Evaluation of global system state thanks to local phenomenona

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Abstract.

This paper presents a new approach for the evaluation of a system's global state properties. The approach is intented for the application to reactive multiagent system (RMAS) and adresses the evaluation of emergent properties such as global stabilisation. This approach is inspired by statistical physics and thermodynamics, as a way to link the microscopic and a macroscopic points of view. It gives an important role to partition function Z as defined in statistical physics. From this mathematical function can be extracted indicators that represent the global evaluation of the system state based on local phenomena. In this paper, the approach is put into practice by considering a classical reactive multiagent system: bird flocks simulation. The methodology was applied to analyze system stability. Experimental results obtained with a multiagent simulation platform are presented.

1 Introduction

Multiagent systems (MAS) can now be considered as a wide spread technique for the simulation of complex systems. They have been applied to a wide range of applications.In order to simulate complex systems, the reactive approach, in which interaction and emerging phenomena prevail in the definition of the agents themselves, is pertinent. It brings relevant properties such as adaptation skills, reliability or robustness to parameters change. The main drawbacks of the reactive approach is the lack of theoretical background in convergence proofs and emergence characterization. The goal of this article is to propose a method based on partition function Z [2] as it is defined in statistical physics. Statistical physics is generally considered to be one of the first scientific disciplines where statistical methods succeed to link the microscopic and the macroscopic points of view. From this mathematical function can be extracted indicators, the computation of which is based on local estimations, represent global measurements of the system state. This article is structured as follow. After a paragraph dealing with the related works found in literature, partition function is defined relatively to physics. Then, we explain through a simple physics inspired example how to apply partition function theory. Last part deals with the application of partition function to a classical multiagent model based on Reynolds Boids [7]. Finally, we conclude drawing some extends to the work presented.

2 Related Works

As stated in the introduction, one of the main problem in MAS is the evaluation of the accuracy/efficiency of the system relatively to the task to perform and to the local mechanisms involved. Those evaluation methods can be classified in 3 categories : (i) Indicators tied to the application field [5] (ii) Indicators based on a global point of view on the system and on its topology [6] (iii) Global Indicators based on local estimation [4]. Solutions found in literature usually take inspiration from biology (fitness functions, etc), sociology (altruism, etc), agency theories (utility functions, etc) or physics (state functions, etc). Moreover, some of them are based on strong mathematical background such as [8] but seem to be hardly applicable to any kind of pratical MAS. Among these methods, the physics inspired solutions are the most widespread. For instance, entropy [1, 6] has been widely used in reactive MAS in particular in order to represent disorder/organisation in the system. Even if this measurement can be useful in many cases, it has two main drawbacks: it depends on the past transformations of the system and it is a global measurement that does not take into account local mechanisms of the system. In order to overcome these drawbacks, other approaches can be used. One generic solution is the computation of energy as a state function on both agent and system levels [3].

3 Evaluating global state properties

3.1 Description of the approach

The approach applies to reactive multiagent systems based on interaction models inspired by physics. The environment must be limited and the number of elements fixed. If the system respects these conditions, the following methodology can be applied:

1. All interaction forces are computed.
2. System Energy is computed from agents energy at every time step.
3. Partition function Z is computed from system energy.
4. Thermodynamic potential A is plotted in real time.
5. Studying evolution of Helmholtz free energy A explains the system evolution and the time to equilibrium.

3.2 Application to classical reactive multiagent system

Flocking represents an approach to solve some kinds of problem such as spatial distribution. This is a model [7] for the coordinated motion of groups of entities called boids. Craig Reynolds [7] realized that the motion of a flock of birds could be modeled by applying three simple rules to be followed by each boid: **Cohesion**: steer to move toward the average position of local flockmates, **Separation**: steer to avoid crowding local flockmates alignment diagram, **Alignment**: steer towards the average heading of local flockmate's cohesion diagram.

