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AGENT BASED SYSTEMS: THEORETICAL AND PRACTICAL GUIDE

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ABSTRACT

Purpose of this paper is to review the literature of Agent Based Systems. This research area became popular since 1980's within Distributed Artificial Intelligence domain. Even though, it is a new emerging research area many research studies are performed regarding to its theory and practice. Moreover, there are many debates regarding to definition of Agency notion. By this review issues regarding to this notion is tried to be clarified by mostly citing reviews of Jennings et. al. and Jennings and Wooldridge. With this respect, from theory to practice every aspect of agency is tried to be explained.

Keywords: Agent Based Systems

1. INTRODUCTION

One another day comes to an end, you are exhausted when you come home and time is getting closer there is a research project that you still have to do. There are a lot of publications like papers, books that you have downloaded from internet but who would read them all. Moreover, you do not even know whether these documents, which you found by searching some keywords, are really appropriate to your subject area or not. Alas! If only somebody would have come and just put corresponding publications even by highlighting related texts in front of you among hundreds of papers and books. Do not you have a personal library agent yet? Perhaps if you had a personal agent that is autonomous and situated in your computer to archive your electronic documents according to your interest areas and inform you about unnecessary documents, then writing your research project task would become very pleasant. Likewise, would it complete your project! Oh, do not be so impatient.

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Software world that covers wide application areas provides diverse software products to its end-users. Recently, new demand trend is formed in software products that are autonomous, situated, goal driven and social proactive and so on. In some cases requirements in developing these products became so interesting such that mental qualities that are peculiar to human are needed to be represented. Because of these expectations agent notion is born in the domain of Distributed Artificial Intelligence (DAI) even it is controversial.

When origins of agent notion is concerned, it can be found that pioneer of Artificial Intelligence (AI) John McCarthy puts forward the agent term in the middle of the 1950's and after a few years agent term is conceptualized by Oliver G. Selfridge. According to their view agents are softbots that perform action in computer environment where they are situated. Some researchers put forward that agent are needed to be concerned as intentional systems that is formalized by Dennett. In 1994 Singh asserts many pragmatic and technical reasons to support this statement. Among these reasons, agent abilities that include understanding and explaining complex system behaviours and reasoning about intentions of other agents are the most significant.

By using Artificial Intelligence techniques intelligent tool can be developed and these tools act heuristically in different environments; therefore they can also be considered as agents. For all assertion on agents should be at the core of the Artificial Intelligence, intelligent agents subject is ignored for long time. Change in this attitude has occurred in 1980's, at that time researchers of Artificial Intelligence start studying on isolated constituents of intelligent behaviour like learning, reasoning, problem solving, etc… One assertive definition of agent term can be given as a subfield of information systems that tries to represent some aspects of intelligent behaviour and according to this description agent term is the essence of AI.

Many agent definitions is put forward until now. Like intelligence term, researchers have not yet come to an agreement on the definition of agent term. Moreover, in 1995 Wooldridge and Jennings proposed weak and strong agent expression. According to their declaration situated, social, reactive and goal-directed software can be classified in the notion of weak agency. On the other hand, strong agent term not only covers the given weak agency notion but also requires representation of peculiar attributes of human beings like mental and emotional properties.

In the same year Russell and Norvig defined agent concept as entities that sense their environment by their sensors and act according to their senses by their effectors in their environment. According to Maes, autonomous agents are situated in complex and dynamic environments in order to achieve some special tasks or aims. He continues by saying that they are digital systems which sense and act autonomously in their environment. As a result, Nwana states that agent term is like umbrella which covers many diverse agent types.

In 1998 by "A Roadmap of Agent Research and Development" Jennings et. al. defines agent term by the following expression: "an agent is a computer system, situated in some environment that is capable of flexible autonomous action in order to meet its design objectives.". By considering both Nwana's and Jennings et. al.'s definitions, given expression can be accepted as the minimal sets of components that an agent should have. In the past, even simple automatas are sometimes considered as agent because of definition deficiencies. Therefore, situatedness, autonomy, and flexibility are the key factors of agency and it is tried to explain these features subsequently.

By the term of situatedness software system that is capable of getting sensory data and performing actions to change its environment is implied. Environments that agents are situated can be internet or physical structures. Agents are different from disembodied expert systems due to this property.

Autonomy infers a system that can perform action without assistance of human or other agents. Moreover, this system has the ability to control its internal state and its actions. Russell and Norvig go further and append that agents are the systems that can learn from its experience. This assertion gives stronger sense of autonomy.

As stated by Jennings et. al. only situated and autonomous systems should not be considered as agents. There are a lot of instances of these systems like thermostat and nuclear reactor control systems. Even tough these systems are situated and autonomous process control systems, absolutely they are not agents.

Flexibility is the last feature that an agent should have, in other words, agents should be capable in performing flexible action in order to accomplish their design objectives.

