space relative to humans" (Morton, 2013a, p. 1). The criteria presented for hyperobjects are not completely crisp, leading some critics to charge that the concept of "hyperobject" is simply too vague and eclectic to do any useful work (Heise, 2014). Nevertheless, Morton does present five important attributes viz. viscosity, nonlocality, temporal undulation, phasing, and interobjectivity, and it is worth considering the extent to which IoT may be said to exhibit these characteristics.

- *Viscosity*

  Hyperobjects are viscous because we experience them with immediacy from which we cannot withdraw—"we find ourselves caught in them" (Morton, 2013a, p. 31)—"hyperobjects are here, right here in my social and experiential space" (Morton, 2013a, p. 29). For IoT, this immediacy can be seen most clearly when considering "IoT as ENCHANTED WORLD"—in which humans are absorbed into the sensory experience of IoT, and in fact become part of IoT as "citizen sensors" (see *Section 5.2.10: IoT as ENCHANTED WORLD* above).

- *Nonlocality*

  Nonlocality means that hyperobjects "do not manifest at a specific time and place but rather are stretched out in such a way as to challenge the idea that a thing must occupy a specific place and time" (Morton, 2012)—"in other words, any 'local manifestation' of a hyperobject is not directly the hyperobject " (Morton, 2013a, p. 10). It is easy to relate to the "nonlocality' of IoT, in the sense that it is a globally manifested idea, force and trajectory but yet finds its most concrete manifestation in localised and locale-dependent use cases (*Section 5.2.9: IoT as CONTEXT OF USE* above).

- *Temporal undulation*

  Hyperobjects, "envelop us, yet they are so massively distributed in time that they seem to taper off, like a long street stretched into the distance" (Morton, 2013a, p. 49). "Harman writes that, because objects withdraw irreducibly, you can't even get closer to objects. This becomes clearer as we enter the ecological crisis—'Has it started yet? How far in are we?' This anxiety is a symptom of the emergence of hyperobjects" (Morton, 2013a, p. 50). This description of temporal undulation is very reminiscent of "IoT as FORCE" (see *Section 5.2.2: IoT as TRAJECTORY* above). It will be recalled that there is tension and ambiguity in the literature as the temporal status of IoT: Is IoT something which has already been with us, in one form or another, for a long time? Is IoT a recent creation? Is it something which in the process of being realised, and if so when (if ever) will this process conclude? Or is it a horizon which moves ahead of us into the future? This temporal uncertainty has much in common with Morton's notion of temporal undulation. Morton's interpretation of this uncertainty is that, "since objects don't float in an infinite void, every entity has its own time, both in a physical and in a deep ontological sense" (Morton, 2013a, p. 58). Thus IoT is difficult to make sense of in our framework of time because it carries with it its own temporality.

- *Phasing*

  "Hyperobjects are phased: they occupy a high-dimensional phase space that makes them impossible to see as a whole on a regular three-dimensional human-scale basis. We can only see pieces of hyperobjects at a time. The reason why they appear nonlocal and temporally foreshortened is precisely because of this transdimensional quality" (Morton, 2013a, p. 60). The data analysis (see *Section 5.2: Inside the Empirically*

Derived Ontological Categories above) has demonstrated the complex shape of IoT of IoT across both space and time, which allow it to be apprehended only in part. For my own part I remain sceptical that a complex distribution over space and time can *only* be accounted for in terms of higher dimensionality. The complexity of IoT is, nevertheless, certainly consistent with Morton's account of phasing.

- *Interobjectivity*

  Hyperobjects "consist, of, yet are not reducible to, interactions between a large number of entities" (Morton, 2012). Hyperobjects thus disclose "interobjectivity", which is intersubjectivity ("a shared space in which human meaning resonates" (Morton, 2013a, p. 69) much expanded to embrace non-humans as well as humans (Morton, 2013a). The resonance with IoT, with its myriad connections which blur the line between humans and things, is striking.

IoT thus exhibits all the main characteristics of hyperobjects as described by Morton viz. viscosity, nonlocality, temporal undulation, phasing and interobjectivity. Even allowing for some blurriness in Morton's definition, this suggests that IoT is akin to a hyperobject.

Another useful concept is that of the tran-scalar, a trans-scalar entity being one which is, "capable of moving across otherwise discrete scales, such as small to large, singular to collective; past, present and future" (Bradshaw, 2017, p.2). This is similar to the ideas of non-locality, temporal undulation and phasing described above. It is helpful to understand IoT as being a trans-scalar entity, in that it exists at different spatial, temporal and conceptual granularities. Thus the view at a single level of granularity is necessarily incomplete.

In summary, then, Object-Oriented Ontology is able to provide a rather successful underlying ontology for IoT, preserving the ontological heterogeneity found in the texts, while providing a level of consistency and coherence. The proviso is that a rather exotic object be admitted to the ontology.

Each of the six philosophical ontologies has now been considered as an underlying ontology for IoT. This discussion has helped us to better understand the challenges and demands facing such an ontology. It has also highlighted the different ways that the various philosophical ontologies are able to meet these challenges and demands, with each revealing characteristic strengths and weaknesses.

The next chapter will bring this discussion together with the summary of *Chapter 5: Data Analysis*. I will then derive some overall conclusions in answer to the research question defined in *Chapter 4: Research Question, Methodology and Method* above. This will be followed by a discussion of some unanswered questions, and suggestions for future research.

7. Conclusions and directions for future research

In this, the final chapter of my thesis, I will first review some of the conclusions drawn in *Chapter 5: Data Analysis*, before summarising the points presented in *Chapter 6: Ontological Investigation*. Because the argument is somewhat complex, and spread over much of the thesis, I judged that it would be helpful to rehearse the main points in a condensed form. Leading on from this summary I will then draw conclusions which will directly address the research question, as formulated in *Section 4.1: Research Question*:

What does an ontological investigation of the Internet of Things, informed by prominent philosophical theories regarding the ontology of technology, reveal about the ontolog(ies) of the Internet of Things? Conversely what does such an investigation reveal about the philosophical technologies themselves?

