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**A typology, method and roadmap for HUMAN-MACHINE NETWORKS**

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# Systematic Literature Review

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<b>Abstract</b>	The report reviews current research of relevance to human-machine networks (HMNs). Focusing initially on the interactions among humans and between humans and machines, we identify eight initial types of HMNs: public-resource computing, crowdsourcing, web search engines, crowd sensing, online markets, social media, multiplayer online games and virtual worlds, and mass collaboration. We systematically select literature on each of these initial types and review it with a focus on design implications. Our discussion helps identify opportunities for designing and developing new kinds of HMNs. Using this as a basis, we then abstract a set of connection primitives to be used to design and define HMNs. We validate this initial set of primitives on the basis of one of the HUMANE use cases, and then against three further use cases not within the original HUMANE set for independent validation. Drawing together the initial types and the connection primitives, we finish off with a brief discussion of the implications of complex HMNs in terms of the behaviours and interactions that are described in this way. We also discuss how the limitations of our approach suggest directions towards a more bottom-up and flexible typology.
<b>Keywords</b>	Survey, networks, crowdsourcing, mass collaboration, crowd sensing, social media, peer-to-peer, complex networks, human-machine networks, network elements, network types

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## Abbreviations

Abbreviation	Definition
ANT	Actor-network theory
HMN	Human-machine network
MOG	Multiplayer online game
OSS	Open-source software
P2P	Peer-to-peer
PRC	Public-resource computing
QoE	Quality of experience
QoS	Quality of service
SM	Social media
VW	Virtual world
WSE	Web search engine

## Executive summary

The intention of this deliverable is to review literature relevant to human-machine networks (HMNs), identify and summarise the main features and challenges in relation to HMNs, and provide a basis for going forward for other work in the HUMANE project.

HMNs are complex systems of human actors and computing devices or sensors that interact to produce synergy. In other words, human-machine networks result in outcomes that neither a human social network, nor a computer network can produce independently. We often use computers to communicate with others but most of the time the computers are simply a medium for an interaction that could have otherwise occurred face-to-face. E-mail and phone conversations are good examples of machine-mediated communication. Sometimes, however, computers can radically transform how we interact and what we produce. HUMANE focuses exactly on those network instances.

HMNs comprise of humans and machines that interact. Focusing on the human-to-human, human-to-machine, and the machine-to-human interactions, we identify eight different HMN types: public-resource computing, crowdsourcing, web search engines, crowd sensing, online markets, social media, multiplayer online games and virtual worlds, and mass collaboration. For each type, we collected articles that concern issues related to the design of such a network and that are either new and promising or already well cited.

Summarizing the literature, we provide a useful overview of current knowledge. However, we also go beyond the state of the art by formulating what constitutes HMNs in more generic terms. We do this by proposing a set of primitives, or basic conceptual elements to visualize HMNs, and demonstrating it on four actual networks.

Finally, we also discuss other factors that we need to investigate and integrate into an overall typology: HMNs are not simply about the types of connections or interactions, but enable potentially unforeseen development and innovation in behaviour. The static top-down approach we assume here is limiting compared to a classification that emerges as the result of exploring HMNs according to more generic characteristics and that captures dynamic networks that can change states. Thus, in the work that follows in the HUMANE project, we need to seek a more exploratory approach by profiling HMNs through key dimensions.

Thus, this deliverable provides more than a systematic literature review. In addition, it begins to develop and explore the foundations upon which an HMN typology can be established (in WP2), the base considerations for interactions with the HUMANE use case projects (WP3), and, the roadmapping to be carried out as part of WP5.

## TABLE OF CONTENTS

<b>Executive summary .....</b>	<b>5</b>
<b>1 Introduction.....</b>	<b>10</b>
1.1 Background .....	10
1.2 Scope.....	13
1.3 Methods, tools, and techniques used in the study of HMNs .....	13
1.4 Analytical layers .....	15
<b>2 Actors .....</b>	<b>15</b>
2.1 Humans .....	15
2.2 Machines .....	17
<b>3 Interactions.....</b>	<b>18</b>
3.1 Human-human interactions .....	18
3.1.1 Social ties in human-human interactions.....	19
3.2 Human-machine interactions.....	20
3.2.1 Human input in human-machine interactions .....	20
3.2.2 Machine output in human-machine interactions .....	21
3.3 Machine-machine interactions .....	22
<b>4 Networks.....</b>	<b>23</b>
4.1 Public-resource computing .....	25
4.2 Crowdsourcing .....	27
4.3 Web search engines .....	29
4.4 Crowd sensing .....	31
4.5 Online markets.....	32
4.6 Social media .....	33
4.7 Multiplayer online games and virtual worlds.....	35
4.8 Mass collaboration.....	36
<b>5 Extending the initial types .....</b>	<b>38</b>
5.1 The eVACUATE Case Study.....	38
5.2 Extended primitives for HMN description.....	40

5.2.1	Nodes .....	40
5.2.2	Edges .....	41
5.2.3	Networks .....	41
5.2.4	Connection Primitives .....	42
5.3	Validating the connection primitives .....	43
5.4	Further developments .....	47
<b>6</b>	<b>Behaviour.....</b>	<b>47</b>
6.1	Entities .....	47
6.2	Connections (edges).....	48
6.3	Emergent behaviours .....	48
6.4	Network evolution .....	49
<b>7</b>	<b>Future.....</b>	<b>49</b>
<b>8</b>	<b>References .....</b>	<b>51</b>
<b>9</b>	<b>Appendix A: Systematic literature search .....</b>	<b>67</b>
<b>10</b>	<b>Appendix B: List of key literature by network type .....</b>	<b>69</b>
10.1	Public resource computing .....	69
10.2	Crowdsourcing .....	70
10.3	Web search engines .....	71
10.4	Crowd sensing .....	73
10.5	Online markets.....	75
10.6	Social media .....	76
10.7	Multiplayer online games and virtual worlds .....	78
10.8	Mass collaboration.....	79

**LIST OF TABLES**

<b>Table 1: Four types of nodes in HMNs. ....</b>	<b>40</b>
<b>Table 2: Keywords for the systematic literature search. ....</b>	<b>68</b>

**LIST OF FIGURES**

<b>Figure 1: Initial types of human-machine networks.....</b>	<b>24</b>
<b>Figure 2: Geographical space and interaction duration of human-machine networks. ....</b>	<b>25</b>
<b>Figure 3: First attempt to represent the eVACUATE human-to-machine network using initial primitives .....</b>	<b>38</b>
<b>Figure 4: An initial set of connection primitives for complex HMNs .....</b>	<b>42</b>
<b>Figure 5: An alternative dual-connection type.....</b>	<b>42</b>
<b>Figure 6: The HMN for TRIFoRM using our initial set of connection primitives.....</b>	<b>44</b>
<b>Figure 7: The HMN for OPERANDO using our initial set of connection primitives .....</b>	<b>45</b>
<b>Figure 8: The HMN for PAL using our initial set of connection primitives .....</b>	<b>46</b>
<b>Figure 9: Method for the systematic literature search. ....</b>	<b>68</b>

# 1 Introduction

Machines are human-made multi-part entities that transform input into output (an intended action or result). Historically, even as far back as the cave drawings at Lascaux, there was a motivation to collaborate for mutual benefit, as well as to communicate and celebrate with others. From the invention of the Gutenberg press, machines have had a transformative impact on human interaction. By the Industrial Revolution, machine influence on how we communicate, exchange, and cooperate with each other had become more immediate and more pervasive. The first car was invented in 1886 and today, a continuous transportation network covering the whole Earth allows billions of people the opportunity to interact face-to-face with strangers from distant cultures. A little earlier, the telephone was patented in 1876 and since then, multiple advances in communication technologies have allowed us to keep in touch with friends and family while we drive a car, while we walk towards the bus stop, or even during a camping trip in a remote forest. The invention of the Internet has changed even more dramatically the organization and functioning of our society. ARPANET, the prototype for the Internet, was created in 1969 and the first bulletin board system, a precursor to the World Wide Web, was initiated in 1978. The Web itself was first envisioned in 1989 and during the quarter century since then, it has greatly expanded and taken over how we shop, interact, acquire knowledge, work, and spend our free time. Now, with smartphones, we are connected to the Web everywhere, 24/7.

Human actions and interactions have been so interrelated with technology that it is difficult to know whether society changes because of technology or the other way around. Increasingly, though, because of these interactions, new kinds of system form. It is not just the pace of technological change that is important, though, it is the creativity and innovation of users that determines how far that technology will go. Most importantly, it is what possibilities working with machines allow humans to aspire to. We conceptualize these systems as human-machine networks. There is a need to understand these systems better, as they do not simply function as the sum of their constituent parts. They do not behave in the same way as face-to-face social interaction networks and they cannot be developed in the same manner as computer networks. There is a unique, and perhaps unpredictable, contribution from both. This makes the study of human-machine networks crucial in understanding where to go next.

## 1.1 Background

Some scholars have already attempted to conceptualize humans and machines in a single system. This has resulted in three prominent theoretical developments: socio-technical systems, actor-network theory, and the study of social machines.

**In the socio-technical systems (STS) approach,** technologies are referred to as socio-technical systems to emphasize that any technology will be implemented and used in a social (work) context that will shape whether and how it is adopted, and subsequently also influence the work environment (Leonardi, 2012). STS started out as an action research approach with the aim of reframing work organizations as socio-technical systems to account for and examine technological

innovations in work-contexts in order to obtain the best match between the technological and social components with an emphasis of how to retain job satisfaction (Trist, 1981). The study of organizational change, particularly in the context of technological change, requires recognizing organizations as complex systems of humans and technology that aim to reach given goals in the context of a given organizational environment (Emery & Trist, 1965). In essence, it is an approach to studying organizations that focuses on the interrelation between the network of people who work in the organization and the technologies they use. Its main aim has been to improve productivity, increase cost savings, and reduce absenteeism, while retaining and improving work-life quality (Pasmore, Francis, Haldeman, & Shani, 1982). In other words, socio-technical research has been concerned with design and change processes but restrictively in the context of formal organizations. In the context of HUMANE, our focus cannot be tied merely to formal organizations, yet an important take-away from the socio-technical systems approach is the subtleness of analysing and understanding technology, while keeping the human and societal benefits as core objectives.

**Actor-network theory (ANT)** is a sociological theory that fundamentally revises what should be considered part of the social. Whereas classical sociology tends to focus on how humans live together, and how society shapes humans, ANT argues that we explicitly need to take into account that any social system is an association of heterogeneous elements such as humans, norms, texts, devices, machines and technology (Latour, 2005; Law, 1992). ANT's relevance for HUMANE relates to the emphasis given to the roles that non-human entities can hold as mediators in networks. In ANT, "network" is used as a concept to understand how human and non-human entities interplay and influence each other. Both human and non-human entities can take the role as intermediary or mediator. Intermediaries merely pass on meaning without transforming or affecting it: Input = output. Mediators, on the other hand, affect or translate the meaning: Input  $\neq$  output (Latour, 2005). If we, hypothetically, take out the non-human mediating entities from the actor-network, we would inevitably change the social system; our social order being an effect generated by heterogeneous networks of human and non-human entities. Hence, these heterogeneous networks participate in and shape the social (Law, 1992).

ANT is a valuable contribution because it grants equal weight to humans and non-human (machine) entities in the analysis of the social. However, its analytical toolkit is not general but tied to the context (Pouloudi & Gandecha, 2004). In the context of HUMANE, ANT nevertheless represents much potential for understanding human-machine networks, and two concurrent developments grant additional relevance to examining the significance and interference of non-human elements: we often and increasingly relate to and interact with machine elements without seeing them explicitly, and machine nodes increasingly act in responsive ways adapted to different input. In short machine nodes are increasingly becoming pervasive, invisible and responsive. We do not see the software, sensors, algorithms and codes (we see what software does), yet they undoubtedly affect what we experience, what we can do and the messages and content we access. These invisible systems are known as cyber-physical systems (Rajkumar, Lee, Sha, & Stankovic, 2010).

**The concept of "social machines"** refers to systems that combine social participation with machine-based computation (Smart, Simperl, & Shadbolt, 2014). The concept is related to socio-technical

systems but rather than focusing on organizations, it focuses on Web services (Meira et al., 2011). The World Wide Web as a social machine in itself connects with Tim Berners-Lee's original vision of the web more as a social creation than a technical one, "to support and improve our web-like existence in the world" (Berners-Lee, 2000, p. 123), a vision that now appears more apt than ever with the panoply of read/write technologies and social network sites (Hendler & Berners-Lee, 2010). There are multiple recent attempts to define social machines more concretely and to create taxonomies and typologies to describe them (Burégio, Meira, & Rosa, 2013; Shadbolt et al., 2013; Smart et al., 2014). Yet, there has been little progress beyond defining the scope of the field, and delineating visions for more effective next generation social machines based on the semantic web (Hendler & Berners-Lee, 2010). Social machines enable human-machine networks, and as such the two notions are fundamentally related. In this report, we will hence sometimes refer to HMNs as enabled by social machines.

Even if these three different theories conceptualize humans and machines as forming a single system, as opposed to perspectives where social structures are seen as merely mediated in machine networks (e.g. social network theory), they do not provide the insight and guidance needed to support the design of contemporary and future HMNs. Furthermore, these theories do not contribute to a unified framework for understanding HMNs, as is seen from the plethora of theoretical positions in which current studies of such networks are based. The volume of publications concerning HMNs is rapidly increasing across a wide range of academic fields. Such breadth in academic attention is beneficial for the development of knowledge on HMNs. However, this breadth also implies a potential risk for fragmentation, barring opportunities for the transfer of knowledge and experiences across academic, as well as practical fields of study.

To initiate the broad theoretical basis needed to bridge the rapidly evolving field of HMNs, we conduct a cross-disciplinary literature review of key studies that concern different types of HMNs. Multiple surveys of particular types of HMNs exist (Crowston, Wei, Howison, & Wiggins, 2012a; Guo et al., 2015; Guo, Zhang, Wang, Yu, & Zhou, 2013; Pejovic & Musolesi, 2015a; Yahyavi & Kemme, 2013a) but we are the first to present a comprehensive overview of the field within a unifying framework. Our objective is to delineate the phenomenon of human-machine networks better and provide an overview of relevant recent research. Our definition of HMNs focuses on the synergy in these networks and our analytical framework focuses on their structure and function. Furthermore, we pay particular attention to issues of design, maintenance, and growth. Our approach is dictated by our desire to understand the structure and functioning of HMNs and identify opportunities for further research, development, and innovation. Our review provides a first step towards integrating current academic efforts to understand the emerging phenomenon of HMNs. Furthermore, the analysis demonstrates how the identification of key characteristics in different HMNs may serve to expose issues related to design of HMNs, as well as to support the transfer of knowledge and experience across academic disciplines and types of HMNs.

