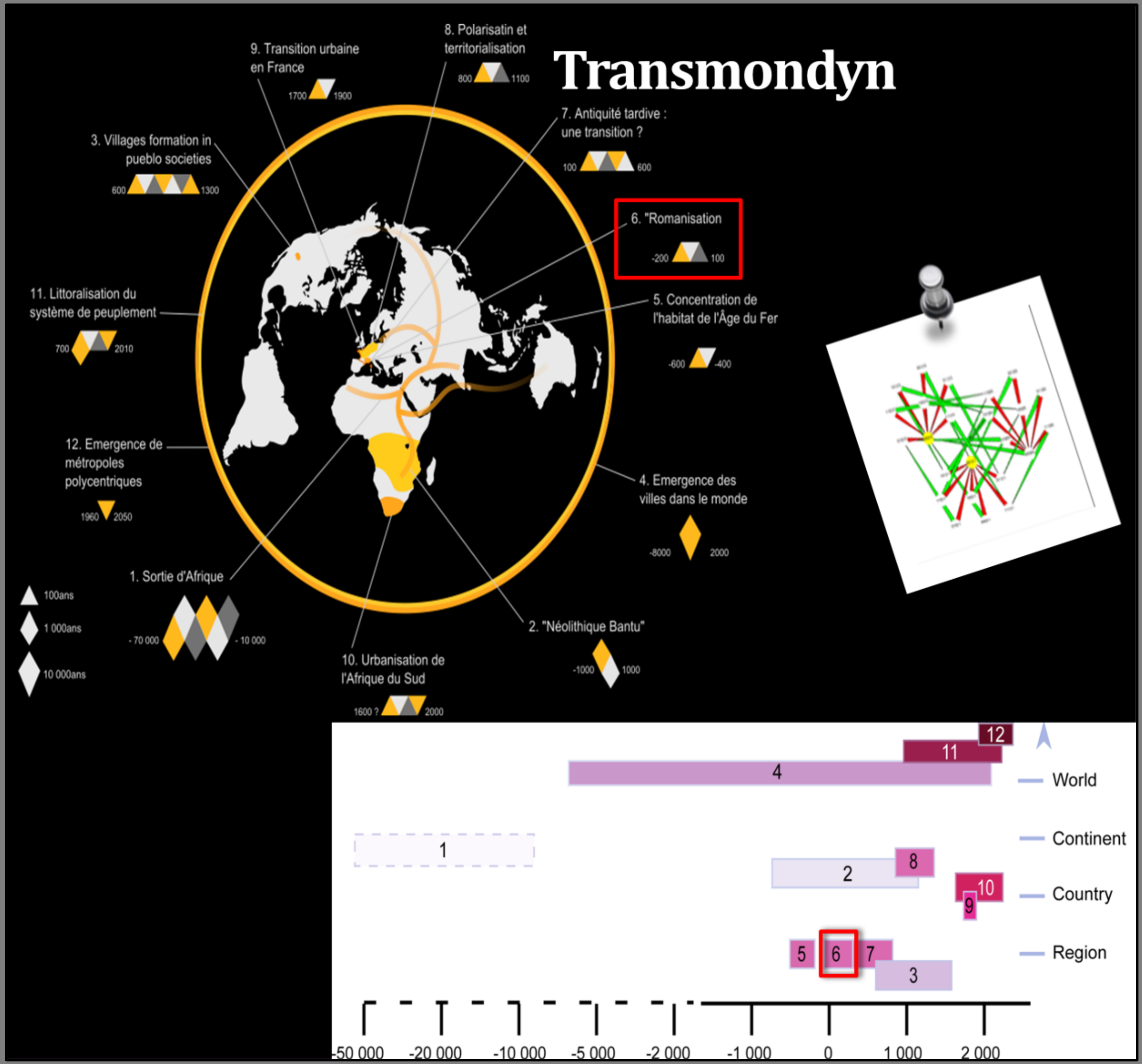
Game theory and romanisation: the reorganization of city-systems after the Roman conquest in southern Gaul.

Alain Franc, Marie-Jeanne Ouriachi and Frédérique Bertoncello
(BioGeCo, UMR 1202 Bordeaux, CEPAM UMR 7264 Nice)

The WSU Department of Anthropology and College of Arts and Sciences Pullman, November 10-14th, 2014



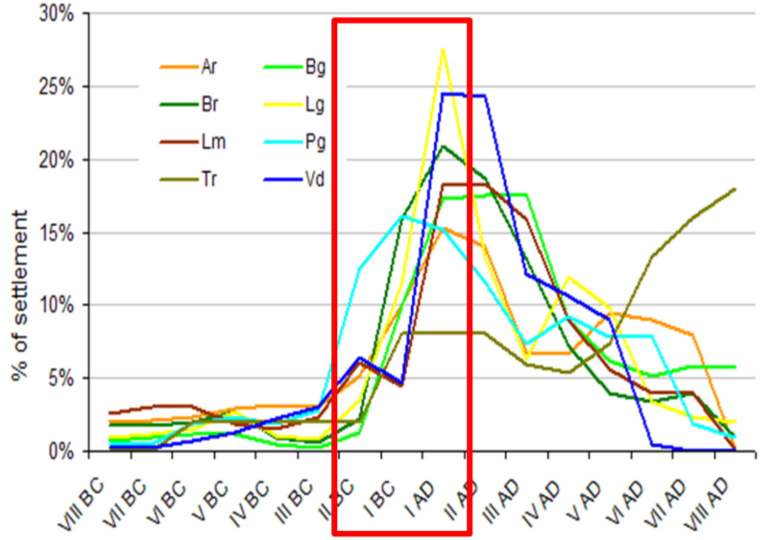
Transition number 6 of the TransMonDyn project is called Romanisation and corresponds to the transformation of the Gallic settlement system under the Roman conquest, between the 2nd c. BC and the 2nd c. AD.

- Between the 2nd c. BC and the 2nd c. AD: strong changes in the settlement system in southern Gaul
- 125-118 BC: Roman conquest of the southern Gaul (Transalpine -> Narbonensis province)
- « Romanisation »: transformations of the Gallic society under Roman influence
- But some of the transformations of the settlement system certainly originated within the Gallic society itself

The Narbonensis province

Archaeological evidence show strong changes in the settlement system in southern Gaul during this period that corresponds to the first contacts between the Romans and the Gallic people during the 2nd c. BC, which is followed by the Roman conquest of the southern Gaul at the end of this century, between 125 – 118 BC. This area, called the Transalpine by the Romans, will then become one of the Roman provinces, the Narbonensis, after the name of its capital, Narbonne. The name of the transition, Romanisation, refers to the process of transformation of the Gallic society under Roman influence, although some of these transformations certainly originated within the Gallic society itself, before the Roman conquest.