To conclude I will outline the implications of my findings, before noting a few unanswered questions and suggesting possible directions for future research.

7.1. Conclusions

Chapter 5: Data Analysis considered a sample of influential IoT literature from an ontological standpoint. Ontological references to IoT—that is, references to what IoT is–were identified within this literature. These ontological references were identified from the texts themselves, without recourse to the philosophical theories of ontology considered in the literature review.

Significant ontic differences (i.e., differences in factual details) were found between references. For example, references differed as to the number of architectural layers which IoT has, or which standards are most important, or which use cases will predominate. Such differences are perhaps only to be expected when dealing which such a large corpus on a fairly recent topic. These ontic differences do not necessarily imply any ontological multiplicity, that is, different accounts of the factual details of IoT do not necessarily imply that IoT is more than one kind of thing. Indeed, different versions of factual details imply at least some degree of ontological consensus. For example, disagreements about standards and architectural layers require some agreement that IoT is the kind of being for which standards and architectural layers are important constituents.

The ontological references identified in the texts were then grouped and analysed. By grouping these references it was established that according to the literature in the sample, IoT is ontologically multiple, that is, that IoT is more than one kind of thing. In fact, it was shown that IoT was referred to in the literature as at least 12 different kinds of thing viz. a trajectory, a technological artefact, a force, an idea, a business opportunity, a contested term, a social actor, something threatened and threatening, a context of use, an enchanted world and a human endeavour. I say "at least" because a number of categories have been shown to be capable of further subdivision, and because some possible categories were rejected due to insufficient evidence (see *Section 5.3: Considering the categories* and *Section 5.2.13: Other possible categories*). In addition, the categories do not all have the same frequency or prominence in the texts. It is not claimed that lines between these categories are hard and fast, or that the categories are universal or unchangeable. Indeed the categories may be regarded as philosophically naïve in that they have emerged inductively from the texts, without any reference to philosophical theories of ontology Nevertheless, having analysed the corpus of texts on its own terms (i.e., without reference to philosophical theories of ontology) the impression of ontological multiplicity is unavoidable.

In addition, this ontological multiplicity occurs in a dense form: categories are found "entangled" with each other in single texts and indeed in single paragraphs and sentences (see *Section 5.5: Relationships between categories*). In addition, the categories were found to be fairly uniform with respect to both source and time period, with the same categories occurring across different periods and sources. It is thus difficult to separate out the categories, in order to parse out mutually distinct versions, for example, to attribute distinct sets of categories to distinct sources, authors, article-types or periods. Instead, IoT, in the literature, appears to be ontologically multiple at any point that is examined.

In the next step of the analysis, the categories were brought into dialogue with the six philosophical ontologies of technology described in the literature review (see *Chapter 6: Ontological Investigation*). Resonances were detected between the categories and the philosophical ontologies, in the sense that certain categories accorded very well with certain philosophical ontologies. However, the pattern derived was not orderly or comprehensive. For example, no philosophical ontology resonated with more than a third of categories, and there were categories which did not resonate with any philosophical ontology. Of the philosophical ontologies, only Object-Oriented Ontology did not resonate with any of the categories. In addition, it was notable that, while certain categories aligned naturally with certain philosophical ontologies, the categories did not, in themselves, exclude the possibility of other philosophical ontologies being valid.

The juxtaposition of categories with the philosophical ontologies served to emphasise the extent of the ontological multiplicity exhibited by IoT: not only is IoT different things In the literature, these things are sufficiently different that they can only be properly explained by recourse to different philosophical ontologies on the ontology of technology in general.

The first major conclusion of the thesis is thus that IoT, as it is found in the literature, is ontologically multiple. In other words, IoT, as it is found in the literature, exists in a number of different ways (see *Section 6.2.10: Analysis*). It would be possible to leave it at that, to conclude the analysis at this point. There is, however, something unsatisfactory with this account. It is as if we are told that what we are encountering is a snake, a leaf, a rope and a wall—and yet never get to see an elephant. We are left with the question, "*How* is IoT ontologically multiple?" We are left wondering whether there is not some deeper pattern or unity—some further ontological insight—which can help us make sense of ontological multiplicity.

To address this lingering question, the possibility of an *underlying* ontology was considered—the possibility that there is a deeper level of ontological explanation which provides a coherent account of the ontology multiplicity of IoT (see *Section 6.3: Underlying ontologies*).

Three criteria were set for an underlying ontology (see *Section 6.3.1: Underlying ontology: role, requirements, candidates*):

1. It must be an ontology—it must provide a coherent and convincing theory of being.
2. It must account for the observed categories: it must explain how IoT is what it is said to be in the texts. In particular, it should account for the ontological perspectives of the protagonists as ontological—rather than (for example) assuming the observers are simply mistaken.
3. It must be preferable (e.g., simpler, more plausible, or have greater explanatory power) than merely accepting all the individual perspectives collectively.

Each of the six philosophical ontologies of technology was considered in terms of its suitability as an underlying ontology (see *Section 6.4: IoT as Artefact* to *Section 6.8: IoT as System of Relations*). Because each of these constitutes a coherent ontology, each was considered to meet criterion (1). Indeed, as they represent the main streams of ontological thought about technology, these are the only candidates (or at least the most obvious candidates) capable of meeting criterion (1).

