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# A Stylized Model of Individual-Society Interaction Based on Luhmann's Theory

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**Abstract.** The computational modeling and simulation of social phenomena based on social theory as a theoretical framework is a challenging endeavor. Mainly, due to the difficulties to translate abstract conceptualizations of the social sciences into formal languages. The main goal of this paper is the translation of some Luhmann's concepts such as perturbation, dissipation, social communication and power, into a model using a spatial social subsystem as a metaphor, to make more concrete these very abstract concepts. The model has been used to improve the social theory understanding and to evaluate the effect of different parameterization in the global stabilization and authorities' distribution. It has been designed to comply with the Luhmann's social theory, and to be scalable and simple to understand. The experiment implemented one instantiation of the proposed model and showed how it can be used to evaluate a micro-macro interaction based on a simple mechanism of Luhmannian social communication.

**Keywords:** Social theory · Social communication  
Evolutionary power

## 1 Introduction

According to [43], to model a social phenomena it is necessary to define an *object of research* that precises what should be modeled, a *reference framework* that will guide the mental model construction, a *social theory* that will instruct what aspects of the society will be modeled, and a *generic formal model* based on this theory which formalizes computationally or mathematically the abstractions and conceptualizations of the theoretical framework. Hence, the *model* will be one instance of the object of research using this generic model as reference, and it could be used to simulate the social dynamics to foresee different scenarios.

The *social phenomenon* that inspired this study is the collective action and power relations in the councils of Rural Territories in Brazil [39,41,42]. Rural

Territories are new institutions for regional sustainable management at the landscape level. They had being created by two federal territorial public policies, the National Program for Sustainable Development of Rural Territories (PRONAT) [27] and the Program Territories of Citizenship (PTC) [5]. To formally study this social phenomenon, da Silva [39] conceptualized each Rural Territory as a complex socioterritorial system (CSTeS) based on the works of Moine [28,29].

As the conceptualized CSTeS suggests, one *referential framework* is the Complexity Science. In fact, the studied social phenomenon is considered to show the properties of a complex social system as stated by [7]. Another referential framework is the systemic approach which aims to describe the social phenomenon by identifying the key components and relations between them [20].

Also considering the referential framework, there are, at least, two epistemological alternatives to model a social phenomenon, the critical-realism and the constructivism [7]. According to Castellani and Hafferty [7], the former is more connected to the theories and methods of the natural sciences, and the other more attached to the historical and qualitative analysis from the social sciences. This division becomes more clear when you observe the differences between behaviorist approaches at the micro social scale [34] and sociological approaches at the macro scale [6,17]. In fact, in this work it is used these two epistemological currents in a constructive way.

Considering the object of research, the CSTeS, and the complex systems as referential framework, the choice for the *social theory* should be compliant to the systemic approach and the complexity paradigm. So, despite the myriad of theoretical sociological systemic propositions it is worth to realize the relevance and completeness of the Luhmann's Social System proposition [11,23–25]. The Luhmann constructivism work reinterprets the concepts of complexity and systems theory, adapting it to his sociological studies, and sheds light on important aspects of our society as the social evolution by recursive mechanisms of self-differentiation by social communication.

Despite the compliance of the Social Systems with the complexity and systemic approach, the high level of Luhmann's abstraction makes the proposition of a *generic formal model* a very challenge task. In general, the models based on Luhmann's theory focus on specific aspects of the theory as observed in [3,10,12,13,15,21,38].

This research proposes a translation of some Luhmann's concepts (social subsystem, perturbation, dissipation, social communication and power) into a generic model using a stylized spatial society as a metaphor of a Luhmann's social subsystem. The model has been used to improve the social theory understanding and to evaluate the effect of different parameterization in the global stabilization and power distribution.

The model has been based on an existing experience [38] and is focused on the implementation of the mechanisms of perturbation/dissipation between the social subsystem and psychic system, and the translation into computational language of the Luhmann's societal power and communication process based on three selections (information, utterance and meaning).

This paper is organized as follows. Section 2 presents the concepts and definitions of the Luhmann’s Social Systems. The Sect. 3 shows a brief review of some models designed from Luhmann’s propositions. The Sect. 4 unveils the proposed generic formal model and the stylized spatial-social subsystem. The Sect. 5 shows the results and discussion of a simple simulation experiment. Finally, the Sect. 6 presents the conclusions.

## 2 Luhmann’s Social Systems

### 2.1 General Description

According to Luhmann [23,25], Social Systems can be interpreted as a type of *autopoietic system* (self-reproductive system) and are divided into three classes (society, organizations, and face-to-face interactions) (Fig. 1). *Society* is unique and composed of interrelated subsystems (e.g., economy and politics) that are intertwined in a complementary way. *Organizations* are formalized systems for decision making, guided by goals and operational capabilities. The third component is the personal, *face-to-face*, interactions between individuals, represented in the Luhmann’s formulation as *psychic systems*, separated from the society.

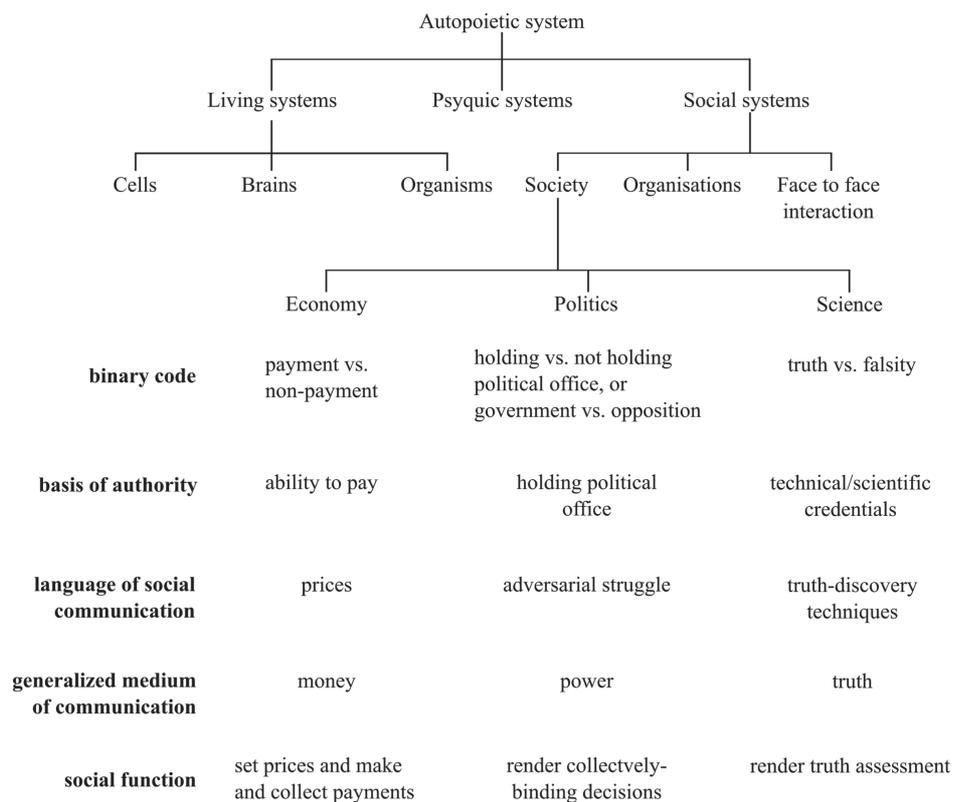


Fig. 1. General organization of the Luhmann Social Systems [23].

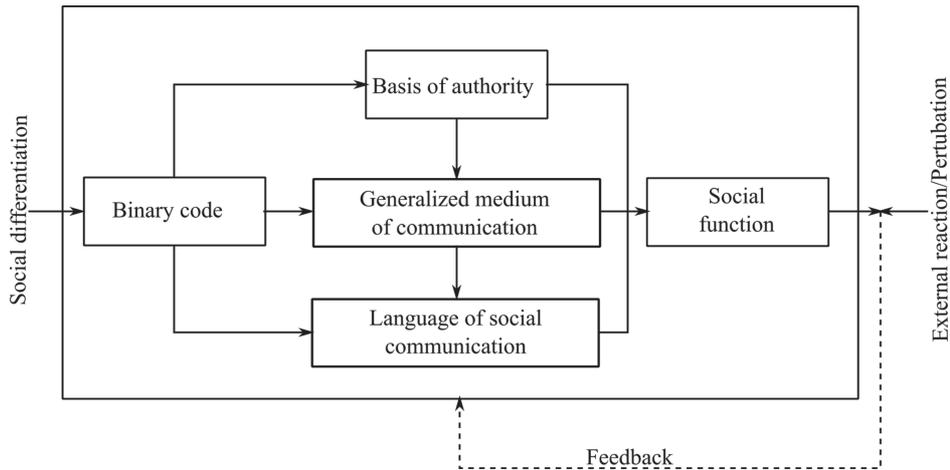
The societal subsystems interact with each other according to internal and external processes of social communications. The existence of each subsystem

is due to a mechanism of differentiation, which is responsible to reduce the inherited complexity of the human society. The scientific subsystem, for example, emerged from the society need for falsifiable scientific statements that will be used by scientists and appropriate by organizations at some point in a recursive way [32].

## 2.2 Rempel's Terminology

Rempel [32] organized the Luhmannian subsystems according to its five components, namely: the binary code, the basis of authority, the language of social communication, the generalized medium of communication and the social function (Fig. 2). According to Rempel, the *binary code* is a linguistic construction that establishes how dichotomized a social subsystem will behave vis-à-vis the environmental disturbances. The *basis of authority* refers to the effective capacity of negotiation, communication and action of the subsystem to be legitimized by the possession of a jurisdiction in a specific area. In the *language of social communication* we will find the rules and conditions for the operation of the subsystem. The *generalized medium of communication* is what is exchanged, communicated, and must be recognized by all members in a subsystem. Finally, the *social function* is the purpose of the subsystem.

For instance, the political subsystem shown in Fig. 1 has as a binary code holding or not a political office, and this political position will be the basis of authority. The language of social communication in the political world is the adversarial struggle, so they fight for strategical positions trying to increase their power, which is interpreted here as a generalized medium of communication. Every side of this political scenario must interact to allow the political subsystem to render collective decisions for the society.

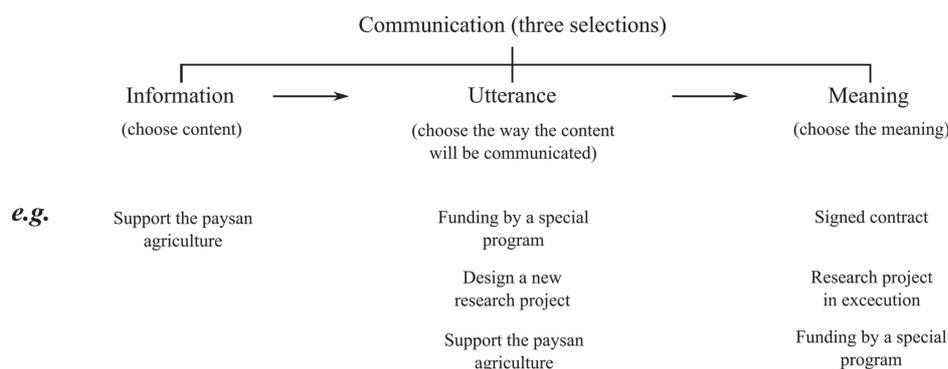


**Fig. 2.** The five components of each subsystem as defined by Rempel [32].

### 2.3 Social Communication

The Luhmannian work opposes the methodological individualism, but without eliminating the subject, the individual [1, 30, 36]. In Social Systems, the society is not anthropogenic, because the social processes are very far from the individual. However, for Luhmann, the actions of individuals are necessary for the social dynamic and they make it happen by a coupling mechanism between the social and psychic systems (individuals). So, a intervention mechanism of *perturbation/dissipation* is responsible for the connection between the psychic system and social systems, and this ignites the social communication process (a micro-macro linking process).

