Multi-Agent Systems for Healthcare Simulation and Modeling:
Applications for System Improvement

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Chapter 11

Role of Multi-Agents System in Creation of Collaborative Environments within Mental Health Domain

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ABSTRACT

Mental illness is becoming one of the major problems of our society. The World Health Organization predicted that depression would be the world's leading cause of disability by 2020. The exact causes of many mental illnesses are still unknown, mainly due to the complex nature of mental health. In this paper, the authors propose a multi-agent system designed to assist in effective and efficient management, retrieval and analysis of mental health information. They utilize the TICSA approach to define different agent Types, their Intelligence, Collaboration paths, address Security problems and Assemble individual agents. They use UML 2.1 Sequence and Composite diagrams to model social and goal-driven nature of the multi-agent system. The proposed multi-agent system has the potential to provide and expose the knowledge that will increase our understanding and control over mental health and help in development of effective prevention and intervention strategies.

INTRODUCTION

Mental illness is becoming one of the major problems of our society. The World Health Organization predicted that depression would be the world's leading cause of disability by 2020 (Lopez & Murray, 1998). The number of mentally ill people is increasing globally each year. This introduces major costs in economic and human terms, to the individual communities and the nation in general, both in rural and urban areas. The recognition that many mental illnesses may not become chronic if treated early has led to an increase in research in the last 20 years.

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Research into mental health has increased and resulted in a wide range of information and publications covering different aspects of mental health and addressing a variety of problems. A huge body of information is available within the mental health domain. This information is dispersed over various information sources which are heterogeneous in structure and content. As the research continues, new papers or journals are frequently published and added to various databases. Portions of this data may be related, overlap or semi-complementary with one another. No tool exists which helps us identify these kinds of relationships, overlaps, complementarities and redundancies.

Retrieving specific information is very difficult with current search engines as they look for the specific string of letters within the text rather than its meaning. In a search for "genetic causes of bipolar disorder", Google provides 95,500 hits which are a large assortment of well meaning general information sites with few interspersed evidence-based resouces. Medline Plus (http://medlineplus.gov/) retrieves 53 articles including all information about bipolar disorder plus information on other mental illnesses. A large number of articles is outside the domain of interest and is on the topic of heart defects, eye and vision research, multiple sclerosis, Huntington's disease, psoriasis etc. PubMed (http://www.ncbi.nlm.nih.gov/pubmed) gives a list of 1,946 articles. The user needs to select the relevant articles as some of the retrieved articles are on other illnesses such as schizophrenia, autism and obesity. Moreover, the user needs to read each article individually and establish the links between the selected articles manually. We need to take a systematic approach to making use of the available information that cannot reach its full value unless it is systematically analysed and linked with other available information from the same domain.

Wilczynski *et al*. (2006): "General practitioners, mental health practitioners, and researchers wishing to retrieve the best current research evidence in the content area of mental health may have a difficult time when searching large electronic databases such as MEDLINE. When MEDLINE is searched unaided, key articles are often missed while retrieving many articles that are irrelevant to the search." Wilczynski *et al*. (2006) developed search strategies that can help discriminate the literature with mental health content from articles that do not have mental health content. Our research ideas go beyond this. We go a step further and apply data mining algorithms on mental health data. We propose the design of a multi-agents system that will give a consistent format to all mental health information. This will bring the mental health information under one umbrella and enable us to organize this information in a systematic way. This will allow automatic data analysis techniques such as data mining to effectively use mental health data, reveal data patterns hidden within the large body of the mental health data, and expose the knowledge that will help medical practitioners develop better prevention and intervention strategies.

LITERATURE REVIEW

Complexity of the Mental Health

The increase in mental health research has resulted in increase of information but the exact causes of many mental illnesses remain unclear. However, it has been proven that mental illness is a causal factor in many chronic conditions such as diabetes, hypertension, HIV/AIDS resulting in higher cost to the health system (Horvitz-Lennon *et al.* 2006).

As mental illness is still a grey area of medical research, and the exact causes of mental illness are unclear, precise treatment strategies cannot be developed at this stage. Doctors are often forced to prescribe medication which may provide temporal relief but in reality mask the real issue and often result in side effects that will make the patient's situation even worse (Pacher & Kecskemeti, 2004; Check, 2004; Friedman & Leon, 2007; Werneke *et al.* 2006). The drugs used to treat mental illness have negative effects on both physical and mental health. Specifically, the negative effect on cardio-vascular health is evident (Pacher & Kecskemeti, 2004). The mental health of patients taking drugs often becomes worse. The drug may mask one mental problem, but another mental problem that has never existed before may appear. Suicidal thoughts (Check, 2004; Friedman & Leon, 2007) are the most common and dangerous side effect of the drugs. Additionally, sexual dysfunction (Werneke *et al.* 2006) is another side effect that may negatively effect marital relationships of the patient and, in turn, create additional problems and pressure.

