Exploring Interaction Design for the Social Internet of Things

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Abstract The Social Internet of Things (SIoT) builds social capital by incorporating principles of Social Networks (SNs) into the design of the Internet of Things (IoT). With the ambition of improving network navigability and service availability, research targets granting smart objects the ability to autonomously socialize with each other. The resulting independently defined social network for things will allow devices to communicate with both human beings as well as other devices.

Autonomous decisions made by social things require them to understand the context in which they operate. However, the perception and interpretation of context remains fallible. As social things act without explicitly making this visible to the user, there is an increasing inability to grasp, let alone control, what is happening behind the screens. By providing intelligibility or defining personalities, the user gains a better awareness of the system's functionality.

In this chapter, we start by providing a short history of things that socialize and review related research. By gaining insights into the nature of interaction with both the world and autonomous systems, we frame interaction challenges with social things. We look towards literature in both the SIoT and context-aware computing to outline possible design techniques for addressing these challenges. Lastly, we discuss how future work can build upon our considerations to ensure natural and intuitive interaction with the SIoT.

1 Introduction

The Internet of Things (IoT) has long been a speculative paradigm as the next wave in computing. Interconnected networks of everyday objects with integrated sensors range from smart phones and smart watches that monitor the user's location and

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state, to vehicles capable of analyzing the driver's behavior. The increase in autonomous processing capabilities has guided the integration of these objects into embedded and connected systems towards more general cyber-physical systems, such as smart homes or smart cities [26, 52]. The ongoing evolution of the underlying technologies opens up vast opportunities for applications of the IoT to improve the quality of our lives.

The Social Internet of Things (SIoT) builds social capital by considering the integration of social networking principles into the IoT [4]. Research in this field explores techniques and benefits of the incorporation of social structures and behaviors. Ensuring network navigability and service discovery can be guided by defining the composition of a SIoT network similar to the structure of a social network and can increase trust management between interconnected objects by leveraging relationship types. Consequently, existing models to study social networks can be reused to study SIoT. The resulting independently defined social network for things will allow devices to communicate with both human beings as well as other devices.

Throughout this chapter, we use the notion of a *social thing* to indicate autonomously socializing things within the SIoT. As social things act without explicitly making this visible to the user, there is an increasing inability to grasp, let alone control, what is happening behind the screens. Autonomous decisions made by social things increase the system's complexity and require an understanding of the context. As the perception and interpretation of context remains fallible, the user must be able to retain control over the system's actions.

In this chapter, section 2 starts by providing an overview of the history SIoT and its basis of social capital, followed by basic relationships for social things, an architecture for the SIoT and example platforms and implementations from both literature and commercial applications. Section 3 considers how we interact with the world, how autonomous socialization changes this, the need for contextual awareness and the interaction challenges that arise. The role of the human is framed in section 4, followed by two techniques to improve and enrich the interaction in different fields, namely designing for intelligibility and control and designing the behavior of interactive objects. We conclude by discussing how future work can utilize and build upon our considerations to ensure natural and intuitive interaction with the SIoT.

2 An Internet of Social Things

The vision of the Social Internet of Things (SIoT) encourages the adoption of social networking paradigms into the Internet of Things (IoT). This work focuses on socialization between SIoT objects which aims to benefit from the concept of social capital. We elaborate on the history of social objects and address the basic SIoT relationships. From a literature perspective, we describe platforms and implementations that advance towards socializing objects.

2.1 Social Capital for Things

The SIoT applies social networking concepts and technologies to the IoT [4]. This work focuses on socialization between objects, which builds on the idea that networks of social relationships provide benefits to the entities functioning within that society. This is founded on the theory of *social capital* which states that these relationships are valuable resources providing members with 'credential' [10]. In turn, credential allows to build trust and trustworthiness which facilitates the actions of individual members [27]. As members gain access to previously inaccessible resources, their exchange and more specifically their integration results in value creation through innovation.

Social capital in terms of a SIoT environment transfers the benefits of social relationships to IoT objects [3]. Essentially, autonomous socialization adds a highly adaptive aspect into the smart environment. Social relationships, being dynamic by nature, are able to shape the network structure based on the active requirements. This leads to improved network navigability which opens up the IoT environment for cooperation and collaboration between objects. Social navigation enhances resource visibility and service discovery while scalability is guaranteed. Based on the level of interaction between things and the type of relationships, a level of trustworthiness can be imposed on objects, providing reputation management. Most importantly, social relationships lead to value creation though service composition and source crowding within the SIoT.

Social networking paradigms support the connections between the users' social organization model and their ubiquitous IoT devices [53]. As these principles are gathered from existing literature, models and algorithms for analyzing social networks can be re-used in SIoT environments. This provides us with the tools to allow social awareness to increase system performance and Quality of Experience [2]. Social relationships and socialization between IoT objects will be essential properties of future smart environments.

2.2 Things that Socialize

The foundation of the IoT refers to interconnected networks of everyday objects equipped with sensors and actuators, while having individual and autonomous processing capabilities. The integration of these objects into embedded and connected systems, results in more general cyber-physical systems such as smart homes or smart cities [26, 52]. This leads to a highly distributed network of devices communicating with human beings as well as other devices.

Considering economic and sociological studies, Atzori et al. [5] motivate that the technological advancements of smart devices enable them to undergo an evolution similar to that of human evolution.To illustrate, three categories of IoT objects can be distinguished in relation to their social consciousness, namely *res sapiens* or smart objects, *res agens* or acting objects and *res socialis* or social objects.

