Cooperating Intelligent Systems for Electricity Distribution

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1 INTRODUCTION

Artificial Intelligence (AI) techniques, and expert systems technology in particular, has often been used to tackle the most difficult automation problems. This is especially true in industrial applications where conventional software and teams of operators were unable to cope with the demands of rapidly changing, complex environments. After more than a decade of exploitation, hundreds of expert systems have been deployed. However as this technology has proliferated and individual systems have increased in size and complexity, some well documented problems have begun to emerge. These include the fact that systems do not easily scale up, that they are brittle and that consistency is difficult to achieve.

Various techniques for circumventing these problems have been advocated. These include building an extremely large base of common-sense knowledge (Guha and Lenat 1990) and allowing the sharing and reuse of knowledge (Neches et al. 1991). However the approach pursued in this work was to build systems of smaller, more manageable components which can communicate and cooperate. In such multi-agent systems: knowledge, resources, control and authority are distributed amongst community members who then work together, in a coordinated and coherent manner, to solve problems.

The ARCHON project has developed a general-purpose framework which enables multiple problem solvers, some of which may be pre-existing, to be interconnected so that they can cooperate whilst solving problems (Jennings 1991, Wittig 1992). This paper concentrates on the project's CIDIM (**C**ooperating **I**ntelligent Systems for **DI**stribution System **M**anagement) application which is in the domain of electricity distribution management.

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We show how the ARCHON mechanisms facilitate cooperative problem solving in this application and highlight how the integration of expert and conventional systems produces benefits over and above those of the systems in stand-alone mode.

In CIDIM, a multi-agent approach has several major advantages over centralised systems. Firstly divide and conquer has long been championed as a means of constructing large systems because it limits the scope of each processor. The reduced input domain means the complexity of the computation is lower, thus enabling the components to be simpler and more reliable. Secondly, unlike the majority of other multi-agent frameworks, ARCHON allows pre-existing systems to be incorporated into a cooperating community. This is especially important for CIDIM because of the substantial amount of software which is already available and which could benefit from sharing information and processing with related problem solving entities. Finally, because of the diverse range of functions which need to be performed, no individual problem solving model would be universally applicable. A multi-agent approach allows each distinct function to be implemented using the most appropriate model (be it expert system, database or conventional software), but retains the benefits of sharing information between different functional areas.

Section two briefly outlines ARCHON's functional architecture and describes its main problem solving components. Section three describes each of the agents in the CIDIM application and how they may be integrated into a cooperative problem solving community. Section four describes two cooperative scenarios in detail and section five highlights the benefits of cooperation in this application.

2 THE ARCHON ARCHITECTURE

The aim of the ARCHON framework is to create an environment in which cooperative interaction is possible. However pre-existing or stand-alone problem solvers have no knowledge of how to adapt their behaviour or take advantage of the fact that there are other entities in the environment. All they possess is the knowledge necessary to solve domain-level problems, e.g. how to detect faults and how to diagnose them. Such systems are called **Intelligent Systems** (ISs). ISs may be expert systems, database or conventional numerical software. For social behaviour to be realized, ISs must be augmented with knowledge which enables them to engage in cooperative activities. They need to know how to initiate, maintain and respond to cooperative situations and to be able to assess the needs of the community as well as their role within it. This awareness is achieved by enhancing each IS with a series of modules embodying the necessary social knowledge. This collection of modules is collectively referred to as the **ARCHON Layer** and the combination of an intelligent system and its ARCHON Layer as an **agent** - see figure 1.

