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An Agent-based Architecture for Managing the Provision of Community Care - the INCA (Intelligent Community Alarm) Experience

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Community Care is an area that requires extensive co-operation between independent agencies, each of which needs to meet its own objectives and targets. None are engaged solely in the delivery of community care, and need to integrate the service with their other responsibilities in a coherent and efficient manner.

Agent technology provides the means by which effective cooperation can take place without compromising the essential security of both the client and the agencies involved as the appropriate set of responses can be generated through negotiation between the parties without the need for access to the main information repositories that would be necessary with conventional collaboration models. The autonomous nature of agents also means that a variety of agents can cooperate together with various local capabilities, so long as they conform to the relevant messaging requirements. This allows a variety of agents, with capabilities tailored to the carers to which they are attached to be developed so that cost-effective solutions can be provided.

Keywords: Community Care, Agent Applications, Multi-Agent Systems

1. Introduction

Current health and social care policy reflects the view that most older frail or disabled people would prefer to live in their own homes rather than in hospital or nursing home settings. "Community care" refers to the range of services delivered in the person's own home or community setting, in order to help them to continue to live independently. Typical services include home helps, meals, domestic help and community medical and nursing services. Information technology within community care currently involves a number of autonomous systems; home monitoring, community alarms, care management systems and emergency systems command and control systems. Each element of care is provided by different autonomous bodies, which maintain their own individual management information systems. The overall management of the care typically resides outside of these systems, protecting individual bodies from disclosing sensitive and irrelevant information. A useful review of current work has recently been reported [10] but this concentrates mainly on the technologies that can be applied rather than the communication mechanisms that can be deployed to support those receiving care.

Recent years have seen a shift in focus in the services provided to older and chronically sick people from institutional care to care in the community. Community Care is typically provided by a range of independent organisations and agencies, each needing to meet its own targets and objectives and to integrate the service with their other responsibilities in a coherent and efficient manner. This often leads to serious service inefficiencies as there are inadequate systems in place to share relevant information without compromising the security of the information held. Another fac-

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tor is that a considerable amount of community support is provided by informal carers who are excluded from the general care management system because of difficulties in integrating them without breaching the official confidentiality requirements. Agent technology, and in particular mobile agents, provide a means by which effective co-operation (information sharing and communication between autonomous information systems) can take place without compromising the security of the client and the agencies involved, particularly in the highly volatile environment of community care. Since each agent has complete autonomy it can respond according to the rules of the organisation it represents, providing an effective and assured guardian that is totally under that organisation's control. No other architectural framework for Distributed Information Systems gives this capability without serious reliability problems.

In this paper we describe the principles behind a distributed multi-agent-based Integrated Community Care (INCA) system. A demonstrator system, implemented using the ZEUS agent-building toolkit [16] is also described in order to demonstrate the feasibility of the approach and its potential practical benefits. This demonstrator shows that the technologies proposed allow effective communication without compromising integrity and privacy. In particular they provide an approach where it is possible to ensure the minimum collection of information in that the Home Service agent can be configured so that it only releases private or sensitive data in case of an emergency, when such information is of value.

Although the humanitarian perspective is compelling, the delivery of community-based services presents a number of organisational, managerial and logistical problems that undermine the effectiveness and efficiency of services. While community care has typically involved limited use of information technology, recent developments have seen significant application development, a trend that is likely to significantly develop in the future.

The objective of the INCA Project is to investigate how community care can be developed in the internet age through the use of multi-agent technology. The motivation for this has been a consideration of the agent society's social abilities in:

- Promoting effective care systems that:
  - provide better services and resources to clients,
  - enhance social interaction between them, and with their carers
  - deliver more effective care
- Providing the high-abstraction level care management strategies by linking all relevant agencies into a single framework of accountability.
- Giving an in-depth understanding of the health information framework that underpins the delivery of high quality, effective community care, including the formularisation of the links between the disparate agencies involved.
- Establishing a single agent-based care monitoring facility that can be used by all care professionals to assist in effective monitoring and diagnosis.
- Developing cooperative structures within the community structures to change service provision and care policies through the use of automated agents involvement in planning, scheduling, organising (both formal and informal) care and even directing care service programs.
- Devolving care management and responsibility to those providing the care by providing shared supervision and teamwork and by separating the organisational from the social requirements, developing a much more responsive and client centred environment that adapts rapidly to changing needs.