The first five philosophical theories considered were artefact-based ontology, technological essentialism, social constructivism, relationism and postphenomenology. Each of these was found to resonate with one or more of the categories (see *Section 6.2: Applying theoretical perspectives to attributed ontologies*). In addition, each of these was found to display a similar pattern of strengths and weaknesses when considered as an underlying ontology. Unsurprisingly, each ontology was strongest when accounting for those categories with which it most resonated. For example: artefact-based ontology can provide a very coherent account of IoT as an artefact; technological essentialism can well explain IoT as a force or trajectory; social constructivism can furnish a nuanced and insightful account of IoT as an idea … and so on.

It was, however, more difficult for these ontologies to account for the categories with which they do not resonate. (For example, essentialist theories account better for the broad sweep of IoT than for the details and nuances displayed by IoT in particular contexts of use.) In general, such an accounting could only be accomplished by translating the category in question into the ontology's own terms. This meant that, instead of accepting a category as ontological in its own right, the category must first be described either as the sum of constituent parts, or as being itself a constituent of some larger whole. These translations are what Object-Oriented Ontology describes as "undermining" and "overmining" respectively. As an example of the former: relationism can only account for IoT as a force not by accepting its forcefulness as something real in its own right, but rather by explaining forcefulness as the emergent product of relations between multiple actors. As an example of the latter, social constructivism can only account for IoT as an artefact not by accepting its "artefact-ness" as something real in its own right, but rather by explaining that it is produced as part of a project of social construction.

This difficulty in accepting the categories as ontological in themselves means that these five ontologies (viz. artefact-based ontology, technological essentialism, social constructivism, relationism and postphenomenology) are not able to fully meet the second criterion for underlying ontologies that was established above. The usefulness of these ontological approaches in dealing with IoT should nevertheless not be underestimated. Each of them enables IoT to be "handled" in a distinctive way which is particularly suited to certain purposes. For example, an artefact-based approach provides access to a rich array of vocabulary and tools which are invaluable in the construction of technical artefacts for IoT; an essentialist approach enables the overall direction and implications of IoT to be grasped in compelling terms (whether positive or negative) which enable support to be mobilised for or against the IoT initiative.

Two approaches to accounting for ontological multiplicity were also considered: boundary object theory, which arises from social constructivism (see *Section 6.6: IoT as Social Construction*), and ontology-in-practice, which arises from within the relationist tradition (see *Section 6.8: IoT as System of Relations*). Both of these approaches were found to be useful in explaining the different versions of IoT encountered in different texts. For example, one text may discuss selected technical features of IoT in comprehensive detail, with no consideration of its business application; another may thoroughly explicate IoT as a business tool, while treating its technical features in a summary and superficial manner. The difference between the versions in the two texts may be so great that the two accounts of IoT are very hard to reconcile. Both boundary object theory and ontology-in-practice are able to provide useful explanatory models in this regard.

In terms of boundary object theory, disparate versions of IoT are versions of the same labile object as it is encountered by different social groups. In terms of ontology-in-practice, disparate versions of IoT are different objects enacted by different modes of practice. However, neither of these approaches is useful in dealing with a key aspect of IoT's ontological multiplicity. This problematic aspect is that, while IoT is different in different places (e.g., in different texts), it is multiple *everywhere*; that is, it is ontologically multiple within the confines of a single text, or indeed within a single passage. This "dense" form of ontological multiplicity cannot be easily accounted for in terms either of different social groups or different modes of practice, as it is difficult to understand how these difference could manifest within space of a single text or paragraph. Thus, while both being helpful, neither boundary object theory nor ontology-in-practice delivers a full explanation of the ontological multiplicity of IoT.

In addition, boundary object theory and ontology-in-practice inherit the ontological assumptions of the theoretical systems in which they originate. Thus boundary object theory, arising from social constructivism, must ultimately account for the different versions of the IoT boundary object as being, not real in themselves, but rather social imaginaries, that is, socially constructed ideas. In a similar way ontology-in-practice, arising from relationism, must ultimately account for the different IoTs as being, not real in themselves, but rather as the product of praxis, that is, of a system of relations. Thus neither boundary object theory nor ontology-in-practice is able to fully meet the second criteria for an underlying ontology stated above viz. acceptance of the ontologies encountered in the texts as ontological. It follows that neither boundary object theory nor ontology-in-practice is fully satisfactory in providing an underlying ontology for IoT.

The final philosophical ontology to be considered as an underlying ontology for IoT was Object-Oriented Ontology (see *Section 6.9: IoT as Inexhaustible Object*). It will be recalled that Object-Oriented Ontology was the only one of the philosophical ontologies which did not resonate with any of the categories. This might, at first, appear to be a weakness of Object-Oriented Ontology. On closer analysis, however, it becomes clear that this lack of category-alignment increases the usefulness of Object-Oriented Ontology as an underlying ontology for IoT: Object-Oriented Ontology not only lacks strong resonance with any category, it also lacks strong dissonance with any category. This is in contrast to the other five philosophical ontologies, whose resonance with some categories contributes to their difficulty in accounting for others (e.g., artefact-based ontology is resonant with IoT as a technological artefact, but this makes it difficult for artefact-based ontology to *also* account for IoT as an idea).

As noted above, the ontologies previously considered must in general resort to some form of over-mining or undermining in order to account for those categories with which they do not resonate. The rejection of such overmining and undermining is axiomatic in Object-Oriented Ontology, which accepts all levels of reality as "equally real". Object-Oriented Ontology is thus able to accept all the categories as ontological, that is, as equally real. If we accept Object-Oriented Ontology as an underlying ontology for IoT we can accept that IoT really *is* a trajectory, a technological artefact, a force, an idea, a business opportunity, a contested term, a social actor, something threatened and threatening, a context of use, an enchanted world and a human endeavour. This is in contrast to the other ontologies considered, which require us to accept that IoT *is* some of these things, and *appears to be* others. Object-Oriented Ontology is thus the only one of the ontologies considered which meets the second criterion for underlying ontologies stated above viz. the ability to account for the categories *as ontological*.