=> Densification of the occupation



Regional curves of the % of settlement per century (ArchaeDyn 1)

=> Change in the settlement pattern: Diversification of the settlements' types (towns, hamlets, villas, farms…)

Archaeological survey data from various french regions show an increase in the number of rural settlements from the 2nd c. BC onwards, which usually peaks during the 1st c. AD.

There is also a diversification of the settlement's types and the appearance of a typical Roman form of dwelling and land exploitation: the villa.

=> Reorganisation of the states (« cities ») capitals

Ex.: state of Nîmes:

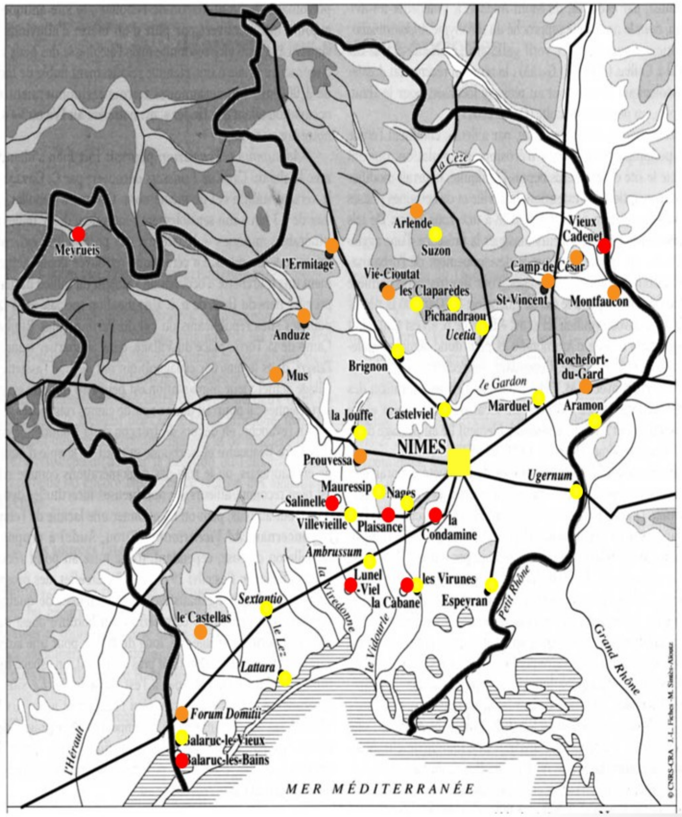
-Before 1st c. BC: a network of independant city-states

- End of the 1st c. BC: concentration of the political and administrative power in one city: Nîmes becomes the state capital

Date of creation of the towns

- Iron Age (before 2nd c. BC)
- End of the 2nd c. – 1st c. BC
- 1st c. AD

Nîmes: ctate capital at the end of the 1st c. BC



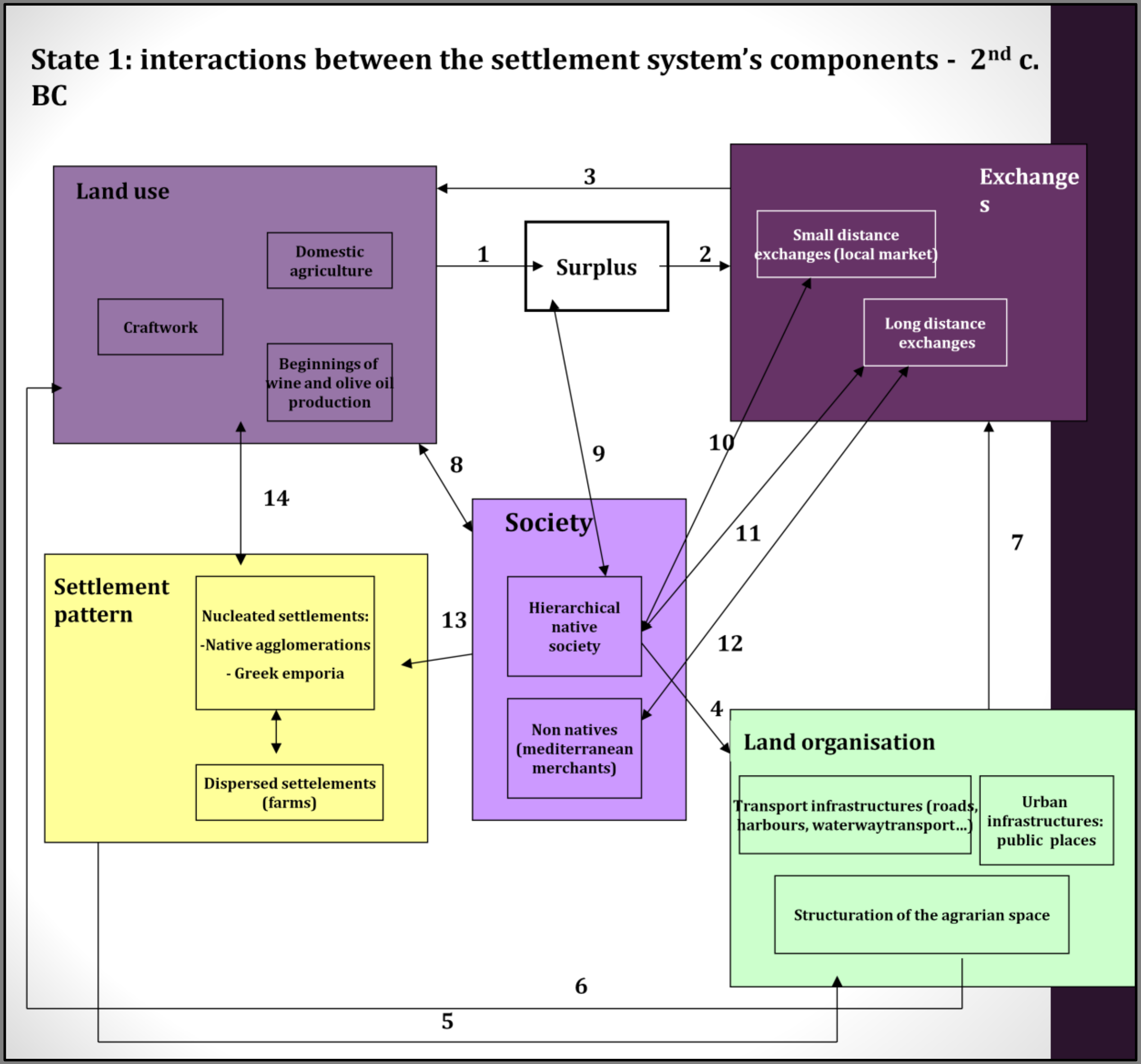
The towns of the state (city) of Nîmes during the Early Roman Empire (from J.-L. Fiches)

The Roman administration of the province also led to the transformation of the settlement pattern by giving to some towns the status of state capitals. These capitals could be either chosen within the existant Gallic cities, such as in the case of Nîmes, or be new Roman foundations such as the colonies of Roman veterans.

