Department of Informatics
School of Economies and Commercial Law
Göteborg University

Master Thesis in Informatics, 20 p., IA7400

Intelligent Agents

- *A New Technology for Future Distributed Sensor Systems?*

Lisa Andersson and Åsa Rönnbom
Spring 1999

Abstract

This master thesis deals with intelligent agents and the possibility to use the intelligent agent technology in future distributed sensor systems. The term future distributed sensor system refers to a system based on several sensors that will be developed within a period of five to ten years. Since researchers have not agreed on a more precise definition of intelligent agents, we first examined what constitutes an intelligent agent and made a definition suited for our application domain. We used our definition as a base for investigating if and how intelligent agents can be used in future distributed sensor systems. We argue that it is not interesting to come up with a general agent definition applicable to every agent, instead one should make a foundation for a definition. When this is done we can decide on more specific features depending on the task the agent will perform and in what domain the agent will work in. Finally we conclude that it is possible to use the agent technology in sensor systems and present four different agent types applicable to future distributed sensor systems.

Supervisors:
Staffan Björk, The Viktoria Institute
Torbjörn Andreasson, Ericsson Microwave Systems AB

Sammanfattning

Den här magisteruppsatsen diskuterar den nya tekniken och konceptet intelligenta agenter och möjligheterna att använda denna teknologi i framtida distribuerade sensorsystem. Begreppet framtida distribuerade sensorsystem syftar på system som är baserade på flera olika sensorer och som kommer att utvecklas inom fem till tio år. Då forskare inte kan komma överens om vad en intelligent agent är, undersöker vi först vad som utgör en intelligent agent och gör en definition som går att applicera på vårt ämnesområde. Vi har sedan denna definition till grund för att undersöka hur intelligenta agenter kan användas i framtida distribuerade sensorsystem. Vi poängterar dock att det inte är intressant att skapa en generell definition som går att applicera på varje agent. Det är mer intressant att skapa en grundläggande definition och därefter besluta om vilka egenskaper agenten ska ha beroende på vilken omgivning agenten ska arbeta i och vilken uppgift agenten skall utföra. Slutligen konstaterar vi att det är möjligt att använda agentteknologi i sensorsystem och presenterar fyra olika agenttyper skapade för framtida distribuerade sensorsystem.

Thanks

We would like to thank several persons involved in this master thesis.

Torbjörn Andreasson, who is our instructor at Ericsson Microwave Systems AB, for great support and guidance. Without his visions and ideas this master thesis would never have been initiated.

Staffan Björk our instructor at the Viktoria Institute, for all the guidance and time he spent with this thesis. He has transformed this report from a beast to a beauty.

Lennart Steen for making it possible for us to attend the PAAM’99 conference held in London.

Malin Wallin for social skills and making us feel welcome at Ericsson.

Finally we would like to thank those who agreed to be interviewed and took time to answer our questions and all employees at FY/L and FY/D who encouraged us during this period.

Contents

1 Introduction

As software applications have become more and more complex, the need for the software industry to constantly seek new ways to create easy to use software and software that support the user grows. A proposed answer to this is intelligent agents, which are software entities that have an internal goal and acts on behalf of a user. Most people that hear the word agent think of the secret agent James Bond, who performs missions all over the world in unknown territories with the help of extraordinary social skills. All these ideas can be found in how intelligent agents are defined.

The aim with this thesis is to examine if the new technology of intelligent agents can be used in future distributed sensor system, such as radar systems. This work has been done in co-operation with Ericsson Microwave Systems AB in Mölndal.

1.1 Background

Intelligent agents have become one of the most popular buzzwords in the software application business and applying the technology is the focus of intense interest [14]. This is the case since researchers believe that the agent technology is the solution to the problem with complex applications [9]. An intelligent agent, in its simplest explanation, is a software program with the purpose to offer assistance to its user [9, 29]. This is a very general explanation and not of practical use. Many researchers have tried to make a definition of what an intelligent agent is, but today there is no general consensus of how to define intelligent agents in a more formal way.

The research into intelligent agents exploded with the breakthrough of the Internet, and still most of the existing research is done with Internet at focus. Other areas where researchers have tried to include or are trying to include intelligent agents are many. Examples of these areas are telecommunications network management, air traffic control, business process re-engineering, data mining, information retrieval/management, electronic commerce [27, 28] and power management [1]. The software business is beginning to discover the possible benefits of the intelligent agent technology and Ericsson Microwave systems AB is not an exception.

Ericsson Microwave Systems AB is divided into two parts. One part is developing mobile nets and the other defence products like radar. During this master thesis we have co-operated with the department that produces radar systems. As a knowledge intensive company, they are interested in new technologies and would like to examine how intelligent agents can be used in their *future distributed systems*, i.e. systems that will be up and running in about 5 to 10 years time. It is important to investigate in this time perspective so that they can have an advantage over their competitors. In particular, they wish to explore how the agent technology can be applied to future sensor systems. One example of such a future sensor system can be found in the project called *Baltic Watch* which objectives are to increase the security and surveillance on the Baltic Sea. The project aims to produce a future civil-security system in order to discover unusual activities for example oil spill from cargo ships on the Baltic Sea. To find out if the new agent technology is something that they can use and should invest in, they have initiated this thesis.

1.2 Purpose

The purpose of this master thesis is to examine the relevance of using intelligent agents in *future distributed sensor systems.* As there today exists no common definition of what an intelligent agent is, every researcher and developer in the field have to create their own definition on what constitutes an intelligent agent. Before investigating how intelligent agents can be used in future distributed sensor systems, it is significant to understand what an intelligent agent is.

Therefore it is important to examine different researcher opinions on intelligent agents, to define a theory of our own, so that we can have this theory as a base for our further research. Thus our first question is:

1. What is an intelligent agent?

Since the research area of intelligent agents is young and still undefined. We expect that intelligent agents in a near future will be applied to a number of different settings. Therefore it is interesting to investigate in what ways intelligent agents can be used in practical settings, in our case future distributed sensor systems, and what advantages and disadvantages they have. On the basis of this discussion we formulate our next question:

2. How can the intelligent agent technology be used in future distributed sensor systems?

In conclusion with the experience drawn from answering the first question, we will examine if and how intelligent agents can be used in future distributed sensor systems. We will do this having the Baltic Watch project as an example of a future distributed sensor system that can include intelligent agents. We will also try to answer the question with the background of studies that have been done in other areas within the research of intelligent agents in practical applications.

1.3 Restrictions

This master thesis deals with intelligent agent and future distributed sensor systems. It does not deal with other areas that include intelligent agents, like entertainment or net commerce. We do not intend to investigate the technologies for building intelligent agents, rather concentrate on how intelligent agents can be used in the future, in specific regarding how they can be used in future distributed sensor systems. There are practical agent systems outside the Internet on the market today. We are going to look at these systems to see how agents can be used but we are not going to evaluate these systems.

1.4 Target group

This thesis is written for those who are familiar with computers and the software business and who are interested in the complexity of today's software products and distributed sensor systems. First and foremost our target group is employees within Ericsson who are involved in developing distributed sensor systems and secondly researchers in the area of intelligent agents. It is not written for those who do not have any experience in computers or in designing software applications. Furthermore the thesis is easier to understand if the reader is familiar with the object-oriented paradigm.

1.5 Disposition

The structure of this master thesis is as follows:

In chapter 2, **Method**, we will describe what views this work is based on and which research method we used to gather information about the problem area.

In chapter 3, **Intelligent Agents**, we will present six different researchers definitions on intelligent agent and look closer at some agent characteristics. We will account for the result of gathered information, by combining literature studies, interviews, and information from a conference, to create our own agent definition.

In chapter 4, **Agents and Sensors**, we give examples of practical agent applications and describe what a sensor system is. We will then discuss the possibilities of using intelligent agents in future distributed sensor systems. We will do this by combining interviews, literature studies and information gathered on a conference, and have our former defined agent theory as background.

In chapter 5, **General Discussion**, we present our thoughts on agents in sensor systems. We will draw conclusions and give a proposal to further research.

Appendix 1 gives a deeper explanation of the Baltic Watch Project.

Appendix 2 contains a list over interviews and questions asked during the interviews.

Appendix 3 contains information about the PAAM'99 conference.

2 Method

A method is a plan that you follow to perform a certain task. In research it is common to follow a research method; it allows the researcher to structure his work and others to redo the investigation. Different methodologies and views can be applied in the research method depending on the problem at hand and the researcher's standpoint. The purpose of using a method is to guarantee that the researcher is scientifically valid, i.e. that the work is done in a planned fashion and documented. It also helps the reader understand the researcher's starting point and the steps he/she has taken during the work [9]. The method is a process that the researcher uses to know how to approach and analyse a problem, utilising experience from other researchers. The most suitable method to use always depends on the nature of the problem and the theoretical conditions at hand.

2.1 Positivism versus Hermeneutics

Today there are two major scientific theories; the positivistic school and the hermeneutic school. The positivistic theory emerged from the natural science and the hermeneutic theory is based on the social science as a reaction to the positivistic school. The positivistic theory emphasises that reality can be observed objectively while the hermeneutic theory says that the reality is subjective [33].

The core idea in the positivistic theories is that there exists only one true reality, which the researcher can gain knowledge about by observations. The theory assumes that the researcher has the ability to study the problem with a clear distinction between himself and the object under examination, to get as objective results as possible. Further the positivistic theory strives to control all known uncertainty factors to be able to collect as objective and reliable research results as possible [38]. The purpose is to predict or control the reality. The positivist use deduction to reach their goals i.e. they try out existing theories or assumptions in their research [33].

The idea of hermeneutics is to interpret the environment and try to understand a certain phenomenon. Interpretation and understanding is a very central matter as the hermeneutics think that the human individual is the focus of interest. The purpose with the interpretation is to increase knowledge and understanding about a specific situation [38]. The hermeneutics emphasise that the human individual creates its own reality, i.e. each individual perceives the external reality differently. To understand this reality the researcher must take part in the person's thoughts and understand how the person perceives its surroundings. The hermeneutic theory is a subjective research and therefore acknowledges that the researcher in some extent effects the result. The hermeneutic theory emphasises the importance of understanding the whole, which at the same time means that all parts should be studied [33].

These definitions are described in their most extreme appearance and normally they are brought closer together. You can even find research where they use parts from both the positivistic and the hermeneutic theories [38].

When comparing the two schools, we found that the thoughts of the hermeneutic school were most suitable to our research. The objective with this thesis is to examine the agent technology in a specific environment i.e. distributed sensor systems. This has not previously been done, which makes it difficult to compare a sensor system that includes agents to one that does not use the agent technology. Since we do not have the time to develop such a system it is not possible to use positivistic methods. We wish to understand what an intelligent agent is and how intelligent agents can be used in future distributed sensor systems. This approach is typical for the hermeneutic who strives to understand and increase knowledge about a phenomenon rather than trying to find one absolute truth. Since we have pre-knowledge about information technology, it is not possible for us to be absolutely objective. Our previous knowledge will somewhat effect the results, this also makes our investigation more hermeneutic then positivistic.

2.2 Qualitative and Quantitative methodology

Qualitative and quantitative methods are two different ways of approaching the gathering of information. Qualitative methods are used when you want to investigate something on a more profound level than on the broader perspective [33]. For example if you investigate how many drivers that behave strange when driving, you concentrate on statistics and perform a quantitative research. If we instead perform a qualitative research it would be more interesting to investigate what caused the driver to behave strange.

The most important difference between these two methods is the way numbers and statistics are collected and what kind of data that is of interest. The quantitative method uses statistics and numbers to analyse collected data, for example to describe how common a situation is, to compare different phenomenon or to express statistical relations between characteristics. Quantitative methods are most suitable when you do comparable research for example if you investigate the difference in men and women’s grades. This research is countable and therefore it is quantitative [33].

In qualitative methods you concentrate more on texts and more on non-measurable data. Observations, interviews and analysis of documents are some of the techniques used to collect this data. Qualitative methods are suitable when the researcher is uncertain about which characteristics that are going to be measured or when the problem is impossible to quantify [33].

We have chosen a qualitative method because our area is almost impossible to quantify in order to achieve our objectives. It is not interesting to quantify data, in means of examine what others have concluded, in a statistical way. We do not think this way of approaching the problem would have given much of interest, since we want to create an agent definition of our own. A difficulty with the qualitative method is to make the research objective. We are well aware of this fact and therefore we will make a clear distinction of what we think and what others have concluded. We will also try to discuss both positive and negative aspects of the agent technology. Another way of minimising subjectivity when performing research is to be critical against the sources used.

2.3 Source criticism

When performing research every researcher has to be critical of the data collected and the sources from where the data comes. To be able to determine the credibility of a source one should try to find internal independent documents on the same subject and then compare them. This applies to documents as well as interviews and other kind of sources. In some extent you can also determine the credibility of a source by the way it is written; if it seems objective or disputable [33].

The estimation of the value of a source depends on the subject and purpose with the research. In an investigation you should be more critical to secondary sources than primary sources. A primary source is written by someone who has first hand information, i.e. the writer has been part of the situation or has observed the situation by himself. Secondary sources are based on what others have seen heard or concluded [33]. This does not mean that one should not be critical to primary sources. The credibility depends on the situation at hand as well as the person's role in the situation. An independent observer might be more trustworthy than an active participant.

2.4 Research and Informatics

Informatics is a relatively new interdisciplinary science with a rich variety of different approaches. Because of this there is no given method on how to perform research with an informatic approach. Dahlbom says that perhaps it is not interesting exactly how you perform your research but that you do it with the use of information technology in mind [11]. Informatics is not like the natural sciences with their explicit interest in nature or the social sciences that do not dare coming close to technology. As Dahlbom puts it "…*informatics is not afraid of getting its hands dirty with script and protocols, since they are integral elements in the complex combine of information technology use.*" [11, pp. 9]

With the above alignment we will also position our work according to Vidgen's and Braa's triangle [38] which has been created to enable the positioning of research about information systems. The triangle's corner represents three different goals with the research: change, prediction and understanding. *Change* means that researcher examines a phenomenon in order to change something in a situation. The researcher achieves this by learning first handed how information systems are developed in a certain organisation. *Understanding* means that the researcher is interested in understanding the phenomenon he examines and getting an insight in the information systems (IS) of an organisation. This is often done by case studies. *Prediction* means that the researcher predicts something and then tries to show that the prediction is true. The *purified research disciplines* (see figure 1) clearly apply only one of the three corners in the triangle and a *hybrid research* combines at least two of the above-described disciplines.

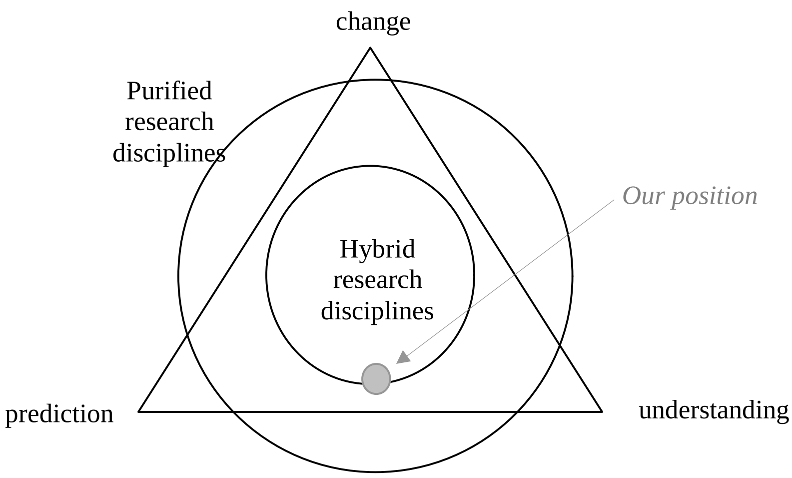

Figure 1, Vidgen and Braa's triangle of research disciplines

Looking at Vidgen and Braa´s triangle [38] (see figure 1), we place the goal with our research somewhere between prediction and understanding. This since we are trying to understand what an intelligent agent is and predict the use of agent technology in future distributed sensor systems. This means that we are situated between the two extremes among the hybrid research disciplines.

