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The Engineering of Micro Agents in Smart Environments

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Abstract—Agent concepts are natural to describe intelligent and adaptive systems in a distributed and collaborative scenario. In this paper we outline the different aspects we have considered in order to build a tool for supporting developers to handle the complexity they are faced to when designing smart environments. Such tool uses agent-based technologies, and therefore this paper presents the use of micro agents in a general-purpose framework for ambient intelligence. The framework provides all the information about people, places, and things (any objects) with computational functionalities to assist and annotate them. Using a Zigbee wireless network to provide real time people tracking and environmental sensing information to the Home Sapiens –the smart home framework– the micro agents can offer location-aware and personalized services. The framework enables users to develop rules directly accessing its services from an application program interface and to analyze its reliability in a real home automation application.

Keywords— *Smart Homes; Micro Agents; Zigbee; Wireless Sensor Networks; Home Automation; Domotics; Control Systems; Home Sapiens.*

I. INTRODUCTION

Intelligent systems are able to act rationally to seek optimal solutions for their design objectives [26]. From the user perspective, ambient intelligence enables us to be surrounded by electronic environments that are sensitive and responsive to people. This means delivering context-aware human-like services with minimal user effort.

Therefore, the system may need to reason about and adapt to individual users and modify its behavior accordingly. In the example of a smart home scenario, the system should provide customized services that are rational to the people it's serving, and learn to accommodate their particular needs. Such systems represent a significant increase of program complexity and raise new engineering challenges.

To enable the applications to adapt and to accommodate the user needs, large amounts of explicit knowledge and explicit reasoning are needed for generating the services. Here, monolithic techniques fail to support explicit knowledge and reasoning. To effectively address these issues, distributed development constructs are needed [23].

Using micro agents makes the framework application-independent. The main feature which is achieved when developing these kinds of systems is flexibility, since the agents can be added to, modified and reconstructed, without the need for rewriting of the application. These systems also tend to be rapidly self-recovering and failure proof, usually due to the heavy redundancy of components and the self managed features [18]. Therefore, the framework enables various location-aware and personalized services to be constructed.

The framework presented here enables micro agents to be spatially bound to people, places, and things that the agents assist and annotate. It has been built based on a smart home simulator called Home Sapiens. The simulator itself, its interfaces and control systems are detailed in [5]. The original simulator emulates all the data exchanged between software-based sensors and actuators and the control systems. That approach depletes the simulation process hiding details which are usually observed in a real scenario. In [5] a data exchange interface was added to Home Sapiens in order to acquire external real time sensing information. The data interface, based on a Zigbee network, introduced rich detailed information about the interactions of people on a daily basis in a smart home living situation. In addition, it also provides a way to change the state of actuators and other electric-electronic devices in a real scenario through the graphical interface provided by Home Sapiens.

This paper is structured as follows. Section II presents a brief introduction to Domotics and the motivations for developing home automation applications. Section III presents the most relevant researches about agents in smart environments, followed by Section IV where the proposal is presented. Future Plans are in Section V and Conclusions are in Section VI.

II. DOMOTICS AT A GLANCE

Home networks (data, control and multimedia) and home automation devices have become increasingly important in the last few years pushed by the Internet and by mobile communications [27,10]. They not only provide better ways to transfer information within homes, but also to improve time management. In addition, they also improve the quality of our lives by automating some of the electrical home appliances [28]. On the other hand, great research is still needed to handle all this smart stuff in order to develop non-invasive full-time operating systems and devices, bringing real comfort and safety to smart house owners.

Devices to make homes smarter are not new. X-10, D2B and HBS appliances have been sold since the late 70's. The benefits and features of smart homes have been highlighted again in the last years, supported by new technologies of home networking, re-introducing applications of remote control and monitoring in the residential environment.

The use of such smart devices in a house and the immersion of people in an active computational environment allow several discussions and questions when the human behavior is analyzed. In this context, a young science –Domotics– takes place, inheriting many ideas, viewpoints and techniques from other disciplines as Engineering, Computer Science, Artificial Intelligence, Sociology and Philosophy [4]. Domotics not only comprehends all technological subjects related to smart homes, but also concerns all sorts of user interactions in a 24-hour active computational environment.

