Visualization of Dynamic Behaviour of Multi-Agent Systems

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ABSTRACT

The extension of our research on analysis of a single agent or agent communities combining advanced methods of visualization with traditional AI techniques is presented in this paper. Even though this approach can be used for arbitrary Multi-Agent System (MAS), it was primarily developed to analyze systems falling into Artificial Life domain. Traditional methods are becoming insufficient as Multi-Agent Systems (MAS) are becoming more complex and therefore novel approaches are needed. In this paper we present an extension of our recent visualization tools suite. The previous approach was not suitable well to present the dynamics of the MAS, even though the development of MAS state parameters in time was presented. Our new technique, which is presented in this paper, addresses this problem by visualizing the changes of the MAS along with their quality and context. This transparent approach emphasizes MAS dynamics by providing means for discovery of changes in its tendencies or in behaviour of either single agent or agent communities. A simulated artificial life environment with intelligent agents has been used as a test bed. We have selected this particular domain because our long-term goal is to model life as it could be so as to understand life, as we know it.

Keywords
Multi-agent System, Artificial Life, Visualization, Dynamic, Analysis.

1. INTRODUCTION

Agent technology covers a wide spectrum of areas including virtual enterprises and worlds, computer games, mobile robotics, artificial life, social and evolutionary systems, process control applications and many others. Autonomous Agents as fundamental units of these applications differ in behaviour, architecture, purpose and capabilities. Agents' deployment environments vary from standalone software application or Internet distributed applications to real environment of robotic and control applications. MAS are becoming complex and thereby harder to assess because: (i) agents have lots of rapidly changing properties, (ii) the system under consideration consists of many objects and agents, (iii) agents usually have different, not very transparent architectures, variety of perceptors, actuators and deployment domains and also (iv) environment or MAS is complex and time varying.

The popularity of MAS together with all the above mentioned difficulties have resulted in an increasing effort dedicated to development of new approaches to its classification, action selection of one agent, knowledge representation and derivation by one agent, learning and adaptation, communication and collaboration among agents and finally global characteristics of MAS. Scientific visualization and human cognition research results [Gre99] has proven its ability to help with all of these requirements [Sch01] [Sze99]. Other authors agree on the fact, that visualization of MAS is a largely neglected area with large research potential.

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In this paper we discuss the topic of visualization of the MAS trends and dynamics. This issue is very important, because specific changes can destabilize the system and thus inhibit dangerous behaviour. The quality of the changes and trends in the simulated MAS is reflected in the inflexion points of the systems' state parameters, including its components.

As a testing MAS we have used the Artificial Life Simulator (ALS) [Kad02] developed at CTU, Department of Cybernetics, Prague.

2. THE VISUAL ANALYSIS TOOLS

Architectural components common to most agents are sensors, actuators, Internal State Model (ISM) and Action Selection Mechanism (ASM) and various optional blocks as planning, sequencing, memory etc. Sensors and actuators differ domain by domain in purpose and complexity. Regardless of their purpose, agents have a perception layer, which transforms feedback (information) from MAS (other agents, objects, ambient environment) to their internal representation and an actuation layer, which transforms agent's internal representation of actions to physical actions. These physical actions may be considered as communicative or non-communicative acts. Then there is usually a set of control blocks, which transform perceived inputs into motivations for an agent to make decision. These motivations (action stimuli) are combined in ASM (Action Selection Mechanism), where the best action is selected in order to maximize progress towards its (time varying) goals. Information we use for the analysis are agent's state (selected properties of its control blocks) gathered via state observer, motivations (action stimuli) and selected actions [Kad03].

It is obvious that looking on a system of agents from one point of view doesn't provide enough information for sufficient analysis. Multiple interlinked views with different levels of detail have proven to be a successful approach to solve this task. Our research has resulted in development of various incorporated Visualization Analysis Tools (VATs) delivering means for seamless analysis on various levels by the utilization of modern visualization methods and standard AI techniques. So far we have developed VAT1, VAT2 and VAT3, which use various visualization techniques like parallel coordinates [Ins91], analogy of ThemeRiver [Hav02], glyphs and more. Detailed description of VATs can be found in [Reh03] [Kad03].

This paper presents an extension of this tools suite for trends and inflexion detection.

