Agent Based Modeling and Bayes Inference to learn about the past: the need for High Performance Computing.

Simon Carrignon

September 2018

Learning about the past

The Roman Empire.

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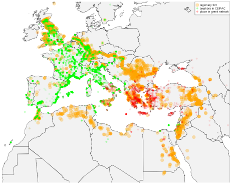

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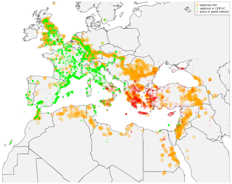

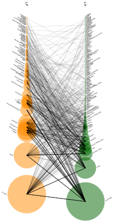

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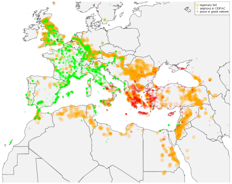

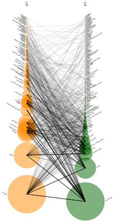

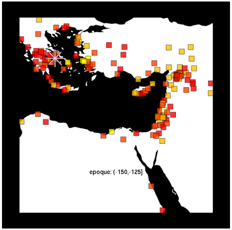

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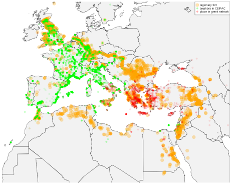
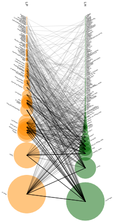
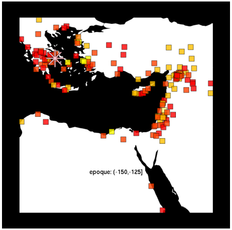
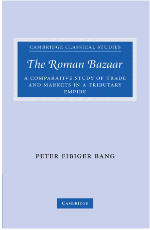






→ Historians and Archaeologists building hypotheses and theories.

Example of the economy (from Brughmans and Poblome 2016):



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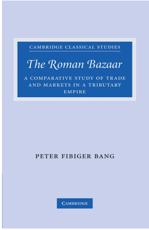

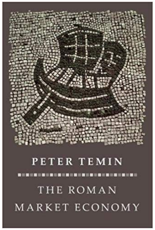

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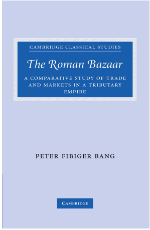

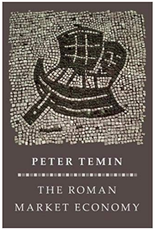

- No general theories
- No common framework
- …

How to compare, quantify, test those theories?

Theoretical Framework

Change in past society:

Succession of social interactions.

Theoretical Framework

Change in past society:

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- Highly stochastic,

Theoretical Framework

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Not so far from problems encountered by Evolutionary Biology

Theoretical Framework

Change in past society:

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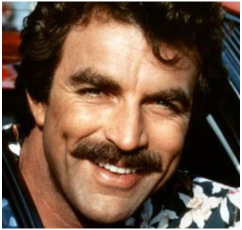
Not so far from problems encountered by Evolutionary Biology
Cultural evolution as an evolutionary process

Evolutionary Process

Social Traits:

Evolutionary Process

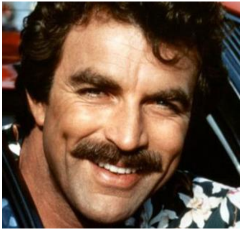
Social Traits:



80's

Evolutionary Process

Social Traits:



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Evolutionary Process

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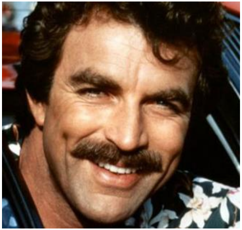

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now

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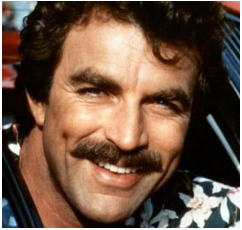

80's

90's

now

Same way biologist study frequencies of biological traits to understand past biological phenomena, we can use frequencies of cultural traits to understand past social changes.

Cultural Evolution

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- Culturally transmitted, socially learnt

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- Different probabilities of transmission (differential reproduction → bias)

Cultural Evolution

- Culturally transmitted, socially learnt
- Different probabilities of transmission (differential reproduction $\rightarrow$ bias)

$\rightarrow$ What mechanism drive the evolution of such traits?
generate such pattern?

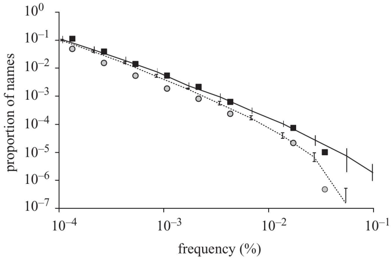
What Generate Those Cultural changes?

Simple mechanisms (Bentley et al, 2004):

What Generate Those Cultural changes?

Simple mechanisms (Bentley et al, 2004):

- Random Copy



Square: male names
Circle: female names
Dotted and plain lines: model result with different copy probabilities.
From Bentley et al, 2004.

What Generate Those Cultural changes?

Simple mechanisms (Bentley et al, 2004):

- Random Copy
- Frequency biased (conformist/anti-conformist...)

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Simple models, could be represented with equations and solved.

What if such mechanisms act on traits linked to economics?

A social traits an economic weight

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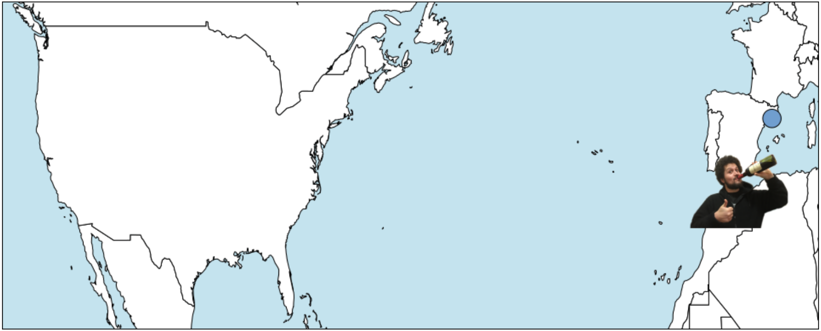
Co-evolution of Economy and Culture



