# Agent-Based Evolving Societies

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## ABSTRACT

This paper is an attempt to solve two important questions: which are the underlying mechanisms that make societies evolve, and how complex organizational structures may arise from simpler ones. Using theories describing the evolution of human societies, we have designed a Sugarscape-like multi-agent based model that illustrates how societies may evolve through a sequence of generic social stages (tribe, chiefdom, state). Each stage is the consequence of life conditions shaped by two sources: environmental conditions and the social organization of the previous stage. Our NetLogo implementation shows that the resulting behavior is in accordance with the social theories, societies emerging through a bottom up multi-level emergence process. This implementation is one possible solution to the problem of building societies that grow through stages. We derive a generic meta-model from this implementation and give design advices on how to build such a society, independently on the applicative context.

## Categories and Subject Descriptors

I.2.11 [**Distributed Artificial Intelligence**]: Multiagent systems; I.6.5 [**Simulation and Modelling**]: Model Developments; J.4 [**Social and Behavioral Sciences**]: Sociology

## General Terms

Design, Experimentation, Human Factors

## Keywords

Artificial societies, Emergent behavior, Simulation techniques, tools and environments, Social simulation

## 1. INTRODUCTION

How a society can change its organizational form depending on the circumstances? Consider a team of robots performing a rescue mission. Many conditions may change along the time: social conditions (changes in the team size), goal conditions (an additional objective is added on the fly) or environmental conditions (restriction in movements or in coordination). This team should be capable to reorganize itself, possibly from creating new roles to changing the organization paradigm itself. For instance, if the team becomes bigger than usual, a leader may emerge to coordinate the group efficiently.

Managing the evolution of groups and societies is also largely investigated in games. Many building games (like Civilization or SimCity) are devoted to the construction and the growth of societies. Even closer to reality, some serious games explicitly invite the player to influence societies to make a reorganization (e.g. "A force More Powerful"). These games abstract from the individual level to simplify the design and avoid the loss of control caused by a bottom-up approach. But, in doing that, they overlook many details that can enrich the game experience. Conversely, role playing games, working at the individual level, completely hardwire (if not overlook) the impact of individual choices over societies and their evolution.

This paper is a first step towards building societies dynamically evolving and expanding themselves. We focused on finding minimal means to create social change, emerging from the agent internal decision making process. The main point is to build some internal criteria, which, once reached, trigger new behaviors leading to the extension of the society with a new social organization.

We built a model conforming reasonably with the theories of social development, that we abstracted into a general meta-model for performing this kind of simulation. This model is in the vein of Sugarscape [5] and New Ties [7]. We were concerned with the logic of the evolution of societies, not with having accurate models of actual societies. We tried to decipher the most simple and general principles underlying social systems and implement them in a simulation, as Artificial Life has done with biological systems [8].

We used qualitative theories that come from sociology and history. Because most sociological research involves very precise human situations, we focused on theories providing explanations about the development of generic societies. In particular, we were inspired by Diamond's theory from [3] and developmental theories from [1].

In the Section 2, we detail the social science theory and computer science models we were inspired by. In Section 3, we present the model of our simulation and we detail its observed behavior in Section 4 to check whether it matches the social science expectations. Then, we retro-engineer our model to present a meta-model to build generically evolving societies in Section 5. Finally, we conclude this article with discussions about applications and future work.

**Appears in:** *Proceedings of the 12th International Conference on Autonomous Agents and Multiagent Systems (AAMAS 2013)*, Ito, Jonker, Gini, and Shehory (eds.), May, 6–10, 2013, Saint Paul, Minnesota, USA.

# 2. RELATED WORK

## 2.1 Evolving: Social Sciences Perspective

Diamond [3] formulates the theory that most of societies can be classified and that they evolve through 4 generic *stages*: band, tribe, chiefdom and state. Bands and tribes are similar organizational entities, with the difference that bands are smaller and nomadic. Because our aim is to observe societal organizational changes through stages, our analysis of Diamond's theory starts with the tribe stage.

This stage classification holds as well for past societies as nowaday ones. Moreover, societies evolve or decline one step at a time, from one stage to the next or to the previous one, without skipping stages. Each social stage matches a certain type of organization, this organization is fit for a given a population *scope* (or range). Matching a stage with a population out of its range leads to social trouble. For instance, a society with 100 members and another of 10000 cannot be ruled the same way for obvious practical reasons (like resource management or decision making). The social stages of the former and the latter must be different. A summary of each social stage, its organization and its scope can be found in Table 1.

How does a society evolve from one stage to another? The population increases until reaching environmental limits or going above the scope of the current its current stage. In the second case, the social structure is not fit anymore to cope with the current social challenges, bringing social trouble. This situation is solved by a change in the social structure, leading to a new social stage. Reciprocally, when a society fades away and the population is below the scope of the current stage, the society drops the social structures of the current stage, leading to the previous one.