In the first phase of the IoT, proposed systems comprised of mainly heterogeneous devices that functioned within personal ecosystems. As these smart objects inhabited their own supporting infrastructure isolated from interaction with external environments, initial *res sapiens* were bound to these fragmented networks. Innovations in inter-device communication, object visibility, and service discovery and integration, have improved the operability of these objects with external systems. The ability of communicating with the external world through common standards and protocols enabled them to participate in human social networks.

In the second phase, objects are granted the means to actively participate in their surrounding environment. *Res agens* are able to manifest their own pseudo-social behavior, such as the creation of a spontaneous networking infrastructure through temporal relationships with their neighbors. Objects are not only connected anymore, but actively participate in social networks.

In the natural world, the creation of a network of social relationships enables animals *to master complexity and the difficulties that characterize the environment in which they live*. In the last phase, *res socialis* considers autonomous socialization between smart devices as a means to collaborate in self-constructed social networks, creating complex services in object social networks. The novelty in the future evolution towards *res socialis* lies in the fact that the autonomous networks are defined by the relationships among objects. This results in social networks by objects for objects in which they may exchange information and utilize each other's services. Even though communication is still aimed at supporting humans, they have no direct role or control over the network.

A similar construct can be found in *Cybermatics*, a concept which considers a cyber-physical-social-thinking (CPST) architecture or hyperspace [28]. Cybermatics builds upon the notion of cyber-physical systems by considering characteristics of the *social space*, i.e. social attributes and social relationships, and issues of the *thinking space*, i.e. the process of analysis, synthesis, judgment and reasoning. Within the social space of the CPST hyperspace, relationships between human beings, physical objects and cyber entities build both human and thing societies. The SIoT resides within the thing society established through autonomously created relationships between *res socialis*.

2.3 Relationships and Architectures for Social Things

While initially framing the SIoT, Atzori et al. [4] described the responsibilities for the SIoT by deriving the basic relationships between social objects and proposing a network architecture to support them. The set of social relationships of objects is built upon the four relational structures for human beings as proposed by Fiske [16], i.e. *communal sharing*, *equality matching*, *authority ranking* and *market pricing*. As argued by Pintus et al. [37], Fiske's model can be mapped to the social aspects of a Humanized IoT (H-IoT). In the domain of *communal sharing*, the IoT can serve as a basis for users to share their things with others. This can in turn serve the basis for *equality matching* to provide a good balance between benefits and contributions of sharing of devices and data. Based on the relationships within an IoT, access and restrictions need to be applied to warrant *authority ranking*. Considering the SIoT, social relationships serve as the ideal foundation for authority through the concept of social capital as things can autonomously build 'credential'. Lastly, IoT systems need to consider *market pricing* of resources to ensure rational cost-benefits over things usage.

The derived relationships are:

- *Parental Object Relationships* (POR) between objects of the same production batch, usually homogeneous objects from the same manufacturer;
- *Co-location Object Relationships* (C-LOR) established by objects operating in the same environment;
- *Co-work Object Relationships* (C-WOR) built by objects providing a common purpose;
- *Ownership Object Relationships* (OOR) involving heterogeneous objects belonging to the same user;
- *Social Object Relationships* (SOR) constructed because their owners come into contact with each other.

The proposed architecture for the SIoT, shown in Figure 1, takes a similar approach as the three-layered model for IoT presented in [55]. This model consists of a sensing layer for data acquisition and short range collaboration, a network layer for data transmission and an application layer for data storage, processing and analysis. The architecture considers three components to be essential for an SIoT system.

The SIoT server is responsible for most of the functionality, while gateways and objects remain mostly limited. Through ID management and profiling, the server respectively assigns objects with IDs for reference and configures information about these objects. The owner control (OC) regards the activities that can be performed by an object, the information that can be shared, as well as the type of relationships that can be set up. The server manages relationships using the relationship management (RM) module, while services are managed and integrated respectively by the service discovery (SD) and service composition (SC) components. Lastly, the reputation or 'credentials' of objects are assessed in a trustworthiness management (TM) part. These components collaborate to support the main SIoT processes,

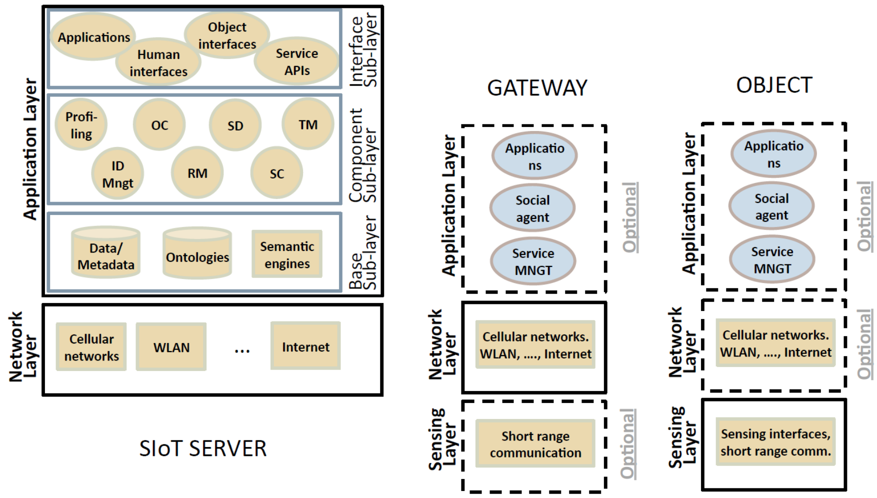

Fig. 1: Overview of the proposed architecture using a three-layer model for SIoT by Atzori et al. [4]. For more details please refer to their paper.

namely the entrance of a new object, the discovery and composition of services, the establishment of new object relationships, and the provisioning of services.

