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Agents for Recognizing and Responding to the Behaviour of an Elder

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Abstract

We are building an agent-oriented system to aid elderly people to live longer in their homes, increasing the duration of their independence from round-the-clock care while maintaining important social connectedness and reducing caregiver burden. Independent LifeStyle Assistant™ (I.L.S.A.) is a multiagent system that incorporates a unified sensing model, probabilistically derived situation awareness, hierarchical task network response planning, real-time action selection control, complex coordination, and machine learning. This paper describes I.L.S.A's agents and present a scenario of the information flow.

Introduction

Historically, 43% of Americans over the age of 65 will enter a nursing home for at least one year. When it becomes apparent that a loved one can no longer safely take care of themselves, a nursing home is often the only option, in spite of the financial and emotional strain placed on the family.

We are developing an automated monitoring and caregiving system called the *Independent LifeStyle Assistant*™ (I.L.S.A.) that will be a better alternative [13]. Researchers and manufacturers are developing a host of home automation devices that will soon be available. I.L.S.A. will integrate these individual functions, augmented with advanced reasoning capabilities to create an intelligent, coherent, useful assistant that helps people enjoy a prolonged independent lifestyle.

This paper briefly introduces the architecture, then describes the agents we are implementing. We present a scenario, and then detail the decisions that agents make, and interactions between agents.

Architecture

Every I.L.S.A. installation will (1) be in a home with a different layout and suite of sensor and actuator capabilities, and (2) supporting a potentially technophobic client with unique capabilities, needs and care-giving support network. Devices and software may be provided by third party vendors. As a result, the system must be highly modular, support dynamic discovery of capabilities, and have a publicly available ontology.

We have adopted an agent-oriented approach for two main reasons:

- multiple independent computational threads, and
- the task-centered model of computation that it encourages [34].

We evaluated several popular agent development frameworks, and considered developing our own agent architecture. We selected JADE [2] because it met most of our multi-agent infrastructure need, is easy to use, and well supported (although informally). JADE provides a conceptual box in which agents are designed and provides support such as threading and message transport. JADE provides generic functionalities and structure – it does not implement the internals of the agents or contribute directly to the intellectual and research aspects of I.L.S.A.[1]

The I.L.S.A. architecture is defined as a federated set of *agents* that define *agent interfaces*. This approach both allows modularity of design and enables interaction. Below we summarize the main points; [13] contains more details;

We define an I.L.S.A. *agent* as a software module that

- is designed around fulfilling a single task or goal, and
- provides at least one sensor, reasoning or actuation (SRA) *agent interface*.

To facilitate description of functionality, we describe I.L.S.A. capabilities according to a layered heirarchy, as shown in Figure 1. Communication between agents is through SRA interfaces [13], and agents describe their capability with the I.L.S.A. ontology.

The Agents

Figure 1 shows not only the layered hierarchy, but also a set of candidate agents.

[1] Agent frameworks of this kind are important infrastructure but the provide functionality that is more akin to distributed objects than they do direct infrastructure for building complex agents, i.e., planning and coordination technologies are not part of the framework.

