Intuitive Human Governance of Autonomic Pervasive Computing Environments

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Abstract

This paper proposes an intuitive configuration tool for autonomic pervasive computing systems. Specifically the paper presents a system for the inference of user task intentions from a variety of sensed information and describes how this can be readily configured by users to meet their needs for performing particular activities in particular spaces. The approach taken combines the capture of user task concepts and policies with their integration into a 3D virtual reality model of the environment being used so that these concepts and policies can be mapped intuitively but accurately onto the sensed physical environment.

1. Introduction

Autonomic systems are adaptive systems, the behavior of which is constrained by on-going human governance. Such governance is specified through interpretable policy rules which define human goals that the system must aim to achieve and the constraints within which the adaptive behavior of the system must be confined. People modify these rules as those goals or constraints are changed. For systems that are mobile, or likely to be deployed in a wide range of environments, humans may also modify policy rules to reflect the different operational context spaces which provide the terms in which those rules are expressed.

Here, we are concerned with the study of Autonomic Pervasive Computing, i.e. pervasive computing systems whose context-aware adaptivity is subject to human governance. Autonomic pervasive computing spans both Autonomic Computing, in managing the complex range of application services offered to pervasive computing users, and Autonomic Communications, in managing highly adaptive networks such as sensor networks and mobile ad hoc networks. Autonomic Pervasive Computing differs from these in that the adaptivity it offers, and thus its governance, is highly user-centered, with the distinction between users and administers often being blurred. It is also distinct from current approaches to autonomic computing and communication in that it is highly ad hoc and heterogeneous, both technologically and organizationally. This is because pervasive computing infrastructure is drawn opportunistically from sensing, processing and actuating capabilities embedded in the widely diverse fabric of everyday life, and thus owned and operated by all manner of individuals and groups above and beyond commercially-motivated service providers. Adaptive behavior in pervasive computing is driven by changing context that is not just drawn from the electronic domain, but also sensed from the physical and social environment.

Autonomic Pervasive Computing brings into sharp focus, therefore, the position of autonomic systems in a continuum between purely adaptive systems and purely automatic systems. Purely adaptive systems adapt their behavior in response to sensed changes in their operational context. However without ongoing human governance, this behavior must either be constrained at design-time, making the system inflexible to application in different context spaces, or left unconstrained, which may result in undesirable behavior. Purely automatic systems also aim to constrain the adaptive elements of their behavior, but through automated inference of human goals and conventions rather than through explicit conversations with human users. Such automatic systems therefore require extremely effective mechanisms for interpreting human intent from sensed human actions and for sensing and learning from human satisfaction or dissatisfaction of the resulting machine governance of adaptive behavior.

This paper describes some results from using Bayesian Networks to support a degree of human intent inference that could form an element of an automatic pervasive computing system. These investigations have highlighted the need for the automatic intent inference mechanisms to itself be subject to human governance if the resulting

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adaptation is to accurately reflect real human needs. In other words effective automation in an open context environment requires the human governance characteristics of an autonomic system. This paper therefore focuses on how the governance of automatic intent inference is supported in an intuitive manner accessible to its target users. This is performed by allowing users to establish the terms in which their policies are described by combining the annotation of a 3D simulacrum of the physical space they are using and the conceptual expression of the social and system context space they see themselves working within. This expression is captured in the form of semantic knowledge that is readily presentable within a larger space of commonly understood contextual concepts.

2. Driving Adaptive Behaviour from Intent Inference

Pervasive computing environments will necessarily involve a proliferation of devices, as well as fluid population of mobile users. Each device will have its own interface capabilities, while the users will have their expectations and demands for interaction with the environment as a whole, often being unaware of many of the devices present. Reconciling these is vital to the successful delivery of automated user support in a pervasive environment; however this success must empower the user to ensure their acceptance of the system. The user must be placed at the centre of whatever support is offered, and all efforts must be taken to configure the system around the user, not the other way round. Thus we aim for environments to adaptively offer support on a per-user, per-task basis.