2.4 Example Platforms and Implementations

The first notion of socialization between objects in literature addressed how smart artifacts could establish temporal relationships, and how users are able to retain control over these relationships [19]. In ubiquitous computing, proximity-based communication stems from the notion that the location of devices is central to support temporal connections between artifacts [20]. In this work, authors use proximity-based communication in context-aware devices to propose the idea of *context proximity* for selective artifact communication. Their smart objects called Smart-Its derive their context from an abstraction of raw sensor data, generic perceptions extracted from sensors, and artifact- or application-specific information. Deriving from this context, they envisioned two ways of communication, namely implicit and explicit connections.

Often referred to as the Social Web of Things, existing platform implementations can be found in both literature and commercial applications. Both the platforms Xively[1] and Paraimpu[2] [36] provided frameworks to interconnect social net-

[1] IoT Platform for Connected Devices— Xively by LogMeIn, https://www.xively.com/, last accessed Jan. 11th 2018

[2] Paraimpu - You are Web, http://www.paraimpu.com/, last accessed Jan. 11th 2018

works with things and their composed services in a Web of Things (WoT). Additionally, authors describe an interconnection between cognitive robots and the Internet of Things by adding a social dimension to human-robot and robot-robot interactions [45]. However, as connecting objects together was left to the user, there was no notion of autonomously establishing social relationships.

More recently, autonomous socialization between things was supported by the Evrythng Platform [3]. Individual things are assigned a unique active digital identity (ADI) to ensure a permanent online presence. Evrythng proposes manufacturers to utilize ADIs for their IoT objects to support relationships between devices, however, most interaction is still occurs between the user and an object.

In more recent work, the *Socialite* framework differentiates not only between object relationships, but includes social relationships between users as a requirement to collaboratively reach goals within a SIoT environment [21]. A relationship between human friends, a *Friendship*, is contrasted to a relationship between things, a *Thriendship*. The latter can be considered equal to an SOR, while they support the concept of OOR as *Ownership*, C-LOR as *Collocation* and POR as *Kinship*. The proposed concept and architecture aims to drive more responsibility on the individual objects within the system as to take advantage of the distributed nature of SIoT. In order to empower end-users, the *Socialite* framework was extended to include end-user programming and sharing rules [22].

Utilizing the relationships defined in the *Socialite* framework, a system for autonomous cooperation in the IoT was designed using a virtual proximity based P2P communication protocol [33]. Their implementation aims to support humans to be social with each other by providing users with a personal *mascot* which is able to connect with other *mascots* and smart benches. Their work focused on the autonomous socialization functionality of things within the SIoT application to support communication between users.

[3] EVRYTHNG IoT Smart Products Platform, https://evrythng.com/ – last accessed Jan. 11th 2018.

3 Interaction in the Social Internet of Things

In order to understand interaction and the role of the human in the SIoT, we start from Donald Norman's stages of action to explain interaction with everyday things. Using this framework, we formulate the changes and limitations autonomous socialization causes and address the need for contextual awareness. These concepts serve as the foundation to frame the challenges which hinder the user's capacity of understanding and interacting with SIoT systems.

3.1 Interaction with the World

Understanding interaction with complex systems starts with an understanding of how we interact with the world around us. The Stages of Action model was conceptualized as a means to analyze how we interact with everyday things in our environment [31]. The model identifies the components and their stages which come into play when we want to perform an action in the world around us (Figure 2).

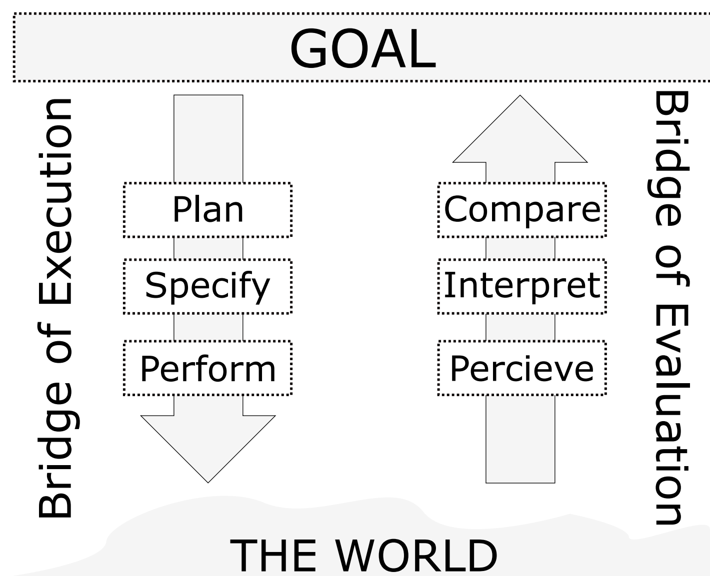

Fig. 2: Overview of Norman's Action Cycle [31], figure adapted from [46].