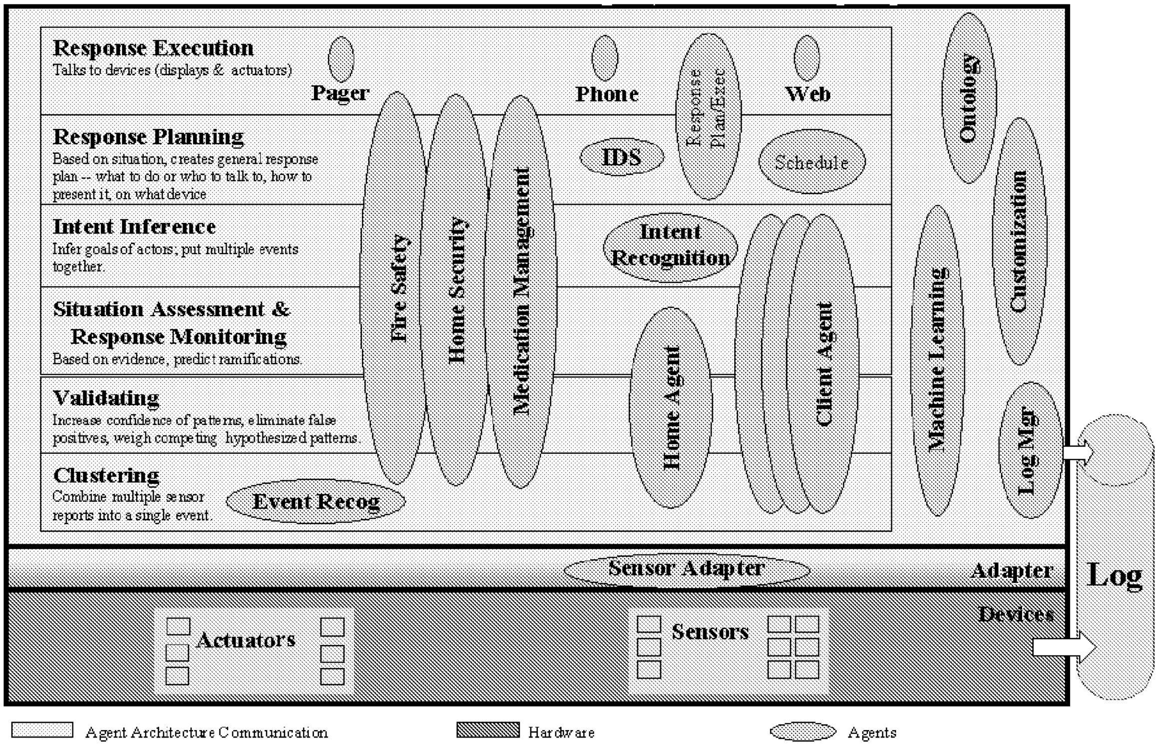

Figure 1: I.L.S.A. reasoning architecture.

Log Manager

The database manager controls access to the database. It provides data only to authorized agents, and provides only the data that is requested.

Configuration & Customization

This agent allows the installer to input configuration information about the client, the care givers, other actors in the domain, and also all relevant information about the house. Information about people includes capabilities, telephone numbers, schedules, and what kind of messages to send to whom. Information about the house includes house plan, device layout, and mainenance schedules.

Ontology

The ontology is common vocabulary that lets agents (human or computer) communicate with precision about some aspect of the world (domain). It structures the domain knowledge in ways that allow it to be analyzed, making assumptions more explicit. The ontology agent parses the heirarchical structure of the ontology to understand relationships between items.

Sensor Adapter

The sensor adapter reads the log of sensor firings, compensates for any latencies in data transmission, and then forwards the data into the agent architecture.

Event Recognition

The event recognition agent combines multiple sensor reports into a single event. For example, the following four sensor reports all indicate that the person has entered a room: pressure-pad outside the door, followed by door-beam, followed by pressure-pad inside the door, followed by motion in the room. Note that this functionality effectively filters sensor data.

Clients & Home Agents

The client (home) agent montors and manages information about the client (home). This information would include both current and past information, such as location, activity, and capabilities, as well as preferred interaction mechanisms. The information may be configured (by the client or a care giver), inferred (situation assessment or intent recognition) or learned (machine learning).

Note that if we expect multiple actors in the home (e.g. a spouse), then there will be a similar agent for each actor.

Intent Recognition

Intent Recognition is the process of inferring the goals of an actor on the basis of observation of the actor's actions. Intent Recognition is only valid for actions taken *by the actor*. We are using the probabilistic task tracker developed by Geib et al [8].

The stream of observations for IR is the set of recognized events. The IR agent combines multiple events to infer the goals of the actor.