The literature review is conducted as part of the HUMANE project, where the aim is to develop new knowledge and methods to strengthen the future development of HMNs. The literature review is the

initial work conducted in the project. In particular, the review will inform the subsequent development of a typology and method to support human-centred design of HMNs.

## 1.2 Scope

Here, we restrict our focus to networks of humans and machines whose interactions have synergistic effects. Synergy means that the combination is greater than the sum of its parts. The idea is that interactions in the human-machine network (HMN) result in outputs that neither a pure social network, nor a computer network can achieve independently. Thus, the networks of main concern in HUMANE are those where the synergistic effects between humans and machines are immediately evident, such as in systems for mass collaboration. Networks of lesser interest include, for example, simple communication and broadcasting networks such as telephone, telegraph, e-mail, or TV networks, as the medium here may be said to hold more the role of an intermediary. In other words, for a network to be considered as an HMN, the machines need to transform not just transmit. The legacy to actor-network theory is here evident: machines may serve as non-interfering intermediaries or as mediators; in the latter case, the machines affect and transform the interaction that takes place. Our choice to a priori consider certain medium-enabled networks as less interesting is slightly simplistic: e.g. when your e-mail system mistakenly and automatically rejects legitimate e-mail as spam and re-directs it to your spam-filter with the possible consequence that you never read it, should we not consider the e-mail system as transforming the interactions in the human-machine-human network? Some cautions are hence warranted in our decision to approach certain medium-enabled networks as less relevant. However, for this literature review, this theoretical (more than in-practice) distinction makes sense to limit the scope.

Further, we place a particular emphasis on the *network* part in HMNs. That is, we concentrate on the relations and interactions among the elements of the network (humans and machines) rather than on the features and attributes of those elements. This also influences how we will construct our typologies.

In order to systematically review the literature of relevance to HMNs, we develop our in-house scoping and filtering criteria. In selecting the articles, we considered two main factors: article age, with the focus on more recent articles, and article impact, gauged by scientometric indices. Details of our selection procedure are described in Appendix A.

## 1.3 Methods, tools, and techniques used in the study of HMNs

HMNs are complex and studying them requires a diverse set of approaches and tools: surveys, qualitative approaches, network analysis, data mining techniques, experiments, and simulations.

**In-person or online surveys** of HMN users are often used to study the problems of motivation and privacy (Choi & Kim, 2004; Dwyer, Hiltz, & Passerini, 2007a; Hars, 2001; Oreg & Nov, 2008; Sheehan, 2002), as well as acceptance of information technology (King & He, 2006; Lin & Lu, 2011; Sledgianowski & Kulviwat, 2009). The data is then analysed with factor analysis to identify conceptual

groupings and regression analyses or structural equation models to establish correlations with behaviour.

**Qualitative approaches** are helpful for in-depth enquiries into motivations, experiences and barriers. For example, qualitative data from interviews with users are analysed to provide more detailed user-experience accounts (Froehlich et al., 2009a), or for inductive theory development and for inducing propositions for future research (von Krogh, Spaeth, & Lakhani, 2003).

**Log data** of human behaviour and human-machine interactions can be obtained from the HMN, by directly accessing the service database, downloading it with the service API, or scraping it with custom-built software. Researchers can then apply descriptive statistics, network analysis, or data mining techniques to these data.

**Network analysis** is used to investigate the structure of relations among actors (Wasserman & Faust, 1994). Since HMNs involve different types of actors and relations, they are better perceived as multiplex networks (Szell, Lambiotte, & Thurner, 2010) or two-mode affiliation networks (Grewal, Lilien, & Mallapragada, 2006). These complex networks will need to be considered in some detail as we take the HUMANE work forward. The structure of HMNs can be described with many different metrics: degree distribution, degree assortativity, detected communities, clustering, to name just a few. It is also possible to trace how the structure evolves over time.

**Data mining** aims to discover meaningful patterns in large data sets by combining different computational techniques, one of which is machine learning (Witten & Frank, 2005). Machine learning employs various algorithms: cluster analysis, decision trees, Bayesian networks, support vector machines, and many others. These algorithms “learn” from the data to discover patterns in them. These patterns can be used for short-term predictions but they may not be meaningful outside of the particular context.

**Experiments** are used to establish the causal direction in observed correlations in human behaviour. On the one hand, researchers can conduct controlled experiments in computer laboratories (Lorenz, Rauhut, Schweitzer, & Helbing, 2011; Toma & Hancock, 2013) or even more commonly now, online, with subjects recruited from the Web (Mason & Watts, 2010). Such experiments allow for nearly full control over the interaction conditions and any environmental factors (Falk & Heckman, 2009). On the other hand, researchers can make interventions “in the field,” directly in online HMNs (Centola & van de Rijt, 2015; Kramer, Guillory, & Hancock, 2014). In such cases, they hold less control over external factors but obtain better external validity.

**Simulation experiments** can be used as an alternative to experiments in situations where experiments with human subjects are unviable or prohibitively costly (Hu, Chen, & Chen, 2006; K. L. Huang, Kanhere, & Hu, 2010; R. Zhou & Hwang, 2007). Modelling and simulating HMNs is a challenge due to their complex non-linear nature. Agent-based simulation is a discrete-event simulation technique that lends itself to modelling complex non-linear systems to capture emergent phenomena (Bonabeau, 2002). Agent-based models allow these emergent properties to be simulated by representing interacting logical, physical or human system components as agents

(Zambonelli & Van Dyke Parunak, 2003), software entities that have the ability to interact and respond with other agents in their environment.

The above methods can be used to not only analyse existing HMNs but also design, develop, and test new networks. Machine learning techniques can be used to design new reputation systems, recommender algorithms, or search result filtering techniques. In the early stages of development of an HMN, simulation enables investigating different design options and what-if scenarios otherwise not possible to test. Once a new engineering solution for an HMN is well developed, experiments allow testing it and comparing its performance to existing deployments.

## 1.4 Analytical layers

In this report, we take a multi-level analytical approach. We start by the *actors* as the smallest units of analysis and we discuss the features of humans and machines as the basic elements of HMNs. We continue by focusing on the different type of *interactions* between the actors. Having introduced the actors and interactions, we discuss different network topologies emerging from the permutations of interactions and actors. Finally, we consider the overall function of the HMNs at the *behaviour* level.

The content below is structured to follow these analytical layers. Chapters 2 and 3 discuss the actors and interactions to delineate our conceptual framework of HMN types. Chapter 4 presents the findings from the literature along the conceptualized network typology. Chapters 5, 6, and 7 extend our conceptual framework, discuss the behavioural level and point to important avenues for future research and development. These last three chapters contain our reflections following the review.

# 2 Actors

## 2.1 Humans

In the context of HMNs, a “human” means an entity that behaves like a single person (even if the entity is an organization). In contrast to machines, humans have the capacity for emotions, attitudes, sociality, meaning-making, creativity, and complex problem-solving. Also in contrast to machines, human behaviour is unpredictable, yet susceptible to influence.

In most cases, any person can participate in an HMN. Participation is more often determined by the benefits and costs the individual perceives than the individual’s social status or geographic location. The benefits can be divided into economic, intrinsic, and social (Ardichvili, 2008; Chiu, Hsu, & Wang, 2006; Yee, 2006). Individuals profit economically when they receive payments (in money, goods, or services) or obtain skills and qualifications for their paid career. They gain intrinsically (feel a “warm glow”) when they contribute to a good cause, share knowledge, or help others (Andreoni, 1990). Some are also intrinsically motivated to gain or create knowledge for its own sake. Individuals may

also benefit socially if participation in the HMN allows them to create, build, and maintain reputation and social relations, or simply enjoy social interaction. In general, people often have complex motivations to participate and contribute.

Time and effort are the two obvious costs that people incur when they participate in HMNs. Another significant cost is the risk of breached privacy (Krasnova, Spiekermann, Koroleva, & Hildebrand, 2010; Sheehan, 2002). Leaking private information to the public and stealing a user's identity can entail significant financial losses, family distress, and social embarrassment. Some HMNs require participants to reveal their real identity, for example, in order to complete economic transactions or render services in the offline world. In other HMNs, participants can maintain an online identity that is decoupled from their real identity. Even further, they sometimes can participate and contribute anonymously. In all of these cases, however, personally identifying information can be obtained and exploited by ill-intentioned third parties or by the service providers themselves. While in some cases de-anonymization can be beneficial, such as in preventing cyber-bullying and harassment, in most cases people perceive threats to privacy as a significant drawback.

When discussing humans as parts of HMNs, in most cases we need to address (1) the associations or ties between the humans involved and (2) the purposes of the HMNs in question. Both aspects may influence the experiences, motivations and behaviours of humans, and they need to be considered in tandem. Three examples may illustrate the point.

- **Facebook:** Whereas Facebook as of 2015 is a multi-purpose service, increasingly serving as a platform for the dissemination of editorial content and entertainment (likely to a large degree enabled by the existence of the massive network as an asset), it initially was an SNS connecting and re-connecting peers and friends with an offline relationship (Ellison, Steinfield, & Lampe, 2007). This social embeddedness of Facebook to a large extent fuelled and indeed made possible the extensive online sharing practices we have witnessed over the last few years.
- **Sensors:** Electronic devices with connectivity and sensors are increasingly used to measure e.g. personal activity, environmental hazards, transportation habits and health status. The data can be used for personal monitoring only, or shared for medical monitoring reasons with professional health professionals (typically health conditions); shared within social groups and peers (typically sports/activity data); or shared on an aggregate level for public good (typically environment data or traffic information) (Khan, Xiang, Aalsalem, & Arshad, 2013a). Whether, how and with whom the data is shared hence link closely with the purpose and the type of data gathered.
- **Freenet:** Software development requires specialised domain-knowledge and experience, with contributors taking part in intensive learning processes. This is also the case for open source software development, representing a HMN with the purpose of combining the efforts and skills from voluntary developers to collectively create software whose source code is available for modification and enhancement by any user. Open source software may at first seem to suggest that complex tasks can easily be completed collectively between participants with no prior knowledge and ties to each other. Yet, open source projects become communities with formal and informal social scripts to be followed by newcomers. In von Krogh et al.'s (2003) study of the Freenet software development process, the authors analyse how joiners to the developer

community need to adhere to an implicit social joining script before being granted access to the developer community. Signalling interest and experience to the Freenet mailing-list matters less than suggesting hands-on solutions to technical problems and demonstration of technical knowledge in the form of submitting software code.

These three examples are distinctly different in terms of the purposes of the HMNs, yet they all depict how social characteristics need to be discussed as part of the analytical register in order to understand the characteristics and dynamics of the different HMNs. This is particularly the case for HMNs that in some way attempt to connect humans and/or benefit from the collective efforts of distributed resources available in social networks (which is the case for all HUMANE case-studies, but not necessarily for all HMNs). We return to the theoretical reasoning behind the importance of social ties and HMN-purposes in section 3.1.1.

## 2.2 Machines

Though surprisingly not the first entry, the Oxford English Dictionary offers the definition “A material structure designed for a specific purpose, and related uses”<sup>1</sup>, leading to a traditional view of a machine as a task-specific labour-saving device designed to offload mundane, time-consuming or dangerous operations. War machines such as the trebuchet were able to launch heavier and larger objects at enemy strongholds from a safe distance; the printing press was able to produce printed copy with greater accuracy and speed, as well as in greater quantities than scribes or illustrators. To a large extent, earlier machines were designed assuming close human supervision. Human-machine interactions were therefore very much on an unequal basis: humans had to monitor how the machine was running, and intervene if problems arose.

However, machines have subsequently and more recently developed greater autonomy and flexibility (Shoureshi, Swedes, & Evans, 1991). Computers are now capable of running different and more complex operations, in direct collaboration with human operators as well as unsupervised, taking on ever-increasing sophistication. Miniaturisation has meant that this intelligence can be embedded into other machines: a fridge can now monitor food freshness, a domestic heating system can respond to sudden and unpredicted temperature changes, and cars are able to monitor other vehicles and conditions, as well as communicate with each other (Lyytinen & Yoo, 2002). Human-machine interactions are now, therefore, much more on if not equal certainly complementary footings (Norman, 1993).

In consequence, now any electronic device with connectivity can be part of an HMN: personal computers, smartphones, tablets, wearable technology, sensors, embedded chips, servers running algorithms, and so on. These machines take input in the form of text, media, or sensor data, such as vital signs or environmental measures, printed or coded instructions and software, signals and alerts from multiple sources, including other machines as well as humans. This input can be entered by the user or collected automatically. A machine with computational capabilities can aggregate, clean or otherwise transform the input data in order to output something else or even fuse data from

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<sup>1</sup> <http://www.oed.com/view/Entry/111850?rskey=aVj3MO&result=1&isAdvanced=false#eid>

different sources to make complex decisions to be interpreted by other machines or by human experts and operational staff (Atzori, Iera, & Morabito, 2010; Castells, 2011; K.-M. Lee, Min, & Goh, 2015).

To facilitate the functioning of the HMN, the machines need to be available, connected, and secure. Compared to humans, the machines do not have motivation, do not experience trust or reliance, and do not behave altruistically or irrationally of their own volition: they have no agency in that sense (Jia, Wu, Jung, Shapiro, & Sundar, 2012; Rose, Jones, & Truex, 2005). They follow orders and are programmed by a human. Their behaviour and output can appear unpredictable if it is predicated on a combination of outside factors, often requiring human intervention to explain and correct. With autonomic computing, however, there may be a promise of some level of self-regulation and ‘healing’ (Huebscher & McCann, 2008; Kephart & Chess, 2003; White, Hanson, Whalley, Chess, & Kephart, 2004). At the same time, machines are increasingly capable of solving complex data analysis problems which humans would struggle to tackle not least at such speed, though affective responses and the subtlety of nuanced behaviours remains elusive (Norman, Ortony, & Russell, 2003; Pantic & Rothkrantz, 2003; Picard, Vyzas, & Healey, 2001). In such cases, a *quasi*-balanced collaboration is required. Machines are therefore now becoming increasingly significant contributors to HMNs, and no longer communication channels or facilitators of highly-distributed human-to-human connectivity.

