# Thing Theory: Connecting Humans to Location-Aware Smart Environments

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## ABSTRACT
As architects, entrepreneurs, hoteliers, healthcare professionals and others embrace the Internet of Things (IoT) and the Smart Environment paradigms, developers will bear the brunt of constructing the IT relationships within these, making sense of the big data produced as a result, and managing the relationships between people and technologies. We explore how PolySocial Reality (PoSR), a framework for representing how people, devices and communication technologies interrelate, can be applied to developing use cases within integrated IoT and Smart Environment paradigms, giving special consideration to the nature of location-aware messaging from sensors, and the resultant data collection. Based on this discussion, we suggest ways to enable more robust messaging, and eliminate redundant messages by enlisting a social awareness of software agents applied in carefully considered contexts.

### Author Keywords
Dual Reality, Mixed Reality, Blended Reality, PolySocial Reality (PoSR), Ubiquitous, Pervasive, User Experience, Agents, Time, Space, Asynchronous, Artificial Intelligence, Logic, Internet of Things (IoT)

## INTRODUCTION
Each component in a location-aware Smart Environment network can generate data and send messages that must be processed, understood and responded to in some manner. PolySocial Reality (PoSR) relates the outcomes of multiplexed messaging within a group of agents to synchronous and asynchronous contexts, in particular the impact on shared understanding through overlap of messages needed for message-based communication to be effective. Sharing or overlap becomes critical in highly heterogenous environments, comprised of people from many points-of-view using a range of channels for communication in multiple languages. As humans, we depend upon successful cooperation with each other for our survival. A location-aware Smart Environment is another layer in the already highly heterogenous system of communication. People will enter location-aware Smart Environments with the expectation that their devices will integrate, their location will be incorporated, and the environment will respond to them. To plan and design effective location-aware Smart Environments, tools for integrating and responding to human needs and anticipating human intents and desires is significant.



We suggest a framework based on the agency of both humans and environmental components: Thing Theory, a logic based agent framework that evolves the discussion on how to connect humans to an environment that is designed to function for their benefit.

## THING
The 1960's Addams Family television series was based on a cartoon by Charles Addams [1]. The Addams Family lived in an enormous old mansion, full of taxidermy and other curiosities, located adjacent to a cemetery near caves, quicksand, and a swamp. Thing is a disembodied hand (and forearm) that has been with the family for many years and is described as both a 'family retainer' and 'friend.' It inhabits a series of tabletop boxes in different rooms of the house that could be compared to a type of roughly cobbled physical network.

**Figure 1. Thing inhabits a series of tabletop boxes.**

Thing also inhabits plant pots, clocks, the breadbox, glove compartments and other devices to use as a base for interaction. Thing communicates with the family by gestures, sign language, writing out notes, or tapping out messages in Morse code. Thing serves the family by accessing a portal in contextual proximity to what is needed. Thing will answer the phone, by taking the receiver off the hook (and later replacing it), pour the tea, retrieve and deliver the mail, play castanet accompaniment to the Butler's harpsichord recitals, light cigars, return hats, offer advice, put its finger on a bow for tying up a present, or whatever else might be needed or desired at the precise moment required, in the precise room or context needed. Thing is not only a ubiquitous agent, but an anticipatory one that migrates within the environment. Although the family displays a "Beware of the Thing" sign on their front gate, Thing is shown to be courteous, friendly and helpful.

We consider the Addams Family's Thing, minus the Uncanny Valley [2] issues, as a good potential starting point for how agent behavior and interaction could support people in location-aware Smart Environments. The sensing, response and location-awareness of Thing is a useful aspirational model, even if the goal isn't for disembodied hands to pop out of boxes and serve tea. As an agent of sorts, Thing learned about and possessed data knowledge of every member of the household, their preferences, needs and desires and was sensing and aware as to what type of contribution it could make to the successful outcome of their actions. It worked with their location and required nothing from them to be able to assist them, outside of their accepting its non-verbal limitation. Thing had sensors, data, and was location-aware. It also managed in part, the relationships between members of the household. This is what we would expect of an agent in a Smart Environment and what we hope, within the range of sensitivity to privacy, might be achieved. Developers will have to think like Thing in order to take into account how to manage the multiplexed communications, needs and messages that come from multiple sensors and actuators at different locations within the environment. People, sensors or actuators might be moving within the environment requiring location awareness on the part of the overall environment to use the capabilities of the space. Physical spaces are gradually shifting, with the aid of pervasive technology, from being mainly locations or destinations (with space in-between), towards the notion of being places that 'host transitions'[3]. It becomes even more critical for the developer to design agency-based and aware systems to design the algorithmic underpinnings of the Smart Environment to be useful, yet unobtrusive.