Moreover, flexibility has three constituents: responsive, pro-active and social. Systems that can understand its environment and respond to the changes that occur in its environment are called as responsive. Pro-active systems can perform actions and take initiative according to their objectives. Finally, social term infers systems that are able to interact with humans and other agents and help them in their activities.

Besides these given attributes, in the literature there are many other properties like mobility, honesty, benevolence, rationality and sensibility. In some special applications it is probable to ascribe these mental qualities to agents in order to meet some specific objectives. On the other hand given three attributes constitutes essence of agenthood. Moreover, these properties are the key paradigms that clarify the difference of agent systems from the other systems like object-oriented software, distributed systems and expert systems.

Interaction between an agent and its environment should be evaluated when it is considered that agents are only a computer system. By this manner, issues surrounding agent and environment can be clarified when mentioning about agents that have prescribed properties. As seen in the Figure 1., agents sense their environment by their sensors and act in the environment where they are situated by their effectors. Effectors and sensors are the parts of the agent as seen in the given agent based system in Figure 1. In other words, they represent two separate components that are not part of the controller. Controller's duty is to get data from sensors and control effectors.

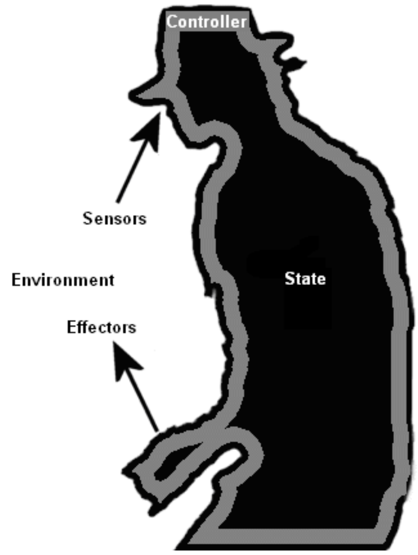

Figure 1. Visual representation of an agent.

State of the agent determines the action that is going to be taken according to sensations. In the beginning it is thought that agent should have known all the information surrounding its design objectives. Therefore, human like behaviour can be represented by an agent in this manner. On the other hand, it would cause computational problems. Determinism like Laplace and Newton (i.e. knowing everything by explaining them in cause and effect relations) would result in requirement of infinite information representation in state of the agent. In contrast to this situation, state should be finite. In other words, by giving free-will to the agent environment can be defined as indeterminate and problems are going to be resolved. While mentioning about an agent, having a free-will means that agent has choices.

2. THEORETİCAL INFRASTRUCTURE OF AGENCY

2.1. Intentional Systems and Agents

Intentional systems have become the basic building block of theoretical infrastructure of agency. Dennett puts forward three attitudes in order to understand systems that interact: physical stance, design stance and intentional stance. To understand computer systems usually intentional stance is utilized. In order to achieve this; beliefs, desires, intentions, likes, dislikes and other mental qualities of computer programs have to be ascribed. Dennett mentions that intentional systems have different levels of intentionality. First-order intentional systems have only beliefs and desires. On the other hand, second-order intentional systems have beliefs and desires on beliefs and desires including those of others and their own. By this assertion Dennett does not only infer beliefs and desires but also means other intentional stances.

McCarthy goes further by stating in which conditions intentional stance is to be ascribed to machines. According to his opinion, it is more appropriate to use intentional stance for agents and machines when such an ascription expresses the same information about them that it expresses on person. On the other hand, very simple things like automata can also be characterized by intentional notion. From this point of view, it can be expressed that only intentional stance is not sufficient for conveying agents. But also it provides a good theoretical infrastructure.

In the frame of this reference, attitudes that forms intentions consists information attitudes and pro-attitudes. While information attitudes cover knowledge and belief; pro-attitutes include desire, choice, commitment, intention, obligation, etc... Jennings and Wooldridge gives the following explanation regarding to information attitudes and pro-attitudes:

> "Thus information attitudes are related to the information that an agent has about the world it occupies, whereas pro-attitudes are those that in some way guide the agent's actions. Precisely which combination of attitudes is most appropriate to characterise an

agent is, as we shall see later, an issue of some debate. However, it seems reasonable to suggest that an agent must be represented in terms of at least one information attitude, and at least one pro-attitude. Note that pro- and information attitudes are closely linked, as a rational agent will make choices and form intentions, etc., on the basis of the information it has about the world."

2.2. Representation of Intentional Notions

Many methodologies are put forward to represent intentional notion within logical framework. Most important issue of agent theories is to define the relations between different attitudes. Therefore, these methodologies have importance in reasoning about intentional notions.

Basic logic has two fundamental problems in representing intentional notions. First of these problems is syntactic and the second one is semantic. Usually intentional notions like belief and desire cover so connotational expressions that it is nearly impossible to apply basic logic. In other words, their content does not allow applying basic logic. To express it frankly, basic logic explains events as true or false. Therefore, it cannot represent beliefs and desires which are referentially opaque.