Some of these objectives have already been investigated in the medical domain through the use of multi-agent system architectures. For example, the GUARDIAN system [11] considered patient monitoring in a Surgical Intensive Care Unit. Support is provided for collaboration among specialists, each an expert in a specific domain but fully committed to sharing information and knowledge among each other and the nurses that continuously monitor the patient in the physicians' care. In [15] a system devoted to diabetes care has been presented, where cooperation not only between the medical specialists, but also others, such as administrators is supported within the agent community. Another example is the agent-based system has also been described that supports collaboration among general practitioners and specialists about patient healthcare [12].

A more general agent-based telemedicine framework has been reported [6] that can assist special-

ists in diagnosing difficult cases through information sharing, cooperation and negotiation. In this case each specialist has their own Telemedicine-Oriented Medical ASsistant (TOMAS) agent that behaves as a medical assistant and has two generic functions:

- an agenda for managing appointments, and
- methods for access to patient records.

Support for telemedicine is given by software features for remote exchange of patient data, cooperative annotation of cases and negotiation of appointments. These approaches have been greatly assisted by moves to standardise medical information through attempts to standardise patient and other records [7]. The INCA project aims to take these forward from the purely medical domain and integrate them into the general community care environment, where the linkages are less formal and effective cooperation and negotiation is essential if appropriate care is to be delivered. A major difference is that it is rarely possible to share information as freely as within the purely medical domain because of the involvement of different agencies and individuals with widely differing requirements. The agent community therefore has to act as a coordinator and filter to ensure that appropriate and correct information is distributed to all concerned.

2. The Agent Environment

An agent mediated approach makes it possible to integrate the existing care systems in a way that makes cooperation natural between highly independent agencies. This is because only the communication now has to be standardized, not the internal data structures and representations, as would be necessary if a distributed database approach using shared schemas was adopted [8]. The INCA system can therefore interface directly to a wide range of existing databases, knowledge bases and control systems that are already in place. This can include not only the home monitoring systems, but the management databases that manage care provision and the care providers own information management systems without having to give access to commercially sensitive data which such systems inevitably contain. The much broader care picture can therefore be monitored that is of great help to care managers in developing the most effective and efficient care programme for each individual, including the elimination of unnecessary duplication of resources.

A significant focus of the research is to ensure that the most appropriate assistance is provided in a reasonable time. The various potential agencies have differing capabilities and can respond to a request in various ways, and in differing time frames, each having its own defined cost. Depending on the nature of the incident to which a response is required a decision as to the most appropriate response has to be arranged. This will require multi-dimensional negotiation at a number of levels if acceptable levels of service are to be assured. The current arrangements have great difficulty with this as only limited information is available. It may for example be appropriate to notify an informal carer who can respond rapidly because they are close to the scene either in place of or in addition to a professional carer or the emergency services so that at least some assistance is available at the scene. This more sophisticated approach can only work effectively with full cooperation and information exchange between all parties involved.

The issue of timely intervention when delivery of the promised assistance fails also needs to be addressed, in case that the appropriate agent must identify the anticipated failure as soon as the problem becomes evident. It must then attempt to renegotiate its commitment, either by finding another agent that will take it on, or by making a revised commitment. The agent can then develop a record of the reliability of the various agencies and build this into its negotiating strategy. The process of negotiation is not as well founded in conversation theory as request and response exchanges, because there are many more conditions that may apply. In the case of the INCA project these are simplified somewhat as it can be expected that all agents will use their best endeavours to meet all commitments that they enter into. This simplifies the analysis, without losing too much generality.

A major advantage of this approach is that the Home Unit (and sensors attached to it) can provide a range of services, rather than just one, as in the case of a Home Alarm or simple monitoring unit. Services can be added, modified and removed as required, providing a very high level of flexibility so that the changing requirements of the client

can be met in the most effective manner. This flexibility also extends to the various care agents who may be linked through their existing command and control systems or through special mobile agents or both, depending on their position and current status. This approach follows that outlined by Beer et al. [3].