A user with a specific goal in mind has to cross the *Gulf of Execution* in order to attempt to modify the state of the world accordingly. During the 3 stages of execution, the user devises a plan to perform the action, specifies the sequence of atomic actions required and performs them. At any given moment the user may cross the

Gulf of Evaluation to inspect the state of the world. This will provide valuable information regarding the result of an action and allows to align or modify future actions. Evaluation consists of perceiving what has happened in the world, interpreting these changes and comparing them in order to conclude if this result is wanted. Essential to this process is the understanding of how an item within the world works and which effects it might produce. Norman puts forward the idea that understanding should be mitigated through design.

Two scenarios relevant to the SIoT, namely autonomous system actions and implicit user input, modify the action cycle in such a way that they may cause confusion or frustration with the user [46]. Autonomous system actions occur when actions are performed which are not based on explicit input from the user, but triggered from an event in the environment. The absence of the *Gulf of Execution* might imply that the user is not expecting a change to occur as she is not explicitly paying attention to the system's state. The responsibility to inform the user with appropriate feedback lies entirely with the system. In the case of a SIoT environment, two social things approaching each other might decide to establish a relationship and share resources. A user not notified by the system of this event, remains unaware of the availability of novel resources or even of potential breaches in privacy.

Likewise, while providing the user with feedback of passed events communicates the updated system state, it might not always be the most suitable technique. When these events occur in abundance, the user will be flooded with information, leading her to ignore or mute notifications. In such cases, feedback related to highly important system events will not be able to reach the user's awareness. It is therefore crucial that the system provides *feedforward*, i.e. it informs the user how certain environmental events, such as implicit actions performed by the user, influence the behavior of the system before these events take place. An autonomous system must provide visibility into and discoverability of its functionalities [31].

3.2 Context-Aware Systems

The vision of ubiquitous computing, first outlined by Mark Weiser in 1991 [49], describes the third wave of computing. This era in which many devices become integrated into the user's daily environment by moving beyond the desktop, grows out of the first wave of mainframe computing and the second wave of personal computing. As people are surrounded by intelligent and intuitive interfaces, computers become an integral, invisible part of their lives. This shift demands for a new relationship towards the user as the 'the invisible computer' needs to offer its services, without demanding attention. Taking into account the desired state of mind of the user, computing needs to promote *calm technology*, which moves easily from and back to the periphery of our attention [50, 51].

As technology needs to remain invisible unless attention from the user is needed, ubiquitous or pervasive computing systems require a context-aware perspective [41]. A system is context-aware or sentient, if *"it uses context to provide relevant informa-*

tion and/or services to the user, where relevancy depends on the user's task" [1, 13]. In a broad sense, context is defined as *"any information that can be used to characterize the situation of an entity"* where an entity is *"a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves"* [1, 13]. Having systems consider the context of the user, allows them to react more accordingly without requiring explicit input.

The growing amount of data accumulated by sensing technologies in IoT environments, will eventually lead to the generation of *big data* [54]. Without interpretation, analysis and understanding, the mere collection of this data does not hold any value [34]. Additionally, as socialization between IoT objects increases the system's level of complexity, autonomy and dynamic behavior, understanding context will be a core element to support the future of the SIoT. By considering contextual awareness, we are provided with the tools to mitigate the gap of comprehension.

3.3 Challenges of Interaction

As there is a growing interest in autonomous socialization between things, it is necessary to consider the implications these inter-device relationships will have on the interaction with the user.

The first issue lies with the user's awareness of what is happening behind the screens. Without explicitly making this visible to the user, social things will communicate various sensor and actuator values with each other. There arises a clear lack of visibility as these network connections and exchange of data realized by social things are not transparent by default [31]. Due to the dynamic nature of the constructed network connections, a user is left to wonder what is exactly being transmitted and where it has been, leaving awareness of what is happening behind.

Additionally, data received from sensors and actuators and even other objects are potentially being processed using complex processing algorithms to make sense of this information [14]. As the user is the one generating the data, he has the right to know the reason and type of processing that is applied by the system [31]. Allowing users to see what a system has learned from their behavior data, is a cumbersome, be it not impossible, task due to the complexity of the processing algorithms.

As social things will coordinate themselves in order to serve novel services for a particular set of goals, the complexity of the network quickly rises. It will be impossible for users to be aware of the exact role and contribution a specific thing and its sensors contribute to each service. Therefore it will be imperative for each object to convey their role and contributions [15].

Adaptability and scalability can be considered core properties of SIoT networks. This leads to the second issue, found within the control a user will have (or lack) over an autonomous social network. A SIoT application will evolve over time by updating, replacing or integrating new Social Things within the network and these things will have sensors and actuators that can vary greatly in type, precision and behavior. Finding a balance in notifying the user of events in an active and dynamic environment is essential to maintain a certain level of usability. Providing end-user control will be a critical aspect of future SIoT applications [11].

Lastly, while services and relationships are being established and data is actively being shared throughout the network, a social thing needs to have a notion of trust. As indicated by Atzori et al. [4], trustworthiness management builds the basis of reliability, which is connected to the user's privacy and sense of security within an open system. Notions of centrality and prestige in well-know literature are crucial to social networks for things.

While contextual awareness gains a better understanding, its main contribution provides the basis for autonomous acting based on the inferred context [12]. IoT systems with pervasive sensing technologies collect implicit input from the environment which allows them to build a notion of the user's context [42]. However, as autonomous actions taken by a system usually result from complex reasoning, the system's behavior might be difficult for users to comprehend. Additionally, the interpretation of a sensed context might be prone to errors. This leads to users being unable to notice mistakes made by the system since they expect them to do 'the right thing'.