When mentioning about a belief, it must be formulated. By using first-order logic representation, assume that the following statement represents an intention that is a belief of Ahmet which means Ahmet believes in that Lao Tzu is the writer of the two-chapter-book The Way and Its Virtue: "Belief(Ahmet,Writer(Lao Tzu, The Way and its Virtue))". In first-order logic belief term should refer to something that represents both the word of belief and formula that expresses syntactic knowledge. With this respect, there is a semantic problem regarding to this representation since this expression cannot explain a formula by itself. Other problem in classical logic is related to supreme deity. Actually most of the people know "Tao" but not "Lao Tzu". Moreover, these two names are representing the same person. In the frame of this reference, "Belief(Ahmet,Writer(Lao Tzu, The Way and its Virtue))" and "Belief(Ahmet, Writer(Tao, The Way and its Virtue)) should have the same meaning but in classical logic these representations are not the same. Because believing that the writer of The Way and its Virtue is Lao Tzu and believing that the writer of The Way and its Virtue is Tao is not the same thing. This state is called as the semantic problem of the first-order logic. Moreover, it must be stressed that in one of his speech Tao says that "Tao which can be named as Tao is not true Tao.". If this sentence is also considered the semantic problem would become much more complex!

To overcome syntactic problem using meta-languages is the first solution. By using meta-languages intentional notions can be represented and axioms are considered as suitable. The other alternative for syntactic problem is to use modal logic which includes non-truth-functional modal operators. Possible worlds model is offered to cope with semantic problem. But possible worlds model has a big gap which is called as logical omniscience problem that infers agents should know everything as in Newtonian determinism. Therefore, many alternatives to the possible worlds model are proposed.

2.2.1. Meta-Languages

Superficially meta-languages are languages that have the power of representing one another language in itself. By using meta-languages, some locutions in object languages can be represented symbolically to describe agents with some formulae. Even tough meta-languages have obvious benefit in this problem, they are said to have some inconsistencies.

As stated before "Belief(Ahmet,Writer(Lao Tzu, The Way and its Virtue))" is representation in first-order logic. If it is represented by using a meta-language, it could have been as follows: "Belief(Ahmet,⌈Writer(Lao Tzu, The Way and its Virtue)⌉)". If ⌈…⌉ notation denotes an object language formula that signifies meta-language term then it can be expressed that in this manner some formulae are represented in the frame of first-order logic.

2.2.2. Modal Logic

Present-day agent theorists utilize modal logic which is proposed by Lewis in 1918 in order to overcome contradictions in propositions of first-order logic. Before going in details of modal logic and its operators, classical symbolic logic is to be concerned. In 1911 Russell and Whithead developed modern logic which is symbolic on the basis of classical logic that is also called as logic of Aristotle.

In symbolic logic while explaining simple expressions atoms or propositional variables that are roman letters in lower case like “p,q,r,...” are used. More complex expressions are represented by using logical operators. First logical operator is represented with (¬) or (~) symbol and it means “not”. If “p” propositional variable represents “Weather is rainy.”, then “¬p” would mean “Weather is not rainy.”.

In order to represent compound expressions, simple expressions are changed by using other logical operators. Other logical operators and their meanings are as follows: “and (&)”, “or (˅)”, “if…then (→)” and “if and only if (↔)”. If “q” represents “Ground is wet.” proposition and “r” represents proposition of “Weather is rainy.” then “q↔r” representation means “Ground is wet if and only if weather is rainy.”

Modal logic is developed by adding two logical operators to the classical logic. These operators are “necessarily (□)” and “possibly (◊)”. In this symbolic representation “□p” means “It is necessary that p” and “◊p” means “It is possible that p”. With this respect, “□p” infers the following expression “It is necessary that weather is rainy.” and “◊p” infers the following proposition “It is possible that weather is rainy.”.

If A = {p, q, r..}is assumed as set of atoms that can be counted then syntactic rules of modal logic can be given as follows: (1) If p Є A then p is a formula; (2) If § and ψ are formulae then “¬§” and “§ ˅ ψ” are also formulae; (3) If § is formula then “□§” and “◊§” are also formula.

Modal operators’ semantics are defined by introducing accessibility relations into models for the language. If “§” is true in current world and every accessible worlds then “□§” formula is also true. If “§” is true in at least on accessible world from the current world then “◊§” formula is also true. Moreover, modal logic operators are dual of each other. The following expressions explain duality:

“□§ ↔ ¬◊¬§” “If necessarily § and only if not possibly not §.”
“◊§ ↔ ¬□¬§” “If possibly § and only if not necessarily not §.”

Modal logic has two basic properties that can be explained by axioms. First property is as follows: "□(§ → ψ) → (□§ → □ψ)" and the second one is as follows: "if § is valid, then □§ is valid." First axiom is called as K and the second one is called as necessitation rule.