The miniaturization of the smart appliances and a straightforward possibility of being connected to others devices have opened up a wide variety of new applications, motivating researches about subjects never thought before. With a bunch of new appliances surrounding users all day long, some paradigms had to be restructured. One example is the man-machine interfaces that have been remodeled in order to promoter a better interaction by any user inside the house, including elders, children and any person with some kind of disability.

Furthermore, the evolution of wireless technologies made this an attractive solution to connect such devices. The interest in using wireless sensor networking in home automation applications is to provide a common communication network to enable all the functionalities (e.g. energy conservation, environment control, lighting control, safety and security) in a house, since the characteristics of each of these functions need similar performance requirements. Other reason in applying a wireless scenario is to reduce installation costs (cabling, labor, materials, etc.) [6].

Brazilian Research on Domotics

The reasonable prices of system control devices have stimulated its implementation in new situations. Researchers working on smart home applications and technologies focused their work mostly on the achievement of a better use of natural resources, gaining notability of the scientific community. In Brazil, the high import duties, taxes and the exchange rate stimulate initiatives for the local development of house automation products. The deregulation worldwide of the home automation market and standards also promote these initiatives. Many non-standard products and solutions have appeared. Custom planning, product installation and configuration, and other related services have been a source of a good income (Aureside - The Brazilian Home Automation Association recently posted some statistics about the market [3]). But, if more solutions are better for market competition, giving consumers greater selection and better products, ironically, the lack of interoperability is seen as the main barrier to the growth of the home automation market.

In Brazilian Universities the number of projects related to pervasive environments and home automation technology has increased considerably in the last five years. Students have seen a bunch of smart home advertisements in magazines or on TV and they want to participate in this relevant market. But, once they start reading the bibliography available, they find out how big the universe of smart homes really is. They realize they can do more than light control applications (the first idea about a home automation project for most of them) and develop nice devices and services to really help people in their homes.

Nowadays, home automation has also been pointed out as a tool for a rational and efficient use of energetic resources in a water, oil and electricity scarceness era. The control systems have been optimized to cooperate with other systems to achieve maximum comfort, safety and efficiency in the use of such resources. But, even though Brazil has large energy resources (e.g. oil, hydroelectric, solar, sugar cane and corn) there are some issues that do not allow it to be in a better position than others countries. Since energy is being sold overseas, the international price is becoming too high for Brazilian industries and people. The situation overturned and now Brazil has to increase the efforts to reduce energy consumption in order to survive the next decade. In this scenario, home automation shows up again as an important tool to develop energy efficient houses and devices [4].

III. RELATED RESEARCH

The research about Smart Homes has been in the past largely focused on network and hardware oriented solutions [13, 19, 30]. AI-based techniques have not been examined to the same extent, although notable exceptions can be found.

Some, like the MIT AIRE group [2] and the Stanford Interactive Workspaces Project (i-Room) [12], design rooms with integration between devices and multiple user applications in order to facilitate work environments. The Gaia project [21] adds operating system functionality to these spaces so that both physical and virtual devices can seamlessly interact. Both, i-Room and Gaia consider smart office application scenarios. i-Room focuses on human computer interaction (HCI) in a single interactive meeting room. Gaia defines Active Spaces as physical spaces coordinated by a responsive context-based infrastructure. Abowd's work focuses on ease of interaction with a smart space [1], and work such as the Gator Tech Smart House [15] customizes devices for elder care. Mozer's Adaptive Home uses a neural network to control lighting, HVAC, and water temperature [20]. The approach taken by the iDorm project [14] is to use a fuzzy expert system to learn rules that replicate inhabitant interactions with devices. Cambridge University's Sentient Computing project [24] provides a platform for building location-aware applications by using locating systems. Microsoft's EasyLiving project [25] provides context-aware spaces, with a particular focus on home and office.

Several studies have focused on enhancing context awareness in mobile computing. Locatelli and Vizzari [17] describe context as a relational property that holds between objects or activities; in particular, something may or may not be contextually relevant in relation to some particular activity. Dourish [9] emphasizes that new opportunities have engendered considerable interest in context-aware computing. The world can become an interface to computation, and computation can become an adjunct to everyday interaction. One example is HP's Cooltown [16], which uses the technologies behind the Web to provide pervasive nomadic computing in urban environments. In Cooltown, interest places and resources are tagged with URLs or other identifiers that can be retrieved by users' personal devices.