This task tracker considers all hypotheses, and actively reweights them as new evidence is added. It can recognize that one event sequence may mean two different things (competing possibilities), and is aware of how confident it is in the recognized sequence. It is resilient to missed observations.

The library of plans that describe the behaviour of an actor are provided by the Domain Agents.

Domain Agents

Each installation of I.L.S.A. will likely have multiple domain agents. Each domain agent is a 'specialist' in a functional area of interest to the elder or their caregivers. Example domain agents include fire safety, home security, medication management, mobility, sleeping, toileting, and security. When the client installs a particular domain agent, new sensing or actuation devices may need to be installed as well. These new devices may be unique to a particular domain agent, or may be utilized by all the domain agents in the system.

A domain agent is responsible for all the reasoning directly related to its functional area. It does situation assessment, provides intent recognition libraries, and creates initial response plans:

- Situation Assessment answers the question "What is the state of the world." Assessment can be done on the basis of a single event, whether or not the event was performed by the actor. Information will include the state of devices, and may include the state of actors. For example, an agent may need to know whether the TV is on or off, its volume, and current channel.
- The domain agent also needs to provide plan libraries for the intent recognition agent. A plan will describe the set of observed actions that contribute to recognizing a behaviour of interest. For example, "taking medication" requires going into the room, approaching the medication cabinet, opening the cabinet, taking the pills, closing the cabinet, and leaving the room. "Grooming" requires entering the room, and one or more of (a) taking a shower, (b) running water the sink, and (c) using the toilet, then finally leaving the room.
- Finally, the domain agent needs to propose an appropriate response to the situation. It needs to decide whether to wait for more evidence, explicitly gather more evidence, or interact. It needs to decide what devices to use and which people to contact. The domain agent proposes an interaction based only on its specialized knowledge, in other words it proposes a "context-free" response.

Interaction Design System (IDS)

IDS decides, based on the task, how to present the data. IDS designs an interaction that meets the requirements as best as possible. Requirements include the capabilities of the person, how urgent the message is, and what type of data is being presented. IDS dynamically responds to the current situation, and allows a more flexible accomodation of interaction devices.

Response Coordinator

The Response Coordinator coordinates the responses of the domain agents. It will merge and suppress all interactions as appropriate, based on context. For example, if the client has fallen (alarm state), the RC will suppress a reminder to take medication. Multiple reminders to the client will be merged into one message.

Merged messages will be sorted in priority order, where priority is defined by the domain agent (e.g. fall monitoring is more important than eating), as well as by the type of message (i.e. alarms are more important than alerts). Merged messages can be used by a recipient to infer activity about the domain; for example "ALARM fire. ALARM fall. ALERT no mobility. NOTIFICATION unexpected midnight motion on stairs" could be used by a care giver to infer that the client tried to escape from the fire, but fell on the stairs and hasn't moved since.

In our implementation, the response coordinator centralizes agent coordination. We chose this approach because all of the involved agents interact with a small subset of humans through a small subset of devices. In other words, all activities involving communications with the outside world are strongly interrelated.

Device Agents

Device agents manage individual actuators. Each agent is a specialist for a particular device; examples include a telephone agent, a television agent, and a lighting control agent.

Machine Learning

Machine learning capabilities allow the system to improve its behaviour over time [12]. They will enable I.L.S.A. to automatically configure itself, and to adapt to changing conditions. ML will learn models of the environment and of the actors in the environment. The learned information can be used by any of the other agents in the system. For example, the domain agents may learn what the most effective response is for a given situation. The intent recognition agent may learn the structure of behaviours for a particular elder [11]. The interaction design system may learn the most effective way to present information.

Scenario

To better understand the capabilities of each of the agents and I.L.S.A. functionality, Table 1 presents a scenario in which our client, Lois, forgets the teakettle on the stove. We follow with a detailed system-level description of what I.L.S.A. does for each step of the scenario.

