Curious Places: Curious, Proactive, Adaptive Built Environments

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Abstract. Advances in intelligent agent research, such as curious agents and motivated learning agents, make possible a new kind of intelligent environment: a curious place. Previously, intelligent environment research has focused on developing reactive and interactive systems that control sensor and effector architectures, achieve context awareness and support human activities. This paper identifies the key attributes of curious places that differentiate them from existing intelligent environments and proposes new focus areas for intelligent environment research: proactive problem finding, life-long adaptability and enhancement of human activities. An example of a curious place application is discussed with emphasis on its adaptability and its potential to enhance human experiences.

1 INTRODUCTION

Recent intelligent agent research developing intrinsically motivated learning agents presents opportunities for the design of places able to respond with motives such as interest and curiosity to support and enhance human activities. Maher et al [7] introduced three motivated learning agent models for intrinsically motivated intelligent sensed environments that incorporate computational models of motivation with reinforcement learning, supervised learning and unsupervised learning. These models aim to achieve adaptive responses using motivation to direct learning towards useful or interesting behaviour.

When computational models of curiosity are used as the model of motivation in intelligent environments, a new kind of space emerges: a curious place. In addition to supporting human activities, the environment is able to proactively anticipate and identify courses of action to enhance the human experience. These abilities suggest new focus areas for intelligent environment research: curiosity and proactive problem finding, life-long adaptability in dynamic environments and enhancement of human activities.

This paper discusses these focus areas and motivates the need for further research in these directions. An example of a curious place application is discussed with an emphasis on how it extends the capabilities of traditional agent-based approaches to similar systems.

2 INTELLIGENT ENVIRONMENTS

A practical application of intelligent environments is the C-Bus home automation package [2] where computational processes monitor activities within the home and respond by turning lights on and off, locking and opening doors, triggering zoned heating or cooling and activating automatic watering systems. Such home automation systems are possible with sensors and effectors that are programmed to respond deterministically to predefined triggers.

Another approach to intelligent environments is to use agents. Agents reason about the use of the room in order to facilitate human activity. This research started with the Intelligent Room Project [1, 3] and has progressed in several directions, from sensor technology and information architectures, to possible agent models for intelligent reasoning [5]. Agent societies in intelligent environments have the potential to exhibit complex emergent behaviour as a result of collaboration between agents performing different roles [11]. However, while existing agent-based systems go beyond the home automation systems to proactively support human activities, the agents still respond with programmed reflexes to predefined triggers. Curious places introduce the use of intrinsically motivated agent models to the design of intelligent environments.

3 ATTRIBUTES OF A CURIOUS PLACE

Brooks [1] and Coen [3] argue that intelligent environments should:

- adapt to and be useful for everyday activities;
- assist the user without requiring the user to attend to them;
- have a high degree of interactivity; and
- be able to understand the context in which people are trying to use them and behave appropriately.

Projects such as Active Spaces [8] and the Interactive Workspace Project [6] have produced environments that support everyday activities without user attention and can behave appropriately within a context. Motivated learning agents [7] are a type of agent that provides a way to extend the usefulness of intelligent spaces by giving them the ability to better adapt to changing patterns of human activity and potentially allowing them to anticipate user demands.

Motivated learning agents use a model of intrinsic motivation to reward activities that may be beneficial to the long-term development of the agent but may not have an immediate extrinsic reward attached. Figure 1 illustrates how the motivation process $\mathcal{M}$ takes inputs from the sensors and memory of the agent and produces output events and rewards that can be used by other processes of the agent to guide action selection and learning.

Curious agents [9] are a type of motivated learning agent that produce an intrinsic motivation reward based on the perceived novelty of a sensed experience. Computational models of curiosity incorporate adaptive components that monitor and learn from experience by paying attention to unexpected, or novel, changes in the environment. Curious agents model interest in new experiences based on their similarity with remembered experiences. Curious agents can also model

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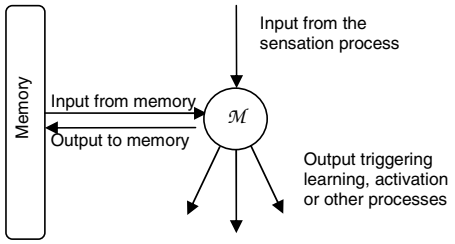

Figure 1. Interaction of motivation with other agent processes.

boredom, for example, when the agent's level of interest over multiple experiences falls below a threshold.

The research presented here focuses on the development of intelligent environments using curious agents that adapt to changing user behaviour and anticipate user demands. The following sections outline three focus areas for curious place research that have the potential to extend the ability of intelligent environments to:

- proactive problem finding;
- life-long adaptability; and
- enhancing human activity.

3.1 Proactive Problem Finding

Research in intelligent environments and intelligent agents has typically focused on the development of systems that solve known problems by learning, planning or rule-based responses. The significant problem of identifying interesting problems, unknown at design time, has received less attention.

Curious places can generate their own problems to solve. The generation of a problem is triggered by a curious agent becoming bored with a predictable routine of experiences. The level of interest an agent has in a generated problem can be determined from how similar the new problem is to one that the agent has solved before [10].

3.2 Life-Long Adaptability

Human activities are not static: the daily, monthly and yearly behavioural cycles of individuals and groups shift and change over time as a result of changing biological, cognitive and social needs. Human activity is often characterised by creativity that leads to unpredictable changes in behavioural patterns. Consequently, it is difficult for system designers to predict in advance all the human behaviours that an intelligent environment may need to adapt to.

Although Brooks [1] and Coen [3] identified adaptability as a key requirement of intelligent environments relatively little research has focussed on building systems that can monitor and respond to unexpected changes in human behaviour. Machine learning has been used in intelligent environments but the focus has been on learning responses to human behaviours the system's designers have identified in advance as being important.

Curious places can monitor human activities and can identify unexpected, or interesting, behaviours. Identification and adaptation to interesting behaviours is strongly rewarded by the model of curiosity, providing the necessary feedback for a curious place to respond and adapt to novel human behaviours as they emerge.

3.3 Enhancement of Human Activities

The ability to support and be useful for human activities is a key requirement of any intelligent environment. Curious places have the potential to not only support human activities but also provide new services that enhance the human experience and can, in turn, modify the way humans interact with their environment.

Curious places can autonomously explore the potentials of their sensors and effectors allowing them to develop new behaviours or, when connected to appropriate sources of information, discover new information that was not provided by the system architects. Research in this area is thus a step in the direction of building intelligent environments that can not only assist with routine tasks but anticipate and actively contribute to creative activities within the space. The curious research space described in Section 4 is an example of such a system.

4 A Curious Research Space

We are currently implementing a curious place in our university environment as a 'curious research space'. This application is situated in a university meeting room that is equipped with sensor and effector hardware and a device control layer as shown in Figure 2.

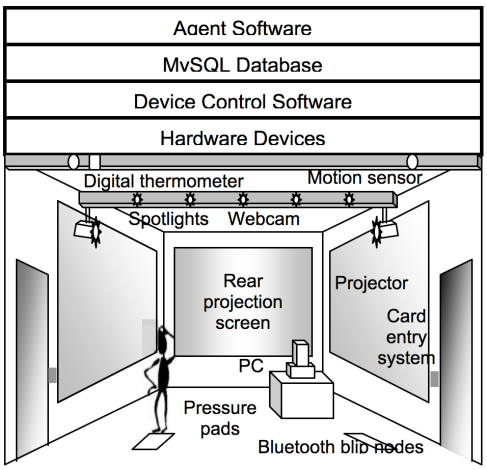

Figure 2. System architecture for a curious place.

Traditional research environments provide a physical space where human researchers can perform research activities, disseminate research findings, store equipment and collaborate. Curious research spaces extend the built environment with motivated agent technology to monitor and actively contribute to research by conducting their own research activity.

The curious research space is implemented as a society of motivated reflex agents (MRAs). MRAs incorporate models of motivation into reflex agent architectures such that actions are triggered not only by environmental stimuli but by the agents motivations. This allows MRAs to exhibit adaptive behaviour. MRAs use motivated reflexes to reason about motivation and the environment. Motivated reflexes trigger behaviour according to conditions about both the environment and the motivational state of the agent. Motivated reflexes can be implemented as rules with the following form:

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if condition(environment stimuli) and
   condition(motivational state)
then behaviour
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Environmental stimuli may be an observed state of the environment or an observed change in the state of the environment. Conditions define constraints on the observations or changes that trigger a particular response. A behaviour may be a single action or it may be a sequence of actions that achieve some goal. Motivation may be intrinsic as described in Section 3 or extrinsic, from the environment, e.g., rewards from other agents. In MRAs reasoning is characterised by three processes: sensation, motivation and activation as shown in Figure 3. The sensation process transforms raw sensor data into three structures: a set O of observations of the current state of the environment; a set E of events representing changes between successive states of the environment; and an environmental motivation M_e.

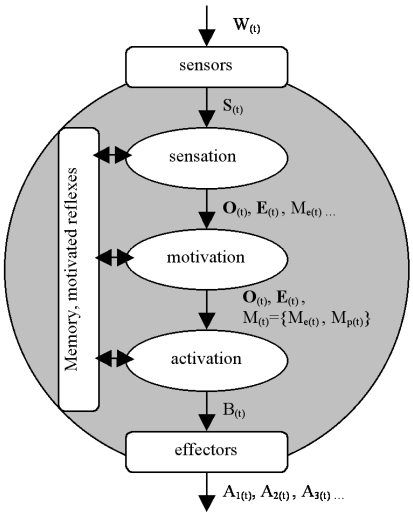

Figure 3. The motivated reflex agent architecture.

The motivation process computes intrinsic motivation, M_p, and combines it with extrinsic motivation to produce a motivational state M. The activation process uses rules representing motivated reflexes to select a behaviour B comprising actions A_1, A_2, A_3 ... that trigger effectors to make changes in the environment.

In societies of MRAs, agents playing different roles are defined by different rule sets. We define a curious research space using a society of MRAs that play the roles of keyword agents, search agents, content agents, and narrative agents. Keyword agents analyse presentations given in the room and extract interesting keywords. Keywords are communicated to search agents using the FIPA [4] communication protocol. Search agents use interesting keywords from one or more keyword agents to search the internet for related documents. Content agents analyse documents found by search agents to identify interesting documents. Structure agents identify interesting phrases, sentences or illustrations and build slides. Narrative agents construct slide shows and presentation agents perform those slide shows while monitoring the human audience.

5 DISCUSSION

We envisage that future curious places might be developed as intelligent rooms, entertainment arcades or data centres. As an intelligent room a curious place observes the actions of its inhabitants, identifies novel or interesting actions, learns about them using unobtrusive techniques, then modifies the physical environment to meet the changing needs of its users.

A curious place as an entertainment arcade might include characters or augmented reality displays that directly interact with occupants via active learning methods such as reinforcement learning. Characters and displays would be capable of actively seeking novel stimuli to provoke interaction and entertain users.

Finally, a curious place as a data centre would observe the actions of its inhabitants, or even a wider space such as an entire building or the internet, identify novel or interesting phenomena to learn about using techniques such as data mining, then modify a digital environment to reveal these finding to users.

The idea of a curious place promises a kind of sensed environment that is interested in the people that inhabit it and that may in turn be interesting to its inhabitants. Curious places extend intelligent environments with proactive problem finding ability, life-long adaptability and the ability to enhance human experience in the environment. In addition, curious places have the potential for long term support of human activity by adapting to the changing behavioural cycles of their human inhabitants.

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