By summarizing the previous statements, we define the following challenges for interaction:

- Providing the user with an awareness of what is happening in the system;
- Granting insights into who has access to the user's data and how it is being processed;
- Presenting an overview of the growing complexity of the autonomous system;
- Warrant control over the dynamic composition of devices within the system;
- Ensuring a notion of reliability and trust based on credential;
- Safeguard visibility of the system's perceived context of the user and the environment.

4 Designing Interaction with Social Things

In order to design interaction with social things while considering the challenges outlined in the previous section, we first consider the role of the human in the SIoT. Building upon this, we address two thought-provoking techniques for the design of interaction that have the user in mind, designing for intelligibility and control and designing the behavior of interactive things.

4.1 The Human and the SIoT

To gain a better understanding of how to design interaction with social things, we first need to address the role of the human in the SIoT. Considering interactions with the IoT, the human fulfills three possible roles [32], as a communication node, as a processing node or as an actuator. In the context of a communication node, the devices carried by humans collect data and interconnect disparate systems and objects. In this way, things are able to take advantage of human mobility to more effectively distribute information throughout the network. Secondly, the decisions made and the tasks executed by the human are the result of how they observe the environment and process the information obtained. These actions make the human a processing node as their behavior influences how the system reacts. Lastly, as an actuator, humans directly interact with physical things in the environment, modifying the world around them.

Supporting user-centered interaction, requires the understanding of human behavior and needs by sensing the context. Context-aware computing is an important evolutionary step towards better interaction. In the case of context-aware systems that make autonomous decisions, it would be unrealistic to assume that the sensed context is always in line with the expectations of the user. Failure is inevitable as context is a dynamic construct with many dependent variables and might not even be able to be sensed or even to be inferred [8, 17].

Empowering end-users for the SIoT where social things autonomously socialize begs the question how to approach the design of the interaction. Mobile agents are able to mitigate interaction by acting as mediators between the system and the human [6]. They assist the user by gaining an understanding of the their goals and requirements [40]. However, from a more general perspective, it is important to warrant the user's understanding of the system. Two prominent methods, are designing for intelligibility and control and designing the behavior of interactive objects.

4.2 Designing for Intelligibility and Control

As argued by Bellotti and Edwards, the increasing degree of autonomy gained by systems which act on our behalf, especially when doing so in relation to other people, requires us to monitor their every move [8]. This can become a complicated task as the internal process of making complicated decisions might be extremely complex and is not made visible by default. To make this possible, they propose the design principle of *intelligibility*, meaning systems have to inform users about their interpretation and understanding of the user and the environment and provide insights into its functionality. Complementary to *intelligibility*, users should always retain *control* over the system in order to recover from possible mistakes or override inappropriate actions [46].

Design Space

To better understand the possibilities and design opportunities, Vermeulen proposes a design space to support intelligibility and control [46]. This design space serves two purposes. Firstly, it can be used to analyze, compare and relate different existing and future techniques. Secondly, given a specific problem, it can be used to generate and iterate over different design alternatives for supporting intelligibility and control. The design space consists of six dimensions and can be seen in Figure 3.

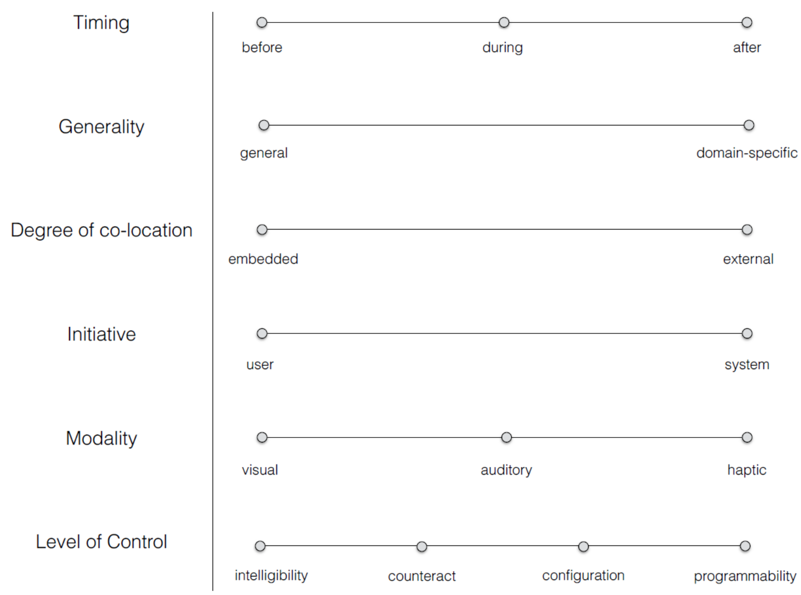

Fig. 3: Design space for intelligibility and control [46].

Timing During different phases of the interaction, intelligibility and control can be supported. The design space discerns between the moment before, during or after an event takes place. Consider the case of a social thing taking part in a service composition event with another social thing. Depending on the preferences of the user, the timing of the notification for this event would imply different meanings. Coming before the fact, a user is able to prevent unwanted results, while after the fact notifications would be aimed at informing the user of the availability of a novel service. During the fact notifications might communicate live progress.