According to the architecture described earlier, we require 14 agents to support this scenario, and approximately 10 sensors and actuators (with some devices act-

One night Lois is on her way to turn off the teakettle when she's distracted by the phone's double ring and flashing red light which tells her that Marge is calling. The TV, which was loudly broadcasting Jeopardy, automatically mutes itself so that Lois can better hear the conversation. After Lois hangs up, she forgets all about her tea and goes back to watch Jeopardy. Later, the water in the teakettle has boiled away, and I.L.S.A. senses particulate buildup through the kitchen's air quality sensor. I.L.S.A. readjusts the household fans to clear out the smoke.

Since Lois still has the same stove she bought in 1952, I.L.S.A. itself is unable to turn off the burner, so it must communicate with Lois directly. First it must find her, though, because the insurance company didn't cover the full motion sensor suite. Because Lois recently used the remote control in the living room, and the television is still on, I.L.S.A. suspects she might still be there. It presents a message on the TV screen: "Lois, turn off the stove," along with an image of a stove and smoking pan. A spoken message would have been required if Lois had been blind, or if I.L.S.A. had thought she was asleep, but neither is true. Given that Lois has responded more frequently to visual text and image combinations in the past, I.L.S.A. chooses this interaction method.

Unfortunately, Lois is no longer watching TV. She has gone to the bedroom for her knitting during a commercial. Because she hasn't responded to the alert, and this is an emergency, I.L.S.A. flicks selected lights on and off several times throughout the house to get her attention. In her bedroom, Lois checks the bedside I.L.S.A. display and hurries to the kitchen to turn off the stove. She arrives just in time, too – any longer, and I.L.S.A. would have called the next-door neighbor or other help if necessary.

Table 1: An I.L.S.A. scenario: "The Teakettle"

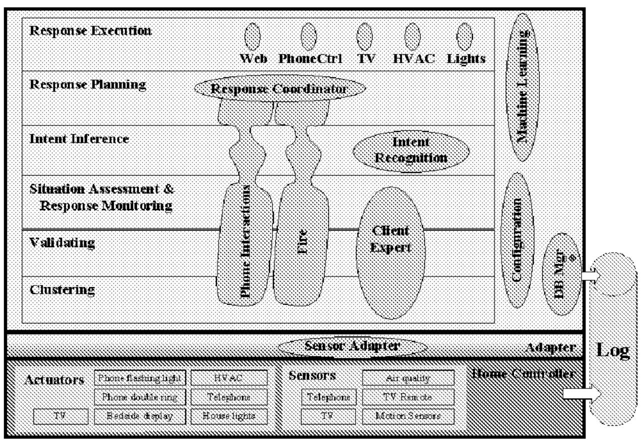

Figure 2: Agents to support the Teakettle Scenario

ing both as sensors and as actuators). Figure 2 shows how these agents break out.

Prior to Scenario. The installer uses Configuration to input information about Lois, Marge, the next-door neighbor and the house. This information includes capabilities, telephone numbers, relevant alerts, and layout. DB Mgr stores this information in the database.

Telephone call arrives. Signal from telephone (with caller ID) goes through Sensor Adapter to Phone Interactions. Phone Interactions needs to decide whether to filter the call; the two important factors are (a) who is calling, and (b) what Lois is doing.

To find out who is calling, Phone Interactions asks DB Mgr for the status of the telephone number. DB Mgr reports that the number is valid – Marge is calling. Phone Interactions then asks Client Expert what Lois is doing. Client Expert has been subscribing to activity messages from Intent Recognition, and so knows that Lois is awake and in the kitchen where a phone is located.

Phone Interactions decides not to filter the phone call. It asks Response Coordinator to enunciate the phone call. Response Coordinator requests Lois' capabilities from Client Expert. Client Expert has previously asked DB Mgr for all information relevant for Lois. Client Expert reports a hearing difficulty, so Response Coordinator decides that visual cues are needed, with additional lights.