While explaining necessitation only "K" is not sufficient. Therefore, in modal logic there is one another valid basic axiom and by some authors this axiom is called as "M", while the others call it as "T". This axiom corresponds to reflexive accessibility relation and it is represented as "□§ → §". When together with "K", they form basic modal logic. If "§" propositional variable represents "Earth is spherical" proposition then reflexive accessibility relation can be exemplified as follows:

M: "□§ → §" "If it is necessarily that earth is spherical then earth is spherical."

Some of the logicians put forward that when expressing necessity and probability "M" axiom is not still enough. Therefore, they assert new axioms to be utilized in modal logic. Most common known axioms are as follows: "D: serial accessibility relation", "4: transitive accessibility relation" and "5: euclidean accessibility relation".These axioms are the properties that corresponds to accessibility relation.

D: "□§ → ◊§""If it is necessarily that earth is spherical then it is possible that earth is spherical."
4: "□§→□□§" "If it is necessarily that earth is spherical then undoubtly it is necessarily that earth is spherical."
5: "◊§ → □◊§" "If it is possibly that earth is spherical then probably it is necessarily that earth is spherical."

These axioms can be used together. For instance when "4" and "M" are used together, S4 system or "4M" is obtained. Likewise by using "5" and "M" together, S5 system or "5M" is obtained. It can be put forward that there is no difference between "undoubtly A is necessary" and "A is necessary". On the other hand, using these axioms together has much importance in theoretically defining intentions of agents.

2.2.3. Possible Worlds Model

Hintikka proposed possible world model for epistemic logic and doxastic logic. It is now formulated by using techniques of normal modal logic that is developed by Kripke. In semantic context possible world model is logically expressed by using epistemic logic that is formulized in modal logic. In epistemic logic, to use modal logic "□§" formula is assumed as "It is known that §". In possible world modal beliefs of agents are represented by a set of possible worlds in such a way that agents have knowledge about possible worlds and reason about set of possible worlds in the view of this knowledge.

To clarify possible worlds model agent that plays bridge game by using Aces Scientific declaration system can be given as example. Bridge is a card game that is played by four player two of which form one team. Team members sit facing each other and they use a declaration system like Aces Scientific System to talk to each other at the beginning of the game. By using declaration system team members decide following issues if they intend to enter the auction with either by a call or by a bid: (1) How many tricks can they take?; (2) Do they intend to play game with trump or without trump (no-trump)?.

Like in many card games, bridge is also played with a single deck of cards. In one deck there are 52 playing cards and these cards include 13 spades (♠), 13 hearts (♥), 13 diamonds (♦) and 13 clubs (♣). Each type of these include following cards which is given from the biggest card to the smallest card: "ace (A), king (K), queen (Q), jack (J), ten (10), nine (9), eight (8), seven (7), six (6), five (5), four (4), three (3), two (2). In the beginning of the games 13 cards are dealt out to each player randomly. Bridge is one another trick-taking game. To play chess game, players assign points to the cards which they have on hand and according to the sum of these points they form their declarations. When a player enters the auction by using their declaration system, its teammate tries to guess his partner's card combination on hand. Moreover, if their opponents' enter the auction and only if players know their opponents' declaration system, and then they can also try to guess which cards their opponents' have.

In such type of card game, when the game cards are first dealt none of the players know their cards. Therefore, in the beginning possible worlds for each player are card alternatives that include only combination of 13 cards within 52 play cards. After cards are dealt if bridge playing agent takes its cards and takes a look at them then he can extract his from 52 cards to guess the other players cards combination. After knowing its cards, possible worlds for the other player becomes a narrow set of alternatives that covers only combination of 13 cards within 39 cards that is obtained by removing its own cards on hand.

Bridge playing agent, who use aces scientific declaration system, may first enter an auction by saying 1 ♠. This decleration implies that agent would like to bid the game and play spade (♠) as trump. Moreover, hes declares to his partner that he has 13 or more points on hand. In bridge game usually points are assigned to cards as follows: ace – 4 points, king – 3 points, queen – 2 points, jack 1 point. Besides in order to enter an auction with 1 spade, player should have at least five spades. When turn comes to agent's partner if he declares that 2 ♠ that implies that he has at least four spades and he has enough points to support agent. At a point of that time agent can reason about possible worlds that represents each alternatives that its teammate has. Its teammate should have at least 4 ♠ and agent should guess the combinations among the other 39 cards which includes 4 ♠ or more ♠. Each of these combinations represent an alternative which is called as possible world.

Player give decision on how many trick will they take and will they play the game with trump or without trump (no-trump) at the end of the auction. After clarifying these issues teammate of the first declarer of who win the bid opens its hand. Assume that bridge playing agent and its teammate agreed on 4 ♠ and it means that they plan to take 10 tricks in a game.

