Intelligent Buildings – A multi-agent approach

Ueli Rutishauser, Alain Schäfer, Rodney Douglas, Josef Joller
Institute of Neuroinformatics, University of Zurich and ETH, Zurich, Switzerland and
University of Applied Sciences Rapperswil, Rapperswil, Switzerland

Contact: urut@ini.phys.ethz.ch, Project Homepage (Papers, Sourcecode) : http://www.easc.ch/aha

uni | eth | zürich
HSR UNIVERSITY OF APPLIED SCIENCES RAPPERSWIL
COMPUTER SCIENCE

1. Introduction

Modern approaches to the architecture of living and working environments emphasize the dynamic reconfiguration of space to meet the needs, comfort and preferences of its inhabitants. The configuration can be explicitly specified by a human building manager, but there is now increasing interest in the development of intelligent buildings, which adapt to the needs of it's inhabitants without human intervention.

We developed a cooperative multi-agent system that provides intelligent control of 30 rooms. The building is equipped with a variety of sensors (e.g. presence, temperature, illumination, humidity, wall-switches) and effectors (e.g. lights, window blinds) typical of a modern office building.

The intelligent system is realized as a collection of software agents which together form a multi-agent system. Every agent is responsible for one specific task and offers this task as a service to the other agents. There is no central agent that acts as a general coordinator, all agents act independently of each other.

Within each agent the actual decision making process is a fuzzy logic controller (FLC) which takes decisions by continually evaluating the input data against a fixed fuzzy ruleset which specifies the governing rules of the system. A fuzzy inferencing process is used to analyze the input values at hand.

Sensors and effectors

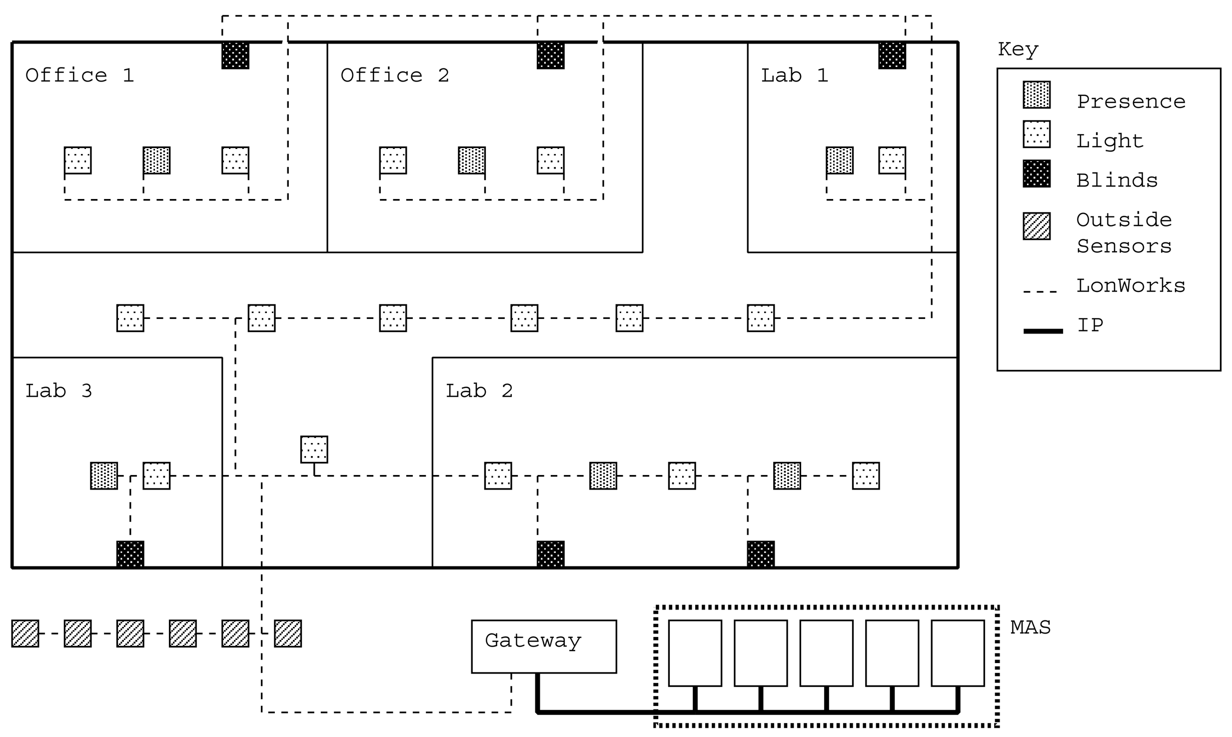

Figure 1: Sensors/Effectors of a intelligent building

Sensors: temperature, humidity, radiation, illumination, presence detectors, switches
Effectors: Light, Blinds