2.1. The Problem Area Addressed

While community care covers a wide range of activities, five basic scenarios are considered in this chapter, chosen to illustrate the effectiveness of the agent-based approach in developing a fully cooperative environment for providing the care required:

1. The development and updating of an Individual Care Plan. Care Planning is the specification of a *package* of care services according to an assessment of the needs of the individual.
2. The provision of routine care as specified by the Individual Care Plan and provided to an individual on a routine basis to support day-to-day living.
3. The provision of positive care to maintain and enhance the quality of life.
4. Emergency support in response to some unexpected event, such as an accident or medical emergency.
5. The monitoring of the delivery of care to ensure that it is delivered as specified by the Individual Care Plan.

A number of organisations and individuals play a part in these activities. They can be grouped effectively into groups of actors, as shown in Table 1. The interactions between these actors can then be shown in the form of Use Case diagrams.

Table 1
The Actors

NAME	DESCRIPTION
Care co-ordinator	The agency responsible for providing the range of services necessary to ensure that the Older person is properly cared for. The Care co-ordinator is responsible for preparing a Care plan and for monitoring its effectiveness in meeting the needs of the Older person. This is often the Local Authority or some other official body with a legal duty to provide the necessary care.
Care provider	The various agencies and individuals responsible for providing the care specified by the Individual Care Plan. This will include Social Workers, Health Care Professionals, Care Assistants, Emergency Services, Social Services etc. who can provide an extremely wide range of care services, if required.
Informal carer	The various relatives, friends, neighbours etc. who provide some form of support and assistance in an informal way (i.e. outside the Individual Care Plan). This is often essential to allow the Older person to remain living at home. This is often flexible and responsive and can range from totally unstructured and so not recognised at all in the Individual Care Plan through to fully recognised and integrated with the efforts of the professional carers.
Older person	The person who lives in their own dwelling (either an ordinary house or a sheltered home) and who receives a package of community care services. This package may range from very minimal interventions, such as social alarm systems, through to an intensive mix of community support services.

2.1.1. Developing an Individual Care Plan

Before care can be provided effectively, the care co-ordinator has to assess need, and develop an individual care plan that meets the Older persons requirements. This can be quite difficult, particularly with the severely disabled or those with dementia. If assessment is undertaken at an assessment centre it ignores the specific circumstances and problems that occur in the home environment. However observation of a person in their own home requires considerable resources if an effective result is to be achieved. The monitoring facilities of the INCA system are a potentially invaluable source of information for such purposes.

The stages in doing this are shown in Figure 1.

2.1.2. Positive Care

Once the Individual Care plan has been prepared, it has to be delivered. In general, Professional Care Providers actually deliver the care. Informal carers are however extremely important in providing help and support, and need to be fully integrated into the care delivery system. Quality of life (or positive care) aims to improve the psychological and social well being of the Older Person. The INCA system facilitates this by:

- Enhancing social interaction between the client, informal carers and care providers
- Providing information about activities and opportunities for leisure. These are actively

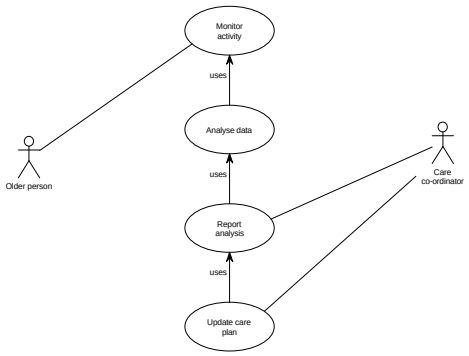

Fig. 1. Individual Care Plan Development Use Case

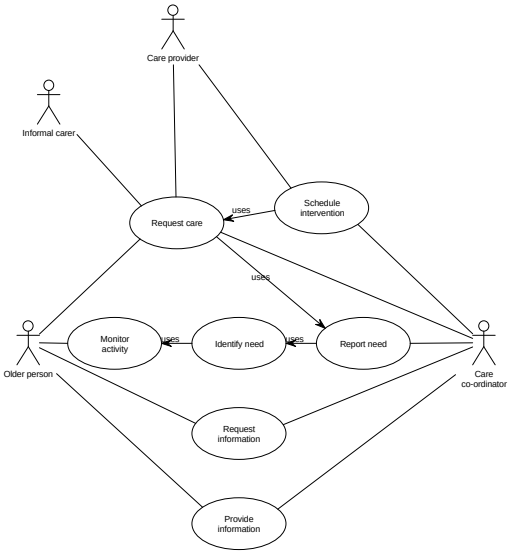

Fig. 2. Routine Care Use Case

filtered to give up-to-date and accurate information that is relevant to their needs.