Researchers believe that mental illness is caused by various factors. For example, genetic analysis has identified candidate loci on human chromosomes 4, 7, 8, 9, 10, 13, 14 and 17 (Liu *et al.*, 2003). There is some evidence that environmental factors such as stress, lifecycle matters, social environment, climate etc. are important (Craddock & Jones, 2001; Smith *et al.* 2005). Some researchers suggest that a bacterial or viral infection may cause mental illness (Wenner, 2008). More research is required to explain why mental illness appears to be transmittable; is it really caused by a microorganism and why the wellness/illness appears to be 'contiguous'? Additionally, interest in the relationship between religion and spirituality and mental health has increased in recent years. Hill and Pargament (Hill & Pargament, 2003) illustrate that dimensions such as closeness to God, religious or spiritual orientation, source of motivation, religious and spiritual support and religious and spiritual struggle, are significantly tied to physical and mental health. Schumaker (1992) reviews the work of various scientists who examined the relationship between religion and spirituality with various aspects of psychological well-being including depression, suicidal thoughts, substance abuse, anxiety, fear of death, sin and guilt, self-esteem, meaning of life etc. Research into mental health has been made even more complicated through the existence of various types of specific mental illnesses such as chronic, postnatal and psychotic types of depression.

Identification of the precise patterns of causal factors responsible for a specific type of mental illness still remains unsolved and is therefore a very active research focus today. Many research teams focus only on one factor and perhaps one aspect of a mental illness. For example, in the paper "Bipolar disorder susceptibility region on Xq24-q27.1 in Finnish families" (PubMed ID: 12082562), the research team Ekholm *et al.* (2002) examined one genetic factor (Xq24-q27.1) for one type of mental illness (bipolar disorder). As mental illnesses do not follow Mendelian patterns but are caused by a number of genes usually interacting with various environmental factors, ever factor for all aspects of the illness needs to be considered. We believe that data mining techniques have the power to simultaneously analyse the data and expose the data patterns invisible to human eye simply because of the large volume of mental health information.

Multi-Agent Systems

Multi-agent systems (Wooldridge, 2002) are being used more and more in the medical domain. One of the main advantages of agents is their autonomy. They can act independently from the user and from the rest of the system, and make decisions on their own. Even though the agent is able to act autonomously, it has to be sociable and collaborate with other agents of the system in order to address more complex problems. Only through cooperation, coordinating their actions, sharing tasks and results with other agents, can multi-agent systems reach their full potential. The collaborative nature of agents enables the multi-agent system to find solutions to complex problems through carrying out distributed problem solving. Some agents are mobile i.e. they are capable of migrating to different places. This feature can increase dynamics and efficiency of the whole system.

Being goal-driven is a feature of many different agents. The fact that an agent has an overriding goal, regardless of the specifics of its processing, endows it with many other features. Specifically, it is proactive, i.e. it takes actions on its own initiative, and it is intelligent, i.e. it reasons and chooses to perform the most beneficial actions towards achieving its goals.

The multi-agent systems greatly contribute to the design and implementation of complex health information systems. Effective implementation of multi-agent systems within the health domain could result in a revolutionary change that will positively transform the existing health systems. Some of these agent-based systems are designed to use information within specific medical and health organizations, others use information from the Internet.

The information available to organization-based systems is limited to a specific institution and these multi-agent systems help the management of the already available information. They do not have a purpose of gaining new knowledge regarding the disease in question. For example, Agent Cities (Moreno & Isern, 2002) is a multi-agent system composed of agents that provide medical services. The multi-agent system contains agents that allow the user to search for medical centres satisfying a given set of requirements, to access his/her medical record or to make a booking to be visited by a particular kind of doctor. AADCare (Huang *et al.*, 1995) agent architecture is a decision support system for physicians. It connects patient's records with the predefined domain knowledge such as knowledge regarding a specific disease, a knowledge base of clinical management plans, a database of patient records etc. MAMIS (Fonseca *et al.*, 2005) is a Multi-Agent Medical Information System facilities patient information search and provides ubiquitous information access to physicians and health professionals.

Other multi-agent systems retrieve information from the Internet. BioAgent (Merelli *et al.*, 2002) is a mobile agent system where an agent is associated to the given task and it travels among multiple locations and at each location performs its mission. At the end of the trip, an information integration procedure takes place before the answer is deployed to the user. Holonic Medical Diagnostic System (Ulieru, 2003) architecture is a medical diagnostic system that combines the advantages of the holonic paradigm, multi-agent system technology and swarm intelligence in order to realize Internet-based diagnostic system for diseases. All necessary/available medical information about a patient is kept in exactly one comprehensive computer readable patient record called computer readable patient pattern (CRPP) and is processed by the agents of the holarchy. Different web crawling agents (Srinivasan *et al.*, 2002) have been designed to fetch information about diseases when given information about genes that when mutated may cause these diseases.

We have highlighted the importance of multi-agent systems within mental health domain in our previous works (Hadzic & Chang, 2008a; Hadzic & Chang, 2008b). In this paper, we go a step further by (1) describing such system in greater detail and (2) using the UML 2.1 diagrams to expressing the ideas more effectively.

