Meta-Structures as MultiDynamics Systems Approach. Some introductory outlines.

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ABSTRACT

We consider how processes of dynamical, multiple, overlapping, interfering, correlated interactions establishing collective systems are *analytically* intractable. The meta-structures project has the purpose of using mesoscopic (rather than macroscopic or statistical) representations to allow interventions which can suitably modify various properties acquired by emergent collective behaviours. We consider mesoscopic variables and mesoscopic properties as suitable for representing such systems of interactions. Properties of collective systems, such as coherence(s), are considered to be suitably represented by mesoscopic dynamics. Finally, mesoscopic interventions are considered as suitable for acting upon collective systems.

Keywords: Coherence, Dynamic, Interaction, Mesoscopic, Perturbation.

1. INTRODUCTION

We consider here populations of *homogeneous interacting entities*.

To fix the ideas *entities* are intended as having observable properties. Examples are molecules, boids, particles, words, pictures, cars, buildings, and people.

Entities can be considered as *homogeneous* when they *possess*, or *acquire* in processes of emergence, the *same* properties, e.g., oscillators *possessing* periods or flocks *acquiring* the same shapes as detected by an observer [1] However, properties may be possessed or acquired in partial or discontinuous ways. *Sets* of entities (*sets* because entities share the same property/ies) are considered as populations when entities *interact*. Moreover, entities, considered in finite number, say *k*, fixed or possibly varying over time, can *interact*, i.e., one's property, such as behaviour or temperature, can *affect* another's behaviour or temperature. Interaction can occur, for instance, through the exchange of energy (e.g., collisions), or information (e.g., networks, such as the Internet). Furthermore, *indirect information transfer* is possible when *mediated* by direct interaction between entities.

The classical *general* representation of collective interaction within a system *S* [2] characterized by suitable state variables $Q_1, Q_2, \ldots, Q_n$, whose instantaneous values specify the state of the system, is given by the time evolution of the state variables governed by a system of *ordinary differential equations*, such as:

$$\begin{cases} dQ_1 / dt = f_1 (Q_1, Q_2, \ldots Q_n) \\ dQ_2 / dt = f_2 (Q_1, Q_2, \ldots Q_n) \\ \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \\ dQ_n / dt = f_n (Q_1, Q_2, \ldots Q_n) \end{cases} \qquad \text{Eq. (1)}$$

The system (1.1) specifies how a change in the value of a given state variable Q_n, affects all other state variables through f_n, representing their *collective interaction* being governed and structured by f_n.

On the other hand, collective *non-structured*[1] interactions occurring in populations of entities may not lead to the acquisition (emergence) of any collective property as is the case for Brownian motion.

Collective non-structured interaction is more interesting in that it *acquires* some coherences and collective properties. This is the case of *emergent systems* such as flocks, swarms, anthills, road traffic, industrial districts, cells, cities, markets, lasers, etc. [3].

Rather than well-specified analytical fixed interaction as for f_n in (1.1), there are interesting cases of collective non-structured interactions between entities when the *structural dynamics* relates to:

a) Multiple interactions used by entities differently over time and in different dynamical combinations;
b) Interactions which can *interfere*, and be correlated, i.e., when combinations of interactions are not the linear sum of interactions;
c) Interactions which can start at different times and have different durations;
d) Interactions which can cease to be available at different times and for different sets of entities variable over time;
e) New interactions which can become available at different times and for different sets of entities variable over time; Multiple Systems or Collective Beings [4] when entities and results given by specific interactions *unwittingly* adopt contextual multiple roles or multiple significances.

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[1] A collective interaction is *structured* when performed through well-defined structures such as electronic circuits connecting components (entities) and as represented in Eq. (1). Collective interaction is intended as non-structured when the f_n are continuously changing and combining as in points a)- f).

Such collective non-structured interactions are clearly *analytically intractable*. There are various well-known approaches for modelling such collective phenomena. Some of these are of a stochastic, statistical nature while others are based on modelling, for instance, through Cellular Automata. Other recent approaches consider, for instance:

1) The interaction range between entities, e.g., interaction is limited to a certain number of entities (topological distance);
2) The correlation *outside* the interaction range where the information used to interact is transferred through intermediate entities (such as l*ong range correlations*);
3) The correlation length as large as the entire, interacting population under study (scale-free correlation);
4) Collective behaviours modelled as networks.

2. THE META-STRUCTURE PROJECT: VARIABLES, PROPERTIES, AND DYNAMICS

The meta-structure project [5. 6.7] considers mesoscopic levels of representation as *areas of continuous negotiations between micro and macro*. The approach considered here is based on the philosophy of the 'middle way' [8]. As is well-known, the mesoscopic level of description lies *between* microscopic and macroscopic levels in the sense that it does not ignore any microscopic information, as occurs for macroscopic representations, but still considers some microscopic information.