## PERVASIVENESS AND POLYSOCIAL REALITY

If we examine the current state of the distribution of pervasive technology, we discover that it permeates some areas, and barely covers others. As service by sensors and actuators becomes pervasive, human expectation, and some level of fusion with the systems that support sensors, will become more and more intertwined.

To smooth the transition for society into a sensor/actuator services economy, conflicts within a culture with regard to adopting and adapting new technologies must be resolved by those developing and deploying pervasive technologies. Technological practice that is 'marked' (e.g. unabsorbed) cannot be pervasive. When technologies become 'unmarked' (e.g. absorbed) into the 'unawareness' of daily life in society, there is a successful technology acceptance [3].

Humans are constantly trying to communicate whether we are static or in motion or in proximity or distanced. When we communicate with others we might talk through closed doors. We also often disrupt, interrupt and try our best to be heard and to listen. Digital mobile technology enables people to be in the same place at the same time, or not, mobile or not. Due to time, space, and conceptual differences, people may not be in the same 'plane of reception' at the same time even if they share time and space coordinates. To the extent that people share common sources of information while interacting with each other, the greater their capacity to collaborate becomes. If they share too few channels relevant to a common goal, there may be too little mutual information about a transaction to interact and communicate well collaboratively. Poor collaborative interaction can lead to further relational fragmentation with the potential to promote isolated individuation on a broad scale [4]. By changing the means that humans use to manage space and time during their daily routines, developers can shift our experience from individuated, user experiences to enhanced sociability within a multi-user, multiple application, multiplexed messaging environment. In Smart Environments, we have multiple channels creating multiple communications, which may or may not be coordinated or multiplexed, and receiving multiple communications in kind that may or may not be synchronous, all while people may be moving through the environment, it can add up quickly to being overwhelming [5].

We have suggested PolySocial Reality (PoSR) as a conceptual model of the global interaction context that emerges when use of the social mobile web and other forms of communication contribute significantly to instantiating intentions [4;6]. PoSR describes the aggregate of all the experienced 'locations' and 'communications' of all individual people in multiple networks and/or locales at the same or different times. PoSR is based upon the core concept that dynamic relational structures emerge from the aggregate of multiplexed asynchronous or synchronous data creations of all individuals within the domain of networked, non-networked, and/or local experiences [5].

Network and mobile communications tends towards message multiplexing that results in a PoSR messaging environment that goes well beyond the limitations of human physiological systems to directly engage [5]. Thus, the interaction environment described by PoSR implies that there are great challenges in using upcoming technologies to improve the social integration of people and their environments, and the entropy of location-awareness combined with PoSR creates a complexity problem that might benefit from a particular kind of Artificial Intelligence (AI) agency to solve on an as needed basis. When environments have the potential to be 'social' (even between themselves as machine-to-machine) there exists a high potential for fragmentation (e.g. partial or complete isolation from ensuing social transactions) due to PoSR related multiplexing. In physical terms, the ability to parse multiple messages in location-aware environments is certainly possible, through sensors and processors, but collating that material and sifting through what is critical is where an integrative agent can contribute. This is where Thing excels as an agent, mostly based on knowledge of the family, their habits, and what is going on in context in real time; the capabilities of the present environment. We will need to have well considered somewhat transparent software and hardware in order to design agents with the utility of 'Thing' to manage multiplexed communications, needs and relationships.

## THING THEORY

Thing operates through observing, reasoning and then taking action. Thing's observations and reasoning are based on knowledge of the family that it has gained over time through understanding and learning what type of tasks they require assistance with on a regular basis. Thing expands the agency of family members and greatly enhances their experience within their rather complex home by acting as an agent on behalf of a wide range of different services and facilities the house has to offer, connecting these to intentions of the family. Thing transforms a complex jumble of services into a successful technological context. We argue that successful technological contexts are those users use to expand their agency outside that technological context proper; the technology expands their general capacity to choose.

We can try to specify how our Thing-agent might improve a Location Aware Smart Environment by specifying some principles that Thing must satisfy. Foremost, we would argue that a Thing-agent will facilitate people exercising agency.

Agency is the capacity to make and execute nondeterministic choices intended to advance to a goal as events unfold. For example, humans exercise agency when deciding whether to turn on a light or to walk across a street to avoid a possible obstacle. Agency implies that agents' future choices are not intrinsically fixed or stochastically predictable except on the basis of secondary principles of reasoning, such as rationality, cooperation or enmity. The foundation of a social relationship requires a mutual presumption of agency on the part of the other; social relations require that each party assumes the other has some level of agency [5].

In any given circumstance, people have a set of options upon which they could base choices. In many cases they will not be aware of some options, a situation that discovery might advance. In other cases they will lack the means to usefully enact an option because of a lack of skill or knowledge, even though they are aware of it. In still other cases, options might not be available because the contexts within which these would be available cannot be deployed. Agency is a direct function of how well people can exercise available options into choices. Agency can be expanded by making new options available by discovery or invention, or through supplying the knowledge and skill required to exercise an option. Agency can be reduced by removing options or the capacity to exercise options.

Often these options and corresponding choices are somewhat predictable due to the assumption of cultural and social frames for reasoning that will vary between people depending on social roles, relative power and specialist knowledge. High levels of predictability will be based on mutual understanding of the different points-of-view by each participant.

If someone wanted to turn on a lamp, they would most likely try a wall switch, the switch on the lamp, check the plug, or in rare cases, depending upon TV exposure, clap their hands [7]. We might not expect or anticipate that they would put their head in the refrigerator to make use of its automatic light. However, they can, and do so. This is the difficulty in developing adaptive software for an Agent (Thing). Fixed decision tree choices are good, but do not have enough information within them to fully satisfy human agency. An environment, to be truly smart, must learn from the cumulative data within its realm to understand and guess what likely choices might be for a given agent and then facilitate or enact these on behalf of that agent.

The first principle of Thing Theory is that the Thing-agent operates as a meta-agent over the entire technology context, not as a sub-component. Our Thing-agent assembles capabilities (e.g. whether or not the refrigerator light is suitable as a lamp) that are extensible based on what subcomponents of the system happen to be available. In short, what Thing can do is ultimately limited by the basic capabilities of various system subcomponents in combination with its knowledge about these and how to combine capabilities to make new more context sensitive capabilities. The second principle of Thing Theory is that to increase the Thing-agent's capabilities, more information from subcomponents must be shared. The third principle of Thing Theory is that the Thing-agent must be context aware, and able to identify that different combinations of capabilities are available in different contexts, and has a corresponding capacity to manipulate contexts (e.g. enact, repress, aggregate) to 'reveal' new capabilities, many of which may be 'innovations' based on context discovery (invention). The fourth principle of Thing Theory is that a Thing-agent extends the capabilities of other meta-agents. In order for the fourth principle to work, the meta-agents (a social network of at least one Thing-agent and another meta-gent) must have some type of transparency or at least shared permissions for exchange of capabilities and contexts. To describe or analyze such multi-agent systems, we must take into account the social as well as the individual behaviors of the agents [8].

| | Principle | Function |
|---|---|---|
| 1 | Thing-agent is meta agent | Operates over entire context |
| 2 | Thing-agents's capabilities are based on system subcomponents. | Thing-agent's capabilities of extension are limited by system subcomponents capabilities. |
| 3 | Thing-agent must be context aware. | Thing-agent must be able to identify different capabilities in different contexts and to select most appropriate one to take action. |
| 4 | Thing-agent works with other meta agents | Thing-agent works with other meta-agents to expand their capabilities when required. Shared permissions/context/capabilities are required as is some transparency between other meta-agents. |

**Table 1. Principles of Thing Theory and their Functions.**

## CONCLUSION: IMPLEMENTING THING THEORY

There are two approaches to implementing Thing theory in location-aware Smart Environments as an interface to user-agents, and as an interface between multiple smart technological contexts that maybe using and supporting the same location. A Thing-agent must do both to be effective, where the Thing-agent serves at a minimum as a means to inform user-agents of the capabilities of the Smart Environment in pragmatic terms that make sense to the user-agents, and ideally provides a high level interface to these.

The Thing-agent must be able to discover the capabilities of the various sub-systems it ranges over, and to possess a representation of the pragmatic contexts in which the capabilities are expressed. This must be done in a way to where Thing-agent facilitates choices by user-agents, rather than forcing user-agents into specific choices.

For most technology the user-agent interface is approached by implementing a metaphorical interface that people can adapt their understanding of to parasitically exploit this adaptation. This works reasonably well for simple technological contexts, though it often takes a very long time for designers to find just the 'right' metaphor for implementation.