### 2.1.1 Tribes

Tribes are groups from 80 to a few hundred people, organized in sets of families living in a village. The population is small enough to keep the familial distance between 2 individuals short. Thus, when 2 individuals enter in conflict, many of their family relatives are linked tightly enough to interfere between the 2 conflicting individuals. Information-sharing and decision-making are egalitarian: everyone shares the same information and decisions are reached through consensus of all members. Economy is limited to peer to peer exchanges (no centralized tax collection and redistribution). Population is low enough to let each individual produce its own food. Because of the equality between each member (caused by no specialization), each individual has to produce its own food, preventing specialists to produce luxury goods or knowledge. When resources are sparse, tribes may attack other villages to pillage them, but the relative inefficiency of food production prevents the development of slavery (the benefit of a slave is outweighted by its cost).

### 2.1.2 Chiefdoms

When the population grows, the average familial distance between random individuals increases. Consequently, the familial conflict resolution process cannot work anymore. Moreover, reaching consensus on decision making and resource management becomes harder when the number of inhabitants increases. These limitations trigger the social transition from tribe to chiefdom.

Chiefdoms are groups up to a few tens of thousands of individuals. The presence of a leader solves the problems of tribal consensus reaching for decision making and information sharing in letting one individual (the leader) control the power and the information. The leader also centralizes resources via a tax system. Thus, the leader can feed a militia to manage inter-individual conflicts and specialists to build luxury goods and institutional structures. Consequently, because of the increase of food production and the specialization of individuals, extortion and slavery are frequent practices in chiefdoms. Thanks to hereditary transmission, the social structure remains relatively stable across generations.

### 2.1.3 State

At the chiefdom's stage, the leader's capacity for managing critical information and decision making is the bottleneck of the society. When the society increases in size, the leader is overwhelmed and has to delegate a part of his/her power to subordinates. But, without control, subordinates tend to take over the leader. The bigger the population is, the more subordinates, so the higher risk.

A successful strategy to prevent such a situation consists in constructing an ideology/culture (e.g. law, norm, religion) supporting the system and the leader. Such an ideology links humans with each other and brings a motive to obey the leader and his/her rules. To apply the ideology, this has to be spread via Cultural Harmonizers ($CHs$). $CHs$ are people whose activity implies spreading intellectual values (e.g. priests, professors, itinerant storytellers).

The state stage generally occurs when the society exceeds 50.000 of members. A state is a set of villages sharing a common ideology. The social structure is deeply hierarchical. Each node is allocated to a given task and each subnode assumes part of this task. Each person is linked to a social status and is expected to behave according to this status, creating casts. The economy is redistributive, but a special institution (tax collection) performs it. A part of the income is redistributed to provide ways to unify culture (feed literate elites, instruct population masses), thus perpetuating the system.

Table 1 provides a summary of the observed specifcities for each social mode.

## 2.2 Evolving: Computer Science Models

Some frameworks investigated the emergence of societies from bottom up, the most famous ones being Sugarscape [5] and New Ties [7]. We try to find the answer to the same question: what are the minimal mechanisms to generate a given social phenomenon while keeping agent rules as simple as possible?

Sugarscape [5] introduces a very simple grid-like environment and simple agents with simple rules. But, in adding slight variations on top of this environment and agents (like reproduction, fight and trade), Epstein and Axtell were able to display a wide range of social phenomena (e.g. genetic selection, global wars, real-world market facts).

New Ties [7] aims at building an artificial society with socially high mental and linguistic capabilities, but with simple agents and simple environment. The goal of New Ties is to build autonomous entities, living and adapting to the world due to learning. Moreover, these agents are capable to produce their own culture and share it with other agents. The research objectives of New Ties aim at a better understand-

**Table 1: Social patterns generally observed for each social stage (based on Diamond's theory)**

| | Tribe | Chiefdom | State |
|---|---|---|---|
| Number of people | Hundreds | Thousands | Over 50.000 |
| Settlement pattern | 1 village | 1+ villages | Many villages |
| Decision making | "Egalitarian" | Centralized | Centralized |
| Leadership | Big man | Hereditary | Institional role |
| Force and information monopoly | No | Yes | Yes |
| Conflict resolution | Informal | Centralized | Law, judges |
| Exchange | Reciprocal | Redistributive (tribute) | Redistributive (taxes) |
| Indigenous Literacy | No | No | Yes |

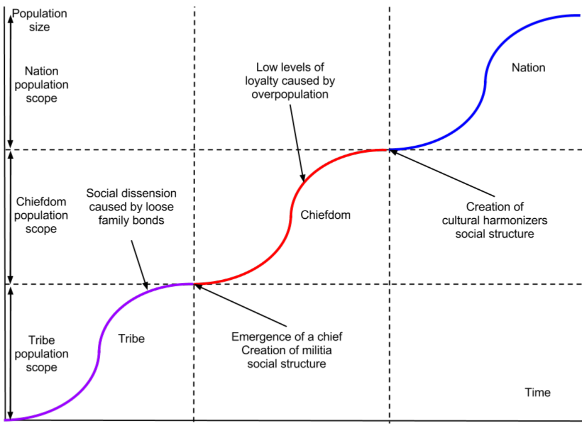


**Figure 1: Expected behavior of the simulation**

ing of culture formation and linguistics.