## 3 Interactions

### 3.1 Human-human interactions

Machines enable new forms of interaction between humans. Different HMNs allow participants to interact with different levels of intensity and involvement. In some networks (for example, crowdsourcing platforms such as Amazon Mechanical Turk<sup>2</sup>), participants do not have the opportunity to directly interact. In others, they can *observe* each other’s contributions. Depending on the application, they can browse all contributions (as in an online market such as eBay<sup>3</sup>), see algorithmically selected contributions (as in Reddit<sup>4</sup>, which is a content site), see algorithmically customized contributions (for example, via the Newsfeed algorithm on Facebook), or only view aggregate results (as in prediction markets). Once being able to observe contributions, participants can then *evaluate* them by approving them (for example, “likes” on Facebook), approving or

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<sup>2</sup> [www.mturk.com](http://www.mturk.com)

<sup>3</sup> [www.ebay.com](http://www.ebay.com)

<sup>4</sup> [www.reddit.com](http://www.reddit.com)

disapproving them (“upvotes” and “downvotes” on Reddit), rating them (Amazon<sup>5</sup> product “stars”), or commenting on them. Finally, participants can sometimes *modify* others’ contributions by editing or deleting them. For example, Wikipedia editors can revert edits and Linux developers can fix code contributed by others.

Human-human interactions largely depend on trust (Dwyer et al., 2007a; Jones & Leonard, 2008). Phenomena such as trolling, cyber-bullying, and cyber-stalking signify the erosion of trust. Human-human interactions also involve social influence (Bond et al., 2012; Muchnik, Aral, & Taylor, 2013; Onnela & Reed-Tsochas, 2010). Social influence can lead to large-scale behavioural or emotional contagion. This can be both positive, if it results in the spread of pro-social or health-conscious behaviour, and negative, if it leads to dangerous herd behaviour or unproductive groupthink.

### 3.1.1 Social ties in human-human interactions

Understanding the dynamics of different forms of human-human interactions requires understanding social ties, and further connects with the notion of social capital. Whereas we might be quick to point to the importance of good/close friends in our everyday lives, from the perspective of HMNs we are at least equally interested in the importance of connecting peers with limited or no previous relations.

Granovetter (1973, p. 1361) proposed to define the strength of an interpersonal tie as "a combination of time, the emotional intensity, the intimacy (mutual confiding), and the reciprocal services which characterize the tie". In Granovetter's account, ties are strong, weak or absent, with the latter including ties without substantial significance (e.g. nodding to someone living on the same street). The point is that information, or whatever else to be diffused, can reach more people when passed through weak ties. The benefits of weak ties are likewise stressed in research on knowledge building and access to non-redundant information and ideas. As people tend to focus on activities inside their own groups, structural holes between different groups are created, and these different groups will possess information that is non-redundant to the other (Burt, 2004). People connected across groups (structural holes) are consequently more familiar with alternative ways of thinking and behaviour. The ability to deliver valuable ideas is hence less a consequence of being a creative genius, and more creativity as an import-export business across structural holes (Burt, 2004: 388).

Given the benefits of weak ties for dissemination of information and knowledge building, and the potentials of networked technologies to strengthen bridging social capital (Ellison et al., 2007), one may be tempted to jump to the conclusion that this potential is easily and straightforwardly realized. Chiu et al. (2006) examine whether the social capital developed in virtual communities is strong enough to overcome the barriers of complex knowledge sharing. This is a very relevant question to pose: whereas the benefits of crossing structural holes are evident, collaboration, mutual trust and responsibility are more typical for strong ties (Haythornthwaite, 2005). Hence, HMNs that concern simple dissemination of information, data or experiences may require less strong ties compared to HMNs that concern complex collaboration, sharing of more sensitive data, behavioural change or

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<sup>5</sup> [www.amazon.com](http://www.amazon.com)

interactions involving trust and mutual confiding. For example, in a randomized controlled trial of political mobilization messages on Facebook, strong ties were found to be instrumental for spreading both online and real-world behaviour (Bond et al., 2012).

Yet, what is often sought in HMNs is to enable collaboration and sharing of resources in networks where ties are initially absent. Research suggests this is possible, yet in interacting with an online community, social bonds and a sense of community develop. In the study by Chiu et al. (2006) referred to in section 2.1, the authors find that social interaction, reciprocity and identification with the community increased individual's quantity of knowledge sharing, and that community-related outcome expectations are associated with knowledge sharing. Consider also the informal social scripts that successful joiners to the developer community of Freenet software were found to adhere to (von Krogh et al., 2003). The technical systems or the infrastructure for these communities make a connection technically available and support latent social network ties; i.e. ties that are technically possible but not yet activated socially (Haythornthwaite, 2005). Once someone starts interacting with the community, these technically enabled latent ties are converted from latent to weak.

### 3.2 Human-machine interactions

When the role of the machine in a HMN may be seen as that of a mediator (that is, its output does not equal the input from the other nodes in the HMN), it is relevant to analyse the human-machine interaction. As the human input in human-machine interactions will have different characteristics than the machine output, it is useful to discuss these separately.

#### 3.2.1 Human input in human-machine interactions

To some degree, human-machine interactions are gated only by the communication protocol used. Early computers, for instance, needed punched card or tape, whereas more recently, input can be provided via different input channels including keyboards, data channels, and even speech, movement and gesture. Interactions in HMNs are therefore increasingly multi-modal, with different HMNs allowing individuals to contribute or interact in different ways sometimes dictated only by ease of use (Lin, 2003; Lin, Zhang, & Watson, 2003).

In respect of what humans input, individuals will make contributions to different extents. In some networks, users do not have to do anything to contribute data beyond interacting with the service or even simply turning on the service. In these cases, participants *contribute passively*. Their social interactions, personal characteristics, and site behaviour are automatically collected by the service. These data are then analysed and often used to recommend actions (as some crowd sensing applications do), social contacts (as in LinkedIn<sup>6</sup>), or products (as in Netflix<sup>7</sup>). In other HMNs, contributors need to make the effort and take the time to *contribute actively*. They contribute by filling out surveys, composing and editing text, writing code, sending sensor measurements, or uploading videos, photos, and news links. In more extreme cases, participants can also *modify* the

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<sup>6</sup> [www.linkedin.com](http://www.linkedin.com)

<sup>7</sup> [www.netflix.com](http://www.netflix.com)

content on the HMN or the rules by which the content is collected, managed, and distributed. Consumers have therefore become “prosumers,” and can still switch between the two modes as suits the service or their own needs.

Trust plays a major role in human-machine interactions. Participants may have different concerns in different contexts. They may struggle with a concern that the technology will undermine their own position, or be unwilling to rely entirely on the capabilities of the machines (J. D. Lee & Moray, 1992; J. D. Lee & See, 2004). Others are mainly concerned with the security of their private data (Dwyer, Hiltz, & Passerini, 2007b). In response, machines need to be transparent and predictable, to create a perception of trustworthiness (Cheshire, 2011; Corritore, Kracher, & Wiedenbeck, 2003; McEvily, Perrone, & Zaheer, 2003; Schoorman, Mayer, & Davis, 2007). On the other hand, they may also need to identify and counteract deliberate malevolence: hacking, vandalism, and intentional abuse of their algorithms, such as Google bombs and link farms.

### 3.2.2 Machine output in human-machine interactions

The converse of how and what humans input to machines in their interactions is how and what machines output in response. Once more, and just as input can be multi-modal sometimes at one and the same time, the output channel may well depend on the service or application (signage, broadcasting, experimentation, web searches, and so forth) and may also depend on the preferences of the recipient (a recorded message, a printout, a visual display).

On top of that, different HMNs may introduce different levels of control over the content. Machines may simply list or *show the contributions*, as is common in online marketplaces and in direct response to a specific query. Alternatively, they may employ complex algorithms to filter and *select contributions*, as Web search engines do, for example, personalising or customising results to reflect previous user behaviours. Or they may even use bots and human intelligence to *modify contributions*. For example, Wikipedia uses vandalism-detection algorithms and forums employ censorship algorithms, while content sites like Digg<sup>8</sup> maintain centralized content management.

Machine interventions to the content that observers see and use can lead to undesirable self-reinforcing feedback loops that can negatively impact the service rendered. For example, if the number of users who see a particular contribution increases the chance of others seeing it, the diversity of content can decrease. From the participants’ point of view, there is also the problem of trust, since the machines in HMNs often employ “black-box” algorithms that can affect one’s behaviour and mood without the participant’s knowledge and explicit consent (Bond et al., 2012; Kramer et al., 2014). These two and similar effects have been labelled “filter bubble” (Pariser, 2011). However, such filtering or adaptation of content may be both necessary and beneficial. Without such filtering, the result may be information overload on the humans in the HMN. Further, from a machine network perspective, the size and amount of content to be delivered will impact network performance and therefore potentially undermine the quality of experience (QoE) for the user. This

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<sup>8</sup> <http://digg.com/>

may lead to the monetisation of content delivery, imposing strict controls and monitoring of throughput especially in last-mile segments.

### 3.3 Machine-machine interactions

A concern for QoE in machine-human interactions is closely related to quality of service (QoS) between machines within a network supporting HMN capabilities. In traditional plain old telephone service (POTS) networks, this often came down to routing and providing redundant configurations to ensure that point-to-point communication could be guaranteed irrespective of potential failures or bottlenecks. HMNs similarly require complex assemblages of multiple computers and devices; in some cases dedicated links and subnetworks are required to guarantee QoS at least (such as Content Delivery Networks). The machines communicate via Bluetooth, the Internet, or satellite, depending on proximity and the required QoS. Since not all such machines will be owned by the same service provider or carrier, contractual arrangements must be in place in support of agreed levels of service. As and when these are in place, there is also potentially the issue of transmission speeds and throughputs, leading to dedicated networks, packet-inspection and/or local caching. Although justified on the basis of service delivery, this could compromise fairness as well as privacy (Gedik & Liu, 2008; Julian, Chiang, O'Neill, & Boyd, 2002; Kamble & Sharma, 2004).

With privacy and data sensitivity in mind, there may be a need to impose a logical network on top of the existing structures (Virtual Private Network, or VPN), requiring specific security protocols agreed between the different components of a network. Security architectures often mimic interpersonal trust relationships in this way, effectively introducing trust transfer into a purely machine-based exchange (Hardjono & Weis, 2004; McEvily et al., 2003; Stewart, 2003). In other cases, often in connection with issues of robustness as well as privacy, dedicated networks, including private and reserved broadcast wavelengths will be used to carry data for specific purposes or in special cases (Chiti, Fantacci, Maccari, Marabissi, & Tarchi, 2008; Salkintzis, 2006). There may even be specific automated practices introduced to impose security compliance without human intervention<sup>9</sup>.

Another significant challenge faced by the machine-machine sub-network is scalability (He et al., 2011; Ugander & Backstrom, 2013). As the number of humans in HMNs grows, machines need to connect, communicate, and compute in a more efficient way, including sometimes sophisticated routing and resource allocation management to ensure connection between the right user(s) and the right machine(s) (Baran & Wu, 1989; Broch, Maltz, Johnson, Hu, & Jetcheva, 1998; Cardellini, Colajanni, & Philip, 1999). In addition, they need to be able to provide consistently good bandwidth, guarantee compatibility between different communication protocols and operating systems, and improve data structures for efficient querying, caching and storage (Chen, Doumeingts, & Vernadat, 2008; Mehlhorn & Näher, 1989).

For HMN analysis to be feasible, it will be necessary to simplify the analysis of machine-machine interactions. In particular, in the case of underlying or enabling machine networks that are perceived

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<sup>9</sup> Personal communication (FI-STAR project): it is possible for patient data to be erased automatically from the personal data devices of medical staff as they leave a hospital.

as one and the same unit by all the relevant nodes of the HMN, this network will be analysed and represented as a single node whose inner workings are considered a “black box.” This is not to say that machine-machine interactions will not be considered; rather, they will be considered only to the extent that is valuable to the analysis at hand.

## 4 Networks

The discussion of machine-machine interactions requires a sufficient amount of technical background in computer and electrical engineering, which is beyond the scope of this part of the literature review. As a result, our discussion of HMNs focuses initially on the human-human and human-machine interactions in the context of contemporary human machine-enabled networks. There are clearly differences in the relative roles and status of machines and human actors across the different types of network. For instance, there will be cases where the machines act as a “human proxy” to facilitate what is essentially human-to-human relationships. In other cases, they become semi-autonomous agents that act alongside and in collaboration with human agents in the network. In particular, the analysis must be based on the existence and intensity of these interactions and the extent to which they are essential for the functioning of the HMN. Here we identify and differentiate between eight initial types of HMNs (see *Appendix A: Systematic literature search* for how these were identified): public resource computing, crowdsourcing, Web search engines, crowd sensing, online markets, social media, multiplayer online games and virtual worlds, and mass collaboration (Figure 1: Initial types of human-machine networks).

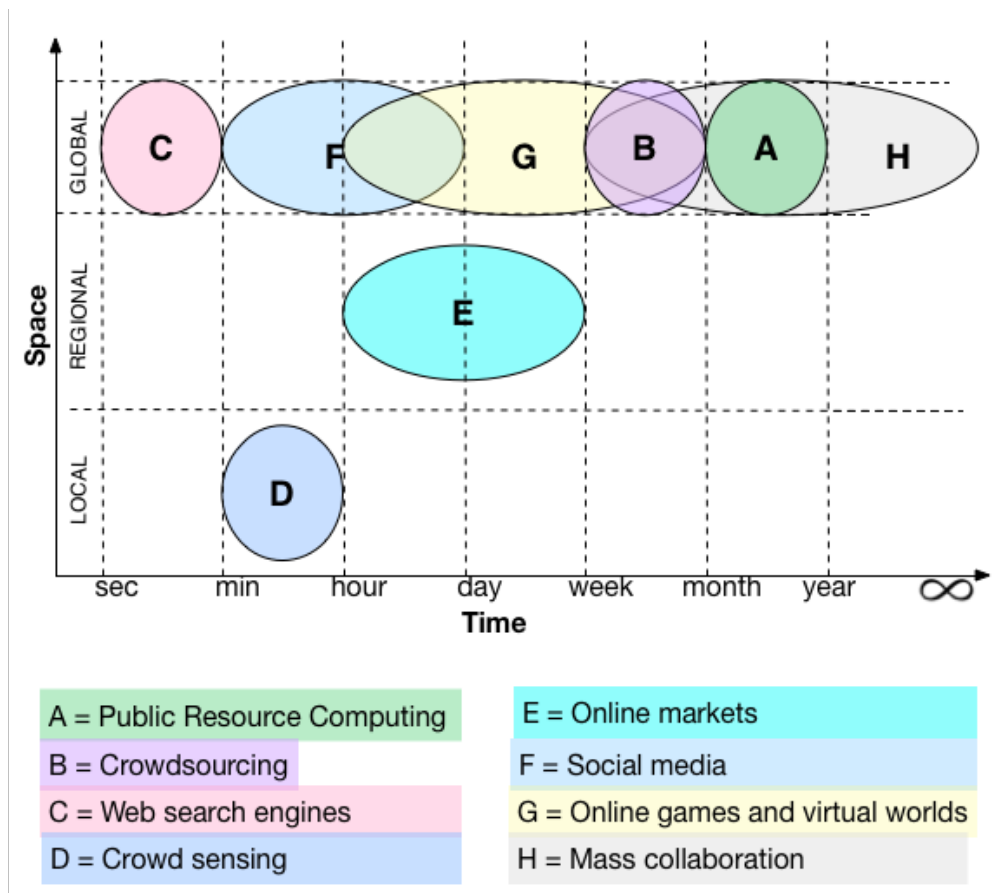
The initial types are to be seen as a starting point for the review, not as a complete or validated HMN typology.