The question then remains whether Object-Oriented Ontology as an underlying ontology for IoT satisfies the third criterion for underlying ontologies, namely that It must be preferable (e.g., simpler, more plausible, or have greater explanatory power) than simply accepting all the individual categories collectively.

My conclusion is that Object-Oriented Ontology meets this criterion on four grounds.

Firstly, the alternative (simply accepting all the individual categories collectively) is more problematic than it might at first appear. Although the categories can be accepted collectively, the same is not true of the philosophical ontologies. This is because, as discussed previously, each of the philosophical ontologies contains an element of foundationalism, of assuming that one part of being is ontologically prior to the others. This makes it impossible to be whole-heartedly committed to artefact-based ontology, technological essentialism, social constructivism, relationism and postphenomenology, all at the same time. Thus, while we may be able to accept all the categories as equally valid, we cannot do the same with all the philosophical ontologies which resonate with the categories (this is a consequence of the categories being more "naïve"—less thoroughly worked out—than the philosophical ontologies, which makes conflict between the categories less obviously problematic than conflict between the philosophical ontologies). It follows that, without an underlying ontology, we are left, not with a heterodox philosophical foundation for the multiplicity of IoT, but with no coherent philosophical foundation at all. The prospect of such a gulf in our understanding is an argument in favour of accepting the most plausible underlying ontology available to us.

Secondly, the existence of an underlying ontology provides an explanation for the relationship between the different categories. With Object-Oriented Ontology as an underlying ontology, the different categories may be understood as different aspects of the same object. Without it, we are hard-pressed to explain how the categories are related, or indeed why the categories continually recur in such close proximity to each other.

Thirdly, Object-Oriented Ontology as an underlying ontology helps to explain a key feature of IoT. It is axiomatic in Object-Oriented Ontology that any object is "inexhaustible"—that it has hidden attributes which can never be fully explicated, no matter how many relations the object enters into. For IoT this would mean that the categories are true of IoT but do not exhaust it. Further analysis of IoT could reveal further categories of reference, or further attributes of IoT could be exposed as IoT unfolds. This is a powerful and attractive feature of Object-Oriented Ontology given the contingence of the categories (e.g., on the text sample and research method adopted) and also the emerging nature of IoT. An Object-Oriented Ontology based ontology cannot only give an account of categories which were found, it can also provide assurance of being able to account for those categories which were missed, or which are yet to emerge.

Fourthly, the non-anthropocentric stance of Object-Oriented Ontology allows it to effectively account for a non-anthropocentric phenomenon such as IoT. IoT is non-anthropocentric because, as noted above, one of the characteristics of IoT is to de-centre humans from the internet, and to elide the difference between human-thing, thing-thing, and human-human relations.

In the final part of the analysis, IoT was compared with the key characteristics of a "hyperobject"—a type of object described by Object-Oriented Ontology theorist Timothy Morton (see *Section 6.9: IoT as Inexhaustible Object*). IoT was found to display the five main characteristics Morton claims of hyperobjects; namely viscosity, nonlocality, temporal undulation, phasing, and interobjectivity. IoT was also discussed as trans-scalar: existing at multiple levels temporal, spatial and conceptual granularity.

In conclusion, then, Object-Oriented Ontology emerged from the analysis as the single plausible candidate for an underlying ontology for IoT—the only one of the six philosophical ontologies which could meet the criteria set for an underlying ontology viz. (1) that it is an ontology, (2) that it can account for the ontological possibilities suggested by the claims in the texts, and (3) that this account is in some way preferable to merely conceding ontological multiplicity without further explanation. In addition, IoT was found to correspond well with the criteria for "hyperobjects"—a kind of complex object already described in Object-Oriented Ontology. The second major conclusion of the thesis is that, of the philosophical ontologies considered, Object-Oriented Ontology, and in particular the theory of hyperobjects, provides the most satisfactory underlying ontology for IoT as it is encountered in the literature.

To restate the research question and my major conclusion in response:

Research question

What does an ontological investigation of the Internet of Things, informed by prominent philosophical theories regarding the ontology of technology, reveal about the ontolog(ies) of the Internet of Things? Conversely, what does such an investigation reveal about the philosophical technologies themselves?

Major conclusions

(1) IoT as it is found in the literature is ontologically multiple.
(2) Different philosophical theories regarding the ontology of technology complement each other by highlighting different aspects and modalities of technology.

(3) Of the philosophical theories considered, Object-Oriented Ontology, and in particular the theory of hyperobjects, provides the most satisfactory underlying ontology for IoT as it is found in the literature.

7.2. Limitations of this research

Some caveats need to be applied to this conclusion.

It is, of course, reliant on the research method employed (e.g., the way documents were sampled, the way categories were identified), as discussed in *Chapter 4: Research Question, Methodology and Method* above. For example, some potentially significant aspects of IoT are not addressed, because they did not occur in the data sample. One example of this is dystopian views of IoT, as discussed in *Section 5.2.10: IoT as ENCHANTED WORLD* above. Another example is the potential environmental and sustainability dimensions of IoT.

Different methods might well uncover different evidence—indeed this is to be expected given the inexhaustible nature of objects in Object-Oriented Ontology. This evidence might support the conclusions given above, or require some of them to be reconsidered. Also, it must be noted that only six philosophical ontologies were considered, and consideration was limited (for reasons of space) to rather broad-gauge versions of these ontologies. These six theories represent the main currents of thought regarding the ontology of technology—nevertheless, it is possible that other ontologies, or alternative versions of the six considered, might be viable candidates for the underlying ontology of IoT.

Thus, I cannot claim to have produced incontestable proof of the nature of IoT. Nevertheless, the evidence I have considered recommends Object-Oriented Ontology as an underlying ontology for IoT, and also suggests that IoT is a hyperobject. These are, of course, falsifiable conclusions which warrant further investigation. Some possible directions for such investigation are suggested below.