2.5 Used method

Founding our research in the hermeneutic and qualitative schools of research, we divide our master thesis into two major sections. The first part investigates what an intelligent agent is and the second part focuses on how intelligent agents can be used in future distributed sensor systems. The first part forms the theoretical base needed for the second part. The research will be a hybrid discipline between understanding and prediction as shown in the triangle illustrated above.

To reach the goals with this work we have used a *triangulation approach* [33]. Triangulation means that different approaches are applied to the same problem, for example by a combination of different sources or different methods. The approach is not placed in the hermeneutic school or the positivistic school, as it depends on what fields the researcher chooses to combine [12]. There are even examples of researchers that have combined methods from both schools (triangulation of theories), but this is something that is not recommended [33]. There are several categories of triangulation, we choose to use a *methodological triangulation* that combines different methods for data collection [12]. We choose to combine *literature studies* with information gathered from *conferences* and *interviews*. Literature studies are important for forming an understanding about intelligent agents and interviews are necessary for understanding sensor systems and to get an opportunity to ask researchers about their opinions on intelligent agents. By attending a conference we would get the absolute latest ideas of using intelligent agents and since the area is evolving all the time we felt this was necessary for our objectives.

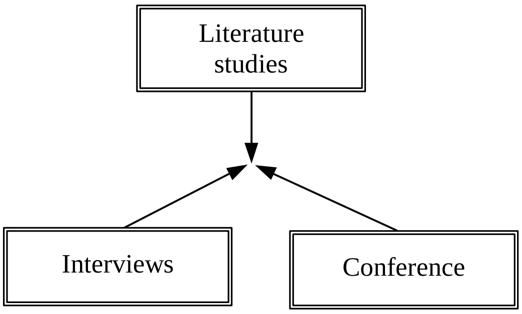

Figure 2, Our Triangulation

By combining different sources of information we can achieve a better understanding of the problem and reach more reliable conclusions [34]. A difficulty with the triangulation approach is that it generates vast quantities of information, which can make it difficult to study the overlying question [33]. We encountered this problem, with information and articles about the definition of intelligent agents.

We used the triangulation approach for both our research questions i.e. the approach is used for part 1, Intelligent agents as well as part 2, Agents and Sensors.

2.5.1 Part 1: Intelligent agents

To get an overview of what constitutes the area of intelligent agents we began our research with literature studies of intelligent agents. With the gained knowledge we continued with a deeper literature study to answer the question: *What is an intelligent agent?* To find interesting literature we used the Internet, a mailing list[1] (an electronic discussion group) and became members of the Association for Computing Machinery[2] (an educational and scientific society for Information Technology).

[1] For further information see http://www.cs.umbc.edu/agents (05/09/1999).
[2] For further information see http://www.acm.org (04/26/1999).

To complement the literature studies we decided to interview researchers who work with intelligent agents, to get first hand information and practical knowledge. The main purpose with the interviews was to complement our literature studies and to fill in when the articles could not present the latest news in the area and to get different angels for example negative aspects that usually not appear in articles.

We also thought that visiting a conference would give us basic knowledge in the area of intelligent agents and a deeper knowledge that is important when discussing a subject on a more profound level.

The goal with this part of our investigation was to answer our first question in order to build a theory that we could base our second research question on. Our theory is a definition of intelligent agents.

2.5.2 Part 2: Agents and Sensors

With part 1, Intelligent agents, as a theoretical base we continued by doing literature studies on existing practical agent and sensor systems to draw conclusions about *how can intelligent agents be used in future distributed sensor systems.* In the initial stages of this thesis, we considered building a prototype to apply our theory to a practical application. However that was not possible due to time constraints. Another limitation with building a prototype is that a simulation of a sensor would not have been realistic. We do not have the necessary technical details and it would not have given realistic results applicable to real sensor systems. Another point is that with a prototype we would have been limited to focus on only one aspect of intelligent agents in co-operation with sensors. Therefore we decided that we would get the best results by interviewing researchers in the field of intelligent agents and sensor systems to confirm or decline our thoughts.

We decided to do interviews with developers who have worked with the construction of sensor systems in order to understand what a sensor system is and to be able to investigate if it is possible to use agents in sensor systems. We also wanted to see if there were any existing problems or difficulties with sensor systems that the agent technology could do something about. We started the interviews with a presentation of our theory of an intelligent agent so that the interviewees would understand what an intelligent agent is and be able to relate the agent technology to sensor systems.

To find out how far the researchers have come in developing practical applications and to see what they think will happen in the future with intelligent agents, we attended a conference on practical intelligent agent applications and interviewed researchers who work with agents in practical applications. We also wanted to validate our ideas of how agents in sensor systems could be implemented in the near future.

2.5.3 Literature studies

We started out this work by doing literature studies on intelligent agents. There is a huge amount of information on this topic, especially on the Internet. This made it difficult to select appropriate articles and knowing when to stop searching for more information. It was difficult to know when we had good enough material to bee sure the research would bee thoroughly done. We encountered the opposite problem with sensors and sensor systems. Most literature on sensor systems is secret documents therefore we had to rely on open information and on information we got from talking with sensor system developers. To gather information for the literature study we used the Internet, the Association for Computing Machinery and a mailing list.

2.5.3.1 The Internet

The Internet has become a popular source of information but one should question its credibility before using the information. To judge its reliability it is important to know the origin of the information. The problem with information on the Internet is the varying quality and the fact that there is a problem with determining responsibility for the published material. This problem makes it even more important to be critical in judging the information found on the Internet. Another problem is that links and web-sites are dynamic, i.e. they are often removed or altered. This could make it impossible to find the same texts again.

Because of these problems we have tried to use articles that are published on the Internet as well as in research or scientific journals. We chose articles from acknowledge research facilities and articles by authors who are well respected in the intelligent agent community. Mostly we only used the Internet as a medium to get easy and quick access to journals and articles but on some occasions we used information on the Internet, like information about real agents that runs on the Internet.

2.5.3.2 The Association for Computing Machinery

The Association for Computing Machinery (ACM)[3] maintains one of the largest databases with published articles on Information Technology. The access to this database is limited to members of the organisation. Since this database was recommended to us we became members. We found that the ACM was easy to use and the database provided us with the majority of the articles on intelligent agents.

2.5.3.3 Mailing list

A mailing list is a forum for exchanging information on a specific subject via the Internet. The participants communicate by sending electronic mails to a server that delivers the message to all participants on the list. We were members of the software

[3] For further information see http://www.acm.org (04/26/1999).

agents mailing list[4]. This mailing list was the only one we could find with intelligent agents as a topic. We used the mailing list to gain further information about the subject and to clarify things that we did not understand in the existing literature. When we first started to use this mailing list, we did not have high expectations about it being a serious forum. However, we discovered that even well known researchers use this list for exchanging information. The e-mails have provided us with pointers to find recent articles and the possibility to ask specific questions to experts in the field. The only disadvantage we had when using the mailing list is handling all the unrelated e-mails received.

2.5.4 Conference

The agent community grows rapidly and articles that are only a few years old can therefore be out of date. We attended a conference on intelligent agents to get the latest ideas in the area. There are quite a lot of agent conferences all over the world, we chose to attend the conference *"Practical Application of intelligent Agents and Multi-agent systems (PAAM'99)"* [5]. PAAM'99 is a conference with the objective to present how the agent technology is overcoming today's business problems, what developments we expect to see in the future, what the tangible benefits are of investing in agents and what new opportunities those agents provide. The conference suited our goals perfectly since these subjects were in line with our interests. The conference was situated in London and held in April, which for us was an appropriate time. On the conference we attended all the different tracks and tried to cover as much of the lectures as possible. For more information about the conference lectures see Appendix 3.

The conference, which lasted for three days, was very giving and fulfilled all of our expectations. It was very interesting to see how far research has come in this area and to get new ideas. However it was difficult to understand some speakers due to language problems.

2.5.5 Interviews

Interviews for scientific research can be divided into two different styles: structured or unstructured. Structured interviews are performed by using predefined questions. Unstructured interviews are less formal, having only guidelines to keep track of what questions the interviewer needs to ask. This allows the interviewer to freely follow interesting topics that arises during the interview. A problem with unstructured interviews is that it can be harder to analyse the data [32].

[4] agents-owner@cs.umbc.edu, for further information see http://www.cs.umbc.edu/agents (05/09/1999).
[5] For further information see http://www.practical-applications.co.uk/PAAM99 (05/10/1999).

We chose to do unstructured interviews because we wanted personal experience from different researchers on intelligent agents and how to create applications based on the agent technology. We also wanted information on how sensors work and how sensor systems are organised. Since we did not have much knowledge on sensor systems we thought unstructured interviews would be more suitable than structured interviews where all questions have to be created before the interview, this way we had the opportunity to ask new questions as the interview proceeded.

To decide whom we should interview, we chose to use a method called *"Subjective selection"* [5]. The idea behind this is that the researcher himself/herself can choose the people to interview on a reasonable basis. The chosen interviewees must of course represent the population.

2.5.5.1 Interviews on intelligent agents

When we chose which researcher to interview on intelligent agent we looked at the following criteria:

- The researcher should have some practical experience in constructing intelligent agents.
- The researcher should have been in contact with intelligent agents for a longer period.
- The researcher should have contact with booth the research community and the industrial world.

The first two persons we interviewed were from the Viktoria Institute, located in our immediate proximity. The first interviewee has developed an application based on intelligent agents, which makes it possible to create collective networks that will preserve and use the knowledge in an organisation. He also has close contact with an industry. We will call this interview person interviewee A. The other researcher we interviewed has developed information agents and analysing agents in connection with the Internet. We will call him interviewee B.

Most researchers in the area of intelligent agents are international. Therefore we thought it would be a good idea to use the visit at the PAAM'99 conference to get in contact with international researchers that we could talk to. We had arranged two meetings prior to the conference. The first appointment was with a researcher from Linköping who has created a framework for developing agents and also constructed some simpler agents with help of this framework. Unfortunately the researcher got ill and could not participate in the conference or meet with us. The second interview during PAAM'99 was with an Australian researcher, who has been developing agent systems for the last thirteen years. He has done this in co-operation with several different business companies. We went to his tutorial on the first day of the conference, during which he answered all of our questions that we were going to ask him during the interview. We spoke to him and he promised to answer any questions we might have later on. We tried to get an interview with one of the other famous researchers that participated in the conference but without any luck. On the poster session on Tuesday evening we found a very interesting poster about sensors in military domains. We had an informal conversation with the writer of the poster and he promised to send us some more material on the system. We will call him interviewee C.

The questions asked were very much influenced by our own experience on intelligent agents as well as the researchers' interest in the field. We asked specific questions to each researcher to get as much information about the different researchers' work. We were interested in the researchers' experience when developing intelligent agents and what can be done with intelligent agents rather then general information. For more information about the interviews see Appendix 2.

2.5.5.2 Interviews on sensor systems

When deciding which persons to interview regarding sensors and sensor systems we looked at the following:

- The person must have developed sensors or sensor systems or have practical knowledge about sensors.
- The person should have been working with sensor system during a longer period.
- The person should have some knowledge about the thoughts of the future regarding sensor systems.

We interviewed three persons. The first was an expert on sensors and provided us with basic knowledge about sensors: we will call him interviewee D. The other two persons were developers of sensor systems, we will call them interviewee E and F. We did these interviews to get more information about sensor systems. This information was not available to us in published or other written material due to security and classification reasons. We thought it was crucial for our work to have a conceptual understanding of how the technology used in sensors work and how sensor systems are organised. We also wanted to understand what kind of problems that exists and limits the use of these systems today. Another reason for these interviews was to see if our suggestions about intelligent agents in sensor systems would be possible to accomplish. The people we contacted were very co-operative and gave us the basics for how sensor systems work. The information was general because details on sensors and sensor systems are not public material; therefore the chapter on sensors systems is not so detailed. For more information on the interviews see Appendix 2.

3 Intelligent Agents

Since the field of intelligent agents is such a young research area we will try to give a clear definition of what really constitutes an intelligent agent. Unfortunately, there is not yet a consensus on the definition of an agent. Therefore we will present some of the definitions used by researchers in the field. We will do this by presenting the result from the literature studies, the interviews and the conference together in the following sections. We have chosen to present the results this way since it makes more sense than separating them into different categories and to avoid repeating the information. After this we will describe some of the most important characteristics an agent can have and make our own definition of an intelligent agent.

3.1 History

Intelligent agents originally come from Artificial Intelligence (AI) and Distributed Programming. The two areas where joined together and became Distributed Artificial Intelligence (DAI) and from this field the idea of intelligent agents emerged [35]. The idea of an intelligent entity called an agent first appeared in the mid-1950 but nothing really happened until the late seventies. The area as we know it appeared in the early stages of the nineties, at the same time as the breakthrough of the Internet [9]. The similarities between object-orientation and the agent technology are striking. This is not strange since they both have emerged from the fields of distributed programming and artificial intelligence [35]. They both try to solve problems with complex situations, but the agent-orientation takes the object-orientation one bit further by giving an agent a goal with its existence. When talking about intelligent agents the researchers do not refer to human intelligence rather artificial intelligence suitable for artefacts such as computers [30].

Intelligent agents are software programs with different kinds of characteristics, they exist so that they can help their user. They do this by being independent, autonomous and by being aware of the goal with their existence. For example, if you are interested in new articles on sport events, a software agent can be used to continuously search the Internet for you without the need of your supervision [41]. The next time you log on your computer the agent presents the new material it has found to you. The idea is that the user saves a lot of time by delegating tasks and to be provided with the information sought for when convenient. The described agent is a so-called Information agent which is the most common agent that exists today [31], but there are also many other different kinds of agents. The main research in the field of intelligent agents is done with focus on the Internet. Other domains outside the Internet has now come into focus but unfortunately has not many applications with agents in these areas reached the market yet [27].

One way of describing agents is to look at the technology as a natural step into a new software paradigm where the agent technology builds on previous technologies (see table 1).

	Monolithic Program	**Structured programming**	**Object-Oriented Programming**	**Agent-Oriented programming**
How does a unit behave? (Code)	External	Local	Local	Local
What does a unit do when it runs? (State)	External	External	Local	Local
When does a unit run?	External	External (called)	External (message)	Local (rules; goals)

Table 1, Increasing Software Localization according to Van Dyke Parunak [40]

The table describes the development from a monolithic program, where the smallest unit is the complete program, to the object-oriented programming where the smallest unit is an object with local behaviour and execution. The next step in the development is agent programming with increasing localisation and encapsulation. Each object in the agent technology encapsulates its own code, data and invocation, as well as locating its own thread of control and its own goals [40]. Bradshaw has quite a striking definition of an agent that shows this way of viewing the agent technology:

"Agent-oriented programming can be thought of as a specialisation of object-oriented programming approach, with constraints on what kinds of state-defining parameters, message types, and methods are appropriate. From this perspective, an agent is essentially ***'an object with an attitude'****."* [9, pp. 28]

The notion on agents being a programming approach is not something that is a reality today. There are even discussions around the new technology of agents surviving or not. Some researchers agree that the agent technology definitely will be the next big programming paradigm but only if problems with the technology that exist today are solved[6], others are more cautious. Another approach defines three different possible outcomes of the agent community. The first one visions that the interest for agents will increase and become a natural part of every software that is produced. The second scenario for agents implies that the interest will stagnate and that agents will become a programming paradigm as the object-orientation is. The last scenario described that the agent technology will become a niche that is used by a very small group of researcher[7]. Many researchers point out that it is important for the survival of agents that it becomes easier to develop applications based on the agent technology. This is only achieved by the creation of products and standards [36].