These initial HMN types deliberately expand beyond the specific HUMANE case studies (as described in D3.1), with the objective of developing network components with relevance also for human-machine networks not covered by the limited number of case studies in HUMANE. These networks occur over different expanses of geographical space and over different periods of time (Figure 2: Geographical space and interaction duration of human-machine networks).

On the basis of the initial set of components and types in Figure 1, we will then develop our ideas further into multiplex and complex networks to validate our approach and show its applicability to a number of related projects involving human-machine networks. This will then provide a basis for further work in HUMANE to develop these types further and start to build up a roadmap of where HMNs may develop in the future.

Our discussion of the eight types below concentrates on the design issues related to human participation and to the human-human and human-machine interactions. The conceptual boundaries around the eight networks are blurrier than our simplified analytical framework suggests. In fact, our review leads to the conclusion that the internal interactions in such HMNs tend to intensify and that the types begin to overlap. Nevertheless, the framework has been useful for the initial structuring of our discussion and covering a large class of use cases.

**Figure 1: Initial types of human-machine networks.**



**Figure 2: Geographical space and interaction duration of human-machine networks.**

The types outlined in the figures above therefore provide us with a set of components to consider different types of networks: nodes (human or machine), connections (the directional arrows describing the influence the connected nodes have on each other). The types may also be discussed in terms of other characteristics, such as their temporal and spatial properties (as visualized in Figure 2); note, however, that the illustration of temporal and spatial properties of the initial HMN types are only meant as an exemplification.

In the following sections we will expand on a description of each of these initial types before moving beyond the state of the art to consider how the primitives used to describe these types may be applied to more complex human-machine networks.

#### 4.1 Public-resource computing

Public-resource computing (PRC) projects are distributed computing networks, where each processing unit is a voluntarily offered personal computer. The majority of PRC projects are dedicated to scientific projects in fields as diverse as astrophysics, mathematics, molecular biology, and seismology. PRC networks are the simplest HMNs as far as the human-human and human-machine interactions are concerned. Once volunteers sign up for a PRC project, they are no longer

required to actively contribute time or effort. At the same time, they will not receive any substantial feedback from the project either.

The first PRC systems were launched in 1996-1997: GIMPS (The Great Internet Mersenne Prime Search) and Distributed.net (Anderson et al., 2002). SETI@home is another early instance of a PRC network. It was launched in 1999 with the goal to analyse radio signals from space in search of extra-terrestrial intelligent life. Further examples include the World Community Grid, intended to tackle scientific research projects in any field (Hachmann et al., 2011) and GPUGRID, designated to molecular dynamics simulation methods (Buch, Harvey, Giorgino, Anderson, & De Fabritiis, 2010).

The design of PRC systems crucially depends on building the machine-machine interaction infrastructure. Nevertheless, considerations regarding the recruitment and motivation of contributors remain important. To attract participants, successful CPR platforms have emphasized the social value of their scientific projects and let mass media news coverage and word-of-mouth do the rest (Anderson et al., 2002). To retain participants and increase contributions, they have built reputation systems based on numeric measures of contributed computation and allowed the ability to view others' profiles, participate in message boards, and form and join teams (Anderson, 2004; Beberg, Ensign, Jayachandran, Khaliq, & Pande, 2009). Such infrastructure stimulates individual and group competition. Empirical research suggests that team competition is particularly important. Being affiliated with a team significantly increases one's contribution. More importantly, being part of a team maintains high levels of contribution over time (Nov, Anderson, & Arazy, 2010).

As PRC systems have grown in popularity and sophistication, new design challenges have emerged. These have been reflected in the structure of the machine-machine sub-network. One of the major issues in PRC is managing the expected high rates of machine node unavailability. In current PRC implementations, this has led to redundant computing (Anderson, 2004; Mayer, Velasco, & Klarl, 2015). Redundancy also helps resolve erroneous computational results due to malevolent users or, more often, malfunctioning machines. Alternative solutions to node unavailability include designing a framework core architecture that contains an extra layer that monitors, manages and brokers resources (Cuomo et al., 2012) and designing a hybrid resource architecture by supplementing volunteer computers with a small set of dedicated, reliable computers (Lin et al., 2010).

Another major problem in current PRC systems is the backend bottleneck due to the centralized storage of results. This problem can be resolved by combining PRC with public resource storage, thus limiting the volume of data transfer too (Beberg et al., 2009). Additional issues of unique authentication, authorization, resource access, and resource discovery can be resolved by borrowing ready-made solutions from grid computing (Foster, 2001).

Finally, current implementations of PRC are limited to tasks with independent parallelism, meaning that participating machines are not required to communicate with each other (Anderson et al., 2002). Newer projects, however, take the form of peer-to-peer networks. For example, Marozzo and colleagues (2012) develop a MapReduce-based peer-to-peer PRC system in which autonomous nodes are dynamically assigned slave roles, master roles, or backup master roles. In another example,

Mayer et al. (Mayer et al., 2015) implement a cloud system of a loose set of voluntarily provided heterogeneous machine nodes that uses a gossip-style protocol for communication.

## 4.2 Crowdsourcing

Jeff Howe originally coined the term crowdsourcing in the June 2006 issue of *Wired* magazine to denote situations where a company or institution take a function once performed by employees and outsource it to an undefined network of people in the form of an open call (Howe, 2006). The term “crowdsourcing” has since been used in a very broad sense to denote a broad range of HMNs (Doan, Ramakrishnan, & Halevy, 2011; Geiger, Seedorf, Schulze, Nickerson, & Schader, 2011). Here, we use it to denote systems that are based on open calls for the voluntary undertaking of tasks (Estelles-Arolas & Gonzalez-Ladron-de-Guevara, 2012b), hence closely aligned with Howe's original definition. Crowdsourcing is as such a top-down initiated process, and usually distinctly different from mass collaboration in, for example, open software development (see Section 4.8). Since these tasks are well defined, contributors can be potentially remunerated. The defining characteristics of these HMNs are that humans actively select tasks and contribute to them but do not generally interact and collaborate with each other. More importantly, humans rarely receive any feedback from the machine – they do not obtain any information on or direct benefits from the project they contribute to. In a sense, crowdsourcing platforms are similar to distributed computing systems: each user is equivalent to a processor that needs to solve a task requiring human intelligence (Kittur et al., 2013).

Prominent examples of crowdsourcing HMNs include online markets such as Amazon Mechanical Turk<sup>10</sup> and Crowdfunder<sup>11</sup>, voluntary mapping websites such as Ushahidi<sup>12</sup> and OpenStreetMap<sup>13</sup>, and citizen science projects such as Zooniverse<sup>14</sup> and FoldIt<sup>15</sup>. Companies and organizations may also crowdsource innovation tasks to the general public (as with Threadless<sup>16</sup>) or experts beyond the organization's boundaries (such as InnoCentive<sup>17</sup>) (Brabham, 2008), a practice which is often also termed open innovation. In crowdsourcing as open innovation, interaction between human participants in the form of commenting and collaborative refinement of ideas can be decisive for companies' abilities to benefit from the efforts of the crowd (Di Gangi & Wasko, 2009). In consequence, we might understand the ideation process of open innovation as crowdsourcing, yet the process of developing and refining ideas may more appropriately be understood as a form of mass collaboration (see 4.8).

Perhaps the crowdsourcing project that is most familiar to the general public is reCAPTCHA. Web users contribute to reCAPTCHA when they take a Turing test on a website in order to confirm that they are human and not a computer. As part of the test, they transcribe scanned words that state-of-

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<sup>10</sup> [www.mturk.com](http://www.mturk.com)

<sup>11</sup> [www.crowdfunder.com](http://www.crowdfunder.com)

<sup>12</sup> [www.ushahidi.com](http://www.ushahidi.com)

<sup>13</sup> [www.openstreetmap.org](http://www.openstreetmap.org)

<sup>14</sup> [www.zooniverse.org](http://www.zooniverse.org)

<sup>15</sup> <https://fold.it/>

<sup>16</sup> <https://www.threadless.com/>

<sup>17</sup> <http://www.innocentive.com/>

the-art Optical Character Recognition programs failed to recognize and thus help digitize large volumes of old publications.

The successful functioning of crowdsourcing HMNs requires recruiting and maintaining a pool of intelligent, diverse, and capable contributors (Saxton, Oh, & Kishore, 2013) and managing and processing their contributions.

Various approaches can be undertaken to successfully recruit and keep contributors. One way is to make the contributions implicit, as in reCAPTCHA. Most individuals complete the task unbeknownst to them – they are simply trying to register or make a purchase online. The two words in reCAPTCHA (one for the test and one for the project) are longer than the usual short string of randomly generated characters in a regular CAPTCHA. However, since humans are accustomed to patterns in natural language, the test is neither more difficult nor more time-consuming (von Ahn, Maurer, McMillen, Abraham, & Blum, 2008).

Another method to motivate contributors is to remunerate them. Payments can be fixed or success-based. They can come in the form of a piece rate, a piece rate with a bonus, a quota rate, or a contest prize. Experimental research has shown that higher piece rates increase the quantity but not the quality of contributions; further, quota rates result in higher quality work for a smaller budget than piece rates (Mason & Watts, 2010). Prize-based contests are optimal for highly uncertain innovation problems as they involve high number of entrants who execute multiple independent trials, which increases the probability for a maximally performing solution (Lakhani et al., 2013). The effect of payment is not always straightforward, however, as it may crowd out social motivation (Frey & Jegen, 1999).

Much participation in crowdsourcing projects is voluntary and indeed driven by intrinsic and social motivation. To attract more volunteers, crowdsourcing platforms can emphasize the connection between people's contributions and the project outcomes. For example, citizen science projects can keep participants updated on the articles published as a result of their contributions (Cooper et al., 2010). Volunteer-mapping sites can successfully rally on social media around natural disasters (Zook et al., 2010).

Gamification is another strategy to recruit volunteers and encourage their prolonged engagement in a crowdsourcing project. A game offers the players a varied motivation set that leverages ambition, competition, and cooperation. Thus, a gamified crowdsourcing project should allow for short-term and long-term rewards through tracking game score and player rank, social praise by allowing comments on chats and forums, and collaboration by enabling the formation of teams (Cooper et al., 2010). These strategies have been successfully implemented in biology projects for discovering protein structures (Cooper et al., 2010), aligning multiple sequences of DNA (Kawrykow et al., 2012), and solving in vitro RNA design problems (Jeehyung Lee et al., 2014).

Managing the contributors' work poses the second major challenge in designing crowdsourcing platforms. Contributions need to be collected, processed, and aggregated. Although the *quantity* of contributions is what makes crowdsourcing work (Surowiecki, 2005), the *quality* of contributions remains of paramount importance.

One major issue is dealing with biases and errors in contributors' submitted work, whether malevolent or accidental. Quinn and Bederson (2011) propose multiple techniques to do this: output agreement, input agreement, economic incentives, defensive task design, reputation systems, redundancy (combined with majority consensus), ground truth seeding, statistical filtering, multilevel review, expert review, and automatic check. Allahbakhsh and colleagues (2013) add to the list run-time support, workflow management, worker selection, and contributor evaluation. The latter two have been implemented in sophisticated algorithms that assign weights to workers based on the quality of their contributions in order to account for biased responses (Ipeirotis, Provost, & Wang, 2010; Raykar et al., 2010) and eliminate responses by spammers (Raykar & Yu, 2011).

Beyond correcting for intentional or unintentional errors that have already occurred, one could implement more foresighted strategies to improve the quality of contributions. These strategies usually involve creating and structuring interactions between contributors. For example, Kittur et al. (2011) and Bernstein et al. (2010) implemented frameworks that manage the coordination between users to let them complete complex tasks such as writing and editing articles. Silvertown and colleagues (2015) purposefully connected participants with experts in a hybrid learning-crowdsourcing platform for the identification of biological species. Khatib and others (2011) introduced tools for free collaboration between contributors that lead to the discovery of new algorithms for the folding of proteins. Bayus (2013) suggests that encouraging contributors to comment on diverse sets of ideas proposed by others could prevent creativity stagnation due to the "fixation effect" and help maintain an on-going supply of good new ideas in idea-generating crowdsourcing platforms.

### 4.3 Web search engines

A Web search engine (WSE) is a system that searches and returns content from the Web. Apart from formulating queries, users do not actively contribute to the system. Their contribution is passive: the WSE observes and analyses their search behaviour to improve and customize search results. Additionally, the search results are filtered and ranked, which is the most important function of these HMNs.

The greatest challenge that WSEs need to address is scaling up along with the Web (Arasu, Cho, Garcia-Molina, Paepcke, & Raghavan, 2001; Brin & Page, 2012). Since this problem entails complex technical solutions at the level of machine-machine interactions, it is out of the scope of the present report. Instead, we here focus on design solutions related to the input and the output (human-machine interactions) of WSEs.