Response Coordinator, seeing no other requests for interactions and no current alarm state that might suppress the phone call, tells PhoneCtrl to let the phone ring and flash the lights.

TV mutes. Response Coordinator recognizes the interaction between the phone and other devices – Lois may not hear the phone ring or the conversation if the house is too noisy. As a result, Response Coordinator decides to reduce other sounds. It tells TV to mute the television. TV uses the IR control signals (like the remote control) to mute the television.

I.L.S.A. senses particulates and starts responding. The air quality sensor raises an alarm. The domain agent Fire asks Intent Recognition whether Lois is likely to turn off the stove. Intent Recognition knows that she has not been in the kitchen for a while (her departure was reported by Client Expert), and reports that she is not likely to turn off the stove. As a result, Fire realizes that it needs to respond. As there is no device agent StoveCtrl, Fire realizes that it can't turn off the stove, and needs to use a different mechanism to respond.

I.L.S.A. adjusts the Household Fans. The HVAC system is a good choice to reduce the smoke level, so Fire asks Response Coordinator to turn on the fans in the kitchen. Response Coordinator passes this message to HVAC.

I.L.S.A. tries to contact Lois. At this current (low) level of urgency, it is appropriate to contact Lois first (waiting until later to contact others). Fire first needs to select which devices to use. All communication devices in the house are appropriate: the television, the phone, the bedside display, and the lights.

The television and the bedside display provide rich visual information, while the phone and the lights draw attention quickly. In order to prioritize these devices, Fire asks Client Expert where Lois is and what she is doing. Client Expert is still subscribing to activity messages from Intent Recognition; based on recent device use (the television remote and power to the television), Intent Recognition has reported that she is probably in the living room watching television.

Fire selects the television as the best interaction device, with lights and phone indicated as also appropriate, and the bedside display eliminated. Fire asks Response Coordinator to raise an alert to Lois on one of these (prioritized) devices. Response Coordinator looks at all the other pending interaction requests to select the best overall device. Since there are none, Response Coordinator tells TV to raise the alert.

TV asks Client Expert what is the best way to present the message. Earlier, Machine Learning recognized that Lois responds more frequently to visual cues, especially when text is combined with an image. Client Expert tells TV to presents a message on the television screen: "Lois, turn off the stove," along with an image of a stove and smoking pan.

Alert escalates. Fire is monitoring what happens in the house to directly combat the fire. Lois has not acknowledged the alert on the television remote control. Intent Recognition therefore has reduced its confidence in the belief that Lois is watching the television, and moreover has not observed any activity in the kitchen either, so there are no pending high-confidence hypotheses. Client Expert, upon asking Intent Recognition for its most likely hypotheses, realizes that Intent Recognition has no idea what Lois is doing. As a result, Fire decides it needs to escalate the alert level.

Fire reissues the alert, requesting both a high intrusiveness device (lights preferred over phone), and an informational device (bedside pad preferred over television). Response Coordinator, recognizing that the lights and the bedside pad (and the ongoing request for the television message) do not conflict with each other, tells the device agents Lights and Web to raise the alert.

Lights flicks the lights on and off several times. Web asks Client Expert what to present, and (as above) is told to combine text with images. Web tells the bedside pad to display the message.

About to call the neighbour. Before Lois gets to the stove, Fire prepares to escalate the alert again. It asks DB Mgr whom to send fire alerts to; DB Mgr responds that the neighbour is the first contactee.

However, before the alert goes out, Intent Recognition sees Lois enter the kitchen, and infers that Lois is responding to the fire. Instead of sending the alert, Fire requests that the fans get turned off.

If smoke levels increase again, Fire would raise an alarm.