[6] Van Dyke Parunak, H., Introduction speech to Panel Discussion, PAAM'99 (04/21/1999).
[7] Rao, A. S., Introduction speech to Panel Discussion, PAAM'99 (04/21/1999).

3.2 Different agent definitions

In the area of intelligent agents the professional researchers can not agree on a common definition of an intelligent agent. What agents are capable of doing and that agents have a specific goal is general agreed upon, but it has proven more difficult to find a commonly accepted definition that is more specific [35].

"Some have tried to offer the general definition of agents as someone or something that act's one one's behalf, but that seems to cover all of computers and software. Other than such generalities, there has been no consensus on the essential nature of agents." [30, pp. 1]

One possible explanation to this lack of consensus, is that those who have built their own agents, often constructs a definition of agents based on what their own agent can accomplish [30]. Because of the disagreement on an agent definition, we have chosen to present six different opinions on what an intelligent agent is. These researchers are experienced in the field of intelligent agents and their definitions illustrate the most common differences in defining intelligent agents.

3.2.1 The Nwana agent

Nwana acknowledge the fact that it is difficult to precisely define what agents are [29]. According to him, one might loosely define an agent as a component of software that is capable of acting in order to accomplish tasks on behalf of its user. He says that the word agent is difficult to use since there are lots of other businesses who use the word like travel agents or real-estate agents, still he would like to describe the term agent as an umbrella term which covers a range of other more specific agent types.

To describe these specific agent types, Nawana classifies agents according to the attributes they exhibit. The British Telecommunication Laboratories[8], where Nwana works, have identified a minimum requirement of three attributes; autonomy, learning and co-operation. An agent should at least have two of these attributes to be an intelligent agent (see figure 3). An agent is *autonomous* if it can operate on its own without the need of human guidance. It has its own individual goal and state and it acts to meet the goal of its user. The ability to take initiative on its own is an important feature. By *co-operation* with other agents, more complex tasks can be executed. This is according to Nwana were agents really come into their right element. For agents to be intelligent or smart they must have the ability to *learn*. The learning process develops during interaction and/or reaction to their external environment. He does not mention why it is important that the agents are smart, just that the goal is to create smart agents.

[8] For further information see http://www.labs.bt.com (03/01/1999).

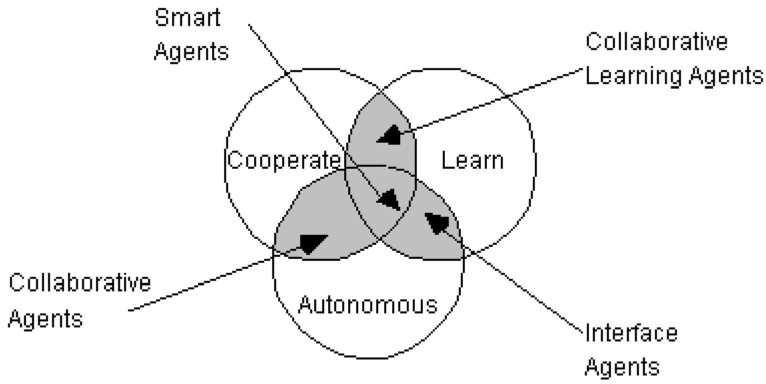

Figure 3 – An agent topology according to Nwana

With these three minimum attributes (learning, co-operation and autonomy), four different types of agents can be identified: *Collaborative agents*, *collaborative learning agents*, *interface agents* and *smart agents* (see figure 3). Nothing outside the intersecting areas (see figure 3) is considered to be agents. Preferably an agent should have all three attributes (i.e. smart agents) but this is seen as more of a vision rather than perceived reality.

Nwana mentions two other dimensions to classify agents besides the typology mentioned above. The first one considers whether an agent is *mobile* or *static*. A mobile agent has the ability to move over a network and be executed on a different server than where it vas created. Static agents do not have this ability.

The other dimension classify agents according to the role they have, as in the case of the sport agent, which had the purpose of gathering information and thus is an information agent. Still this agent must have two of the features autonomy, learning, and co-operative, it may also be mobile or static.

Even though Nwana shows that there are different ways of classifying agents, he only calls a software component an agent if it occurs within the intersecting area of the topology in figure 3. So even if we classify an agent from its ability of being mobile, it still has to have two or more of the attributes autonomy, learning or co-operation.

Comments

Nwana emphasises autonomy, learning, and co-operation as characteristics that are very important in an intelligent agent. The definition of autonomy is good and thorough, but Nwana does not mention intelligence and the term intelligent agents are not used at all, the closest concept is smart agents. We believe that he avoids the word intelligence so that he does not have to define it and be caught up in a discussion about it. Intelligence is a charged word but we do not think that he solves that problem by just ignoring it.

3.2.2 The Foner agent

According to Foner an agent must have certain characteristics which must be fulfilled in some way or another for an agent to be called an intelligent agent [14]. The characteristics mentioned are autonomy, personalizability, discourse, risk and trust, domain, graceful degradation, co-operation, anthropomorphism and expectations.

Autonomy means that an agent should be relatively independent from its user, take initiative and act spontaneously. These actions should lead to benefits for the user of the agent.

The agent exists to make certain tasks easier for the user. This can be done if the agent has the ability to learn and memorise different tasks that the user performs. This way the agent executes tasks that are normally performed by the user. This feature is called *personalizability*.

It is important that the user knows that the agent is able to perform the tasks it is set to do. This is achieved by a two-way communication, a *discourse*, between the agent and the user, with the goal to establish the intentions and ability of both the user and the agent.

The delegation of a task to some other entity, here an agent, demands that the user *trusts* the agent to carry out the task properly. However there is a certain *risk* with delegating tasks, if the task is not performed like expected, it might be costly to the user. This implies that the user has to balance the trust in the agent with the risk of the agent doing something wrong.

A user who employs an agent must also respect that agents work within a specific *domain*. The nature of the domain decides the agent's behaviour and characteristics, it is not useful to create general agents, applicable to any domain. It is closely related to the concept of risk and trust. If the agent acts within a computer game, the consequences might not be to severe if the agent does something wrong, but maybe the user would think both once and twice before he installs an agent in a nuclear reactor.

Graceful degradation implies that, if a communication mismatch or domain mismatch occurs, it is better that an agent fulfils parts of the task than nothing at all. This has to do with risk, trust and domain, if the agent acts it gives the user more reliability in the agent, then if it does not act at all.

The user and the agent must also *co-operate* to come to a conclusion of how to reach a specific goal. This is done in a two-way communication where the agent specifies what it can do, and the user expresses what he wants the agent to do. In this two-way communication both sides can ask questions to make sure that they understand each other.

Anthropomorphism deals with how humanlike agents are. Foner does not think an agent has to be anthropomorphic but he thinks this is a feature that always will be discussed when it comes to agents. Some agents may have anthropomorphic characteristic but yet others can be agents without having any of it.

The last feature is *expectation.* Foner explains that the interaction between user and agents is much more successful if the agent performs the way its user expects it to [14]. That is, it is important that the user's expectations on the agent match the reality.

Example of an agent according to Foner is Julia, which runs on a MUD[9]. Julia participates in the MUD as any other user but has knowledge about the MUD. If you can access Julia and get this knowledge you have an advantage over the other players. The knowledge Julia has is about the different rooms in the MUD and also knowledge about different players. Julia fulfils all Foner's criteria for an agent and takes independent actions when "walking" around. Julia remembers things about the users of the MUD and has the same domain knowledge they have. Foner also states that he does not think most of the so-called "agents" that are being used on the Internet today are agents. Just because these "agents" are anthropomorphized does not make them agents according to Foner's way of viewing agents [14].

Comments
Foner talks about the trust between the agent and the user and that the user has to believe in the agent's capability to perform tasks. He says that an agent should be autonomous otherwise it is not an agent, it should also be able to communicate and co-operate with its user. His definition of autonomy is clear and straightforward, and he also mentions that you have to respect the domain for which the agent is intended. A good point that Foner has is that a program is not an agent just because it has lifelike features.

3.2.3 The Petrie agent

A general description of an agent as someone or something that acts on ones behalf, is according to Petrie not a sufficient definition, since this description can be applied to all computers and software [30].

One problem Petrie points out is the meaning of agents being *intelligent.* The word intelligence in context of agents is a problematic issue due to three different reasons. First intelligence is not an attribute that necessarily would distinguish intelligent agents from other technologies. There are other software that also has intelligence as an attribute, like software based on Artificial Intelligence technologies. Secondly creating agents with the goal to make them intelligent is a poor target, instead agents should be created according to the task they are set to accomplish. And the third

[9] MUD – Multi User Dimension. A text-based role-playing game played over the Internet. For further information see www.arcanum.org/tfaq.htm (02/10/1999)

problem Petrie points out is that intelligence is defined differently, that different people assign different meanings to intelligence.

Petrie states that instead of talking about intelligence, we should use autonomy as a way of separating agents from other software. This is one of the reasons that he finds the definition of Franklin and Graesser appealing. Petrie does not make a definition of agents himself, so he refers to the definition of Franklin and Graesser:

"An autonomous agent is a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to effect what it senses in the future." [30, pp. 1]

They say that this is an extensive definition and that agents should be divided in to categories under this definition [15]. As examples, they mention the following ones: reactive, autonomous, goal-oriented, temporally continuous, communicative, learning, mobile, flexible and character. These classifications are based on properties that agents may have, agents may also be classified by tasks they perform. Petrie adds one thing to this definition, that autonomy is a crucial characteristic, and autonomy implies taking initiatives.

Finally Petrie does not agree with Foner about the agent Julia. He makes clear in his article that he does not consider Julia to be an intelligent agent. This because Julia does not take initiative, she speaks only when spoken to. Julia might strike users as a person and therefore she gives the appearance of being autonomous or intelligent. But Petrie does not think that she differs from other software that performs background tasks [30].

Comments

Petrie talks about an important aspect of agents, that is, if we should call agents intelligent or autonomous. This is a very interesting question since the word intelligence is so charged and maybe autonomy is a more important characteristic than intelligence. Something that we see as a weakness in Petrie’s definition is that it is to broad and comprises almost any software program that is only slightly autonomous.

3.2.4 The Jennings and Wooldridge agent

According to Jennings and Wooldridge an agent must be *autonomous* [21]. An agent is autonomous if it is capable of acting without any direct guidelines from either humans or other agents. This means that the agent itself has control over its own actions and behaviour, i.e. the agent encapsulates its behaviour and internal state. If an agent is compared to an ordinary object that also has an internal state we can see an important difference; that there is at least one method in an object that can be invoked by another component. This implicates that an object is not autonomous.

This is not the case with agents, according to Jennings and Wooldridge agents have control over their own actions, i.e. agents are not seen using methods that belong to other agents, rather requesting other agents to perform a certain task. And it is up to the corresponding agent to decide if it wants to perform the action asked for by the first agent.

There are many examples of existing systems, which are autonomous, e.g. the thermostat can be seen as an autonomous device since it monitors the environment and take appropriate action when changes occur. Wooldridge and Jennings refer to these systems as agents but make a distinction between agents and intelligent agents. An intelligent agent should be capable of *flexible* autonomous actions. Flexibility means that the agent should be social, responsive and proactive. An agent is *social* if it interacts with humans or other agents, to be able to solve problems or help others. *Responsive* implicates that the agent should perceive its environment and respond to it whenever changes occur. And finally an intelligent agent should be *proactive*, which means that the agent not only acts in response to its environment but can also take initiative on its own to achieve a goal-oriented behaviour.

Jennings and Wooldridge believe that these four attributes (autonomy, responsive, proactive and social) represented in one single component is what differentiate an intelligent agent from other software entities like an expert system. These four attributes do not exclude that agents can have additional attributes.

Comments

Jennings and Wooldridge make a very good distinction between agents and objects when they talk about the way entities are invoked. They also make a good definition of autonomy and they are not afraid of talking about intelligence. Jennings and Wooldridge make a distinction between agents and intelligent agents. They say that it is flexibility that separates them. What we do not agree with in this definition is that an artefact like a thermostat is viewed as an agent.

3.2.5 The Maes agent

According to Pattie Maes an intelligent agent has to *understand* its environment, which can be dynamic and unpredictable and it has to have the ability to *make decisions* in order to fulfil its goals. Further an intelligent agent has to *learn* from experience so that it can become better at accomplishing specific tasks. An agent must also have the ability to *communicate* with other agents and humans. These are the basic functionality an agent should have according to Maes. Maes also mentions other agent characteristic such as fast, reactive, adaptive, robust, autonomous and "lifelike" [25].

With *lifelike* Maes means something that is non-mechanistic, non-predictable and spontaneous [25]. The lifelike attribute is naturally most applicable to interface agents, where the agent is personified and can show facial expressions [22]. This is particularly interesting in the field of entertainment. Interface agents that have the goal to assist its user are often referred to as *personal assistants*. An important feature is the agent's ability to learn from the user by watching the users way of performing different tasks, as well as watching other agents assisting the user. By copying the user's behaviour the agents can help its user and function as a personal assistant. The personal assistant is specifically interesting now when we use the computer more and more to perform tasks and users will need help with information and work overload [24].

Comments

The most important thing Maes mentions is that agents, in order to help its user, have to be able to learn. Further the agent has to have humanlike characteristics like spontaneity which is an important feature that contributes to make the agent intelligent. These two characteristics are the most important ones according to Maes, but she also mentions other features. The problem however is that she never points out if agents must exhibit these characteristics or if they are merely typical characteristics that agents can have. It is a pity that Maes definition is so diffuse otherwise it would probably have been a very good definition.

3.2.6 The Hayes-Roth agent

Finally we would like to present the following definition of an intelligent agent by Hayes-Roth:

"Intelligent agents continuously perform three functions: perception of dynamic conditions in the environment; action to affect conditions in the environment; and reasoning to interpret perceptions, solve problems, draw inferences, and determine actions." [19, pp. 3]

By this she means that an agent first understands an event in the environment, then reasons about it and determines what to do and finally acts on that decision [19]. The agent exists in dynamic environments and must have ability to adapt its behaviour according to the situation. Hayes-Roth is very distinct in one point in her definition and that is that an agent belongs to a specific domain. This area can be dynamic and the agent can not work outside this specific area. You have to respect the agent for which domain it was built and just use the agent here. In what kind of domain an agent can work is decided by the agent's architecture, and the architecture in turn decides what kind of behaviour the agent will have. This must be respected when deciding on the agent's objectives. Therefore Hayes-Roth suggest that when building an agent one must first decide what the agent will do, then decide what behaviour that is required to fill the niche in which the agent will work. And last the most suitable architecture is chosen for the agent. Hayes-Roth has developed an agent architecture that can work in more complex niches, which demands that the agents are adaptive.

Comments
Hayes-Roth emphasises the importance of defining a specific agent on the base of where the agent is used and what purpose the agent is intended for. It is important to respect this and to understand that agent characteristics and what task the agents perform depends on the domain they are intended for. Unfortunately Hayes-Roth has not put as much energy into making a clear definition of what constitutes an agent. She talks of agents only in relation to its environment and she does not mention what characteristics that would be needed to carry out the intended behaviour.

3.3 Agent characteristics

As noticed above there are great disagreements on what defines an intelligent agent. Yet most researchers agrees that an agent is a software program with the purpose to offer assistance to its user, but when it comes to which characteristics an agent should have the opinions drift apart. Some researchers define agents very precisely while others are quite general in their descriptions. One reason for these different views could be that those who have built their own agent try to make a definition, which will suite their agent best. This means that they try to make a general definition with their own agent as a base [30].

Most researchers who have made their own definition of an intelligent agent have ascribed different characteristics to the agent. Therefore we have structured this part by a number of important agent characteristics. We have chosen these characteristics since they often appear in the work of researchers as important features that an agent must posses to be labelled an intelligent agent and because most researchers mention these characteristics in some way or another. However they are by no means the only characteristics an agent can have. Some researchers mention lots of other characteristics as well.