Assume that agent and its partner have the cards that are shown in Figure 2. After his partner put his cards on the table every player will be able to see that cards. In the view of the given figure agent will be able to reason about their opponents' cards. There are 26 cards that is unknown

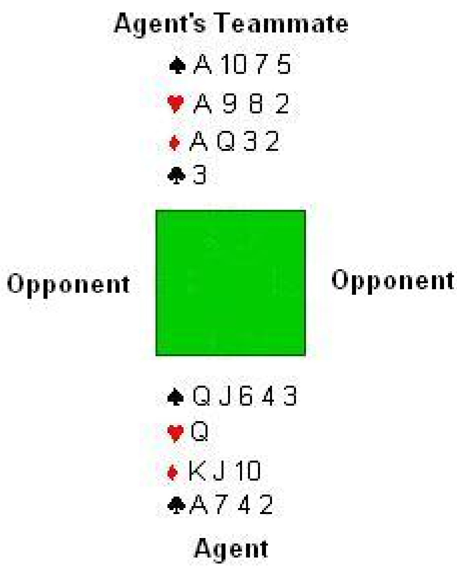

Figure 2. A chimerical card distribution. Cards of bridge playing agent and its teammate are shown.

by the agent so its opponents should have combination of 13 cards distribution among the other 26 cards. With this respect, each alternative represents one of the possible worlds.

Hintikka puts forward epistemic alternatives term by considering that each alternative distribution in possible worlds model represents a state. By this term possible worlds are tried to be defined regarding to someone. Each epistemic alternative is accepted as a belief that belongs to an agent. In this model worlds are considered as epistemic alternatives and from a given world which worlds are accessible is defined by accessibility relations.

When there are many agents to arrange each agent's information, indexed set of accessibility relations are to be added to this model for each agent. Therefore, an indexed set of unary modal operators K_i (where $i \in 1,\ldots, n$) is used instead of logical operator "□". By giving the same semantics to K_i as "□" then "K_i §" means "i knows that §". With this respect, information regarding to agent i is defined in this manner.

When considering representing belief or knowledge by using modal logics, there is difficulty regarding to axiom "K" and necessitation rule. "K" axiom and necessitation rule imply that agent should know all symbolic expressions and agent is put under the care of a guardian of its logical consequences of its beliefs. Therefore, logical omniscience problem arises. As a result, it causes Newtonian determinizm that makes it impossible to utilize possible worlds semantics in real world situations.

If axioms "D", "M", "4" and "5" are considered, it can easily be deducted that axiom "D" implies that beliefs of agents are non-contradictory. In other words, "If i knows that §, then i do not know not §": "K_i § $\rightarrow \neg K_i \neg$§". "M" axiom shows the difference between knowledge and belief; therefore, usually knowledge is defined as true belief: "i knows that § if i believes that § and § is true". With this respect, defined knowledge satisfies "M" axiom.

Axioms "4" and "5" are called as inrospection axioms. "4" which is positive introspection axiom implies that agent is aware of the things it knows. Likewise, "5" which is negative introspection axiom refers that agent is aware of the things it does not know.

As it is explained before these axioms can be used together. With this respect, "KMD45" axioms are called as a logic of idealised knowledge and "KD45" axioms are considered as a logic of idealised belief.

2.2.4. Alternatives of Possible Worlds Model

Regarding the problems of logical omniscience, researchers begin to search thoroughly new approaches to represent beliefs and they adopted possible worlds model. Moreover, some other researchers proposed wholly new approaches which have no roots in possible worlds model.

Most commonly known alternative of possible worlds model is sentential, or interpreted symbolic structures approach. This approach represents belief in a particular data structure symbolically. Each belief is associated with an agent. If "§" exist in agent's data structure, then it is assumed that agent believes in "§". Other alternatives of possible worlds model belief and awareness, deduction model and pro-attitudes: goals and desires.

Belief and awareness approach focuses on solving logical omniscience problem. According to this approach belief is categorized as explicit and implicit belief. According to this approach agents have set of narrow explicit beliefs and set of very large implicit beliefs. These implicit beliefs are the logical result of explicit beliefs. Two operators are developed for representing explicit and implicit beliefs by Levesque. Weakened possible worlds semantics is used for explaining the semantics of explicit belief operator. On the other hand, semantics of implicit belief operator is given by using possible worlds model.

One another alternative is deduction model and it is developed by Konolige in 1986. This model aims to model beliefs. Deduction model is typical instance of knowledge based systems and it consist two main components. First component is formulae that is given in terms of some logical languages to represent beliefs. The other component is logically incomplete inference mechanism. According to this approach, when it is possible system applies inference rules then generates its beliefs.

Pro-attitutes: goals and desires is the other alternative that is adotion of possible worlds semantics. According to this approach desires bring forth goals. However this approach is criticized for having a side effect problem; since, in some cases agents should be able to have goals without having desire.

2.3. Agent Theories

Most critical obstacle of agent theories is to represent properties of agents in the logical framework. While defining these properties, undoubtly interaction between each of these properties should also need to be determined. When determining relations how alterations and interactions like change in the cognitive states of agents according to change in the time occur must be defined. In the previous sections of the paper, only one aspect agency is considered but in this section studies that combine properties is examined.