3. TRENDS AND ANTICIPATION

Trends and anticipatory behaviour belong to the key issues that artificial life and control domain deals with [Bro91]. As the MAS changes in time, some changes (in general) or their combination can push the system into unstable state (e.g. bad feelings across the whole agent population with reciprocal impact on every agent).

Such highly dynamic changes play an important role in MAS analysis. The quality of these changes is reflected in inflexion points of the development of systems' internal parameters in time. The importance of inflexion points results from the facts, that appropriate counter-actions can be performed in advance to stabilize the system. When analyzing the results of a recorded simulation, previously unclear states that the system went through can now be explained.

Single Agent

VAT level 1 [Kad03] provides a solid framework for visualization of inflexion points of agent's internal parameters development – the 3D mesh (fig. 1). Originally the mesh is coloured to emphasize the values of each parameter. Colour served only as a support visual feature. However, colour can be used to a greater extent; it can carry more information.

To visualize the inflexion points and local extremes a simple colouring scheme was developed. In fact, there are two types of inflexion points: when a convex curve turns into a concave one or vice-versa. Both types have different explanation context from the Alife point of view. The first type of inflexion point colours the corresponding mesh vertex green, the second is white. The rest of the mesh is coloured according to the result of the first derivative of each parameter evolution – presents the rising or falling trend (fig. 2, 3). The main contribution of this approach is the ability to visualize the inflexion points in direct relation to the actual parameter values and trends of evolution.

However there are some limitations in this simple approach. First, and also the main important, is somewhat hidden. Since we are using discrete data, which are far from ideal and contain noise, we often get "fake" inflexion points (fig. 1). These points are usually the result of the following problems:

- Limited range of floating point values, mostly the underflow effect. This effect comes hand-in-hand with the fact, that the nature of many changes in the system is very slow, even though continuous.
- Limited exactness of the values, which incorporates all kinds of noises and processing limitations

To overcome these problems we implemented various approximations, which turned out to be a double-edged sword, because the approximation often filters out real inflexion points. The classification of the real/fake points is left on the user; VAT provides support facilities to help the user in tracking the inflexion points. The support facilities are as follows:

- Thresholding of the first derivative in the place of an inflexion point helps to distinguish rapid changes from gradual ones. The threshold setup is interactive and the changes are immediately visible (fig. 2).
- Time interval selection helps tracking important changes in a specified time interval only.
- Local extremes on a specified time interval

More Agents – Lines of Life Extension

The same colouring engine from VAT 1 is used to colour the Lines of Life [Reh03]. In this case a result of the sum of weighted parameter values serves as the input. Any arbitrary combination of parameters and their actual weights can be used and thus provides a powerful tool for interactive analysis. Since the same colouring engine powers Lines of Life, the similar problems with data noise have to be solved. Fig. 3 shows the Lines of Life with inflexion points colouring.

4. CONCLUSION

In this paper we have presented our research in analysis of multi-agent systems in the ALife domain. Our approach is largely inspired by Biology, and more specifically by the field of Ethology, which attempts to understand the mechanisms, which animals use to demonstrate adaptive and successful behaviour. We see that the key information to understand MAS lies in identifying changes in its tendency – changes in behaviour of single agents, community or environment. To facilitate these challenges, the visualization tools we have developed were added a new colouring engine, which helps us to study the trends of the MAS in a broad context. VAT level 1 focuses on visualization of agent's internal state (its properties), visualization of its action selection mechanism and relationships (or correspondence) between agent's state and resulting actions – agent's behaviour. From VAT level 2 on, the system works with multiple agents. These methods present agent's state in context to its position, other agents or surrounding environment.

The designed colouring approach gives good results. We have been able to discover interesting states of our simulated MAS. Some of them are even unexplainable from the human point of view, but perfectly reflect the point of view of an animal, e.g. a snake or a spider. So far we are still unable to analyze the top level behaviour whole agent society, because of lack of suitable models, simulations and data. Just like every model works within some limits, almost all our simulations have been targeted on special case situations, targeted for specific situations, like predator avoiding, food seeking, and partner finding or just surviving in the virtual ecosystem.