In fact, *social communication* in Social Systems is a mechanism for reducing the complexity (choose one, among an infinite set of options) by three types of selections: *information selection* (choice of content), *utterance selection* (choice of how that content will be communicated) and *meaning selection* (choice of meaning) (Fig. 3). For example, if the government chooses the content of supporting family farming (information), this can be implemented by special public funding or developing a new research project (utterance). The utterance process results in one or more contracts between small farmers and banks or research agencies (meaning).



**Fig. 3.** Social System's communication according to Luhmann's theory.

In the Luhmannian social communication, there is not a clear message sent by a transmitter that passes through a transmission medium to reach a receiver within a period of time. In his formulation, Luhmann states that the social communication is not deterministic, neither synchronized, suffer from lack of accuracy and there is no general persistence in the selections of information, utterance and meaning. This definition of social communication is important to understand the reinterpretation of Luhmann's theory by Borch [4] and Rempel [32] in order to define *power*.

### 2.4 Social and Individual Power

Power can be interpreted in the Luhmann's work in three ways. As the mean of generalized medium of communication of the political social subsystem [22, 24],

as the basis of authority of all social subsystems [32] and as a capacity to generate meaning through time by the social communication process [4, 18, 32].

The power as the mean of generalized medium of communication of the political social subsystem can be interpreted as a capacity to influence someone as proposed by Castelfranchi [8].

The power as the basis of authority can be viewed as a capacity to act by means of internal (e.g., cognition) or external (e.g., resources) abilities also as exposed in [8].

The power as a capacity to generate meaning can be interpreted as an efficient and evolutionary production of meaning by psychic systems (individual) actions as exposed by [4, 18] and in the same direction as proposed by Foucault [14]. In fact, Borch [4] established a bridge between the Foucault's notion of power and its relation with the knowledge production/location and the theoretical formulation of meaning generation in the Luhmannian social communication. According to Borch [4, p. 159]:

*This definition of power, as a relation between action and action, is equivalent to the Foucauldian definition of power (in the form of government) as conduct - with the application that Luhmann is explicitly concerned with the regulations of selections, of selected action up selected action.*

Borch [4] presents some convergences between Luhmann and Foucault, such as: focus on differentiation instead of identity; social communication and its evolution through time as the main driver of society, instead of action and structure; power exercise as a cooperative game, not zero-sum one; power as a mechanism of regulation, not coercion.

So, individual power can be interpreted as the basis of authority (power-of [8]) as the social power as a measure of capacity to generate meaning by the Luhmannian social communication.

### 3 Related Work

The initiatives to design models inspired by the Luhmann's social theory can be divided into three groups: emergence of social order according to agents' expectations [3, 10, 15, 16, 21, 26]; social subsystem implementation [13, 18]; and micro-macro link [38].

#### 3.1 Emergence of Social Order

The models focused on social order start from the Luhmann's idea that it emerges as a result of mutual expectations (double contingency) among the social agents during a social communication process [10]. Dittrich et al. [10, p. 2] stated that "... every entity expects that the other entity has expectations about its next activity". In fact, the authors explored the interpretation of the double-contingency concept to design a mechanism of information proliferation using

the expectations as the main social process between agents. Barber et al. [3] and Fullsack [15,16] used the same idea to design their model of expectations. The main characteristic of this approach is that the communication between agents is implemented as a face-to-face interaction using the Shannon paradigm [35]. Analogously, Leydesdorff [21] proposed a system of anticipation [33] based on iterative expectations in an information flow based on face-to-face interactions.

The solutions proposed by these authors present some similarities, such as: there is no need to have an observer to send messages across the agents; each agent has all knowledge about his own actions in the system, for instance, they know how the others reacted from his own action; the social relations are dyadic and explicit; and all agents have memory to be able to perform anticipatory actions.

### **3.2 Social Subsystem**

One of the first initiative to model a social subsystem can be found in Grant et al. [18]. The authors interpreted the Luhmannian society as a dynamic system where the six main subsystems coexist and communicates with each other by means of state variables and information (inactive and active) transfers according to the Ashby Cybernetics [2]. They proposed a model which represents different reaction times for each social subsystem, the rate of the social randomness, the power of each social subsystem to transform one inactive information into active and the amount of information inside each social subsystem. The authors coupled a socio-ecological system (collective livestock) with a stylized law social subsystem to emulate a coercitive effect on the natural resource use. So, without coercion this social system falls into the Hardin's Commons Tragedy [19], and with coercion the socio-ecological system reaches a sustainable state.

Fleischmann [13] implemented a simple Luhmann economy model based on scarcity and on the ownership code (the first economic level in the Luhmann's formulation of the economic evolution [13]). The main assumptions in this model are: (a) the social structure is based on expectations; (b) the communication is a matter of rejecting or not utterances; (c) and the systems are defined by its own operators; and (d) psychic and social systems co-evolve. The goal of this simple economic system is the accumulation of wealth and the result is inequality. This model confirmed the Luhamnn's hypotheses where he stated that the economic subsystem starts from inequality and reproduces it indefinitely to maintain its own existence.