7.3. Suggestions for future research

This thesis opens several new lines of enquiry, which might be profitable directions for future research.

Firstly, as noted above, the evidence produced is dependent on the method employed. I have employed text-based research, and focused this on a sample drawn from influential sources. It would be worthwhile to see whether the conclusions drawn could be replicated using an alternative research method, or an alternative sample. For example, would a close observational study of a particular IoT project find similar evidence of ontological categories of reference? What categories would be revealed by a survey of other text-based sources relating to IoT such as blog posts, chat room discussions, patent applications, IoT standards or educational material? Would these categories be the same as those identified in this study?

Secondly, it would be valuable to investigate to what extent the conclusions of this thesis apply to other technologies. While the conclusions have been drawn specifically with respect to IoT, there is no obvious reason why they should not apply more broadly. A similar method to that employed in this thesis could be extended to other recent large-scale technological phenomena such as the internet, "big data" or artificial intelligence. A somewhat modified method could be applied to historical technologies such as the telegraph or railroads.

Thirdly, it would be useful to consider the consequences and implications of the conclusions drawn here. For example, if IoT is accepted as a hyperobject, what does this mean for our engagement with it? Could an approach to the development/management of technology be developed which builds on this ontological insight? Such an approach would need to take into account the ontological conclusions developed in this thesis: for example, it would need to take into account the fact that IoT is many different things, all of them equally real and all of them closely entangled with each. If such an approach could be developed, how would it differ from those currently employed? Above, I have suggested that the conclusions drawn in this thesis may be applicable not just to IoT, but to many other similar technological phenomena (see *Section 4.1: Research Question*). If this is indeed the case, a methodology founded on the conclusions in this thesis might also have general applicability across multiple technological phenomena.

In summary, this thesis suggests further research to verify its conclusions using other methods, to extend its conclusions to technologies other than IoT, and to explore its implications for our engagement with, and use of, technology.

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Appendix: nVivo Coding Summary

Hierarchical Name	Files Coded	Coding References
Nodes\\IoT and RELATED TRENDS	44	78
Nodes\\IoT and RELATED TRENDS\5G	1	2
Nodes\\IoT and RELATED TRENDS\Artificial Intelligence	1	2
Nodes\\IoT and RELATED TRENDS\Cloud factory	1	1
Nodes\\IoT and RELATED TRENDS\Consumer Internet of Things	3	3
Nodes\\IoT and RELATED TRENDS\Context aware computing	1	1
Nodes\\IoT and RELATED TRENDS\Cyberphysical systems	1	1
Nodes\\IoT and RELATED TRENDS\Data management	1	1
Nodes\\IoT and RELATED TRENDS\Data source	2	3
Nodes\\IoT and RELATED TRENDS\Digital twins	1	1
Nodes\\IoT and RELATED TRENDS\Electrical storage	2	2
Nodes\\IoT and RELATED TRENDS\Energy management	2	2
Nodes\\IoT and RELATED TRENDS\Everything as a Service	2	2
Nodes\\IoT and RELATED TRENDS\Green IoT	2	2
Nodes\\IoT and RELATED TRENDS\Industrial IoT	2	2
Nodes\\IoT and RELATED TRENDS\Industrie 4.0	1	1
Nodes\\IoT and RELATED TRENDS\Integration	1	1
Nodes\\IoT and RELATED TRENDS\Intelligent products	1	1
Nodes\\IoT and RELATED TRENDS\IoT and Big Data	6	8
Nodes\\IoT and RELATED TRENDS\IoT and Blockhain	1	3
Nodes\\IoT and RELATED TRENDS\IoT and Cloud	6	8
Nodes\\IoT and RELATED TRENDS\IoT and Cloud\CloudIoT	2	2
Nodes\\IoT and RELATED TRENDS\IoT and Edge	1	1
Nodes\\IoT and RELATED TRENDS\IoT and fog	5	6
Nodes\\IoT and RELATED TRENDS\M2M vs IOT	2	2
Nodes\\IoT and RELATED TRENDS\One of a list of innovations	13	13
Nodes\\IoT and RELATED TRENDS\Smart city	3	4
Nodes\\IoT and RELATED TRENDS\Smart dust	1	1
Nodes\\IoT and RELATED TRENDS\Social networking	3	3
Nodes\\IoT as ARTEFACT	75	211
Nodes\\IoT as ARTEFACT\Components of IoT	13	14
Nodes\\IoT as ARTEFACT\Definition - technical	4	4
Nodes\\IoT as ARTEFACT\Enabling Inudstrie 4.0	1	1
Nodes\\IoT as ARTEFACT\Infrastructure advance	1	1
Nodes\\IoT as ARTEFACT\IoT architectures	3	4
Nodes\\IoT as ARTEFACT\IoT as a business platform	2	2
Nodes\\IoT as ARTEFACT\IoT as a class of technologies	2	2
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies	20	45
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Addressing schemes	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\B2B	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Communication	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Data and Signal Processing	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Data storage and analytics	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Discovery and search engine	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Hardware	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Identification technologies	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\M2M	2	2
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Middleware	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Network discovery	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Networking technologies	3	3
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Power and energy storage	2	2
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Relationship Network Management	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\RFID	4	4
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Security and privacy	6	6
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Software	1	1
Nodes\\IoT as ARTEFACT\IoT as assemblage of technologies\Visualisation	1	1
Nodes\\IoT as ARTEFACT\IoT as PHYSICAL NETWORK	20	28
Nodes\\IoT as ARTEFACT\IoT as PHYSICAL NETWORK\Cyberphysical network	3	3
Nodes\\IoT as ARTEFACT\IoT as PHYSICAL NETWORK\Cyberphysical network\IoT as Cyberphysical	1	1