Movement to a cooperative environment requires a change in the requirements of an individual IS, which the ARCHON Layer must support. Whilst in the asocial situation, each system plans its activity exclusively on the basis of domain knowledge; in a multi-agent

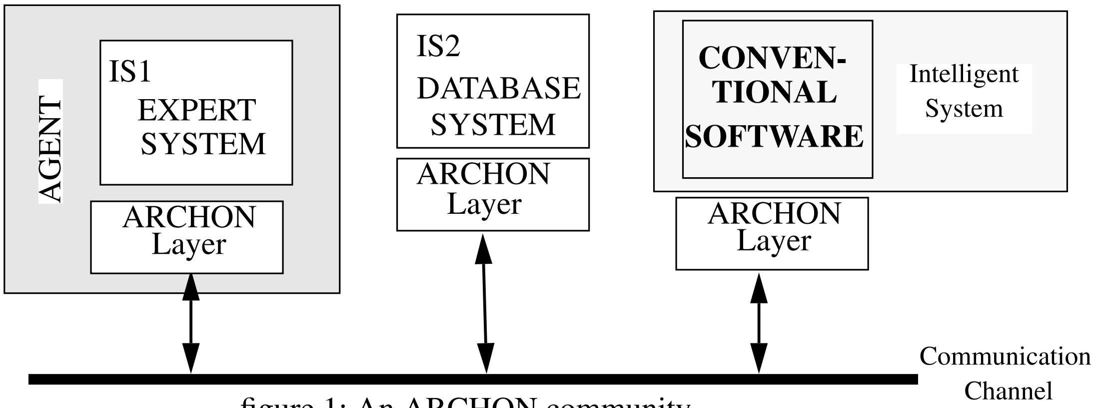

figure 1: An ARCHON community

context, however, an agent's activities are planned on the basis of both domain and social knowledge. ARCHON agents have two distinct, but related, roles to satisfy: that of a team member acting in a community of cooperating agents and that of an individual. Therefore when designing the ARCHON Layer both aspects should be catered for:

- Control local problem solving

  e.g. which tasks to launch, when they should be launched, their relative priorities, how best to interleave their execution and how to recover from local exceptions

- Coordinate local activity with that of others within the community

  e.g. when and how to initiate cooperative activity, which cooperation protocol to employ, how to respond to requests for cooperation and which activities require synchronization.

These two perspectives provide the design rationale and separation of concerns upon which the ARCHON architecture is based - see figure 2. The Monitor is responsible for controlling the local problem solving activity while the Planning and Coordination Module (PCM) is responsible for controlling an agent's social interactions. There is, however, a grey area between these two modules which has to deal with the impact of local decisions on the global perspective and of global decisions on the local activity. As choices about such interactions effect both the Monitor and the PCM they are jointly dealt with.

The other components of the ARCHON Layer are there to support these two modules. The High Level Communication Module (HLCM) provides the types of dialogue necessary for decentralized problem solving and coordination; offering facilities such as message scheduling, message filtering and intelligent addressing. The HLCM interfaces to an extended Session Layer which means ARCHON communities can be installed over networks conforming to the OSI standard. AIM (Agent Information Management) provides an object-oriented information model, a query and update language to define and manipulate the information and a distributed information access mechanism to support the remote access and sharing of information among agents.

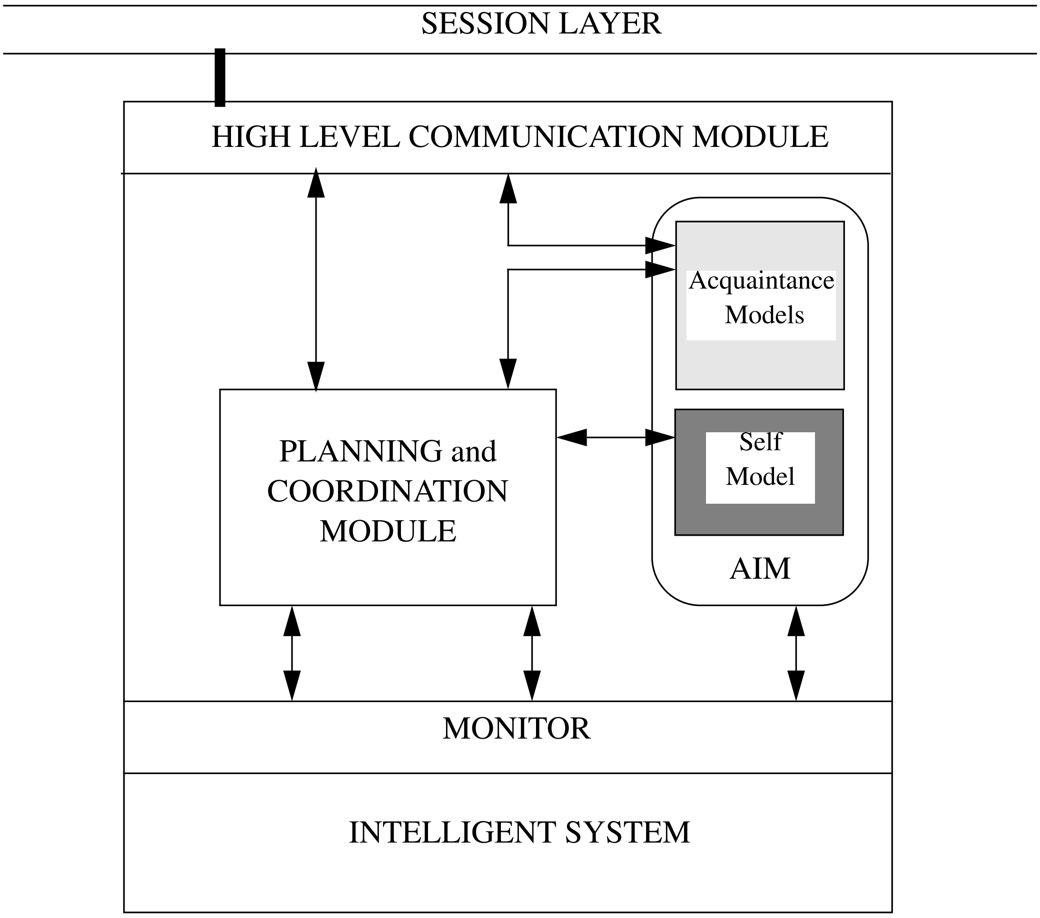

figure 2: Detailed structure of the ARCHON Layer

Sophisticated cooperation requires participants to have knowledge of other team members. The acquaintance models provide this knowledge - representing an abstract description of the other community members with which the agent has to interact. They are used by the PCM and the Monitor for determining and mediating cooperative interactions. The type of information they maintain includes the capabilities of others, their intentions and plans, current state of processing and what information they can generate/are interested in (Jennings et al., 1992). The self model provides a similar meta-level description of the underlying intelligent system and is used by the Monitor to reason about controlling the local system. The information maintained includes the status of active tasks, which tasks are pending, which tasks are waiting for which pieces of information and the relative priority of the various tasks.

3 DETAILS OF CIDIM

CIDIM is being developed as an aid to the Control Engineer (CE) whose job it is to ensure continuity of electricity supply to customers. Maintenance work has to be planned and carried out safely in coordination with the Field Engineer (FE) and faults on the network have to be identified and remedial action taken to restore supply should this be necessary. The electricity network control system allows remote operation of circuit breakers and also reports via telemetry, automatic switching operations in response to a fault, alarms and load readings. The control system covers the high voltage network and part of the low voltage network, but for much of the low voltage network switching for maintenance purposes is done manually by the FE in radio contact with the CE. It is for the low voltage network that use is made of customer telephone calls - reporting loss of supply - due to the lack of telemetered protection equipment. In addition the CE can make use of information about lightning strikes which may be the cause of a fault and so indicate a good starting point for the FE to look for damaged equipment.

CIDIM will be able to assist the CE by automatically providing such services as fault diagnosis, user driven restoration planning and security analysis as well as automatically collating much of the information the CE now does manually by reference to stand-alone systems. Some of the services, such as security analysis, would not previously be available for on-line use due to a lack of access to up to date network information. Using ARCHON helps information from conventional knowledge sources, such as a database or the telemetry system, to be shared by the other agents within the system. Thus the expert systems have greater data consistency than in the stand-alone mode. Interaction between the agents will be controlled by the ARCHON Layer with reference to predefined plans in the Monitor and information from the acquaintance models. Automation of some of the tasks the CE performs is thus achievable. CIDIM will consist of ten agents which are described briefly below (and see figure 3). Some of the agents contain conventional programs and some expert systems, some pre-existing and some built within the ARCHON project. This mixture demonstrates that it is possible to integrate with existing technology and to bring expert systems into real world use.

Telemetry Agent (TA)

Receives telemetry and converts it to a standard format; different Regional Electricity Companies (RECs) within the UK have different telemetry systems and CIDIM should be able to work with any of them with minimum change. Telemetry is sent to interested agents (interests are determined from the acquaintance models) and is also stored for future reference.

Information Agent (IA)

An “object oriented” front end to a relational database, the structure of the database is hidden from the application and so it is possible to provide a standard interface to different databases. The database has all the static information about the network such as