Data Mining

Data mining is a set of processes that is based on automated searching for actionable knowledge buried within a huge body of data (Han & Kamber, 2006). Data mining algorithms have great potential to expose the patterns in data. Data mining help to extract information, to find hidden patterns and knowledge, and to make predictive models for decision making and new discoveries. Data mining draws work from areas including database technology, machine learning, statistics, pattern recognition, information retrieval, neural networks, knowledge based systems, artificial intelligence, high-performance computing and data visualization (Sesito & Dillon, 1994). Some advantages of data mining over the traditional approaches include:

- efficient processing of large and complex data (scalability)
- automatically analysing, detecting errors and inconsistencies, classifying, and summarizing the data with no human intervention (automation)
- extracting novel and useful patterns which leads to new knowledge and discoveries (knowledge extractions)
- combining the advantages of various disciplines (multi-disciplinary nature)
- reducing costs and time associated with the data analysis (cost and time efficiency)

Within the health domain, data mining techniques have been predominantly used for tasks such as text mining, drug design, gene expression analysis, genomics and proteomics. The data analysis necessary for microarrays has necessitated data mining (Piatetsky-Shapiro, & Tamayo, 2003). The data mining algorithms can be applied to derive patterns specific to mental illness, such as exposing a unique combination of causal factors responsible for onset of the illness in question and providing an indication of influence. This can greatly contribute in the identification of precise patterns of genetic and environmental factors and in development of prevention and intervention strategies. The extracted data patterns can provide useful information to help in mental illness prevention, and assist in delivery of effective and efficient mental health services.

Much of the mental health information is not in strictly structured form and the use of traditional data mining techniques developed for relational data is not appropriate in this case. The majority of available mental health information can be meaningfully represented in XML format, which makes the techniques capable of mining semi-structured or tree structured data more applicable. In our previous works (Hadzic *et al.*, 2008a; Hadzic *et al.*, 2008b; Hadzic *et al.*, 2008c), we have demonstrated the potential of the tree mining algorithms to derive useful knowledge patterns in mental health domain. We have used our previously developed IMB3-Miner algorithm and showed how tree mining techniques can be applied on mental health data represented in XML format. We discussed the implications of using different mining parameters within the current tree mining framework and demonstrated the potential of extracted patterns in providing useful information.

Ontology

Ontology is an enriched conceptual model for representing domain knowledge. Ontology captures and represents specific domain knowledge through specification of meaning of concepts including definition of the concepts and domain-specific relationships between those concepts. Ontologies provide a shared common understanding of a domain and have been suggested as a mechanism to provide applications with domain knowledge and support knowledge integration, use and sharing by different applications, software systems and human resources (Gómez-Pérez, 1998).

An ontology, particularly in medicine, grew out of a perceived need for a controlled vocabulary (Cimino, 2006; Smith, 2006). The importance of ontologies has been recognised within the biomedical domain and work has begun on developing and sharing biomedical ontologies (Ceusters *et al.*, 2001; Burgun, 2006). The Gene Ontology (GO) (http://www.geneontology.org/) project works on establishing consistent descriptions of gene products in different databases by using the GO to annotate major repositories for plant, animal and microbial genomes. The Unified Medical Language System (UMLS) (Kim & Park, 2004) is a collection of many biomedical vocabularies and it consists of Metathesaurus, Semantic Network, SPECIALIST Lexicon and a number of software tools. There are one million biomedical concepts in UMLS, and 135 semantic types and 54 relationships are used to classify these concepts. Human Disease Ontology (Hadzic & Chang, 2005) captures and represents the knowledge about human diseases. It consists of disease types, symptoms, causes and treatments subontologies. Protein Ontology (http://proteinontology.info/) (Sidhu *et al.*, 2006) provides a unified vocabulary for capturing declarative knowledge about protein domain and to classify that knowledge to allow reasoning. It acts as a mediator for accessing not only relational data but also semi-structured data such as XML or metadata annotations and unstructured information. A great variety of biomedical ontologies is available via The Open Biomedical Ontologies (http://obofoundry.org/) covering various domains such as anatomy, biological processes, biochemistry, health and taxonomy.

UML

Multi-Agent Systems (MAS) are increasingly being proposed and used within the biomedical domain. One of the ongoing issues within the modelling of multi-agent systems is the lack of a standardized modelling language. Some research groups have proposed the use of UML to model agent-based systems. Others have extended UML to suit modelling requirements specific to multi-agent systems. We have noticed a number of problems with the existing approaches. The major problems relate to the inconsistent semantics of the existing UML Diagrams, and the unintuitive and complex notation.

Kavi *et al.* (2003) propose to extend UML with a number of modeling constructs. Next to the Agent, the additional modeling constructs include (1) Belief, Goal and Plan - to enable modeling of the reactive and proactive behaviors of agents, and (2) FIPA Performative, KQML Performative and Blackboard - to model agent's communication. The authors give an impression of using the Sequence Diagram. However, they have changed the semantics of the Sequence Diagram by using smiley faces, thought clouds, and the like. Da Silva *et al.* (2004) propose MAS-ML as a modeling language to support modeling of multi-agents systems. MAS-ML is an extension of UML and uses Organization, Role and Class Diagrams to model static aspects of an application while Sequence Diagrams are used to model the dynamic aspects of an application. We notice changes in the semantics of rectangles without the use of a stereotype. Additionally, the use of <<role_change>> is syntactically correct but the resulting diagram appears complex and is difficult to follow. VisualAgent (De Maria *et al.*, 2005) is a Java-based development environment which uses the MAS-ML and is composed of three tools: a graphical tool, a transformation tool and a code generation tool. The VisualAgent can be used to present some preliminary ideas, but does not allow for detailed presentation as it virtually lacks existing UML diagrams or stereotypes. Da Silva *et al.* (2005) use UML2.0 Activity Diagrams to model agent plans and actions. They consider a plan to be an activity, decompose them into a number of actions and define the action execution sequence. The strength of this approach is that it allows definitions of stereotypes for Activity Diagrams. However, the chosen notation appears to be difficult to understand and to follow.