Hierarchical Name	Files Coded	Coding References
Nodes\\IoT as ARTEFACT\IoT as PHYSICAL NETWORK\Instantiated physical network	2	2
Nodes\\IoT as ARTEFACT\IoT as PHYSICAL NETWORK\IoT as ecosystem	4	5
Nodes\\IoT as ARTEFACT\IoT integration	1	1
Nodes\\IoT as ARTEFACT\IoT platforms	2	2
Nodes\\IoT as ARTEFACT\IoT reference architecture	18	23
Nodes\\IoT as ARTEFACT\IoT reference architecture\Architecture layers	13	15
Nodes\\IoT as ARTEFACT\IoT reference architecture\New Node	0	0
Nodes\\IoT as ARTEFACT\IoT reference architecture\No common reference architecture	4	8
Nodes\\IoT as ARTEFACT\IoT standards	17	21
Nodes\\IoT as ARTEFACT\IoT technical design concepts	8	9
Nodes\\IoT as ARTEFACT\Mobile robots	2	2
Nodes\\IoT as ARTEFACT\Origin of IoT – RFID	10	13
Nodes\\IoT as ARTEFACT\Part of digital	1	1
Nodes\\IoT as ARTEFACT\Part of IT	2	2
Nodes\\IoT as ARTEFACT\Standards soup	14	19
Nodes\\IoT as ARTEFACT\Sufficient standards in place	1	1
Nodes\\IoT as ARTEFACT\Technological topology	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY	53	103
Nodes\\IoT as BUSINESS OPPORTUNITY\Business scenarios	5	5
Nodes\\IoT as BUSINESS OPPORTUNITY\Enable new business model	11	12
Nodes\\IoT as BUSINESS OPPORTUNITY\Enterprises	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\Industry competition	11	16
Nodes\\IoT as BUSINESS OPPORTUNITY\Investment	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY	29	51
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Business benefits	6	8
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Business benefits\Only incremental benefits	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Call to action	10	12
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Demanding a response	2	2
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Democratisation	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Enabling business transformation	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\IoT as business improvement	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\IoT driving value	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Lack of understanding	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Opportunity	10	13
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Potential	3	3
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Productivity benefits	2	2
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\Risk of ignoring	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\IoT as OPPORTUNITY\ROI case	2	3
Nodes\\IoT as BUSINESS OPPORTUNITY\Land grab	2	2
Nodes\\IoT as BUSINESS OPPORTUNITY\Market	1	3
Nodes\\IoT as BUSINESS OPPORTUNITY\Market demand	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\Market\Immature market	1	2
Nodes\\IoT as BUSINESS OPPORTUNITY\New business model required	4	5
Nodes\\IoT as BUSINESS OPPORTUNITY\Not on CEO radar	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\Ownership within enterprises	1	1
Nodes\\IoT as BUSINESS OPPORTUNITY\Technology Service Providers	2	2
Nodes\\IoT as CONTESTED TERM	50	67
Nodes\\IoT as CONTESTED TERM\Disputed meaning	3	3
Nodes\\IoT as CONTESTED TERM\Hype	14	17
Nodes\\IoT as CONTESTED TERM\Inverted commas or not	2	2
Nodes\\IoT as CONTESTED TERM\IoT as adjective	4	4
Nodes\\IoT as CONTESTED TERM\Mere term	24	24
Nodes\\IoT as CONTESTED TERM\Mirage	1	1
Nodes\\IoT as CONTESTED TERM\Multiple IoTs	2	2
Nodes\\IoT as CONTESTED TERM\Unclear definition	9	10
Nodes\\IoT as CONTESTED TERM\Unclear definition\IoT = IoE = IIoT	1	1
Nodes\\IoT as CONTESTED TERM\Wild West	1	1
Nodes\\IoT as ENCHANTED WORLD	30	60
Nodes\\IoT as ENCHANTED WORLD\anthropomorphic things	1	1
Nodes\\IoT as ENCHANTED WORLD\autonomous things	8	8
Nodes\\IoT as ENCHANTED WORLD\Conscious things	1	1