CONCEPTUAL MODEL OF THE INTERACTIONS WITHIN THE SETTLEMENT SYSTEM:
- State1 (« pre-Roman »)
- State 2 (after the Roman conquest)

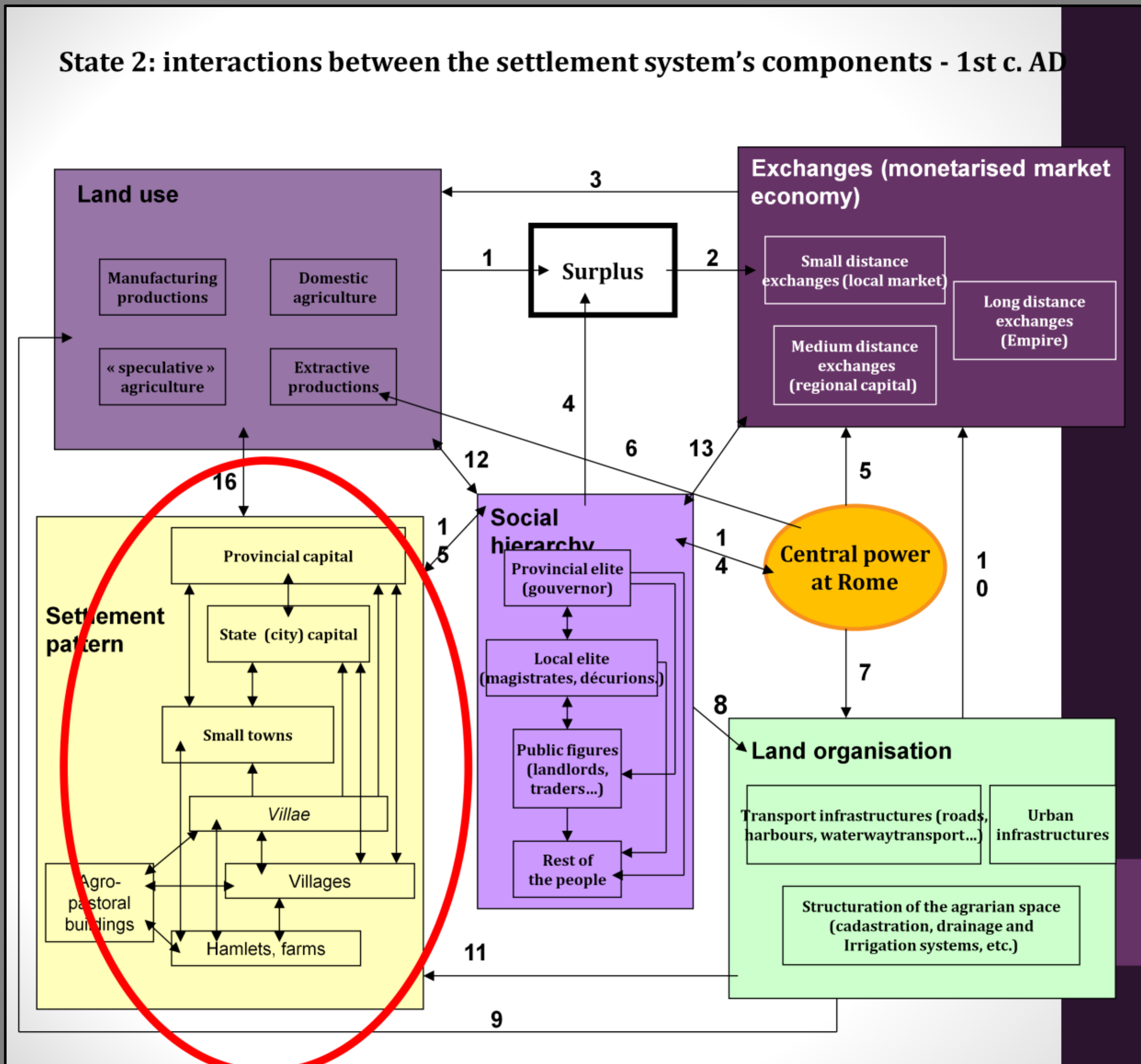
In order to better understand the processes underlying these transformations, we tried to identify the various components of the Gallic settlement system and to model their interactions at two states:

- State 1 : before the Roman conquest : « pre-Roman system »: 2nd c. BC
- State 2 : after the Roman conquest : 1st c. AD



5 main components of the Gallic settlement system were identified at state 1:
Types of land use
Types of exchanges
Land organisation
Social organisation
Settlement pattern and types of settlements

We won't go into detail on this graph here but I would like to stress that this is not a Directed Acyclic Graph: the links between the boxes are not ordered, which means that the arrows'numbers do not represent a chronology of the interactions between the components of the system, but only the links existing between them.



At state 2, during the 1st c. AD, these links are reorganised by the intervention of the Roman central power, which impacts the different components of the system.
Within this complex system of relations, we focused our attention on the reorganisation of the settlement pattern and the emergence of state capitals after the Roman conquest.