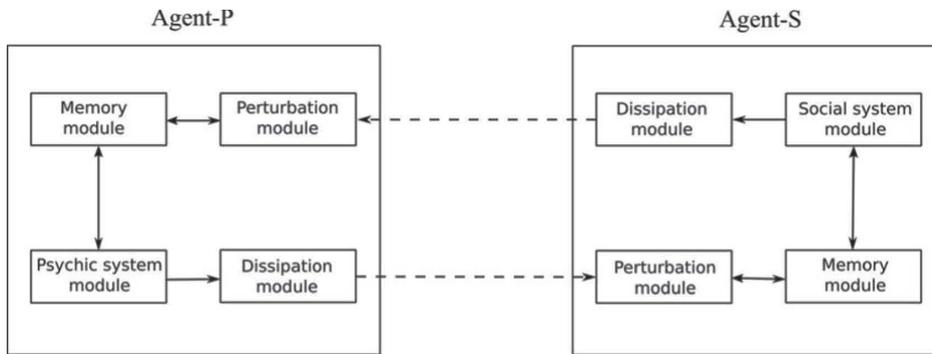
In these models there is no reference to perturbation, the social communication is very simple and the mechanism of co-evolution is not clear.

### **3.3 Micro-macro Link**

da Silva et al. [38] proposed a quite complete model to investigate the micro-macro link, or the interaction between the social system (macro) and the psychic system (micro). This model mapped many Luhmann's concepts like expectation,

perturbation, dissipation and social and psychic communication. Despite the usefulness of the model as shown in [38] it is important to note that there are so many modules and connections between them that limits the results interpretation. Another remark is that it uses the same mechanism of communication for both micro (Agent-P) and macro (Agent-S) agents.

The Fig. 4 shows a simplified diagram of the model proposed by [38] and used as the basic framework of the proposed model. Both the social systems (Agent-S) and the psychic system (Agent-P) are composed of a dissipation module dedicated to send information to the environment (other systems) motivated by internal deliberation or external stimulus, a perturbation module which is responsible for the interpretation of dissipation actions by other systems, and a memory module where the experiences, knowledge, and rules of the system are stored. The Agent-S has a social system module which implements the social dynamic strategies. The Agent-P has a psychic system module which is responsible for the implementation of the behavioral aspects of the micro (individual) level.



**Fig. 4.** Simplified diagram of the model proposed by [38].

In the original proposition [38], these modules were implemented in a very detailed way in an attempt to implement a generic model for any social subsystem. For instance, the psychic system module was composed of four submodules: central analyzer, contingency analyzer, dissipation manager and expectation manager [38]. In fact, the excess of inputs-outputs makes the general simulation output interpretation a very difficult task. Besides, the communication mechanism in both agents, Psychic and Social, is implemented in the same way and is not entirely compliant with the original Luhmannian formulation of social communication based on the three selections (information, utterance and meaning) as stated in Sect. 2.

### 3.4 Comparison Between These Three Groups

In summary, Luhmann's Social Systems are not fully represented by these models. In general, it is necessary to oversimplify the model as in [10] to make possible the formalization of some Luhmann's abstractions like the double contingency

and expectations. On the other hand, da Silva et al. [38] proposed a very comprehensive formalization of the Social Systems which makes the interpretation of the simulation outcomes a challenge task or even meaningless.

One of the drawbacks of the analyzed models is the implementation of the social communication process. In all propositions it is treated as a simple traditional message transfer among agents.

Therefore, the proposition of [38] appeared to be the most complete computational formalization of the Luhmann’s theoretical abstraction and was used as reference in this paper. Table 1 summarizes the comparison between these three groups of models based on Luhmann’s theory.

It is also worth noting that none of the analyzed models interpreted the Luhmann’ social subsystems as proposed by Rempel [32], and did not explored any interpretations of the power concepts.

**Table 1.** Comparison between the three groups of models based on Luhmann’s social theory

	Emergence of social order	Social subsystems	Micro-macro link
Goal	Formalization of the core concepts of the Luhmann’s theory	Model and simulation of a particular social system [13, 18]	Model of macro behavior of the social system
Technology	Multi-agent systems [3, 16]; social network [10]; and anticipatory systems [21]	Dynamic systems [18] and multi-agent systems [13]	Multi-agent system
Implemented Luhmann’s concepts	Double-contingency, anticipation, expectation and social communication	Social communication, the binary code and the interface between social subsystems	Double-contingency, anticipation, expectation and social communication
Other theories used	General System Theory, Shannon’s Information Theory and Anticipatory Theory [21, 33]	Ashby’s Cybernetics [18]	Lewin’s Field theory

## 4 Proposed Model Using a Spatial Social Subsystem as a Metaphor

### 4.1 A Stylized Spatial Social Subsystem

To overcome the problems shown in Subsect. 3.3, it is proposed in this work a simple mechanism for each module for Agent-P and Agent-S, based on a stylized

spatial social subsystem as a metaphor of the Luhmann' social subsystem. The goal is to make a parallel between a well-known field of research, Spatial Analysis, and its problems (e.g., spatial dependence) and methods (e.g., spatial autocorrelation measure) with a formalization of the Luhmann's theory using multi-agent paradigm. So, our generic formal model subsystem will be composed of a set of neighbors cells, where each one can be associated to an Agent-P (Agent-P has authority over this cell). These agents will have stakes at disposal to change cell's values (Agents-P actions). The main goal of each Agent-P is to increase their authorities (number of cells under their control), and the main goal of the Agent-S is to increase the overall positive autocorrelation measure.

The rest of the section will describe the S4Luhamnn model according to the Rempel's terminology, the proposed Luhmannian social communication process, a new power definition based on propositions of Rempel [32], Borch [4] and Luhmann [22,24] and, finally, the details about Agent-S and Agent-P.