Odell *et al.* (2001) uses non-standard extensions of UML since they do not use stereotypes and changes the semantics of existing UML constructs. In particular, (1) no use of stereotypes was made to define an agent and (2) the definition of classes and instances are mixed up in sequence diagrams. It was specified that one defines agent as Agent: Role/Class in Figure 6, but names of classes in Figures 8-10 were underlined which implies that they were instances. We will not use underlining throughout this paper in order for it to be clear that we refer to classes, not instances.

As a third point we notice in sequence diagrams a rectangle to be defined as a Agent/Role combination. In particular, this meant that a single Agent was represented by multiple rectangles, each one representing a single role. On contrary, we use a single rectangle to represent a composite class (which corresponded to an Agent) with ports (see UML 2.1) to represent roles. Thus we work within the existing framework of UML 2.1 whilst only making extensions within the framework of UML (i.e. by use of stereotypes).

The latest version of UML, UML 2.1, has greater expressive power over previous UML versions. This allows representing more complex scenarios and introducing greater details into the modeling process enabling effective capture and representation of multi-agent actions and interactions. We use UML2.1 to define and describe multi-agent systems by not changing the semantics of the diagrams, which is a critical point that makes our use of UML 2.1 valid. In this paper we illustrate how UML 2.1 can be used to model a multi-agent system specifically designed to intelligently store, use, manage, analyze and retrieve mental health information. We believe that UML 2.1 has not only enabled the introduction of a notation for MAS, but also effective capture and representation of the dynamic processes associated with these MAS.

TICSA APPROACH TO THE MULTI-AGENT SYSTEM DESIGN

In this project we focus on creating a collaborative environment for the mental health research domain. Different mental health researchers working on different aspects of the shared problem would be able to come together, share their information effectively, cooperate with each other and jointly build solutions to common problems. This is of vital importance for the mental health research community as mental illnesses are caused by different factors, and most researchers work on a single causal factor. Sharing of the information will enable the examining each factor in the context of other factors.

In our previous work (Hadzic & Chang, 2008c), we have described five important aspects (TICSA) that need to be addressed during the design of multi-agents systems. These include:

1. Identify Agent **T**ypes According to Their Responsibilities
2. Define Agent's **I**ntelligence
3. Define Agent's **C**ollaborations
4. Protect the System by Implementing **S**ecurity Requirements
5. **A**ssemble Individual Agents

In this paper, we will use this approach to design a multi-agent system that will help to use mental health information effectively and efficiently.

Identify Agent Types According to Their Responsibilities

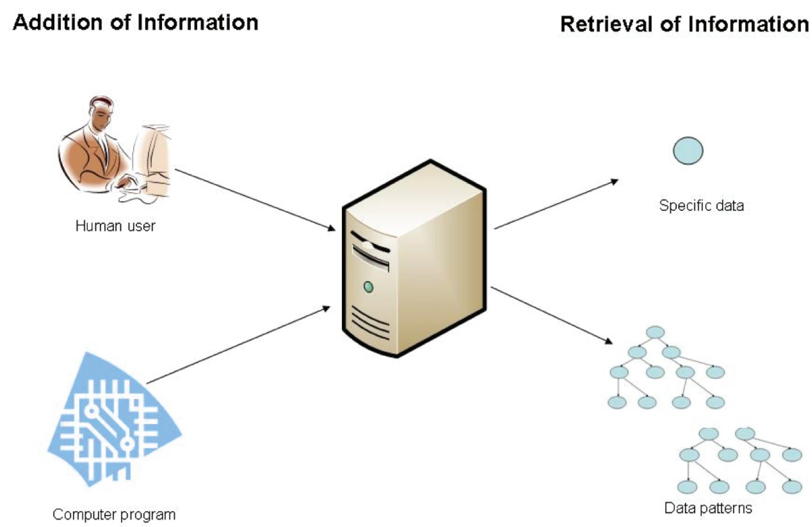
A multi-agent system is a community of agents. Each agent type plays an unique function within the multi-agent system. The different agent types have different but complementary capabilities and are cooperatively working towards the shared goal. The agents are required to work in unity and coordinate their actions.

When identifying agent types, it is important to:

- establish intuitive flow of problem solving, task and result sharing
- identify agent types that will match their responsibilities within the system needed to establish this kind of flow

We propose a system that will make use of different types of agents to add and retrieve information from the system. It will be possible to add information in two different ways. Human users as well as computer programs will be able to add

Figure 1. Different ways of adding and retrieving information from the system



information. Additionally, the information may be retrieved in two different ways. Human users will be able to retrieve specific data as well as to retrieve data patterns specific to problem at hand. This main idea is represented in Figure 1. The resulting system is a combination of human and software agents working together creating a collaborative and mutually beneficial environment. The users of the system are not only information consumers but are also information providers.