3.3.1 Autonomy and Intelligence

Most researchers and developers agree on the fact that agents should be capable of autonomous actions. An agent is autonomous if it has control over its actions and behaviour, if it can act without interference from users or other agents and take initiative to pursue its objectives [21]. This is clearly an important feature of a software agent.

One problem is that researchers, even though they have the same opinion on what characteristics an agent should possess, have different definitions of the characteristics. This is clearly illustrated in Petrie’s and Foner’s definitions of intelligent agents. Even though they both think an agent should be autonomous, they have different opinions about the agent Julia. Foner thinks Julia is a very good example of an intelligent agent and that it fulfils all of his criteria and foremost it is an intelligent agent because it is autonomous and takes initiative [14]. Petrie on the other hand does not think Julia is autonomous and takes initiative on its own and therefor he does not consider it to be an intelligent agent. He can not se any difference between Julia and a software program that performs background tasks [30].

Some researcher equals autonomy with intelligence. They mean that being able to take initiative is what makes an agent intelligent. They emphasis that it is not human intelligence they are talking about, but machine intelligence [30]. There are other researchers who make a difference between just agents and intelligent agents. According to Jennings and Wooldridge an agent is much simpler than an intelligent agent. An intelligent agent must be flexible otherwise it is just an agent [21]. Yet others do not explain intelligence at all and refer to agents without involving the word intelligence [14, 28]. Petrie also states that perhaps we should not talk about intelligent agents at all but only about autonomous agents. He states that it is difficult to talk about intelligence since most people associate intelligence with human intelligence instead of machine intelligence, like the researchers do [30].

3.3.2 Learning

One characteristic that is involved in the word intelligence is learning. Does an agent have to be learning in order to be intelligent? This is probably the case and therefore it might be wiser to talk about autonomous agents since the question if agents have to be learning or not is very debated among the researchers. Some think learning is a very important feature of an agent [14] while others do not mention the ability to learn at all [21]. According to interviewee A, the most important feature of an agent is adaptability or learning[10].

There is no way we can know all situations that an intelligent agent may encounter if it exists in a dynamic environment. Therefore an agent that can adapt and learn from its environment and use this experience to solve tasks, has an advantage over one that can not. A software program that has the ability to learn, is a program that can remember things and use this memory to solve other problems. Agents can learn from its user by observing his actions, it can learn from other agents or learn from changes in the environment. Furthermore it can learn which agents to trust and co-operate with and which ones to avoid [7].

There are different ways of describing what machine learning is. One of them expresses the learning ability in terms of a way of acquiring specific important knowledge. Physically this is achieved by the agent’s ability to “program itself” [24].

[10] Interview with interviewee A

3.3.3 Communication

Communication is a two-way discourse between the agent and the user or between two agents. This means that an agent can communicate in two different ways; interacting with the user using a natural language or symbolism and exchanging information with other agents using special agent communication languages such as KQML [7]. If agents do not have the ability to communicate, some researchers would not think of these as agents [14, 21, 24]. Other researchers think of communication as a supplement to an agent but not a necessary feature [29, 30].

3.3.4 Co-operation

The essences of co-operation is that agents work together to solve problems that would be too complex for just one single agent to solve by itself [29]. Trough co-operation agents can agree on which goals to reach and how these should be accomplished. Co-operation is often mentioned as one of the main advantages in using agents [28].

Foner emphasises co-operation between the user and the agent to solve problems instead of co-operation among agents to solve specific problems [14]. One definition does not have to exclude the other. There can be co-operation at two different levels, first between user and agents to figure out how to solve a problem and secondly co-operation between agents to actually find the solution. It is not a necessity for agents to co-operate in order to solve tasks, but it can certainly bring about that more complex tasks can be carried out. In complex problems it is useful if several agents co-operate and perform smaller tasks of the problem, to decrease the complexity [35]. One could imagine that co-operation would not exist without communication but this is not the case. Agents can co-operate by observing each other and then decide whether to act to help other agents, this is a way of working together without interaction via communication [9].

3.3.5 Lifelike

The goal of making agents lifelike is to create an illusion of an agent that is capable of emotions and significant social interaction. The creation of lifelike computer characters requires a wide variety of technologies and skills, including speech recognition, natural language understanding and animations. An understanding of dialogue mechanisms and social psychology is also essential [9].

It is a controversial matter to ascribe agents with humanlike characteristics, such as emotions, which can be displayed via a graphical representation like a realistic human face [22]. There are researchers who think that agents should show lifelike features [25] and others who do not think that it is necessary for an agent to be lifelike [14]. Lifelike means that the agent should be spontaneous, non-mechanistic and be able to act non-predictable. All these characteristics are typical human features and if an agent shows these features it would certainly distinguish them from other software programs [25]. If an agent has lifelike features it is easier to engage the user in the application or task at hand. This might be useful when a program requires an engaged user as in educational or training programs. However one problem is that the user tend to spend too much time trying to interpret the humanlike images [22].

3.3.6 Mobility

Mobility means that the agent is able to move around the network, for example the Internet, to different computers to perform tasks where they are most suitably performed. For example, to share resources or optimise the execution times on the Internet. Many researchers believe that mobile agents will offer a new and important method of performing information retrieval and transactions in networks [18]. For example, an agent can go out on the Internet on your behalf to find the cheapest flight to a certain destination by checking all possibilities. The agent travels form server to server to select the best information without you having to be online the whole time. When the agent has found the most optimal flight, only this information (and how it calculated this) is transferred back to your computer. A static agent can of course get the information, but then you will receive a tremendous amount of information since the agent does not select the best information before transferring it to you, and you will have to stay on line the hole time. The disadvantage with this is the amount of information you receive and that the speed of the connection gets slower if everyone is connected all the time sending vast amounts of information over the lines.

In a study from the IBM [18] they conclude that there is noting that a mobile agent can do that can not be done with other means as well, except for remote real-time control. The disadvantage with a mobile agent is problems with security, the receiving server can never fully control the agent, so it will never know if the agent causes any damage to the server [29]. According to interviewee B mobile agents only work in theory today, and there are too many technical problems to solve, before mobile agents can become a reality[11]. But on the conference PAAM'99 a mobile system was presented by Hung *et.al* [20], they said that mobile agents can be used in closed systems and they showed a successful application with mobile agents.

3.4 Single-agent and Multi-agent systems

An agent is a software program that should be of assistance to its user. But should agents act alone or should they co-operate? Is there a general answer if one should choose single-agent or multi-agent systems, or is it dependent on the context in which the system functions?

[11] Interview with interviewee B.

Using a single-agent approach does not imply that there can be only one agent in the domain. There can be several, but the single-agent does not recognise the other agents as agents, it sees them as a part of the environment without any goals. Single agents are often more complex then multi-agents, since multi-agents can divide the task between several agents while the single-agent has to do all the work by itself. Communication among agents increases the complexity and therefore an agent that does not communicate and is part of a multi-agent system has the simplest internal structure [35].

A single-agent system can be described as a centralised system [35] (see figure 4). One example of a single-agent system is a mail-agent[12], which usually studies the user's actions and learns what to do. When new mail arrive, the agent tries to predict the user's action based on earlier events that the agent remembers. It then presents suggestions of actions to the user and modifies it's prediction function based on the correctness of that suggestion [24].

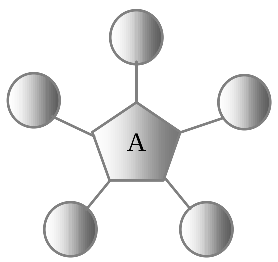

Figure 4, A centralised single agent system, where the single- agent supports several entities. Based on Bradshaw [9].

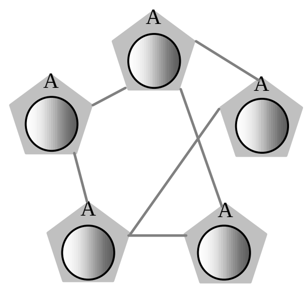

Figure 5, A decentralised multi-agent system, where each agent represents an entity. Based on Bradshaw [9].

In a multi-agent system the agents are aware of each other and co-operate in order to solve specific tasks. To carry out the co-operation the agents model each other's goals and actions. Co-operation is one of the advantages of using multi-agent systems, like Nwana puts it:

"Co-operation with other agents is paramount: it is the raison d´être for having multiple agents in the first place in contrast to having just one". [28, pp. 30]

Agents do not necessary have to communicate in order to co-operate. When agents in a multi-agent system do not communicate they can observe each other in order to gain required knowledge. A difference between single-agent systems and multi-agent systems is that in multi-agent systems other agents can affect the environment and change the conditions for the agent. Multi-agent systems can be watched as

[12] For further information see http://www.zmr.com/products.htm

distributed systems since the agents can help each other or share tasks [35] (see figure 5).

There are many reasons for using multi-agent systems. For example, some domains can includes different organisations that have different goals and therefore must be represented by different agents. With multi-agent systems you can use parallelism, which speed up the system by parallel computation. You also gain robustness, scalability and the programming becomes easier [35]. Systems that are naturally distributed e.g. geographically like in sensor systems or air traffic control systems are suitable for multi-agent solutions, as well as systems that require a fusion of information and system that are of “expert system” character. Of course there are objections against always using multi-agent system, you should not use multi-agent system when it is just used for enhancing the modularity, speed, reliability, efficiency and flexibility. Further multi-agents are not suitable when used only to decentralise a system normally modelled as a centralised system. One should not try to provide multi-agent solutions to the wrong problems, it is foremost important to focus on the problems the multi-agents are meant to solve and not the possible benefits [29].

Today the focus of agent research is more on multi-agent systems than on single-agent systems, since agents that co-operate and/or communicate can solve much more complex tasks than just one single agent is capable of [27]. This trend towards multi-agent systems was very obvious at the PAAM’99 conference, where only a very few agent systems with single agent architecture were presented.

3.5 An agent definition

To be able to talk about agents in sensor systems later, we will now make a definition of intelligent agents. It is based on other researcher’s definitions, however it is presented in a way that hopefully is more constructive and useful for our application domain. Notice that this is not a general definition that is accepted among leading researchers, only our own opinion of what constitutes an intelligent agent based on other researchers’ definitions.

We define an intelligent agent as an entity that has a goal; a purpose for its existence and which has been created to help a user with a specific task in a specific domain. This is the basic idea of intelligent agents and most researchers would agree with this definition [9, 15, 39, 28]. We think that apart from these elementary requirements, the agent must have a number of specific characteristics to be called an intelligent agent. We see it as the primary attributes of an intelligent agent to be autonomous and be able to learn.

Autonomy in an agent is important, otherwise it is just like any other software program. Autonomy means that the agent can act on its own and make its own decisions. The purpose of an agent is to help its user and by being autonomous it can relieve pressure from its user by releasing some workload and thereby give the user time to spend on other issues.

Agents have an internal encapsulated state, which is an important difference between agents and other entities like objects and this features enables autonomous action. This is something that is strongly emphasised by Jennings and Wooldridge. An object can be initiated by another component via a call to one of the object's public methods. This is not possible with agents. Agents can only communicate via specific agent communication languages and the agent can decide for itself whether it should act or not [21]. We argue that this difference is what separates agents from objects and also what makes the agent independent. The agent can decide for itself if it will perform a task or not, an object does not have that choice. Because of the importance of autonomy in agent systems, we define it as a *compulsory agent characteristic* (see figure 6). This importance can also be seen in the fact that many researchers wish to talk about autonomous agents instead of intelligent agents, as we have seen not only in Petrie's definition but also examples of at the PAAM'99 conference.

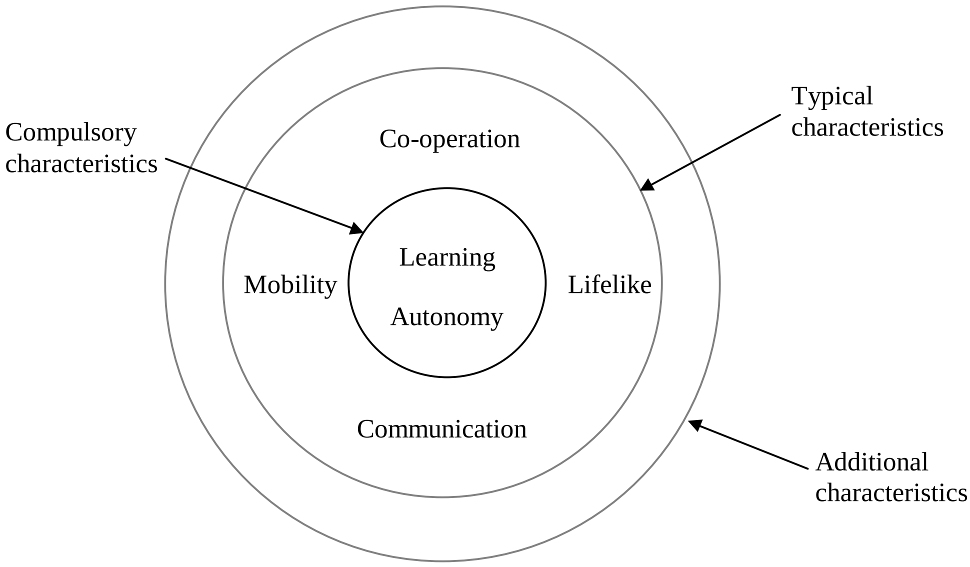

Figure 6, Agent specific features by our definition

The agent should also be able to *learn* as it proceeds and use this knowledge to solve new problems. If an agent for example exists in a dynamic environment and the environment changes then the agent has to learn about the changes to be able to carry out its mission. When the agent can learn more and more about how the user acts or what information he finds interesting, the agent can become more useful. To be able to learn is an important human characteristic and it is one of the things that enables us to be intelligent, therefore we think it should be a characteristic of an *intelligent* agent. Like Nwana states: *"… for agents to be truly 'intelligent', they would have to*

***learn** as they react and/or interact with their external environment: such that with time, their performance increases.”* [28, pp. 30] The essence of Artificial Intelligence is the ability to learn and use knowledge, and since agents are developed from the Artificial Intelligence community we think that it is also a central matter for the agent technology. Different agents should have different levels of learning ability, depending on what kind of task the agent is assigned. We think it is an important feature of an intelligent agent to have the ability to learn and we think this feature and autonomy is the main thing that separates an intelligent agent from an ordinary software component. So in our definition learning makes the second *compulsory characteristics* (see figure 6).

Furthermore agents can also communicate, co-operate, be mobile and have lifelike features, but these are not essential characteristics rather *typical agent characteristics* (see figure 6).

Something we discovered and argue for is that if an agent has the ability to learn it can learn by watching its user or other agents, it does not have to *communicate* with them. This certainly simplifies the internal structure of the agent. It can for example be good if a user has no time to teach the agent by communicating with it, instead the agent can “watch” the user and learn from the user’s behaviour. However, it is probably more useful with agents that have the ability to communicate with users and/or other agents, then agents that lack that ability. The fact that several communication languages have been developed like KQML [7], implies that this is an area that engage many researchers and developers.

Agents that *co-operate* with each other can solve much more complex tasks than if they have to work by themselves. By dividing a task between several agents, the task becomes less complex and easier to solve. Co-operation means that the agents can share information with each other, this results in that not all agents have to seek the required information. There is a strong connection between communication and co-operation, the agents can co-operate without communicating by watching each other, but communication makes co-operation much easier.

We do not think that agents have to show *lifelike* features but if they do it is not going to be a disadvantage. We agree with Maes that lifelike features means spontaneity and non-predictability [25], if an entity acts spontaneous it can provide us with additional information that we have not asked for but might be interested in.

Mobility is one characteristic that we think is important to mention. It is a very interesting area and a new way of solving certain problems and it is a characteristic foremost associated with agents. With a very slow net it can be a benefit if the agent can emigrate to a another computer to execute a task, rather then use a lot of band width to solve the same task [18].