**The Proposed Stylized Spatial Social Subsystem According to the Rempel's Terminology.** Using the terminology of Rempel [32] to describe this stylized spatial-social subsystem we have as **binary code**, holding or not holding cells values; the **basis of authority** is the capacity to change spatial cells; the **language of social communication** is the struggle for cells authority; the **generalized medium of communication** is the artificial stake at disposal of each Agent-P; and the **social function** is the increasing of the positive spatial autocorrelation.

**The Luhmannian Social Communication.** The proposed social communication process for the S4Luhamnn model is resumed in Table 2 and consists of an information selection based on the reinforcement of positive autocorrelation, the utterance selection that will allow positive or negative incremental changes in cells at each time step, initiated by the Agent's-P and approved by the Agent-S, and a meaning selection where Agent-S changes the status of neighbor cells according their values, affecting the power share.

**Table 2.** The Luhmannian social communication in the spatial subsystem

Selection mechanism	Description
Information	Reinforcement of positive autocorrelation
Utterance	Positive or negative incremental changes in cells at each time step
Meaning	Agent-S changes the status of neighbor cells according their values, affecting the power share

**The Rempel-Borch-Luhmann Power Definition.** The power of each Agent-P can be interpreted as the number of cells under his authority. And the power of the Agent-S as a measure of positive spatial autocorrelation. Both powers may be originated from the Luhmannian communication process of perturbation/dissipation between Agents-P and Agent-S. It is important to note that there is no face-to-face communication among Agents-P.

## 4.2 Proposed Model

**Agent-S - Social Subsystem.** Agent-S is unique and composed of one spatial rectangular board divided in regular cells. Each cell of the Agent-S may be active (admit changes) or inactive (do not admit changes) and assume a value in  $[0, 100]$ . The main goal of the Agent-S is to increase his Moran's  $I$  spatial autocorrelation [9], expressed by the equation

$$I = \frac{N}{\sum \sum w_{ij}} \frac{\sum \sum w_{ij} (X_i - \bar{X})(X_j - \bar{X})}{\sum (X_i - \bar{X})^2}$$

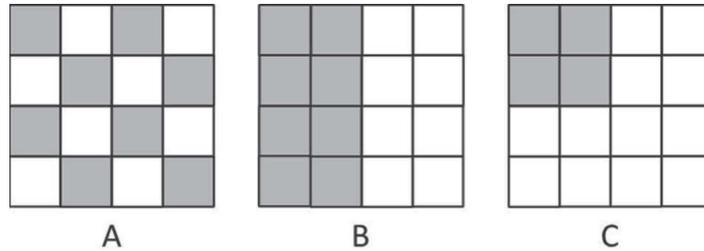
where  $N$  is the number of cells,  $w_{ij}$  is an element of the spatial neighborhood (rook type) matrix  $\mathbf{W}$  and assumes the value 1 if  $i$  and  $j$  are neighbors or 0 otherwise,  $X$  is the variable of interest (value of each cell) and  $\bar{X}$  the mean of the  $X$ . The Agent-S admits internal perturbation by Agent-P and irritates Agent-P at a probability  $p$ . At each time step the social subsystem evaluates their Moran's  $I$  index and change the authority of each cell (capacity to change the cell values by Agent-P) if there is a local spatial correlation (see dissipation module description in Table 3). Table 3 summarizes the mechanisms of the four modules for the proposed Agent-S.

**Table 3.** Description of the elements of the proposed Agent-S

Agent-S module	Description
Perturbation	Admit internal perturbation (changes in $X$ by Agent-P) at a probability $p$
Dissipation	If a cell and his neighbors (rook type) have similar values in some of two extremes, according to some thresholds, then put them as inactive. Thresholds: for Agent-P Alter $[0, 30]$ ; for Agent-P Ego $(70, 100]$
Memory	Spatial rectangular board divided in regular cells. For each cell is associated a real value in $[0, 100]$
Social	Evaluate the Moran's $I$ statistics

To clarify this mechanism, let's use a hypothetical example of a spatial-social subsystem (Agent-S) composed of a  $4 \times 4$  spatial board following the mechanism described above, with two Agents-P (Alter and Ego). In fact, Agents-P are struggling to increase their power on the spatial board without a direct

communication between them. The Fig. 5 shows three hypothetical final spatial board configurations after a number of social simulation steps where empty squares represent cells with values near zero (under Alter’s authority), and gray squares represent cells with values near 100 (under Ego’s authority).



**Fig. 5.** Hypothetical final spatial board configurations after a number of social simulation steps. (A) negative spatial autocorrelation; (B) positive spatial autocorrelation with the same authorities for each Agent-P; (C) negative spatial autocorrelation; (B) positive spatial autocorrelation with different authorities for each Agent-P

In the Fig. 5-A each Agent-P has the same amount of power (8 cells for each) but the general goal of the social subsystem was not achieved because with this configuration the Moran’s  $I$  will be equal to minus one (strong negative spatial autocorrelation). The Fig. 5-B shows a similar situation where each Agent-P shares the same amount of power (8 cells for each) but with a strong positive spatial autocorrelation. The Fig. 5-C shows also a strong positive spatial autocorrelation, but with an imbalance of power between Agents-P. The final configuration of the spatial board will depend on the social communication mechanism.

**Agent-P - Psychic System.** The goal of each Agent-P is to approximate the values of cells in the social board memory toward his own target. In this proposition there are two types of Agent-P, Alter and Ego. So, at each time step Alter act in order to change one cell value, at random, of the space board, toward zeros, and Ego do the same but the cell’s values are pushed toward the value 100 by adding negative and positive increments, respectively, by the dissipation mechanism.

The amount of the increment and the localization of the cell is defined at random in the entire board or in a defined area of it. So, each Agent-P changes the value of one cell at a time using one of two strategies: (1) choosing one cell completely at random; (2) choosing one cell in a small area of the board, also chosen randomly, depending on the increase of the level of authority of the agent, that will be checked periodically. Table 4 summarizes the mechanisms of the four modules for the proposed Agent-P.

**Table 4.** Description of the elements of the proposed Agent-P

Agent-P module	Description
Perturbation	Admit internal perturbation by Agent-S at a probability $q$
Dissipation	Propose changes in cell's values of the spatial board by adding or subtracting a $\Delta X$ value
Memory	Information about the past levels of power on board cells
Psychic	Each Agent-P has a <i>capacity of action</i> and they use part of this "energy" to act. There are two possible strategies: (1) tries do change a cell chosen at random considering all possible cells in the spatial board; (2) tries do change a cell chosen at random considering a small portion of cells in the spatial board. The Agent-P can use only the first strategy or switch between these two options according to the level of Agent-P's power (authority over cells), checked in a defined time delay

### 4.3 Implementation

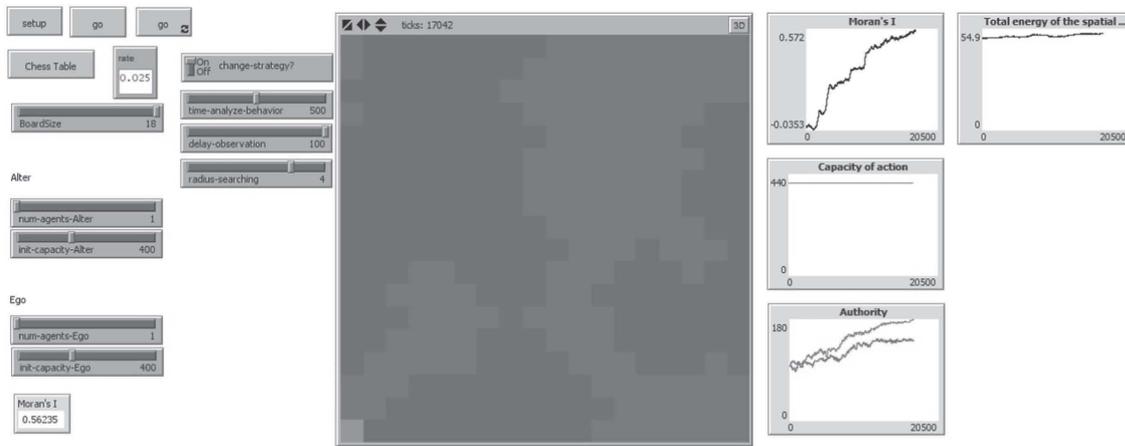
The model, called Stylized Spatial-Social Subsystem based on Luhmann's theory (S4Luhmann), had been implemented using Netlogo platform and it can be retrieved at [40]. Figure 5 shows a snapshot of the Netlogo implementation of the proposed model. Following it is described the variables, the social dynamic, and the model's observable results.

**Variables.** In this implementation, there are ten variables:

1. *rate*, which is the amount of rate of energy used by agents to change the cell's values by small positive and negative increments;
2. *BoardSize*, the side length of the squared regular spatial board;
3. *num-agents-Alter*, number of agents which aim to approximate the cells' values toward zero;
4. *num-agents-Ego*, number of agents which aim to approximate the cells' values toward one-hundred;
5. *init-capacity-Alter*, the amount of stakes available for Alters to change the values of the cells;
6. *init-capacity-Ego*, the amount of stakes available for Egos to change the values of the cells;
7. *change-strategy?*, if true the Agents-P use two strategies, otherwise they will use only one strategy;
8. *time-analyze-behavior*, interval of times that the Agents-P will check if they need to change behavior;
9. *delay-observation*, the length of the memory of each Agent-P;
10. *radius-searching*, the radius of searching for the second strategy.

**The Model Dynamic.** The spatial board is initialized with random values between  $[0, 100]$  and every cell is active. The two types of Agents-P (Alter and Ego) are instantiated. At each discrete time  $t$  the Agents-P sends messages to change spatial board cells. Agent-S accept or not these changes. After the cells update, the Agent-S act making groups of neighbors cells inactive according to its internal rules. At each time step the Agents-P evaluates if it is necessary to change the strategy used to change cells according to their level of authority. The simulation stops when all cells are inactive.

**Observable Results.** The graphics on the right of the Fig. 6 show the Moran's  $I$ , the total of energy of the board, and the capacity of action and authority of each type of Agent-P. The spatial board shows the final spatial pattern of distributed authority between Alters (gray) and Egos (dark gray).



**Fig. 6.** Snapshot of the Netlogo implementation of the proposed model.

#### 4.4 Sociological Interpretation

There is a direct relationship between the proposed model and the Rempel's decomposition of the Luhmann's social subsystems [32]. Then, the model's outputs can be interpreted as stylized outputs of real social subsystems such as the economic or politic social subsystems presented in Fig. 1. For instance, the model can represent a political subsystem composed of two political parties struggling for power (*authority over each cell*) and the final configuration of the spatial board of the Agent-S may represent the general distribution of power (very *fragmented* if low Moran's  $I$  or *cohesive* for high  $I$ ).

The *spatial distribution* of authorities in the Agent-S's spatial board may also be a representation of a persistent pattern originated from the Luhmannian social communication. As explained in Sect. 2, the result of a social communication is originated from the meaning selection process output, and this can be a signed contract, a research project in execution, a funding by a special governmental program or something else (see Fig. 3). Using the model in this way, the model

could be used to verify if there is any correlation between the pattern observed in the real world (spatial or not) and the spatial pattern of the model's output.

*Power* is a important concept in many fields of research as in sociology, social psychology, political science, behavior science, etc. As stated by Rempel [32] and Borch [4], the Luhmann's theoretical framework can be extended to embraced the Foucault's evolutionary definition of power [14]. Therefore, the model can be used to observe different mechanisms of *power evolution* according to different parametrization or agent's strategies.

Observe power relations dynamics in complex socioterritorial systems (CSTeS) can follow these approaches. Thereby, the CSTeS can be viewed as a political social subsystem and the Agents-P implemented as political groups. Another way is to implement how the CSTeS council's members communicate and observe the emergent power's pattern, such as persistent arguments, decisions, relations, etc.

In fact, at this moment, the model may be used as a tool to test theoretical speculations about Luhmannian social communication, power (individual and social) evolution and individual-society interaction.

## 5 A Simple Simulation Experiment

Let's consider a model of a stylized political subsystem where Alter and Ego represents two political parties and the Agent-S the society and its political preference distribution. The experiment using the proposed model should evaluate the effect of the two Agents-P strategies (see Table 4 in Sect. 4) on the general power distribution (share of authority), the spatial distribution of each party influence and the cohesiveness of the spatial aggregation by means of the Moran's  $I$  statistics.

The experiments were conducted considering some variables as constants ( $rate = 0.0125$ ;  $BoardSize = 18$ ;  $num-agents-Alter = num-agents-Ego = 1$ ;  $init-capacity-Alter = init-capacity-ego = 400$ ;  $p = q = 100$ ) and the others varying according to some subset of values ( $change-strategy? \{true, false\}$ ;  $time-analyze-behavior \{500, 1000\}$  time steps;  $delay-observation \{50, 100\}$ ;  $radius-searching \{3, 4, 5\}$ . The time limit steps for each run was set to 20000, for 10 runs.

Analyzing the mean of the Moran's  $I$  of the spatial board and of the authority's share for each type of Agent-P, Figs. 7 and 8, it is easy to identify a huge change when comparing these two strategies. The experiments 04, 05, 07 and 10, which the Agent-P uses two strategies, showed a very sharp increase in the Moran's  $I$  when compared with the only random strategy. The same difference is observed when looking at the shares of authority. In the experiments 04 and 05 the level of global positive spatial autocorrelation is greater than the other experiments due to the combination of a short time-analyze-behavior (500) and a greater memory delay-observation (100). In the graphic of authority it is observed that the Agent-P Ego end with more authority in both cases, but this is not true all the time, and the authority tends to be similar due to the fact that the Agents-P share the same strategies.

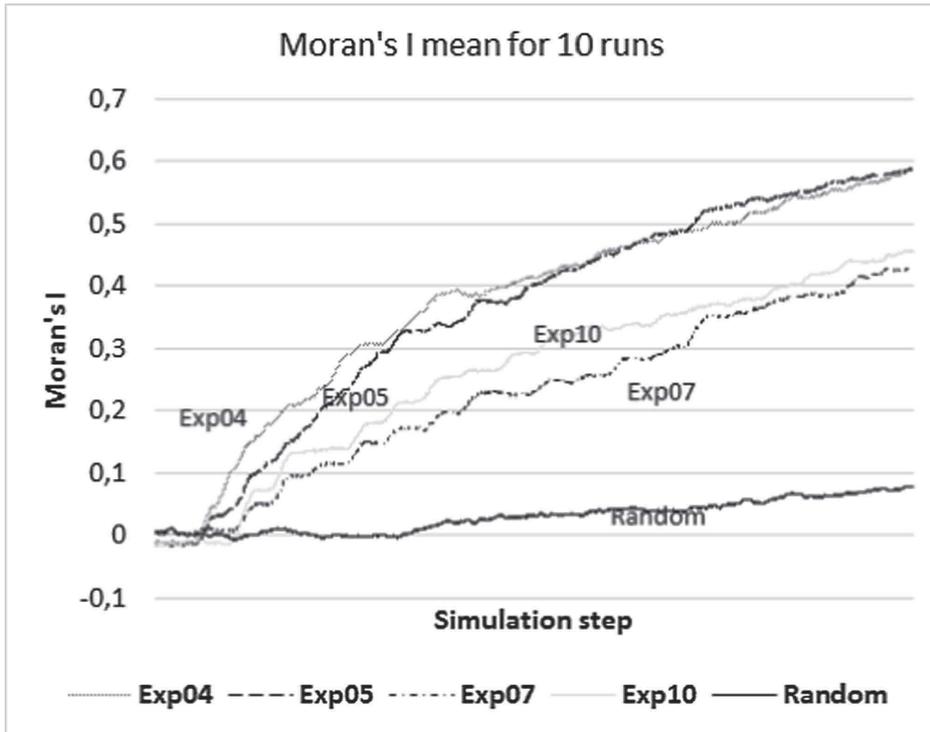


Fig. 7. Moran's  $I$  mean for 10 runs, 20000 time steps each.