We want to design a system where users are able to (i) add information to the system as well as (ii) query the system for the specific information or for data patterns. Additionally, a program will be designed to automatically add data to the system.

A range of actions is required to establish this flow. To add information to the system, these include (1) user login, (2) validation of data, and (3) data storage. To retrieve information from the system, it is required to (1) translate the user's query into a machine-understandable language, (2) activate appropriate agents to retrieve the target information, (3) select appropriate information, and (4) present the retrieved information to the user. For automatic population of the database, (1) search must be activated, (2) retrieved results validated, and (3) the data added to the database.

Our next task is to identify agent types that will have different responsibilities within the system and help us establish the intuitive flow of problem solving, task and result sharing. *Interface agent* is required to assist the user to add information to the system and to retrieve information. *Database agent* is needed to store, access and retrieve the data when needed. As the system will be queried for data patterns, a *Data Mining* agent is necessary to find the patterns hidden in the data. For the automatic addition of the data, two additional agent types are needed: *Controller agent* to request scout and *Spider agent* to find and retrieve data.

In this first step, we have identified five different types of agents. In the following step, we will discuss their intelligence.

Define Agent's Intelligence

The agents need to be equipped with the knowledge that will enable them to perform their task intelligently e.g. to communicate with each other, to retrieve relevant information, to analyze and manipulate information, present information in a meaningful way, etc. Currently, knowledge bases have been predominantly used to provide agents with intelligence and enable them to perform their action efficiently and effectively. Ontologies are high expressive knowledge models and use of ontologies over knowledge bases is preferred (Maedche, 2003).

We have designed Mental Health Ontology (Hadzic *et al.*, 2008d), and this ontology can be used to increase the overall intelligence of the system. Mental Health Ontology provides a shared common understanding of the mental health domain. It captures and represents mental health knowledge. It is organized according the following three sub-ontologies:

(1) disorder types (such as psychotic disorders, anxiety disorders, personality disorders, mood disorders, substance-related disorders, etc.) which define different types of mental disorders;
(2) causal factors, which are classified under 5 categories (genetic, physical, environmental, personal and microorganisms) and describe various causes of mental disorders
(3) treatments (such as pharmacotherapy, psychotherapy, group and family therapy, electroconvulsive therapy and psychosurgery) and describe various treatments of mental disorders.

Mental Health Ontology can be used for different purposes within our system. Firstly, the ontology can be used to meaningfully organize mental health data within the dedicated database. All information on a specific ontology concept can be put together. For example, all publication claiming that a mental illness is cased by a virus can be put together. This will greatly facilitate data access and retrieval. Secondly, ontology can significantly help in deriving meaningful data patterns form the data. This approach is described in greater detail in (Hadzic *et al.*, 2008b) where the tree mining algorithms were used to mine ontological data. Thirdly, ontology can be used to present the retrieved information to the user in a meaningful way. The use of ontologies adds an extra dimension to the results and makes it possible to present the user with the map of related answers.

Define Agent's Collaborations

In the first stage of the TICSA approach, we described how to identify different agent types according to their different functions and roles within the multi-agent system. Here, we focus on structural organization and position of agents within the system. The aim of this step is to:

- define system architecture that will enable the most optimal performance of agents
- establish correspondence between different agent types and positions of these agents within the multi-agent system

Here it is important to organize the agents so that the problem solving process can easily flow towards its completion and that the communication between different agents can be easily established. In combination with capabilities of individual agents, these two features are major factors determining efficient and effective system performance.

The agents of the proposed system are sociable. This means that they are able to interact with each other in order to cooperate, collaborate and negotiate with respect to information, knowledge and services. The agents are cooperatively working on different levels within this multi-agent system and are dependent on each other with the respect to the same goal. To reduce the complexity of the overall tasks, it is subdivided among various agents. Individual agents work only on their aspect of the problem.

We will discuss each of the four interaction cases in the rest of this section. We will use UML 2.1 diagrams to represent interactions and sequences of actions within the system. A Sequence Diagram is generally defined across the page by a series of rectangles, each of which represents a class. Each of these rectangles has a dotted line running vertically down the page. These dotted lines are known as lifelines. As you go down the page, time passes as messages flow between objects. UML 2.1 allows for a particular class to have more than one lifeline. Namely, a particular class may have many ports, each one with its own lifeline. The agent may be represented by a rectangle, and have many ports, each with its own lifeline.

We will use a Sequence Diagram where Composite Classes have more than one port and represent different roles of the same agent. This will enable us to model the multi-agent system and represent agents which play more than one role concurrently. Each port has its own lifeline. If there are two ports, this signifies two roles that are played by the agent from which the ports come. We use Composite Class as a rectangle at the head of lifelines in a Sequence Diagram, and each port to represent a role played by the Composite Class, rather than repeating rectangles for each class. In the examples shown in Figures 2-5, a number of agents play multiple roles which is represented by multiple ports. Depending on which role the agent is acting in when it sends/receives messages, the sequence diagram shows arrows to/from a particular lifeline for the agent.