These four *typical characteristics* (communication, co-operation, lifelike and mobility) are agent specific and it is very likely that the agents we encounter posses some of these features, even though agents can manage without them. However this does not mean that agents can not have other features as well. The *additional characteristics* are features like reliability, robustness etc (see figure 6), these do not have to be explicit agent characteristics they can be characteristics that other software component have as well.

When deciding which features an agent shall have, we agree with Hayes-Roth that it is very important to first decide in what domain the agent are going to work [19]. Otherwise it is possible to wind up with an agent that is too complex for the task it shall perform. According to interviewee B an agent is not better just because it has more features then another agent, a simple agent may be the better solution[13]. We argue that the domain were the agent will reside is very important when you decide which features an agent should have. We should view the agent characteristics as a toolbox where we can pick the tools needed for a certain problem. We think that the agent has to be autonomous, be able to learn and that the kind of tasks the agent shall perform implies what other characteristics that are suitable for the agent to possess. This means that except from autonomy and learning no characteristic is more important then another characteristic. Which characteristics that are important are decided by the task the agents shall perform and in what domain they will work.

Another point we would like to mention is that if you do not trust the agent you will probably always double-check the information you receive and then time saved by using the agent might be lost. We agree with Foner when he says that if you can trust other people and delegate tasks then you can also use agents [14].

Whether we should talk about intelligence in agents is another difficult matter. The problem is that the word intelligence has a very subjective meaning and there are many definitions of intelligence. We know so far that agents do not practise human intelligence, so it is quite misleading to call agents intelligent. Therefore we argue that we should use the term autonomous agent instead of intelligent agent, or name the agents according to their purpose or characteristics, like information agents or smart agents like Nwana does [29]. Most suitable would be to call agents for autonomous agents since this is of one the most important characteristics that differentiate agents from other software entities.

Something that perhaps does not fit in an agent definition is the question if you should use a single- or multi-agent system. We would like to say that it depends on the system that you are going to build. When we look at intelligent agents in sensor systems we advocate that a multi-agent approach is most suitable. This since just one agent would be to complex and an agent that does not communicate or co-operate with other agents will not add anything to the system.

[13] Interview with interviewee B

3.5.1 Summary

To make a definition that we think could be possible to implement in a sensor system, we have taken the best parts out of each researcher's definition. We would like once again to point out that this is not a general definition applicable to all agents, rather a definition that we will use when investigating the agent technology in relation to future distributed sensor systems.

The conclusion of this definition is that agents must possess autonomous features and have the ability to learn. Other characteristics might be suitable depending on the domain the agent will work in. We defined two different levels of these other characteristics, either they are typical agent characteristics or additional characteristics.

We hope this definition will make the following discussion more comprehensible to those that have not been in contact with the concept of intelligent agents before. We also want to point out that we from now on, when talking about agents or intelligent agents, have our definition of an agent in mind. Even though we think agents should be called autonomous instead of intelligent, we will continue to use the word intelligent agent since this is the established word.

4 Agents and Sensors

We have formed a theory about what an intelligent agent is and will now move on to investigate if it is possible to use the agent technology in sensor systems. We will first explore in what kinds of systems we can use the agent technology. Secondly we look at some existing agent systems outside the Internet, to get an idea about how intelligent agents can be used in sensor systems. And finally we will describe what a sensor system is and look at some existing problems in sensor system. We will do this by combing literature studies with interviews and information gained from the PAAM´99 conference. When we have described these aspects we will discuss if we can use the agent technology in sensor systems and if so, how we can use the agent technology to solve existing problems in sensor systems. We want to pinpoint that sensor systems refers to sensor systems that are or will be developed at Ericsson Microwave Systems AB, if that is not the case it will be clear in the text.

4.1 Where to use agents

According to Parunak, agents are best suited in systems that are modular, decentralised, changeable, ill structured and complex and therefore the agent technology is very useful in many different kinds of applications [40]. The categories where agents are most suitable are also discussed by several other researchers and developers, e.g. Jennings & Wooldridge [21] and Bradshaw [9]. This indicates that it is a common opinion that these categories are the areas where agents can be applied.

Modular - Agents are well suited for applications that fall into natural modules, this since the agent technology is a specialisation of the object technology where the benefits of modularity are well used.

Decentralised – Applications that can be decomposed into stand-alone process, which can act on their own without any interference form some other process, are well suited for agent technology. This because it is one of agents' basic functionality, to act on its own and take appropriate actions when it is necessary.

Changeable – Systems that are both modular and decentralised are systems that can handle change. Modularity allows the system to change one bit at a time and decentralisation minimise the impact one module has on another module when it changes. Since agent are good for systems that are modular and decentralised they are also good for systems that are changeable.

Ill-structured – An ill-structured system is a system where not all of the necessary structural information is available when the system is designed. In these kinds of systems agents are well suited, since agents have a distinct notion about themselves and know that their environment can change, by other means agents can handle a dynamic environment.

Complex **–** Today's applications becomes more and more complex and harder to handle. The agent technology can be one solution for this since they provide us with ability to model each component and its behaviour instead of program each possible thread of execution that the system can have.

Real-Time **-** According to Akkerman *et al.* that has developed a system for choosing the best time to use energy, agents are also suitable to use in systems that demand real-time control [1].

4.2 Agents in practical work

Not many systems that include intelligent agents have been developed and commercialised since late 1994 [27]. The greatest progress has been seen in the field of Internet agents, where agents can act as personal assistants (helping to sort mail or collecting information) or entertainment agents (for example used in computer games). These agents are relatively simple compared to agents that are created to work in large practical systems. In this section we will introduce some agent systems that are developed for practical use outside the Internet, some are under construction and others ready to be used, this means that they are tested but are not yet installed.

4.2.1 Air traffic management

Air traffic all over the world is growing every day. This requires more efficient and advanced monitoring systems. To meet these demands a system prototype, with intelligent agents, for air traffic management has been developed. It aims to control the infrastructure and revile air traffic controllers of their heavy workload. The system, OASIS, manages and controls the arrival of aircraft at airports [16].

OASIS provides the following functionality:

- Calculates estimated landing time for each aircraft
- Determines in what sequence aircraft will land giving the least total delay, and advises the air traffic controllers of appropriate actions to achieve this sequence
- Notifies the controller of significant differences between the established sequence and the actual situation, and gives advice on appropriate action
- Responds to sudden changes in the environment such as meteorological conditions and aircraft emergencies

To carry out this functionality intelligent agents are used to handle the need for problem solving in the above areas. Specific agents are designed to operate in different task areas in the air traffic management system. Each agent solves its part of the task independently, i.e. acts autonomous and co-operates with the others to produce the overall system behaviour [16].

There are two types of agents in the OASIS system, first those that perform computations and reasoning relevant to each aircraft, called *the Aircraft agents* and second those which co-ordinate and reason around other outside matters, called *Global agents* [23]. The system assigns an aircraft agent to each arriving aircraft. These agents contain all aircraft specific data as well as its position, speed and altitude collected from surrounding radar. In the system there also exists five global agents, the *Co-ordinator agent*, the *Sequencer agent*, the *Trajectory checker agent*, the *Wind model agent* and the *User interface agent*. The Co-ordinator agent can be seen as the head chief agent, since it co-ordinates the activities of all the other agents in the system. The Sequencer agent tells the aircraft in what sequence they are scheduled to land, the Trajectory checker agent controls the instructions given by the system to the aircraft. The Wind model agent collects data about wind conditions form the different aircraft agents and calculates what winds the aircraft is likely to encounter and the User interface agent handles all communication with the air traffic controllers. OASIS can handle more than one hundred Aircraft agents, each interacting with the various Scheduling and Co-ordination agents. The OASIS prototype took about two and a half years to build and was successfully tested at Sydney airport in 1995, but the system was never scaled up and actually implemented.

4.2.2 Traffic applications

The use of information technology in traffic situations is a growing area of interest. Many traffic applications have been developed as multi-agent systems to achieve a more efficient traffic situation, save resources and improve ecological aspects. A system modelled by the multi-agent architecture is appropriate since traffic is distributed both in means of geography and functionality, with high levels of autonomy and dynamics. Agents in these systems represent different roles, depending on the system task, such as; users involved in the traffic, different means of transport like cars and trains, infrastructure, or different branches and traffic modalities like railroad traffic. With the help of agent-oriented technology tools it is possible to simulate and model complex situations that can arise in a traffic situation [10].

One example is to use agent-oriented technology (AOT) to improve traffic control systems like the traffic-lights systems. Most of the present systems are huge and have to deal with great amount of data gathered by distributed sensors [10].

One example of an existing traffic system based on agent-oriented technology is the TLCA (Traffic Light Control Agent) [2]. This is an autonomous and learning agent that is capable of controlling the traffic light at a road crossing. The TLCA is able to intelligently process images taken by cameras for all the directions in a crossing, and thereby determine which lights should be green and which should be red. Today the dynamic traffic lights are controlled by so called blind sensors. The advantages of a TCLA are several. First of all the TCLA can estimate the number of vehicles in each direction and with this information determine the duration of green lights. By learning the TCLA can tune the duration of green light granted to each direction depending on the number of vehicles. Further it can also capture approaching vehicles from a long distance, which is not the case with the blind sensors. One possibility with the TCLA that has not yet been implemented, is the ability to detect events that may occur like accidents or approaching ambulance or police cars in duty. The TraMas (Traffic Control thorough Behaviour-based Multi-Agent System) is another agent system that has the same objectives as the TCLA namely to control traffic lights at crossroads. This prototype has been successfully implemented [13].

4.2.3 Simulation

Intelligent agents have shown to be a very powerful tool for developing simulation applications. With the help of the intelligent agent technology a person can practice specific tasks in a specific situation or environment. The agents help the user by simulating this specific situation [31].

One example of such simulation applications is an air-combat modelling system (SWARMM) [16]. In this system agents are used to simulate pilots to create a combat scenario. Real human pilots can then interact with these automated pilot agents to practice and prepare for real future situations. The system simulates both the characteristics of the aircraft like sensors, weapons etc as well as the tactical knowledge and reasoning that the pilot can exhibit. The pilot system was implemented in mid 1996 at the Royal Australian Air Force for studies involving 64 surrogate pilots. The agents in the system are autonomous and they can co-operate to reach a predefined goal. They also act in a dynamic environment, this since the action of the real pilot is unknown [26].

Another example of a simulation system is a monitoring system for nuclear power plants, developed in Germany [17]. This system includes a component that simulates the airborne dispersion of radioactive particles and their effect on the human body. The agent-oriented paradigm was used because agents provide distributed components, communication between agents, awareness of other agents, social intelligence, and autonomy, which the developers felt were important characteristics for this application. The application is based on a multi-agent approach with several different kinds of agents that provide different services:

- The *Client agents* starts the simulation or ask for other services,
- the *Simulation agents* encapsulate different simulation models and carry out different parts of the simulation,
- the *System agents* manage the user interface and system resources,
- the *Data agents* obtains different data based on different sources or methods,
- There also exist other agents that cover other tasks such as administration, calculations, and managing results and reports.

The data used in the simulation are data about nuclide inventory, emissions of nuclides and weather conditions collected by different sensors. This project has not yet been fully implemented but the developers are very optimistic that it will be finished on time [17].

4.2.4 C^4I - systems

C^4I stands for Command, Control, Communications, Computers and Intelligence, which is systems that has an increasingly important part of battlefield, naval and air operations, but they are also used in civilian application areas such as air traffic control and emergency services. Most C^4I systems collect data about the situation by using sensors such as radar[14].

The EUCLID (EUropean Co-operation for the Long term In Defence) is a collaborative military research program including a number of western European countries, that has developed several C^4I decision support systems using the agent technology [37]. One of these systems is the RACAS (Resource Allocator for Close Air Support) that provides support for identifying targets for air support missions and artillery fire support. The commander is informed of the best resource allocations at the current situation i.e. the system presents the feasible assets and potential targets on a map, and the user may select the assets and targets to be used in the resource allocation plan. The user also has the ability to assign priorities to targets and define damage criteria for targets. This application is an advanced prototype developed during a five-year period and it has been successfully implemented and tested.

To carry out services of the application several different agents were created. The agents were all autonomous and co-operative so that they together could solve the coming task and the agents could also communicate with each other. The three main agents were, the *Theresa agent* an agent that handles the interaction between the user and the application, one agent called the *Deca agent* that exhibits domain knowledge and one agent that generates possible solutions to resource allocation that was labelled the *Grap agent.* The main purpose of using agents in this system was to encapsulate capabilities and knowledge in order to gain the advantage of reusability. This is possible with the agent approach since agents act autonomous and encapsulates its behaviour. One thing found when this system was developed was that the system designers easily could comprehend the abstraction of agent as components performing a certain task for a user or another agent[15].

4.2.5 Personal service assistants

One field in the research of intelligent agents that is submitted to a lot of research is the area of personal service assistants, as we noticed at the PAAM'99 conference. A personal assistant is an agent that represents a user and learns his or hers behaviour and acts on the users behalf on the Internet or Intranet [8]. Interviewee A has developed one such application. In this system each person can have up to five

[14] Conversation with interviewee C
[15] Conversation with interviewee C

different agents to represent different interests of the user, the agents then search the Intranet for information that is of interest to the user. The agents also look for other agents with similar interest so that they can co-operate with each other and exchange information[16]. The most important features of these agents is that they are autonomous, learning and that they can co-operate. There are lots of similar systems under development such as the Ricochet system developed by France Telecom [8], and CASMIR developed at Salford University [6], both presented at the PAAM'99 conference. Both systems have similar ideas of using personal assistant agents as described above.

4.3 Sensor systems

A sensor can be described as a system, which detects signals or objects of a specific type. Depending on, if the sensor is a radar, TV-camera, infrared camera, acoustic sensor, transponder, passive radar or any of the many other types of sensors, it provides some information about events or environmental settings. A radar can for example detect objects at long distances and on a TV-camera you can more precisely identify objects. By combining different kinds of sensors, each which gives a different picture of a situation, one can get a richer picture, either by having a larger area examined or by having several types of information about one area. In order to provide the application domain for our research question, we will present examples on sensor systems based on how radar work and are organised. The following examples are based on sensor models from Ericsson Microwave Systems AB.

4.3.1 How radar systems work

A radar covers a specific geographic area and can capture information about objects (e.g. aircraft, boats and even birds) in that area, like the object's position, size and it is also sometimes capable of identifying large objects. It is difficult to identify objects but possible, the speed of the object and how visible the object is can be clues to the object's identity. Radar does not present everything it detects to its user because that would mean that the radar would present everything from falling leafs to aircraft. It is however difficult to know were to draw the line of what is an interesting object and what is not, this is decided when the system is built so that the user of the radar does not have to bother with these kind of problems[17]. The user gets a filtered picture from the system and his job is to decide what kind of boat or aircraft he sees. Radar are specialised to have different capabilities, such as detecting objects at long ranges, precisely estimating sizes and velocities of objects, discovering unusual events that do not fit expected patterns etc. To get better estimations of objects, the various specialised radar are combined to sensor systems.

[16] Interview with interviewee A
[17] Interview with interviewee D

If two radar are placed so that they cover a common area then the identification of an object in that area can be more precise (see figure 7)[18]. Since the radar staff can talk to each other and come to a conclusion on what kind of object they are looking at.