WSEs can use information on users' search queries to provide automatic search assistance. For example, Huang and Efthimiadis (2009) propose to use each user's own input. They suggest that information on the user's action after an initial query, together with information on the type of subsequent query reformulation, can improve query assistance. Another approach, which makes even better use of the WSE as an HMN, is to use other users' inputs. This approach has been applied in techniques that automatically expand queries in order to provide more relevant results. This type

of automatic query expansion technique, known as search log analysis, relies on mining query associations that users implicitly suggest in their own search and click behaviour (Carpineto & Romano, 2012). The same technique can be used to solve the problem that is opposite to expanding short queries -- limiting verbose queries to essential keywords (Bendersky & Croft, 2008).

WSEs can also use information on users' behaviour to filter and rank search results. The links between Web pages implicitly provide such information. A link from page A to page B implies that the creator of page A recommends page B to the users (Arasu et al., 2001). This idea stands behind the Google PageRank algorithm, which determines the importance of a page based on the importance of the pages that link to it (Page, Brin, Motwani, & Winograd, 1999). In essence, the PageRank algorithm simulates a user who randomly traverses the network of links on the Web; the most important pages are the ones that the user is more likely to visit. Another well-known ranking algorithm, HITS<sup>18</sup>, also uses recursive logic to differentiate two types of important Web pages, hubs and authorities: hubs are pages that point to many authorities and authorities are pages that are pointed to by many hubs (Kleinberg, 1999). Newer ranking algorithms tend to use even more information about the linking structure. For example, ClusterRank takes into account not only a page's number of linked neighbours and the neighbours' influences but also the neighbours' links with each other (D.-B. Chen, Gao, Lü, & Zhou, 2013).

Influencing user behaviour by how users implicitly behave can lead to recursive processes and systematic biases that can affect the function and the value of WSEs (Introna & Nissenbaum, 2000). Cho and Roy (2004) use a simulation model to show that new Web pages are at a severe disadvantage when users follow search engine results, compared to randomly following links. Based on an empirical analysis of 28,164 web pages, however, Fortunato and colleagues (2006) show that popular pages get less traffic than expected compared to both the search-only and link-only predictions. With the help of a simulation model, they suggest that diversity in the topical interests of users can account for the relative egalitarian Web traffic pattern observed. Gollapudi and Sharma (2009) suggest that WSEs need to intentionally diversify results to improve user satisfaction.

To personalize search results and improve their relevance, WSEs can also analyse individual behaviour (Steichen, Ashman, & Wade, 2012). For example, Collins-Thompson and colleagues (2011) propose algorithms to re-rank search results based on an estimation of the users' reading proficiency. Jansen et al. (2008) suggest that WSEs can use knowledge of user intent (whether informational, navigational, or transactional) to provide more relevant results.

Finally, WSEs can also use peers' behaviour to improve the results from individual searches. This relatively recent model is known as social search. First, WSEs can potentially incorporate search data from social bookmarking (Heymann, Koutrika, & Garcia-Molina, 2008). Second, WSEs can mine the profiles of a user's online social networks friends and return results based on their recommendations (Morris, Teevan, & Panovich, 2010). Further, WSEs can be adapted to support collaborative search in real time (Morris & Horvitz, 2007; Morris, 2013).

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<sup>18</sup> Hyperlink-Induced Topic Search.

## 4.4 Crowd sensing

In crowd sensing applications, users with computing and sensing devices (for example, smartphones or fitness trackers) share data and the application uses the data to measure and map certain phenomena (Ganti, Ye, & Lei, 2011). The contributions by users can be active, as well as passive. The contributions are then analysed and action and behaviour recommendations are sent back to the user.

Crowd sensing has been employed in many different areas, including traffic, health, and environmental monitoring (Khan, Xiang, Aalsalem, & Arshad, 2013b). Applications have been developed to create real-time awareness of earthquakes (Faulkner et al., 2014), track and encourage physical activity and healthy lifestyle (Consolvo et al., 2008), track personal transportation patterns to encourage “green” transportation behaviour (Froehlich et al., 2009b), and predict bus arrival times (Zhou, Zheng, & Li, 2012), among many others.

Participating in crowd sensing incurs real costs: increased consumption of energy and bandwidth, as well as increased risk of leaked personal information (Ra, Liu, La Porta, & Govindan, 2012). As a result, most research on crowd sensing has focused on designing monetary incentives for participation, reducing participation load, improving energy efficiency, and guaranteeing privacy.

To guarantee an adequate number of participants, some researchers have proposed monetary incentives through reverse auctions, whereby users claim bid prices for their sensing data (Koutsopoulos, 2013; Lee & Hoh, 2010). Others have suggested that this could be achieved through opportunistic sensing, that is, sensing that is fully automated and does not require the user’s active involvement (Lane et al., 2010). Full automation, however, is difficult to achieve technically, as the application needs to combine data from multiple sensors to infer the context. Instead, others have focused on improving the energy efficiency of the crowd sensing applications. Lu et al. (2010) present methods to turn sensing on and off depending on the quality of input data and the user’s long-term behaviour and mobility patterns. Sheng, Tang, and Zhang (2012) propose a collaborative sensing approach, whereby data collected from mobile phones is analysed in real time on servers in a cloud in order to calculate the best sensing schedule and inform the phones when and where to sense.

Guaranteeing privacy is a more challenging problem to solve. Sensing applications are in danger of leaking personal data such as user’s location, speech, potentially sensitive images, or biometric data (Christin, Reinhardt, Kanhere, & Hollick, 2011). Even if sensing data looks safe, they may be reverse-engineered to reveal invasive information. Last but not least, there is also the “second hand smoke” problem: a person with a sensor can undermine the privacy of nearby third parties (Lane et al., 2010).

Effective privacy-protection measures can be implemented at every stage of the data’s path from collection to consumption (Christin et al., 2011). When reporting data, spatial cloaking techniques can be combined with data perturbation to improve user anonymity without affecting aggregate data estimates (Huang, Kanhere, & Hu, 2010). During that stage, phones can also combine their data with data from their neighbours before transmitting it to the application server (Li, Cao, & Porta, 2014). Techniques like this can be effectively combined to allow even for anonymity-preserving reputation

systems (Wang & Cheng, 2013). However, it has been shown that even if the collected temporally and geographically tagged data are anonymized, only few data points can be uniquely linked to individuals in large crowds (Montjoye & Hidalgo, 2013).

Processing and analysing the collected data presents the second substantial design challenge for crowd sensing systems. Due to user mobility, density, and privacy preferences, the data delivered often has many measurement gaps in both time and space (Ganti, Pham, Ahmadi, Nangia, & Abdelzaher, 2010). In order to be able to generalize from a sparse sampling of high-dimensional spaces, one needs to employ sophisticated data interpolation techniques (Mendez, Labrador, & Ramachandran, 2013). Further, to make best use of the data a user reports, often the context needs to be inferred, which can be done with the help of machine learning techniques (Pejovic & Musolesi, 2015b). Finally, context-rich data from multiple users can be combined to predict models of future behaviour and offer action recommendations (Pejovic & Musolesi, 2015b).

#### 4.5 Online markets

Under the initial type “online markets” we group a number of HMNs that involve the exchange of goods and services. The things that are exchanged differ but what unites these HMNs is the common relational structure. In particular, users can view each other’s contributions and in some cases can evaluate them, but cannot modify them. More importantly, while users actively make contributions, the service does not filter or rank them but simply lists them, either individually or in an aggregate form. In other words, the service usually does not bias the content a user is exposed to.

Online markets are very familiar to most Web users. First, there are consumer-to-consumer markets such as Craigslist, eBay, Uber, and Airbnb, which connect users who offer material goods and services with users who seek those goods and services. File sharing networks such as Gnutella and BitTorrent are similar with the exception that the exchanged goods are digital. Finally, prediction markets, such as the Iowa Electronic Markets and TradeSports, where users trade “stocks” tied to future events, are another prominent example of online markets.

Peer-to-peer (P2P) and file-sharing markets involve unregulated direct inter-user transactions and as a result, their functioning crucially depends on trust. The problem of trust online is most commonly addressed by designing and implementing reputation systems (Jøsang, Ismail, & Boyd, 2007). In a reputation system, users rate each other after a transaction and the aggregated ratings inform other users in their own transaction decisions. When designing reputation systems, it is important to take certain well-established empirical facts about social influence in consideration. Previous research has shown that when users deal with unknown sellers or providers, positive reputation matters but negative reputation is much more decisive (Standifird, 2001). The opposite appears to be true when users interact with well-known brands: positive information has a stronger effect on purchasing decisions than negative information (Adjei, Noble, & Noble, 2010). High reputation means high trust by others but who those others are also matters (Baek, Ahn, & Choi, 2012). For example, recognition by a well-known other, such as an institution, affects one’s trust positively to a higher extent than recognition by one’s peers (Jones & Leonard, 2008). The idea to weight reputation by the trustee’s

importance in the trusting network has been implemented in two recent reputation algorithms. The EigenTrust algorithm (Kamvar, Schlosser, & Garcia-Molina, 2003) is based on the rule of transitive trust: if I trust a user I am also likely to trust the people that that user trusts. The PowerTrust algorithm (Zhou & Hwang, 2007) relies on the idea of identifying the few power users who can indisputably serve as authorities.

Individuals' estimated trust and reliability could also inform structural re-designs of the online market. For example, Saroiu, Gummadi, and Gribble (2001) propose to use this information to delegate different responsibilities to different users in P2P file sharing applications. Such intervention is intended to mitigate free-riding, where most users consume without paying back to the community in return (Hughes, Coulson, & Walkerdine, 2005).

Information on existing social structure can be used to improve not only trust and cooperation in online markets but also content search. Sripanidkulchai (2003) proposes to preserve the anonymity of the system but artificially group users by interests. Since users who already share interests are likely to have more interests in common, a content location algorithm that exploits the interest overlay network results in faster content queries, lower system load, and improved scalability. Such implicit grouping by similarity in interests and behaviour has already been implemented in "collaborative filtering" recommender systems, which are common in online markets (Schafer, Konstan, & Riedl, 1999; Schafer, Konstan, & Riedl, 2001). In contrast, Pouwelse and colleagues (2008) go further: to improve content discovery and recommendation, they propose de-anonymizing the P2P system by introducing social-network capabilities.

Prediction markets differ from P2P and file sharing markets because the exchanges in them are centrally regulated. Consequently, they are less affected by the problem of trust. Instead, the major problem they face is how to improve predictions. Once again, the solution has to do with careful design of the underlying user-to-user interaction structure. Prediction markets work because of the diversity of users (Surowiecki, 2005). This makes them robust to manipulation by a small group of individuals (Hanson, Oprea, & Porter, 2006; Wolfers & Zitzewitz, 2004). However, social influence can undermine diversity: it both shifts the average estimate and increases the users' confidence in it (Lorenz et al., 2011). Hence, prediction markets should reduce possibilities for interactions between users, such as observing users' current prediction, past performance, or formal expertise. Nevertheless, to improve the prediction market performance, it is possible to combine the predictions by the crowd with predictions by a panel of experts (Prokesch, von der Gracht, & Wohlenberg, 2015).

## 4.6 Social media

In one of the most cited definitions, social media (SM) is defined as "a group of Internet-based applications that build on the ideological and technological foundations of Web2.0, and that allow the creation and exchange of User Generated Content" (Kaplan & Haenlein, 2010, p. 61). Kaplan and Heinlein's definition is very broad, with the consequence that they include virtual worlds such as Second Life and mass collaboration projects such as Wikipedia as examples of social media. A more

subtle definition and understanding of social media is needed. Considering types of human-machine networks and attempting to advance our knowledge of these, we consider it necessary to start from the nodes in the network and their typical interactions. In social media, human nodes assess each others' contributions (rather than modify each others contributions) (see Figure 1). SM is intended to enable users to form online communities and interact and share information in them (Kim, Jeong, & Lee, 2010). In SM, users can contribute content actively. They are also actively involved in observing and evaluating each other's contributions. The applications use these evaluations to filter the content that users receive. This filtering can be site-wide or user-specific.

SM included social network applications such as Facebook and LinkedIn. In these applications, users maintain a profile and a list of users with whom they are connected, both of which can be viewed by others (boyd & Ellison, 2007; Donath & boyd, 2004). SM also includes content communities such as Reddit and Tumblr, where users share news and media and vote and comment on each other's contributions. Some SM applications have the properties of both social network and news-sharing applications, e.g. Twitter (Kwak, Lee, Park, & Moon, 2010). Additional examples include review and rating applications such as Yelp and TripAdvisor and discussion forums and question-and-answer sites such as Yahoo Answers and College Confidential.

Participation in SM highly depends on users' motivation and concern for privacy. Enjoyment is the strongest motivator to use SM (Lin & Lu, 2011). Still, utilitarian considerations play a role: users often use SM to organize social events and disperse news in an effective way (Xu, Ryan, Prybutok, & Wen, 2012). Further, SM is self-affirming, in the sense of satisfying the users' need for self-worth by allowing them to exhibit a successful, attractive, and well-connected version of themselves (Toma & Hancock, 2013). More interestingly, there is a network externalities effect on motivation. High levels of adoption of SM among one's peers not only increases the perceived enjoyment of the SM (Lin & Lu, 2011) but also directly increases one's likelihood to use it (Sledgianowski & Kulviwat, 2009).

Protecting personal data and privacy is a complex problem in SM. Even if users keep their profiles private, their friendships and group affiliations sometimes remain visible. In addition, some of their friends may have public profiles. Previous research has shown that friendships, group memberships, and rating behaviour can be used to infer sensitive personal attributes and information (Kosinski, Stillwell, & Graepel, 2013; Zheleva & Getoor, 2009). Users' privacy is threatened by other untrustworthy users, ill-intentioned third parties, as well as the SM providers themselves. To protect users from other users, SM developers can analyse the SM network structure to infer users' trust (Mislove, Marcon, Gummadi, Druschel, & Bhattacharjee, 2007). Further, they can develop machine learning models to describe a user's privacy preferences towards each of his network contacts; these models can then be used to configure that user's privacy settings automatically (Fang & LeFevre, 2010; Gilbert & Karahalios, 2009). For even more strict privacy, the architecture of SM can be decentralized so that users store their private data on other users' machines, such as individuals whom they trust in real life (Cutillo, Molva, & Strufe, 2009).