Implementation

We are building an I.L.S.A. implementation that demonstrates I.L.S.A. functionality along several axes. The implementation demonstrates the complete cycle of I.L.S.A. interactions, from sensors to reasoning to alerts and home control. This implementation will also be used as a field study to determine commercial viability of the product. Features include:

- Active Monitoring: panic button
- Passive Monitoring: toilet use, basic mobility, medication compliance, sleeping, modes (on/off)
- Cognitive Support: reminders, coordinating multiple caregivers
- Alarms, Alerts and Notifications: auto contacting caregivers (by telephone or email)
- Reports: summary reports of client behaviour
- Remote access to information (allowing users to monitor or interact with the client/home)

Other high-priority features to add in future releases include fall detection, environment monitoring (temperature, fire, etc), security, eating, and to-do lists. We conducted an in-depth knowledge acquisition effort to identify potential features for an I.L.S.A. system; the final list contained apporximately 300 capabilities of interest to elders, their caregivers (formal or informal), and other interested parties (e.g. insurance).

For this field study, we are using the Honeywell Home Controller system as the backbone communications infrastructure for I.L.S.A. (a product would likely use a different, less expensive, platform). Sensing devices use a simple XML schema to record events. JADE provides the agent communication layer.

The system has been installed in the homes of four of the project engineers, with 12-20 sensors per home. These sensors include motion detectors, pressure pads, contact switches (door and cabinet open), flush sensors, a medication caddy, and a panic button. Interaction devices for this implementation are email, WWW browsers and telephones.

Currently there are 16 agents in the system, including device controllers, behaviour recognizers, response planners, and system management. Specific examples include:

- SensorFilter (remove noisy signals, cluster signals from one device)
- IntentRecognition (probabilistic task tracking [8; 10; 7] to infer the goals of the actors)
- Ontology (parse ontological components and their relationships)
- Medication (monitor use of medication caddy, raise alerts and generate reminders)
- Mobility (calculate statistics about the elder's mobility, raise alerts)
- Panic Button (monitor alarm signals from the body-worn panic button)
- ResponseCoordinator (suppress and merge alters and reminders as appropriate, select contactee; see [33] for more details)

- PhoneAgent (format alert for presentation and manage communication with contactee)

We have been collecting data from this prototype system since July 2001. Our main focus for the first six months was on configuring the hardware (the response capability was disabled). We had numerous sensor difficulties – door sensors for example, are designed for security systems to raise an alarm when the door is opened. Since doors are often left open for long periods of time, the sensor starts 'shouting' and drowns out the signals of other sensors, and is hence not appropriate for a a continuous monitoring environment.

We have started the initial phases of a field study in which I.L.S.A. will support 20 elders in their homes for a period of six months. We have partnered with EverCare to install approximately 10 systems in Presbyterian Homes in Minneapolis, and the University of Florida's Institute on Aging will install and administer 10 systems. At this stage, we are waiting for IRB approval for human subjects studies, and have specified the capabilities of participants. We hope to install by mid June.

Beyond work to enhance the capabilities of these existing agents, adding additional sensors, actuators and interaction devices, we are also developing agents that

- capture the required configuration knowledge for a given user need
- use vision to track the location of people [23],
- use an interactive design system, e.g. [24; 25], to format interations on-the-fly based on the current task and the person's capabilities (e.g. hearing or sight impaired).
- use machine learning to identify frequent observed behaviours [12; 11].

We envision certain agents as providing a service to the community, while others meet a user's specific needs. For example, the ontology, the task tracking, and each of the device agents each provide services. Individual agents are constructed depending only on the capabilities their designer wishes to impart, and through which tools those capabilities are rendered. For instance, the medication agent needs to understand the intent of the client with regards to taking their medication, so it subscribes to messages from the task tracker. The mobility agent, on the other hand, only calculates statistics about the elders' motion, and hence does not uilize the services of the task tracker.

Related Work

Over the last ten years, numerous efforts have been made to create monitoring systems for elders.

Togawa *et al* [30; 31; 35] was one of the first projects to use passive sensing of everyday activities to monitor subjects. Their main focus is to monitor physiological parameters, but they also monitor, for example, sleep hours, toileting habits, body weight and computer use. The systems collect data for analysis by a caregiver, and do not raise alarms or automatically respond to the data in any way.

