The Development of Emergent Properties
In Massive Multi-Agent Systems

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Abstract: - Emergent behavior results in complex systems. Emergent behavior can be observed in various systems - a colony of ants, an economy, a brain or a large network of computers - these are all systems with complex emergent behavior. The behavior of a complex system as a whole emerges in a highly non-linear manner from the behaviors of the low level constituent elementary units. This makes traditional linear analysis difficult, if not impossible. In this paper I will focus on emergent properties of massive multi-agent systems. I will present how these properties can be utilized to model global behavior of the system.

Key-Words: - Emergence, Multi-Agent Systems, Decentralization, Evolutionary Computation

1 Introduction
Multi-agent systems present a new paradigm in many fields of computer science. These systems are ones in which multiple computational entities, called agents, interact with one another. Much of the power of multiple agent systems is not in single agents, but in their mutual interactions and emerging global results, which overcome properties and capabilities of single agents. This is true especially for massive reactive multi-agent system, where particular agents need not to be individually complex for the system to demonstrate complex behavior overall [1][2][3]. Reactive agents have no presentation of the universe in which they operate and merely react to their local environment. Typically all agents are identical or belong to one of few groups of identical agents. The clearest example of an organization of this kind is that of the anthill [4].

The defining characteristic of a complex system is that some of its global behaviors, which are the result of interactions between a large number of relatively simple parts, cannot be predicted simply from the rules of those underlying interactions. With that in mind, let us hypothesize the concept of an emergent phenomenon as a large scale, group behavior of a system, which doesn't seem to have any clear explanation in terms of the system's constituent parts [5]. A more formal definition can be found: A true emergent phenomenon is one for which the optimal means of prediction is simulation. [5]

The pragmatic relevance of emergence is intimately related to Descartes Dictum: “How can a designer build a device, which outperforms the designer's specifications?” To be useful in amplifying our own creativity, emergent devices must have both a degree of structural autonomy relative to us as well as richness of potential structure [6]. However, it is difficult to design a collection of individual components and their local interactions in a way that will give rise to useful global information processing.

2 Designing Massive Multi-Agent Systems
The up-down approach to the analysis and design of multi-agent systems is appropriate in particular for multi-agent systems with just few agents. In the case of massive multi-agent systems this approach usually fails to be successful because of non-reductional nature of emergent phenomena. In opposition to up-down approach, bottom-up strategy is more suitable for designing massive multi-agent systems. It is used mainly for development of multi-agent simulation systems and for the construction of synthetic worlds [1]. On the other hand, when developing massive multi-agent that should exhibit some desired global behavior, this approach is not appropriate as well. The problem is that emergent phenomena are not linear and therefore it is very difficult to predict what will be the global behavior of the whole system on the basis of the behavior of single agents.
One possible solution to design of massive multi-agent systems with desired behavior is to combine bottom-up strategy with evolutionary computation. Instead of building a multi-agent system explicitly on the level of single agents, we can take the way of implicitly design agents with evolution of emergent phenomena using genetic algorithms. In this way we evaluate the fitness of the whole system and genetically operate on one or few groups of identical agents and not on single agents, as it is typical in the field of artificial life [7][8].

3 Levels Of Emergence
When we analyze an emergent system we can observe the whole system as a single-step result of constituent parts’ properties. The decision what to take for a constituent part, depends on a particular point of view.

If the gap between constituent parts and the resulting system is too large it is very hard to understand how such an apparent complex global co-ordination emerges from simple individual actions, and the design of the emergent system is difficult. On the other hand if constituent parts, themselves, are too complex then the problems and difficulties move to the constituent parts.

As Douglas Hofstadter and Gary McGraw stated, we have to pay far more explicit attention to the level of concepts and analogies, and move away from the magical hope that such a phenomena as an intelligent and creative system, with their extraordinary richness and complexity, will simply emerge somehow all by themselves, as a result of training networks of artificial neurons [9]. The real question is: What kinds of intermediate-level structures and mechanisms, located somewhere between very simple constituent parts and the desired complex behavior, do the work that counts?

A possible answer to this question is the introduction of emergence hierarchy. Emergent systems can be observed as the result of properties and interactions of subsystems, which themselves can be emergent systems. This hierarchy introduces a partial order on the system. In this way understanding and the design of the system is divided in more portions, which are easier to overcome. It is necessary to mention that emergent systems, in computational “sense”, are generally flat systems, where interactions between subsystems are local. This is also a natural way of looking at complex systems - a system that consists of a large number of interacting subsystems is called a complex system [10].

3 Emergence Hierarchy as a Pyramid
This hierarchical view at emergent systems helps the design process not only because the gap between a subsystem’s constituent parts and a subsystem’s resulting behavior is smaller, but also because control hierarchy can be introduced in emergent systems during design process [11]. In a control hierarchy, subsystems at each level control the level below. Subsystems in a control hierarchy are structurally similar. They get information from its child subsystems and send back control information. Central control is a top-level subsystem in control hierarchy. Central control is the most important subsystem, because it essentially defines the system.

In design process the top-level subsystem defines the overall behavior of the system (or vice versa). The interaction between levels is bi-directional. It is not only that higher levels control lower levels, but lower levels can influence the behavior of higher levels as well. Each subsystem can control more than one subsystem so that this organization leads to a pyramidal hierarchy in the design process of an emergent system.

The top-down control information consists of demands pressures from a given system to its lower level subsystems. The word pressure is used because demands are not mandatory for subsystems. This information is guidance for determination of goals for lower levels subsystems. In the case of evolutionary approach to multi-agent systems this information is produced by a selection process and an offspring generation process.

The bottom-up information consists of emergent properties of subsystems. This information is then used by the system to construct new demands pressures for lower levels. In the case of evolutionary approach to multi-agent systems this information is obtained as a fitness value of subsystems’ emergent phenomena.

4 Conclusion
Allowing global co-ordination to emerge from decentralized collection of simple components has important advantages over explicit central control in both natural and human-constructed information-processing systems (i.e. robustness, speed...)

Even if an emergent system is computationally flat, emergence hierarchy can be introduced in
system analysis and control hierarchy can be introduced when designing such a system. Emergence hierarchy helps us to understand complex behavior of a system and is used as a base structure for control hierarchy in design of an emergent system. In this way, the process of design can be partially automated. But maybe an even more important consequence of this method is that not only the system behavior itself is complex and unpredictable but also the design of a system is highly unpredictable, too and could surprise us with good results.

The implementation of presented idea is not easy. At the faculty of computer and information science, we are developing a software system, which is used for testing and evaluation of evolution of emergent properties in massive multi-agent systems. The main difficulty is to match the system into the emergence hierarchy. However, I think that the obstacles can be passed and the idea is worth being developed and implemented.

References: