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iForest: Exploring Crowd-based Intelligence as a Means of Improving the Human-Computer Interface in the Cloud-of-Things

Idham ANANTA[a,1], Vic CALLAGHAN[b], Jeannette CHIN[c], Matthew BALL[b], Jazi Eko ISTIYANTO[a], Susi DARYANTI[a] and Michael GARDNER[b]
[a] *Universitas Gadjah Mada*
[b] *University of Essex*
[c] *Anglia Ruskin University*

Abstract. The Cloud-of-Things is a holistic vision about the future of pervasive computing which joins together many topics including the Internet-of Things, Intelligent Environments, Cloud Computing, Embedded Computing and People. Clearly such system can lead to very complex arrangements and relationships especially when an attempt is made to scale up existing approaches into large heterogeneous interconnected intelligent environments. This paper highlights the problems and requirements for such a model and proposes an architecture we call iForest that can address these problems based on the use of crowd-based intelligence as a means of supporting users of heterogeneous interconnected devices with in a Cloudof-Things paradigm. In particular we present a computational model, based on graph theory, that we hope is a significant step to these ends. This work is ongoing and we will be reporting onour prograss in furture workshops and conferences

Keywords. cloud-of-things, internet-of-things, intelligent environments, cloud computing, collective intelligence, crowd intelligence, embedded computing.

Introduction

One of the most popular uses of the Internet is for social activities which are facilited by tools such as social networking, communications, blogs, product recommenders, and crowd funding. These tools empower people by enabling them to harness the potential of community action. Even since the creation of the web, the social aspect has been one of the most influential factors. Tim Berners-Lee, the inventor of World Wide Web is quoted as saying [1] "*The web is more a social creation than a technical one. I designed it for a social effect to help people work together and not as a technical toy. The ultimate goal of the Web is to support and improve our web-like existence in the world. We clump into families, associations, and companies. We develop trust across the miles and distrust around the corner. What we believe, endorse, agree with,*

[1] idham@ugm.ac.id.

and depend on is representable and, increasingly, represented on the Web. We all have to ensure that the society we build with the Web is of the sort we intend".

Likewiset pervasive computing pioneers, such as Mark Weiser, aspire for technology to support the social nature of people as was well articulated in his vision for the "disappearing computer", where he said [2]"*By pushing computers into the background, embodied Virtuality will make individuals more aware of the people on the other ends of their computer links. This development carries the potential to reverse the unhealthy centripetal forces that conventional personal computers have introduced into life and the workplace. Even today, people holed up in windowless offices before glowing computer screens may not see their fellows for the better part of each day. And in virtual reality, the outside world and all its inhabitant effectively cease to exist. Ubiquitous computers, in contrast, reside in the human world and pose no barrier to personal interactions. If anything, the transparent connections that they offer between different locations and times may tend to bring communities closer together*"

From these quotations it is clear that both Berners-Lee and Weiser's vision intended that intelligent environments should support social activities. From a user's point of view, the main difference between an intelligent environment and a virtual world is that, in a virtual world people need to login to it in order to interact with the system whereas people an in intelligent environment are already an integral part of the system, interacting it physically, without the need to explicitly login. Thus, in an intelligent environment, the system is part of the real world where real people have some private and public spaces. In fact, because intelligent environments are social spaces, interaction between two or more people would seem inevitable.

Managing more than one user and more than one environment, and dealing with its complexity is a 'hot topic' in pervasive computing research. This paper will highlight the problem of complexity in the heterogeneous intelligent environments, and propose a novel model, iForest, that harreness social interation in the form of collective intelligence as a means to provide a better alternative to conventional AI for putting the 'intelligence' into intelligent enviroments. In support of this we also ouline a representation scheme for human and devices relationships in such environments.

1. Related Work

The notion of user-centric ambient intelligence goes beyond simply embedding technology into the society, but also seeks to also reinvent interaction between computing and the user in a new way. Using computers has traditionally demanded a significant amount of a knowledge and learning, whereas ambient intelligence seeks to decrease this cognitive load by providing more user-friendly interaction between users and computers [3].

