Workshop
W2

Socio-Economics Inspiring Self-Managed Systems and Concepts (SEISMYC)

Monday, 27 September 09:30-17:00
Room Rome

Organizers:

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Towards Analysing and Controlling Self-Organising Systems with Socio-Economic Principles

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***Abstract*—The increasing complexity of large-scale distributed applications motivates the study and development of self-organising systems. However, engineering self-organising systems is still a challenge. Despite their benefits, self-organising systems suffer from a lack of control and stability, so that methods and tools are needed for improving their understanding and control.**

In this paper, we consider socio-economic concepts as a tool for analysing and controlling self-organising systems. We propose an approach to enhance existing self-organising mechanisms with high-level representation and reasoning abilities based on socio-economic models. This approach has the advantage of preserving the typical performance, flexibility and robustness of a self-organising system, while improving its stability and making it more understandable to its users. We illustrate the approach with the example of a flexible manufacturing system we have evaluated, and we explore further directions based on this example.

I. Introduction

The increasing complexity of large-scale distributed applications motivates the study and development of self-organising systems [1]. A self-organising system is typically composed of a large number of entities producing a simple individual behaviour, while a complex collective behaviour emerges from their mutual interactions. Self-organising systems have been applied in different domains, such as networking, middleware, distributed optimisation, distributed simulation, logistics management, peer-to-peer systems [1], [2].

Engineering self-organising systems is known to be quite a challenge. These systems are often the result of a long lasting engineering, relying on successive rounds of simulation for parameter adjustment. Despite their benefit and success, they suffer from a lack of control, of stability and are difficult to understand. We need methods and tools for improving the understanding and control of self-organizing systems.

To address these issues, we consider socio-economic concepts as a tool for analysing and controlling self-organising systems. We propose an approach which decouples analysis and control from engineering of the self-organising system itself, thus integrating existing self-organising mechanisms (e.g., based on mathematical or biologically-inspired techniques) and enhancing them with high-level representation and reasoning abilities. This approach has the advantage of preserving the typical performance, flexibility and robustness of a self-organising system, while improving its stability and making it more understandable to its users.

In this paper, we first highlight some socio-economic concepts to be considered as tools for analysing and controlling self-organising systems (section II). Section III introduces an approach for integrating socio-economic model with a self-organising system and section IV discusses direction for evaluating this integration. Finally, a brief overview of related works (section V) and a summary (section VI) conclude this paper.

II. Some Useful Socio-Economic Concepts

In some self-organising systems, in particular systems which exhibit decentralised coordination properties, the emerging organisational structures could be described with a social metaphor, attributing roles to entities and outlining the structure in the organisation (e.g., in ants colonies [3]). More generally, we are interested in considering socio-economic principles which could be used as tools for analysing and controlling self-organising systems. In this section, we highlight some relevant work using socio-economic concepts, developed in particular in the field of multi-agent systems.

For illustration purpose, we consider a simple self-organising mechanism in a flexible manufacturing system. In this system, workpieces are transported between workstations using a system of conveyors and intersections. Several paths between workstations are possible, so that the system is capable of compensating breakdowns and congestions by redirecting the workpieces. For doing so, it uses a simple algorithm in which each component (workstation, conveyor, and intersection) is represented as an agent which can communicate with its neighbours. Each agent can offer to transport a workpiece to a destination at a given cost: this cost depends on the cost offered by its neighbours (which it needs to complete the task) and its own cost. During the operation of the system, costs change depending on breakdowns or congestions, resulting in a propagation of costs along the line and in an adaptation of the chosen path [4]. The structure of the system (the paths between workstations) is self-organised, since it is not designed globally but results from simple, local interactions between agents. In the following, we will use this example to illustrate the possible use of socio-economic concepts on such a system.

A. *Markets*

Market-based techniques are based on an analogy with economic market encountered in human societies. Numerous works consider this type of approach in the field of multi-agent system [5], [6], [7]. In a typical setting, entities (called agents) are self-interested and are exchanging resources in order to maximise their own utility. The market-mechanisms enable to match supply and demand, i.e. to define the optimum price of goods. For such kind of systems, each agent has to consider its preferences regarding the goods, in order to decide if it is rational for it to do the transaction or not. Typically, an agent defines its preferences based on the utility of the outcome of different possible interactions, thus choosing interactions (e.g., buying or selling) which are expected to yield the best results.