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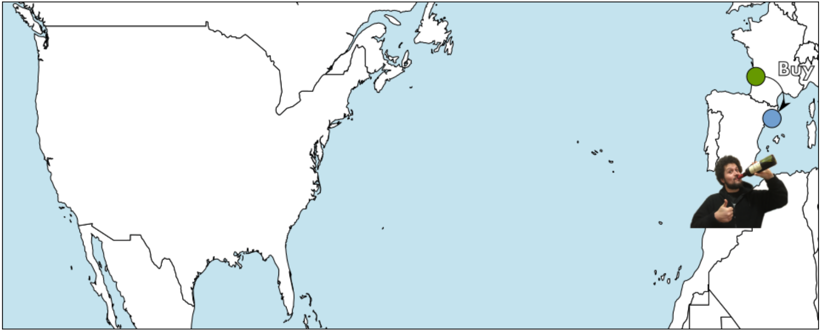

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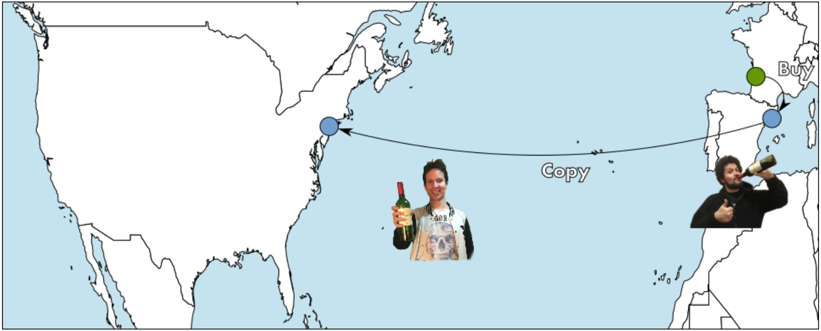

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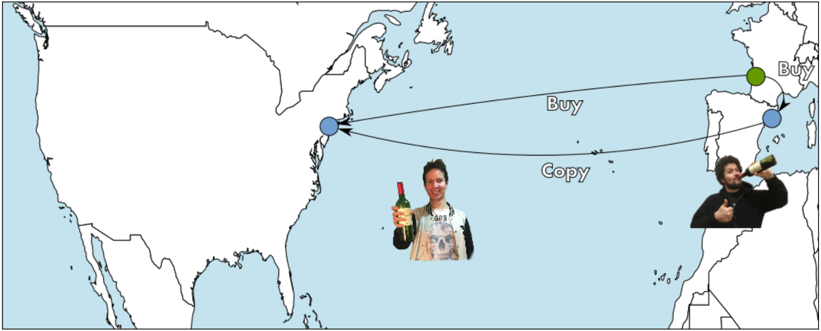

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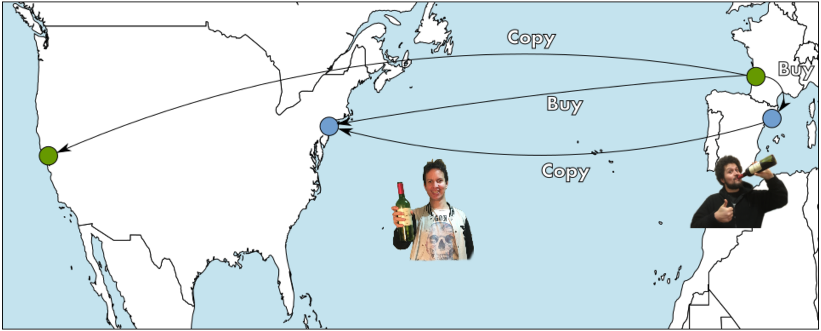

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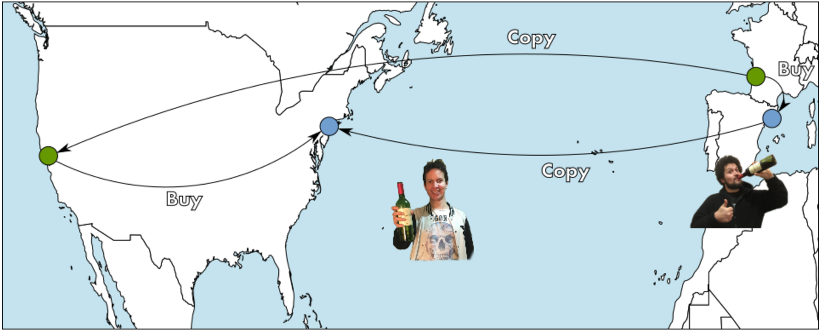

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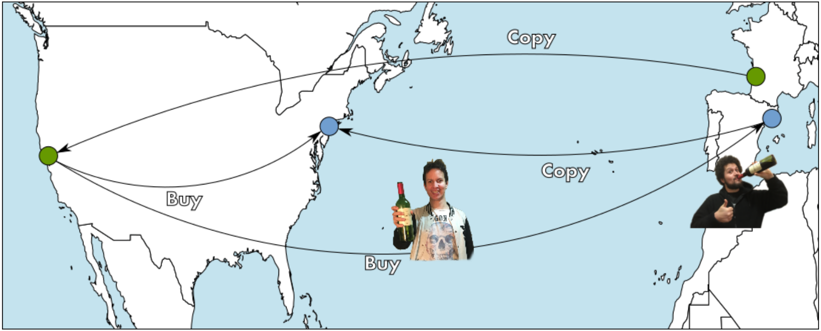

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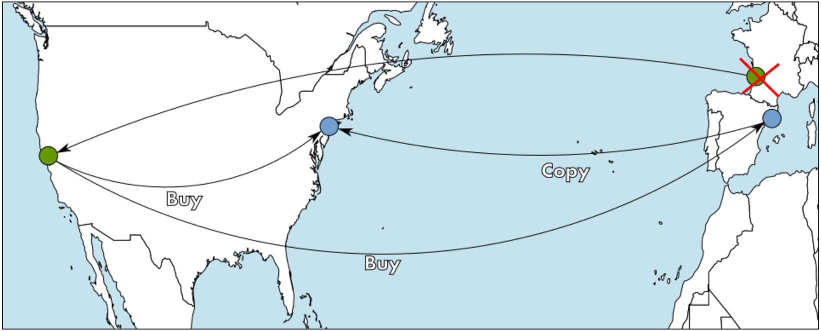