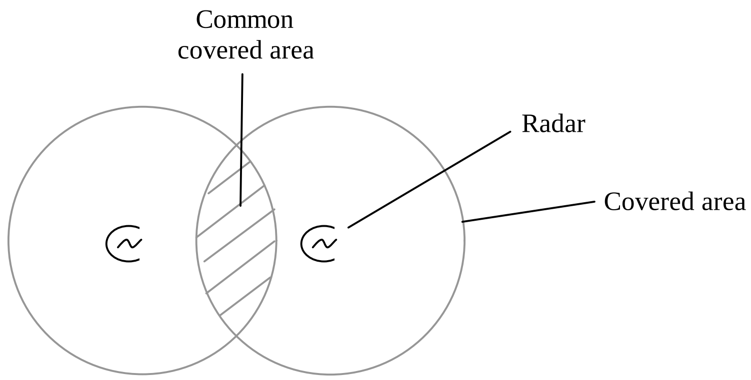

Figure 7, Two radar that overlap

However, this situation can cause problems to the radar staff since it can take time to find out that they actually look at the same object. Each radar gives each object an identification numbers, which means that two radar do not have the same number for the same object, i.e. they do not have the exact same picture. This picture is called a situation picture and shows the objects visible in the area covered by the sensors.

4.3.2 Radar co-operation

Today only a few radar have the ability to co-operate with other radar, the information about objects detected by two different radar is mostly correlated via speech and/or radio communication (see figure 8).

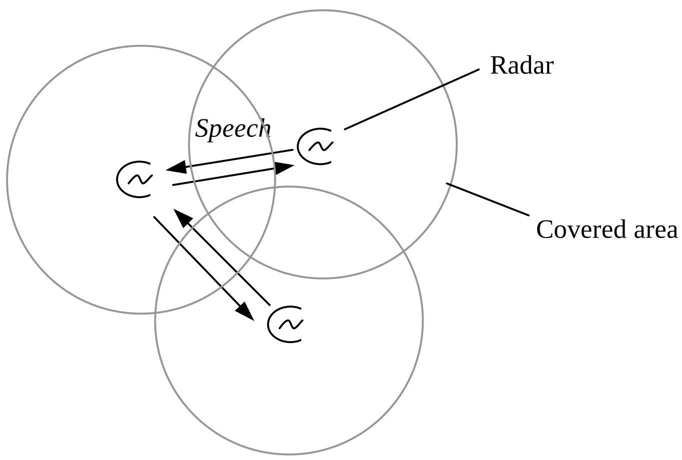

Figure 8, Communication between radar today is mostly handled via speech and radio communication.

[18] Interview with interviewee E

However systems are being developed that will provide automated communication and correlation of the common situation picture[19]. Figure 9, shows an example of how radar can be organised to form a system consisting of several radar that communicate with each other. In this system a radar can create a situation picture with the help of other radar.

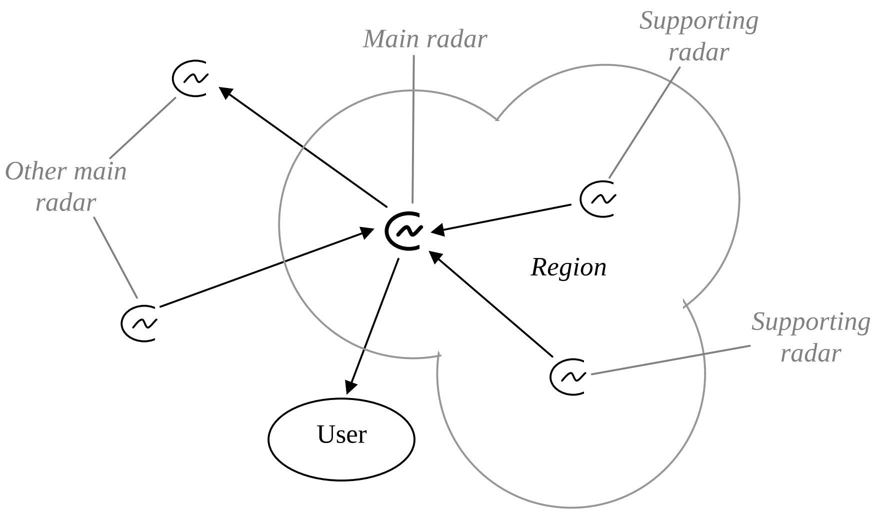

Figure 9, example of a radar system

In figure 9, the *main radar* has the ability to detect objects in its area, as well as receiving information about other objects from other radar, it acts like a spider in its web. Objects detected by the main radar are called *local objects.* One main radar can have several *supporting radar* that cover other areas or part of the same area, together they form a *region*. Information about objects from the supporting radar is transmitted to the main radar. All objects detected in the region are *regional objects.* Furthermore there can be other main radar connected to the main radar, that send information collected in their own region. In sensor systems several radar are used so that the most precise identification of objects can be done. The main radar receives information from other main radar and gets information about local objects and about regional objects. The main radar can also send its local information to other main radar but it can not send information it receives form other main radar. This limit is set so that the radar do not start to send the same information back to the first radar since this would cause an information overload in the system. Now the main radar decides which representation of objects that gives the most precise information. The results are called *system objects*, and they represent all the objects detected by all the connected radar in the system. Information about the system objects is finally transmitted to the user and the user receives the situation picture. The co-operation

[19] Interview with Interviewee E

between the radar will increase the correctness of the situation picture, instead of getting one picture from each radar and then try to put this picture together the user now gets a correlated picture from the beginning[20].

Sensor systems provide several advantages over just single radar; they can cover a much larger area, they can discover more objects, and they can with more data have more secure measurements. The most important advantage is that the user can get a correlated picture of the area covered by all radar in the systems, instead of different pictures from every radar. One problem however is that every radar creates its own situation picture based on its own detections and information from the other radar, there does not exist a common picture of the entire covered area. This means that a user connected to one radar only receives the picture from this radar, if the user had been connected to another radar in the system he would get a different picture[21]. This because the different radar just receives information from the closest radar, so depending on which radar the users is connected to the situation picture is different.

4.3.3 Optimising the use of radar

As radar which are active for a long time easily can be detected, they are turned on and off to minimise the chance of being located. This activation is at the present mostly done manually by the radar staff in different intervals. If it would be possible to automate the activation of the radar, the radar staff could concentrate on more important tasks like identification of objects in the area. Radar usually cover parts of the same area, the problem is that they still have to be turned on and off manually. This means that they can be turned on and off at the same time and this is not an optimal use of the system.

A vision is that all the radar in a country will be connected and that someone or something controls them so that they cover the area as optimal as possible [22].

In a sensor system there are many different kinds of radar, one problem today is that these radar are not connected into a complete system and therefore they can not co-operate with each other. This means that if an aircraft is discovered by a radar, that radar can not ask the next radar to be activated so that the asked radar can follow the object in the area it covers. If that radar is not activated or does not cover just that sector were the plane enters, the track of the aircraft is lost for a couple of seconds[23]. If the radar could co-operate to synchronise the activation of radar, the advantages would be an optimal use of the radar and activation when necessary.

[20] Interview with Interviewee F
[21] Interview with Interviewee E
[22] Interview with Interviewee D
[23] Interview with interviewee E

4.3.4 The future

Existing sensor systems are continuously improved, and one vision is that every sensor should be connected in a common information space (see figure 10). One example of this is the Baltic Watch project, where all sensors are going to be connected to an Intranet or the Internet to give each participant easily access at any time[24].

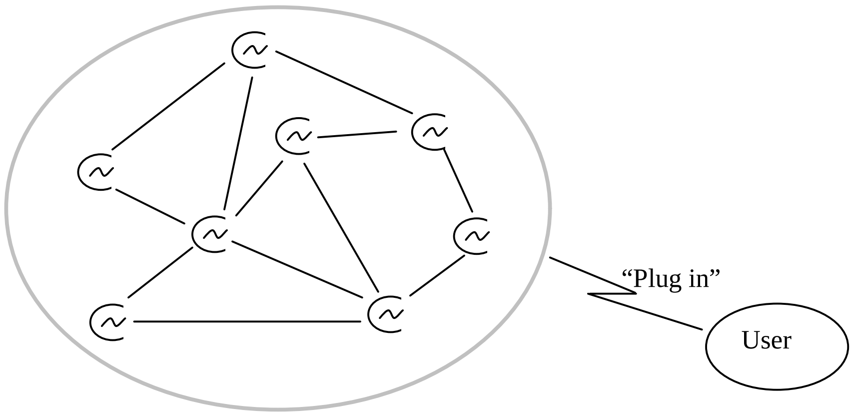

Figure 10, All sensors connected to an Intranet or the Internet

4.3.5 The Baltic Watch project

Since the catastrophic accident on the Baltic Sea in 1994 there has been much discussion on how to increase the security on the sea. The Baltic Watch is a project that aims to see what can be done to increase the security in the region. The basic thought in this project is that all the states around the Baltic Sea will share information, operational resources and facilities in order to improve the security. The security involves traffic control, meteorology observations and search for environmental changes or pollution etc. [4]. A problem with this project is how to secure reliable information between different parties such as country governments or other agencies. There might be parties that would benefit from spreading wrong information or withhold information when they find it suitable.

The Baltic Watch idea is to create an overall picture of the situation at the Baltic Sea, this will be achieved by using different kinds of sensors and transponders. The sensors monitor the sea and shore and send the collected data to a central processing component, which fuses and interprets the data to information, that finally will create the overall picture that is presented for the operators. Human reports may also be used in order to create this picture.

[24] Interview with interviewee D.

The sensors are situated on land (at the coast), at the surface, in the water and in the air. The more sensors that are being used, the better the information presented to the operators will be. The Baltic Sea is already supervised by a large number of sensors, the idea is to use these existing sensors along with new sensors, and connect them to create the Baltic Watch surveillance system. Coastal radar, air surveillance radar, airborne radar, underwater sensors, satellite based sensors, and sensors on buoys, masts and ships, are examples of sensors that can be used to monitor the sea and shore around the Baltic States (see Appendix 1).

4.4 Agents in sensor systems

Having provided the relevant background material, we can analyse the issues around our second research question:

How can intelligent agents be used in future distributed sensor systems?

Having the Baltic Watch project in mind, we will now try to answer this question. The base to this reasoning is first the analysis about the definition of intelligent agents and secondly the presented information about multi- and single-agent systems. Furthermore we will use the information on sensor systems, the examples of different intelligent agent systems and how they have been applied in practical settings, to answer this question. The idea is to give different examples on how intelligent agents could be used in future distributed sensor systems. We are not going to consider the fact that these examples, at the present moment, could show to be impossible to implement in sensor systems due to technical, social or political aspects. This is not a critical issue since we are talking about future sensor systems with a perspective of 5 to 10 years, and due to the fact that we are answering the question from an informatics point of view, not from a social or political view. Furthermore we will use the vision that sensor system will be connected via a common information-space, like the Internet or an Intranet, as a base for our examples, this thought is supported in the Baltic Watch project.

As mentioned before agents can be used in systems that are ill structured, complex, modular, changeable and decentralised. If we look at the future Baltic Watch system we can see that it is *modular,* i.e. the system is divided into different parts. You have different sensors, countries and organisations each forming different parts of the project. It is also decentralised since it is composed of different stand-alone sensors. Sensors can break or be taken out of the system, new parties can be connected to the system and so on, this implies that the system is *changeable.* The system also fulfils the fourth criterion that agents can be used in *ill-structured* systems. The Baltic Watch system or any other sensor system is ill-structured since you can never know when a sensor breaks down or a new kind of sensor is taken into action, i.e. all information about the system is not known in advance. The system is of course also *complex* since there are many sensors involved. There is a lot of data to analyse and the number of sensors in the system is not known. This suggests that it should be suitable and even advantageous to use agents in the Baltic Watch system and therefore it should be possible to use agents in other sensor systems. We have also encountered a system based on sensors that uses intelligent agents, namely the previously presented C^4I system[25]. This strongly implies that the agent technology could also be applicable to sensor systems developed by Ericsson Microwave Systems AB.

In our definition of what an intelligent agent is we concluded that autonomy and learning was the most important characteristics that an agent should posses to be labelled an agent. We will have this definition as a starting point in our further reasoning about agents in the Baltic Watch system.

4.4.1 The sensor agent

In the Baltic Watch system there are many different kind of sensors, these different sensors are put together into one system to get the best possible picture of the reality. For example if we have a radar and a TV-camera monitoring the same part of the sea, then the TV-camera might only have to be turned on if the radar discovers something in the sea that needs to be identified. With other words we need to optimise the use of the sensors. There is no point in having different sensors that covers a specific area, turned on at the same time, it is much better if they are used when needed.

We think it is possible to optimise the use of sensors with help of intelligent agents. This could be achieved by creating one agent to each sensor in an area. This agent could inform the corresponding sensor when it should be activated (be turned on) and when it should not. The agents in a specific area would have to communicate and co-operate with each other and reason about which sensors that should be in use. By adding this functionality, one agent would be able to tell the other agents in the same area that there is an object for the other sensors to detect. *The sensor agent* should be able to calculate which sensors that would be able to detect the object depending on the object's direction.

Other information, stored in a knowledge base, could be used by the agents to calculate which sensors that should be in use at a particular time. This should be specific information about certain situations or specific information about certain sensors, like information that would enlighten the agents that a certain sensor has to be turned on all the time due to the fact that that sensor covers a particular sensitive area.

The agents could also use this functionality to let other agents know when that sensor has no possibility to cover its area and another sensor should cover the area instead. This might happen if one of the sensors breaks down. When the agent asks another sensor to cover its particular area, it is important that the agent has the ability to learn

[25] Interview with Interviewee C

which sensors that can provide the most appropriate help, so that the agent do not spend time searching for the right agent to ask for help. This is an important characteristic since time is a critical aspect in these systems. If a sensor has broken then its area is not monitored and it is important to quickly get another sensor to cover the area.

It is clear that the sensor agents exhibit autonomous actions i.e. it has control over its own actions and behaviour and can take initiative to pursue its objectives. Even if the agent gets input from another sensor agent to activate the sensor, the agent could determine not to do so on other preferences. This implies that the sensor agent has control over its own actions. The sensor agents can also learn, communicate and co-operate. To be able to optimise the use of the sensors the different sensor agents has to communicate and co-operate in order to find the optimal solution to the raised problem, the agents can of course also communicate with the user of the system. The agents learn as they proceed, if an agent gets help from another sensor agent and remembers this, it can ask the same sensor agent again for help.

If the sensors can be connected and co-operate like described it would result not only in an optimisation of the sensors but also that resource sharing would be obtained. We found a parallel to our sensor agent in the examples of traffic applications (see section 4.1.2). Here it exists a similar sensor agent, the Traffic Light Control Agent (TLCA), which controls the traffic light sensors at crossings. Both our sensor agent and the TLCA control sensors and decide when to activate the corresponding sensor.

4.4.2 The object agent

If a sensor detects an object in its area it would be a good thing if the next sensor could pick up the trace when the first sensor can not see the object any more. Today there is no communication between the sensors that can provide this functionality. This means that each sensor creates its own picture of the current situation.

There can also be other benefits from following the object and store data about it. For example if the system detects an oil spill on the Baltic Sea, the system can control the stored data about different boats in the area and present the boats that is most likely to have caused the pollution. Today it is almost impossible to find out who caused the pollution, if they are not discovered in action.

A solution to this tracking problem can be to create an agent for every object that enters the Baltic Sea area, such as boats, aircraft etc. This agent is born when a sensor detects a new object in the system and the agent “travels” along with it and gathers information about the object. So if a sensor agent detects a problem in its area, it can easily retrieve information about the object presently being detected.

The object agent could also be able to co-operate with the sensor agents to see where the object is heading, this way it can also get information from the sensor agents about the object it is following. The benefit with this idea is that every sensor gets the same picture of the situation and when they refer to one object this object is the same to every sensor. These thoughts of agents following and monitoring objects have been implemented in the OASIS system described above (see section 4.1.1). In this system each aircraft is assigned an agent that stores information about the aircraft such as velocity, identification and position.

The object agent is clearly autonomous, it monitors its object without any interference from the user. The user can of course interact with the agent and ask him question and the agent can of course contact the user if it is something the user should know or if the agent want to know something. The object agent is also learning it remembers everything about the object, like which way the object has travelled and how the object behave. Communication and co-operation is important features for the object agent, it communicates with both the user and the sensor agents it also co-operates with the sensor agents. One features that the object agent maybe should have is mobility, then the agent actually can travel with the object it supervise this means that the agent is not depending on one computer instead it travels the internal net of the system.