We got best results on a special case simulation, where the ecosystem was basically a valley with hills around and a river – the one and only source of water available. After a couple of simulation cycles the agents tended to settle on the hills but very close to the river. We have been able to analyze the system and we have found out that this was the best location for a prey agent, because it could easily scan the surrounding area for threat (predators) and also have its vital resources (water) closely available.

To sum up the main advantages of our system; tendencies, mutual relations and dependencies can be discovered, when going through the recorded simulation results step-by-step. Traditional AI analysis approaches bound with modern interactive visualization methods provide a well balanced view of the analyzed data in such a way, that we get valuable feedback for preparation of new experiments.

5. FUTURE WORK

Our current colouring mechanism of inflexion points and trends needs to be backed with more sophisticated framework, which will be able to distinguish between noise in the data and real inflexions and trends. Automation of the process of filtration of "fake" inflexions will be definitely helpful in the task of MAS analysis.

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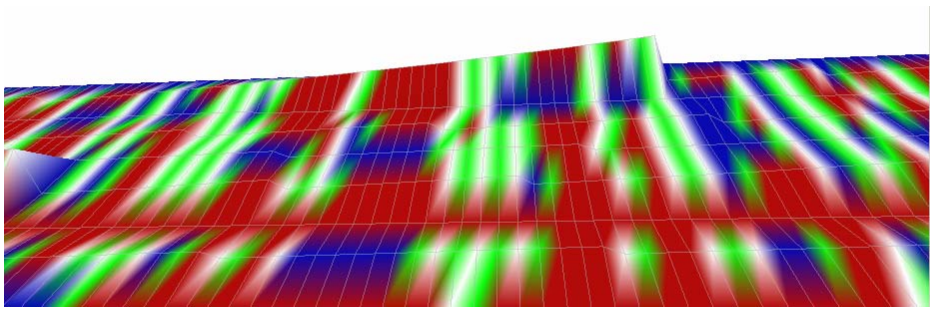

Fig. 1 – Noise in the input data produces "fake" inflexion points (white and green segments)

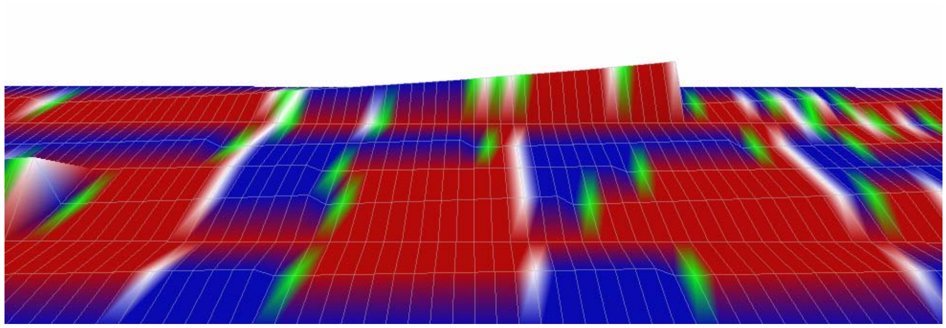

Fig. 2 – Some of the "noise" inflexion points have been filtered out

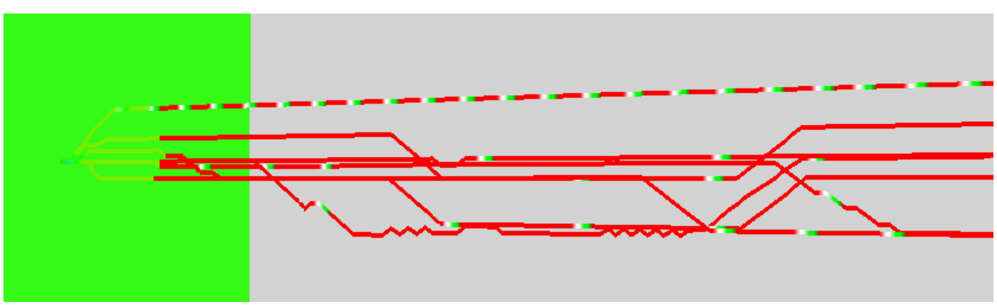

Fig. 3 – Lines of Life coloured with inflexion points. This case displays the changes of the hunger parameter of each agent. Red segments represent rising tendency, white and green segments represent inflexion points.