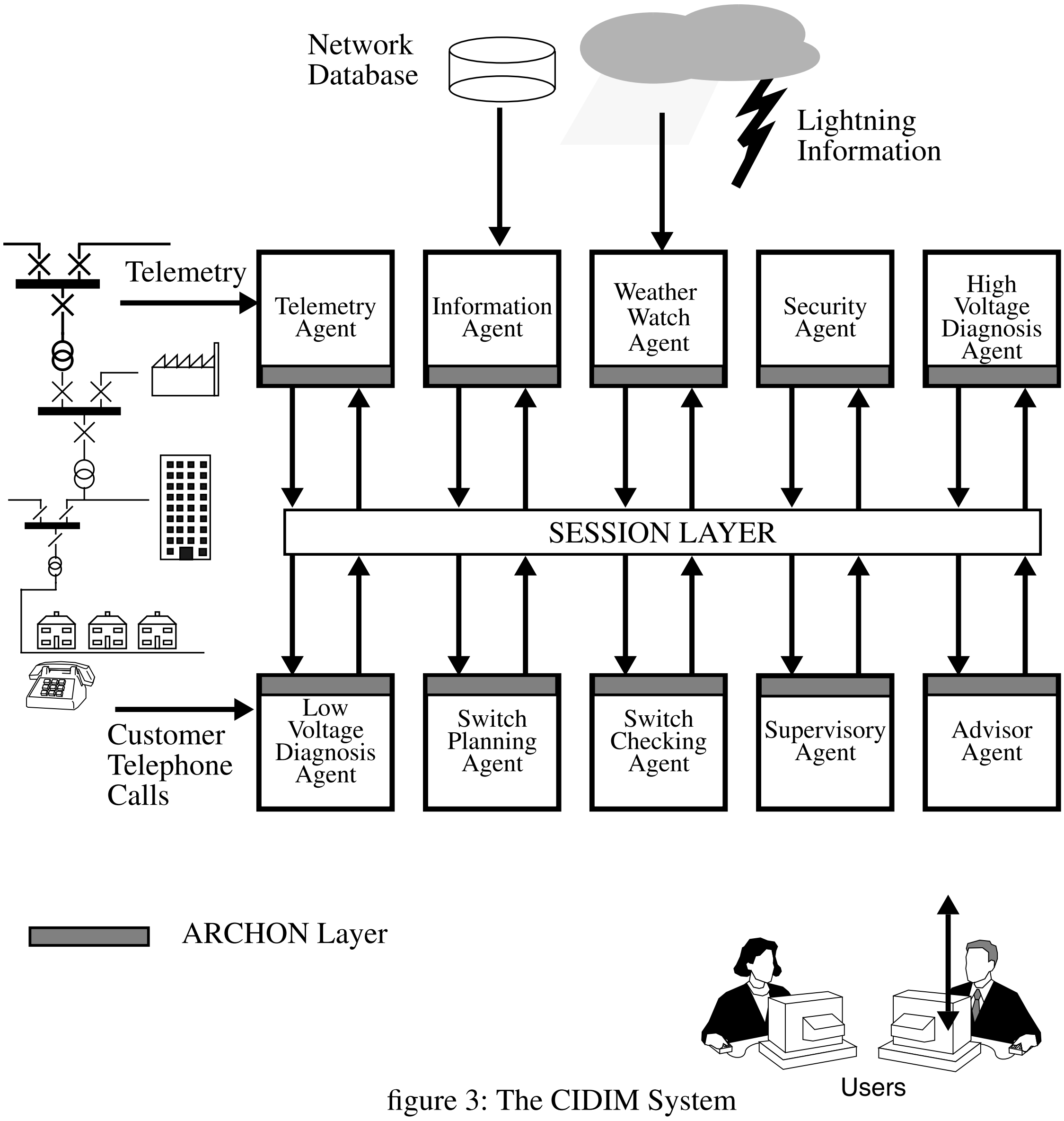

figure 3: The CIDIM System

connectivity of pieces of plant. This information is made available to other agents on request.

Weather Watch Agent (WWA)

Receives on-line data about lightning strikes from the EA Technology Lightning Location System (Scott 88, Lees 92). The WWA can display these on a map and can also answer queries so that it is possible to find out if there were any lightning strikes near a fault at a given time.

Security Agent (SA)

It is important to consider the security of the network i.e. possible overloads, should a fault occur on any line of the network. A security analysis does these “what if” calculations and can allow the CE to take avoiding action. Previously such programs would be run in an off-line mode for planning purposes.

High Voltage Diagnosis Agent (HVDA) (Bramer et al. 88, Cockburn et al. 91a)

Using telemetry from the TA the HVDA will diagnose the location, time and type (permanent or transient) of faults on the network. It can also identify where there is no power - deadzones - whether these are caused by faults or by work on the network.

Low Voltage Diagnosis Agent (LVDA) (Cockburn 92)

The LVDA uses customer telephone calls and lightning information as well as telemetry in order to diagnose faults. Customer connectivity to the network is not recorded in all cases and is estimated by postcodes. Since there is a large amount of low voltage network the LVDA will load network data from the IA and network state from the TA as it is required.

Switch Planning Agent (SPA) (Brailsford et al. 87, Cross et al. 92)

For repair and maintenance work the network needs to be safe to work on, i.e. the faulted region must be isolated from the rest of the network. The SPA allows the user to create switching plans and automatically checks these for safety.

Switch Checking Agent (SCA)

Rather than make a full switching plan the Control Engineer may want to just check that it is safe to operate one switch. This may be because the switch is being operated to restore power to an area by providing an alternative route. As well as these safety checks the SCA will be able to recheck a Switching Plan nearer the time it is carried out. This automatic rechecking will be handled by a predefined plan within the Monitor.

Supervisory Agent (SVA)

Receives fault reports from both the HVDA and LVDA and Switching plans from the SPA. It will allow queries on this data so that a subset can be accesses e.g. to be displayed by the Advisor Agent to the user. The SVA will also look for relations between the information it receives such as when a fault occurs in an area where work is soon to take place. In this case a warning to the user may help re-plan the work rather than find out it is not possible. These checks are triggered by plans defined in the Monitor of the ARCHON Layer and make this conventional ‘result storage’ system more intelligent than it would otherwise be.

Advisor Agent (AVA)

The AVA is the user interface agent to the CIDIM application. It will display events to the user and accept user input. Since the user interfaces of some of the existing systems are highly developed they may be used directly e.g. the SPA is a user driven planner and has an interface developed for this. In these cases the AVA would act as a window manager.

4 COOPERATION

Control engineers will gain considerably from interactions between the aforementioned ISs. Cooperation means not only information exchange, but also coordinated actions within an agent community. Thus an individual's behaviour is influenced by the intentions, results, and failures of other agents as well as the input from the electricity network and the users.