Figure 2 shows the interactions involved in informing all concerned of the care required at any time. The actual delivery of routine care has to be fully monitored against the Individual Care Plan. The objective is to provide the assistance necessary to make up for the disabilities of the individual, such as help with eating, washing, assistance with bodily functions and getting in and out of bed. The main problem with existing systems is the lack of responsiveness of the services providing it. In high

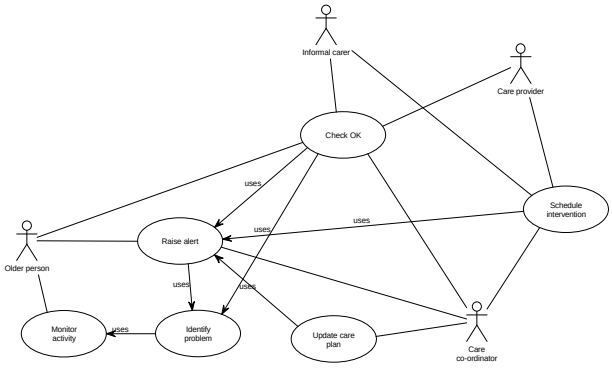

Fig. 3. Emergency Support Use Case

quality residential settings this kind of care is delivered whenever the person requires it. In a community setting, this care is usually provided on a very rigid schedule unless informal carers are willing to take on a very large burden. The INCA system is designed to enhance the responsiveness of the service by:

- Allowing users to request care directly from care providers and co-ordinators.
- Providing users with better information about care schedules, such as when a care provider will arrive, and also delays and changes to schedules at the earliest possible opportunity.
- Monitoring very disabled people (such as people with dementia) in order to fit care interventions more closely to their patterns of daily activity.

Figure 3 shows the interactions involved.

2.1.3. Care Management

Once the Individual Care Plan has been prepared, the requirements of the Care recipient have to be continually monitored so that the plan can be updated as necessary and the requisite level of care continues to be provided. The Care Co-ordinator, as shown in Figure 5, undertakes this activity. Key to the INCA concept is that the Care Plan should be dynamically updated to meet current needs, rather than simply designed to meet those identified at the original assessment. The key to this is the ability of the system to continuously monitor both requirements and service delivery. It is also important to ensure that all the care specified

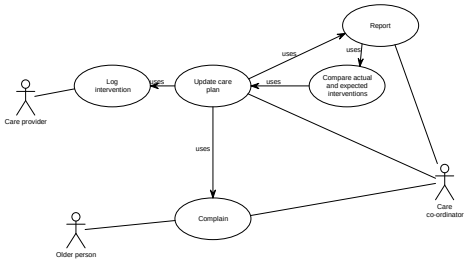

Fig. 4. Quality Assurance Use Case

in the Individual Care Plan is actually delivered to acceptable standards, at the appropriate time and in the right place. Monitoring is problematic in the community context, as direct supervision of care staff is almost impossible. The INCA system facilitates effective monitoring in two ways:

- Care providers log their interventions directly into the system at each visit. These can then be compared directly with the contents of the Individual Care Plan. Any deviations can then be investigated and either the Individual Care Plan can be updated or other appropriate action undertaken.
- Complaints procedures can be based on direct communication to the Care co-ordinator, improving monitoring and responsiveness. The logs can be used to compare actual interventions with those specified in the Individual Care Plan which is then updated to take into account the new information.

Figure 4 shows the interaction involved in Quality Assurance procedures.

2.1.4. Monitoring the Individual Care Plan

It is also important to ensure that all the care specified in the Individual Care Plan is actually delivered to acceptable standards, at the appropriate time and in the right place. Figure 5 shows the interaction involved in Quality Assurance procedures.