Hierarchical Name	Files Coded	Coding References
Nodes\\IoT as ENCHANTED WORLD\Enchanted things	1	1
Nodes\\IoT as ENCHANTED WORLD\Intelligent things	10	14
Nodes\\IoT as ENCHANTED WORLD\Intelligent things vs dumb things	1	1
Nodes\\IoT as ENCHANTED WORLD\Intelligent things\Spimes	3	3
Nodes\\IoT as ENCHANTED WORLD\intelligent world	11	12
Nodes\\IoT as ENCHANTED WORLD\intelligent world\intelligent home	6	7
Nodes\\IoT as ENCHANTED WORLD\social things	1	1
Nodes\\IoT as ENCHANTED WORLD\Things as citizens	1	2
Nodes\\IoT as ENCHANTED WORLD\Things as customers	1	3
Nodes\\IoT as ENCHANTED WORLD\Things as friends	1	2
Nodes\\IoT as ENCHANTED WORLD\Things as workers	1	2
Nodes\\IoT as ENCHANTED WORLD\Things having a voice	4	6
Nodes\\IoT as ENCHANTED WORLD\Things having agency	3	3
Nodes\\IoT as ENCHANTED WORLD\Things with back stories	1	1
Nodes\\IoT as EXPERIENCE	17	26
Nodes\\IoT as EXPERIENCE\Augmented reality	1	1
Nodes\\IoT as EXPERIENCE\Human engagement	2	2
Nodes\\IoT as EXPERIENCE\Human engagement\Digital shadowing	1	1
Nodes\\IoT as EXPERIENCE\IoT as experience	14	22
Nodes\\IoT as EXPERIENCE\IoT as experience\Disappearing from view	2	4
Nodes\\IoT as EXPERIENCE\IoT as experience\Lifeworld impact	10	12
Nodes\\IoT as EXPERIENCE\IoT as experience\Lifeworld impact (2)	2	2
Nodes\\IoT as EXPERIENCE\IoT as experience\User experience	2	2
Nodes\\IoT as EXPERIENCE\IoT as human-centred network	1	1
Nodes\\IoT as FORCE	65	134
Nodes\\IoT as FORCE\Deterministic trajectory	1	1
Nodes\\IoT as FORCE\Deterministic trajectory\Industrie 4.0	1	1
Nodes\\IoT as FORCE\Driving force	7	7
Nodes\\IoT as FORCE\Enabling technologies	13	14
Nodes\\IoT as FORCE\IoT as IMPERATIVE	8	10
Nodes\\IoT as FORCE\IoT as IMPERATIVE\Demanding new technologies	6	8
Nodes\\IoT as FORCE\IoT as IMPERATIVE\IoT as challenge	1	1
Nodes\\IoT as FORCE\IoT driving data management	1	1
Nodes\\IoT as FORCE\IoT driving research program	6	7
Nodes\\IoT as FORCE\IoT era	2	2
Nodes\\IoT as FORCE\Major technology force in future	2	2
Nodes\\IoT as FORCE\Needs and impacts	1	1
Nodes\\IoT as FORCE\New World of IoT	3	3
Nodes\\IoT as FORCE\Technical challenges are not a constraint	1	1
Nodes\\IoT as FORCE\Technical challenges posed by IoT	41	76
Nodes\\IoT as FORCE\Technical challenges posed by IoT\Data management	1	1
Nodes\\IoT as FORCE\Technical challenges posed by IoT\Developing solutions to technical challenges	5	5
Nodes\\IoT as FORCE\Technical challenges posed by IoT\Middleware challenges	1	1
Nodes\\IoT as FORCE\Technical challenges posed by IoT\Security and privacy	17	24
Nodes\\IoT as FORCE\Three ages of farming	1	1
Nodes\\IoT as FORCE\Tide	1	1
Nodes\\IoT as FORCE\Transformational force	7	7
Nodes\\IoT as HUMAN ENDEAVOUR	28	37
Nodes\\IoT as HUMAN ENDEAVOUR\Inventors	1	1
Nodes\\IoT as HUMAN ENDEAVOUR\IoT projects	6	7
Nodes\\IoT as HUMAN ENDEAVOUR\IoT projects\Implementation phases	1	1
Nodes\\IoT as HUMAN ENDEAVOUR\IoT projects\Project issues	2	2
Nodes\\IoT as HUMAN ENDEAVOUR\Limited number of enthusiasts	1	1
Nodes\\IoT as HUMAN ENDEAVOUR\Makers and start ups	2	2
Nodes\\IoT as HUMAN ENDEAVOUR\Movement	1	1
Nodes\\IoT as HUMAN ENDEAVOUR\National initiatives	6	8
Nodes\\IoT as HUMAN ENDEAVOUR\National initiatives\China	1	1
Nodes\\IoT as HUMAN ENDEAVOUR\Need for innovative approach	1	1
Nodes\\IoT as HUMAN ENDEAVOUR\Need to build capability	2	2
Nodes\\IoT as HUMAN ENDEAVOUR\Need to oppose fragmentation	5	5
Nodes\\IoT as HUMAN ENDEAVOUR\Project type	2	2

