Agent-based modeling and the coordination aspects of it

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Agent-based modeling is one of the newer paradigms, especially when compared to something like Object-oriented modeling (OOM). My motivations for researching on this topic were primarily the likeness of an Agent-based model to something that exists in nature, it feels natural, apart from that, with the advent of technology and more computational power at our disposal, we are not limited anymore or restricted to coming up or working with the traditional mechanistic models, in which the relationships are narrowly focused around intended functions (Yu 12) and knowledge of the system is assumed to be whole, both the static and the dynamic aspects of it. Let's just think about it, if there is a drastic change in the structure of what we're trying to model or some addendums are made to it, to reflect these changes or update our model(s), especially in the case of Object-oriented modeling (OOM), it will most probably require a complete overhaul of the model or at the least some major modules of it. It lacks in self-adaptive qualities and is limited by its narrow defined scope. But, with the advent of Agent-based modeling, I believe it will very well be a thing of the past. Before I delve deeper, I'd like to give you an idea of how it's structured, I will begin with defining what an Agent is, how they factor in a model in the Agent-based modeling approach, the coordination or interaction aspects between different Agents, how does it all come together and what we as Software Engineers can take away from it. Apart from that, since it's a newer paradigm, different researchers can have a slightly or completely different outlook than their peers when it comes to certain aspects of it, I'd try to highlight these subtleties and give my opinions on it. Let's get started.

What is an Agent?

There is no one agreement of what it is and what all it encompasses but before I present to you my understanding of what an Agent is, I'd like to present an example, that'd help establish or support my hypothesis. Let's just say we have to model the Android Development team or unit of an organization, how they function, how they fit in the organizational structure as a whole, you get the idea. Now, at the core of this team, this unit, what or should I say, who are the actual drivers of progress, they are the human employees. They show up every day in their work **environment**, they **interact** with each other depending upon their **roles and capabilities** and at the end of the day, this environment of human employees, accomplish something or

work towards something that the organization deems as hard or soft **goals**. So, wouldn't it be right if I say that these employees are the **Agents** of change or progress? This example should give you a rough idea of what I believe constitutes an Agent. To put it in a more literal sense, an Agent can be characterized or defines as follows:

- It is a uniquely identifiable unit with its own set of behaviors and capabilities. Like no two people are the same, similarly, no two agents in an environment are the same. (Macal and North 74)
- Agents interact with their environment and with each other. (Macal and North 74). Let me illustrate this using an example, the Boids simulation shows us the flocking behavior of the birds when they fly, they all fly in a pattern towards a given goal direction and if there is an obstruction on their path in the environment, they self adapt, systematically change their flying configuration and overcome the obstacle. The brilliant part is, it's a leaderless flock, there is no leader leading them. The group's collective behavior is an emergent phenomenon, which is a result of the interactions of the individual entities. (Bonabeau 7280)
- Building upon the previous point, an agent is flexible, having the ability to learn and adapt its behaviors based on experience (Macal and North 74).
- Intention: An Agent should have a sense of intentionality. The older paradigms like the OOM paradigm and the conventional requirement analysis (e.g., as supported by UML) assumes complete knowledge and fully specifies behavior, so there is little need for intentional concepts. But, if we look back at the Android Development team example and consider an employee as an agent-in-the-world, we can attribute intentionality to him or her, so as to characterize alternate realities in the world. For agents-as-software, intentionality is a property that is used to generate the behavior of the agent. For example, there may be data structures and internal states that represent goals and beliefs in the software. An agent can be thought of as a locality for intentionality and instead of having a single global collection of goals, beliefs, etc., these are allocated to separate agents (Yu 11).
- Autonomy: An Agent is autonomous, they are self-directed towards a goal. The real question is though, are they fully autonomous or semi-autonomous? In my personal

opinion, I am inclined towards the latter, for agents depend upon their social relationships to further their goal(s).

- Sociality: The whole paradigm is based on the concept of individual Agents exhibiting rich behavioral patterns, their interaction with each other and as a consequence of which, an emergent phenomenon is observed in the system. sociality refers to properties that must be created in the software to enable them to exhibit richer behavioral patterns (Yu 12).
- Goal: An Agent may have hard or soft goals. The way a soft goal differs from a hard one is that a soft goal does not have any clear cut criteria.

The Coordination or Interaction Aspects

From the above description of an Agent, it is quite evident that the way they coordinate or the interaction amongst them is a prime aspect of Agent-based modeling. Reading through the papers, I've come to realize that all the authors have this tendency to think or model an Agent in the likeness of a human and they wouldn't be wrong in thinking this way, for we humans are prime examples of individualistic beings having Intentions and our ever so dynamic social relationships that propel us towards our goals. But, what about the other inspirations in nature, for instance, even when an ant colony is disrupted in some way, the ants are resilient enough to coordinate and go about their tasks, they adapt and overcome the adversity. A similar kind of behavior can be observed in swarm intelligence or hive mind, which also gives rise to the concept of "diffusion", which in this context implies the effect of the social context on an individual, that is, what others around them do (Bonabeau 7285). In my opinion, this gives us a guideline to work with, an Agent-Based model should be made considering **Evolutionary Game Theory** in mind rather than the traditional variant and to support my hypothesis, I'd like to present an example. Consider there are three people (A, B, C), none of them know each other, A and B are just visitors whereas C is the lifeguard on duty. Let's consider this scenario in which A starts to drown, C jumps in to save him because he's the lifeguard but B jumps in to save him without any contractual obligation, maybe it's his moral compass or perhaps an instinct that he was born with or perhaps he inculcated it inside him over the years by learning and adapting. Point being, the lifeguard C is a prime example of traditional game theory and he has his fixed set of behaviors in this context, akin to Object-oriented modeling, whereas B, on

the other hand, can be characterized as an “Agent”. B exhibits memory, adaptation, and intentionality. The reason I believe that most researchers tend to see Agents in the likeness of Human beings, it’s mainly because of the complexity or intricacy in our thought processes and our interactions with each other and the environment when compared to other simpler beings in nature but I wouldn’t be wrong when I say, that the main factor or characteristic that is at the root of an agent is **sentience** or some notion of it. Now, one might say that how does it differ from the field of AI? Well, Agent relationships represent processes of social interaction (Gilbert and Troitzsch 1999). The fundamental assumption is that people and their social interactions can be credibly modeled at some reasonable level of abstraction for at least specific and well-defined purposes, if not in general. This limited scope for representing agent behaviors in ABMS (Agent-Based modeling and simulation) contrasts with the more general goals of AI (Macal and North 76). Coming up with a general recipe of how to come up with a model and how to define or lay down the foundations for interactions and coordination is hard and a general-purpose model cannot work. The model has to be built at the right level of description, with just the right amount of detail to serve its purpose; this remains an art more than a science (Bonabeau 7287). Nevertheless, before we think about the coordination or interaction between the agents, we must discover or identify the agents in the environment. Now how does one go about that? It can be figured out intuitively given the problem and context, or, a general way as described by Macal And North is to think about them as entities who are the decision-makers, as seen in a belief-desire-intention software model (BDI) or in a Participatory Simulation, in which the agents can be thought of as humans are driven towards their goal, it’s just like a video game but with much more structure. Macal and North have strived to describe these social interactions amongst agents on the basis of topologies, for instance, cellular automata represent agent interaction patterns and available local information by using a grid or lattice and the cells immediately surrounding an agent as the neighborhood. On the other hand, agent interaction topologies such as networks, allow an agent’s neighborhood to be defined more generally and may more accurately describe social agents’ interaction patterns (Macal and North 77).