Up to our knowledge, Sugarscape and New Ties do not investigate organizations extending dynamically the range of their activities because of an observed "failure" of the current organization, as we do in this article.

# 3. A MODEL FOR EVOLVING SOCIETIES

According to Gilbert's [6] classification, our model is descriptive (as few abstraction as possible), spatial (in a $2D$ space), artificial (does not rely on empirical data), positive (to illustrate a theory and find social mechanisms but not aimed for decision making) and with simple agents (opposed to cognitive agents).

In order to build our model, we made some assumptions with regards to the social sciences theory presented in Section 2.1. Each society (each village) evolves in 3 stages (tribe, chiefdom, state). The tribe stage offers social structures to gather and share food. The chiefdom stage extends the tribe with a chief who recruits inhabitants to build a militia (policemen) and to perform research. The state stage extends the chiefdom in creating a social structure to hire a Cultural Harmonizers ($CH$) . An illustration of the expected evolution of the population is given in Figure 1.

Initially, the simulation starts with a village at the tribe stage containing only one family. If life conditions cannot support more than a family, the society remains at the tribe level.

If life conditions are favourable, we assume that humans reproduce and the population increases. But, a larger population has looser familial bonds among its members. Moreover, since we assume that the food input is renewable but limited, the population eventually reaches a point where the food input matches the food consumption of the human. We suppose that humans lacking food are likely to attack people outside their family (the social dissension in Diamond's theory). When the shortage persists, social dissension becomes globally high. Then, we assume that an individual takes the leadership to enforce a control and protection over the population in creating a militia. Lead individuals are protected in return for resource, reducing the overall social dissatisfaction. Thus, the village reaches the chiefdom stage. Otherwise, if no leader appears, the theory says that the population is prevented to increase too much due to the casualties of social dissension.

If life conditions are good enough, the population keeps increasing under the protection of a leader. We assume that the leader feeds specialists who are used to increase food production through better technology and also to increase the cultural variation. We also assume that the more inhabitants are culturally different, the less they are loyal towards their leader and we assume that a leader prefers to keep a high loyalty level. Consequently, the bigger a village is, the less followers are loyal to their leader. To solve this situation, we assume that the leader can hire $CHs$ to unify the culture inside a village, improving the average loyalty. Thus, the village leaves the chiefdom stage to enter the state stage. If the leader does not do so, the loyalty level goes down and either the social dissension emerges again, or the militia costs are too high. Reciprocally, if the food resource is more difficult to collect, the village size regresses. The stage of a society should match the population size.

The Sugarscape [5] formalism can be used to describe our model. The *environment* is a grid (patches in NetLogo [10]) on which *agents* move and interact with. Agents are humans and villages in our simulation (turtles in NetLogo), that are directed by *rules*. A summary of environment and agent variables is given in Table 2. We implemented this model using NetLogo 5.0.2.

## 3.1 Environment

The environment is a bounded $\mathbb{R}^2$ space. Food is represented by a $\mathbb{N}^2$ grid on top of this $\mathbb{R}^2$ space (the NetLogo patch space). Each patch has 3 states: ($sterile, harvested, full$). A *sterile* patch never changes state. A $full$ one can be harvested by human agents, thus becoming *harvested*. A *harvested* cell can become $full$ each round with a probability of 0.005. For our experiments, patches in a radius of 8 around a village are initially $full$. Other patches are *sterile*.

**Table 2: Environment and agent data structures**

| Environment | Agents | |
|---|---|---|
| Patch | Human | Village |
| Soil Status | Energy<br>Hit Points<br>Bag (carried food)<br>Culture<br>Loyalty<br>Social Dissatisfaction<br>Job | Food<br>Social Policy<br>Spent by Leaders<br>Culture<br>Dominations |

Designing environments, even simple ones introduces complex dynamics in the model (as shown in [4]). The important things to know is that the food input is relatively constant each round and sublinear to the number of harvesters. Above 20 harvesters, the gain for each additional harvester is marginal.

## 3.2 Agents

### *3.2.1 Human agents*

Human agents are entities populating the world. They are described by the following variables:

$hp \in [0, max\_hp]$: hit points or physical condition. This value decreases when the agent is attacked. If this value reaches 0, the agent dies. $max\_hp$ is set to 10 in the simulation.