All agents get the input from the same physical reality, however each of them has a different, partial view. The Telemetry Agent gets information about the state of the telemetered part of the network. The Low Voltage Diagnosis Agent gets data from domestic consumers about the state of that part of the network which is mainly non-telemetered. The Weather Watch Agent gets information about lightning strikes. The Information Agent has information about the logical and geographical connectivity of the network. The High Voltage Diagnostic Agent diagnoses faults mainly using telemetry data whereas the Low Voltage Diagnostic Agent predominantly uses customer telephone calls. None of these views are complete and several of them are needed to solve a particular problem in CIDIM.

Agents use the conclusions and results of other agents. In case of a failure, the results of one agent can partially be replaced by those results of another. Sometimes agents can produce results without the help of others, while in other situations interaction is essential. All this requires carefully controlled cooperative activity.

Many cooperative scenarios can be observed in this application. The LVDA can save time by attributing some loss-of-supply calls to high voltage faults if it is informed about these faults by the HVDA. The HVDA can help the SVA produce high level restoration plans for deadzones by sending partial plans. The TA can preprocess and filter telemetry for the LVDA. When telemetry is missing the LVDA can partially replace telemetry for the HVDA. The WWA needs the help of the IA to answer queries, however the WWA can sometimes give its best answer alone which is sometimes “don't know”. The agents have different views of the current state of the network, and these views may be inconsistent; only through cooperative action can they be harmonised.

The ARCHON architecture helps to detect and exploit the cooperative actions in the CIDIM system as we can see in the following example scenarios.

Scenario 1 - Assistance when information is missing/unavailable

The diagnosis of the HVDA is based on the state of high voltage circuit breakers which are usually telemetered, although telemetry messages can be lost from either a single circuit breaker or from a whole substation. In the latter case the TA can recognize this and send an indication that telemetry has been lost. Although telemetry is missing the HVDA may still be able to infer the state of a high voltage circuit breaker because of the known presence of a low voltage fault. The LVDA can diagnose this fault just using customer telephone call complaints.

Normally when the IS of the TA receives a telemetry message, the Monitor within the ARCHON Layer of the TA signals this to the PCM of the TA. The PCM finds out from the Agent Acquaintance Model that the HVDA is interested in telemetry and asks the HLCM of the TA to send the telemetry to the HVDA. On receipt the PCM of the HVDA finds out from the Self Model that this information is useful for high voltage diagnosis and asks the Monitor of the HVDA to start the diagnosis task within the IS of the HVDA.

In the case where the IS of the TA recognizes that telemetry messages are lost from a substation then a report is passed to its Monitor. The PCM within the ARCHON Layer of the TA notices this result and looks at the Agent Acquaintance Model. It finds that the LVDA is interested in this result and sends it as unrequested information to the LVDA through the HLCM.

When the PCM of the LVDA gets this information, it recognizes from the Self Model that this information is locally useful and triggers an activity. This activity stores in the Agent Acquaintance Model the fact that the HVDA is now interested in low voltage faults, due to the lack of telemetry from the substation.

If a high voltage circuit breaker operates in connection with a low voltage outage (planned work) at the non-reporting substation, then no telemetry would be generated and the HVDA would not know of the event. However the customer telephone call reports arrive directly to the LVDA and the Monitor of the LVDA will start a diagnosis. When the LVDA produces the result of the diagnosis, the Monitor of the LVDA signals this to the PCM. The PCM finds out from the Agent Acquaintance Model that the HVDA is now interested in this result and asks the HLCM to send it to the HVDA as an unrequested information.

When the PCM of the HVDA receives the low voltage fault report, it recognizes from the Self Model that this can be a useful information to a high voltage diagnosis and asks the Monitor of the HVDA to start the diagnosis task within the IS of the HVDA.