One, notable example is Task Computing which has proposed a user centric model that utilises a semantic scheme to describe the relationship between users, their role and the task being undertaken, based on a particular context. It was developed with the notion of a SRTM (Semantic-Based Role Task Model) which provided a task computing model that was able offer a particular task to the user based on the particular context. Relationships were described as a map (or graph) interconnecting the user's role, task and context entities. SRTM describes two kinds of relationship between a task and its subtask; Vertical and Horizontal. An example of a vertical relationship between tasks and its subtask might be part-of, instance-of, etc. This type of relationship is called 'functional semantics'. An example of a horizontal relationship between tasks and its subtasks is a sequenced choice. These are expressed in relationships called 'execution semantics' [4]. Herranz developed this idea further by proposing rule based systems, generated automatically by sets of intelligent agents which managed coordination between one rule and another either by constructing comprehensive rules, that describe all the people involved, or by providing a multi users' policy via *"meta-agents"*. The structure of coordination could be regarded as blackboards with graphs created by people, their agents to describe the relationships [5].

From a the wider perspective another project, ATRACO [6], addressed the need for functional, structural and semantic adaptation to maintain a preferred situation in highly dynamic environments. The project proposed the notion of an 'ambient ecology' and an 'activity sphere' to define a 'Bubble' concept, which was a virtual container for people, preferences, and associated devices and services, based on a particular application. The challenge was how to maintain the application sphere when changes took place in the 'ambient ecology'. Sets of intelligent agents and ontologies were devised to create a framework to support this adaptations.

However, these projects also revelealed the shortcoming of current research. For example, complexities arise, when an attempt is made to extend the notion of such user-centric smart environments to a larger scale, involving hundred or thousand devices and services in different configurations with crowds of users conducting their own background activities and based on their own individual preferences. To avoid such complexity earlier studies focus on more isolated approachand, as a consequence, tend to overlook the possibility that complexity might not be all bad, but larger scale might bring some benefits that could actually simplify the implementation, or make it more efficient. In this paper we take this latter view, tand explore the possibility that large scale could offer functional benefits that may improve such systems, in particular the performance of AI components through crowd based techniques..

2. Discovering iForest

In our earlier work we have described the CHAMBER [7] (Crowd-based Heterogeneous Ambient Environment Relationship framework), as a mechanism that can take the advantage of crowd-based knowledge in the intelligent environments; see Figure 1. Our earlier work presented our initial data model as descriptions to represent usable knowledge in the framework. However, in this paper, we challenged the model with following questions:

- How to model global heterogeneous interconnected intelligent environments into measurable, manageable, and widely accessible architecture?
- How to deal with complexity by identifying similarities in massive crowd data (big data)?
- How to model the relationship between people and their environments, ?

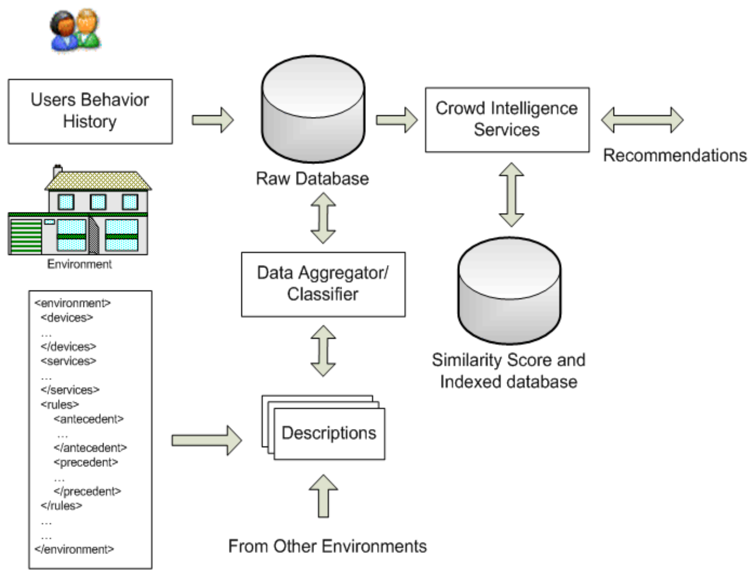

Figure 1. CHAMBER Architecture.

Currently intelligence in pervasive computing is provided in several ways. In small scale systems, software-agents are embedded within the environment (mostly the control devices) to perform simple yet powerful AI operations using techniques such as Fuzzy Logic (these analyze contextual data from networked sensors and user preference to pre-emtively set the environment to meet the user desires). In larger scale systems, researchers frequently use ontology as a knowledge representation, together with a reasoning engine to infer actions.