$energy \in [0, max\_energy]$: remaining energy before starvation. If this value reaches 0, the agent dies of starvation. An agent with less than $max\_energy/2$ units of food is *hungry*, otherwise it is $well\_fed$. $max\_energy$ is set to 400 in our simulation and *energy* decreases by 1 each round. Empirically, high-values of $max\_energy$ acts as the grass in the Wolf-Sheep predation model [11], by preventing humans to overexpand too quick and too far leading to global collapse instead of reaching the next social stage.

$bag \in \mathbb{N}$: amount of carried food. It is filled when *harvesting* and its content can be *stored* in the village.

$culture \in [0, 1]^n$: the cultural orientation, values and ideology of the agent (e.g. clothes, political inclination), inspired by the cultural model from Sugarscape [5]. Cultures can be compared with each other using the Euclidean distance. We set $n$ to 200.

$loyalty \in [0, 1]$: the loyalty towards the leader. It is reduced when the distance between the *culture* of the agent and the $culture_v$ of the village increases. Formally,

$$loyalty = 1 - \alpha.distance(culture, culture_v)$$

where $\alpha \in \mathbb{R}$ is an arbitrary constant to adjust the impact of cultural distance over loyalty. In our case $\alpha$ is 0.1.

$job \in$ {*harvest, attack, protect, harmonize culture, research*}: the activity to be performed during the "perform job" phase. A *harvesting* human moves to the closest food patch, collects it and drops its bag in the village. In the case of multiple villages scenario, an *attacking* human goes to the closest enemy village without domination link and attacks it. A *protecting* human is a member of the militia. It is inactive during the "perform job" phase but increases the probability of the villagers to be under control "meet other humans" phase. *Cultural Harmonizers (CHs)* unifies the culture of the village in performing the *harmonize* action. A *researcher* (a generic name we used to denominate an artist, builder or technician) benefits from the food $spent\_by\_leaders$ to produce technically innovating goods (increasing the $harvest\_tech\_level$) and to bring cultural novelty into the society (changing one item of the *culture* vector of other inhabitants). The harvest technological level is increased by 20 times the square root of the number of researchers. The benefit given by the number of researchers must be sublinear: doubling the number of researchers do not indefinitely double the research output because of redundancy of ideas.

$social\_dissatisfaction \in [0, 1]$: the dissatisfaction against the current society due to lack of physical protection. This value is reduced every round by 1% and increases by 0.2 (but still bounded by 1) when the agent is attacked.

### *3.2.2 Villages*

A village agent accommodates human agents and serves as deposit for their food resources.

A village agent can be *lead* or not. A leader is necessary to establish a *social policy*. A social policy is a triple $SP_v = (R_{police}, R_{CH}, R_{researcher}) \in [0, 1]^3$. Each member of this triple determines the ratio of institutional jobs (policeman, $CH$ and researcher) per inhabitant offered to the population.

$food \in \mathbb{N}$: the amount of food stored by humans. Human agents storing their *bag* increase the value of $food$ by the amount of their *bag* and set *bag* to 0. When the village is lead, a portion of the stored food is used by leaders to buy luxury goods from researchers (added to $spent\_by\_leaders$ instead of in $food$). In other words, the collected food (which is not spent by leaders) is equally shared amongst every agent. This mechanism represents generically the ressource redistribution for each stage (tribal exchange or chiefdom and strate tax collection and redistribution). The salary of institutional workers is the ability to eat from the common pot. It is possible to implement more complex mechanism to achieve the same task of redistributing resource (in particular in the multi-stage setting), but our objective concerns finding minimal mechanisms to observe the change of stages.

$spent\_by\_leaders \in \mathbb{N}$: quantity of food used by leaders, the amount of food which is taken but not redistributed to the population.

$culture_v \in [0, 1]^n$: the culture of the village. Without a leader, it is the average *culture* of its inhabitants, otherwise it is the *culture* vector of the leader.

$harvest\_tech\_level \in \mathbb{N}$: the food production efficiency of the village (technological and environmental). When a human agent harvests some food, it puts $harvest\_tech\_level$ units of food its bag. Increasing the number of researchers increases this value (sublinearly). Empirically, the size of the society is approximatively the value of this variable. We set its values from 10 to 300.

*dominations*: the set of villages under the domination of the current village. A domination link is created when an attack occurs with a high ratio attackers/defending inhabitants. A dominated village sends a fraction of its food income to its dominator.