Once the facilities required for supporting community care have been provided, they can be used with little or no additional hardware to provide other useful services. For example, if it were programmed to act as a burglar alarm when the house is empty, it would ask the facilitator for a different service mediator which handles burglar alerts, and a different set of responses would be triggered, that would be appropriate to that situation. This would be implemented by activating a different set of conversation classes, with their own guard, post and completion conditions. In this way, the operation of the burglar alarm service can be kept separate and independent from the community alarm services. Only the requirements of the various community alarm services are considered here, as these need to be kept independent from each other, and additional services are simply extensions of the architecture proposed.

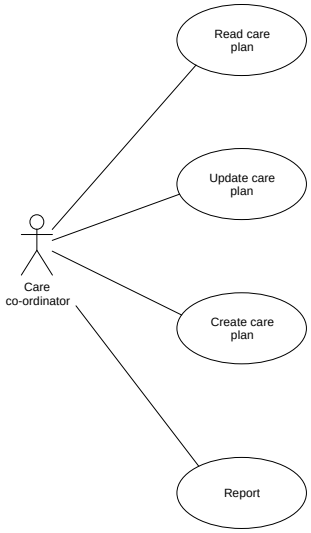

Fig. 5. Preparing and updating the Individual Care Plan

3. The Design of the Conversation Classes

The previous section shows that a wide range of activities can be supported effectively by the INCA system. Traditional database design techniques have difficulties with this richness, as each scenario contains actors with the same roles performing differently depending on their beliefs and intentions within that scenario. Agent approaches are specifically intended to address these issues. This can be illustrated effectively by considering the management of communication for dealing with emergencies.

An alarm condition is raised only when the home unit detects sensor readings outside the normal range. A similar architecture has been reported elsewhere [10] except that the raw data is uploaded to a central server for processing, and that server raises the alarm condition when it considers it necessary. Such an architecture requires a different response mechanism than our own, where a facilitator is contacted to obtain the address of a suitable service mediator, which is then alerted. This mediator routes the alert to a suitable service provider after adding additional information from the service database. The service provider's mediator determines the appropriate course of action and notifies the necessary carer, possibly via further mediators. This allows considerable additional flexibility, as for example, a Warden may only be available during certain hours, on certain days of the week. A mediator can ensure that all alerts are appropriately routed to obtain an immediate response.

One of the main features of the work described is the specification of the conversational abilities of agents. In line with KQML [14], the conversational abilities of an agent will be determined by a set of speech acts, which that agent can perform, and a set of speech acts to which it can respond. *Speech acts* are used here in the familiar way, deriving from Searle [18]. A speech act comprises a *performative*, indicating the illocutionary and intended perlocutionary force of the act, together with an *argument*, typically a proposition.

The semantics for the speech acts are provided as follows, following Labrou:

- a set of pre-conditions for the performance of the act,
- a set of post-conditions to be enforced immediately on performance of the act, and
- a set of completion conditions which are to apply when all the intentions associated with the act have been finally satisfied.

This means that the completion conditions may be achieved at some time after the communication being described has taken place, after some further conversation has occurred. This means that conditions or acts with such conditions can provide a context for later utterances. Performatives provide the building blocks for conversations between agents. However, for conversations to take place, they must be co-ordinated in a way appropriate to the particular conversation. Barbuceanu et al [1] show the necessity for this level of coordination. In that paper, conversations are specified by using state transition diagrams, but greater uniformity can be achieved by extending Labrous method and representing the conversation rules as additional preconditions, post- conditions and completion conditions on the speech acts they use. Experimental use of this approach has been reported in [4], which describes the specification of conversation rules for several dialogue games. Thus far the performatives are specified in a way that is neutral between the agents that perform and respond to them. In our particular application, however, there is a need to customise the act to particular agents. It is essential for confidentiality reasons that an agent should be required to respond to questions from some particular class of agents only under particular conditions. Such constraints can be included uniformly in the specification above by including pre and post conditions local to individual agents expressing heuristics and policies. For example:

- Personal information must only be provided to those involved in the provision of care to that individual and then only when it is required in the provision of that care.
- Communication between agents that is only relevant to those agents must be handled appropriately. Examples of this would be messages between the Care co-ordinator and the Older person to check the level of care being provided. Another example would be where the care Co-ordinator is scheduling the carer. This will usually involve information about a number of Older people that the carer is scheduled to visit.