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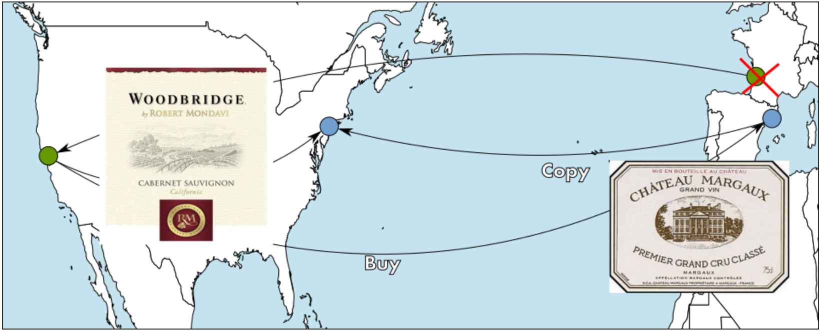

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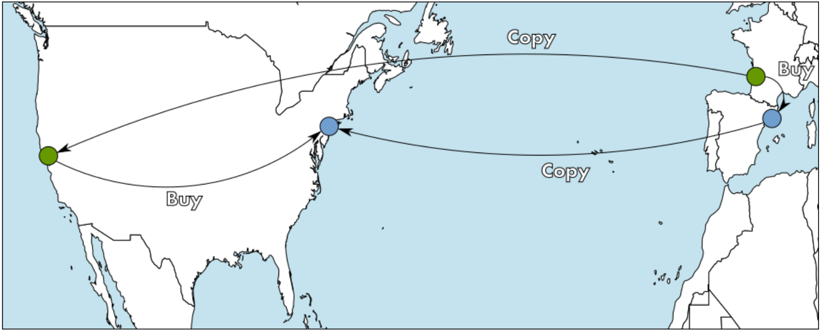

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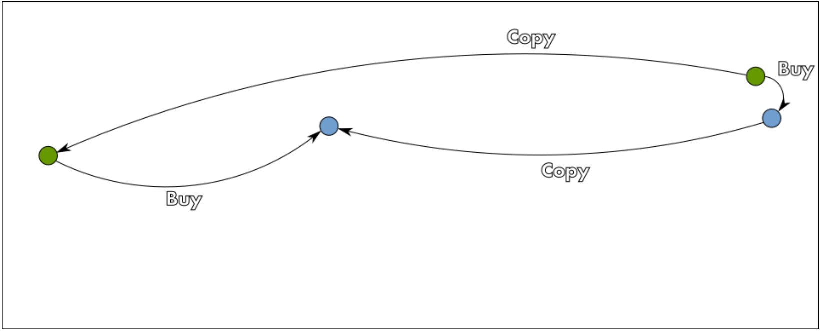

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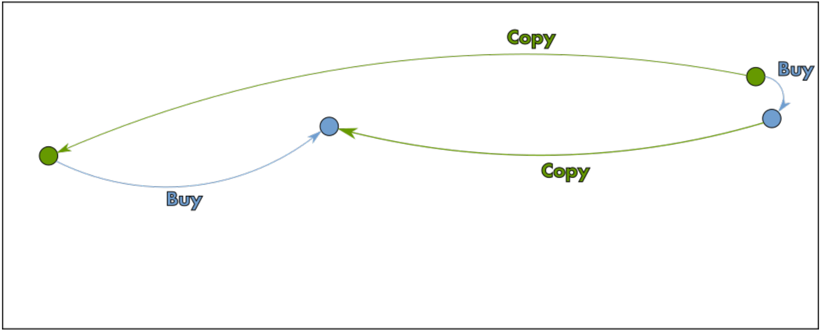

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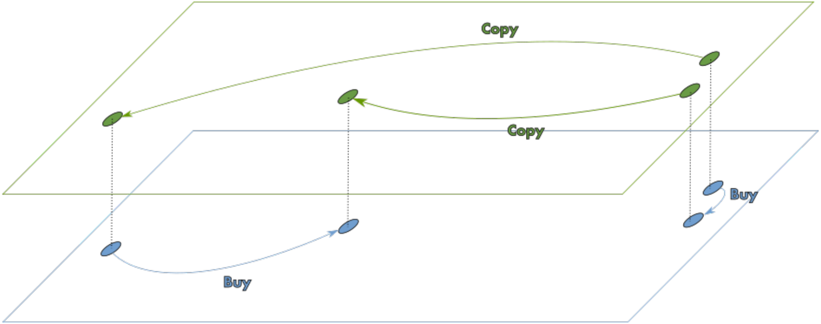
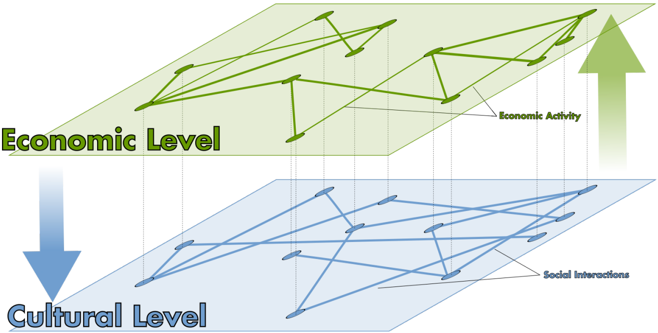


General Modeling Framework



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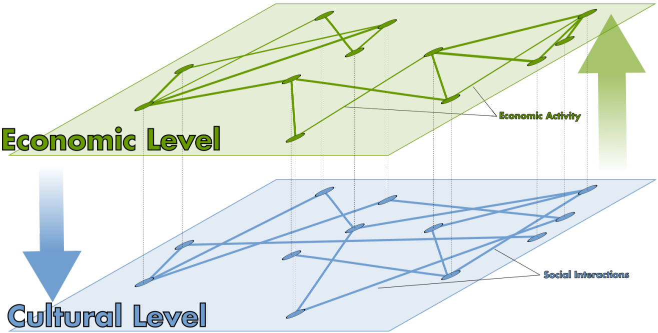
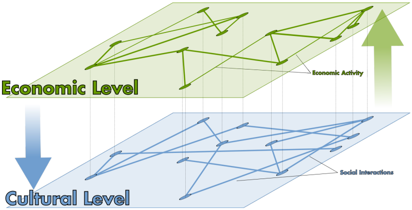


Equations?

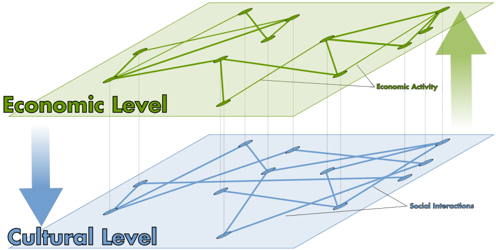
General Modeling Framework

Agent Based Model: A general framework where we can implement hypothesis and theories.