Now that we know what an Agent-Based model can be thought of as, in the next section, I’m going to discuss about Agent-based modeling but from a requirements engineering or analysis perspective.

Agent-Base modeling from a requirements analysis and engineering standpoint

The conventional requirement analysis and engineering practices are mostly primed towards the Object-Oriented Modeling (OOM) paradigm but with the advent of the Agent-based modeling paradigm and the differences that it has from the former. For instance, the traditional UML based modeling accounts for the static and dynamic aspects of the system but it doesn't cover the intentionality aspect. Traditionally, systems tend to be developed in isolation in relation to other systems. So the simplifying assumptions were that global goals could be identified, and that differences could be resolved to achieve agreement across the system. This mechanistic world view doesn't go along with the social aspect of the social worldview that comes with the Agent Paradigm (Yu 4). So, I believe that it is imperative to research and develop methods, tools, and instructions that would prime the Requirements Engineer or consultant to think in a way that is conducive to the Agent-based way while eliciting requirements from a client or modeling a real-world problem. Professor Eric Yu in his paper talks about such a solution based on i* modeling framework, which is constituted of two types of models: the Strategic Dependency (SD) model and the Strategic Rationale (SR) model.

- *Strategic Dependency (SD) model:* This model is basically a graph, where each node represents an actor and the link between two actors indicates a dependency of one on the other in order to achieve a goal. This model can be thought of as a network of such dependencies. The figure is taken from his research paper (Yu 7).

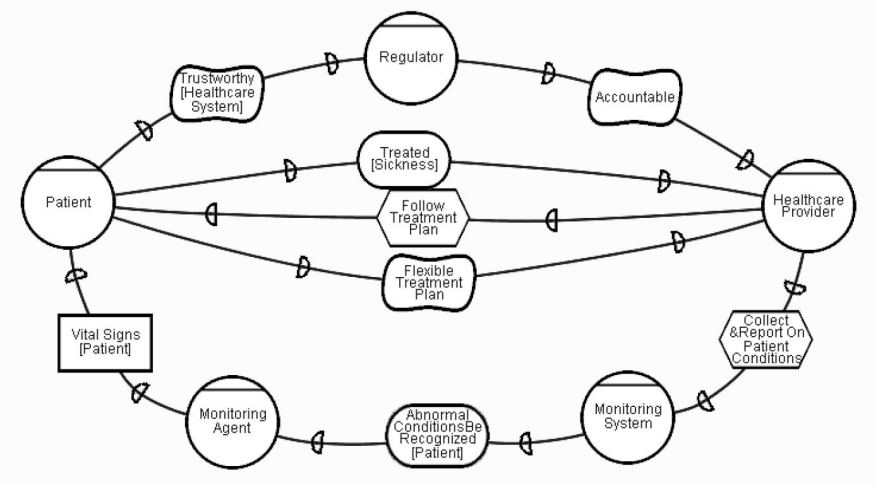

Fig. 1. A Strategic Dependency model

- *Strategic Rationale (SR) model:* The model on the other hand, when compared to the *Strategic Dependency (SD) model,* provides support for modeling the reasoning of each actor about its intentional relationships. The SR model is a graph whose nodes are goals, tasks, resources, and soft-goals (Yu 8). Figure below taken from the research paper (Yu 9).