Hierarchical Name	Files Coded	Coding References
Nodes\\IoT as HUMAN ENDEAVOUR\Push	1	1
Nodes\\IoT as HUMAN ENDEAVOUR\Standards bodies	5	5
Nodes\\IoT as HUMAN ENDEAVOUR\Tinkering	1	1
Nodes\\IoT as IDEA	55	105
Nodes\\IoT as IDEA\Common understanding	1	1
Nodes\\IoT as IDEA\Dream	1	1
Nodes\\IoT as IDEA\Emergent but also pre-existing	3	4
Nodes\\IoT as IDEA\Evolving concept	2	2
Nodes\\IoT as IDEA\Existing for a long time	7	7
Nodes\\IoT as IDEA\IoT as conceptual and physical	3	4
Nodes\\IoT as IDEA\IoT as utility	1	1
Nodes\\IoT as IDEA\IoT space	1	1
Nodes\\IoT as IDEA\Lack of consensus on realisation	2	2
Nodes\\IoT as IDEA\Limited vision	1	1
Nodes\\IoT as IDEA\Longstanding concept and vision	5	6
Nodes\\IoT as IDEA\Longstanding concept and vision\Widely anticipated	1	1
Nodes\\IoT as IDEA\Multi-faceted	2	2
Nodes\\IoT as IDEA\Paradigm	11	13
Nodes\\IoT as IDEA\Physical – electronic boundary	13	16
Nodes\\IoT as IDEA\Umbrella concept	1	1
Nodes\\IoT as IDEA\Vision	21	31
Nodes\\IoT as IDEA\Vision\Essence	3	4
Nodes\\IoT as IDEA\Vision\Heady	1	1
Nodes\\IoT as IDEA\Vision\Multiple visions	7	9
Nodes\\IoT as IDEA\Vision\Multiple visions\data-centric	1	1
Nodes\\IoT as IDEA\Vision\Multiple visions\Internet-oriented	4	5
Nodes\\IoT as IDEA\Vision\Multiple visions\nano-things	1	1
Nodes\\IoT as IDEA\Vision\Multiple visions\Semantic	1	1
Nodes\\IoT as IDEA\Vision\Multiple visions\Thing-oriented	3	3
Nodes\\IoT as IDEA\Vision\Multiple visions\web-of-things	4	5
Nodes\\IoT as IDEA\Vision\Multiple visions\Wifi vs Bluetooth vs Cellular models	1	1
Nodes\\IoT as IDEA\Vision\Part of Future Web vision	1	1
Nodes\\IoT as IDEA\Vision\Preceding reality	1	1
Nodes\\IoT as IDEA\Vision\Technology hiding behind vision	1	1
Nodes\\IoT as INTERNET	35	50
Nodes\\IoT as INTERNET\Analagous to internet	1	1
Nodes\\IoT as INTERNET\Expansion of the internet	25	31
Nodes\\IoT as INTERNET\Future Internet	5	6
Nodes\\IoT as INTERNET\IoT vs Internet of Everything	3	3
Nodes\\IoT as INTERNET\Three waves of the internet	8	8
Nodes\\IoT as LOTS OF THINGS	38	51
Nodes\\IoT as LOTS OF THINGS\billions of things	26	30
Nodes\\IoT as LOTS OF THINGS\billions of things\trillions of things	3	4
Nodes\\IoT as LOTS OF THINGS\billions of things\zillions of things	1	1
Nodes\\IoT as LOTS OF THINGS\Characteristics of IoThings	1	3
Nodes\\IoT as LOTS OF THINGS\Connected vs unconnected	1	1
Nodes\\IoT as LOTS OF THINGS\Heterogeneous list of things	5	5
Nodes\\IoT as LOTS OF THINGS\Less than anticipated	1	1
Nodes\\IoT as LOTS OF THINGS\Thingification	1	1
Nodes\\IoT as LOTS OF THINGS\Things by type	4	5
Nodes\\IoT as LOTS OF THINGS\Things by type\Bluetooth beacons	1	1
Nodes\\IoT as LOTS OF THINGS\Which things are IoThings	4	4
Nodes\\IoT as ONTOLOGICAL LEVELLER	17	28
Nodes\\IoT as ONTOLOGICAL LEVELLER\Agents = People, Things	3	4
Nodes\\IoT as ONTOLOGICAL LEVELLER\Cyborgs	1	1
Nodes\\IoT as ONTOLOGICAL LEVELLER\Humans as part of IoT	5	7
Nodes\\IoT as ONTOLOGICAL LEVELLER\Humans as part of IoT\Human augmentation	1	1
Nodes\\IoT as ONTOLOGICAL LEVELLER\Humans as sensors	5	8
Nodes\\IoT as ONTOLOGICAL LEVELLER\Humans as sensors\Sensing	1	3
Nodes\\IoT as ONTOLOGICAL LEVELLER\Humans as sensors\Sensing\Community sensing	1	1
Nodes\\IoT as ONTOLOGICAL LEVELLER\Humans as sensors\Sensing\Personal sensing	1	1

Hierarchical Name	Files Coded	Coding References
Nodes\\IoT as ONTOLOGICAL LEVELLER\People, business, things	5	5
Nodes\\IoT as SOCIAL ACTOR	49	115
Nodes\\IoT as SOCIAL ACTOR\Benefits	14	18
Nodes\\IoT as SOCIAL ACTOR\Benefits\Economic benefits	3	4
Nodes\\IoT as SOCIAL ACTOR\Benefits\Social benefits	6	6
Nodes\\IoT as SOCIAL ACTOR\Consumers	1	2
Nodes\\IoT as SOCIAL ACTOR\Contributing to economic development	3	3
Nodes\\IoT as SOCIAL ACTOR\Different social groups	12	17
Nodes\\IoT as SOCIAL ACTOR\Different social groups\Industrial groups	1	1
Nodes\\IoT as SOCIAL ACTOR\Different social groups\Research bodies	7	7
Nodes\\IoT as SOCIAL ACTOR\Different social groups\Research bodies\Research initiatives	3	3
Nodes\\IoT as SOCIAL ACTOR\Different social groups\Scientific communities	1	1
Nodes\\IoT as SOCIAL ACTOR\Disruption	1	1
Nodes\\IoT as SOCIAL ACTOR\Dystopia	1	1
Nodes\\IoT as SOCIAL ACTOR\Early adopters	1	1
Nodes\\IoT as SOCIAL ACTOR\Economic impact	2	2
Nodes\\IoT as SOCIAL ACTOR\Engineering culture vs digital culture	1	1
Nodes\\IoT as SOCIAL ACTOR\Governance	5	7
Nodes\\IoT as SOCIAL ACTOR\Impact on citizens	2	2
Nodes\\IoT as SOCIAL ACTOR\Impact on industries	3	3
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Nodes\\IoT as SOCIAL ACTOR\Legal constraints	8	13
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Nodes\\IoT as SOCIAL ACTOR\Political obstacles	1	1
Nodes\\IoT as SOCIAL ACTOR\Popular demand for	1	1
Nodes\\IoT as SOCIAL ACTOR\Popular demand for\Diffused	1	1
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Nodes\\IoT as SOCIAL ACTOR\Skepticism	1	1
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Nodes\\IoT as SOCIAL ACTOR\Social concern phrased as technical challenge	1	1
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Nodes\\IoT as THREAT\Ethical questions	1	1
Nodes\\IoT as THREAT\IoT in dangerous world	1	1
Nodes\\IoT as THREAT\Iot-based surveillance	2	3
Nodes\\IoT as THREAT\Liability	0	0
Nodes\\IoT as THREAT\Privacy	32	45
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Nodes\\IoT as TRAJECTORY\Change in focus to applications	1	1
Nodes\\IoT as TRAJECTORY\Emerging	10	12
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Hierarchical Name	Files Coded	Coding References
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Nodes\\IoT as TRAJECTORY\IoT as INFLECTION POINBT\Adopted by organisations	1	3
Nodes\\IoT as TRAJECTORY\IoT as INFLECTION POINBT\qualitative change	1	1
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