In a self-organising system, market-based techniques provide an interesting direction for exploiting the concept of utility and reasoning on (implicit) preferences of the entities. This enables explanations that are more accessible to humans than the real reason for actions of the entities (e.g., the result of running a complex algorithm or based on some information that is not accessible to humans). Additionally, the well-developed theories on market systems can be exploited for a better control of self-organising system. For instance, the adaptive routing mechanism in our flexible manufacturing example is based on a notion of costs, with costs for different situations being defined empirically to provide an acceptable behaviour of the system. In particular, there are no guarantees of equilibrium and stability in this system, which could be solved using a more principled market-based approach.

B. *Dependencies*

Other useful concepts come from dependency networks, which have been studied in social sciences [8] and used in multi-agent systems [9]. Dependency networks offer a formalism for expressing dependency (resp. autonomy) of agents regarding some task (or goal). An agent is said to be autonomous for a goal if it can achieve it alone, dependent if it needs the participation of other agents to achieve it, and mutually dependent if other agents also need its participation for achieving their goals. This serves as the basis for flexible coordination mechanisms such as coalition formation: using reasoning on their dependencies and mutual dependencies, agents decide on participating in coalitions with other agents to help them achieving their goals.

Looking at self-organising systems, expressing dependencies between entities facilitates the understanding of the system. Even if entities themselves are not aware of them, dependencies provide a relevant abstraction for the external observer. As a further step, it is meaningful to enhance entities with reasoning about dependencies created among the self-organising system. The modelled dependencies should be used as a stabilisation and control mechanism, for instance influencing the self-organising mechanisms towards reinforcing existing cooperation patterns rather than randomly creating new interactions. In our flexible manufacturing system, such a mechanism is useful to avoid inefficient search in parts of the system where only one path is possible, and entities are thus strongly mutually dependent. In such a case, entities should recognize a critical failure quickly, by identifying their dependencies and recognizing that no alternative will exist without trying to perform an unsuccessful adaptation.

C. *Institutions*

A third area of research considers electronic norms and institutions [10], [11]. This approach has been particularly developed in the field of e-commerce and open multi-agent systems. These works are concerned with large-scale, open systems, in which numerous, independent entities behave autonomously, interacting, joining and leaving the system in an open way. In such a setting, stability and consistency of the system has to be ensured with a set of social rules, which denote the obligations and interdictions of entities.

In a self-organising system, principles of institutions and norms could be employed as a mean to constrain the autonomy of entities in order to ensure stability of the system. It can be particularly useful to ensure that the misbehaviour of some entities or the unforeseen influence of external conditions does not drive the self-organising system into undesired states. In our flexible manufacturing system, a maximum cost for transportation tasks could be an example of social rule. In particular, this would prevent false sensor readings to trigger an infinite increase of costs due to congestions, ultimately blocking the whole system while no congestion would be occurring in reality.

III. Integrating Socio-Economic Concepts into a Self-Organising System

One of the strength of a self-organising system is that entities are kept small and simple [12]. In order to avoid increasing the complexity and to respect the principles of separation of concerns, our approach is to extend existing entities in a self-organising system with a higher-level, reasoning counterpart, which exploits a socio-economic model. Similarly to other works [13], we consider entities which are composed of a low-level part and a high-level part. The low-level part deals with self-organising mechanisms, usually employing simple algorithms and reactive behaviours. The