One of the most significant functions of SM is user-specific filtering and customization of content. SM employs complex algorithms to predict the news that users would like to read, the media they would like to see, the people they would like to befriend, and the ads they are likely to succumb to. For

example, SM applications can analyse user relationships to select high-quality content (Agichtein, Castillo, Donato, Gionis, & Mishne, 2008). They can also incorporate various behavioural information, such as locational co-occurrences, to recommend new links (Scellato, Noulas, & Mascolo, 2011). SM applications can take even more proactive roles. They can implement algorithms using the political valence of contributions to influence a user's opinion (Bakshy, Messing, & Adamic, 2015). They can filter content based on their emotional content to sway a user's affect (Kramer et al., 2014). They can also encourage links that cut across traditional age and gender homophily in order to expose users to more diverse sources of information and influence (Centola & van de Rijt, 2015).

#### **4.7 Multiplayer online games and virtual worlds**

Multiplayer online games (MOG) and virtual worlds (VW) are simulated three-dimensional environments in which users participate and interact via avatars. Users' actions and contributions impact other users' experiences both directly and indirectly, by affecting the game world as a whole. In fact, in VWs, it is users who create the game world (Ondrejka, 2004). Apart from providing the interaction rules and settings, the MOG/VW service does not usually modify user contributions.

The question why users repeatedly go back to MOGs and VWs has attracted much research attention. As with SM, survey studies have shown that providing optimal personal and social interactions improves users' experience and increases their loyalty (Choi & Kim, 2004). For MOGs, gratification from achievement and social interaction together with game incentives and fairness have been shown to make users more likely to continue playing (Wu, Wang, & Tsai, 2010). For VWs, perceived usefulness has been found to additionally increase the likelihood to participate (Verhagen, Feldberg, van den Hooff, Meents, & Merikivi, 2012). Moreover, the functional, experiential, and social motivations appear to be roughly equally important (Zhou, Jin, Vogel, Fang, & Chen, 2011). What is particularly unique for MOGs and VWs, however, is the sense of immersion or "flow" (Yee, 2006). Flow experience is the mental state of being fully absorbed and losing track of time (Goel, Johnson, Junglas, & Ives, 2013). Providing optimal personal experiences and meaningful social interactions cause individuals to experience flow, which in turn increases their likelihood to continue interacting and playing (Choi & Kim, 2004; Goel et al., 2013). Customization (e.g., of one's avatar) further increases gamer loyalty (Teng, 2010).

How does one design for meaningful social interactions in MOGs and VWs? Users may be involved in both negative interactions, such as attacks, and positive interactions, such as communication and exchange (Szell et al., 2010). Overall, however, observational research has shown that MOG users do not interact directly with other users as much as expected (Ducheneaut, Yee, Nickell, & Moore, 2007). This may be considered suboptimal because, in theory, MOGs and VWs can serve as a venue for informal sociability that fosters bridging social relations, which are relations that improve access to diverse information (Steinkuehler & Williams, 2006). Ducheneaut and Moore (2004) propose to force social interaction among users through the game design. For example, MOG developers can design interdependencies among characters and then design locations where these interdependencies can play out. Another solution to socially engage users is to design for indirect interactions. Ducheneaut and colleagues (2006) argue that MOG users do not interact directly and

collaborate with other users as much as use them as an audience, a source of entertainment, and a source of information and chatter. Hence, MOG design may benefit from improving other users' visibility and instilling a sense of social presence.

Designing a MOG/VW to keep users playing is a different problem from designing it to keep attracting new users. The more users there are, the more interactive and complex the virtual environment is. In order to guarantee continuous growth of the MOG/VW, one can reduce the learning and personalization costs in the short term (Zhang et al., 2014). In the long term, however, the problem of scalability looms large. A successful MOG/VW should provide consistent and secure service with fast response times for thousands of users simultaneously (Claypool & Claypool, 2006; Yahyavi & Kemme, 2013b). Traditional client-server architectures, however, have inherent scalability limitations. In contrast, peer-to-peer (P2P) architectures can achieve high scalability at low infrastructure cost (Hu et al., 2006; Yahyavi & Kemme, 2013b). In a P2P HMN, each node acts both as a server and as a client. In the context of MOGs and VWs, this means that each user's machine may hold master copies of some of the game objects and be responsible for propagating updates to other nodes. Such architectures are vulnerable to cheating, security attacks and churn, problems that remain outstanding design challenges today (Yahyavi & Kemme, 2013b).

#### **4.8 Mass collaboration**

Compared to the other HMNs, mass collaboration networks involve highly intense interactions among humans and machines. They require the highest level of involvement from users in terms of time and effort. Users can modify and reject each other's contributions and affect the project as a whole. Their contributions and the project content are often monitored and adjusted by the project leaders. This centralized oversight can happen automatically, for example, through vandalism-detection algorithms.

Wikis and open-source software (OSS) projects present two of the most prominent examples of mass collaboration HMNs. Wikis enable the collaborative creation, modification, and deletion of content (Tapscott & Williams, 2011). Wikipedia is the largest, most successful, and most popular wiki project. OSS projects allow the collaborative development and free distribution of computer software. The Firefox web browser, the Apache HTTP Server, and the Linux operating system are just three of the many well-known and widely used OSS products.

Mass collaboration projects are developed by geographically and organizationally dispersed contributors, most of whom are volunteers. As a result, recruiting and retaining contributors is a critical design issue for OSS and wiki communities. Von Krogh, Spaeth, and Lakhani (von Krogh et al., 2003) suggest that "joining scripts" are important if users want to gain access to the collaboration community. These "scripts" are implicit constructs that determine the typical level and type of activity a joiner needs to go through before becoming a contributor. Users often decide to join and participate in a collaboration project because they have pragmatic considerations or expect external rewards. Survey results have shown that external rewards have greater weight for participation than internal factors, such as intrinsic motivation, altruism, and community identification (Hars, 2001). In

fact, a high number of developers are paid for their OSS development efforts; others use their participation to improve their own software; still others receive benefits in terms of reputation and self-development. Contributors are able to learn even from mundane tasks such as reading and answering users' questions (Lakhani & von Hippel, 2003). In addition, contributors can benefit by exchanging valuable work with each other. A theoretical model has shown that since more modular codebases with more option value foster such exchanges, they increase recruitment and retention and decrease free riding (Baldwin & Clark, 2006).

Still, external rewards are not the sole motivator. First, they appear to be less important to wiki contributors, compared to OSS contributors (Oreg & Nov, 2008). Second, they appear to be only driving the decision to join but not the decision to stay (Shah, 2006). Sustained participation appears to be better predicted by group identity and community belonging. For example, Hertel, Niedner, and Herrmann (2003) show that self-identification as a Linux developer is one of the factors that determine engagement in the Linux project. Fang and Neufeld (2009) similarly find that situated learning and identity construction are positively linked to sustained participation, at least in the phpMyAdmin OSS community. Bagozzi and Dholakia (2006) confirm that active participation is associated with group-referent intentional actions.

In addition to recruiting and retaining contributors, mass collaboration platforms need to organize the leadership, coordination, and collaboration among these contributors (Crowston, Wei, Howison, & Wiggins, 2012b). Analyses of the e-mail communication network of contributors to several OSS projects reveal that sub-communities emerge naturally to mirror collaboration relations (Bird, Pattison, D'Souza, Filkov, & Devanbu, 2008). The community further subdivides into a core of usually 10-15 developers who create about 80% of the code functionality, a much larger group around the core who repair defects in the code, and an even larger periphery of users who report problems (Mockus, Fielding, & Herbsleb, 2002). Members of the core usually know and trust each other and communicate intensely to manage the dependencies among the contributed code. How do these naturally emerging structures affect the growth and the success of the OSS/wiki project? Crowston and Howison (2005) analyse 230 project teams on SourceForge to find that larger projects tend to have more decentralized communication networks. Based on a longitudinal analysis of an-order-of-magnitude larger SourceForge sample, Singh, Tan, and Mookerjee (2008) conclude that internal cohesion, as defined by repeat ties, third-party ties, and structural equivalence among contributors, is also associated with project success. Similarly, Hahn, Moon, and Zhang (2008) find that a project is likely to attract more developers if prior collaborative relations in the OSS developer network exist. However, contributors' external embeddedness has more complex effects on success. While a high number of external contacts increases success, only moderate technological diversity of the external network and moderate external cohesion are beneficial (Singh et al., 2008). Further, contributors' participation in multiple projects can both improve and aggravate the project's chances for technical success (Grewal et al., 2006).

## 5 Extending the initial types

In the previous sections, we have tried to identify a set of constructs (see Figure 1) which would allow us to describe human-to-machine networks which we subsequently applied within the context of social machines and human-to-machine interactions as described in the preceding sections. Moving beyond the state of the art, however, requires that we take these primitives and map them to our existing use case projects in an attempt to validate, with expansion if necessary, the building blocks previously identified for social machines.

### 5.1 The eVACUATE Case Study

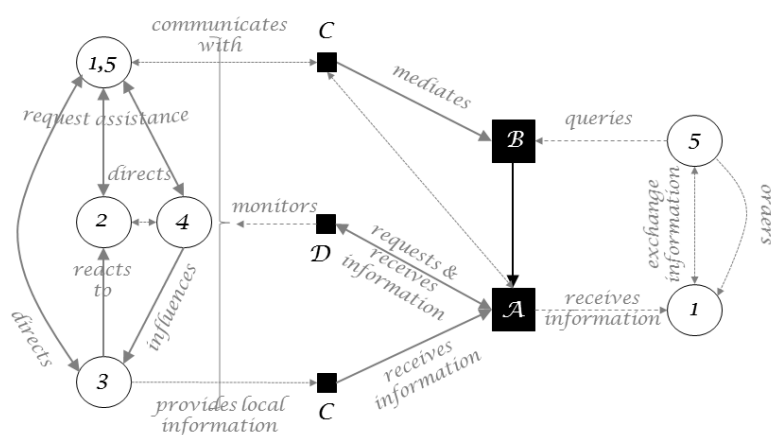


Figure 3: First attempt to represent the eVACUATE human-to-machine network using initial primitives

#### EVACUATE IN A NUTSHELL

The eVACUATE project involves the collaboration of individuals (passengers in an airport or on a cruise liner, sports fan in a stadium, or travellers on the underground) with operational staff and in some cases emergency services for the safe and effective evacuation of a given site in response to a number of different events from extreme weather or similar incident, or to overcrowding or rioting, or to terrorist threat. Operational staff rely on a decision support system with sensor input from various sources and locations, along with predictions about crowd movement and safe routing. Emergency staff may also become involved for medical, fire or other specific situations. The resulting HMN would be both dynamic and context dependent in its nature and the roles assumed by the main actors and systems.

To begin with, consider the eVACUATE case. Figure 3 shows a representation of the human-to-machine interactions for this case and the project is described briefly in the box below. More details is available from D3.1 Case-study Plan. Interactions between nodes (humans and machines) are labelled in an attempt to describe the basic behaviours and characteristics of the interactions shown. The nodes themselves may be understood as follows:

1. Represents the Operational Staff at a given venue or event responsible for identifying and managing any crisis which may arise;
2. Are the Out-group members; and
3. The In-group members;
4. Are the Leaders or Seeds whose behaviour may be taken up by other evacuees; and finally
5. Represents the Emergency Services, should they be called in to assist.

Evacuees would generally be made up of human nodes 2, 3 and 4; although in some cases, such as a cruise ship, may also involve the Operational Staff themselves.

Individual nodes represent:

- A. The decision support system used by the Operational Staff to monitor and manage any given situation;
- B. Any support system(s) used by the Emergency Services;
- C. and D. Peripheral devices, which may include simple sensors (for temperature, air quality etc.) or communication devices (telephones or walkie-talkies etc.) or smart devices (such as remote-controllable signage, smart doors, lighting or floors, etc.).

A number of issues arise straight away. First, there are clearly cases where the human nodes may actually need to be identified in a more complex fashion. Take the Operational Staff/Emergency Services node to the left of the figure. As terminals in a given relationship with different evacuees, they do fulfil a similar role. However, they stand amongst themselves in hierarchical relationships that it is difficult to represent here, but which are functionally important. Secondly, the evacuee nodes 2, 3 and 4 each stand for more complicated and dynamic relationships internally (i.e., within the node itself, such as peer-to-peer as well as leader-led relationships between different group members) as well as externally (i.e., responses to leaders or seeds; but also the fluid nature of interactions between in- and out-group members).

Second, the interactions or connections between nodes, whether human or machines, contain more information characterizing such interactions than we had proposed in connection with social machines in the previous sections. There are hierarchical relationships, for instance: the evacuees (nodes 2, 3 and 4) will request help from the Operational Staff and Emergency Services (nodes 1 and 5) but the response may be a command or order. Similarly, and more commonly perhaps, directions and orders from the Operational Staff and Emergency Services will tend to be initiated by them and not in response to requests for assistance, and will impose an obligation on the evacuees. So the relationships themselves (the connections or ‘edges’) will not always be balanced: one node controls another, and this may change over time. Further, the type of information carried by those edges will differ depending on the interaction. It may be sensor data, but it may also be supplementary information provided in response to a direct request, as well as voice or gestural exchanges.

Third, we need to start to distinguish machine types. For eVACUATE, there is clearly a difference between those machines that can aggregate information from multiple sources and process the results for decision support and the peripheral devices, which mainly provide data input. In other networks, there may be other types such as gateways or routers with specific, dedicated and highly

significant function. For now, though, we should extend the node types to include a third type which we will call *sensors* but which should include all peripheral devices which bring data into the core machines and respond to its commands.


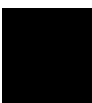

## 5.2 Extended primitives for HMN description


In considering complex HMNs such as eVACUATE, we have already been able to validate the basic types identified in the previous sections as well as begin to isolate others that may need to be introduced. We should perhaps take stock of the connection primitives that make up the larger HMNs to be considered in this section. At the beginning of Chapter 4, we listed a set of eight initial types of technology-mediated social interactions which we successfully applied to a number of different online activities. These were defined as sets of triads each with three nodes (two human and one machine) and the three connections between them. Analysing them into their constituent parts, we have nodes (humans and machines, plus now a third category: *sensors*) and the connections between them describing the behaviours that are associated with those connections. In network architecture terms, these connections are known as *edges* (Radicchi, Castellano, Cecconi, Loreto, & Parisi, 2004). We now need to consider the possible combinations of nodes and edges which might make up a set of connection primitives for us to describe the use-case HMNs and which will go some way to providing a base upon which to consider other network types as well as future networks.