Historical issues

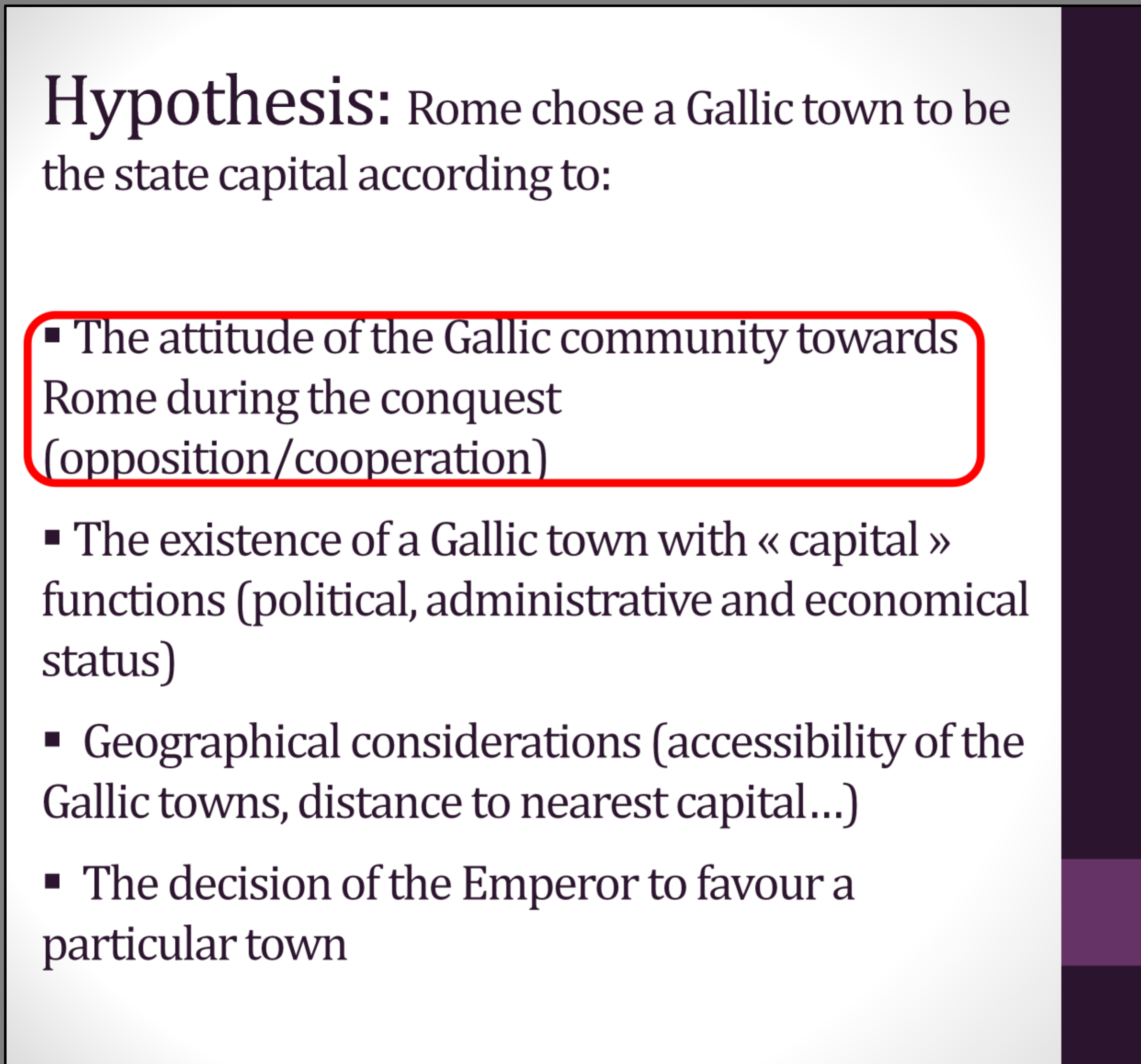
- How does Rome set up the network of state capitals after the conquest ?
- How does Rome decide to promote a Gallic town or to create a new colony ?
- What are the underlying factors for these choices ?
- Context: 1st c. BC: progressive set up of the administrative frame of the Narbonensis province
- Gradual process: conquest, informal administration of the Narbonensis from the neighbouring provinces, creation of the province with a proper governor, evolution of the cities'status…

Our aim is to better understand the process of organisation of the administrative framework of the Narbonensis province:
- What factors can explain the diversity of the state capitals in the Narbonensis province ?

Why Rome decide to promote a town rather than another ?

Why does it give in some cases the capital status to a colony rather than promoting an existing Gallic town ?

The chronological context of the study is the 1st c. BC, when the administrative framework of the province is set up but it is important to note that this is a very gradual process: the capitals were not set up simultaneously and the ancient texts report evolutions in the status of some cities and their territory.



From historical and archaeological knowledge, we make the hypothesis that the choice of a Gallic town to be the state capital could depend on:

The attitude of the Gallic community towards Rome during the conquest: we know from the ancient texts that some communities collaborated with Rome whereas others resisted the conquest;

The existence in the area of a Gallic town with political, administrative and economical functions that would identify it as a capital from a Roman point of view;

Geographical considerations (location of the Gallic towns to the main communication routes, distance to the nearest capital…);

There is also another factor more difficult to assess as we know from the texts that the choice of a capital could also depend on the decision of the Emperor itself to favour a particular town.

To start, we focused on the first element and tried to model the interactions between the Gallic communities and Rome during the conquest.

Modeling choice for interactions between Rome and gallic elites: game theory

- ❑ Apparent paradox: Rome has the power but requires gallic elites cooperation for Province government

- ❑ How is this cooperation set up? How to model it?

⇒ Formalize interests and costs for Rome and for Gallic elites

✓ Define strategies and **quantify** how strategies between Rome and gallic elite fit or not

- ❑ This can be addressed precisely by framework of **« game theory »**

This is a key issue for modeling: how to translate a question stated in words into a modeling framework which can be implemented on a computer. Here, we have selected « game theory », which is classical for modeling rational decision process in human behavior.

Formalisation by « game theory »: payoffs

- Basics : two players (A, B) – one binary strategy (0,1)

- States of the game :

  (A=0|B=0); (A=0|B=1); (A=1|B=0); (A=1|B=1);

  (0|0); (0|1); (1|0); (1|1);

- Payoffs : ∀ state of the game, ∀ acteur, ∃ gain

$$W_A = \begin{pmatrix} w_{00} & w_{01} \\ w_{10} & w_{11} \end{pmatrix}, \quad W_B = \begin{pmatrix} w'_{00} & w'_{01} \\ w'_{10} & w'_{11} \end{pmatrix}$$

This slide and some which follow are pedagogical (we hope so …) presentations of elementary game theory, as a « back to basics ». Those who know about game theory can skip them. The key notion is the one of « payoff », or value. Players will select the state of game with maximum payoff for themselves, ignoring the payoff for the « partner ».

How does it work?

Payoff for A	B=0	B=1
A=0	w_{00}	w_{01}
A=1	w_{10}	w_{11}

I am A

I look at B

if B=0 if $w_{00} > w_{10}$ then I select A=0
if $w_{00} < w_{10}$ then I select A=1

if B=1 if $w_{01} > w_{11}$ then I select A=0
if $w_{01} < w_{11}$ then I select A=1

The same, but reverse, if I am B: I look at A, … w' …

This is very close to an implementation. Next step is to select a programming language and implement this. We have selected R for our model.

How does it work?

Dynamics for A, knowing B

Payoffs for A	B=0	B=1
A=0	w_{00}	w_{01}
A=1	w_{10}	w_{11}

Dynamics for B, knowing A

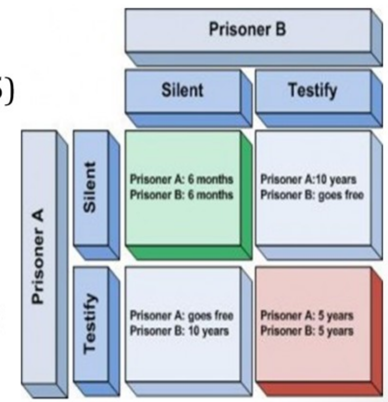
Payoffs for B	B=0	B=1
A=0	w'_{00}	w'_{01}
A=1	w'_{10}	w'_{11}

This presents something which is at the same time simple and tricky. When B strategy is known, the matrix of payoffs for A is constrained to the column selected by B, and A has the liberty to move rowwise in this column only. Reciproqually, when A strategy is known, the matrix of payoffs for B is constrained to the row selected by A, and B has the liberty to move columnwise only.