The Galaxy Service Model [29] provides a hierarchical service structure for a Smart Space Laboratory. Galaxy uses a set of smart devices, which are called u-Textures and Smart Furnitures. It allows exporting services provided by the different smart devices to create applications, which can be composed into other applications, resulting in a multi-layered service composition. COBRA [7] takes advantage of multi-agent systems to develop context-aware applications. The environment is divided in domains, and there is a broker for each domain, which is an autonomous agent that manages and controls the context model of the specific domain.

IV. Our Approach

Home Sapiens is a smart home framework being currently developed at the Integrated Systems Lab of the Polytechnic School at University of São Paulo. The main purpose is the development of a tool to analyze control systems in a residential environment. Home Sapiens is a Java-based software program which provides a graphic interface where the user can set parameters for each of the 14 control systems accordingly to the research perspectives. Fig. 01 shows its main screen. On the left side there is the main floor plan of a home being analyzed. The little geometric drawings represent the state of sensors, actuators and smart devices inside every room (a more detailed window is provided above the floor plan). A climate event generator and the monitor panel are placed at the right side. In the middle, a pop-up screen exhibits control systems buttons. Three virtual characters can be seen playing at the balcony, near the main entrance at the lower-left corner.

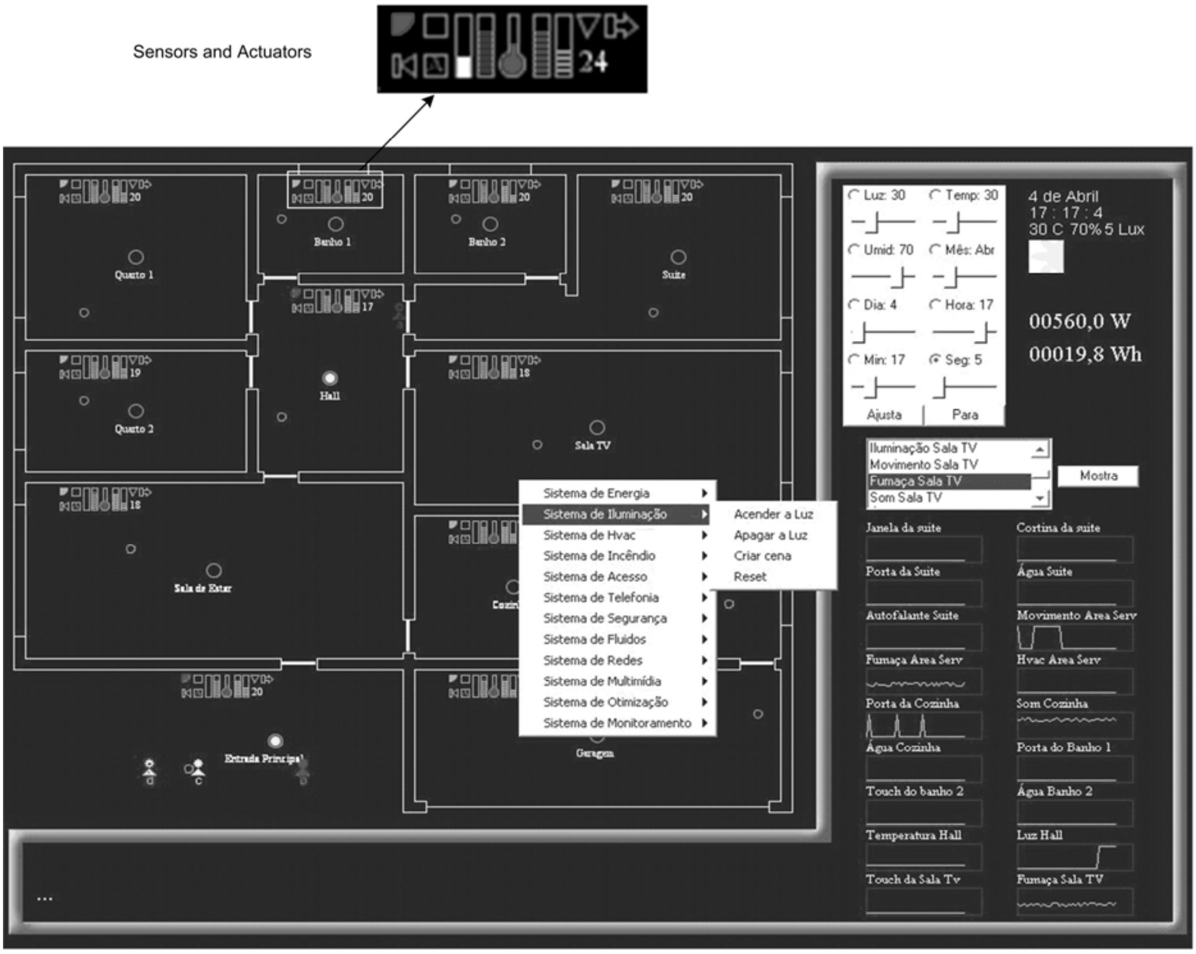

Fig. 01 Home Sapiens Main Screen

A more horizontal, decentralized and dynamic control systems approach is the focus of this version, following the recommendations found in [22, 11, 17]. Our work with micro agents has been conducted incrementally, in order to achieve a distributed control architecture with the following advantages:

- Reduction of the network load: agents can migrate to a destination device where the interaction can take place locally.

- Customizability: the migrating agent on behalf of the customer autonomously travels across the entire network to find the most suitable service.
- Distribution of services control: with migration of agents, some control tasks and services can be handled locally. Furthermore, they can sense the environment and then adjust their reaction to get optimal control effects.
- Asynchronously and autonomously execution: with migrating agents, control tasks can be encapsulated and dispatched into the home network. After being dispatched, the agents can become independent of the creating process and can operate asynchronously and autonomously.
- Robust and fault-tolerant: the decentralized infrastructure avoids a central point of failure and control, and the technology used is cheap enough and simple enough that it can be maintained and expanded by users with limited technology experience.

Fig.02 shows an overall diagram including the wireless network and its connection to Home Sapiens.

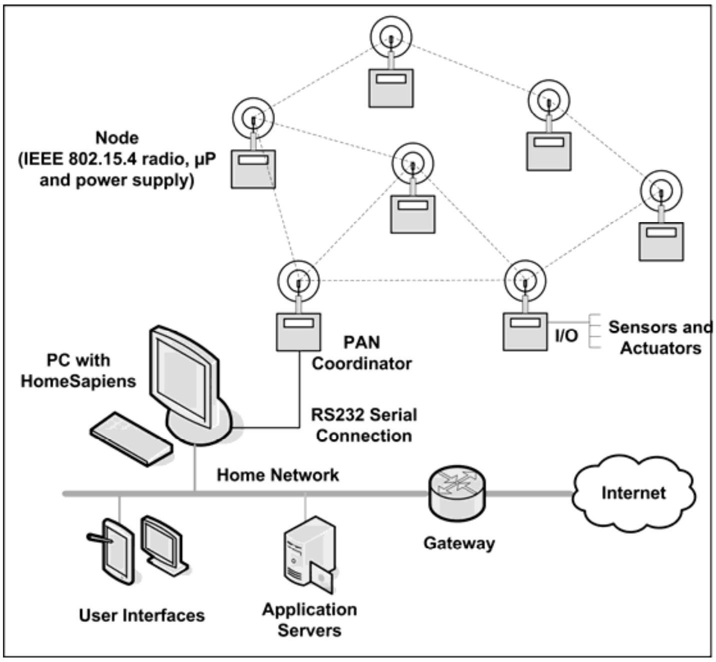

Fig. 02 Overall Diagram: Wireless Network, Home Sapiens and Home Network

We have modeled three types of agents in our design:

• User Agents: these are the smart virtual counterparts of the users that negotiate services with the smart spaces on their behalf. In order to achieve effective interaction with smart spaces, it is necessary to take the user's context into account. In our design, each user is represented by a software agent, which acts according to input from the user, communicating and negotiating with other agents in the smart space.

• Micro Agents: these agents are also smart virtual counterparts of real world entities (places or things), which are specialized on the kind of service they provide to user agents.

• System Agents: these agents do not represent any real world entities in the virtual world. They interact with the user agents and the micro agents, coordinating the operation of the complete assisted environment.