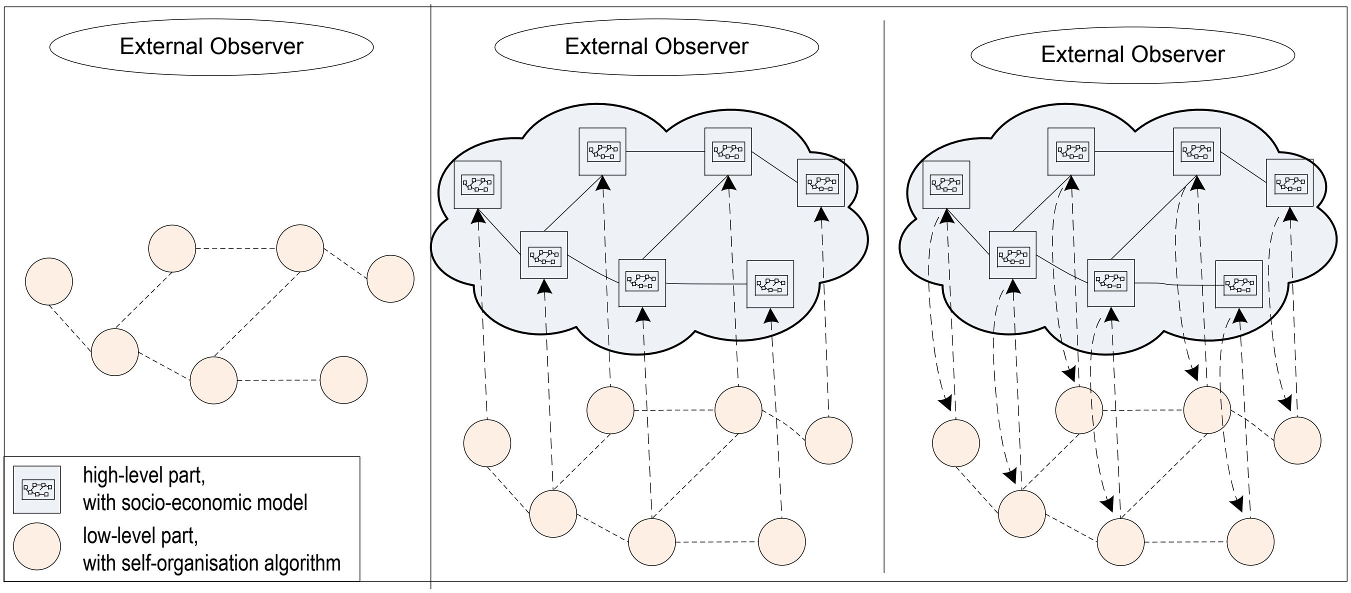

Figure 1. Different levels of integration of socio-economic models with a self-organising system.

high-level part deals with more complex representation and reasoning based on socio-economic models. Such an entity is designed so that all necessary functionalities are provided by the low-level part, while the high-level part may only be activated for specific adaptation tasks or for performing diagnostics.

Based on this general architecture, we can envision three distinct configurations (Figure 1). In the first configuration (Figure 1, left), a self-organising system consisting of entities with only their low-level part activated is depicted. This corresponds to the traditional case, in which entities do not have any representation and reasoning mechanisms, and only interact based on local perception and reactions. In such a case, an external observer (the designer or the user of the system) relies on direct observation of the system to understand its behaviour. In such a setting, the relations between individual behaviours and the global system behaviour may be difficult to render explicitly, and improvement of the system relies on simulation and trial-and-error.

In the second configuration (Figure 1, middle), entities of a self-organising system are enhanced with a high-level part, thus forming a layered system. In the higher-level part, entities use a representation of the system, in particular of interactions and organisation structure with other entities. Such a representation can be based on a socio-economic model, and enable a more global reasoning on the social behaviour of entities in the system. In this setting, an external observer does not have to rely only on direct observation of the low-level part, but can also obtain useful information from the high-level part. Practically, the realisation of such a layered system must take into account the need to decouple the execution of the low-level, self-organising mechanisms from the high-level reasoning mechanisms, in order not to hinder the fast and flexible execution of the base system. In particular, interaction between the low-level and high-level parts is loosely coupled (e.g., based on asynchronous events), with the high-level collecting data and modelling the low-level without actually interfering with its behaviour. Additionally, computation of the high-level part does not have to be executed on the same device as the low-level part: it should rather be distributed on suitable resources, e.g., using cloud computing solutions.

In the third configuration (Figure 1, right), entities of a self-organising system are enhanced with a high-level part which can also influence the behaviour of the low-level part. Based on explicit representation and reasoning about interactions and the social structure of the system, entities become able to adjust parameters of the low-level part, e.g., for correcting a divergent behaviour. In that case, most of the behaviour of the system is directed by the fast and efficient, self-organisation mechanisms, but overall control and stability is enforced by higher-level, self-adaptive mechanisms. Like in the previous setting, an external observer can rely on higher-level models of the system, based on socio-economic principles, and also becomes aware of the adjustment and transitions triggered by the high-level reasoning mechanisms.

IV. Evaluating Self-Organising Systems with Socio-Economic Concepts

The application of the proposed approach opens the door for different kind of evaluations. In this section, we discuss three types of evaluations.