Generality This dimension indicates if the techniques used, are generally applicable or specific to a certain domain or type of application. Each SIoT environment consists of many different devices which might be configured in their own manner. Providing intelligibility and control can be specific to the properties of the device generating the action or might be generalized by the SIoT environment to become more uniform.

Degree of Co-location The degree of co-location depicts if intelligibility and control are offered embedded within the application or exist externally using a separate interface. Depending on the capabilities of a thing, notifications can sent using embedded circuits from within every device in the system. Alternatively, things without suitable output can revert to notifications by contacting mobile agents as well as other social things.

Initiative Intelligibility and control can either be offered upon the initiative of the system or by request of the user. Notifying the user of every service discovered, might flood the user with information. In this situation, it might be better for the user to inquire about new services whenever they required.

Modality Depending on the domain, intelligibility can vary in modality, i.e. visually, auditory or haptically. Social things with embedded actuators can notify the user by activating LEDs, using speakers, moving in a distinct pattern or any plausible combination.

Level of Control In this dimension, four increasing levels of control are distinguished. The most basic level of control is defined as *intelligibility*. In this manner, the control users have over the system is based on their understanding of its functionality. *Counteracting* allows for users to undo actions performed by the system, while *configuration* allows users to tweak predefined system parameters. Lastly, the highest level of control is *programmability* which enables users to (re-)define how the system works.

Implementations

The design space for intelligibility and control was used to create the *Pervasive-Crystal* system, which allows users to understand the behavior of a pervasive environment by posing *why* and *why not* questions [47]. Using a rule-based behavior model, answers try to explain the causes and consequences of system and user actions. The asking of questions to the system, implements 'after the fact' feedback in the *timing* dimension. In contrast to this, the *Feedforward Torch* allows the user to inform about possible events when certain actions are performed, namely providing *feedforward* information [48]. Note that both systems require *initiative* from the user and do not present information pro-actively.

The *OctoPocus* system guides users while performing gestures during pen-based interaction on a table by visualizing the path the user needs to follow in order to complete the gesture [7]. Extending the interaction to mid-air gestures, the *Gestu-Wan* system provides the user with a hierarchical overview of the gesture to be performed [39]. Similar to the *Feedforward Torch*, both *OctoPocus* and *Gestu-Wan* position themselves within the *intelligible* level of control, while the *PervasiveCrystal* allows for *counteracting* and *configuration*.

Design for SIoT

In the context of SIoT, we address this design space for a dual purpose. Firstly, as intended by Vermeulen [46], developers of social things can utilize the space to analyze, devise and implement different techniques to warrant better awareness and enable richer interaction for the user. Given a specific problem, designers can generate and iterate over design alternatives for supporting intelligibility and control. Secondly, we envision extensions of the use of the design space for empowering end-users of SIoT systems to utilize the dimensions in order to configure the behavior of its environment based on the active relationships between social things. For example, a user set on privacy might configure his social things to provide live embedded notifications before the creation of new relationships, while others might want after the fact notifications in a more general manner such as via email summaries. Using these dimensions to pro-actively configure the social things within the environment, the system is able to ensure consistent behavior even while the composition of devices and services remains dynamic.

4.3 Designing for Behavior

The behavior of interactive smart objects is expressed through the autonomous and pro-active decisions they make. As this influences the experience the user has with these objects, designing behavior becomes increasingly important [44]. The field of the Aesthetics of Interaction states that there is a close relationship between efficiency and aesthetics during interaction, as *"attractive things work better"* [30].

Hassenzahl [18] distinguishes between three conceptual levels of the aesthetics of interaction, namely the *what*-, the *how*- and the *why*-level. The *What*-level includes the functionality offered by a product, i.e. the goals users are able to accomplish through interaction. The *How*-level addresses the manner in which a user is able to accomplish these goals, e.g. by pressing a button or turning a knob. The *Why*-level considers the meaningfulness of using an object, e.g. *"feeling close to a loved one"*.

In order to define interaction principles that ensure better aesthetic experiences, connecting the *How*- and the *Why*-levels in an intuitive manner can be done by using an *Interaction Vocabulary* [23]. Previous work has shown that by using this vocabulary, we can consider stereotypical personalities and map them onto the behavior of an object [9, 25, 44, 38, 43]. Norman states that personalities provide humans with a good understanding of behavior and describes them as *"a form of conceptual model, for it channels behavior, beliefs, and intentions into a cohesive, consistent set of behaviors"* [29]. This is closely linked to the field of the *Affective Internet of Things*, where objects within the IoT gain affective personalities through behavior and enables them to induce attachment [35].

We consider related literature in the field of designing for behavior for interactive objects and elaborate on a common design process used by authors. As behavior generates understanding of how objects should behave in interaction and in giving commands, this approach can address interaction challenges related to the user's awareness.

Design Process

While reviewing related literature on designing behavior for interactive objects, we found similar approaches which we combined into a design process consisting of 5 phases, namely *object improvisation*, *personality profile definition*, *interaction improvisation*, *synthesis*, and *behavior implementation & evaluation*. An overview of the phases is shown in Table 1.

Phase	**Details**
Object Improvisation	• Consider Objects of Interest • Consider Physical Limitations and Possibilities
Personality Profile Definition	• Start from Metaphors or Stereotypes • Create Personality Traits
Interaction Improvisation	• Create Interaction Vocabulary • Improvise and Record Interactions
Synthesis	• Combine Personality Traits & Interaction Improvisation
Behavior Implementation & Evaluation	• Implement Behavior in Object • Review if needed

Table 1: Overview of the Design Process for Behavior.

Object Improvisation Behavior is highly dependent on the physical limitations of the object in question. Naturally speaking, a device embedded with more advanced output modalities such as displays, speakers or motors, will have a higher level of expression compared to a device with limited capabilities such as having only one LED. During the *object improvisation* phase, the abilities, function, shape & appearance are considered in order to correctly size up the interaction with the device. This phase can either explicitly be explored by observing natural interactions between objects and users, or is regarded as optional when the object of interest is well-known. Examples for this can be found in [44] by Spadafora et al. where authors record the natural interplay between the users and a 1:1 prototype for designers to review. Contrastingly to this, Ross et al. [38] implicitly perform this step as they start from the functionalities of a well-known object, a lamp.

Personality Profile Definition The notion of personality is essential for the creation of consistent and understandable behavior to facilitate interaction [25]. Therefore, with the outlines for the interaction determined, personality profiles are defined during the *personality profile definition* phase. Recent studies express personality profiles or stereotypes of personalities using the Big-Five personality traits [24]. Currently the theory that is supported by most empirical evidence, the Big-Five describes personality in 5 dimensions, i.e. *Openness to Experience*, *Conscientiousness*, *Agreeableness*, *Extraversion*, and *Neuroticism*. Spadafora et al. [44] contrast each trait with its opposite poles, seen in Table 2. The personality stereotypes can be visualized in a wheel of personality to easily identify duplicates, as can be seen in Figure 4. As a starting point to define personality profiles, literature often refers to stereotypical emotional states from either human behavior [44] or from character behaviro from storytelling folklore [9]. In other work, characteristics are created during a brainstorming session with users in regard to the objects of interest [25].

Personality Dimension	Facets	Opposites
Openness to Experience	imaginative, independent, interested in variety	practical, conforming, interested in routine
Conscientiousness	organized, careful, disciplined	disorganized, careless, impulsive
Agreeableness	softhearted, trusting, helpful	ruthless,suspicious, uncooperative
Extraversion	sociable, fun-loving, affectionate	retiring, somber, reserved
Neuroticism	calm, secure, self-satisfied	anxious, insecure, self-pitying

Table 2: Big-Five personality dimensions by [24], contrasted by opposite poles from [44].

Interaction Improvisation Stereotypical interactions based on the personality traits are improvised, acted out and recorded during this phase, often by professional dancers or actors. When regarding interaction related to tangible objects using phys-

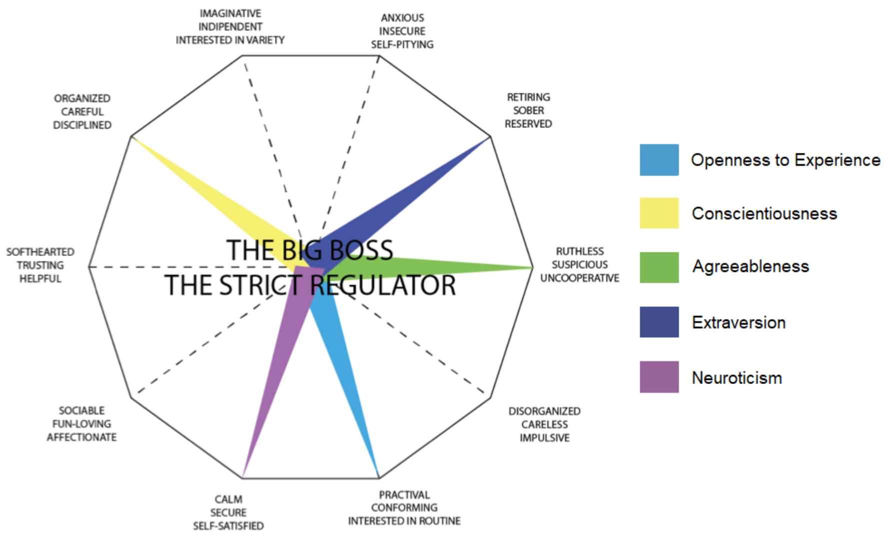

Fig. 4: The *Big Boss* stereotype visualized in the Wheel of Personality from [9, 44].

ical interaction attributes, interaction profiles can be defined using the *Interaction Vocabulary* [23]. In the *Aesthetics of Interaction*, this vocabulary helps to address the *How*-level of interaction through a set of eleven dimensions of descriptive, non-judgmental, non-technology bound attributes of interaction. An example of this can be seen in 5.

Synthesis The personalities generated during the *Personality Profile Definition* are in this phase combined with the results from the *Interaction Improvisation*. This output serves as the material for generating exact behavior.

Behavior Implementation & Evaluation Using the combined results from the *Synthesis*, the exact behavior of every personality can be mapped to the specifics of every device. As the mapping from the results of the *Synthesis* to the device intrinsics could lead to inconsistencies due to a loss in resolution, it is important that the resulting behavior is accurately reviewed.