The meta-structure project is so called because it metaphorically considers large varieties of interactions which are analytically intractable and impossible to represent in explicit ways. Various resulting instantaneous structures, analytically intractable, are active at a given instant and are considered as establishing virtual, effective *meta*-structures [9].

Mesoscopic variables

This project adopts the mesoscopic level of representation [10] because it focuses upon suitable observables able to *transversally intercept* and represent values adopted by aggregates of microscopic variables and grasp the effects of collective, non-structured interactions establishing the collective systems. In reality, the *mesoscopic variables* considered are *dynamic clusters* [11]. They may have different *natures* such as being defined by a) abstract criteria considering variable, context-sensitive threshold levels [5, 6]; b) contextual statistical significances; c) synchronisations [12]; or d) correlations establishing communities and networks [13, 14].

We stress here how mesoscopic variables are *variable*. Consider, for instance, case a) when the value taken by a specific mesoscopic variable at time t_i represents the fact that a number h_i of agents are at the *same* (depending on threshold values on a suitable scale) distance (or have the same speed, altitude or direction). However, the ***n*** elements constituting the mesoscopic variable at instant t_i can, in turn, be placed into groups having the *same* values, e.g., h_1 at distance d_1, h_2 at distance d_2, etc. Accordingly, we may say that mesoscopic variables are not static, but context-sensitive.

Properties of mesoscopic variables

This project considers *properties* of mesoscopic variables, single, clustered or networked [14], such as: a) their values and temporal regularities including periodicity, quasi-periodicity, chaotic regularities around attractors; b) interdependent, cross-correlations; c) statistical properties; d) geometrical (including topological) and statistical properties of sets of generic agents constituting mesoscopic variables, as well as density; e) related to the usage of degrees of constraints[2] allowing a description of the *history of use* and detection of regularities; f) values *specifying* the mesoscopic variables, such as threshold, parametric, statistical values or possibly network parameters.

Mesoscopic Dynamics

First, we consider the properties of the values adopted by the **mesoscopic general vector**

$$V_{k,m}(t_i) = [e_{k,1}(t_i)\ ,\ e_{k,2}(t_i)\ ,\ \dots,\ e_{k,m}(t_i)] \quad \text{where:}$$

k - identifies one of the *k* entities e_k;
i - is the instant of the discretised time *t*;
m - identifies one or more of the *m* mesoscopic properties possessed by elements e_k at time t_i;
$e_{k,m}$ - takes a value of *0* if element $e_{k,m}$ does not possess the mesoscopic property *m* at time t_i or a value of *1* if element e_k possesses the mesoscopic property *m* at time t_i.

Properties of values adopted over time by such a vector will represent the mesoscopic vector behaviour of the collective behaviour.

On the other hand, we can consider mesoscopic dynamics as being described by cases occurring when a) *all* the agents *simultaneously* possess all the *same mesoscopic properties*. The associated mesoscopic and parametric variables have values *constant* over time; b) *all* the agents simultaneously possess all the *same mesoscopic properties* as in the previous case. However, the associated mesoscopic variables have parametric values *changing* with time; c) the agents possess different mesoscopic properties, but the parametric values are constant over time; d) the agents possess different mesoscopic properties and the parametric values are changing with time. Case c) corresponds to complex patterns of collective behaviours and case d) corresponds to the patterns of collective behaviours characterized by the highest level of complexity.

Finally, the mesoscopic changes or dynamics can be considered as being represented by the possible *levels of coherences* between properties of mesoscopic variables. Coherences can be given, for instance, by levels of general, local, or remote *synchronisations*. Other *stronger* forms of coherences can be given by ergodicity [15].

3. MESOSCOPIC INTERVENTIONS

As introduced in the literature, explicit, overall interventions which are expected to have linear effects on the properties, including behavioural ones, of complex systems, are unsuitable or ineffective and inappropriate since they consider only the desired change and neglect the nature of complex systems, and their emergence mechanisms [16].

This project aims to allow the design of non-linear, non-explicit, non-invasive, *soft* interventions on complex systems *making them adopt the desired changes* rather than to processes

[2] Consider, for example, the degree of freedom valid for each of the *k*-interacting agents, given by the fact that the speed of each must not be greater than V_{max} nor less than V_{min}. Consider, instant by instant, the speed $V_{k(t)}$ of each of the *k*-interacting agents. One can calculate the degree of use of the available degrees of freedom as a percentage of the difference between the maximum and minimum permissible velocity
$([V_k(t) - V_{min}] * 100) / [V_{max} - V_{min}]$.

external input considered as suitable, explicit *orders* inherited from the conceptual framework of self-regulatory cybernetics.