All these different kind of agents solve different problems and they also cause some positive synergy effect. If an object enters a new sensor's area that sensor agent can ask the object agent for the name of the object and if one is provided the sensor agent does not have to give the object a new name. This means that some of the correlation problems, when the sensors do not know if they are following the same objects or different objects, that exist between the sensors disappear.

4.4.3 Simulation agents

We also think it is possible to create a *simulation agent*, i.e. an agent that surveys the other agents. If the agent discovers strange activity or moving patterns of objects that are unusual it can construct a simulation to find out which kinds of different situations that might occur. This could for example be done with boats that do not state where they are going, of course it should also be possible for the operator to create his own scenarios where the sensor agent has the responsibility to actually perform the simulation.

For example in the Baltic Watch project one would like to know if there exists two boats with colliding courses. The agent could calculate the boat speed and make predictions of where they are heading. If the agent discovers that the boats might collide, it can report the information to an operator who in turn could alarm the boats or take other appropriate actions.

Another example would be to simulate how oil spill in the water could spread depending on weather, wind and water conditions. Agents could collect this data from different sensors and a central simulation agent could put this information together and simulate different scenarios. These scenarios could then be presented to persons involved in oil cleansing. The simulation agent could have the ability to learn as it proceeds and become better at predicting similar events. These thoughts can be found in the practical agent example of simulation of radioactive dispersion presented earlier (see section 4.1.3). Here simulation agents construct different scenarios with help from other agents, such as data agents that collects information necessary for the simulation, to create simulations on the dispersion of radioactive particles. Similar organisation of agents can be of use in this oil simulation example, where simulation agents actually performs the simulation with help of other agents such as a data agent that collects information about weather and water conditions from different sensors. Other types of simulation agents could include agents that simulate other environmental disasters or that simulate rescue operations.

The idea of using agents for simulations we also encounter in the SWARMM application (see section 4.1.3). Here the agents are used for simulating combat aircraft behaviour as well as modelling the pilots reasoning process. There are several examples of the agent technology being applied in simulation applications and Rantzer states that the agent technology is a very powerful tool for constructing simulation systems [31].

Autonomy, learning and communication are features that the simulation agent possesses. It acts independently and performs its simulation without interference form the user or other agents, the simulations can be initiated either by the user or the agent can start its own simulations. It also learns as it proceeds, when the agent has performed a simulation it gets feedback from the user and this feedback teaches the agent if the simulation was successful or not, later it can use this new knowledge when performing a new simulation. Of course the agent also communicates with the user and the other agents, to get information on how the situation on the sea is and also to give the user the results form the simulations.

4.4.4 The personal assistant agent

In the Baltic Watch project there are lots of different interests in motion, all the different countries involved have different interest in the system and are interested in different kind of information from the system. With help of a *personal assistant agent*, interested parties can get information without searching for the information all the time. The agent can learn the users preferences and what kind of information he is interested in and then go out on the Baltic Watch Intranet or the Internet to ask different object agents and sensor agents for information. This way the user can get a correct situation picture over the area that he wishes to monitor. One advantage is that since the agents watch the area of interest all the time it can make instant updates on the situation picture as soon as something happens. The agent should not only learn what the user is interested in, it should also learn which sensors that give information about the area of interest.

We think that this agent should of course be autonomous and learning but it must also be able to co-operate and communicate both with agents of the same type to get already collected data, but also with the object and sensor agents. This agent should also have an advantage if it is somewhat spontaneous, so if something crucial happens, like oil spill or a collision between two boats, just outside the area of interest the agent should report this as well. This means that the agent has lifelike features. There are several examples of systems with personal assistant agents that co-operate in order to share information, one example we have illustrated in previous chapter (see section 4.2.5). The C^4I system also provides a sort of personal assistant, it calculates what actions the operator can take and make suggestion to the operator.

4.4.5 Summary

The different suggestions on how to use intelligent agents in sensor systems helps to solve different problems with future distributed sensor systems. The sensor agent optimises the use of its corresponding sensor and helps to cover areas where another sensor might fail. This is achieved with characteristics such as autonomy, learning and communication. There are two advantages with the object agent, since it stores information about an object we can control each object and the same situation picture is displayed everywhere. The object agent exhibits features such as autonomy, co-operation, communication and learning. The simulation agents help to simulate different scenarios like moving patterns of objects (such as boats) or environmental changes. This way, possible scenarios can be predicted. Finally the personal assistant helps different persons or authorities to find the right information for specific tasks. These different agents are only suggestions and they do not rule out other possibilities of using intelligent agents.

As we can see the suggested agents form a multi-agent system, Not only because there are four different agent types but also because there are several agents of each type. The different agent types also communicate and co-operate with each other to reach their different goals. The sensor agent and the personal assistant agent also communicate and co-operate within their own agent group. We think that it is possible to use single-agents in sensor systems but we do not think that they will contribute as much as multi-agents. Sensor systems have a lot to gain with the idea of multi-agents being co-operating entities and this can contribute a lot to the organisation of sensor systems.

5 General discussion

Our definition of an intelligent agent is by no means a general definition applicable to every agent or agent system. Because of the disagreement among researchers and developers on the definition of intelligent agents, it is difficult to have a common understanding and perception of intelligent agents. We made our own definition for two reasons: first we wanted to get an understanding about the agent technology and what intelligent agents are, and secondly we wanted to get a common base to reason around when we applied the agent technology to sensor systems. We believe that it is easier to understand how intelligent agents can be used in sensor systems if we have a clear definition of intelligent agents, which is tailored for this investigation.

We believe that one advantage with our definition is that we strongly emphasise the importance of autonomy. Most researchers agree that agents should have this feature but they do not stress it. Another advantage that we can see is that we do not rule out any characteristic. Many researchers provide a list with agent features and thereby rule out any other feature outside the list. We, on the other hand, concentrate on the most important features but do not exclude additional features. This does not imply that agents with many agent specific characteristics are "better" agents than those with just one or two characteristics. The important aspect here is to create agents according to the domain they work in and which tasks they perform. With this in mind we made the different agent types for sensor systems. The problem with this approach is that it rules out the possibility to create agents that are general i.e. that are applicable to any problem area. A weakness with our definition is that we do not discuss the meaning of intelligence in the context of intelligent agents. The reason for this is that intelligence can be defined in so many ways and be confused with human intelligence. Another weakness might be that agents must have the ability to learn in order to be agents, the result of this is that many agents that exist today are not agents according to our definition. However, the purpose with our definition is not to create a general definition applicable to every agent, but merely to create a base for the reasoning around agents in sensor systems. This definition does not solve the problem, with the disagreement among researchers, on how to define agents.

As we have seen, agents are not just used on the Internet, they have also been used in applications for practical situations even though these systems are still quite rare. It is also possible for us to state that agents should be applicable to sensor systems, as we saw in section 4.4, sensor systems fulfils all the five criterions that Parunak put up. We have also shown examples of sensor systems that use the agent technology, i.e. the C^4I system (see section 4.2.4) and the Traffic Light systems (see section 4.2.2). We have given examples of how agents can solve problems in sensor systems and make sensor systems more effective. These examples of contributions to sensor systems could be possible to fulfil but it is impossible for us to give exact answer to how intelligent agents might help the development of future distributed sensor systems. To answer this the agent ideas have to be tested in a prototype. Some of the issues that the suggested agent types deals with are: optimisation, data correlation, information gathering and simulations (see section 4.4). One perceived advantage achieved when using agent technology to solve these issues is that the system can present a common situation picture, i.e. you get the same information either you connect to the system in Finland or in Sweden.

Agents can provide several other advantages. One advantage is that the system can be easier to decentralise, to create natural modules and help with ill-structured problem (see section 4.1). Other advantages are scalability, that it is easy to transform a pilot or prototype agent system into a real system and that agent systems are dynamic, it is easier to reuse components and add new agents. Furthermore agents can help in reducing the complexity of large systems since agents do not have to model every possible behaviour and interaction with the system. Another noted advantage is that developers can easily understand the design and structure of the system by using the metaphor of agents performing a certain task for a user or another agent (see section 4.2.4). Several other advantages can be found with agents that can help the user. One of the main ideas with agent technology is to reduce users' workload, this is illustrated by the OASIS flight traffic system (see section 4.2.1). Some examples of using the agent technology suggest that agents are well suited for systems with real-time demand as shown in section 4.1. If this were the case it would be a great advantage for sensor systems where time is a very critical aspect.

We can also make an even more radical suggestion on how to use agents in sensor systems. Bringing the agent idea to its head, the agent technology could be used in sensor systems by programming the system totally on the principals of agent-oriented programming. Then agents would not be used in specific situations to solve specific tasks; instead the agent-oriented programming would be used throughout the whole sensor system.

The problem with the agent technology is that it is a very new area. There has not yet been developed any languages or products that could help the design of agent systems. There exist some agent frameworks and languages but they are not yet commercialised or widely used. There is a need for standardisation and products that helps developers. Because of these constraints, a very high level of skill and expertise is required to develop an intelligent agent system. One consequence of this is that it takes long time to construct agent systems, which is the case with systems such as C^4I and OASIS.

Now that we have concluded that intelligent agents can be used in future distributed sensor systems, it is relevant to ask if the agent technology will survive and become a programming paradigm as the object-oriented programming paradigm. However, as researchers have pointed out, developers will not start using the agent technology unless it becomes easier to use and this can only be reached if the basic concepts of the agent technology are standardised. Then with the help of standards, tools can be developed to ease the construction of applications (see section 3.1). We believe, after visiting the conference PAAM'99 that the agent technology is going to settle down as a programming paradigm. However, we do not speculate in whether the agent technology eventually will replace object-orientation or if they will live side by side and complement each other, this is for the future to conclude. We agree with Van Dyke Parunak that there are obstacles in the way for the agent technology to succeed e.g. it must be easier to develop agent applications, and that these have to be removed before the technology can make a breakthrough. Since we believe in the future of intelligent agents and have shown that it is possible to use agents in future distributed sensor systems, we argue that Ericsson Microwave Systems AB should consider to use the agent technology in their future distributed sensor systems. Quoting Van Dyke Parunak, *"You might as well use it, because you can bet that your competitors use it"*[26]. This does not mean that agents are the best solution to everything or that agents are the miracle solution to every difficulty with developing software applications. We argue that it is important to know where and when to use agents and what advantages as well as disadvantage agent technology has. One should not overestimate the capabilities of intelligent agents, they are not the silver bullet to the software business even if they might solve many of its problems.

5.1 Conclusion

What are the actual conclusions of this master thesis? This will now be accounted for by presenting the answers according to our two research questions:

What is an intelligent agent?

As we have seen, it is difficult to make a definition of an intelligent agent and perhaps it is not necessary to make a general definition. What we can say is general is that an intelligent agent is an entity that has a goal and shall be of help to its user. According to our definition an agent should be autonomous and have the ability to learn as it proceeds, other agent characteristics should be seen as a toolbox and which tools to use depends on which domain and what task the agent shall perform.

How can the intelligent agent technology be used in future distributed sensor systems?

We definitely think that it is possible to use the agent technology in sensor systems not only due to Parunaks five criteria, which we think sensor systems fulfils, but also due to the successful development of the C^4I system. So how can this technology be used? We think that it is possible to implement a number of different agent types in future distributed sensor systems. We have labelled them: the sensor agent, the object agent, the simulation agent and the personal assistant agent. All these different kind of agents solve different problems and contribute to sensor systems differently, like optimising the use of sensors and creating a unified situation picture of the entire area. Of course there could be even more types of agents that are possible to implement in future distributed sensor systems.

[26] Van Dyke Parunak H., Lecture at PAAM'99 (04/20/1999).

We have support for our different agent types in the different systems presented but some of these systems have not yet been evaluated and we do not know how well they work. To really be able to trust these suggestions they should be implemented in a prototype and proper evaluated in a simulation.

Agents could contribute in several different ways to sensor systems. They could make decentralisation easier, reduce complexity and make the system more dynamic. Furthermore it could contribute to the developing process by providing an abstraction that developers easily can understand and it could also reduce scalability problems.

5.2 Self-criticism

We are aware of the fact that some things could have been done differently in our master thesis. First of all it would have been easier to start with one problem that exist in sensor systems and investigate if it is possible to use the agent technology to solve this problem. Secondly, to actually test if our suggestions could work in practise, would have given us a chance to validate our agent examples. Unfortunately we had to spend a lot of time to find out what an agent is and what the agent technology is all about. This meant that there was no time left to develop a prototype.

One thing that has caused a great deal of consideration is that certain knowledge we have required is confidential, including this material in our thesis would have meant classification of the work. This means that we have not included certain important aspects and therefore the chapter on sensor systems is not described especially detailed. Another thing is that we had to concentrate on how radar works, since we had contact with experts in this area, the possibility to investigate how other sensor works were limited.

5.3 Proposal to future research

This master thesis describes the area of intelligent agents and presents suggestions of possible usage of the agent technology in future distributed sensor systems. Further work in this area could show even more interesting aspects of the agent technology. We suggest that if Ericsson Microwave System AB consider to follow-up this work, they should concentrate on implementing our agent examples in a simulated sensor system environment. This would hopefully validate our agent examples and more specifically show how they could contribute to the development of future distributed sensor systems. It would also be interesting to investigate if Ericsson Microwave Systems AB should use an agent-oriented approach or implement more specific agents, representing different roles.

Further it could be necessary to investigate what level of learning the proposed agents should have, to be useful in sensor systems and how this learning ability more specifically could be implemented.

If Ericsson Microwave Systems AB believes in the success of the agent technology and are willing to invest in it we suggest that they develop an agent framework to be the base for their own agent application development. However, we believe that it would be more suitable to wait until such a framework is developed and the agent community has settled down and established some standards and development tools.

6 References

1. Akkermans, H., Andersson, A., Boertjes, E., Krejic, M., and Ygge, F. (1999), “The HOMEBOTS System and Field Test: A Multi-Commodity Market for Predictive Power Load Management”, In *Proceedings of the Forth International Conference on the Practical Application of intelligent Agents and Multi-Agent technology (PAAM’99)*, The Practical Application Company Ltd, Lancashire, pp. 363-382.

2. Anwar, A. and Franklin, S. (1999), “*TLCA, Traffic Light Control Agent*”, Technical Report, Institute for Intelligent Systems, The University of Memphis, Memphis, TN, see http://www.msci.memphis.edu.

3. Backman, J. (1998), *Rapporter och uppsatser*, Studentlitteratur Lund.

4. Baltic Watch, see http://www.civic–security.com (03/21/1999).

5. Befring, E. (1994), *Forskningsmetodik och statistik*, Studentlitteratur Lund.

6. Berney, B. and Ferneley, E. (1999), “CASMIR: Information Retrieval Based on Collaborative User Profiling”, In *Proceedings of the Forth International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology (PAAM’99)*, The Practical Application Company Ltd, Lancashire, pp. 41-56.

7. Bigus, J. P., and J. Bigus (1997), *Constructing intelligent agents with Java – A programmers guide to smarter applications*, Wiley Computer Publishing.

8. Bothorel, C. and Thomas, H. (1999), “A Distributed Agent Based-Platform for Internet User Communities”, In *Proceedings of the Forth International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology (PAAM’99)*, The Practical Application Company Ltd, Lancashire, pp. 23-40.

9. Bradshaw, J. M., Ed. (1997), *Software Agents*, AAAI Press / MIT Press.

10. Burmeister, B., Bussmann, S., Haddadi, A., and Sundermeyer, K. (1998), “Agent-Oriented Techniques for Traffic and Manufacturing Applications: Progress Report”, In *Agent Technology - Foundations, Applications, and Markets*, Jennings, N. R. and Wooldridge, M. J., Ed., Springer-Verlag, Berlin, Germany, pp. 161-174.