From a wider perspective, where each local environment constructs it's own interpretation about a particular context or preferences, the effort to generate a consolidated intelligence or common sense will be very complicated. Thus, as in our framework, the purpose is to create a global-view model for heterogeneous interconnected intelligent environments. This necessitates the development of a model which can describe all interaction between the user and the intelligent environment based on raw data rather than an aggregation of local interpreted knowledge. This approach is chosen because of following considerations:

- **Similarity discovery -** One of the most important benefits of generating the global view model is to facilitate the exchange of knowledge from one environment to another. However, such knowledge is only useful to others, which have similar/identical contexts and configurations. Thus, finding similarity is very important for this framework. Modeling interaction of users and their smart environments into the raw data model will ease the process to capture their similarities.
- **Effective AI** – AI based predictive systems, such as Microsoft's Intelisense, are notorious for annoying people when their predictions are poor. Thus an important research challenge is how to improve the performance of these systems. Therefore, in our model we are exploring crowd based predictive

mechanisms to provide a more naturistic reasoning capability that we hope will improve the performance of our predictive recommendation engine.

- **Computational Load** - Shifting the computational load from local site into a centralized, but optimized, service has many advantages such as reducing the processing needs of the local device and enabling the market to offer add-on services such as data mining.
- **Open Systems** - Representing pervasive computing worlds using uniform data structures will offer a simple and open interface that is widely accessible for heterogeneous local environments that will encourage third party development and manufacture.
- **Benchmarking** - By using well-specified data structures and procedures, it becomes easier to create shared benchmarks which can generate standardised data that informs research and leads to better designs.

Based on these principles we have proposed a novel graph based model to represent the complex heterogeneous relationships in interconnected intelligent environments. We argue that, in addition to graphs fulfilling the entire requirements described above, they provide an easy to understand yet visually compelling display. However, the linkage of crowd based AI to pervasive computing creates some unique attributes of this model, that differentiate it from other approaches such as tthose found in online recommender engines. In our mind this problem space has some superficial similarities to a forest, so we have call this architectural model the iForest.

The iForest model, is presented in figure 2 and consists of a set of vertices and edges. Vertices represent physical entities such as a person or device, together with abstract entities, like context, preferences, etc. Each entity can have it's own attributes such as a name, ID, or location. Edges represent relationships between vertices. There are many kinds of relationship possible. For example, entitities such a home, room, light and TV might have structural a relationship that might be written as 'a home has a light', or 'a room has a TV'. The attributes 'person' and 'light' might have functional relationship, such as 'a person switches on the light'. Each relationship might also have attributes. For example, in the 'person changes TV channel' relationship, where attributes such as 'time stamp' and 'particular channel' are attributes. Also there are physical or unique relationship attributes, such as 'energy consumption' or 'location' (some functional relationship include mobility describing movement from one location into another) which might be useful for more advanced intelligent environments development.

There are other reasons to choose graphs. From our perspective, the graph is visually compelling and easier to understand. From a mathematics perspective, there are two mechanisms that could be utilized to represent and operate on "crowd-based intelligence schemes, namely vectors and graph theory. The advantage of vector space representation is the abundance of well defined mathematical operators compared to graphs. However, graph had two advantages, which are its flexiblity in term of size or ability to deal with complex topologies, together with their capability to represent binary relationships amongst entities [8] [9] [10]. As the complexity of structure and relationships are two important considerations in our framework, we are exploring the use of graphs.

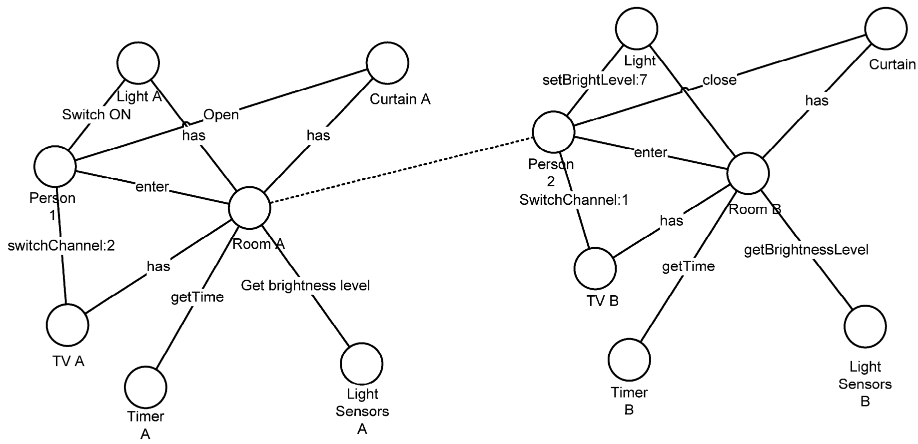

Figure 2. iForest Data Structure.

