On Self-Organising Mechanisms from Social, Business and Economic Domains

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This paper discusses examples of socially inspired self-organisation approaches and their use to build socially-aware, self-organising computing systems. The paper presents different mechanisms originating from existing social systems, such as stigmergy from social insects behaviours, epidemic spreading, gossiping, trust and reputation inspired by human social behaviours, as well as other approaches from social science related to business and economics. It also elaborates on issues related to social network dynamics, social network patterns, social networks analysis, and their relation to the process of self-organisation. The applicability of socially inspired approaches in the engineering of self-organising computing systems is then illustrated with applications concerning WWW, computer networks and business communities.

Povzetek: Podani so primeri mehanizmov samoorganizacije.

1 Introduction

Nowadays computing systems are open systems evolving in a dynamic complex environment. They are designed as sets of interacting components, highly distributed both conceptually and physically. The growing complexity of these systems and their large scale distribution make the use of traditional approaches based on hierarchical functional decomposition and centralised control no more applicable. Increasingly, a real need for new paradigms, mechanisms and techniques allowing endowing these systems with the capacity to autonomously manage their functioning and evolution, is expressed. Existing social systems, for example large scale, decentralised and autonomic human, insect or business and economic systems, are well known to exhibit interesting characteristics, such as robustness, capacity of self-management and self-adaptation, survivability in uncertain and dynamic environments. They can provide a great inspiration for busiding self-organising computing systems.

Socially inspired computing gathers computing techniques that make use of metaphors inspired by social behaviours, exhibiting self-organisation, self-adaptation and self-maintainance of the society organisation. These social behaviours range from those observed in biological entities such as bacteria, cells and social insects to animals and human societies. One important characteristic of these societies is their emergence as patterns developed from relatively simple interactions in a network of individuals. These patterns, are supposed to be driven by self-organising processes that are governed by simple but generic laws [19][5]. This paper is focused on self-organising mechanisms observed in natural social systems and in business and economic ones, and the illus-

tration of their use for building self-organising computing systems. We distinguish natural systems from business and economic systems, since generic laws guiding self-organisation in the first kind of systems is dictated by nature whereas in the others, self-organisation is governed by business and market laws.

From a natural systems perspective, species survival is the ultimate goal. This goal is not expressed explicitly at the individual level, but seems to guide the collective behaviour towards the emergence of *social functions* and dynamics allowing the maintainance of the system organisation. In business and economic systems, individual behaviours are goal-oriented and their primary goal is to increase their profit. In this case, the system's dynamics is handled by the activity developed to face business and economic constraints to reach a global equilibrium through which the system can survive. In both systems, one important issue is their capacity to globally maintain a sufficiently good level of information allowing them to deploy the effective global behaviour that permits the realisation of their intentional or non intentional goals.

In the following, we first present examples of socially inspired self-organising mechanisms in natural business and economic systems. Before concluding, we present example applications of such mechanisms in WWW, computer networks and business communities.

2 The Social Human Behaviour Inspiration

2.1 Social Functions

Human collective behaviour occurs without central control, and through self-organisation. In this case, intimately linked with the notion of self-organisation is the notion of *"emergence"* in the sense that *"social functions"* arise out from (self-interested) human collective behaviour. In social sciences different interpretations of the notion of social functions have been expressed, essentially considering that even if social functions are not intentional and possibly unknown they constitute the ultimate end of the society and explain its existence.

The social functions concept has also been explained as the *"invisible hand"* which would manage forms of unplanned coordination (like market) in which human interest increases [31] through the apparently *"spontaneous emergence of an unintentional social order and institutions"*. As pointed out by [13], the problem with this view is: *"how an unintentional effect can be an end"* for the society; and *"how is it possible that we pursue something that is not an intention of ours"*. An alternative could be avoiding the concept of social functions because of the problems and questions that they provoke. However, this is not satisfactory too, because nevertheless social emergence happens and has the form of a goal-oriented process.