11. Dahlbom, B. (1997), “The New Informatics”, *Scandinavian Journal of Information Systems*, Vol. 8, No. 2.

12. Easterby-Smith et al. (1991), *Management Research – An Introduction*, Sage publications.

13. Fernandes, J.M and Oliveira, E. (1999), ”TraMas: Traffic Control through Behaviour-based Multi-Agent System”, In *Proceedings of the Forth International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology (PAAM’99)*, The Practical Application Company Ltd, Lancashire, pp. 457-458.

14. Foner, L.N. (1997), “What's an agent anyway?”, To appear in *Proceedings of the First International Conference on Autonomous Agents (AA’97).*

15. Franklin, S. and Graesser, A. (1996), "Is it an agent, or just a Program? A Taxonomy for Autonomous Agents", In *Proceedings of the Third International Workshop on Agent Theories, Architectures and Languages*, Springer-Verlag.

16. Georgeff, M. and Rao, A. (1998), "Rational Software Agents: From Theory to Practice", In *Agent Technology - Foundations, Applications, and Markets*, Jennings, N. R. and Wooldridge, M. J., Ed., Springer-Verlag, Berlin, Germany, pp. 139-160.

17. Grohmann, A. and Kopetzky, R. (1999), "An Agent-Oriented Information System for Simulating the Dispersion of Radioactive Particles", In *Proceedings of the Forth International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology (PAAM'99),* The Practical Application Company Ltd, Lancashire, pp. 437-449.

18. Harisson, C. G., Chess, D. M., and Kershenbaum, A. (1995), "*Mobile Agents: Are they a good idea?*", IBM Research Report RC 19887, IBM, Gaithersburg, Maryland.

19. Hayes-Roth, B. (1995), "An Architecture for Adaptive Intelligent Systems", *Artificial Intelligence: special issue on agents and interactivity,* 72, 329-365.

20. Hung, C.C., Peng, C.W., and Tai, J.S.W. (1999), "Mobile Agent Architecture for Agent Warehouse", In *Proceedings of the Forth International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology (PAAM'99),* The Practical Application Company Ltd, Lancashire, pp. 403-422.

21. Jennings, N. J. and Wooldridge, M.J. (1998), "Applications of Intelligent Agents", In *Agent Technology - Foundations, Applications, and Markets*, Jennings, N. R. and Wooldridge, M. J., Ed., Springer-Verlag, Berlin, Germany, pp. 3-28.

22. Koda, T. and Maes, P. (1996), "Agents with Faces: The Effect of Personification", In *Proceedings of the 5th IEEE International Workshop on Robot and Human Communication, Tsukuba, Japan, Nov.*, see http://agents.www.media.mit.edu/groups/agents/publications (05/03/1999).

23. Ljungberg, M. and Lucas, A. (1992), "The OASIS Air Traffic Management System", In *Proceedings of the Second Pacific Rim International Conference on Artificial Intelligence, PRICI'92, Seoul, Korea,* see http://www.aaii.oz.au/research/techreports/abstracts/tn28.html (03/29/1999).

24. Maes, P. (1994), "Agents that Reduce Work and Information Overload", *Communications of the ACM 37*, 7, July.

25. Maes, P. (1995), "Artificial Life meets Entertainment: Lifelike Autonomous Agents", *Communication of the ACM 38*, 11, 108-114.

26. McIlroy, D., Smith, B., Heinze, C., and Tuner, M. (1997), "Air Defence Operational Analysis Using the SWARMM Model", In *Proceedings of the 4th Conference of the Association of Asian-Pacific Operational Research Societies within IFORS*, Department of Defence, Melbourne, Australia.

27. Ndumu, D.T. and Nwana, H.S. (1999), "A Perspective on Software Agents Research", To appear in *Knowledge Engineering Review 1999*, see http//:www.labs.bt.com/projects/agents/index.htm (04/08/1999).

28. Ndumu, D.T. and Nwana, H.S. (1998), "A Brief Introduction to Software Agent Technology", In *Agent Technology - Foundations, Applications, and Markets*, Jennings, N. R. and Wooldridge, M. J., Ed., Springer-Verlag, Berlin, Germany, pp. 29-47.

29. Nwana, H.S. (1996), “Software Agents: An Overview”, *Knowledge Engineering Review, 11,* 3, 1-40, Sept.

30. Petrie, C. J. (1996), “Agent-Based Engineering, the Web, and Intelligence”, *IEEE Expert/Intelligent Systems & Their Applications 11,* 6, pp. 24-29.

31. Rantzer, M. (1996), *Intelligenta Agenter*, Utlands Rapport från Sveriges Tekniska Attachéer.

32. Reaserch Methods Knowledge Base, see http://trochim.human.cornell.edu/kb/qualmeth.htm (05/06/1999).

33. Repstad, P. (1993), *Närhet och distans – Kvalitativa metoder i samhällsvetenskap*, Studentlitteratur.

34. Silverman, D., Ed. (1997), *Qualitative Research Theory, Method and Practice*, SAGE Publications.

35. Stone, P. and Veloso, M. (1997), “Multi-agent Systems: A survey from a machine learning perspective”, Technical Report 193, Department of Computer Science, Carnegie Mellon University, Pittsburgh, PA.

36. Stout, K. (1999), “PA Expo99 Discussion Barriers to the Industrial Takeup of Agent Technology”, In *Proceedings of the Forth International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology (PAAM’99),* The Practical Application Company Ltd, Lancashire, pp. 19-21.

37. The Grace Consortium, EUCLID RTP 6.1, Intelligent agents for situation awareness and planning, see http://public.logica.com/~grace (04/22/1999).

38. Vidgen, R. and Braa, K. (1997), “Balancing interpretation and intervention in information system research: the “action case” approach”, In *Proceedings of IFIP 8.6: Information Systems and Qualitative Research*, Philadelphia.

39. Van Dyke Parunak, H. (1998), “Practical and Industrial Applications of Agent-Based Systems“, Industrial Technology Institute, see http://www.csee.umbc.edu/agents/introduction (03/05/1999).

40. Van Dyke Parunak, H. (1999), “Blue-Collar Agents: Experience and Issues in the Development and Deployment of Industrial Agent-Based Systems”, In *Proceedings of the Forth International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology (PAAM’99),* The Practical Application Company Ltd, Lancashire, pp. 3-9.

41. Wyatt, A., Sterling, L., Lu, H. (1999), “SportsFinder: An Information Agent to Extract Sports Results from the World Wide Web”, In *Proceedings of the Forth International Conference on the Practical Application of Intelligent Agents and Multi-Agent Technology (PAAM’99),* The Practical Application Company Ltd, Lancashire, pp. 255-265.

7 Appendix 1 - Baltic Watch

Ericsson Microwave Systems AB together with Saab AB and CelsiusTech Systems AB has started a project called Baltic Watch[27] which aims to increase the security in the Baltic Sea region. The whole project is a vision of tomorrow, which means that the thoughts in the project are new and it might show to be impossible to realise its goals.

The basic thought in the project is that all the states around the Baltic Sea will share information, operational resources and facilities in order to improve the security around the Baltic sea, i.e. increase the civil-security. Civil-security means that all life, property and environment shall be protected, this includes things like regional stability, border integrity, protection from illegal activities, traffic control, search-and-rescue operations, environment protection, natural-resource management, meteorology, disaster relief and telecommunications.

Objectives

With this kind of system in use the authorities will be able to monitor traffic, detect pollution and traffic and get a better co-ordinated telecommunication.

Traffic Monitoring
By monitoring the sea it will be possible to detect if a collision is at risk and warn the ships involved, this way it is possible to reduce the number of incidents that happens every year. It will also be possible to monitor ships that are important to a country for some reason e.g. ships that carry special cargo, and it is possible to monitor the exploitation of fishing resources. This is going to be accomplished by the use of GP&C, which is a transponder that can tell us the position of a ship and other important information about the ship.

Pollution and traffic detection
Pollution incidents as well as traffic that do not have transponders will be monitored using radar technology. Of course this is already done, but with the Baltic Watch the sea will be monitored much more frequently e.g. by using in-the-water-sensors. If this is done it might be possible to discover oil spill much earlier than today, and other environmental differences like change in the water movement or the salt content.

Telecommunication
Today all of the Baltic Sea is covered by something called the VHF-radio. In the future it would be a great advantage if everyone on the Baltic Sea could use GSM for communication. GSM will give all traffic above and below the surface possibility to connect to the Internet, so that ships not only can talk over the phone but also send

[27] http://www.civic-security.com (03/21/1999)

information. There is also the new technology of the Iridium telephone that can be very useful for early warning and surveillance systems.

Organisation and Information

Another purpose with Baltic Watch is to make information about the situation, available to every country in the region. This is achieved by a large integration of different systems (see figure 1).

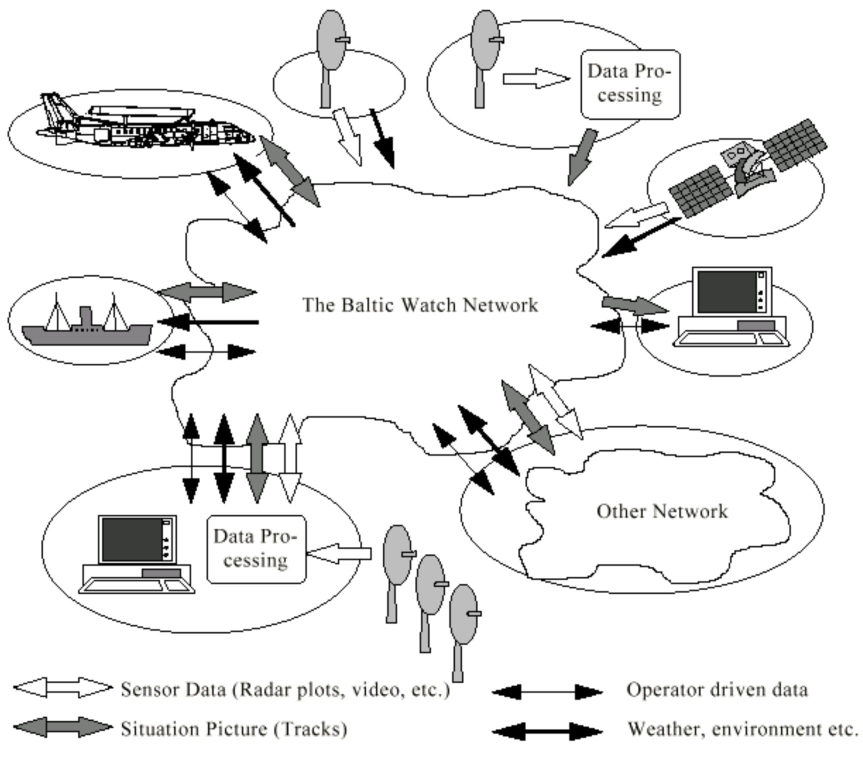

Figure 1, The architecture for the Balitic Watch system

This systems architecture will integrate different sensors, telecommunications, databases and command- and control centres. These facilities are shared among the concerned authorities and agencies in the different countries. One way to distribute this system is to use the Internet and/or Internet based applications, this can give every participant in Baltic Watch with access to the net, a possibility to be an active part in for example a search and rescue mission. An Extranet, is meant to be developed to connect the local Intranet networks among agencies and authorities. It is recommended that a common organisation should be responsible for organising rules, recommendations and system integration. It is also recommended that each country should have a large degree of freedom regarding local implementation.

Different kinds of sensors that could be used in the Baltic Watch are for example; coastal radar, air surveillance radar, airborne radar, underwater sensors and satellite based sensors. *Coastal radar*, are existing radar systems along the coast of the Baltic Sea. Air surveillance radars, are radars that monitor the air space to control the air corridors and identify aircraft. Even *radars that are airborne* can be used; these radars can be placed on aircraft and have the advantage that it is easy to change to another surveillance area. *Underwater sensors* do not yet exist but are important for surveillance of the water condition and environmental protection. They could also be used to guard specific objects in the water to ensure detection of trespassing. *Satellite based sensors* can be used to map different objects in the Baltic Sea like monitoring of ships, alga blooming, weather etc. *Sensors on buoys* are usually environmental sensors that can take oceanographic measurements. Some of these sensors exist today and others must be implemented to monitor the today uncovered areas. By integrating these different sensor systems almost the entire sea and shore can be monitored.

The first steps have been taken to realise the Baltic Watch project, and other countries monitor the progress with great interest. Examples of such countries are Egypt who would like to monitor the Suez-canal and Brazil, who needs to monitor the amazon.

8 Appendix 2 – Interviews

Date for each interview

990401 Interview A
990330 Interview B
990420 Interview C
990305 Interview D
990409 Interview E
990412 Interview F

Used method

Unstructured interviewing. Each interview lasted between one and two hours.

Questions on intelligent agents

The questions asked were different with different researchers depending on what relation the interviewees has with intelligent agents. Since the interviews were unstructured and informal the questions were asked when suitable and new questions were raised during the interviews.

The main directions and most important questions asked are presented below:

Questions on agent definition:

- How would you define an intelligent agent?
- What specific characteristics should an intelligent agent have?
- Is intelligence an important agent characteristic?

Questions about mobility:

- Does mobility work in practice or does it only exist in theory?
- Have you encountered any system that uses mobile agents?

Questions on single and multi-agent systems:

- What would you say is the difference between single and multi-agent systems?
- Have you encountered any practical multi-agent systems?

Questions on constructing intelligent agents:

- Do you have practical experience of constructing agents?
- Was it difficult?
- What was the purpose with the agent?
- What difficulties did you encountered in creating the agents?

Questions about the future:

- How do you think the agent technology will develop?
- Where (what areas) will agents bee used in the future?

Questions on sensor and sensor systems

Before the interviews on sensors and sensor systems we did not have much knowledge in the area. Therefore the questions were very general and we allowed the interviewee to describe the area as much as possible.

Below follows some of the main questions asked:

- How does one sensor work?
- Can several sensors work together?
- How are sensor systems organised?
- How does the communication between sensors work?
- What are the main problems with sensors and sensor systems today?
- Why is it that several sensors cover parts of the same area?
- How is the situation picture created?

9 Appendix 3 – Conference

PAAM'99 – The Fourth International Conference on The Practical Application of Intelligent Agents and Multi-Agent Technology, London 19-21 April 1999

The conference was divided into six tracks that contained three to six different lectures. The lectures were presentations of research progress on intelligent agents and multi-agent technology. Besides the papers accepted at this conference several posters where presented. These posters were not accepted to the conference but were considered to be interesting enough to be presented at a poster session. Below the different tracks are shortly described.

Agents for Managing Internet Communities

This track included papers that described information agents. The systems presented used the agent technology for creating communities where people via their agent can meet and exchange knowledge and information.

Agent Architectures, Frameworks and Platforms

The lectures presented agent architectures developed by different researcher.

Agents for Network Management

This track included presentations that showed how agents can be used to mange and control networks.

Agent-based support for Electronic Commerce

The lecturers presented systems for electronic commerce and here agents where mostly used for representing information.

Agent-oriented Information Management Systems

The lectures presented two different kinds of systems that were developed for managing information. The systems handled agents that one way or another found, sorted and/or filtered information on the Internet. The other kind of systems presented agents in larger practical applications.

Agents for Production Planning and Resource Management

Presented systems that were developed for making industrial systems more effective and how the agent technology was used to achieve this.

Panel discussion

During the last day of the conference a panel discussion on the subject "Barriers to the Industrial Take-up of Agent Technology" was held.

The Researchers who participated in the panel discussion were:

E H Mamdani F.Eng, Imperial Collage, London
Anand S. Rao, Mitchell Madison Group, Melbourne
Norman Sadeh, European Commission, Brussels
Kate Stout, Sun Laboratories, Burlington, MA
H. Van Dyke Parunak, ERIM Center for Electronic Commerce, Ann Arbor, MI