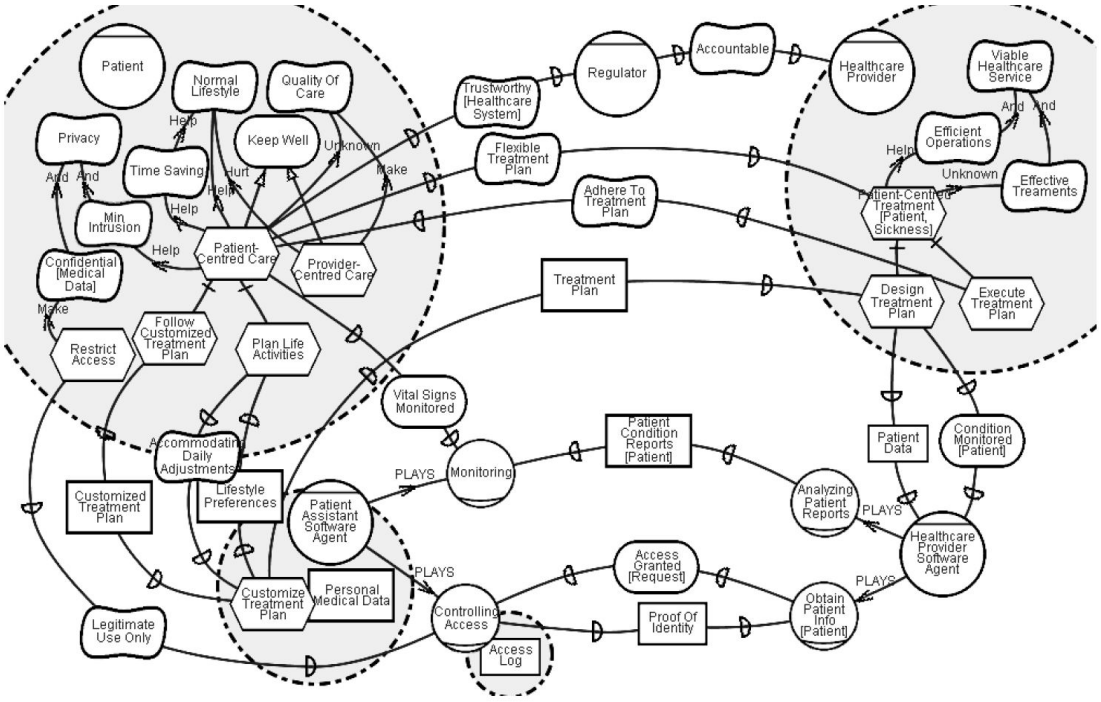

Fig. 2. A Strategic Rationale model showing some reasoning behind patient-centred care

These models and the proposed modeling framework gives us an idea as to how one might go about reasoning during requirements analysis in accordance with the Agent-based modeling paradigm. In my opinion, it might not appear to be the most intuitive or may feel cumbersome to some but it's a good starting point or reference.

Conclusion

This research and survey of the papers have given me a better understanding of the Agent-based modeling paradigm and I believe now I have some knowledge on how to go about building systems based on it, from both a developer and requirements engineer perspective. It is still a young field and from my choice of paper selection, I get the impression that most researchers are “simulationists”, the majority of examples I’ve seen in the papers are trying to solve real-world problems by simulating them on a machine and observing the emergent phenomenon. The paper by Macal and North is more practical oriented, in which they’ve strived to give the reader a basic understanding and guidelines on how to go about building an Agent-based model. Whereas Bonabeau, he’s delved into some core aspects and theory about what he believes an Agent is and when to apply this paradigm as compared to something which is based on differential equations. Apart from that, he’s given some beautiful examples of how Agent-based systems can help solve some of the world’s problems but they’re more of the simulation type and predictive tools. There is this one statement in his paper that I really couldn’t wrap my head around, it is this,” Stochasticity applies to the agents’ behavior. With ABM, sources of randomness are applied to the right places as opposed to a noise term added more or less arbitrarily to an aggregate equation.”. He does not give any reasonable explanation to establish this as a fact, by the end of the paper, it feels as if it is something he observed in his experience or experimentation and that it is highly contextual. Coming to Professor Yu’s paper, it gave me some insights on this modeling paradigm when seem from the perspective of a requirements engineer.

I wanted to add some more detail and touch base on some other elements that I read in these papers but then again, I’m already above the page limit. Nevertheless, I hope, I was able to give the reader at least an abstract understanding of how a person goes about thinking or reason in Agent-based modeling.

References

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