Problems

- huge amount of data – need mechanisms for reducing amount of data
- computational constraints (react in near-realtime)
- moving target – continuous learning
- unsupervised, no training, constant usage (can't shut down for learning!)
- highly complex environment, imprecise inputs (partially observable), noise. (categorization: inaccessible, non-deterministic, non-episodic, dynamic and continuous)
- no explicit feedback (punish/reward)

2. Our approach

- building is a complex, non-linear system, modeling as a Markov decision process (POMDP)
- biologically inspired - distributed, localized decision making
- cooperative multi-agent system (MAS) as basic architecture
- Fuzzy logic for decision making (imprecise inputs, noisy)

Multi-agent system

We are using a **multi-agent system (MAS)** to control the building. The biggest problem in an intelligent building is near-realtime reaction. The huge amount of data coming in from the various sensors of a building make it impossible for a single centralized system to make the necessary decisions fast enough. Several, asynchronously running, agents can deal with this data far more efficient. Every agent only deals with a small subset of the whole input data and only controls a small subset of all available effectors. Every of these agents takes decisions about a small subset of the whole system only. This **localized decision making** makes near real-time reaction possible.

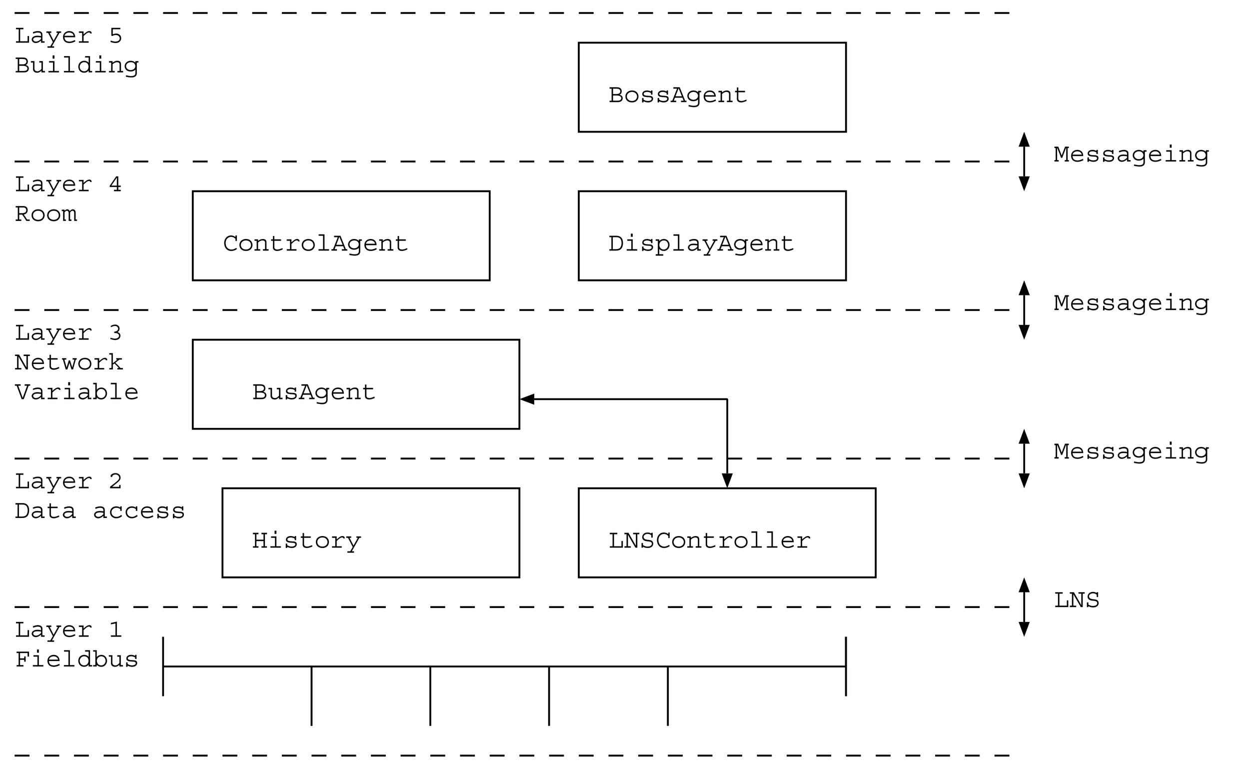

Figure 2: Participating agents

Different types of agents act on different levels of the system. The higher the level, the lower the frequency of decisions. The system is hierarchical in terms of data intensity and frequency of decisions taken but not in terms of control – there is no centralized control. The behavior of the building as a whole is emergent.

Inter-agent communication

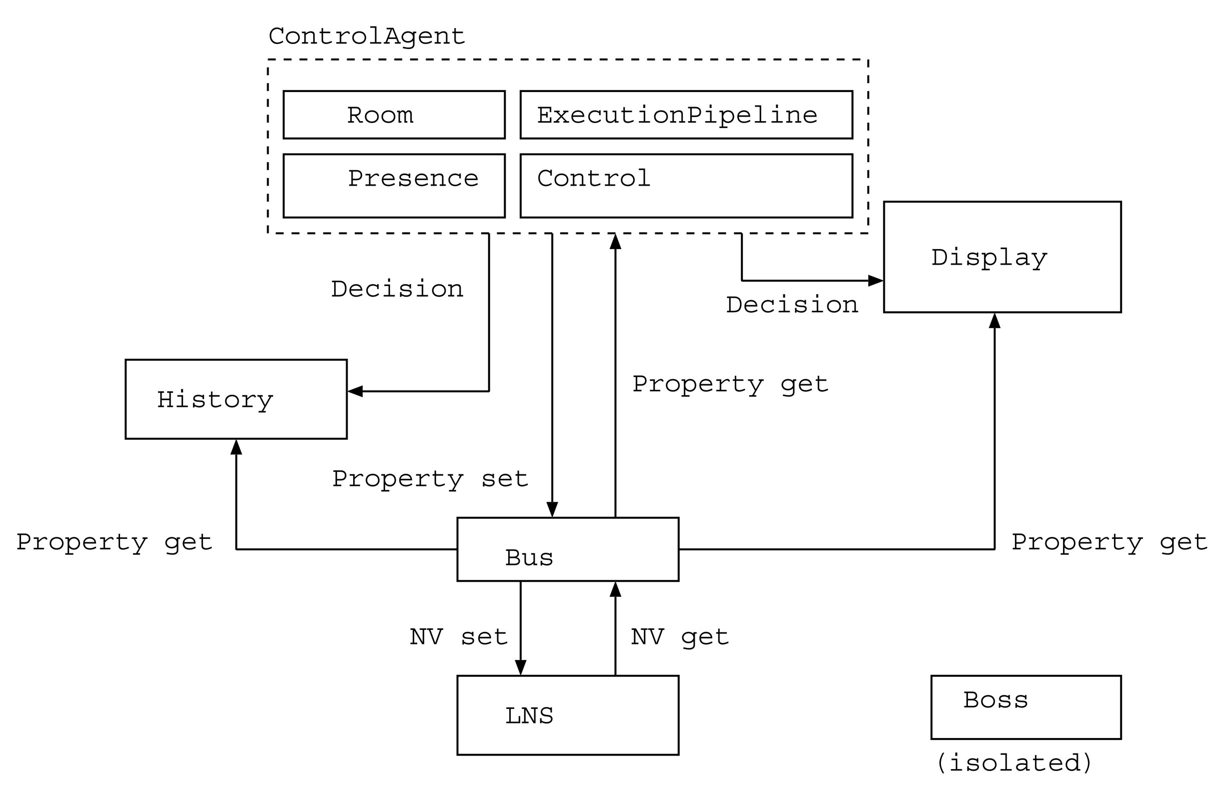

Figure 3: Multi-Agent collaboration

One of the main challenges in such a complex MAS system is inter-agent communication. We are using a **interest based, asynchronous messaging middleware** for inter-agent communication. In such a system, a external instance (the middleware) takes care of message distribution among agents. Every agent declares it's interest in certain messages to the middleware. A agent that wants to send a message to other agents just passes this message on to the middleware. Ensuing the middleware is taking care of all the complex issues of message delivery in a system with many concurrently running agents.