$CHs$ hired by the dominator culturally influences its dominated villages. When the $culture_v$ of the dominator and $culture_v$ of a dominated village are close enough, the dominated village is culturally converted and both villages belongs to same state. Otherwise, the dominated village frequently rebels (with a probability of 0.001 each round), break-

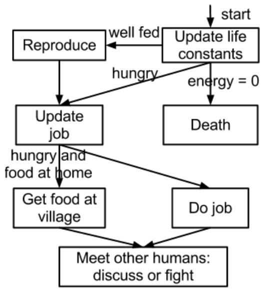


**Figure 2: Conceptual decision process of a human agent**

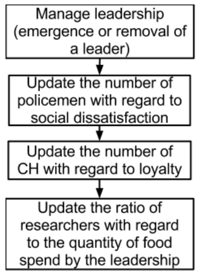


**Figure 3: Conceptual decision process of the village rules**

ing the domination link.

## 3.3 Rules

### 3.3.1 Human rules

Figure 2 shows the main steps of the decision process of a human agent (individual behaviour). First, we update its life constants. The agent dies if its energy is 0 and may reproduce if it is $well\_fed$. Then, human agents can change their current job. Next, if they are fed enough, they perform their job, otherwise, they go home and get some food. Finally, they engage in some social interactions with another human.

*Update life constants:* $energy$ is decreased (starving agents are removed) and $culture$ can be randomly tilted with a probability of 0.2 (an item of $culture$ is set to a random value).

*Reproduce:* the human agent has a chance (probability of 0.01) to produce one child. Its energy value and culture are shared with its child. Other variables are set to default values.

*Update job:* Periodically, humans change their job by updating the $job$ variable. Harvest and attack can be selected by anyone without restrictions. Other jobs (defend, harmonize culture and research), called institutional jobs, can only be selected if offered by a leader (through $SP$). The job selection is simple: agents try first to get an institutional job. If none is available, they select between harvest and attack using light reinforcement learning. To avoid erratic behaviors, agents are committed to the same job for multiple rounds (randomly between 20 and 70 rounds).

*Get food at village:* The agent tries to eat some food from the $food$ supplies of its village. If the agent is at its village and the $food$ value of the village is high enough (bigger than $max\_energy$), the human agent performs an $eat$ action. Otherwise the agent moves toward its village.

*Do job:* The human agent performs its $job$.

*Meet other humans:* each human agent engages in some social interactions with another randomly selected human agent from its village. If these 2 humans are from the same family or under control of a loyal policeman, they discuss with each other and mix their $culture$ vector. Otherwise, if the food is scarce, they come into conflict. One of them is hurt ($hp$ is reduced) and complains about the lack of physical protection ($social\_dissatisfaction$ is increased).

2 agents belong to the same family with a probability $s/|v|$ where $s$ is an arbitrary value (set to 30) representing the family size and $|v|$ is the size of the village. 2 agents are under police control with a probability $P.L_v(police)/|v|$ where $P$ is an arbitrary value (set to 10) representing the number of controllable inhabitants per policeman and $L_v(police)$ is the sum of policemen $loyalty$. Of course, these mechanisms can be implemented in various ways. For instance, kin-ship relationships can be explicitly represented or policemen can patrol and defend their nearby space. The desired characteristics of these mechanisms, for any implementation, is that the proportion of individuals being under control decreases as the population increases.

Each round, the agent acts only once in the environment: during the "get food at village" or the "do job" phases. Available actions are: $move$: moves a distance of 1. $harvest$: sets the local $full$ patch to $harvested$ and fills the agent's $bag$ with $harvest\_tech\_level$ units of food. $pillage$: steals some food from an enemy village located in the current patch. $harmonize$: sets the culture of 10 randomly chosen agent from the village and from 1 agent from a dominated village to $culture_v$. For sake of simplicity, we disregard the physical distance between 2 agents. $research$: randomly changes one item of the $culture$ of every agent in the village. $eat$: the agent removes $max\_energy - energy$ units of food from its village and sets $energy$ to $max\_energy$.

### 3.3.2 Village rules

The village rules (chief orders, if there is a chief) are split in 2 phases: leadership management and the social policy management ($SP$). The leadership management phase manages the election or the removal of a leader. In the absence of a leader, agents perform a vote to decide if a leader is needed (if yes, the human who has survived the more battles is selected). Each agent votes for a new leader if $cl < social\_dissatisfaction$, where $cl$ is an arbitrary value representing the estimated cost of a leader. If the social dissatisfaction is too low and no policemen are present, the leader is removed.

The policy management phase updates $SP_v$ according to the needs of the village. The chief has to cost efficiently keep the social dissatisfaction low. It incrementally updates $R_{police}$ to match the average social dissension with a tolerance value $t$ (set to 0.5). $t$ is carefully set: if $t$ is too low, the population staves because of too many policemen, if $t$ is too high, the population dies out of social dissension. Similarly, the chief tunes $R_{CH}$ depending on the average $loyalty$ and $R_{researcher}$ depending on the resources $spent\_by\_leaders$.