Prisonner dilemma

Payoff A | Payoff B	B=Coop (silent)	B=beTrayal (Testify)
A=C	(1|1)	(-5|5)
A=T	(5|-5)	(-2|-2)

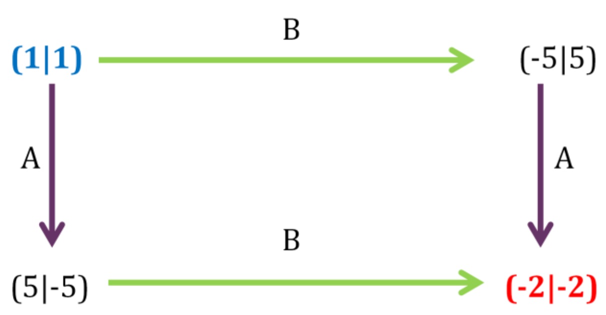
$$\begin{tikzcd}
(1|1) \arrow[r, "B"] \arrow[d, "A"'] & (-5|5) \arrow[d, "A"] \\
(5|-5) \arrow[r, "B"] & (-2|-2)
\end{tikzcd}$$



This is an iconic example: prisonner dilemna, which has been used in many situations where a conflict can be solved by a 'mutual non destruction agreement' or evolve towards mutual destruction. This is explained in later slide. This one presents the payoffs. What is important ist their relative values, more than their aboslute values.

Prisonner dilemma

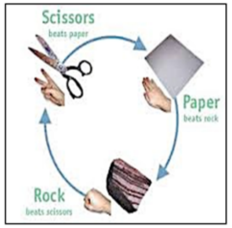
Payoff A | Payoff B	B=C	B=T
A=C	(1|1)	(-5|5)
A=T	(5|-5)	(-2|-2)



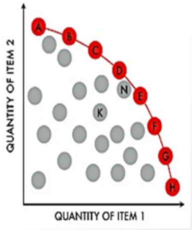
Green arrows describe best choice of B knowing strategy of A. Purple arrows describe best choice for A knowing strategy of B. All arrows converge towards the red state which is a Nash equilibrium. It is a state of mutual destruction. The blue state is called a Pareto equilibrium, and can be reached by an agreement of non mutual destruction. However, one queston remains: how can players reach a Pareto equilibrium in a selfish world? How can cooperation emerge between selfish players?

Two famous equilibria

- **Nash equilibrium**
  - Players don’t communicate
  - Each player plays the more advantageous choice
    (knowing the other’s)
  - Game may (not will) stabilize on a given state
    If one player changes his choice
    his payoff will decrease



- **Pareto equilibrium**
  - Players do communicate
  - If one player changes and ‘wins’, then at least
    another one ‘looses’



This simply is a light description of Nash and Pareto equilibria.

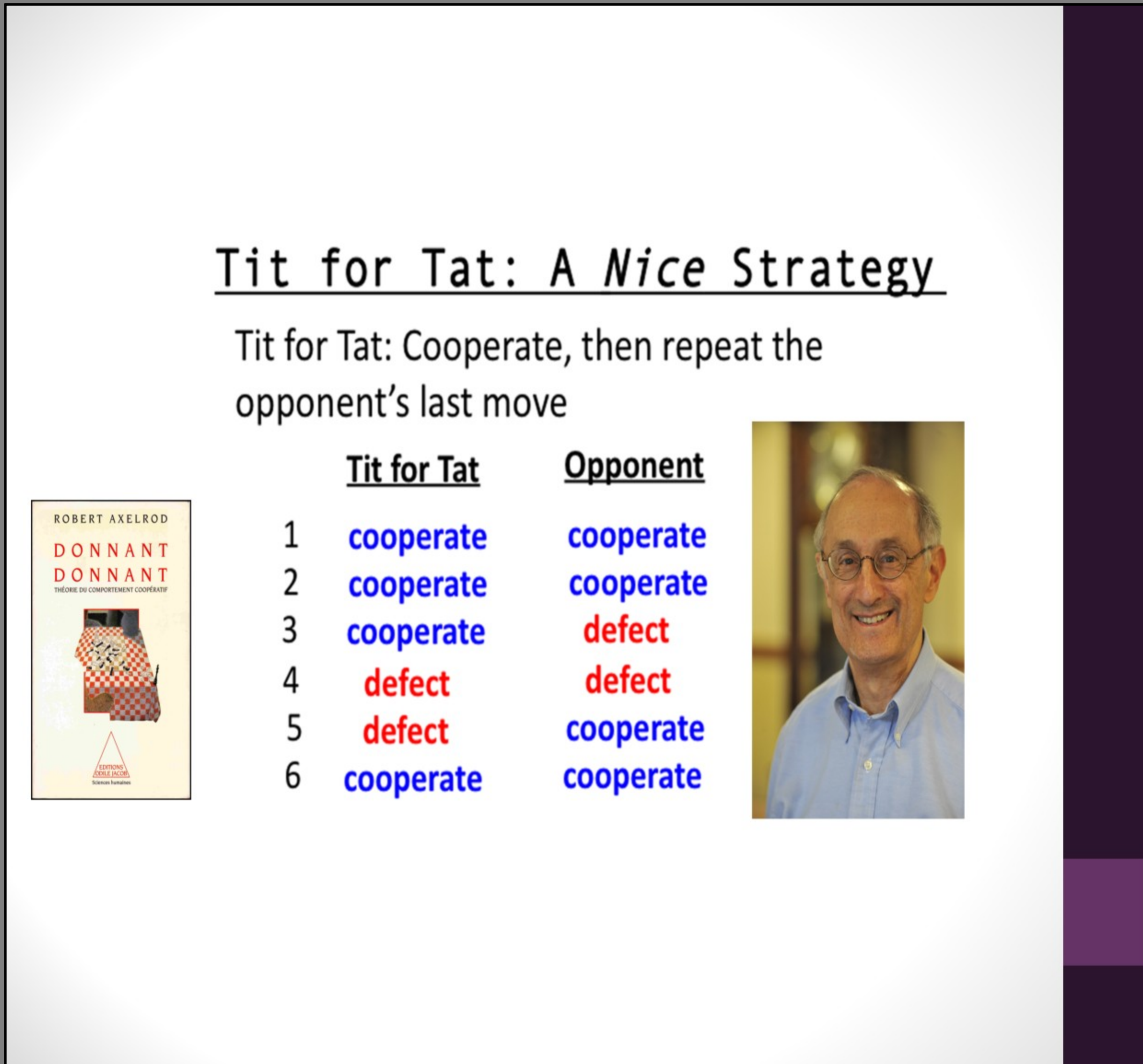
A classical approach: tragedy of the commons

- Selfish games lead to Nash
- Cooperative games lead to Pareto
- But … a Pareto equilibrium is destroyed by selfish behaviour

- ⇒ Tragedy of commons

- Question : How to (I) reach (II) sustain a cooperative equilibrium in a selfish world?