Moore researched on the things that should be known by an agent. He studied on determining pro-attitudes regarding to actions. By the model he developed, he recommended which actions are to be performed in case of incomplete information. He determined how agents should achive its objectives with incomplete information.

According to intention theory: intentions cause problems that are needed to be solved by agents, in order to prevent conflicts in intentions filtering is required and agents perform actions until they reach their goals even if they fail in some cases, agents believe that their intentions are possible and agents believe that they bring about their intentions. According to these criterias Cohen and Levesque proposed a new approach. They developed logic of rational agency and partial theory of rational action. Logic of rational agency is defined in terms of relations between other modal logic operators.

There are a lot of proposals on determining combination of attitudes that are required to build rational agent. Most popular of these approaches is Belief, Desire and Intention that is put forward by Rao and Georgeff. As it can be understood from its name this approach includes three component: belief, desire and intention. Beliefs corresponds to the information that agent has about its environment. Desires represent possible alternatives that can be chosen by agent. Intentions are the choices of the agent. Practical reasoning occurs by updating belief continuously and comparing possible alternatives; therefore, to determine new intentions alternatives are filtered and according to these intentions actions are performed.

3. AGENT ARCHITECTURES

As explained, agent theories focus on reasoning about agents and defining agent properties in a logical framework. On the other hand, agent architectures try to define methodology for building agents. This methodology defines a set of component modules and interaction between these modules. Since 1980's, many diverse agent architectures are put forward and these approaches can be categorized in three groups: deliberative, reactive and hybrid architectures.

Chronologically deliberative architectures are the pioneer approach that is put forward. Afterwards, reactive architectures are developed in order to overcome obstacles of deliberative architecture. Neither deliberative nor reactive architectures is able to provide good enough solutions to real world problems; therefore, finally hybrid architectures asserted to combine deliberative and reactive architectures.

In the beginning knowledge based systems are put forward to represent intelligent behaviour. Physical symbol system hypothesis formulated to combine to form structures and operate symbols. These systems in practice are constitutions that ask questions, give answers to these questions, give advice and make decisions. In order to operate, these systems require a knowledge base. Required knowledge symbolically is given in the system at the phase of development. In this manner these systems said to be generate intelligent action.

Planning systems are one another example of deliberative architecture pioneer of which is STRIPS. This system takes symbolic desired goal state, set of actions and definition of real world. Set of actions cover pre- and post- conditions of the actions. In this manner actions are defined deterministically. This type of planning systems searches all of the possible alternatives and makes a decision. Most important obstacle of these systems is regarding to searching all alternatives and making a decision in a time-constraint situation.

Symbolic Artificial Intelligence community spent much effort on constructing agents that are deliberative. Some other commonly known instances of deliberative architectures are IRMA, HOMER and GRATE. Although community studied hard on developing agent architectures that based on explicit representation, symbolic model of world and make decisions by logical reasoning deliberative agents are criticized as not applicable in practical real world situations.

Rodney Brooks is the first researcher who criticized traditional symbolic Artificial Intelligence. According to these critics he put forward new research area. His ideas base on two findings; real intelligence is not disembodied, it is rather situated in particular environments; and interactions between intelligent entity and its environment constitutes intelligent behaviour. His ideas gave birth in subsumption architecture that is the first reactive architecture.

Three key theses form the infrastructure of this alternative approach. First, First, intelligent behaviour can be generated without explicit representation. Second, intelligent behaviour can be simulated without explicit abstract reasoning. Finally, intelligence is the emergent property of certain complex systems. According to these theses subsumption architecture is founded. It does not have explicit symbolic representations and do not reason according to explicit abstract reasoning.

Subsumption architecture is applied in some applications. Situation and action rules are utilized for mapping in these applications. In this manner current state of the agent determines the actions that are going to be taken. Reactive systems perform actions regarding to current information and they have no information related to the past knowledge.

Real applications of Brooks were more complex; they were getting feedback from the past decisions and perform actions accordingly. In those systems interactions between the behaviour determine the actions that are going to be performed. Brooks' architecture is a layered architecture. Less abstract behaviours are performed by the lower layers; on the other hand, upper layers of the system take more abstract behaviours.

Diverse reactive architectures are proposed by architectures in due course. PENGI, situated automata and agent network architecture are some of the successors of subsumption architecture. Even tough reactive architectures have disadvantages; they are simpler than deliberative architectures. Some disadvantages of reactive architecture can be given as follows:

- These architectures do not employ models of their environment; therefore, performing appropriate actions is not possible in each time
- Current state of the agent defines the decision making process,
- Building agents that can learn from experience is not possible, and
- Interactions between behaviour of agents define agents' actions and this gives result in problems in performing agents' duties.

In 1990's many researcher assert that neither reactive nor deliberative architecture is suitable for real world problems; because, both of these architectures have some deficiencies. According to this view, researchers start studying on hybrid architectures that combine deliberative and reactive architectures. Hybrid architectures have layered structure as subsumption architecture has.