3. Managing Information of Structure, Behavior and Semantic in iForest

iForest has been designed to contain aggregated information about structure, behavior and semantics. The structure describes a hierarchy between physical devices and their attributes (including name, type, and location) which rarely changes over time. Thus in our model, structured information could be considered as a base layer. Behavior information takes the form of an aggregated record of activities that have occured in the environment. A simple action like "Kevin switches the light on" can be mapped into two vertices, one is a person named Kevin, and the other is a light with its status attributes (on/off); both are interconnected with a "switch on" action relation, together with their own attributes such as a time-stamp. As behavior changes over time, the behavior graph in iForest could be seen as a dynamic graph, adjusting its relationships in response to ongoing changes. However all behavior information is stored in a persitent database.

In iForest, structural and behavioral information is created automatically in real-time by the local system, and sent to the cloud (with appropriate provisions for privacy). Becuase the cloud has the potential for significant processing of this data, with the appropriate algorithems, iForest has the potential to augment this sensed data with semantic interpretation based on statistical, structural, or any other pattern recognition on existing graphs. Thus it is possible for iForest to define more abstract entities like context, action, and to suggest rule sets for task composition (eg virtual appliances, meta appliance or applications etc) based on similarity matching across these large graphical data sets. For example, when iForest discovers that most of environments in particular location frequently switch their light on at a particular time, it could offer it as a rule to other environments which have an identical or similar structure/ configuration. Likewise, of a physical cluser of environments are using a set of rules (virtual appliance) for say, a security application (maybe the neighborhood has a crime problem) then it might suggest that virtual appliance to neighbours. iForest is a flexible graph based structure and thus can offer an almost endless set of relationsships so it could, for example, offer such rule/task with attributes like "most-energy efficient" or "most used" or even "most favoured one" to the user.

4. Implementation

Our broader research objective is to facilitate collaborative work between Universitas Gadjah Mada and University of Essex. as part of a research programme to explore interoperability issues amongst heterogeneous intelligent environments. Towards these ends we have been developing CHAMBER Framework and iForest in the iSpace (see Figure 3) located at University of Essex as our initial test bed.

In this research, an initial data set of user preferences based on particular scenarios was generated from an online survey. It asked students about their behavior in their dormitory (eg study, relaxation, sleep etc). The data aggregated from online survey has been aggregated into the iForest model to support the similarity match algorithm, to supplement the rea-time data (as we are unable to get tognificant numbers of environments, we have to generate the date in this way)..

The iForest then offers recommendations w to real iSpace inhabitants, for particular scenario based on an aggregation of real and survey data. By way of an example to illustrate its operation, when the inhabitant going to sleep, it will try to find a best preference match for him/her, using a personalised similarity match. Therefore the iSpace might offer rules to switch the lights off, on, or adjust their brightness level in the dormitory, based on other inhabitants or students similarity level (and preferences).

Figure 3. iForest TestBed

In this way it will also create both social awareness (the inhabitant aware of how many students are studying at the same time, which could motivate him/her to study, for example) and social preferences (when the student wants to watch the TV, he/she could notice the number of the students, who are watching particular TV Show, at the same time).

Thus, both intelligent environment personalisation and social interaction are possible using our CHAMBER framework and iForest model.

5. Conclusion

We have described the need for a data model that can represent the highly complex relationships that exist in heterogeneous interconnected intelligent environments.

Moreover, we have argued that conventional AI is not always the most effective in creating predictive agents for pervasive comuting and intelligent environments, as there is a sparsity of sensing, a shortcoming in the types of algorithms that exist and somewhat weighty computational loading; as an alternative we are proposing the idea of utilising crowd based intelligence to create more naturalistic recommendations engines. However, we have pointed out that implementing crowd intelligence intelligent environments is complex, especially in terms of representing relationships, which can be huge (in quantity), diverse (in nature) and highly dynamic (in physical movement and evloving preferences). Also, for this model to function we pointed out it requires hundreds, if not thousands of examples (ie intsances of other environments). While these do not exist now, we envisage in the future hundreds, or thousand of physical spaces scattered all over the world (each with tesns or husndreads of devices); what we call an interconnected intelligent forest or *iForest*. Such an environment would be occupied by users from various backgrounds, with their own subjective preferences, who actively and continuously interact with intelligent environments around them. At this stage, we have not solved all the problems relating to implementing crowd intelligence in such complex environments, but we have set out the case for exploring this fascinating line of research, together with presenting a computational model, iForest, that we believe is a significant step towards these ends. We will, of course, be reporting on our prograss in furture workshops and conferences.

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