Therefore, it is important to distinguish two kinds of social emergence: 1. the emergent phenomenon is perceived by an observer, but has no effect on the society; 2. the emergent phenomenon has an effect on the society by self-reproducing and enforcing the social phenomenon.

Given the considerations above, Castelfranchi considers that *"in order to have a function, a behaviour or trait or entity must be replicated and shaped by its effects"*.

The principal argument is that *"the invisible hand"* is not necessarily a good thing for society (especially in the case of self-interested agents). The optimum order for the society can actually be bad for individuals or for everybody. For instance, prisons generate criminals that in turn feed prisons. This is a function not a social objective.

The important thing is that *"re-organisation simply maintains the system, but not necessariy the optimal value"*.

2.2 Social Activities Based on Social Networks and Their Inspiration for Computing

Propagation of information or knowledge allowing social activities in social systems lays on the social network formed by the the interaction held between the society individual components during social activities. Social behaviour both shapes and is shaped by such social networks.

2.2.1 Social Learning and Propagation of Knowledge

In social science, it is now established that social interactions play a fundamental role in learning dynamics, and lead to cognitive development. This phenomenon is known as *"Zone of Proximal Development"* which Vygotsky describes it as *"the distance between the actual development level as determined by independent problem solving and the level of potential development as determined through problem solving under adult guidance or in collaboration with more capable peers"* [51] [15]. The effect of socialisation has also been proven to benefit to the propagation of knowledge inside an interconnected population. In [14] the authors considered social learning in a population of myopic, memoryless agents. They have made some experiments to study how technology diffuses in a population based on individual or collective evaluation of the technology. The authors have shown that under a learning rule where an agent changes his technology only if he has had a failure (a bad outcome), the society converges with probability 1 to the better technology. In contrast, when agents switch on the basis of the neighbourhood averages, convergence occurs if the better technology is sufficiently better. These experiments show how a better technology spreads in a population through a mechanism of imitation and thanks to neighbourhood connections. In another work [3], the authors develop a general framework to study the relationship between the structure of these neighborhoods and the process of social learning. They show that, in a

connected society, local learning ensures that all agents obtain the same payoffs in the long run. Thus, if actions have different payoffs, then all agents choose the same action.

2.2.2 Epidemic Spreading and Gossiping Metaphors

As cited in [34] Gossip is one of the most usual social activities. This mechanism allows for the aggregation of a global information inside a population, through a periodic exchange and update of individual information among members of a group. The neighbourhood as well as the level of precision of the exchanged information play an important role on the nature of social learning which occurs by this way. This mechanism provides a powerful abstraction metaphor for information spreading, knowledge exchange and group organisation in large scale distributed systems. In peer-to-peer (P2P) systems, a class of protocols categorised as epidemic protocol has been proposed [50]. These protocols are characterised by their high robustness and large scalability. This metaphor has been also used for routing in sensor networks. For example in [8], a rumour routing algorithm for sensors networks is proposed. This algorithm is based on the idea of creating paths leading to each event and spreading events in the wide-network through the creation of an event flooding gradient field. A random walk exploration permits to find event paths when needed.

2.2.3 Trust and Reputation

Uncertainty and partial knowledge are a key characteristic of the natural world. Despite this uncertainty human beings make choices, take decisions, learn by experience, and adapt their behaviour.