A first direction for evaluation is to assess *how well* *a chosen socio-economic model applies to a studied self-organising system*. To do so, the first step is to define the socio-economic model to consider. For instance, in a market-based setting, we define what would be the utility of different states of the system. Then, we observe the self-organising system, and compute the associated states of the socio-economic model. For instance, we compute the actual utility of each agent in each state. Finally, we verify that the socio-economic model provides a correct interpretation of the self-organising system. For instance, if the utility of some agent is decreasing, it means that the chosen utility assignment does not match the reality of the self-organising system.

A second direction for evaluation is to assess *how well a self-organising system performs regarding criteria of a socio-economic model*. For instance, considering market-based techniques, we make the hypothesis that each entity in a self-organising system is a self-interested rational agent, dedicated to maximizing its utility. Based on the observation of the system, we determine which actions would be chosen if the entities would be rational, and compare them to the actual actions taken. Such a technique enables to verify that a self-organising system actually follows some more general principle, even if they are not aware of it. In a complex self-organising system, this can be used to determine boundary conditions (conditions under which the system stops behaving according to the chosen model).

A third direction for evaluation is to assess *how well a self-organising system with additional socio-economic models performs*, compared to the original self-organising system. Such an evaluation makes sense when a feedback from the socio-economic model to the self-organising system is enabled, i.e., when the entities in the system become self-adaptive. In such a setting, it is assumed that the enhanced system will perform better than the original system, at least in certain conditions. As an example, using dependency networks, entities can recognize a stable system situation, in which self-organising algorithms will always yield the same results, and decide to reuse previous results. In such a case, we measure improvement in the performance of the system (e.g., in terms of computation cycles needed).

As an example, we performed some initial evaluations on the flexible manufacturing system described in section II. This system features a self-organising routing mechanism in which agents rely on interaction with their neighbours for defining appropriate routes. We enhanced this low-level mechanism with a higher-level reasoning mechanism based on dependencies between agents. Thanks to an explicit representation of its dependency to other entities, an agent obtains additional information about its current and future tasks. In particular, this enables detecting inconsistent sensor readings and correcting them. Besides initial work on detecting simple anomalies [14], we designed a larger scale test bed to evaluate the performance of the adaptive routing mechanisms enhanced with additional reasoning mechanisms. In this test bed, additional reasoning to correct sensor readings provide significant performance improvement (in terms of time needed to complete a task), even if the basic self-organising mechanism would ultimately solve the problem as well (by correcting the route at a later stage). These remains however quite basic mechanism, and more elaborated reasoning based on socio-economic models such as discussed in this paper should be evaluated in the future.

V. Related Works

The approach considered here is clearly inspired from the general approach of autonomic and self-adaptive systems [15], [16]. Similarly, we consider a layered structure in which a managed system is adapter by a higher-level manager. However, we specifically consider a self-organising system as the lower-level, managed system, which exhibits more complexity and dynamics than systems usually considered. Additionally, we favour a decentralized approach of management and the use of models inspired from socio-economic principles, which benefits in particular from previous work on multi-agent systems.

The idea of using higher-level model for adapting the behaviour of a system of autonomous entities is particularly present in studies on norms and institutions in multi-agent systems [17]. Similarly, we consider entities capable of realizing a task autonomously, while higher-level mechanisms impose constraint on their behaviour in order to ensure consistency and stability in the global system. We additionally highlight the role of socio-economic principles for improving the global efficiency of the system, so as to leverage both flexible, efficient self-organising mechanisms and powerful socio-economic reasoning mechanisms.

More recently, an approach towards validating self-organising dynamics in a multi-agent system has been proposed in [18]. This work proposes to analyse an existing self-organising system using on hypotheses on its intended behaviour. This work focuses on exploring the causal relationship between macroscopic state variables, which do not capture the social dimension and interaction between entities we consider here.

VI. Summary

In this paper, we consider socio-economic concepts as a tool for analysing and controling self-organising systems. We first reviewed some important socio-economic concepts providing suitable abstractions for self-organising systems. We proposed an approach for integrating socio-economic models with existing self-organising system. This approach decouples analysis and control from the engineering of the self-organising system itself. thus integrating existing self-organising mechanisms and enhancing them with high-level representation and reasoning abilities based on socio-economic models. We then highligthed directions for evaluating such combined systems of self-organising mechanisms with socio-economic models, and described our initial evaluations on a flexible manufacturing system.

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