The level of cultural variation is crucial for the emergence of states and relies on several actors. It should increase

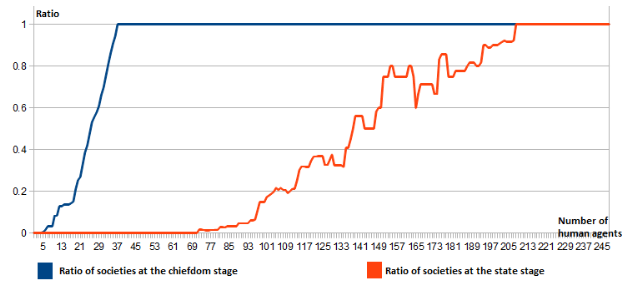


**Figure 4: Social stage related to the society size**

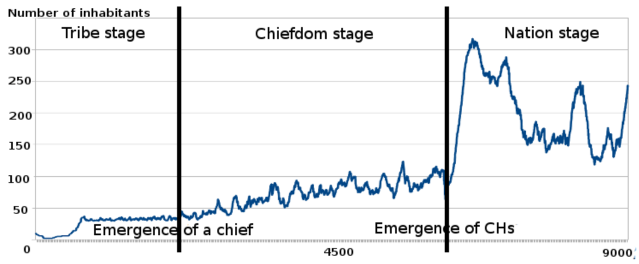


**Figure 5: The evolution of the population with improving life conditions**

when the social size increases, because of researchers and be reduced by $CHs$. It should grow enough to prevent the society to grow too much without $CHs$ but not enough to prevent the state population scope to be reached. Its value is controlled in balancing the efficiency of researchers and cultural uniformization occuring during the "meet other human" phase. A bigger society brings more researchers and less intra-family meetings, increasing the average culture. Then, the efficiency $CHs$ must be high enough to reduce the need for policemen. Otherwise the state stage is more expensive than the chiefdom stage, leading to social collapse when the state stage is reached, bringing the society back to the chiefdom stage.

As for human rules, other implementations can be considered. In our case, we tried to avoid noisy or complex implementations. Our goal is to make expected events occur, even if their occurrence does not exactly match a reality: a chiefdom rarely emerges through voting processes, but via longer and more complex processes. Detailing these would increase the complexity of the model without changing the outcome.

# 4. EXPERIMENTATION

## 4.1 Link Society Size/Social Stage

Diamond's theory states that the social stage fits the social size. We tested this statement in executing our model first with predefined social sizes and then with dynamic social size changes.

In the first experiment, we want to observe the social mode given a social size. As we de not control directly the social size, we manipulate $harvest\_tech\_level$ which directly influences the social size. Results are presented in Figure 4. Villages are in the chiefdom stage if they are bigger than 40 agents and they reach the state stage is they are bigger than 200 agents. This result shows that each social stage matches a population scope. For computational reasons, these numbers do not match with reality (simulating over 50.000 agents for a state being overly expensive), but they can be modified in tuning program constants.

In order to test our model against the expected behavior presented in Figure 1, we ran our model in regularly improving life conditions ($harvest\_tech\_level$ is increased by 1 unit every 20 rounds). Results, displayed in Figure 5 match our expectation: for each stage, the population growth rate is initially important and decreases when the population comes close to the limits of the stage's scope. Within each stage, the social size is monotonically increasing (due to improvement in life conditions) but sublinearly only (due to social limitations). When the society stages up, the slope of the curve dramatically increases again.

We further tested our model with more extreme changes in life conditions. We changed the food input several times during a run: the social size adapts to this input and the social mode adapts to the social size. Stage changes occur in the expected order (tribe, then chiefdom, then state) even with dramatic increase in food input. If the food input is reduced enough, societies do stage down, following the same order.

## 4.2 Preventing Societies To Stage Up?

We show in Section 4.1 that the social stage fits the social size. But, as described by Diamond, even if life conditions are good enough, a state cannot be built directly on top of a tribe. The chiefdom level is needed to successfully change from one to the other. In order to check this hypothesis, let us try to build up a state without a chiefdom. We investigate this question by testing if a society can reach the state stage (hire priests), without going through the chiefdom stage (without hiring policemen). This test always failed for any possible $harvest\_tech\_level$ setup.

If life conditions are too harsh, the society size is below the scope of the state stage, no $CHs$ are hired. With better life conditions, more humans can be fed, but the average cultural variation (caused by researchers appearing at the chiefdom level) is not high enough to need $CHs$ to be hired. Moreover, a society at the state population scope without policemen is not sustainable. As soon as the resources become sparse (which eventually happens), human agents start fighting and no social structure at the state level can prevent that. Consequently, the society collapses, reaching the tribe population scope. After the collapse, because of low resources, humans keep fighting, spoiling their resource input (when an agent dies, its energy is lost). Since fight casualties match the fertility of humans, the system is locked into equilibrium. The number of humans is still far too low to require $CHs$ and no artists influence the culture. Consequently, the society cannot reach the stage $n+1$, without formerly activating the stage $n$.