Trust management systems deal with security policies, credentials and trust relationships, for example issuers of credentials. Most trust-based management systems combine higher-order logic with a proof brought by a requester that is checked at run-time. These systems are essentially based on delegation, and serve to authenticate and give access control to a requester [53]. Usually the requester brings the proof that a trusted third entity asserts that it is trustable or it can be granted access. These techniques have been designed for static systems, where an untrusted client performs some access control request to some trusted server [1, 6]. Similar systems for open distributed environment have also been realised, for instance [38] proposes a delegation logic including negative evidence, and delegation depth, as well as a proof of compliance for both parties involved in an interaction. The PolicyMaker system is a decentralised trust management systems [4] based on proof checking of credentials allowing entities to locally decide whether or not to accept credentials (without relying to a centralised certifying authority). Eigentrust [36] is a trust calculation algotrithm that allows to calculate a global emergent reputation from locally maintained trust values. Recently, more dynamic and adaptive schemas have been defined, which allow trust to *evolve* with time as a result of evidence, and allows to adapt the behaviour of principals consequently. We report here the results of the European funded SECURE [11] project, which has established an operational model for trust-based access control. Systems considered by the SECURE project are composed of a set of autonomous components, called principals, able to take decisions and initiatives, and are meaningful to trust or distrust. Principals maintain local *trust values* about other principals. A principal that receives a request for collaboration from another principal decides to actually interact with that principal or not on the basis of the current trust value it has on that principal for that particular action, and on the risk it may imply for performing it. If the trust value is too low, or the associated risk too high, a principal may reject the request. After each interaction, participants update the trust value they have in the partner, based on the evaluated outcome (good or bad) of the interaction. A principal may also ask or receive *recommendations* (in the form of trust values) about other principals. These recommendations are evaluated (they depend on the trust in the recommender), and serve for updating current trust values. Artificial systems built on the human notion trust as exposed above have the particularity to exhibit a self-organising behaviour [16], as identified by Nobel prize Ilya Prigogine and his colleagues [24]. Additional trust and reputation systems are surveyed in [25], and for the particular case of multi-agent systems they are reviewed in [41].

3 The Social Insects Behaviour Metaphor

Social insects societies such as ants, bees, wasps and termites exhibit many interesting complex behaviours such as emergent properties from local interactions between elementary behaviours achieved individually. The emergent collective behaviour is the outcome of a process of self-organisation, in which insects are engaged through their repeated actions and interactions with their evolving environment [32]. Self-organisation in social insects relies on an underlying mechanism : Stigmergy, originally introduced by Grassé in 1959 [26]. Grassé studied the behaviour of a kind of termites during the construction of their nests and noticed that the behavior of workers during the construction process is influenced by the structure of the constructions themselves. This mechanism is a powerful principle of cooperation in insect societies. It has been observed within many insect societies such as wasps, bees and ants. It is based on the use of the environment as a medium of inscription of past behaviours effects, to influence future behaviours. This mechanisms defines what is called auto-catalytic process, that is the more a process occurs, the more it has a chance to occur in the future. More generally, this mechanism shows how simple systems can produce a wide range of more complex coordinated behaviors, simply by exploiting the influence of the environment. Many behaviours in social insects, such as foraging or col-

lective sorting are rooted on the stigmergy mechanism.

Foraging is the collective behaviour through which ants collect food. During the foraging process, ants leave their nest and explore their environment following a random path. When an ant finds a source of food, it carries a piece of food and returns back to the nest by laying a trail of a hormone called pheromone along its route. This chemical substance persists in the environment for a particular amount of time before it evaporates. When other ants encounter a trail of pheromone, while exploring their environment, they are influenced to follow the trail until the food source, and while coming back to the nest they enforce the initial trail by depositing additional amounts of pheromone. The more the trail is followed, the more it is enforced and has a chance to followed by other ants in the future. Ants foraging behaviour have inspired many works in computing domains, ranging from "Ant Colony Optimisation" (ACO) metaheuristic for optimisation problems [18], to the design of ant-like systems using mobile agents with applications in several domains such as computers network routing and load-balancing [42][17][21], computers network security [20][23], information sharing in peer to peer systems [2], etc.

Collective clustering and sorting is a collective behaviour through which some social insects sort eggs, larvae and cocoons. As mentioned in [7], an ordering phenomenon is observed in some species of ants when bodies are collected and later dropped in some area. The probability of picking up an item is correlated with the density of items in the region where the operation occurs. This behaviour has been studied in robotics through simulations and real implementations [32]. Robots with primitive behaviour are able to achieve a spatial environment structuring by forming clusters of similar objects via the mechanism of stigmergy described above. Moreover, these kind of social insect behaviours have inspired many mechanisms for building artificial self-organised systems [7][32] [30] [39].