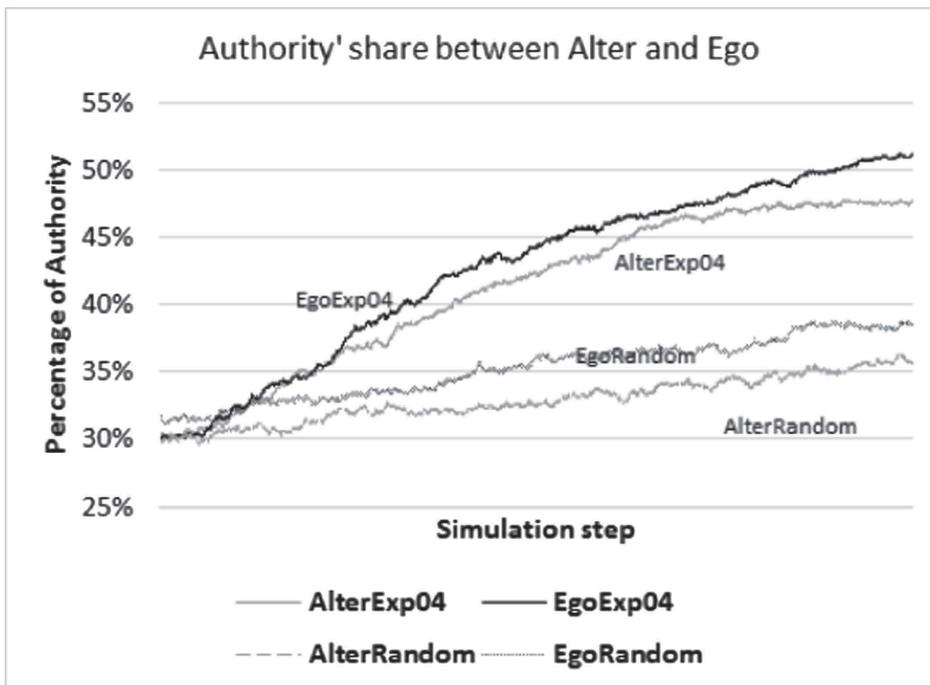
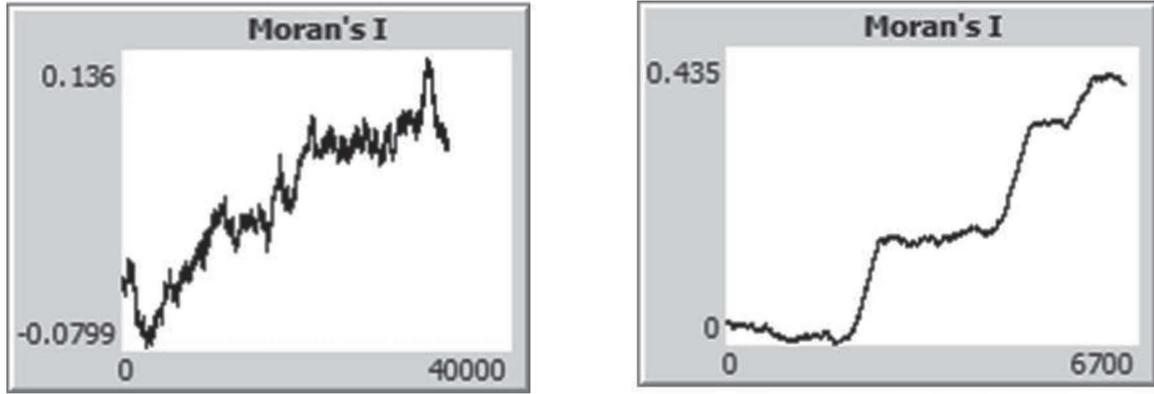


Fig. 8. The share of authority for some experiments.

The Fig. 9 shows the Moran's  $I$  curve for two types of simulation. The first one (left) represents the result of a simulation where Agents-P choose spatial board cells always randomly. The other uses the strategy to switch from completely



**Fig. 9.** Moran's  $I$  curve for one simulation run considering *change-strategy?* = *False* reaching a modest  $I$  less than 0.136 after 30000 simulation steps (left) and considering *change-strategy?* = *True*, *time-analyze-behavior* = 500, *delay-observation* = 50, and *radius-searching* = 3 reaching a Moran's  $I$  greater than 0.4 after only 6000 simulation steps (right).

at random in all spatial board and in a small location of it. It is worth noting that the second strategy (right) converges very quickly and follows a particular pattern between a long time of stability and a sharp increase in  $I$  in a short period of time.

Comparing the two strategies of the Agents-P's according to the share of authority (Agent-P's power), spatial distribution, cohesiveness and Agent-S's power evolution it is possible to elaborate some sociological speculations to be confirmed empirically, if possible.

*Share of authority.* It is observed a increasing of general share's authority for the second strategy, but in all strategies Alter and Ego have the same amount of power due to the fact that there is no different in terms of strategies between them.

*Spatial distribution.* In this case the spatial authority distribution does not allow any conclusion because it was not established a correlation between each cell and a geographical space with a political meaning. Besides, the second strategy generated a more cohesive and segregated political system.

*Agent-S's power evolution.* The positive autocorrelation increasing curve for the second strategy of Agents-P (see Fig. 7) shows a clear pattern for the social power evolution.

## 6 Conclusions

The S4Luhmann model represents one step toward a more comprehensive formalization of the Luhmann's social theory. The metaphor strategy showed to be useful to make the theoretical concepts more concrete for implementation and interpretation.

The Rempel [32] decomposition of the Luhmann's subsystems in five components (binary code, basis of authority, language of social communication, gen-

eralized medium of communication and social function) helped to establish a parallel among social subsystems and facilitated the use of a spatial-social subsystem metaphor as a way to study social phenomenon through the Luhmann's perspective.

From the individual point of view the Luhmannian power can be interpreted as the amount of basis of authority (in our model the amount cell's authority), so, going beyond the Luhmann's proposition of power as only generalized medium of communication of the political subsystem. On the other hand, the society power can be interpreted as a measure of efficiency of the Luhmannian social communication (in our model the Moran's *I* statistics).

A sociological interpretation of the model outputs demands a parsimonious analysis due to the fact that the use of the spatial metaphor may not appropriate to represent all social phenomena.

The simple experiment showed that even a simple change in the way the psychic system and social system interact can generate very different patterns shares and spatial distribution of authority, social cohesiveness and societal power evolution.

Future work may address the implementation of other key Luhmann's concepts such as anticipation/expectation mechanisms as proposed by [3, 10, 15, 21]. Another focus may be the confrontation of this evolutionary definition of power with other formal propositions as stated by Castelfranchi [8], Sibertin-Blanc et al. [37] and Pereira et al. [31].

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