Prisonner dilemna has been widely used for situation where cooperation is useful for managing common resources. Selfish behavior is consuming the resource for oneself. This can lead to depletion of resources. It has been iconized by Hardin as 'tragedy of the commons', as a reference to the depletion of commons in England in 18th century.



Axelrod in very influential papers has suggested that the paradox of reaching an agreement in a selfish world can be solved if both players are repeatedly in the situation of playing together. Then, 'tit for tat' strategy (if the oponent cooperates, I cooperate, if he/she defects, I defect) emerges as a winning strategy in the long run. However, for that, players should no know when the game is ending …

→Modelling the interactions between Rome and the Gallics

- **Step 1** : Identifying the actors:
    - The *imperatores* (the roman generals)
    - The gallic elites.

Step 2: Identifying the objectives of the actors:

1. *Imperatores* : conquest with the lowest number of casualties.
2. Gallic elites : two options – stay autonomous – collaborate to obtain a privileged status.

The following slides present the modelling of interactions between Rome and the gallic elites. At the first step, we indentifye the different actors. In this model, we have retained two actors :
The roman genarals (we call them imperatores).
The gallic elites.

At the 2nd step, we determine the objectives of the actors:
Concerning the roman generals : they have to conquer the Gaul with the lowest number of casualties.
(About the war's cost, we now that the war is a component of political power in Rome and a constituent of imperial power. But a roman general can't obtain a triumph if the war make a lot of roman casualties).

The gallic elites have two options : resist to stay autonomous or collaborate to obtain a privileged status.

Step 3: Identifying the actors' strategies:

I : *Imperatores*

Ia : resort to armed force (0/1)
Ic : grant a privileged status (0/1)
Ie : place settlers (0/1)

E : Gallic elites

Ea : collaborate to obtain a privileged status (0/1)
Ec : accept the roman settlers (0/1)

For example one roman strategy is	(Ia=0|Ic=1|Ie=1)
and one gallic strategy is	(Ea=1|Ec=1)

At the 3rd step, we define the actor's strategies.
We retain three levers for the strategy of the roman general. They can:
resort to armed force or not.
grant a privileged status to a city-state or not.
place roman settler.
And we define two levers for the gallic elites. They can:
collaborate to obtain a privileged status or resist
accept or reject the roman settlers.

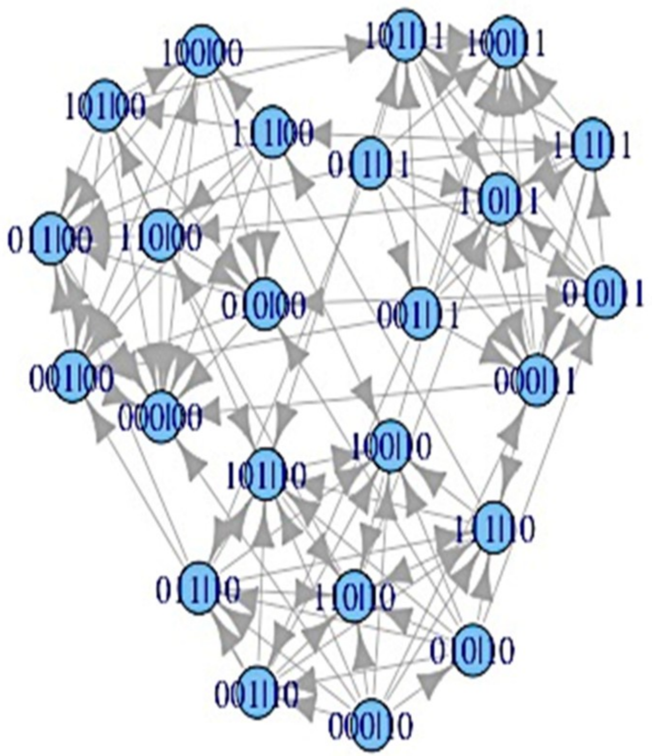
Step 4: set up the matrix of the payoffs for each actor

Imperatores	Gaulois_00	Gaulois_10	Gaulois_11
Imperatores_000	$\boxed{-4}$	4	-2
Imperatores_001	-2	2	3
Imperatores_010	-1	3	2
Imperatores_011	-3	1	4
Imperatores_100	1	-3	-4
Imperatores_101	2	-2	-2
Imperatores_110	3	-4	-3
Imperatores_111	4	-1	1

Gaulois	Gaulois_00	Gaulois_10	Gaulois_11
Imperatores_000	$\boxed{-1}$	2	1
Imperatores_001	-1	1	2
Imperatores_010	-1	2	1
Imperatores_011	-1	1	2
Imperatores_100	2	1	-2
Imperatores_101	2	-1	1
Imperatores_110	-1	2	1
Imperatores_111	-1	1	2

At the 4rth step, we have set up the payoffs matrices. For each pair of stratégies of imperatores and gallic elites, we set up a value for imperatores and a value for gallic elites.

24 states of the game



These are the states of the gain corresponding to the matices. The arrows show the change of the states of the game according the best choice of the actors.