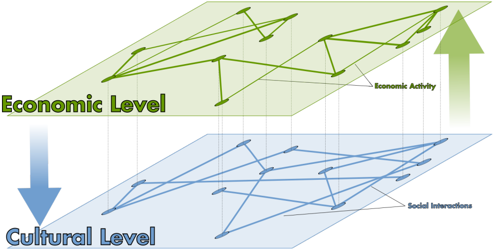
- Different Cultural Mechanisms
- Different Trade Assumption
- Historical and Archaeological Evidences
- Network Constraints
- ...

Limitations



At each level, every action can be very costly:

Limitations



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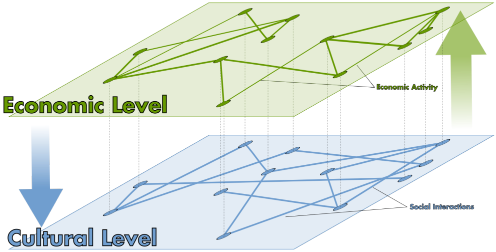

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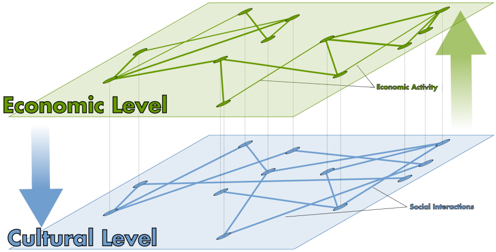

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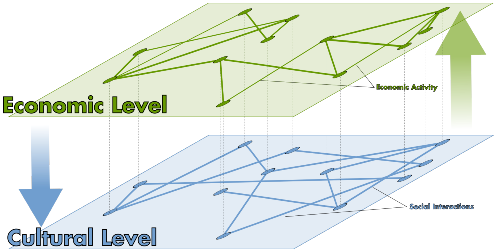

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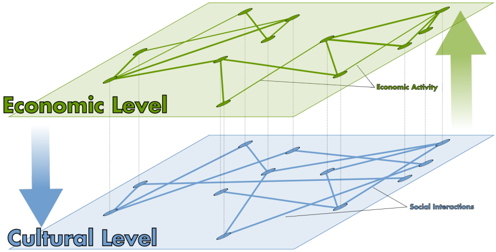

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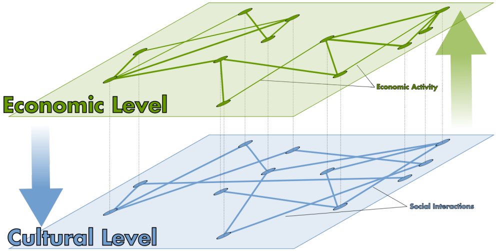

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$\rightarrow$ Need for parallelisation

Pandora

Split space in different sub part run on different node communicating through MPI.

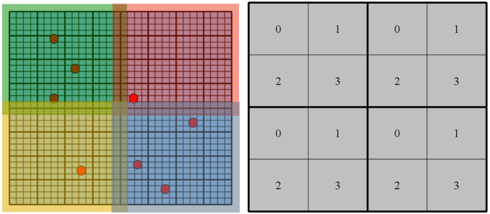
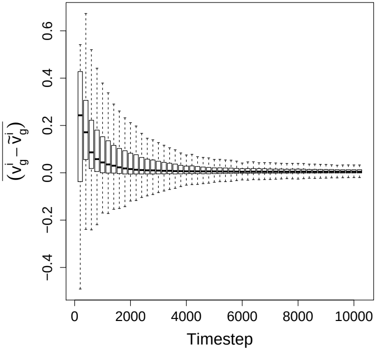


Figure: Repartition of agents between nodes. from Rubio-Campillo 2012.

Results: Economic Dynamics

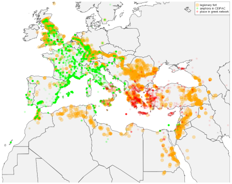
Carrignon, Montanier & Rubio-Campillo 2015, in line with Gintis 2006:

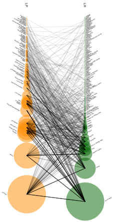
Figure: Example for 3 goods and 500 agents

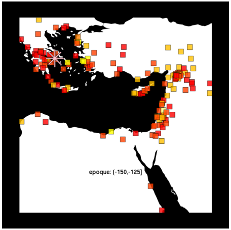


@ Equilibrium: personal values $\rightarrow$ optimal (shared) values.

Now we have a model. How can we use it to learn about:
The Economy of the Roman Empire (work in collaboration with Iza Romanowska & Tom Brughmans).







- Model with lot of parameters and few a priori knowledge of impact of those parameters,
- Incomplete, biased, small dataset

Bayesian Inference:

$$P(A|B) = \frac{P(B|A) * P(A)}{P(B)}$$

What is the probability of something knowing something else?

A can be a model with parameters (θ) and B our evidence (E), the posterior becomes:

$$P(\theta|E)$$

- Test the ability of model to explain the data
- Compare different model against same data set
- ...

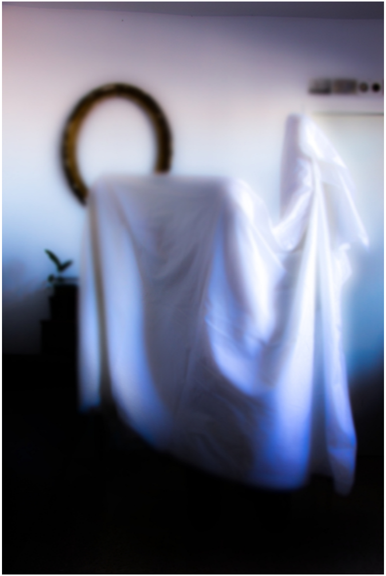
Problem

When you cannot calculate all probabilities, simulate the model.

Approximate Bayesian Computation (Beaumont 2002)
(and its flavors)

$\rightarrow$ After simulations, only the parameter that produces output close enough to the data ($< \epsilon$) are selected to draw the posterior.