Celler *et al* [3] collects data for measuring the behaviour and functional health status of the elderly, and assessing changes in that status. Data analysis is offline, and reports are generated for participants who have demonstrated a consistent change in functional health status.

Inada *et al* [15] was perhaps the first system to incorporate the capability to contact emergency personnel whenever there is a sudden change in the patient's condition, and the patient initiates the call. The system collects biological information, physical activity, and subjective information such as complaints.

Richardson and Poulson [26; 27] describe installments of assistive home control technologies for supporting independent living. The main focus of this work was to make devices more supportive and easier to use by creating a common framework for controlling and monitoring devices, both from within the home and externally. One of the installed bases includes medical monitoring devices and raises appropriate alarms, and they call for systems that raise alarms for all appropriate 'supportive' purposes.

Glascock and Kutzik [9] similarly aims at using non-intrusive monitoring to detect functional activities of daily living. This system does not respond to the collected data in any way; the data is logged and later analyzed off-site. Their patent [17], however, covers the capability of generating a control signal in response to the collected information.

Chan *et al* incorporate the results of machine learning to control environments and automatically raise alarms. A neural network is used to learn the habits of this group of people (temperature and location) [4]. The network is trained over a given period, and then used to control the temperature of a room based on expected occupancy. The authors extend this work to recognize behavioural changes and raise alarms [29].

Sixsmith [28] describes and evaluates results from an intelligent home system installed in 22 homes. The system raises alerts for "potential cause for concern" – namely when the current activity is outside a activity profile based on the average patterns of activity. The system was well-perceived by the elders and their caregivers.

Leikas *et al* [18] describe a security system for monitoring the activities of demented people at home. Vigil [32] has a similar concept, and has fielded over 2000 sites in assisted living facilities.

The paucity of installed systems is most likely due to the complexity of this domain. Vigil's product focusses on a tiny subset of the problem (essentially bedwetting and door alarms). It is our belief that the main reason more complex systems have not been fielded is a direct result of a weak reasoning framework. Prior approaches have focused on the hardware and networking capabilities of the system, and rarely focused on the reasoning or inferencing component. Systems are unable to integrate the information, assess the situation and communicate it in an appropriate fashion. In an effort to find richer reasoning systems, we turn to the intelligent environments community.

Huberman and Clearwater [14] built a agent-based market-based temperature controller. Chatterjee [5] built an agent-based system with three device agents (TV, phone, stereo), and tried to find correlations between the interactions of those agents. The Intelligent Home project [19] researches multi-agent systems in the context of managing a simulated intelligent environment. The primary research focus is on resource coordination, e.g. managing the hot water supply.

The Neural Network House [21] also used neural networks to 'self-program' a home controller. The system learned the users preferred environmental settings, and then controlled the house to meet those settings and optimize for energy conservation.

The Georgia Tech Aware Home [6; 16], MIT's House_*n* [20], University of Washington's Assisted Cognition [1] and Nursebot [22] from Carnegie Mellon and the University of Pittsburgh are current research projects in this area. All of these projects have similar goals to I.L.S.A., but have taken very different approaches. The AwareHome and House_*n* are essentially platforms for researchers, and projects tend to be unrelated to one another; House_*n* started as an architecture design project. Assisted Cognition is less than one year old, and Nursebot is primarily a robotics project.

Conclusion

I.L.S.A. is an ambitious agent-oriented development project. It is advancing the feasibility of agents as the appropriate software abstraction for systems with many computationally complex, interacting processes. We hope to help demonstrate the value of using on off-the-shelf agent architecture, rather than developing our own. We also aim to demonstrate the feasibility of integrating multiple, disparate AI technologies in one cohesive system.

Our project is focussing on the reasoning and inferencing components of the system. We hope that this effort will lay a strong foundation for a viable product that can handle this complex domain and meet the needs of elders and their caregivers.

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