The proliferation of device user interfaces can be addressed in two ways. The first possibility is to design a common interface and replicate it on all devices. The user need only learn it once, and then they will be equipped to deal with whatever devices are before them. However, the input\output characteristics of devices differ as the user moves from small, highly portable devices through to media rich appliances. The limiting factor in the design of a common interface will be the requirements of the most basic device. For devices to be so limited, yet effective, more and more of the burden for driving the interaction falls on the user, increasing the complexity of their interaction with the system.

A second solution, and the one that this paper will examine, is to provide an environmental interface. The user interacts with the environment using the variety of interaction modes offered by the devices and sensors available in a space. With a suitably rich population of devices, these modes can be intelligently integrated to infer the need for and invoke services to satisfy user intentions. The user is thus unburdened and need only focus on their needs, rather than those of the system. In order to make such a system truly empowering, this paper will propose that the user be allowed the greatest flexibility in their mode of interaction. This is supported by allowing the autonomic governance of adaptive system behavior to be conducted by the user actually charged with using the pervasive computing space concerned, rather than by separate system administration specialists.

In such a system, where natural activity could be used as input, the range of data detected by sensors will be highly heterogeneous and ambiguous. It is therefore necessary to consider individual actions, such as a gesture or a verbal comment, not as standalone actions, but rather as elements of more complex user-system interaction dialogue. Taken individually such actions may hint at any number of potential requests, however when appropriately aggregated, patterns of actions should be recognizable as higher level intentions.

The question therefore becomes how to aggregate these heterogeneous data and how to carry out inference based on them. We use Bayesian Networks to achieve this aggregation. This approach was chosen as it provides an efficient method for aggregating data and inferring outcomes.

Nodes in the network at the lowest level represent atomic input events, a position change, say, or a spoken command. These nodes combine to form more complex events and ultimately resolve to high level intentions [6] that can be serviced by the system. Node values correspond to the utility of the node being triggered. Utility is defined as the marginal benefit of preemptively offering support versus not offering it, and also taking account of the user's reaction to these outcomes. This is a technique used in Mixed Initiative [4] systems as well as Attentive User Interfaces [3]. As evidence is observed, it is added to the network until the utility threshold for some given support is exceeded, and the system triggers a request for that support.

We have conducted initial evaluation of this approach using a 2-dimensional simulation of an office. Users were given a number of tasks to complete in the simulator, with input via mouse-position simulating gaze and text input replacing voice. As they interacted with the simulator, their actions were fed into the Bayesian Network until they system was sufficiently confident that it could offer support. In this limited experiment, the 'support' was an output to the user stating the result of the systems inference. In our planned pervasive computing space, the user task inference system would dispatch a suitable request to an automated service composition platform that would return an appropriate composite service [2]. This request would follow the Belief-Desire-Intention (BDI) model used in agent systems [10]. BDI allows for the specification of goal-directed activity, where beliefs describe current knowledge, desires describe preferred end-states and intentions the steps between the current and desired states. In our system, beliefs and desires are supplied to an AI planner that attempts to reconcile them, thus providing a service composition matching the intentions in the BDI model.

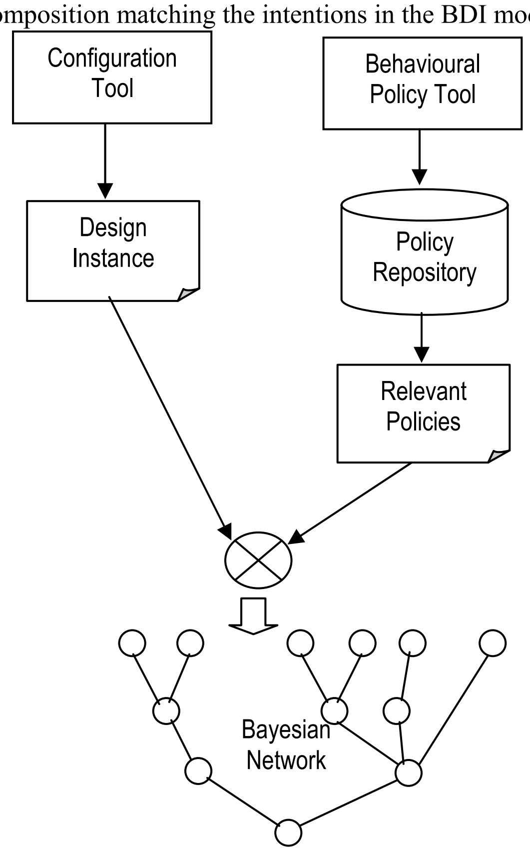

Figure 1: Overall Activity Flow

The design and manipulation of the Bayesian Network was accomplished using the JavaBayes platform [9]. In the network, basic nodes were divided into 'nouns' and 'verbs'. The 'nouns' referred to resources in the space and other task related data, the 'verbs' related to the types of interaction that the user was carrying out, or requesting. Input from the simulator was parsed and then added to the network. Inference was carried out every time there was a change in the state of the network, however for applications involving greater numbers of users and input streams this inference would instead happen periodically and asymmetrically vis a vis input.

3. Intuitive Configuration of Intent Inference Mechanism

Our more recent work involves examining more meaningful applications of this technique in pervasive computing environments. Here, business policy and activity data are captured by users of a pervasive computing space in order to allow them to tailor the space's adaptivity (in terms of user task intent inference) to their particular needs. For example, if the network were to describe the various behaviors that might occur in a meeting scenario, information such as 'all presentations are delivered from the podium' or 'questions are asked by first raising one's hand' might be captured and used to guide inference.

Intuitive user configuration of a space is an important factor in the design of pervasive computing environments. One particularly successful approach to making applications intuitive is to make their conceptual space available graphically [7]. This is especially powerful when portions of the conceptual space are tied to physical spaces with which we are all adept at interacting. We have developed a graphical configuration tool-set for pervasive environments. The first tool will allow the preparation of the Bayesian Network which will be used to guide the aggregation of input data and the provision of support; the second will allow the actual configuration of the environment.

Much work has been carried out in the design of adaptive elearning systems based on creating navigation paths through pedagogical concepts. This paper proposes using a similar approach to the intuitive preparation of behavioral policies for pervasive environments. An authorized user, e.g. an office manager or team leader say, who wants to program a space for a presentation can use such a description to define the various patterns of activity or tasks that can be expected in a presentation. [5] describes a design tool for allowing for such navigation between concepts in an educational scenario, and this system is being modified to provide causal chains of behavior that are tied to higher level actions.

For example, satisfying the following could result in a request to begin recording a presentation session.

- Presentations occur in the meeting room
- Presentations are recorded in video
- If video is not present, audio recording occurs

- The audience takes their allotted seats before the presentation begins
- The presenter delivers their presentation from the lectern
- The presentation begins when the presenter dims the lights

A series of observed events may indicate these, and could result in a request being dispatched to the service composition platform. In a large enterprise, such policies could be available throughout and the relevant individual could choose to apply them 'off-the-shelf'. These pre-defined elements would be described conceptually so that the user need only describe their general requirements and the system could then take responsibility for tying such requests down to the appropriate policy.

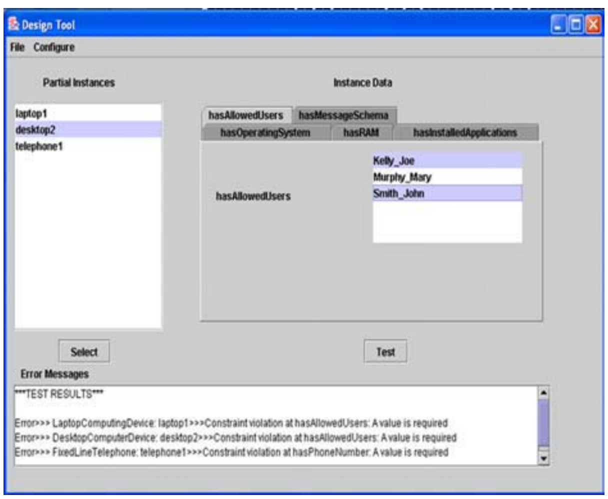

Figure 2. Ontology Completion Tool

The second tool developed presents a graphical interface for configuring such policies. It has a two-step operation; firstly the user provides information on location and orientation by using a 3-dimensional map editor, see Figure 2. The output of this is converted into a suitable set of concepts that is modeled to provide a semantically complete view of the target space. This can then be used by the pervasive environment to configure itself for the proposed application.