The basic mechanism for the home unit to communicate with service providers is shown as a transition diagram in Figure 6. This shows the actions required summoning assistance. The actual service provider summoned depends on a number of factors:

- The type and severity of the problem
- The service providers able and willing to respond
- The anticipated speed of that response
- The cost of that response in relation to the perceived need

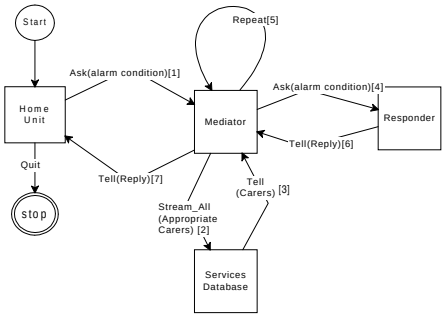

Fig. 6. The Basic Response Conversation Class

The first is initially controlled by the guard conditions on the conversation class [8] and is determined by information local to the Home Unit (the reason for the alarm, whether the home is occupied or unoccupied etc.). Decisions based on the service providers ability or willingness to respond require much more general knowledge than is available to the mediator, which can negotiate with a number of service providers to determine whether one or more can respond in an appropriate way within a reasonable time. If a service provider is able to do so, then the mediator accepts the most appropriate offer, rejecting all others, and informs the Home Unit. In certain cases no single service provider would be appropriate. If, for example, a serious medical emergency was detected and an ambulance would arrive only after some time, the mediator would ensure that a carer closer to the scene was also called and would look after the client until help arrived. This would require several sets of negotiations and many interactions before a satisfactory result was achieved.

4. The benefits of using agents for INCA

The integration of existing care systems facilitates the integration of a wide range of existing databases, knowledge based and control system programs. Agent technologies enable a *controlled* degree of co-operative activity between these independent components. They are *controlled* in the sense that each component within the system be it an organization or information store need only communicate the information required by the system. There should be no requirement to open additional information required for own purposes. Therefore, taking an agent-based approach it is possible for the organizations involved in the provision of care to communicate effectively yet securely, plus have access to much needed information. All of which will lead to a more managed and effective approach to care provision thus providing an increased speed of service and the elimination of unnecessary duplication of resources.

In the past a barrier to coordinated community care has been the incompatibility of the independent agencies systems and procedures. Agent-based methodologies like INCA enable heterogeneous systems to function together effectively in many different configurations. Thus agent technologies provide the means to integrate the different health care agency systems regardless of organizational structure and provide the means for the various agencies to interface on a common domain level.

Within the scope of the term agent technologies falls a wide range of different agent typologies, for example agents may be information agents, reactive agents or collaborative agents. In the context of the INCA architecture, the agents within the system are collaborative agents.

The collaborative nature of an agent places an emphasis on autonomy and co-operation with other agents.

- Autonomy means that agents have the ability to act without the need for human invention and guidance. They are able to achieve goals on behalf of the user and the system in a pro-active manner rather than a re-active manner. In other words, agents are able to take the initiative.
- Co-operation means that agents are able to co-operate with other agents within the architecture in order to achieve domain goals.

The rationale for constructing an architecture of collaborative agents is that numerous collaborative agents provide solutions to inherently distributed problems and are suited to solving problems that are too large for a single centralised agent. Collaborative agents negotiate with the other agents within the system thus organising and accomplishing complex goals and tasks that are often beyond the capabilities of a single agent.

It will be seen that the INCA architecture enhances the co- ordination between the various

health care agencies by enabling the agents within the system-controlled access to the information sources incorporated within the INCA domain. That is, it is essential that the agents within the INCA architecture can interface with the existing agency information sources, including sources such as databases, log files and knowledge bases.

In order to facilitate effective co-ordination, it is necessary to allow the agent within the architecture to read and write domain information to and from the appropriate organizational information source. This can be achieved by the use of data wrappers, which provide an interface between agent and information source. Data wrappers enable the agents to query (read) information, by translating agent requests constructed in the communication protocol of the INCA domain into a form that is understood by the agency's own information system. For example an agent request may be translated into a SQL statement that can be executed against an organizational database. In the same manner, the responses (provided by said information sources) to agent requests are translated or mapped back into the agent communication protocol of the INCA domain.