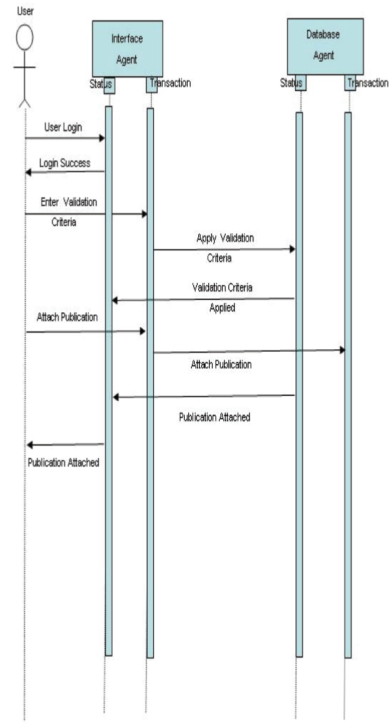
There are three points worth noting in our sequence diagram:

(1) the lifelines of agents are solid throughout since agents tend to be persistent.
(2) each rectangle represents a Composite Class which implements an agent type.
(3) each distinct role played by an agent is represented by a distinct port on the rectangle with its own lifeline.

(1) Human User Adds Data to the System

In the Figure 2, we represent a situation where a human user adds data to the system. The Interface Agent will assist the users (mental health researchers) to input their information in the most effective way. Each user who wants to add data into the database will be registered and given unique ID. This will increase control over the addition of data and prevent malicious actions. The user logs into the system and receives a message from the system letting them know that her/his login is a success. To do this the user interfaces with the Interface Agent. The next step is for the user to enter data that will address the validation criteria for the addition of a publication. This data may include publication details such as the journal, the year of publication, and abstract, table of content of the book/journal/paper where the publication appears. Once the Interface Agent has received this information it will Apply Validation Criteria by sending a message to the Database Agent. The Database Agent will send a message back to the Interface Agent confirming that the Validation Criteria have been applied. The human user will then be in a position to attach the publication, and the data will be sent through the Interface Agent to the Database Agent, which will proceed to add the data to the database. The Database Agent will also manage the database content. Once the publication is added, a Publication Added message will be passed through the Database Agent through the Interface Agent to the human user.

Figure 2. Human user adds data to the system



(2) Computer Program Adds Data to the System

Another way of adding the data to the system is using a program. This is shown in Figure 3. The program finds data automatically and adds it to the database without human intervention. A Controller Agent is stationed on the system machine and will make a request to a Spider Agent to scout for papers on the internet. The Spider Agent will be mobile and proceed to act in its role to find papers in many cases. Each time a paper is found it will generate a status message that a paper is found. Once the message has been received the paper will have to be validated before it can be added to the database. This will occur by the Spider Agent sending a message to the Database Agent to validate the paper. The Database Agent will perform the validation (for example, by getting proof that the paper has been refereed and published) and then send a message back to the Spider Agent that the paper has been validated. The Spider Agent will then send a message through the Database Agent back to the Controller Agent that the paper has been added. This sequence will be repeated for every paper added to the system by the program.

(3) Retrieve Specific Data

In Figure 4, we explain a situation where a human user retrieves simple data from the system. The Interface Agent will assist the user in formulating queries and request the information from the Database Agents. Initially, the person sends a query for data to the Interface Agent. The Interface Agent passes on this query to the Database Agent. The Database Agent interacts directly with the database to execute the query and return the publication(s) requested. The Database Agent then returns the

Figure 3. Computer program adds data to the system

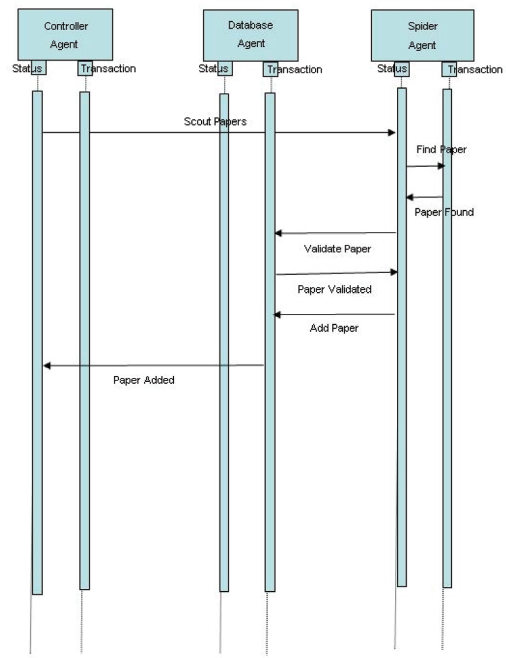
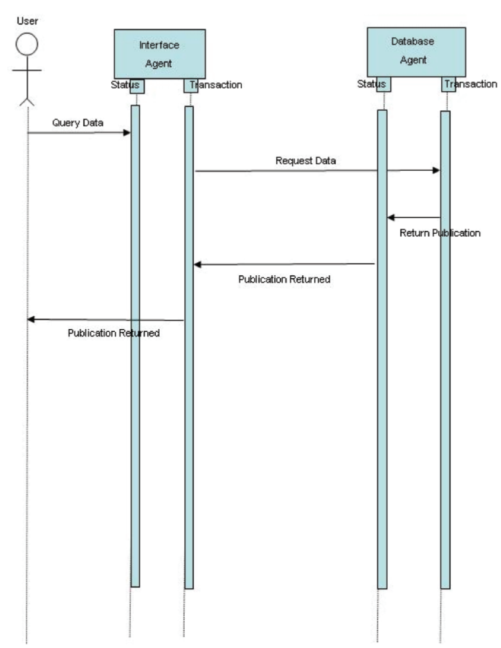