Modeling & Simulation



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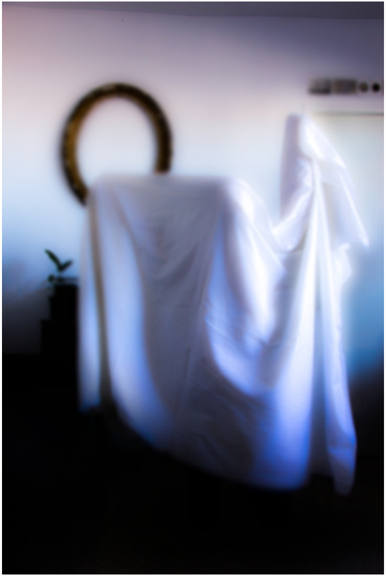

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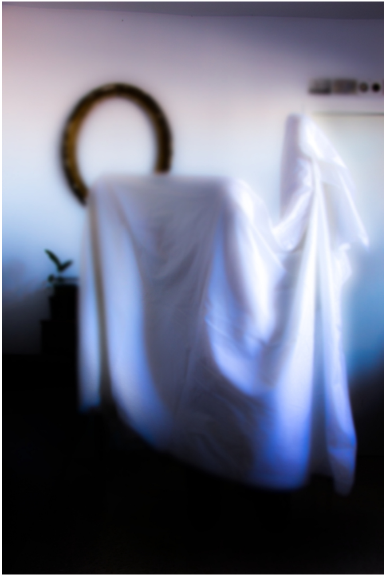

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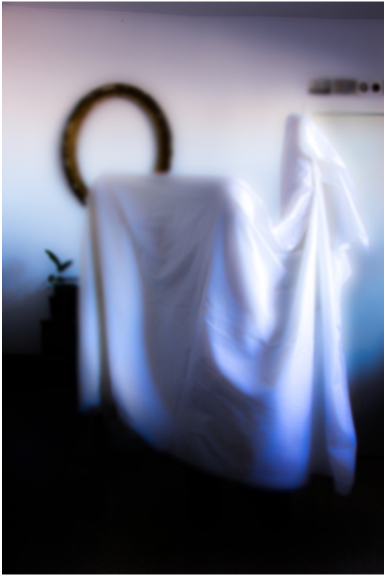

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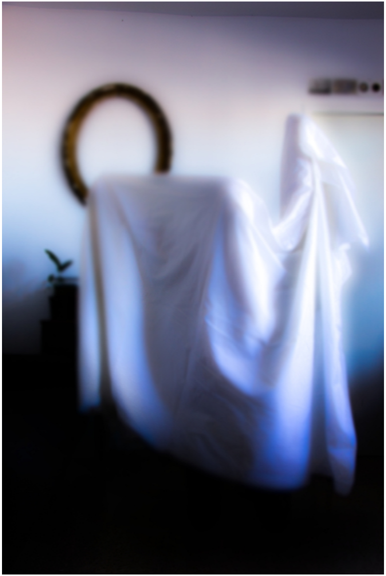

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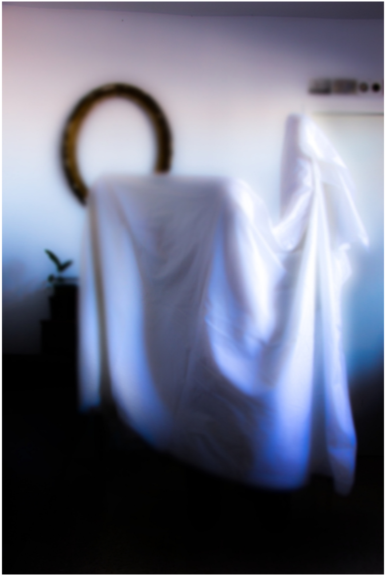

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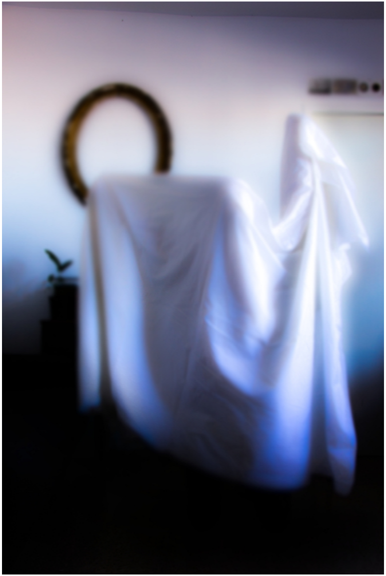

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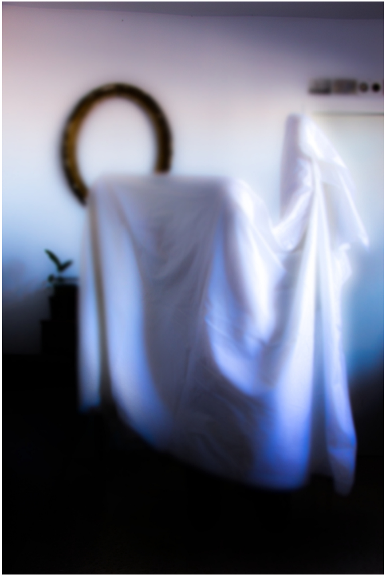

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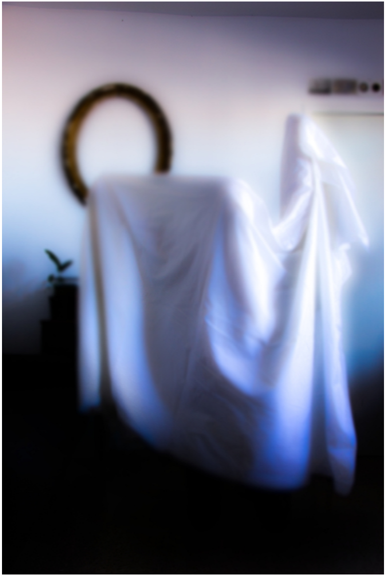

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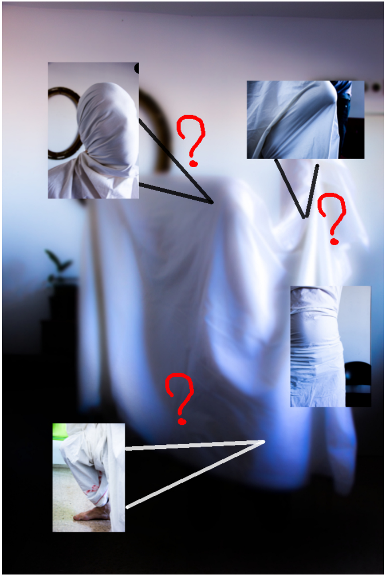
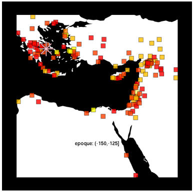