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Dynamique du jeu
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------------------------------------------
000     00              -4      -1
        ----------------------------------
        I       001     -2      -1
        I       010     -1      -1
        I       011     -3      -1
        I       100     1       2
        I       101     2       2
        I       110     3       -1
        I       111     4       -1
        G       10      4       2
        G       11      -2      1
------------------------------------------
000     10              4       2      Nash equilibrium
        ----------------------------------
------------------------------------------
```

As a support for interpretation, we have produced a file which gives possible game dynamics for each state of the game.

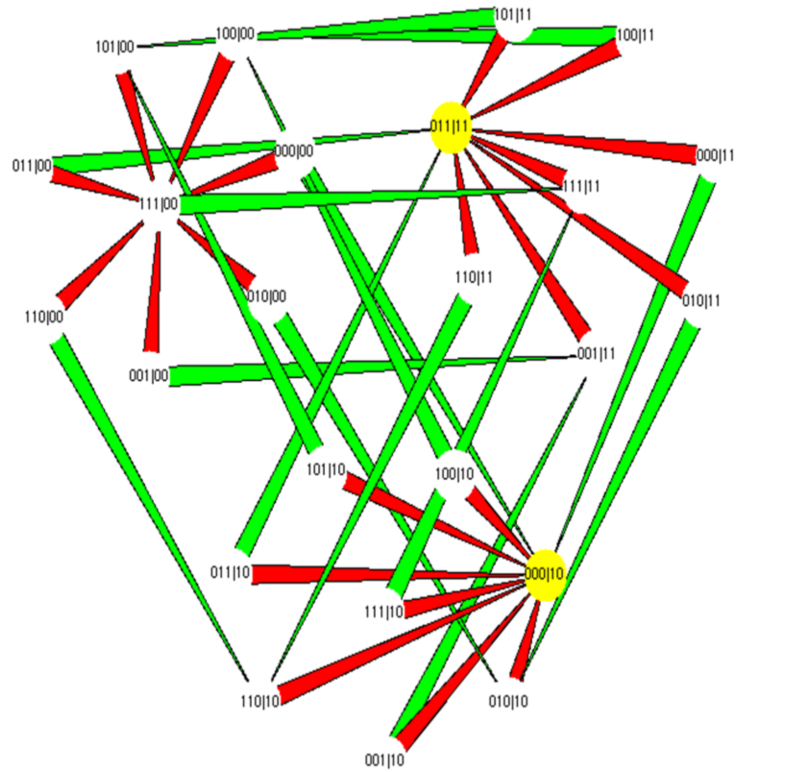
For each state of the game, the game's dynamic indicate first the value for each player and second for each player the possibilities to increase its value. We have 2 types of situation:

Ordinary situation in red (the best payoffs are highlighted).

Nash equilibrium in yellow: in this case, no player can increase its payoff. There's no dynamic.

Red: the *imperatores*; green: the Gallics.

Yellow, Nash equilibria.



This slide shows the change of states of the game with a color code. In the game's dynamic, only one player moves at a time. The arrow's color indicate witch one: green for gallic elites and red for roman generals.

The red arrows converge quickly to one among two states. Each of them is like « an attraction point ». The green arrows displace the state of the game from attraction point to another. Two of them are a Nash equilibrium, which correspond to cooperation of both actors.

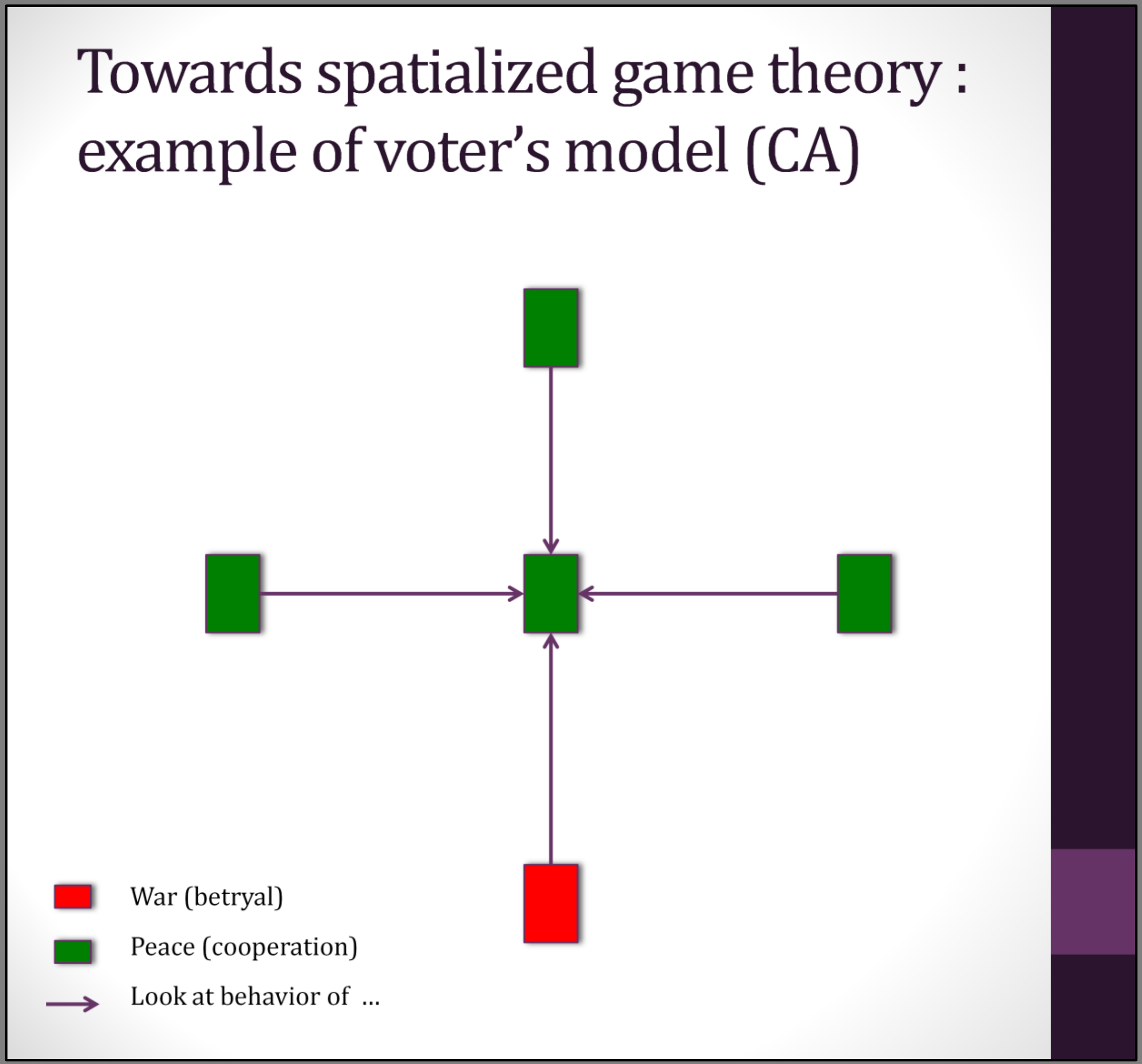
There's no Pareto equilibrium.

Difficulty and limits :

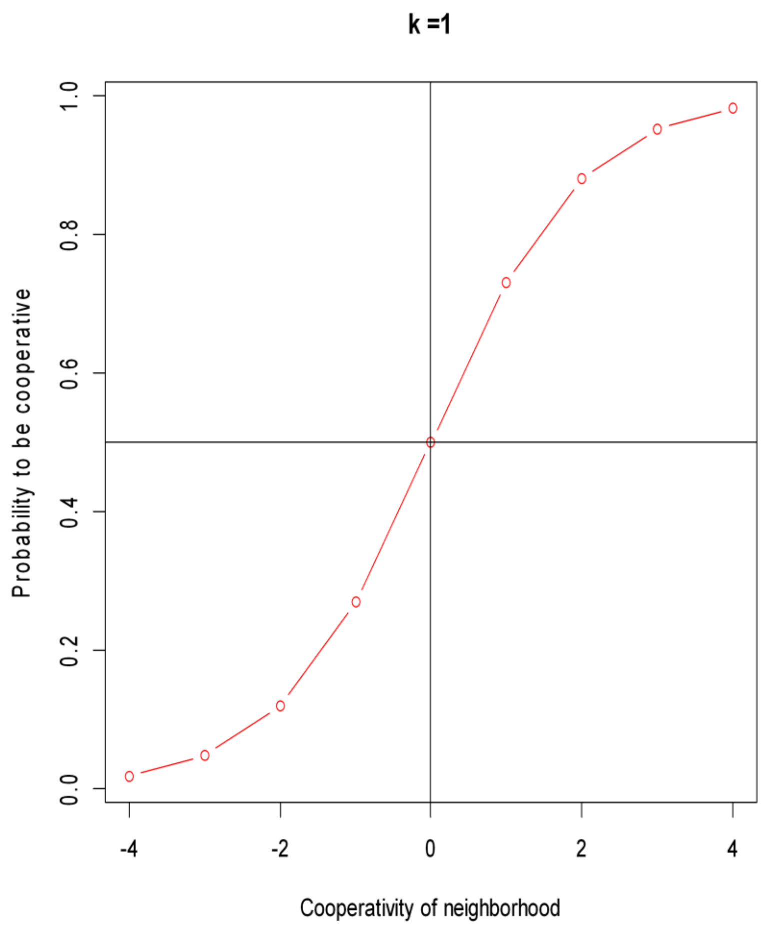
- Difficulty to grasp the Gallics' strategy.
- Difficulty to integrate the time: the strategies have changed during the conquest.

- Figuring out the settlement system implies a spatial approach. Indeed, one of the factors of the evolution of the capital cities' network is their location.