5. Constructing the Demonstrator

Agent based applications can be complex and current levels of agent-related software engineering is rather immature. Ciancarini and Wooldridge [5] have proposed several frameworks, although none are satisfactory for developing complicated agent applications. UML was chosen to model the conversation classes, and based on the work by Bauer et al.[2], this was deemed to be suitable also for modelling the prototype. This approach yielded the collaboration diagram as shown in Figure 7.

To fully represent an integrated health care system, various health care resources should be included within the implementation, and the prototype demonstrator reflected this. Health care is managed by a care co-ordinator, acquiring resources and services from a range of autonomous actors (agencies). These resources and services are then consumed by the community care recipients.

Once the problem domain had been identified, a detailed design for the INCA prototype could be specified.

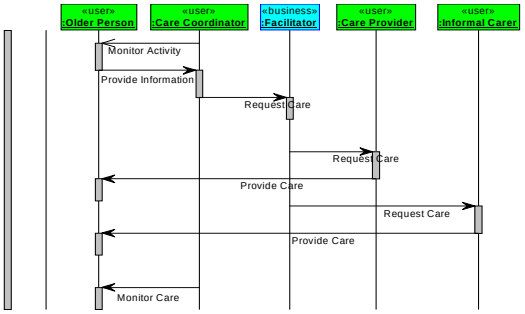

Fig. 7. Collaboration Diagram for the INCA System

5.1. Design of the User Interface

Further to the interface design expounded by the ZEUS toolkits developers [16], the following components of the design were deemed essential for the demonstrator:

- Buttons to simplify common functions such as requesting care to construct an Individual Care Plan, and to initiate requests for agents to organise services and information.
- Visibility of communication between agents, illustrating the extent of conversations during negotiation.
- Input areas to receive text-based messages for the purposes of either entering or retrieving information.

A sample of the interface for the home unit is shown in Figure 8. Messages passed between agents are displayed in the main portion of the window, with button controls for specific functions placed underneath. Requests for assistance can be initiated by pressing the Send Alert button. Care is then provided in relation to the Individual Care Plan, plus the agents current knowledge.

Communication with the Care Coordinator agent is provided via the Enter Message button, allowing descriptive text to be entered into the system.

5.2. Realising the Agents

The process of realising the agent based demonstrator was similar to that used during the design process, and was achieved using the Zeus Agent Generator tool in the following manner:

Fig. 8. The User Interface for the Older Person

Ontology Creation: The first step was to represent the INCA domain ontology, that is, the health care resources that are produced and consumed by the agents within the system. Communication between agents requires a common language and a shared representation of domain concepts, characterising the resources that are utilised within an agent system. Using the ZEUS Ontology Editor, these resources are represented as facts.

Task Agent Creation: The agents main task is identified, named and entered into agent creation editors. In the case of the INCA system, a domain level task would be to acquire health care services and resources required by the client as specified in an Individual Care Plan. A suitable name for this task would be Request Care.

Task Configuration: Details of the agent domain tasks, such as any task preconditions, their effects, costs incurred, task duration and any constraining factors defined during the design stage are entered into the ZEUS Task Editor. For the Request Care task, such preconditions would be the health care resources and services required in order to produce an Individual Care Plan (itself represented by a ZEUS fact).

Utility Agent Configuration: Support for INCAs infrastructure is provided by Utility agents, specified within the ZEUS Code Generation Editor.

Task Agent Configuration: Details of connections to external data sources (an Access database for the INCA demonstrator), together with details of interactions with external programs, are specified for the task agents using the ZEUS Code Generation Editor.

Agent Implementation: Once the above stages are complete, Java source code is automatically generated by the ZEUS Code Generator. The cooperative and collaborative functionality for each agent is implemented using Java code, permitting the necessary social interaction required.

Upon completion of the social/agent level Java code, the developer must implement code for activation of tasks, any external GUI programs, and external resource connectivity.