The Home Sapiens is a research framework for constructing agent-based systems, making it possible for software services to be provided through the cooperative efforts of distributed collections of semi-autonomous agents.

Communication and cooperation between agents are brokered by one or more facilitators. In our case the facilitators are the 14 specialized control systems, which are responsible for matching requests depending on the capability of the agent and the user agent request. Facilitators are not viewed as centralized controllers, but rather as coordinators. That means the facilitators are aware of the location of the requests and they try to send the best micro agent to accomplish the task. Fig.3 shows the architecture of Home Sapiens framework.

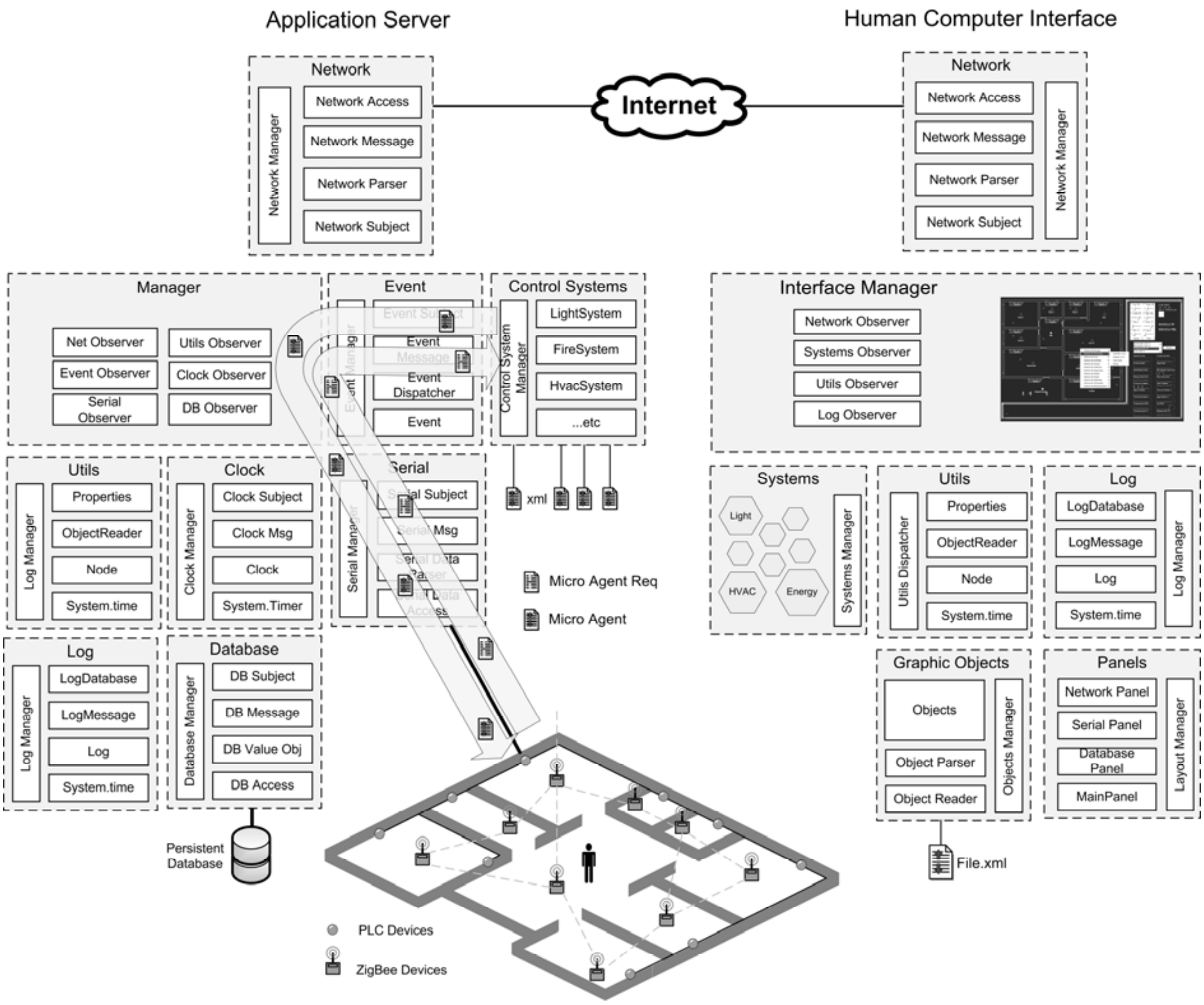

Fig. 03 The Home Sapiens Architecture

The micro agents are tiny pieces of software that can be requested by the nodes or by the facilitators to fulfill the needs of a service. In this paper we focused on the micro agents request and send mechanism. We do not emphasize horizontal information propagation between nodes nor context diffusion. Some nice examples of contextual services using information propagation can be found in [17]. We believe that, as the nodes get more powerful, they get more capable to request micro agents and more distributed the system becomes. But it is always a trade-off because no agent has a full global view of the system, or the system is too complex for an agent to make practical use of such knowledge. In Fig. 03, the curved arrows represent a generalized path of micro agent’s requests and micro agents been sent to the nodes.

In this version, each request is analyzed by the control systems. The privileged member of the control system community releases its specific micro agent to the node. The framework is structured so as to minimize the effort involved in creating new agents, to encourage the reuse of existing agents and to promote dynamism and flexibility in the makeup of agent communities.

The control systems are also agents which cooperate to meet the goals of the smart home but they are specifically responsible for the service depending on its nature: lighting, HVAC, security, etc. The MavHome Project [8] laid the foundation for building these control agents. The technologies within each agent are separated into four cooperating layers:

- The Decision layer selects actions for the agent to execute based on information supplied from other layers.
- The Information layer gathers, stores, and generates knowledge useful for decision making.
- The Communication layer includes software to format and route information between agents, between users and the house, and between the house and external resources.
- The Physical layer contains the basic hardware within the house including individual devices, transducers, and network hardware.

Sensors monitor the environment. All the sensor information is first analyzed by micro agents inside the respective node. There are two options: if they can handle it, they perform the action. If not, they request the control systems to send another micro agent capable of handling the information. In both cases, a message is sent to control systems to analyze the situation in an upper level. If there is a conflict between the action order issued by the Decision layer and by the micro agent, the first prevails. Sometimes this can generate ambiguity, but the ambiguity rate is indeed, a reinforcement, a feedback for the system to build better control systems. This approach has shown to reduce the response time of the whole system once the micro agent is already, most of times, ready to accomplish the task, reducing the amount of information travelling between layers.

This functional domain remotely controls and monitors home devices. In a typical scenario a system operator could check and change home appliances run-time parameters. The system agent provides an interface for the system operator to manipulate the control/motion functions. The function is analyzed by the control systems. Through the system agents, the control systems can check and change the devices status. If the device is not able to perform the function, a suitable micro agent is sent to it. In the agent framework, the responsibility for conversation management is shared between two parts: the control system and the system agents.

V. FUTURE PLANS

A public version of Home Sapiens is being created to offer an API for users aiming to develop micro agents and control agents to interfere in the set of demonstration scenarios (e.g.. home entertainment device infrastructure), which illustrates the use of Home Sapiens.

For our agent-based negotiation techniques, we plan to investigate the feasibility of different criteria. As the number of devices and the number of contexts grow, it is likely that a device will not behave as expected all of the time. We must develop mechanisms to determine unintended side effects, to reduce their frequency and to provide the ability to make corrective actions for the future.

Finally, we would like to point out further issues to be resolved. Since the framework presented in this paper is general-purpose, in future work we need to make it not dependent on the network structure. We plan also to design a more elegant and flexible world model for representing the locations of people, things, and places in the real world by incorporating existing spatial technologies.

VI. CONCLUSIONS

We have presented a framework for control systems configuration and operation support for e-home environments. This framework is based on the use of agents, and therefore we discussed the issues involved in creating, negotiating and testing the deployment of micro agents in a smart home scenario. In particular, we described an approach to manage services and tasks that we are exploring: the use of micro agents right in the control device. We hope to minimize some monolithic approach problems, being able to get closer of achieving the goals of ubiquitous computing.

First simulations of the proposed system have yielded satisfactory results, but some issues remain open to further research. We are now refining the control system layers, with special interest to determine the best balance of control vs. convenience, providing useful feedback to the user and making the framework more reliable and efficient.

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