## 4.3 Other Observations

Other social facts appeared while running our model. The more a village is dominating, the more resources it gets, the bigger it becomes. A dominating village can even reach higher stages in spite of hard life-conditions. When food input is low, agents are not numerous enough and are all busy harvesting. No army is built up or is not big enough to dominate other villages. When the food input increases, more agents populate the world, harvesting all available resource, even supporting jobless agents. These agents can build armies big enough to dominate other villages. But, due to a lack of $CHs$, the domination is non-cultural, hence temporary. Consequently, chiefdoms regularly have to take back rebelling villages, leading chiefdom domination to be local only. With even more food, states emerge, leading to more global and more static dominations. The simulation often reaches a state of mono-cultural or a bi-cultural polarization. In considering a society as a village with its dominations, we observe that tribes are singles villages, chiefdoms encompass several tribes and a state encompasses multiple chiefdoms.

We also observed some unexpected social facts. For instance, when a leader dies, the loyalty falls down for a few rounds due to the culture gap between its successor and the rest of the village. A chiefdom may win against a state. In this case, either the chiefdom becomes a state, or the state rebels and eventually dominates the chiefdom.

# 5. HOW TO BUILD EVOLVING SOCIETIES?

## 5.1 Mechanisms of the Model

The chiefdom emerges because of a global increase of social dissatisfaction. This social dissatisfaction is increased individually when an agent meets another agent outside of its family and the food resource is scarce. If the resource input is bounded, this situation always occurs.

In another words, we created a threshold (the population reaches the family size and consumes all of its resources). When this threshold is met, the value of the social dissatisfaction globally increases. Meeting this threshold also prevents the society to go beyond this stage (in this case, the number of casualties due to fights prevents the society to reach the next level). And then, a solution mechanism (policemen) allows the society to reach the next stage.

A chiefdom becomes a state because of a global reduction in loyalty. This reduction is caused by an increase of the average distance to $culture_v$. This increase in distance is caused by the presence of researchers (which bring novelty to the culture), caused in turn by the chiefdom social stage, resulted from the population size.

Here, we created an individual variable (*loyalty*) that is globally reduced when the population grows. This mechanism prevents the village size to grow beyond a value: low loyalty reduces policemen efficiency (police control is necessary to prevent social collapse when the food resource is sparse). To keep increasing, the society must either hire $CHs$ or increase the ratio of hired policemen to overcome the reduction of loyalty. The second strategy is limited by its own expenses. There is no other solution than hiring $CHs$ and reaching the state stage.

Some patterns are recurrent in these mechanisms to build evolving societies. These patterns can serve as design advices to generically build such societies.

In this generic setting, a society that can evolve is a society that can host some social sub-structures $ss_1, \ldots ss_n$. Each structure $ss_i$ should trigger a behavior $b_i$ at the agent level. $ss_i$ emerges when a factor $f \in \mathbb{R}$ is above a threshold $t_i \in \mathbb{R}$. Since $ss_{i+1}$ should not emerge before $ss_i$, then $t_1 < \cdots < t_n$ and the lack of social behavior $b_i$ should prevent the threshold $t_{i+1}$ to be reached by $f$.

In our case, $f$ is the society size, $ss_1$ is the leader, $b_1$ is the police and research behavior, $t_1$ is the size of the family, $ss_2$ is not explicitly mentioned but is the cultural leadership, $b_2$ is the $CH$ behavior, $t_2$ is an arbitrary size reached when the average cultural dispersion is too high.

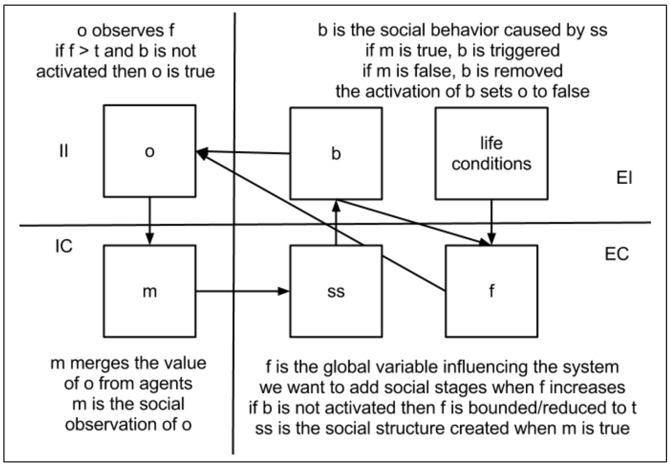


**Figure 6: Conceptual diagram of the meta-model to build up societies evolving in stages, in the MASQ formalism. $II$ (Interior Individual) represents information processing done insides the agent, $IC$ (Interior Collective) represents information shared by the community of agents, $EI$ (Exterior Individual) is what can be observed in the environment and $EC$ (Exterior Collective) is what is globally observable from the simulation (at the collective level).**

For each stage $i \in [1, n]$ the system integrates:

- Every agent possesses an individual observer $o_i \in \{\top, \bot\}$, observing the need for the society to stage up. $o_i$ is $\top$ if the agent observes $f > t_i$ (the threshold is exceeded) and does not observe $b_i$ (no one reacts to this excess). $o_i$ is $\bot$ otherwise.