5.3. The Structure of the Demonstrator

The current demonstrator uses mediator agents to simplify communication and allow structured communication with the large number of home units likely to be deployed. Figure 9 shows how the agents interact. It will be noted that this follows through from the design of the Basic Conversation Class (Figure 6). The 'Call Centre' and 'Emergency Response' agents act as mediators that route messages based on the information given, with reference to Individual Care Plan that is managed by the 'Care Coordinator' agent. This separates out the response management from the individual care provider's management infrastructure. It therefore shows how it is possible to integrate disparate data sources as part of an overall agent-based system. Each Care Provider is modelled individually, based on the services that they are commited to provide. This means that for example a Community Care Provider will deliver different services from a Medical Centre or the Emergency Services. Some require access to the Individual Care Plan as they are contractually bound to it, while others, such as the Emergency Services provide a general service to the whole community, and so do not need to negotiate further.

Current work is looking to integrate the INCA architecture with parallel work on agent systems

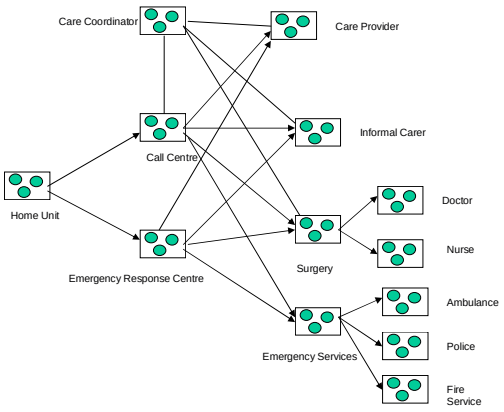

Fig. 9. The Structure of the Current Demonstrator

to manage the provision of general medical care and hospital services. We are also developing mobile agents to provide more information to Informal Carers who have traditionally been provided with only very limited support.

6. Conclusions

Agent-oriented applications such as INCA unveil a tremendous range of challenges and opportunities to create more flexible distributed cooperative working environments by fully utilising agent capabilities and responsibilities, allowing us to open our minds to the possibilities offered by more powerful visions of agent-based community care systems and develop new models of care services. The use of a collaborative agent architecture outlined in this paper illustrates how agent co-operation could potentially be used to integrate health and social care systems. The research carried out had the following key outcomes:

- the effective implementation of an agent negotiation component within the INCA system demonstrates the practical feasibility of the approach and current techniques and tools.
- the ZEUS agent building toolkit has also shown that agent-based applications can be rapidly developed from initial analysis through to a working prototype. Although the demonstrator required the original, theoretical architecture to be compromised considerably to meet the requirements of the toolkit methodology, the development was extremely rapid and a fully functional first prototype was produced within four months.
- the research demonstrated that agent-based technologies could mediate distributed demand and supply issues within an integrated domain space, whilst keeping the actors and agencies (within the domain) independent, with full recognition of each actor's autonomy. Integrating external data sources by the use of wrappers enabled the INCA demonstrator to fully integrate a variety of systems effectively.
- the demonstrator showed that it is feasible to integrate disparate data sources within an overall agent-based system, especially those associated with the various health care organisations which were successfully incorporated within the INCA domain.

The INCA system could be extended to incorporate informal health care providers (such as friends, family and neighbours) and to provide better communication channels between the actors, agencies and organizations integrated within the INCA domain. There are significant opportunities to implement such services using WAP mobile telephones or handheld computers using mobile agent frameworks. These communication devices present opportunities to improve communications capabilities to both care workers in the field, and to those who are currently excluded from the formal structures, such as the informal careers. The current state of agent communications technology has required that significant compromises be made in the communications infrastructure. In particular, the negotiation of prices, and mechanism for authorizing payment for emergency care is quite primitive, being based on a simple auction model. This is an area that urgently needs further analysis, in order to develop appropriate so that proper business-based protocols can be developed. The issue here is that the party requesting and authorizing the necessary care is not that which will eventually pay for it. This is common in business transactions but has not been fully developed within the agent literature, as yet.

A major aspect of the demonstrator is the inclusion of a means to formally represent the informal carers within the INCA domain. Informal carers make considerable contributions to the support

of older, frail and disabled people living at home. Considerable improvements in the effectiveness of services could be achieved if the informal and formal health and social care sectors could be integrated. Agent technology provides the means by which the inherent relative unreliability of actors within the informal sector can be modelled effectively without having to supply each with expensive and difficult to use computing interfaces. As the informal carer supplies health care resources (and as such represents a generic care provider) the *Informal Carer* agent could replace any of the *Care Provider* agents within the current supply chain.

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