In a location-aware Smart Environment, there is usually an intent to 'embed' a technological context within existing contexts that people use. There is an inherent notion of extensibility - new features can be added - and assumption that people will use the environment for many purposes, not all of which can be anticipated by designers. One possible approach to resolving this would be for a Thing-agent to employ an extensible multi-agent simulation that incorporates a specification of each sub-system that relates sensors information and associated services in response to create a model of how the services can interact with each other, and the resulting contexts that emerge from different combinations of interaction. This would provide a basis for a Thing-agent to offer choices to user-agents, but provide feedback in terms of what is likely to occur should the agent make this choice, thus permitting them to 'fine-tune' how they proceed.

Deontic logic has been demonstrated to be a useful basis for constructing simulations of sensitive real-time, time and location aware interactions between agents of different types [9;10]. Casto and Maibaum [11] present a deontic logic suitable for representing the interrelations between agents of different types, including agents exhibiting agency, and [12] is an extended treatment of representing and reasoning with agency in deontic logic. An advantage of modeling with deontic logic is that it is relatively easy to introduce new agents, new conditions and new outcomes into a working simulation and produce results that are instructive to user-agents.

Furthermore, a Thing-agent mediated multi-agent simulation can be useful for designing new pan-context technologies to be incorporated into the location-aware Smart Environment, since these too can take advantage of 'simulation services' provided by a Thing-agent as a part of their decision making, both discovering new capabilities, contexts and a basis for comparing different options. Effectively this facilitates the incorporation of true agency into even subsystems, and thus the capacity for the design of social cooperation between processes, rather than master-slave relationships, exploiting a Thing-agent to ensure that the information that needs to be shared to support agency in the network of agents is available to maximize the capacity for cooperation, and avoid the problems that can arise from PoSR networks of cooperating agents.

A presumption might be that a Thing-agent must have a human intelligence of sorts. A Thing-agent needs to resolve design principles and can do this in non-human ways. Brian Hare's ongoing research on dogs discusses their anticipatory intelligence and is well worth exploring as a alternate type of sensory intelligence [13].

## REFERENCES


1. The Addams Family, Lurch Learns to Dance S01E13, , (06.31). Available Online from YouTube via Anabrans.,http://www.youtube.com/watch?v=2jdCFsw0HFs Accessed 1/22/13. photo via http://monstermoviemusic.blogspot.com/2011/08/addams-family-season-1-episode-13-vic.html accessed 1/22/13.
2. Masahiro, M. "The Uncanny Valley." *Energy 7*, 4 (1970), 33-35. Available online from http://www.movingimages.info/digitalmedia/wp-content/uploads/2010/06/MorUnc.pdf Accessed 01/24/13.
3. Applin, S. A., and Fischer, M.D. Pervasive Computing in Time and Space: The Culture and Context of 'Place' Integration. In Proceedings of the International Conference on Intelligent Environments (IE'11), IEEE (2011).
4. Applin, S. A., and Fischer, M.D. A Cultural Perspective on Mixed, Dual and Blended Reality. In *Proc. LAMDa'11*, DFKI, (2011), 1–4.
5. Applin, S.A. and Fischer, M.D. Applied Agency: Resolving Multiplexed Communication in Automobiles. 4th International Conference on Automotive User Interfaces and Interactive Vehicular Applications. *In Adj. Proc. AutomotiveUI '12*, In cooperation with ACM SIGCHI (2012), 159-163.
6. Applin, S. A., and Fischer, M.D. PolySocial Reality: Prospects for Extending User Capabilities Beyond Mixed, Dual and Blended Reality. In Proc. *LAMDa'12*, DFKI, (2012), 1–4.
7. Srinivas, G., Colmenarez, A.J., and Trajkovic, M. "Method and apparatus for controlling lighting based on user behavior." U.S. Patent No. 6,724,159. 20 Apr. 2004.
8. Dix, J. and Fisher, M. Where logic and agents meet. *Annals of Mathematics and Artificial Intelligence 61*,1 (2011), 15-28.
9. Fischer, M. Cultural Agents: A Community of Minds. Engineering Societies in the Agents World VI. Dikenelli, O., Gleizes, M. and Ricci, A. (eds). *Lecture Notes in Computer Science* 3963, Springer-Verlag (2006), 259-274.
10. M Ryan, J Fiadeiro, T Maibaum. |Sharing actions and attributes in modal action logic. *Theoretical Aspects of Computer Software*. (1991), 569-593.
11. Castro, P. and T. Maibaum. "A complete and compact propositional deontic logic." *Theoretical Aspects of Computing–ICTAC.* Springer Berlin/Heidelberg. (2007), 109-123
12. Horty, J. *Agency and Deontic Logic*. Oxford University Press, Oxford, 2001.
13. Hare, B., & Tomasello, M. Human-like social skills in dogs? *Trends in cognitive sciences 9*, 9 (2005), 439-444.