Scenario 2 - Cooperative answering of a query

The LVDA can make its diagnosis more precise for overhead line networks by asking the WWA the following question: `lightning(time,plant)`, which means: "Was there a lightning at a certain time near a certain plant item?". The WWA cannot answer this question on its own. It has to ask the IA to provide the geographic location of the plant because the database of WWA only contains information on `lightning(time,geogr_loc)`. However the WWA can find out the answer to `lightning(time)`, and the WWA does not need the assistance of the IA if the answer is "No". If the IA is not working then the WWA can only look up in its database the answer to `lightning(time)` and if the answer is "No", then the WWA can answer "No" to the original question: `lightning(time,plant)`, if the answer is "Yes", then the WWA can only answer "Don't know" to the original question: `lightning(time,plant)`.

One possible scenario for the WWA agent is the following:

1 The PCM of the WWA receives the information request `lightning(time,plant)` from the LVDA.

2 The PCM of the WWA looks up in the Agent Acquaintance Model if the IA is working.

3a If the IA is not working, then the PCM orders the Monitor of the WWA to get the best answer from the underlying IS without knowing the geographic location of the plant.

3b If the IA is working and is busy, then the PCM can first give the same order to the Monitor and if the answer is “Don’t know”, only then ask the IA to provide the geographic location of the plant, and order the Monitor to get the answer for the question `lightning(time,geogr_loc)` from the underlying IS.

3c If the IA is not busy, then the PCM can immediately ask the IA to provide the geographic location of the plant, and order the Monitor to get the answer for the question `lightning(time,geogr_loc)` from the underlying IS.

The WWA does not have knowledge of electrical plant since its IS is an existing general purpose system for lightning location. Cooperation with another agent allows it to be used in a specific domain i.e. electricity networks, without decreasing the flexibility of the original program.

5 BENEFITS

The above example scenarios clearly show that in the CIDIM cooperating community the agents can produce partial results when some members are not working properly, and thus increase the robustness of the whole system. The ARCHON architecture has built-in tools to detect the possibility and need of cooperation and coordinate the actions of the Intelligent Systems to achieve the cooperative action. These tools are application independent, the PCM operates on an abstract level and the application dependent information is stored in generic data structures like the Agent Acquaintance Model and the Self Model. The Intelligent System is controlled and interfaced to the ARCHON Layer by the Monitor.

The CIDIM system is built upon separately existing systems which were developed in separate projects using commercially available tools. Using the ARCHON Layer these systems can be integrated to produce an overall system in which information is more readily and quickly available, cross-checking of results is easy and results are exchanged and exploited between the component systems. The integrated CIDIM is more than the sum of the component systems: information exchange is automated and faster, new cooperative situations are exploited.

The delineation of domain and cooperation knowledge has several advantages. It increases software reusability in that the cooperation layer can be used for several applications without having to disentangle knowledge used to guide social activity and knowledge for solving a domain level problem. Also the two components can be developed independently provided that they respect the interface definition, meaning greater productivity through concurrency and the ability to incorporate pre-existing systems.

The benefits of CIDIM over the separate component systems are the robustness, the reliability, automatism and cooperative actions. With the help of the ARCHON architecture the agents can automatically detect those situations where cooperation is beneficial, exploit the advantages of cooperation, can adapt to failures in the CIDIM system and display compacted information on the whole complex system.

6 CONCLUSIONS

Some of the benefits of using ARCHON are listed above and in more detail in (Cockburn et al. 91). In summary these are:

- Previously stand-alone expert systems can be integrated within a community of other agents and used in real world problems, thus greatly increasing their usefulness.
- Automates the exchange of information and starting of tasks between systems.
- Development time of new systems will be reduced since a lot of the control functionality of the ARCHON Layer can be used.
- Network activity is reduced compared to other networked solutions, due to registered interests rather than all information being broadcast.
- The resulting system is generic and extendable since tasks and agents are described in acquaintance models and new agents can be added.

7 ACKNOWLEDGEMENTS

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