### 5.2.1 Nodes

We have up to this point identified three nodes. To this, we may add a fourth to cover robots that do not easily fit the category ‘human’ or ‘machine’. This type of node is seen in industrial networks where work needs to be done in hostile environments, but also in some gaming, serious gaming and leisure activities. We therefore suggest the following four node types:

**Table 1: Four types of nodes in HMNs.**

Symbol	Description
	Any human agent with true autonomy for action and behaviour.
	Any machine platform or device capable of complex data processing in support of human activities or in response to human requests.
	Any robot element, distinguished from the Machine in that it performs general or specific motion-based activities in response to Human or Machine instruction. May also be capable of some level of human-like interaction in pursuit of its primary purpose.

	Any sensor or peripheral device capable of receiving data for onward transmission, commands to alter its current state (on vs off) or to mediate communication between other nodes.
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Nodes are assumed to have some level of agency and be able to initiate and/or complete specific tasks or subtasks in pursuit of some overall goal.

### 5.2.2 Edges

For nodes to interact, there is a need for *edges* or connectors. They are characterized by a given set of properties such as bandwidth, connection type (duplex vs simplex), reliability and so forth. Consistent with our original set of types above, each edge is depicted as a directional arrow, the arrow representing the originator (*source*) and the recipient (*destination*) of the interactional purpose. A double-headed arrow would imply something of the edge that implements it. For instance, it may be assumed to be full duplex (allowing data to pass in both directions simultaneously), and for the resulting interaction between the nodes to be *balanced*, which means that both derive equal benefit from the interaction. This may not necessarily be the case. Referring back to the left-hand end of Figure 3, *requests for assistance* and *directions* coming from the Operational Staff and/or Emergency Services may not be equivalent in terms of scope and validity as well as authority. This subject will need to be addressed at some later stage (see Chapter 6 below).

### 5.2.3 Networks

Once nodes are connected via edges, then *networks* begin to emerge. This we have already seen above in Figure 1. However, as we move into more complex networks, it is more likely that there will be machine-to-machine connections whereby the individual machines communicate and operate independently of human operators. For instance, cash transfers may be initiated by a human, but they will be completed semi-autonomously in exchanges between individual machines and proxies within bank and in some cases beyond. What happens as networks grow, however, is that the overall function and behaviour of the network can change, even developing into unexpected directions. The connectivity between universities provided by JANET, for instance, for the exchange of research, was the foundation not least for the public-resource computing and crowd-sourcing scenarios discussed above (Leiner et al., 2009; Wellman et al., 1996). Internet-based social media networks became important fora during the Arab Spring for individual citizens to engage and keep in contact with the outside world. As government sought to sever or restrict the Internet link, however, the network simply shifted to mobiles and continued to provide information (distributed journalism) as well as mutual support and organization (social media) for those involved (Howard et al., 2011; Khondker, 2011; Lotan et al., 2011). In strangely parallel events following the shooting of Mark Duggan in the UK, a similar network took on a different significance in providing the authorities with framework within which to identify and prosecute rioters and looters. It is important therefore to recognise from

the outset that once nodes can be connected via appropriate and different edges, the use and benefit of the growing network cannot necessarily be predicted from the individual components, but must be allowed to and expected to develop (Clark, Wroclawski, Sollins, & Braden, 2002). We will return to this in Chapter 6 below.

### 5.2.4 Connection Primitives

It would be possible to combine all nodes and all edges to define the logically complete set of connection types. In a preliminary review of the use cases, we believe that the following set may well provide sufficient coverage at the present time.

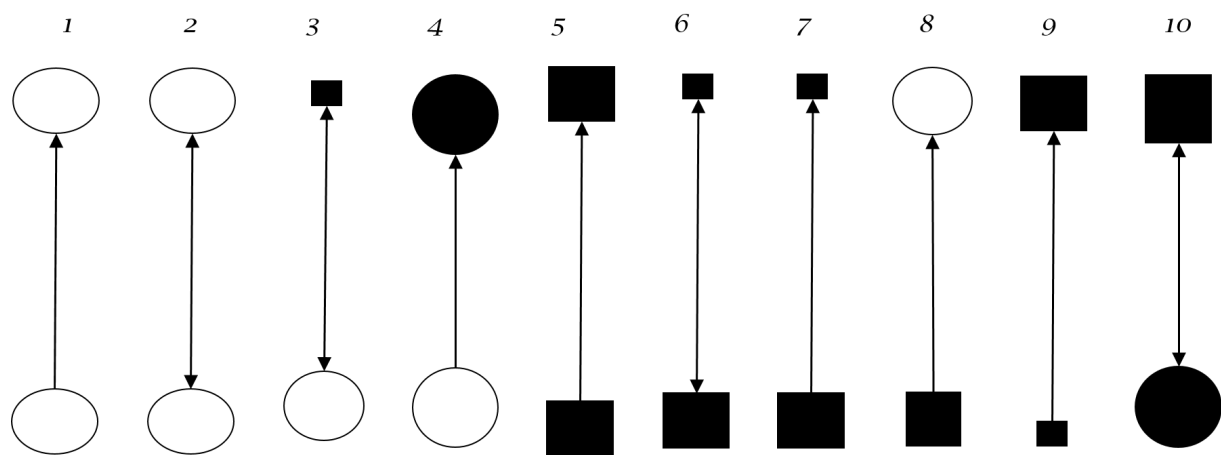


Figure 4: An initial set of connection primitives for complex HMNs



Figure 5: An alternative dual-connection type

These connection primitives may be understood as follows:

1. One human contacting or directing or responding to another.
2. Two humans exchanging information or communicating directly in some way.
3. Human-to-sensor: communicate via a mobile device, for instance, or response to directive on dynamic signage.

4. Human-to-robot: the human telling the robot what to do, etc.
5. Machine-to-machine: standard interface (this should perhaps be supplemented with a bidirectional link).
6. Machine-to-sensor: request information/data and receive input
7. Machine-to-sensor: provide information (alerts, activation request, signage message)
8. Machine-to-human: providing output
9. Sensor-to-machine: provide data
10. Robot-to-machine: download data and receive direction

This list is not exhaustive at this time, but provides sufficient coverage for our current descriptive needs. Further, these connection primitives can be seen in our original, literature-derived triads. For example, [2] can be seen in types E, F, G and H in Figure 1.

As alluded to in the previous section, it is a moot point whether connection primitive [2] should be distinct from a similar type as in Figure 5: An alternative dual-connection type, whereby either the physical characteristics of the edge (bandwidth, throughput, duplex/simplex etc.) or of the interaction (in terms of balance) or both is the same as a standard, fully duplex one. We also, in later HUMANE activities, need to go deeper into our analysis needs concerning the characteristics of human-human and human-machine interactions (as discussed in Chapter 2) and how to integrate such characteristics with the extended set of connection primitives. For now, we will leave this out for reasons of brevity. We do, however, briefly return to the issues of future analysis needs in Section 6.

### 5.3 Validating the connection primitives

Consolidating and extrapolating from the original primitive types at the start of this chapter, we have now revisited the set of connection primitives in connection with one of the present use cases, namely eVACUATE. Taking these primitives, we also examined the HMNs in related projects though not those specifically included within the initial set of HUMANE use cases; these are covered in the following sections.

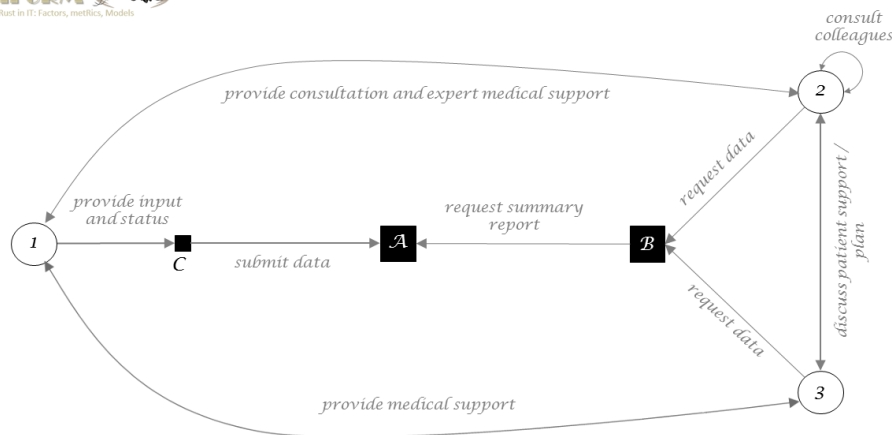


Figure 6: The HMN for TRIFORM using our initial set of connection primitives

Figure 6 represents the interactions between the nodes of the TRIFORM project<sup>19</sup>. Patients, in this case rheumatoid arthritis sufferers, [1] are given an app running on a smart device [C] which does two things: (i) using built-in sensors, it collects information about sufferer movement during the day; and (ii) provides a self-reporting tool for the user to record their daily emotional and physical state. These data are passed to an aggregation engine [A], which collates information for individual users, but is also capable of providing demographic information for the whole cohort of users. Clinicians [2] as well as the rest of the medical team responsible for the patients [1], may access the data via any browser or similar interface [B] to request summary or detailed reports. All human actors are also connected with each other in respect of the on-going care plan of the patient. Further, clinicians [2] (or indeed any of the medical team, as well as the sufferer themselves) may consult other experts for advice, answers to specific questions as well as experience. Such interaction is similar to the Wikipedia case and possibly Zooniverse suggesting we may need to cater for bridging into or out of networks.

## TRIFORM IN A NUTSHELL

Whereas previous research had centred around trustworthiness – that is what makes an online service or application convince users that it is safe, reliable and appropriate – without considering how users themselves develop trust in highly sensitive, critical systems. The TRIFORM project, under the auspices of the ITaaU (*IT as a Utility*) initiative, sought to investigate user acceptance and trust of a technology used in the monitoring and reporting of a chronic medical condition. For the specific healthcare context, *users* were defined as patients, consultants and the specialist medical teams supporting them.

<sup>19</sup> TRIFORM was a short proof of concept project funded by the ITaaU in the UK. See <http://www.itutility.ac.uk/> and <http://www.itutility.ac.uk/2014/10/30/trust-in-it-factors-metrics-models/>

## O{P}ERANDO

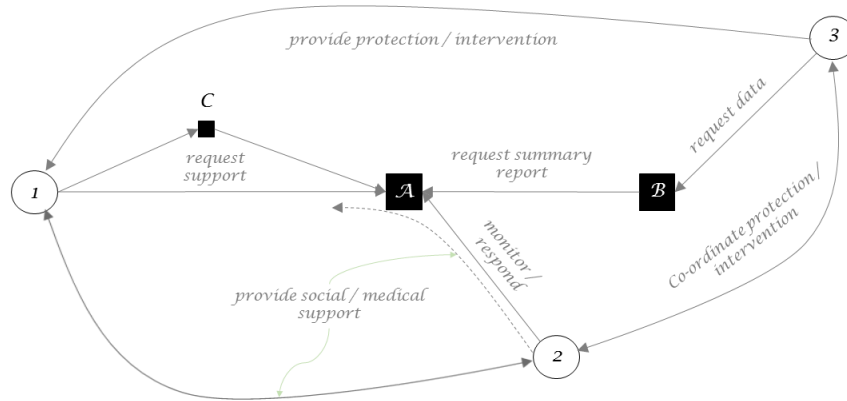


Figure 7: The HMN for OPERANDO using our initial set of connection primitives

## OPERANDO IN A NUTSHELL

Managing sensitive data – such as medical records or information about vulnerable individuals – requires careful oversight and usually specialised and dedicated servers. With the advent of cloud computing, though, there is an opportunity to increase efficiency as well as drive down costs. These two factors (data sensitivity and cost/efficiency) seem to be very much at odds with each other. The OPERANDO project is investigating a novel distributed approach for common social services, such as healthcare and victim support.

The OPERANDO project<sup>20</sup> is similar to TRIFoRM in offering technology enhanced care, though in this case it extends from purely healthcare to social care as well. Service users [1] may access service provider facilities [A] or go via a helpline or mobile app [C] to request help, support and information from the service provider

[2], who may respond directly or via the services platform [B] for reasons of sensitivity. In addition, the service provider [2] has a legally enshrined duty of care to report to the relevant authorities [3] specific criminal or safeguarding issues. The authorities may have their own platform [B] that would connect with the service platform [A] to retrieve information etc. Again all human nodes interact, though the interactions are different with both connection primitive types 1 and 2.

The PAL project<sup>21</sup> introduces a new node type, the *robot*, as well as a complex type of machine-mediated human-to-robot communication, perhaps via an avatar as the virtual representation of the robot linking it back to our social machine type G in Figure 1. Young patients [1] are cared for by a network of social and medical care [2], once again suggesting bridging off to another HMN type. In

<sup>20</sup> [http://www.operando.eu/servizi/notizie/notizie\\_homepage.aspx](http://www.operando.eu/servizi/notizie/notizie_homepage.aspx)

<sup>21</sup> <http://palproject.org.uk/>

addition, the young patient [1] ‘befriends’ a robot [A] whilst in hospital and begins to interact with it in support of their condition and care plan. When leaving hospital, technology-mediated care takes two forms: (i) from the patient [1] to the care system [B] for standard monitoring and reporting (possibly mediated by other human nodes), but also (ii) from the patient [1] to the virtual version and environment of the robot [C] as a form of continuity and familiarity for the child. One major benefit of course is that the child will then switch between the actual robot [A] and its virtual manifestation [C] seamlessly depending on whether they are confined to the hospital or at home.

### PAL Project

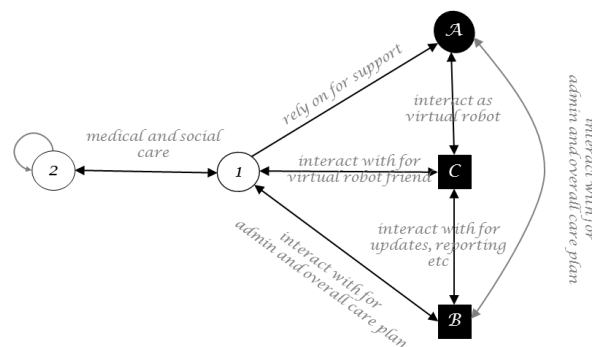


Figure 8: The HMN for PAL using our initial set of connection primitives

Our connection primitives from Section 5.2.4, based originally on our types in Section 5.2.1, and then extended here in the first instance via a review of the eVACUATE case, does provide for components which allow us to identify and define not only the social-machines in preceding sections, but also other machine-focused HMNs.