- → spatialized game theory.

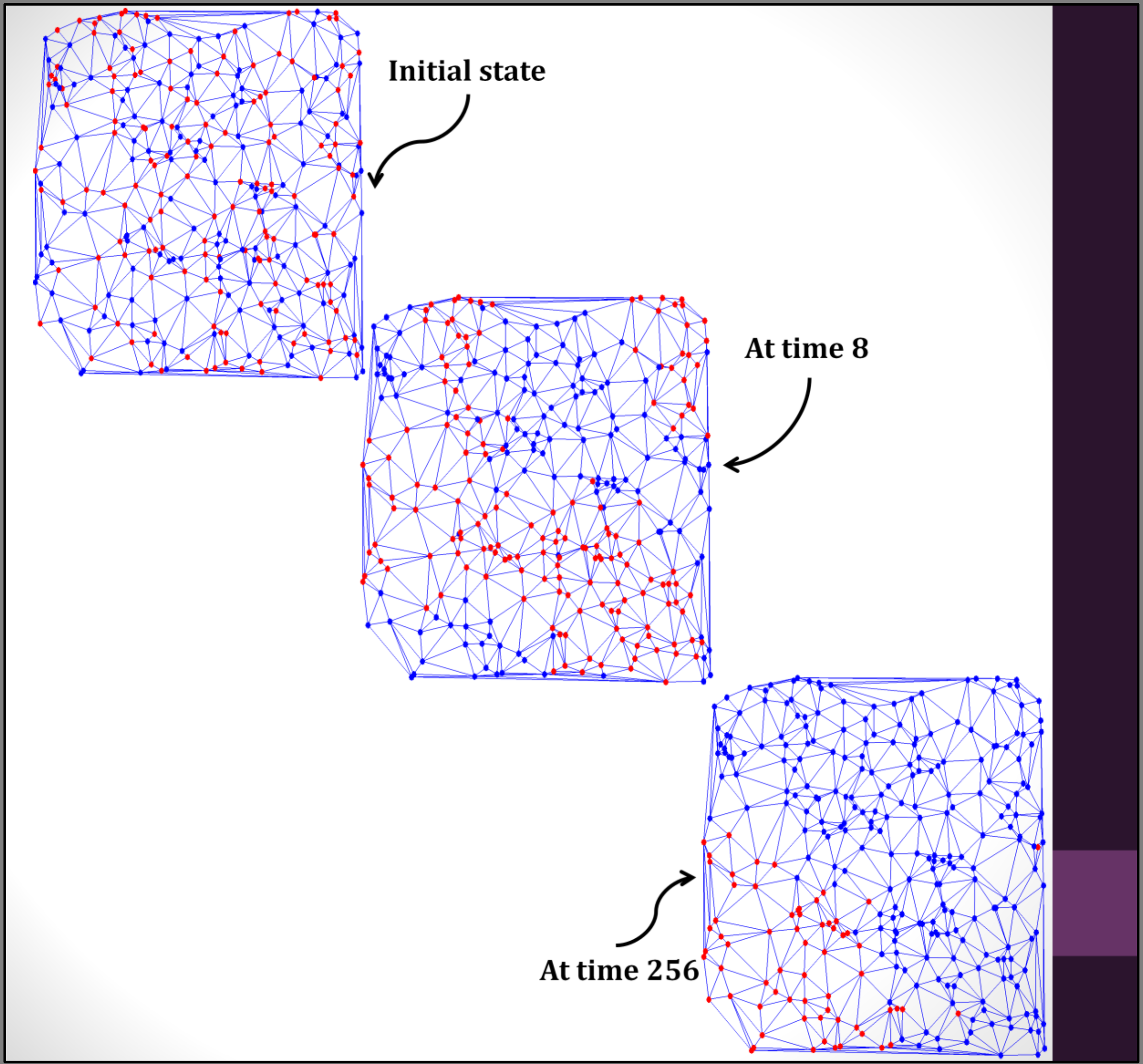
In this modelling, we have had difficulty to grasp the gallic strategies because their capacity to act seems limited. The play is uneven.
In a different register, we have had problem with the time because the strategies of the actors have changed during the conquest.
Finally, we have to work on the spatial dimension. Indeed, one of the factors of the evolution of the capital cities' network is their location.



Next step is to take into account the fact that there are many gallic settlements, and that they may interact to define a policy of reaction to Rome strategy. This leads naturally to spatially expilicit games. Here is an example of a stylised spatial interaction, where a central player looks at the strategy of its four neighbors before defining his/hers.



A numerical simulation of such a game is shown in next slide. The rule behind are those of a voter's model: each player lokks at its neighbors, and selects the rule the majority of its neighbors has selected (majority rule). This graph specifies in y axis the probability a player cooperates knowing in x axis the number of cooperating neighbors. The iteration rule is stochastic, and not deterministic as in prevous non spatialized game.



Here is an iteration of such a model (in fact, a stochastic cellular automata with majority rule) over 256 time steps. Initial spatial situation has been selected as a random uniform localization of gallic settlements, and random allocation of cooperation (blue) and betrayal (red). The neighbors of a given settlement have been selected by a Dirichlet tessellation (space triangulation from settlements). After 8 time steps, it is visible that, although space is homogeneous, some aggregates of cooperative and non cooperative settlements occur. A spatial structure is emerging. After 256 time steps, this dynamics is reinforced, and space is divided into tow collective behaiviors (with very few exceptions). It can be shown rigorously that, with such a rule, there will be a time where the game will stabilize on purely cooperative or purely noncooperaive behaviour. Such a model will be refined and enriched by rational decision making from game theory.