Figure 4. Retrieve specific data



publication through the Interface Agent, to the human user. The Interface Agent will present the information to the user in a meaningful way.

(4) Retrieve Data Patterns

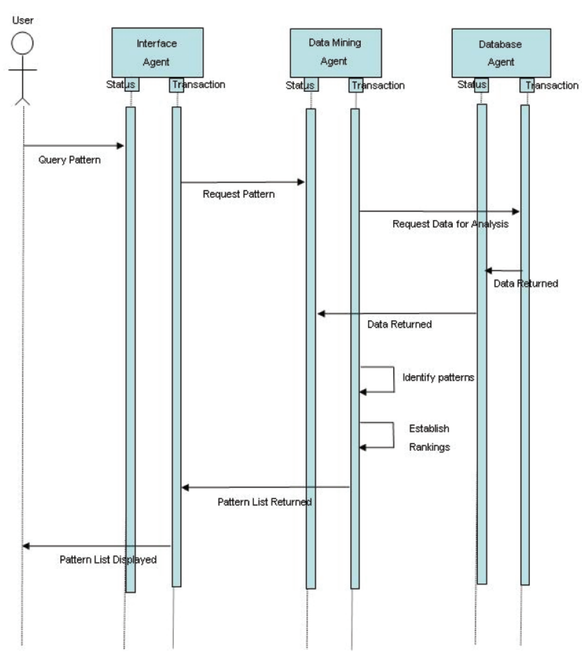
The situation where a human user makes a request for data patterns is represented in Figure 5. Initially the human user will send a pattern query to the Interface Agent, which will send the request to identify a particular pattern to the Data Mining Agent. In order to mine the data, the Data Mining Agent will send a request to the Database Agent to provide data. The Database Agent will interact directly with the database to retrieve the data being mined. A message will then be generated that data has been returned, and data itself will be sent from the Database Agent to the Data Mining Agent in order for it to be mined. The Data Mining Agent will then mine the data by identifying patterns and establishing their rankings. Data Mining Agents will systematically analyse the inputted information and expose the patterns and knowledge hidden in the data. We are specifically looking for the patterns of causal factors responsible for onset of a specific mental illness. Once the data mining is complete, the Pattern List will be returned back to the Interface Agent from the Data Mining Agent. Finally, the Pattern related information will be displayed by the Interface Agent to the human user.

Protect the System by Implementing Security Requirements

Security plays an important role in the development of multi-agent systems. The risks of jeopardizing the system security must be minimized by providing as much security as possible. The aim of this stage is to:

- identify critical security issues within the multi-agent system
- effectively address the identified issues
- implement the security requirements within the system

Figure 5. Retrieve data patterns



The five security properties defined in (Mouratidis *et al.*, 2003) should be taken into consideration:

1. authentication, proving the identity of an agent

For example, Interface agent forwards validation criteria and publications to the Database agent to be stored in the database. They much provide identification to each other before the exchange of data takes place.

2. availability, guaranteeing the accessibility and usability of information and resources to authorized agents

When a user requests a data pattern, Database agent must provide data to Data Mining agent for the data mining to take place and provide the results to the user.

3. confidentiality, information is accessible only to authorized agents

The data from the database are only accessible to the agents of our system, and inaccessible to external agents.

4. non repudiation, confirming the involvement of an agent in certain action

Spider agent must explain the source of its data.

5. integrity, information remains unmodified from source entity to destination entity

All the information that needs to be added to the database either through the user or through a computer program must not change during the process of data transportation and data exchange.

We have identified some additional characteristics which can greatly contribute to the security of the overall system:

1. compliance, acting in accordance with the given set of regulations and standards
2. service, serving one another for mutually beneficial purposes
3. dedication, complete commitment of the agents to the overall goal and purpose of the multi-agent system

The abovementioned properties are critical inside the multi-agent system as well as outside the multi-agent system, such as during the agent interaction with the environment. After the identification of required security properties, it is necessary to effectively address and implement them within the multi-agent system. As different agents have different functions within the system, some agents will be more critical than others in regard to the security of the system. As a consequence, the critical agents will be assigned more security requirements than the others.