Evidences

The ICRATES database:

- 5 types of Sigilata used to produce tableware (bowl, cup, plates)
- 178 sites
- 500 years (200 BC–300 AD)



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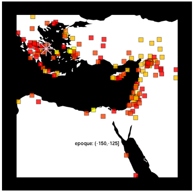
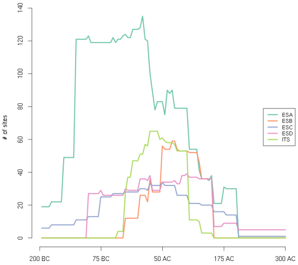
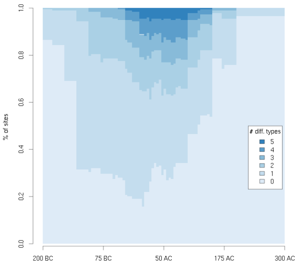
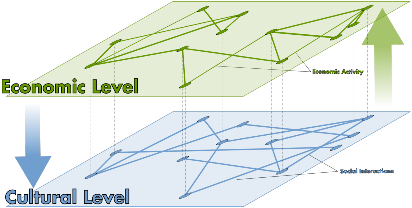
- 178 sites
- 500 years (200 BC–300 AD)







The Model



Agent based model presented before with dynamic processes interacting:

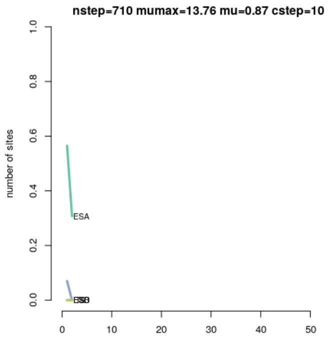
- Cultural activity (people can learn from each other)
- Economic activity (people can trade with each other)

+ one flavor of ABC: Sequential Monte Carlo Sampling:

- The acceptance level is adjusted during the simulation.

Sequential ABC

One simulation



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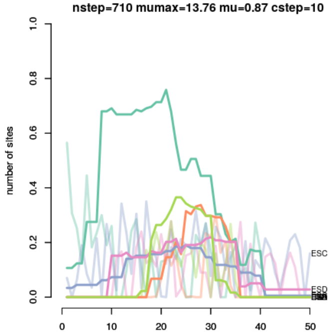

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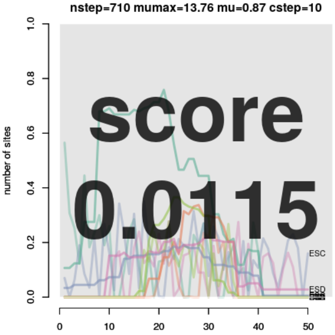

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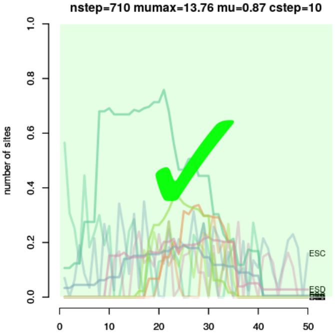

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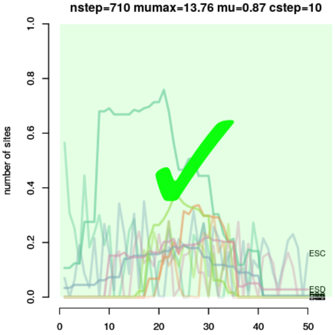

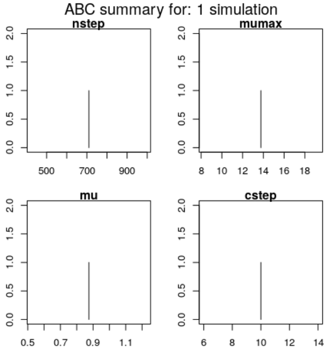

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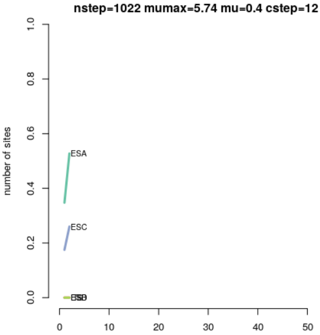

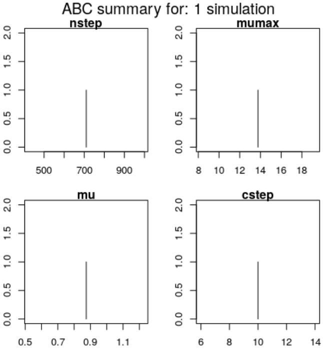

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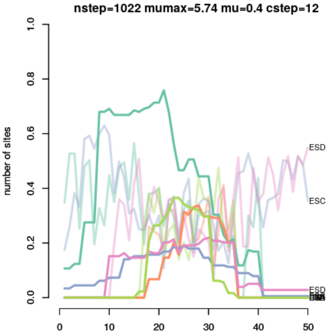

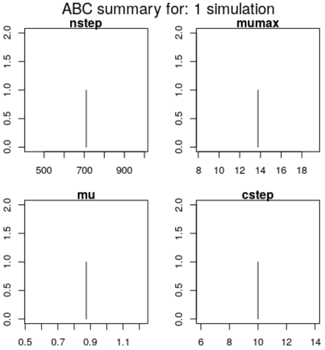

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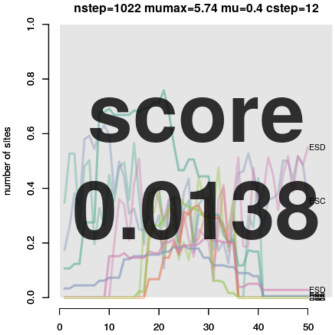

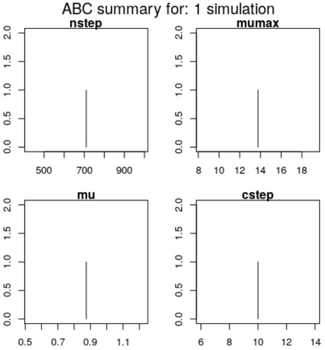

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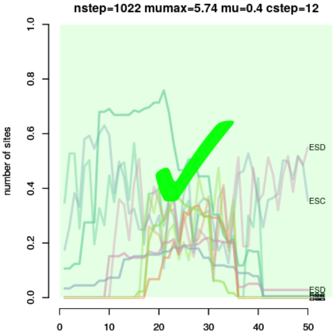