4 Business and Economics Approaches

4.1 Market-based Mechanisms

Market-based mechanisms are built along the lines of economic markets. In this approach, systems are modelled along the lines of some economic model in which participating entities act towards increasing their personal profit or utility. System wide parameters are modelled in a manner similar to macroeconomic variables such as economic growth. The parameters of the individual entities correspond to microeconomic parameters. The key point in such systems is to select suitable micro level parameter values and market interaction rules so that desired system goals, both local and global, are achieved.

Market-based approaches contrast the traditional way of modelling self-organisation and emergence in economic systems, which is primarily based on analytic general equilibrium models, for example as is done in [22]. The main problem with analytic approaches is that they cannot represent all possible situations due to the non-linearity of economic phenomena [10], which is due to the fact that economies are complex dynamic systems [48]. Instead, market-based approaches view macroeconomic phenomena as *emergent results* of local interactions of the economic entities [10, 33, 48]. An example is economic growth which can be *described* at the macro level but it can never be *explained* at that level [12]. The reason is that economic growth results from the interaction of a variety of economic actors, who create and use technology, and demanding customers.

There are numerous variations of market-based self-organisation mechanisms. An exemplar such mechanism which is based on the creative destruction principle is described in the following section.

4.1.1 Creative Destruction

Creative destruction is a term coined by Schumpeter [43] to denote a *"process of industrial mutation that incessantly revolutionizes the economic structure from within, incessantly destroying the old one, incessantly creating a new one."* In other words, creative destruction occurs when a new setting eliminates an old one leading to economic development. According to this view an economic system must destroy less efficient firms in order to make room for new, possibly more efficient entrants. A representative example of creative destruction is the evolution of personal computer industry which under the lead of Microsoft and Intel destroyed many mainframe computer companies; however, at the same time one of the most important technological achievements of this century was created.

The main roles that economic actors play in a market-based economy are those of producer, worker and consumer. Producers produce goods or provide services that consumers demand. Consumers consume the goods and use the services in exchange of some monetary or utility value. When there is high demand producers tend to hire workers to assist them in goods production or service provision in exchange of some wage. Since producers cannot sell their production beforehand, they must hold enough money to pay the workers in order to start up production and they can only get the necessary money by entering debt. According to the creative destruction principle, if producers are not able to pay the worker wages then they go bankrupt and they are removed from the system, for example they are reduced to simple workers, opening the way to other economic entities to try to become successful producers and satisfy the consumer demand.

The creative destruction process is better illustrated in a credit economy. In contrast to a monetary economy where producers can only borrow existing money from lenders, credit economy allows producers to obtain credit up to a

certain level from creditors in order to pay for production of new products. In this way, producers can more easily force their way into the market but the danger of becoming bankrupt is increased. To explain economic development in this framework one only needs to explain why entrepreneurs would want to introduce new products to the market. Effective entrepreneurs survive the battle and increase their profit. Failed entrepreneurs cannot repay their debt and therefore they go bankrupt and they are eliminated. As initially stated by Schumpeter [43] and later evaluated experimentally, for example [9], economic growth in this model is generated in cycles that emerge from the disturbance caused by entrepreneurs entering the market introducing new products.

In such a model there is particular interest from both the global, macro economic perspective and the local microeconomic one. Individual producers can decide on their entrepreneur policy so that to increase their profit and avoid the risk of getting bankrupt. On the other hand the economic system regulators can decide on the self-organisation rules so that to increase overall system production and growth.

4.2 Business Related Mechanisms

Business related mechanisms are based on business models and theories which use self-organisation. In an increasingly complex global economy, businesses are faced with unpredictable behaviours and fast pace of change. As a result, the emphasis in contemporary business models has shifted from efficiency to flexibility and the speed of adaptation.