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3.3 Interaction model

The environment is closed and the number of boids is fixed. Each bird corresponds to an agent. An agent only perceives flockmates inside it's perception distance. The interaction model is based on the three forces defined before, with N Number of neighborhood agent, $\vec{R}_i$ distance between the agent and the neighborhood agent i and $\vec{P}$ agent position.

$$\vec{F}_{Cohesion} = [\sum_{i=1}^{N} \frac{\vec{R}_i}{N}] - \vec{P}_{agent} \qquad (1)$$

$$\vec{F}_{Separation} = \sum_{i=1}^{N} \frac{\vec{R}_i}{\|\vec{R}_i\|^3} \qquad (2)$$

$$\vec{F}_{Alignment} = \sum_{i=1}^{N} \frac{\vec{R}_i}{\vec{R}_i} \qquad (3)$$

3.4 System energy

According to the interaction model, the energy measurement can be detailed as follow :

- **Kinetic energy**: In the following equation, the agent i is represented by its mass m_i and its speed $\vec{V}_i$.

$$E_K = \frac{1}{2} m_i \vec{V}_i . \vec{V}_i \qquad (4)$$

- **Potential energy**: it is computed, for agent i, using the classical expression of the energy U ($U = \delta W + \delta Q$) where δW represents the work done on the system and δQ the heat flow (here, $\delta Q = 0$ since no heat is dissipate). The work done on the system δW is expressed considering a conservative force (Cf. equation 5) with $\vec{du}$ a unit vector in the direction of agent speed.

$$E_p = \delta W = \vec{F}_{total}.\vec{du} = \vec{F}_C.\vec{du} + \vec{F}_S.\vec{du} + \vec{F}_A.\vec{du} \quad (5)$$

From now, each boid's energy and allows to compute the partition function and the thermodynamic potential A, with T,V and N_i constant, $E_i = E_k + E_p$.

$$\begin{cases} A(T, V, N_i) = -ln(Z) \\ Z = e^{-\beta E_i} \end{cases} \qquad (6)$$

3.5 Free energy A evolution during simulation

The simulations use run a group of 100 boids. Every simulation begins with a random boids dispersion environment. The simulation starts (Cf figure 1 top left) with the lower free energy A, because of the great agent dispersion. Then, following to the Reynolds model, boids form a moving group similar to a bird flocks. During this phase, the system tends to the stability. The free energy oscillations indicate that the system is not yet in a stable state. Finally, the boids formed a flock (Cf figure 1 top right) and the system is in equilibrium. Thus, the free energy tends toward a constant value representing system stability.
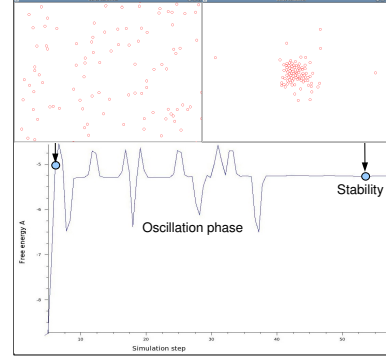

Figure 1. Boids simulation

4 Conclusion

Reactive multiagent systems are becoming an important field of research within application domains characterized by distributed aspects. Particulary developement approaches for reactive MAS should include the posibility to evaluate the quality of ermergent phenomena and even, in some cases to the application objective. The aim of this article was to present a new conceptual frame for the evaluation of the global state of reactive MAS. This evolution is based on a local to global approach, inspired from statistic physics and thermodynamics. Statistical physics is generally considered to be one of the first scientific disciplines where statistical methods succeed to link the microscopic and the macroscopic points of view. In this work, we present an approach for the application of statistical physics to RMAS. A great attention has been given to the justifications and conditions of the use of statistical physics. This approach has been put into practice through a classical example: Boids floking. Simulation experiments have shown the relation between the indicator proposed in this paper and the system evolution. Additional research work is needed to extend the applicability of the approach to more complexe phenomena.

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