  Locally monitoring $f$ is problem-dependant. In our case, $o_1$ is the social dissatisfaction: $o_1$ is $\top$ when the agent is attacked (so the population size is above the family size $t_1$ and the resource is sparse). $o_2$ is the inverse of the agent loyalty: $o_2$ is $\top$ when the loyalty is below a threshold, caused by the fact that $f > t_2$.

- Each society possesses a social merging mechanism $m_i \in \{\top, \bot\}$, representing the social awareness that individuals have observed $o_i$ (so $f > t_i$ and $b_i$ is not active). $m_i$ merges the $o_i$ of the individuals.

  In our case, $m_1$ is a voting process. When too many inhabitants are dissatisfied ($o_1$ is $\top$), they vote for the emergence of a leader. $m_2$ is the average function over $o_2$. Of course, $m$ can be implemented in many ways.

- Each society defines a social structure $ss_i$ in charge of handling the situation caused by $f > t_i$. $ss_i$ emerges as a consequence of the global awareness that $m_i$ is $\top$. Reciprocally, if $m_i$ is false, the system should investigate if $ss_i$ is any longer needed (observing if $t > t_i$) and $ss_i$ should be removed or reduced if necessary. In our implementation $ss_1$ (respectively $ss_2$) emerges instantly when $m_1$ (respectively $m_2$) is true. Of course, more elaborated emergence can be implemented, for instance the leader and policemen of $ss_1$ can be selected in performing a tournament. In our implementation, $m_1$ is false, the power of $ss_1$ is reduced (the number of policemen is decreased). If there are no more policemen, $ss_1$ is removed. A similar mechanism is implemented for $ss_2$.

- $ss_i$ has an enforcement mechanism to make some agents to perform the behavior $b_i$. If $f > t_i$, $f$ should be reduced to at most $t_i$ as long as $b_i$ is inactive. If this property is not implemented, structure in stages is no longer working: the society would reach $t_{i+1}$ and so trigger $ss_{i+1}$ in the absence of $ss_i$. In our case, $ss_1$ (respectively $ss_2$) enforces $b_1$ (respectively $b_2$) thank to the institutional job offer mechanism. In Section 4.2, we have shown that trying to reach $t_2$ without $ss_1$ or trying to remove $ss_1$ afterwards triggers a social collapse, bringing $f$ down to $t_1$.

A schematic representation of this meta-model is presented in figure 6, using the MASQ [9] formalism.

This design guide allows the construction only of very rigid structures but appears to be sufficient as a general model. It is possible to relax these constraints to have a more flexible simulation (as we did in our case). Instead of having boolean values for $o$ and $m$, a real value in $[0, 1]$ avoids too hard thresholding due to binary decision making (like slightly increase or decrease the power of $ss$). This relaxation allows $f$ to be slightly bigger than $t_i$ without $b_i$ activated but still being far too low to reach $t_{i+1}$.

In the current meta-model, the increase of $f$ is the only reason for social change, but the social change can be triggered by other reasons. For instance, in our model, the chiefdom creates policemen but also researchers, triggering in turn the reduction in loyalty when the population increases. In this case, the emergence of the stage $i$ has initiated the need for a stage $i + 1$.

## 6. CONCLUSION AND FUTURE WORK

In this paper, we investigated theories considering the social evolution of humanity through a sequence of social stages based on individual agent behaviour. When the society encounters a social issue that cannot be solved given its current stage, the next stage emerges and builds upon the current one, raising a new social structure solving the current issue. The society can thus develop again until being blocked by another social issue unsolvable by the current stage. Each stage is built upon previous ones, defining a strict order. We successfully implemented this theory in NetLogo for 3 stages (tribe, chiefdom and state). Finally, we presented a generic meta-model to produce such an evolving society from bottom up, independently of the applicative field.

Future work will focus on expanding the model in order to capture more elements from the Spiral Dynamics theory [1]. This theory adds more elements playing a role in the staging process. For instance, it investigates the link between the social stage and the individual perception of the environment. It also highlights that organizations oscillate from competitive to cooperatives from one stage to the next, leading to new design challenges. Moreover, because this theory is also used to analyse human societies, it can serve as a first step to building and analysing self-organizing multi-agent systems.


## Acknowledgements

The first author wishes to thank Melania Borit for her feedback while writing this paper.


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