More recent approaches, for example the one described in [46], increasingly introduce business models originating from the study of complex adaptive systems. Adaptive business organisations are guided and tied together by ideas, by their knowledge of themselves, and by what they do and can accomplish. Therefore, the focus in such models is on the complex relationships between different business components and the effects that a change into some part of the system or its environment, however distant, might have on the behaviour of the entire system.

As examples of self-organising business models we discuss personalised marketing and activity-based management.

4.2.1 Personalised Marketing

Personalised marketing refers to following a personalised market strategy for each individual customer which is evolving according to customer reactions [52]. A typical example of this approach is the *one-to-one variable pricing model* [29], which refers to providing an individual offer to each customer using Internet technologies. The model uses self-organisation in the marketing policies by changing customers targeted and the prices quoted based on market dynamics, customer characteristics and the business goals.

A shift towards to personalised marketing models is viewed as being driven by *syndication* [54]. Syndication involves the sale of the same good to many customers, who then integrate it with other offerings and redistribute it, as is the case in redistributing popular TV programs. An example of a company using syndication is FedEx which syndicates its tracking system in several ways [54]. The company allows customers to access computer systems via its Web site and monitor the status of their packages. For corporate customers FedEx provide software tools that enable the organisation to automate shipping and track packages using their own computing resource. Each customer is offered different prices depending on a variety of parameters. Many websites, such as eBay, also apply variable pricing for their offers.

4.2.2 Activity-based Management

Another example from the area of management is the *theory of activity* described in [49]. In this view a company consists of networks of working groups that can change their structure, links and behaviour in response to business requirements. The aim is to capture the self-organisation decisions that need to be taken during the business operations both by managers and by interactions between employees. The emphasis is on solving potential conflicts of interests in both the inner and the external co-operative activity of the company.

In this approach the structure of the company is virtual. There is no clear hierarchy and control; instead control effects can be initiated both vertically and horizontally via *"round table meetings"*, which are organised along the lines of assessment meetings normally held in companies to assess results and handle exceptions. In these virtual round tables suitable participants soon emerge as de facto leaders due to their knowledge and experience. Subsequently, leaders tend to participate in each newly formed "round table". The view expressed in [49] is that to model the interactions of participants in a "round table", it is necessary to simulate the whole activity of each of them including their reasoning and communication.

5 Socially Inspired Computing Applications: An Illustration

5.1 E-mails and WWW Oriented Applications

Based on the SECURE trust and risk security framework, an anti-spam tool has been developed which allows collaboration among e-mail users by exchanging recommendations about e-mail's senders. An authentication scheme has been combined to the SECURE framework in order to increase the level of sender authentication [44].

On the WWW, a plethora of systems have been developed for content retrieval, filtering or organisation using socially inspired computing. As an illustration, we present here a pioneering work [40], in information retrieval field which combined inspiration of social human behaviours, and economic markets to propose an interesting system for information retrieval on the web. In this work, documents are represented by keyword vectors, representing individuals (agents) of an artificial ecosystem. This population evolves through an evolutionary process of natural selection using a genetic algorithm to find documents which best fit the user request. The user feedback is used to reward (resp. to punish) the fittest individual (the less fitting individual) by giving it a credit value. These credits are then used by agents in a market based metaphor to estimate the cost of inhabiting the artificial ecosystem. The fittest agents have enough credits to continue living in the ecosystem and the less fitting agents will die. Another system called WACO has been proposed in [30]. The WACO system is composed of a population of agents deployed on the web to form clusters of semantically similar documents and dynamically organise the web content. These agent behaviours, take inspiration of social insect behaviours. They combine foraging ant behaviour and the collective sorting behaviour.