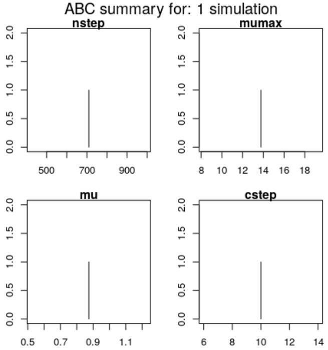

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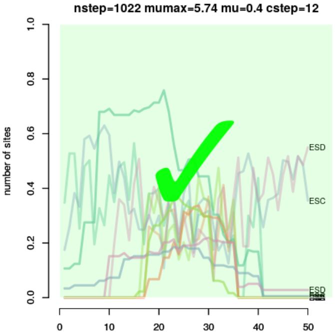

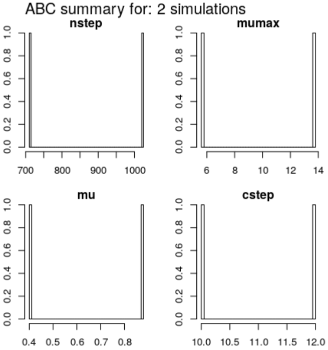

Sequential ABC

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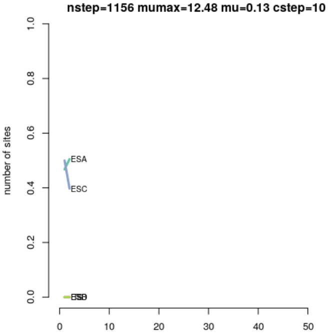

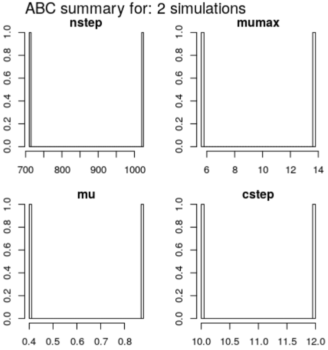

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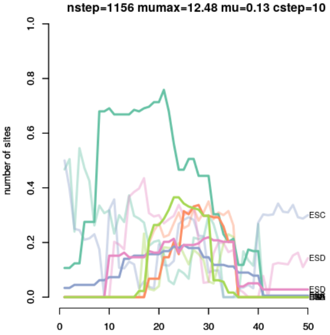

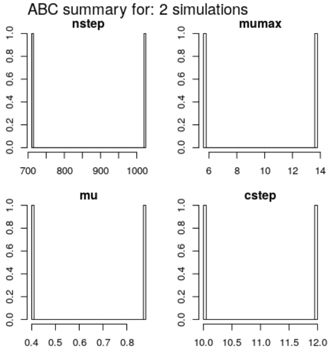

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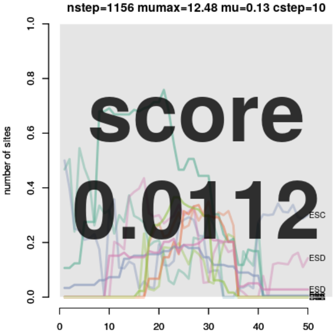

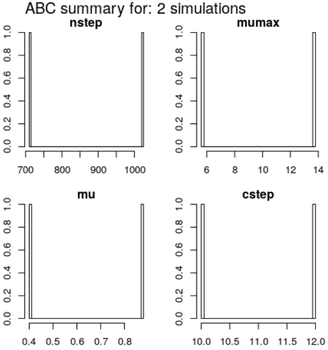

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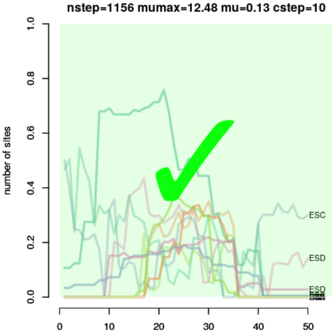

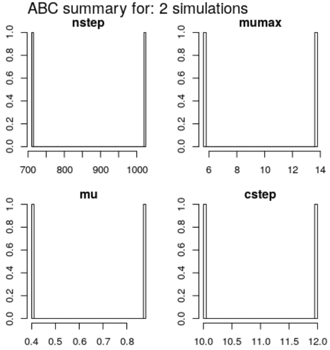

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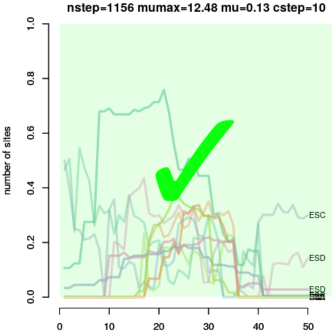
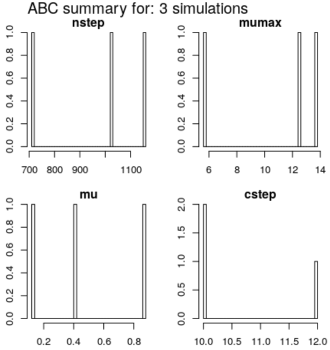
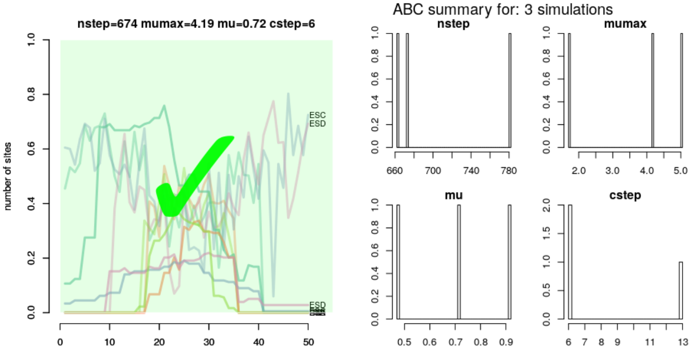