Assemble Individual Agents

In the previous sections, we have discussed functions of agents within a system as well as equipping the agents with intelligence and enabling them to perform these functions optimally, collaborative aspect of agents and security requirements. In this step we focus on bringing these different aspects together and creating a variety of agents. For each agent, it is important to:

- identify required agent components
- assemble the components into an unified system i.e. individual agents

We can use Composite Structure Diagram to define each agent into greater detail. While each Port represents a different role played by the agent, each Part represents a distinct area of processing within the agent. The <<Agent>> stereotype must have a name, at least a Controller part which controls the efforts of the Agent to achieve a goal, and at least one port, which relates to it's playing a role.

The <<Agent>> stereotype based on the Composite Structure Diagram can be used to model each agent within our system. We have chosen to illustrate this on the Interface and Database agents, as shown in Figures 6 and 7.

In Figure 6, we present a Composite Structure Diagram from UML 2.1, which has been stereotyped to represent the Interface Agent that is at the head of a lifeline in the Sequence Diagram discussed earlier. Note that the same two ports (Status and Transaction) that were present in the sequence diagram are also present here. While the Sequence Diagram focuses on the interactions between different Agents in our example, the Composite Structure Diagram illustrates the internal processing within each Agent as well as the different roles played by Agents. In the case of the Interface Agent, there is a Controller part, which would manage state- and goal-related information, a Login part which handles User Login and the subsequent authentication that would take place, a Communication part that handles the incoming and outgoing messages from the Agent to other Agents, and a Query part which would validate and forward Queries related to data to be extracted and presented to the user. The roles performed by this Agent are shown by the 'Status' and 'Transaction' ports shown on the edge of the Agent.

What applies to the Interface Agent, applies also to the Database Agent. What differs of course is the internal processing. The Controller part is also necessary in this Agent. Additionally, a part to Verify publications to be added to the database is essential. The Database Agent also has to be able to handle requests to store data, and this is performed by a Store part. The opposite side of this is to extract data, and the Retrieve part is present for select queries. The Communicate part is present for the same reason as for the Interface Agent, to handle inter-agent communication. Finally, the roles performed by the Agent are shown by the 'Status' and 'Transaction' ports shown on the edge of the Agent.

Figure 6. Interface agent

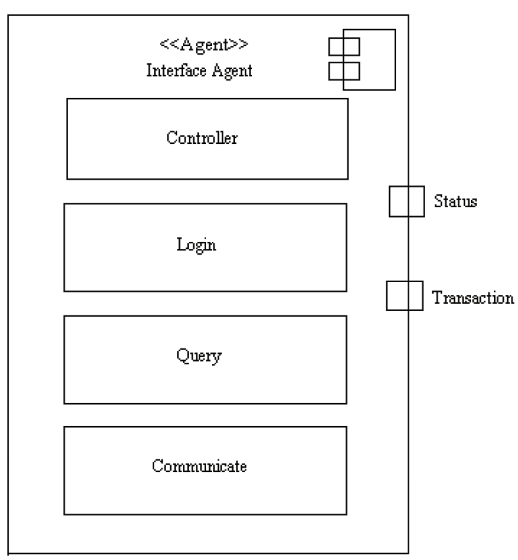
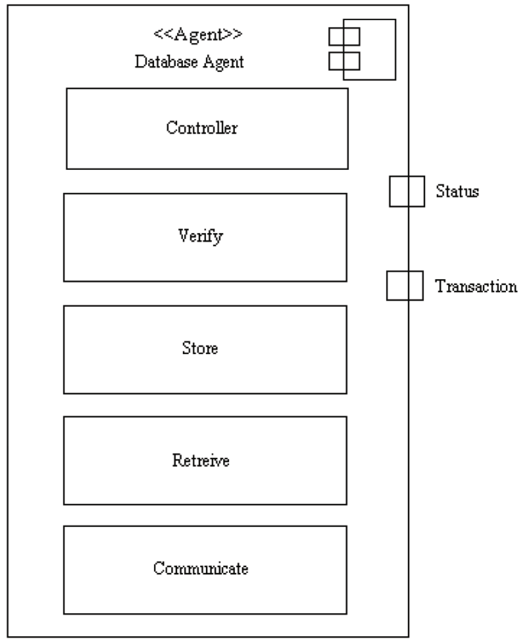


Figure 7. Database agent



CONCLUSION

In this paper we propose a multi-agent system specifically designed to support the creation of a collaborative research environment and illustrate how UML 2.1 can be used to effectively model this multi-agent system. This chapter has three unique areas of contributions. Firstly, it proposes a solution that will enable mental health researchers to effectively share and use mental health information, and help them jointly derive knowledge and better understand causes of mental illness. This will help mental health professionals to develop effective prevention and intervention strategies, and the general public to gain a better understanding and control over their mental health. Secondly, in this chapter we use the TICSA approach to gives a clear and stepwise insight into the design of multi-agent systems. And thirdly, we illustrate how UML 2.1 can be used to effectively model multi-agent systems in general, contributing to the development of standard notation for modeling multi-agent systems. We have used the UML 2.1 Sequence Diagram to capture and represent the sociable nature of agents and UML 2.1 Composite Diagram to model the individual agents in greater detail. The combination of ports which represent agent's roles, and parts which capture agent's internal processes enable effective representation of the goal-driven nature of agents. Additionally, we have not changed the semantics of the UML 2.1 diagrams which is a critical point that makes our use of UML 2.1 valid.

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