5.2 Computer Network Applications

T-Man is a generic protocol based on a gossip communication model and serves to solve the topology management problem [35]. Each node of the network maintains its local (logical) view of neighbours. A ranking function (e.g. a distance function between nodes) serves to reorganise the set of neighbours (e.g. increasing distance). Through local gossip messages, neighbour nodes exchange or combine their respective views. Gradually, in a bottom-up way, through gossiping and ranking, nodes adapt their list of neighbours, and consequently change and re-organise the network topology. The T-Man protocol is particularly suited for building robust overlay networks supporting P2P systems, especially in the presence of a high proportion of nodes joining and leaving the network.

The SLAC (Selfish Link and behaviour Adaptation to produce Cooperation) algorithm [28] favours self-organisation of P2P network's nodes into *tribes* (i.e. into specialised groups of nodes). The SLAC algorithm is a selfish re-wiring protocol, where by updating its links with other nodes in order to increase its utility function, a specific node leaves its current tribe, and joins a new one.

In addition to P2P systems, the SLAC algorithm has many potential applications, for instance to organise collaborative spam / virus filtering in which tribes of trusted peers share meta-information such as virus and spam signatures. This would elimite the need for trusted third parties with central servers.

5.3 Applications in Business and Economics

5.3.1 Business Community Networks

Typical applications of market-based self-organisation mechanisms can be found in the domains of business community networks [37]. An example of such approach is the self-organising semantic network of document indexing agents described in [45].

In such a network, agents maintain indices to actual documents and to other agents as well, treating both in a similar manner - based on the semantics of their content. The key feature in this approach is content dependent query redirection, based on semantic indexing. If an agent is unable find a document on a given topic, it re-directs the received query to the agents which believes are most likely to find it. The connections between the agents adapt themselves based on the history of successfully served queries, forming a distributed self-organising search engine which is capable of executing on heterogeneous servers over the internet and dynamically indexing all available documents. The important aspect of such a search engine is that each node, though possessing only limited amount of local information, can handle global queries.

Each piece of information received from an agent corrects the coordinates of its representation in the semantic index of the recipient. Furthermore, each link to an agent has also its own utility based rating. Those ratings are used for the selction of the right candidates for redirecting queries.

Rating adaptation is done using a *free market* approach. According to this approach agents provide chargeable search services to each other. Each query has some limited amount of network currency, termed *neuro*, which dissipates in the course of query processing in the network. Neuros circulating through the network are used by the agents to update their connections with the other agents, based on their utility, in a similar manner that money flow in a real economy determines the structure of business relationships.

The semantic network economy is based on the following simple rules:

- The cost of each delegated query processing is one neuro;
- The cost of each document (query) transaction is one neuro;
- Agents aim to minimize their expenditures.

According to these rules each agent keeps track of the balance of transactions of all other agents it is linked with. Agents are considered economically rational and aiming to maximise their profit they tend to delegate queries to experts in the query topic, thus minimizing effective cost of search in the network.

Similar market-based techniques are applied in trade networks where the aim is to select trade partners based on continually updated expected payoffs [27, 47].

6 Conclusion

In this paper we have surveyed some self-organising social approaches and presented their use as metaphors for distributed computing systems. These socially inspired computing techniques have shown their effectiveness for systems and applications evolving in distributed and highly dynamic environments, such like current complex networks. Social behaviours ranging from those observed in biological entities such as bacteria, cells and social insects, to animals and human societies, are rooted in the dynamics of their underlying social network. Social behaviour both shapes and is shaped by such social networks. One important characteristic of societies is their emergence as patterns developed from relatively simple interactions in a network of individuals. The obtained patterns are then enforced through dynamics underlying the so obtained social network. These systems are well known to exhibit interesting characteristics such as robustness, capacity of self-adaptation and survivability in uncertain and dynamic environment and tolerance to randomness. We have presented different mechanisms of social behaviours and showed their use in computing environments through some illustrative applications. Socially inspired computing metaphors, provide a real new paradigm for programming highly distributed and dynamic computing systems. However, proposed approaches are still developped in an ad hoc manner, and a real theory for socially inspired computing needs to be provided.

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