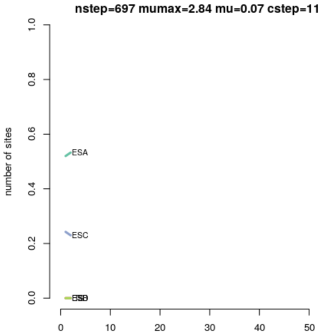
Sequential ABC

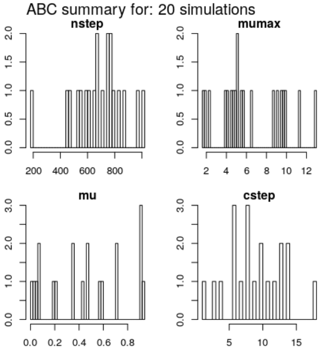
Until you have enough



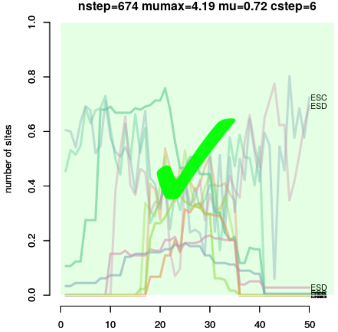
Sequential ABC

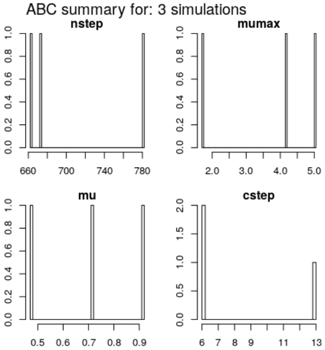
Until you have enough





And repeat the same but being more restrictive:





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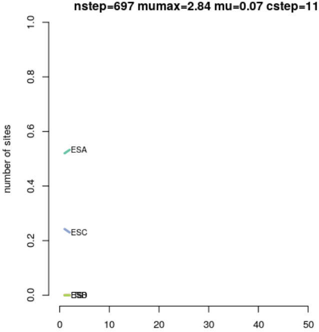
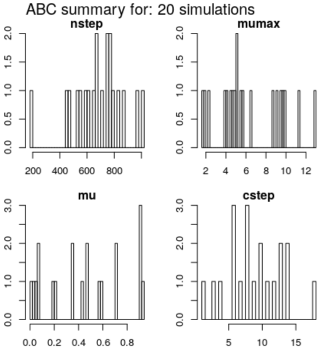
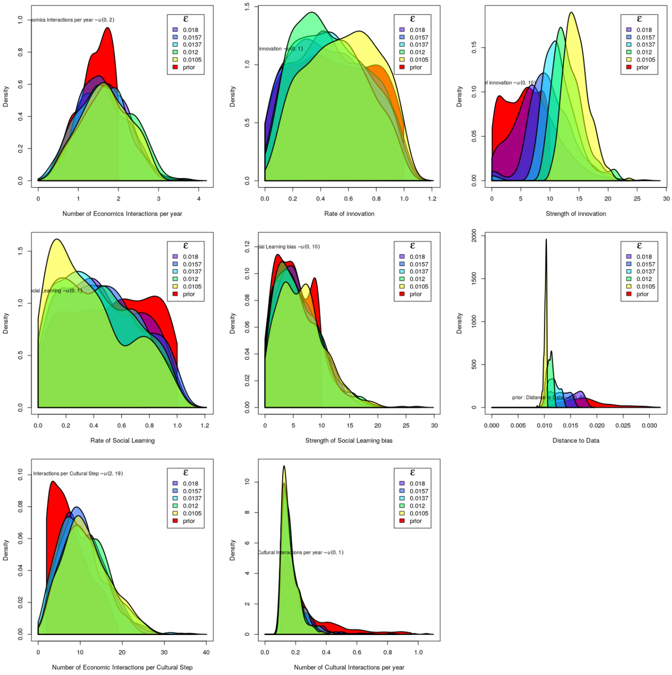





Number of Economics Interactions per year
Rate of innovation
Strength of innovation
Rate of Social Learning
Strength of Social Learning bias
Distance to Data
Number of Economic Interactions per Cultural Step
Number of Cultural Interactions per year
Density
ε
0.018
0.0157
0.0137
0.012
0.0105
prior

Hypothesis Testing

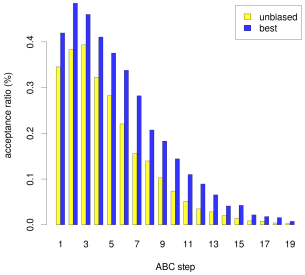
Compare two different hypothesis on the social learning mechanism:

- Copy the bests $\rightarrow$ Random copy

Hypothesis Testing

Compare number of simulation needed to reach the more restrictive epsilons:

- $564\,211$ simulations: unbiased social learning mechanism
- $209\,395$ success-biased: social learning mechanism.



Compare parameters

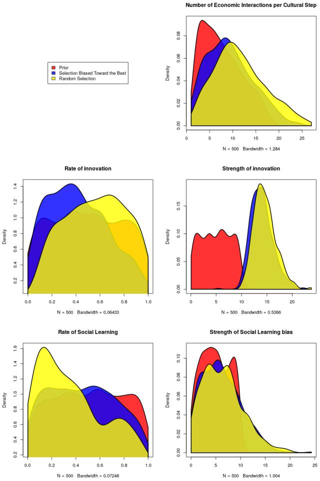


Figure: Posterior distribution for all parameters

the probability that at each time step someone copy the strategies of someone else

ABC summary

Approximate Bayesian Computation allows to link data to models by giving us the probability of one model to reproduce observed patterns.

- Flexible,

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- Few assumptions needed (neither on data nor model side),
- Heavy computational cost,
- Central role of transdisciplinarity (central role interpretation and expert knowledge). No strict answer ($< .05 \rightarrow$ OK,$> .05 \rightarrow$ not OK).

General Conclusion

Status of simulation and computer model vs empirical research:

- Opaque Thought Experiment (Di Paolo, Noble and Bullock)experience on it's own
- Hybrid status in-between experiment and theories.

New ways to know more about something, closer to experimental approach

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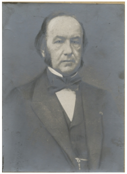

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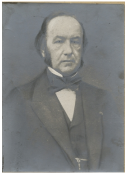

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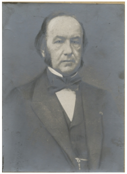

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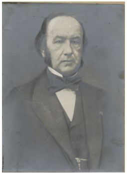

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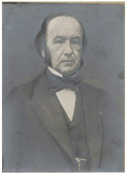

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Limitations

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- Ecological Cost

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The Leverhulme Trust

Thank you for you attention

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