Layers of subsumption architecture were vertically arranged. On the other hand, hybrid architectures can be arranged either vertically or horizontally. In horizontal layering perception is performed by every layer and actions are controlled by every layer. In vertical layering reactive layer is at the lowest level of the hierarchy. While middle level of the architecture deals with knowledge level view of environment of agent, the uppermost level of the architecture represent the most abstract view.

There are many successful applications of hybrid architectures. Touringmachines, Interrap and Cosy are the pioneer applications of hybrid architectures that are developed according to this layered architecture. Touringmachines architecture has three control layers and perception and action subsystems. Subsystems of action and perception interface with the environment. Control layers perform controlling function and mediate between layers. Activities are produced by each layer independently.

One instance of Belief, Desire and Intention is hybrid architecture that is called as Cosy. The architecture has sensors, actuators, communications, cognition and intention. Sensors receive perceptual input, actuators ensure to perform actions and communications send messages. Long term goals, attitudes and responsibilities are covered by the intention component and cognition component mediate between intentions and choose actions to perform. Interrap is also a layered architecture and higher layers represent higher level of abstraction. From bottom to top world interface, behaviour based component, plan based component and cooperation component are layered hierarchically.

Recently Aydin proposed a reactive-causal architecture that can be considered as hybrid architecture. Even though main frame of this architecture is defined in the book called as "Distributed Artificial Intelligence: Story of Reactive-Causal Architecture", this architecture is still in the development phase. Main purpose of this architecture is to simulate causal structure of human intelligence. Currently, this approach goes further and gives a radical role to emotions in decision making process.

4. AGENT PROGRAMMING LANGUAGES

Software development tools that are designed to develop applications of agent technologies are called as agent programming languages. The difference between agent programming languages and the other programming languages is that agent programming languages are designed with the capability of representing mental notions. Many agent programming languages and tools are developed including following instances: concurrent object languages, agent oriented programming, Placa, concurrent Metatem, April, May, Telescript, Able and Zeus.

Concurrent object language that is the ancestor of agent language is developed to execute objects concurrently autonomously. These systems can send messages to other objects with some internal state which is indirectly accessible to the environment. ABCL system and Actor model are the first instances of concurrent object languages. Without needing others, actors form autonomous components of interacting computing systems that communicate by asynchronous message transferring.

Many applications of Belief, Desire and Intention system is developed, the most commonly known of these systems is procedural reasoning system. This system is an instance of practical reasoning architectures and it gave a basis for one of the pioneer agent programming language that is proposed by Shoham. Shoham's agent oriented programming language focuses on social view point of computation.

Agent oriented programming is based on directly programming agents in terms of intentional notions paradigm. Shoham proposes that three components are to exist to develop complete agent oriented programming system. First component is recommended as logical system that defines mental state. To program agents, second component is defined as interpreted programming language. Final component is denominated as agentification process by Shoham to imply compiling agent programs. First developed agent oriented programming language is AGENT0 system. Belief, commitment and ability were the three modalities that are covered by this system. This system is intended as a prototype.

First commercial agent language is developed by General Magic Inc. and it is denominated as Telescript. This technology is covering many methods and notions; in this manner, it provides language based environment t develop agents. Places and agents are the two key concepts of this system. Agents that can be developed by this system are applications of customer and providers that are in an electronic marketplace.

Even though these given systems are develop for specifically developing agent based systems; there are some other applications which are developed by using general purpose programming languages and artificial intelligence programming languages. With this respect, C++, lisp and prolog programming languages are utilized in order to develop agent based systems.

5. MULTI AGENT SYSTEMS

Agent Based Systems notion is concerned with isolated components of agents. With this respect, Agent Based Systems are developed and implemented in terms of agents. Systems that include more then one agent are called as Multi Agent Systems which is one instance of Agent Based Systems. There are some cases only single agent usage is required but in some situations more agent usage becomes necessary. In these situations Multi Agent System concept is utilized to provide a framework for multi problem solving techniques.

Naturally, when designing a system that includes many agents communication becomes one of the most important issues. One of the pioneer theories for communication between agents is speech act theory that is put forward by Austin. Afterwards, this theory is improved by Searle. Basic axiom of this theory is communicative expressions are acts that resembles physical acts. Speech acts are performed by the speaker to cause desired change with its intention which the speaker brings about in the world. With this respect, act of the speaker tends to cause change in the mental state of the listener.

Even though, it is not based directly on speech act theory, ARPA is the most commonly known agent communication language. With this study, two languages are developed: Knowledge Interchange Format (KIF) and Knowledge Query and Manipulation Language (KQML).

Multi Agent including system studies mostly performed under the framework of Distributed Artificial Intelligence (DAI) notion and historically it has two main branches: Distributed Problem Solving (DPS) and Multi Agent Systems (MAS). Multi Agent Systems focus on expressing systems that includes autonomous entities. Moreover, researches within the MAS domain are interested in behaviours of autonomous agents that aim to solve particular problems.