### PAL IN A NUTSHELL

For vulnerable patients suffering chronic conditions, children for example, there is often a lack of continuity between frequent hospital visits and what goes on at home or in the community. For this type of scenario, the PAL project is looking at developing and testing a robotic avatar which a child would befriend and interact with in hospital and then, via a virtualised online version, continue to meet with and rely on for help and support as well as maintaining minute-by-minute information and detail of use once the child returns to hospital again with support of the *real* robot.

## 5.4 Further developments

In providing an initial set of connection primitives as detailed in the preceding sub-sections, we also need to consider a number of further issues. We discussed the relationship between the interaction types in Figure 1 and physical characteristics of the edges that enable the interaction between nodes above (Section 5.2.2). However there is clearly more to the nature of these connection primitives and interaction types: irrespective of the connection primitives and types which go to make up the network, once interactions are enabled, there are emergent behaviours and constructs, as well as broader network affecting issues which become important. For eVACUATE, for instance, there is a fluid boundary between in- and out-groups which needs to be understood and which will be influenced as any particular crisis develops but also in response to the treatment and views of the Operational Staff and Emergency Services. Further, physical edge speeds and reliability are literally critical when it comes to the management of the crisis as well as operational and emergency support: this may be a standard monitor-type network at normal times, but it rapidly changes should a crisis occur. In TRIFoRM, there are clear benefits to technology introduction for the patient: they do not need to remember or keep a diary of how they are feeling and what they are doing, this is done automatically by them. Similarly, the medical team can quickly establish the patient's status without having to waste precious time during a busy consultant appointment. However, for the patient the most important issue once technology is introduced is how this might affect their relationship with the clinician and the broader care team. For OPERANDO, the opposite might happen. Victims of domestic violence, for instance, may find it difficult to approach and be honest with care workers, and yet this may change in the relative anonymity of machine-mediated communication. Finally, in all such cases, the relative status of the human nodes will change and may continue to change once they enter into an interactional relationship.

In summary, there are properties inherent in the nodes and edges themselves. These may change over time or as the immediate context changes. But there are also properties external to the connection primitives as well as to the networks they make up which nevertheless influence the design and operation of those networks. In the next chapter (Chapter 6: Behaviour), we will return to these features and explore their implications in terms of our current models, as well as in relation to future networks and a roadmap for HMNs.

## 6 Behaviour

### 6.1 Entities

Most analysis of networks and behaviour in the past has tended to treat the actors or entities within the network as equivalent within their defined type. Moreover, the characteristics and behaviour of those entities remains fixed and predictable once defined. In order to develop a more advanced and comprehensive analysis of the human machine networks within HUMANE we need to consider that the exhibited characteristics of nodes are dependent upon context, which may change in a complex way in response to a number of different factors. We have seen in earlier examples that a human

actor may be defined in terms of in-group and out-group, which defines their behaviour in relation to other connected humans, which will be different when interacting with their in-group associates to their behaviour when interacting with people in the out-group. Similarly, a human actor may take the role of leader (or ‘seed’) at one point in time, but may relinquish that role in favour of other actors in authority at a later point in time. Machines are, as ever, more predictable than humans, but it is still conceivable that they may take more than one role in a network – for example a mobile phone may be a communication device, it may be a display device or it may be a sensor under different circumstances or different stages of an evolving network situation.

Each entity in the network will be characterised by a number of attributes, some of which are intrinsic to the entity (such as patient, doctor, collaborator, contributor) and some of which will be context sensitive (such as leader, seed, follower, in-group, out-group, passivity). Similarly, the relationship between entities will be characterised as a function of both context and time – so trust and reliance are an attribute of the evolving relationship between two entities, whereas trustworthiness is an attribute of a single entity. As the typology is developed in WP2 these attributes of entities will be further identified and characterised, and ways in which the time-variant or dynamic nature of the relationships can be incorporated will be developed.

## **6.2 Connections (edges)**

The connections between entities in a network, referred to as edges, are often taken simply to represent the existence of a relationship, effectively taking the form of an infinite capacity conduit. We have seen that the edge has direction and the attribute of simplex or duplex operation, but as our analysis develops further we anticipate the emergence of descriptions in which the edge itself will also display characteristics that influence behaviour in the network. The edge is effectively a path across which information flows between two entities, but it can influence both the type of interaction and the perception by a human entity of another machine or human node. So, for example, the connection may be a slow or unreliable link, it will have a capacity limit which determines the type of information it can carry (text, data, audio, images) and as such may influence the level of trust or reliance between nodes and may therefore affect the response that a person has to the information available to them. Future analysis therefore needs to take into account the intrinsic characteristics of the edge as well as relate it to other network characteristics that may be influenced by it.

## **6.3 Emergent behaviours**

In reality, the emergence of new behaviours in a human-machine network is very difficult to predict, although the effect that new user behaviour has on the operation of a network can be profound. We think as an example of the impact of social media usage on networks of people mediated by smart phones. The shift in behaviour from verbal communication (telephony) to text communication has driven the developing capabilities of smart phones and the demand for universal wide bandwidth data connection. The inclusion of cameras of ever-increasing resolution and sophistication and biosensors in smart phones, and the ubiquity of apps has resulted in behavioural change in the users

of such devices and networks. In social media networks such as Twitter and Instagram the emergence of the use of hashtags has revolutionised the sharing and discovery of information and has led to the adoption by the network of concepts such as ‘trending’.

These examples are indications of the way in which human users of any technology will adapt it to their own requirements, often beyond the expectations of the originator of the technology, and once adopted and widespread the technology provider will then move to incorporate the new usage into their offering. This is another aspect of the dynamic nature of a technology-based network, and one that will be recognised in the developing work in the HUMANE project.

## 6.4 Network evolution

That networks evolve has been established above, along with the reasons for its evolution. Any characterisation of a network therefore needs to embody the dynamic nature of the entities and connections between them, particularly in relation to the changing context of both the individuals and the network as a whole. Moreover, the underlying capabilities of the network will evolve with time, possibly leading to ‘tipping points’ at which new or emergent behaviour becomes possible, and this is paralleled by the developing competence of the network users whereby they are able to use the technology more effectively. The very existence of the network and the sharing of experience between people using the network ensure that behaviour can become ‘viral’ and spread rapidly between users. This is not just ‘herd behaviour’, although it can lead to such phenomena, but can also be part of a shared learning phenomenon, which can ultimately lead to modifications in the way that the technological components of the network are implemented.

## 7 Future

This report presented the state of the art in the field of human-machine networks. We initially focused on the actors in these networks and the interactions between them. We identified eight types of HMNs: public-resource computing, crowdsourcing, web search engines, crowd sensing, online markets, social media, multiplayer online games and virtual worlds, and mass collaboration. These types differ in the structure and intensity of the interactions among and between humans and machines. We systematically collected relevant research on these types, with an emphasis on recent and high-impact work. We reviewed this work with a focus on issues related to designing the HMNs: motivating participants, guaranteeing their privacy, designing reputation, recommendation, and content-ranking algorithms, aggregating and processing contributions, and so on. Our review points to four major trends.

First, human-human interactions appear to be intensifying in HMNs. Many systems are starting to allow for social interactions among their users. In addition, many of them are looking for ways to make the social interactions more immediate and intense. In a sense, everything can now become a social network; everything can be “shared.”

Second, and related to the first trend, human-machine interactions are becoming less demanding. By introducing social functionality, HMN designers capitalize on social motivations to encourage participation. In some cases, HMN designers have also started introducing monetary incentives, as in paying for contributions on review and rating sites or for crowd sensing applications. Last but not least, automated data collection is gaining prominence. These changes serve to reduce the effort on behalf of participants and increase their gains from participation. HMNs no longer need to rely on “altruists” to continue functioning and growing.

Third, machine-human interactions are also becoming more prominent. Machines now customize and filter any information that users receive and consume.

Last but not least, not just the nature of the interactions in the HMN but also the actual structure of the HMNs is starting to evolve. There is a trend towards redesigning HMNs as peer-to-peer networks. The major reason for this is that P2P architectures improve the scalability of HMNs. But they also entail certain undesirable consequences. In P2P networks, machines become equivalent with users, as each user contributes a machine to store, process and transmit data. This means that machines start to exhibit some of the problems that humans have: unavailability, unreliability, distrustfulness, and untrustworthiness. This implies that social science knowledge and approaches are starting to be indispensable even for the engineering of HMNs.

The four development trends suggest that the differences between the eight HMN types we identified are starting to blur. Nevertheless, our analytical framework remains useful for identifying specific niches for development and innovation. Citizen science projects that encourage collaboration between users, search engines that rely on users explicitly ranking sites, social network sites that enable file sharing.

Having reviewed the literature in the field, we developed a set of HMN types that could define and characterise such interactions. Then we extended the original components within those initial eight types to be able to define more complex human-to-machine networks; we proposed a set of primitive connections that may be used to build up more sophisticated human / technology networks. The connection primitives were validated on a number of separate use cases by way of illustration. But in addition, looking at the networks and interactions they support in pursuit of a given task, it is apparent that the entities and the connections between them may well lead to unforeseen use and behaviours associated with those networks.

Both the four analytical layers and the connection primitives can be used as input to the typology work in WP2. In delineating the initial set of HMNs here, we took as a starting point eight established prototypical purposes in a top-down approach and then described them. This approach to the classification of HMNs proved highly beneficial for conducting the literature review, as it provided a firm basis for search and analysis. We believe the literature review resulted in a relevant and useful overview of current knowledge on the identified prototypical HMN purposes. However, such a top-down approach is limiting in the sense that the classification is predefined rather than emergent as the result of exploring HMNs according to more generic characteristics. Further, it captures a single type of activity and interaction at a single point in time, failing to capture or facilitate the description

or analysis of state to state transitions and their consequences. To move forward, we will seek a more exploratory approach in the first version of the HUMANE typology and method by profiling HMNs through key dimensions. We will use the findings from this literature review for insight into relevant dimensions. In this way, we provide a bridge in this deliverable towards the typology and roadmapping exercises of other HUMANE work packages. In so doing, we have taken the state of the art to the next level in preparation for a wider examination of the dynamic power behind human-machine networks of many different types.

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## 9 Appendix A: Systematic literature search

First, we identified specific types of HMNs. We did this by brainstorming for concrete examples and then describing the interactions among humans and machines in them. This resulted in differentiating between three kinds of interactions (in addition to “no interaction”) for each of the three directed dyadic relations we investigated (human-human, human input in human-machine interactions, and machine output in human-machine interactions). The grouping of the HMNs resulted in eight types, out of the  $4^3 = 64$  possible.

Second, we used the eight HMN types to systematically collect relevant literature (illustrated in Figure 9). We started by identifying 4-8 “seeds” in each of the types. The seeds were intended to be the most relevant articles with the highest impact. We conducted exploratory keyword search on Google Scholar<sup>22</sup> for each type and selected the articles with the highest number of citations, with an intentional bias for literature review articles. Due to the emphasis on number of citations, there was also a de-facto bias for older publications. We then reviewed the content of the seed articles to manually compile lists of search keywords for each HMN type (Table 2).

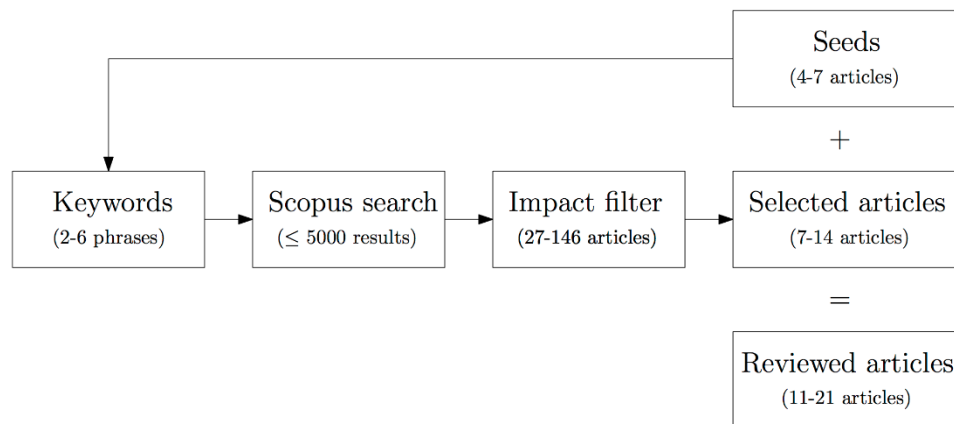
The lists of keywords were used for systematic searches within the titles, abstracts, and keywords of all articles on the Scopus<sup>23</sup> bibliographical database. We then looked at the first 5000 results, sorted by relevance and selected the highest impact articles, according to the following formula:  $C / (2016 - Y)^2 \geq \alpha$ , where  $C$  is the number of citations and  $Y$  is the year of publication of the article. We set  $\alpha=1$  for most cases, with the exception of crowdsourcing and social media, where  $\alpha=2$ , as these research areas are much more populated. The formula was designed to oversample recent articles.

Finally, we went over the abstracts of these articles and manually filtered the ones that focused on issues related to the functioning and the design of the HMNs. This gave us between 11 and 21 articles (including the seeds) for each HMN type to review. In section 10 we list the selected articles and in section 4 we summarize them. Our review is not intended to be exhaustive. In fact, some of the topics we mention are by themselves subject of literature review of similar size as ours. We hope the references we include will guide the readers in finding more information about these topics.

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<sup>22</sup> scholar.google.com

<sup>23</sup> www.scopus.com



**Figure 9: Method for the systematic literature search.**

**Table 2: Keywords for the systematic literature search.**

HMN type	Keywords
Public resource computing	"public resource comput*" OR "volunteer comput*" OR "peer-to-peer comput*"
Crowdsourcing	crowdsourcing OR "crowd sourcing" OR "crowd work" OR "human comput*" OR "social comput*"
Web search engines	("search engine" AND impact) OR ("search engine" AND design)
Crowd sensing	"phone sensing" OR "mobile sensing" OR "crowd sensing" OR crowdsensing OR "participatory sensing"
Online markets	"e-commerce" OR "prediction market" OR "online market" OR C2C; "file sharing" OR "peer-to-peer"
Social media	("social network" AND site) OR ("social network" AND online) OR "social media"
Multiplayer online games and virtual worlds	"online game" OR "multiplayer game" OR "virtual world"
Mass collaboration	"open source" OR wiki OR "mass collaboration"

## 10 Appendix B: List of key literature by network type

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