Implementations

Authors in [44] present *Personalities*, a process to which is showcased by defining the behavior of a social Sofabot which interacts with users in its environment. The defined behaviors are tested in user study using a Wizard of Oz approach to exact the interactions. A similar approach was taken in [43] in order to investigate the social behavior models of a robotic trash barrel. The aim was to study the recognition

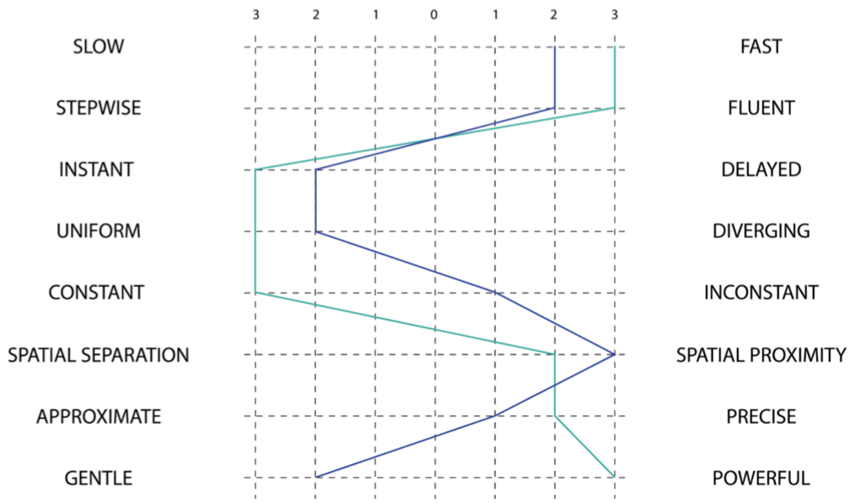

Fig. 5: Example of two interaction profiles for done behavior from [9], plotted using the *Interaction Vocabulary*. Here the blue line represents interaction related to a 'Happy' emotional state, while the green line represents interaction related to a 'Brave' emotional state.

of the varying stereotypes of behavior of the robot and compare how personality influences social status.

Ross et al. [38] focus on the *Aesthetics of Interaction* to utilize the design for interaction in creating various prototypes of lamps. As a result, their experiential prototypes showcase behavior in interaction through abstract expression by dancers.

In order to define personalities in domestic robots, Meerbeeck et al. [25] concentrate on improvisation to support an iterative design process for behavior. Their expressions where visualized using a 3D animation approach, which served a think-out-loud evaluation by users.

Aiming at emotion encoding in drone interaction, authors in [9] start from anthropomorphized emotional states using folklore to create personality in the flight pattern of a drone. User feedback concluded that the behavior in a drone's flight behavior was easily recognized.

Design for SIoT

Although authors in [33] did not approach personalities from a design perspective, their autonomous socialization implementation using *mascots* and benches implemented static behavior based on inter-device proximity. When considering the design process in the context of autonomous socializing things within a SIoT environment, bringing personality to the behavior of social things has the power to positively influence the interaction between the user and its environment. If we consider behavior as an indicator for intentional actions, an in-depth study could analyze how autonomous behavior can be predicted using to personality. A user being able to configure a personality on its SIoT environment and the social things within, will gain awareness of future events, making the system more intelligible.

5 Discussion

Social things autonomously establish relationships, provide services and compose novel interfaces inside the SIoT environment. While benefiting network navigability and service discovery, the increase in complexity does not have the user in mind. While SIoT systems can greatly improve by taking the user's context into account, the perception of the context remains fallible or might not even be possible. Therefore, we must warrant the user's awareness by explicitly visualizing what the system thinks and how it know that.

By designing for intelligibility and control, developers of social things can utilize the space to analyze, devise and implement different techniques to warrant better awareness and enable richer interaction for the user. Given a specific problem, designers can generate and iterate over design alternatives for supporting intelligibility and control. Secondly, we envision extensions of the use of the design space for empowering end-users of SIoT systems to utilize the dimensions in order to configure the behavior of its environment based on the active relationships between social things. For example, a user set on privacy might configure his social things to provide live embedded notifications before the creation of new relationships, while others might want after the fact notifications in a more general manner such as via email summaries. Using these dimensions to pro-actively configure the social things within the environment, the system is able to ensure consistent behavior even while the composition of devices and services remains dynamic.

When considering the design process in the context of autonomous socializing things within a SIoT environment, bringing personality to the behavior of social things has the power to positively influence the interaction between the user and its environment. If we consider behavior as an indicator for intentional actions, an in-depth study could analyze how autonomous behavior can be predicted using to personality. A user being able to configure a personality on its SIoT environment and the social things within, will gain awareness of future events, making the system more intelligible.

6 Conclusion

In the Social Internet of Things (SIoT), social networking paradigms are considered for the Internet of Things (IoT). Things are able to benefit from social capital through autonomously creating relationships between each other and building novel services through service composition. The dynamic aspect of socialization aims to improve network navigability and service availability, while ensuring scalability. However, the addition in complexity comes at the cost of the user's awareness. As social things act without explicitly making this visible to the user, there is an increasing inability to grasp, let alone control, what is happening behind the screens. Therefore it is important to investigate techniques that could mitigate the gap between the system's understanding of the context and the user's mental model.

In this chapter, we started by providing an overview of the SIoT by looking at the motivation for supporting socialization, the history of social things, system architecture and basic relationships for things. To determine and understand the interaction challenges that arise, we framed interaction in the world and the need for contextual awareness. Lastly, we have considered the role of the human in the SIoT. Building on this, we have regarded existing techniques that aim to provide richer interaction and better awareness to the user by investigating the design for intelligibility and control and the design for behavior of interactive objects. Although further research is needed to extend these techniques, both considering intelligibility or defining personalities show great potential in aiding the user to gain a better awareness of the system's functionality.

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