We consider here mesoscopic interventions on the properties of mesoscopic variables and mesoscopic dynamics.

We may consider the *targeted* desired behaviour to be adopted by the collective behaviour of entities as being represented by sets of properties of mesoscopic variables and mesoscopic dynamics.

The *targeted* desired behaviour to be adopted by the collective entities could be artificially simulated using suitable software and thus identifying ranges of *equivalent* values of mesoscopic properties and mesoscopic dynamics.

In the classical view, the differences between instantaneous mesoscopic properties possessed by the collective behaviour and the simulated targeted behaviour should be *dispensed* with. This approach can be appropriate and effective in simpler cases, dealing with only a few variables and interactions. This is where sets of parameters should be adjusted and suitably *regulated*.

In other cases, the large number of parameters, and of crossed mesoscopic equivalences, the mesoscopic dynamics, and the varieties of equivalent coherences make the situation intractable using this approach. One example, presented in the literature, is *mesoscopic slaving* through adiabatic reduction allowed by *order parameters* as considered in Synergetics [17, 18, 19, 20]. However, this approach allows one to model using only a reduced number of variables by lowering the number of degrees of freedom with only a small number of parameters. This does not help to set modifying strategies. One possible approach for the study of suitable modifying interventions consists of using suitable *environmental perturbations* and *Perturbative Collective Behaviours* (PCB).

Environmental perturbations should be such that they are *collectively processed* and induce dynamic collective parametrical resets whilst maintaining coherences. Examples are oriented air flows, suitable changes in lighting, acoustic or electromagnetic perturbations affecting communications, and insertion of suitable dynamical, eventually correlated, obstacles.

A *sophisticated extension* of the last point (insertion of obstacles) consists of the introduction of a suitable *system of context-sensitive PCBs* or even a single PCB. There are several possibilities.

Temporary entities of PCBs can *materialise* and *disappear* as found suitable, as with perturbative systems of vehicles in road traffic or of mobile agents within pedestrian traffic; perturbative systems of economical entities within markets; and, of course, this approach can be easily applied to any kind of simulated collective behaviours.

Entities of the collective behaviour to be modified can temporarily, suitably *mutate* as belonging to a PCB. Such mutation can be *active* as appropriate and involve various different elements over time. Otherwise the PCBs can be composed of new *external* entities (e.g., predators) or combinations with the mutated entities.

In the case of simulation, original entities may be *invisible* to the mutated or external entities following their *autonomous* collective interactions. However, original collective entities will interact by *respecting* constraints with the inserted PCBs by, for instance, avoiding collisions, keeping at a minimum distance, and avoiding overlaps. PCBs can be suitably inserted *within* the collective behaviour to be varied, placed along the borders, or spread out with an appropriate density. PCBs can have various discontinuous temporal durations, possibly correlated. Consider the case where original entities are *visible* to mutated or external ones. Here, however, information is not used to avoid the cases considered above, of exclusive responsibility of the original entities, but to establish *feedback* between PCBs and the original collective behaviour to be varied allowing the former one(s) to change in number and properties, and allowing some kinds of *intelligent adaptive, rather than regulatory,* learning according to the modification to be induced. Such learning corresponds to strategies used by the program introducing the PCBs.

Such strategies depend on the levels of *cognitive autonomy* [21, 22] possessed by entities, from zero for physical entities such as signals or data, up to boids establishing flocks or human agents establishing markets or queues. One strategy to be considered is that based on using, for instance, a large number of perturbative entities forcing the original ones to adapt by adopting the same *unavoidable* mesoscopic properties.

Furthermore, different configurations of entities may establish, at different mesoscopic thresholds, the same mesoscopic variables and satisfy the same mesoscopic properties, and thus be *equivalent* from a mesoscopic point of view. The approach outlined above should also take into account other possibilities such as modelling mesoscopic variables and mesoscopic properties as networks, and mesoscopic interventions as network interventions [23, 24, 25].

4. CONCLUSION

We consider the dynamical, multiple, overlapping, and interfering system of interactions, having possibly different and variable starting times and duration, establishing collective systems. In the meta-structures project, we consider such a system of structural dynamic interactions as being suitably represented by mesoscopic variables and mesoscopic properties, while the coherence(s) of collective systems as being suitably represented by mesoscopic dynamics. We describe how this approach can allow mesoscopic interventions suitable for acting upon the behaviour and properties of collective systems.

The project is being developed using simulated collective behaviours able to make available *all* the instantaneous microscopic information necessary to define mesoscopic variables and properties. A possible non-simulated context where *all* the instantaneous microscopic information can be available is in economics [26].

Conflict of Interest

The authors declare no conflict of interest.

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