Decision making

All decisions are made on basis of fuzzy variables which is very similar to how humans make decisions ("it is cold"). All input variables are converted to fuzzy variables before they are used for reasoning (fuzzification).

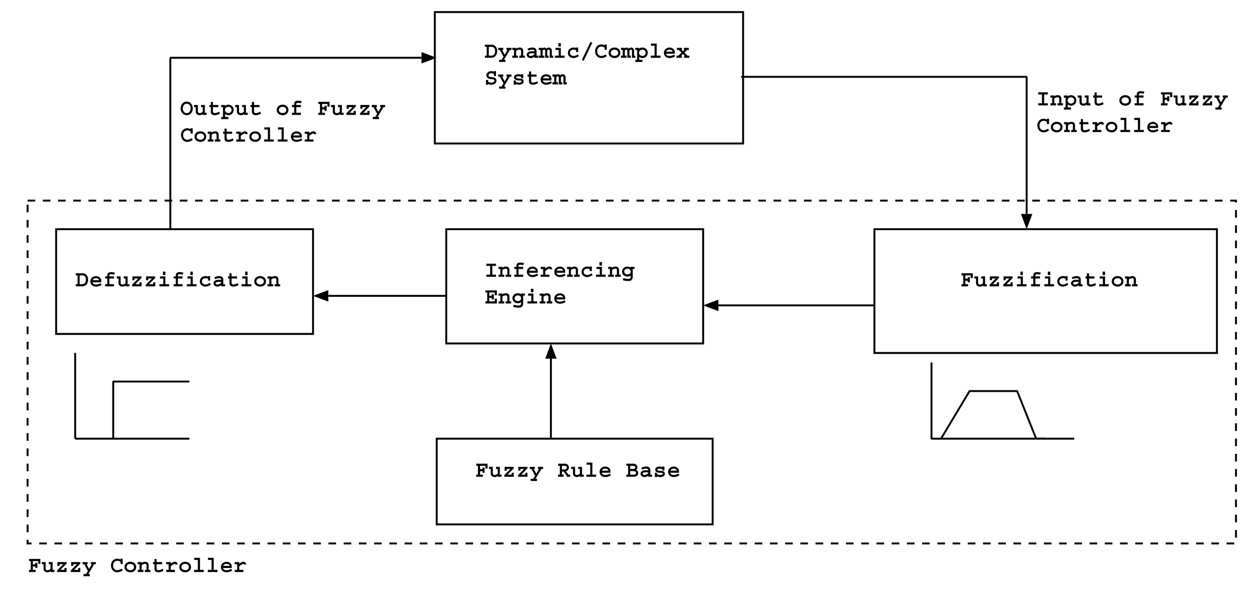

Figure 4: Fuzzy Decision making

All rules are of the form:

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if RadiationEast is completlyDark then BlindAction = DOWN
if DayLightIndoor is dark and Presence==YES then LightAction = ON
if DayLightIndoor is medium and Presence==YES then LightAction = ON
```

3. Results and Conclusion

Experiments confirmed that a multi-agent system is capable of controlling a complex system like a intelligent building without centralized control. **Localized decision making based on concurrently running agents provides a good platform for such a system**. It turned out, however, that **there is a strong need for a middleware framework for inter-agent communication**. Our own asynchronous, interest based message forwarding middleware proved to be a very successful way of doing inter-agent communication in a MAS with a large number of agents.
A building as a physical structure proved to be a very good real-world test-bed for various principles of learning, adaptation and control. It is a very complex environment that has many different and interesting characteristics that can be exploited.

4. Future work

It is our aim to extend the existing system to make it:

- **Adaptive**. The building should learn typical behavior and should adopt it's rules accordingly. We will use a model based world model that is being adjusted with a punish/reward driven learning algorithm.
- **Personalized**. The building should be able to identify it's users. It should be able to learn personal preferences.
- **Self-Organized**. Structures inside a building chance constantly. The behavior should automatically adapt itself accordingly.