The map editor that has been chosen for this component is the Hammer editor that accompanies the Half-Life computer game. This editor allows users to place objects within a three dimensional space. They can give these objects unique identifiers as well as assigning them to different categories and families of objects, e.g. trashcan, computer. When the user is satisfied with their result, they compile the map into a format that the Half-Life game can interpret. The tool then parses this file and converts it into a basic DOM document, ready for further processing.

In order to make the output of the configuration tool as generic and re-usable as possible, it was decided to capture the configuration information as an ontology expressed in OWL, the Web Ontology Language developed by the Semantic Web Community. OWL was selected as it not only has the benefits of RDF (i.e. open language and a growing range of tools), but also a richer vocabulary for describing the meaning and relationships between terms. The output ontologies are based on the Standard Ontology for Ubiquitous and Pervasive Applications, SOUPA [8]. SOUPA provides a minimal set of generic ontologies proposed for describing basic elements in pervasive computing applications.

The output from the map editor, now represented in DOM, is transformed into a partial instantiation of a SOUPA ontology. The transformation schema is dependent on the element currently being parsed. This dependence is guided by mapping the Hammer families of objects to terms in SOUPA, and thus applying an appropriate transform for an appropriate object.

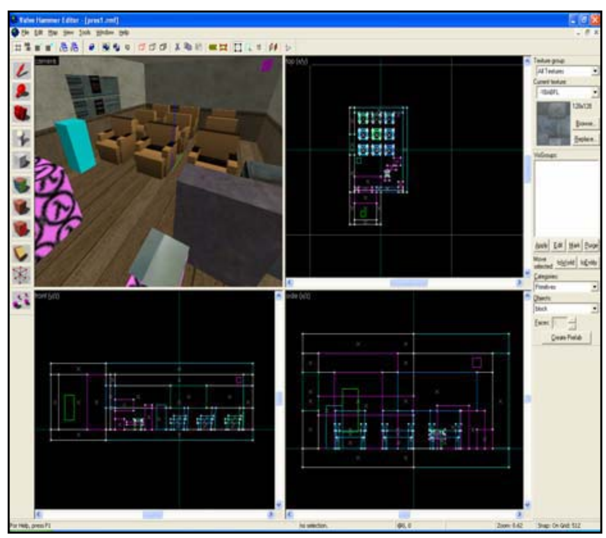

Figure 3: Map Editing Tool

This partial ontology is parsed to check for semantic completeness. This is done using the Protégé-OWL API [11], which allows for closed-world constraints checking of OWL ontologies. The application shown in Where additional information is required, the user is prompted to give it, e.g. the physical location of a PC in the space may be given by the map editor, but the list of those who may access it is not. User interaction and ontology verification is supported by the application shown in Figure 3.

Once the ontology has been verified as complete it can be released to the pervasive environment's management system. This information should be sufficient for this system to appropriately configure devices and services in the space for the planned application. The information from this ontology may also be useful to the Bayesian Network. For example, in the presentation example earlier one of the policies was that audio should be used when video is not available. This can be immediately ascertained by consulting the configuration ontology; if no video has been set up, then it will not be available to the recording service.

These two components, the Bayesian Network designer and the environment configuration tool are both built around the user and attempt to present the user with an intuitive interface. As such they place the user, irrespective of the technical expertise at the centre of the governance of the pervasive computing environment.

4. Conclusions and Further Work

This paper highlights that, within the domain of pervasive computing, completely automatic behavior is unlikely to yield satisfactory results with current technologies, such as Bayesian Networks. We therefore assert that the development of *autonomic* pervasive computing should be a priority, with a focus on making the human governance interface as intuitive to use and cognitively close to the user experience as possible.

Our future work will aim to evaluate this ease of use, in particular with a view to assessing the level of user empowerment, whereby the user feels 'in charge' of adaptive behavior rather than at the mercy of opaque automated decision making. This assessment will be based on a series of experiments, which will be task driven with users attempting a number of scenarios. Evaluation will be based on questionnaires to establish pre-use conceptions and post-use feedback, as well as passive observation of the test subjects and user commentary. The experiments will involve both the individual components as well as an over-arching final set which will examine the overall operation of the system. These experiments are scheduled to take place in the coming weeks, starting with the configuration tool.

5. Acknowledgements

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