In Multi Agent Systems, each agent has incomplete knowledge or ability to solve a problem. In these systems, each agent has a limited viewpoint and there is no global control over system. Moreover, data is distributed and computation is asynchronous. Multi Agent Systems provides interaction between systems, manages and controls distributed knowledge and increases efficiency.

Multi Agent System researches mainly focus on solving following issues:

- Designing a system that includes many agents and assigning problems to those agents,
- Formulating interaction and communication between agents,
- Defining relations between local and global decisions,
- Achieving coordinating among autonomous agents,
- Solving intention conflicts among agents, and

- Improving efficiency in local computation.

When planning single agent only objectives, abilities and environmental constraints are to be evaluated. On the other hand, when designing Multi Agent Systems, constraints regarding to each agent, decisions that are given by single agent and their effects on the other agents and predicting undetermined environment become the key issues that are to be considered.

Among the studies of Distributed Artificial Intelligence, pioneer study is about group of agents that focus on common objectives. Agent interactions are directed by cooperation strategies that assist in developing performance of all agents. Pioneer studies on distributed planning used planning before action approach.

In the area of cooperative Multi Agent planning, one another research field is modelling teamwork. Especially, when agents may possibly fail or in dynamic situations that can give result in new opportunities teamwork models are very useful. In these types of situations, team should be able to observe its performance and reorganized accordingly. Joint intentions framework is an extension of practical reasoning. It is an approach that focuses on representing team's mental state. If the team members commit to complete an action together, team is in the intention of cooperatively completing action

Interaction between agents is called as negotiation in the domain of self interested Multi Agent Systems. Negotiation refers to an approach that communicates to solve plan changes, task assignments and constraint violations centrally. When developing applications negotiations are required to solve the conflict between agents in decentralized manner. These conflicts should be resolved by self interested agents in such circumstances that there are incomplete information and bounded rationality. Moreover, agents should communicate and exchange their proposal and counter proposals.

Persuader that is developed by Sycara and study that is performed by Rosebschein is the pioneer researches of self interested agent in the field of Distributed Artificial Intelligence. Study of Rosenschein is based on game theory. Agents reason about alternatives in order to find alternative that have maximum payoff. Afterwards, agents select that alternative. Persuader approach is utilized for reasoning about negotiations between employees and employers. This system includes three agents and it is inspired from human negotiation mechanism. Each agent has multi dimensional utility model and they include some private knowledge. By persuasive negotiations beliefs in agents' utility models change to reach common agreement.

6. APPLICATION AREAS AND SOME SELECTED APPLICATIONS

Today agent technologies are used in many industrial and commercial applications. Up to now agent technologies are applied in the following areas: games and entertainment, medical, industrial and commercial. Here some applications are given briefly but more applications can be found in "A roadmap of agent based systems, autonomous agents and multi-agent systems".

Today agent technologies play an important role in developing computer games, interactive theatre and virtual reality applications which are covered in the framework of games and entertainment area. Creatures game is the pioneer game that utilized agent technologies to create interaction between user and synthetic agents. In theatre-style applications within the frame of believable agents there are some applications that provide illusion of life.

Applications of health industry cover patient monitoring and health care systems. Guardian is the first instance of patient monitoring applications. In the area of health care, a prototypical agent based medical care system is designed to integrate patient management process.

Industrial systems cover manufacturing, process control, telecommunications, air traffic control and transportation systems. Yet Another Manufacturing System is developed for manufacturing control and Explantech is designed for production planning. Archon systems' aim is to control process and some other process control systems tend to monitor and diagnose faults, control climate, control spacecraft, etc…

In the area of telecommunications some applications cover the following issues: network control, transmission and switching, service management and network management. Oasis is one instance of air traffic control system to control air traffic in real time. There are car pooling and supply chain management applications which can be categorized as transportation systems.

Commercial applications are mostly inspired from the requirements of the mass market. Most critical problems of information technologies are filtering and gathering information. With this respect, agent applications that focus on these issues are developed commercially. Today mail programs that are used by most of the people at home somehow include agency notion to gather and filter information.

In the area of electronic commerce many applications are developed like Kasbah and BargainFinder. Moreover, Telescript programming tool is especially developed for building electronic marketplaces. Final area of commercial applications is business process management. In this application domain adept project is proposed to assist management of business processes. Other applications of business process management covers the issues related to workflow management.

CONCLUSION

From the given review it can easily be deducted that agent based systems and agent technologies are promising in developing applications to solve real world problems. Moreover, there is no systematic method for application development and required application development sets are not sufficient. It has traditional obstacles that distributed and concurrent systems have. Furthermore, complex relations and interactions between autonomous entities make it much more difficult to realize these systems. All of these factors give result in difficulties in designing and developing agent based systems. Even though these obstacles, from theory to practice by the help of the philosophy, logic, psychology, linguistics and engineering disciplines agent based systems are promising in forming the future of Management Information Systems.

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