



AARHUS INSTITUTE OF
ADVANCED STUDIES

Exploring past economies with HPC-enabled agent-based modelling

IZA ROMANOWSKA
SIMON CARRIGNON
TOM BRUGHMANS



(01)

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(05)

The winter of discontent

Global Pandemic

A new disease ravaged cities and the countryside across the world.

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Climate change

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New sects emerge and more and more people turn to extreme forms of religion.

The winter of AD 166



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The Ancient World



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02

- Battles and treaties
- Great personalities and their lives
- Innovations and discoveries
- How things looked like
- Local histories

What happened in the past?



The Ancient World



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02

Economy and Trade
Resource Acquisition
Cultural Evolution
Resilience and Climate Change
Migration and Movement

How do human groups operate over long time periods?

Archaeology

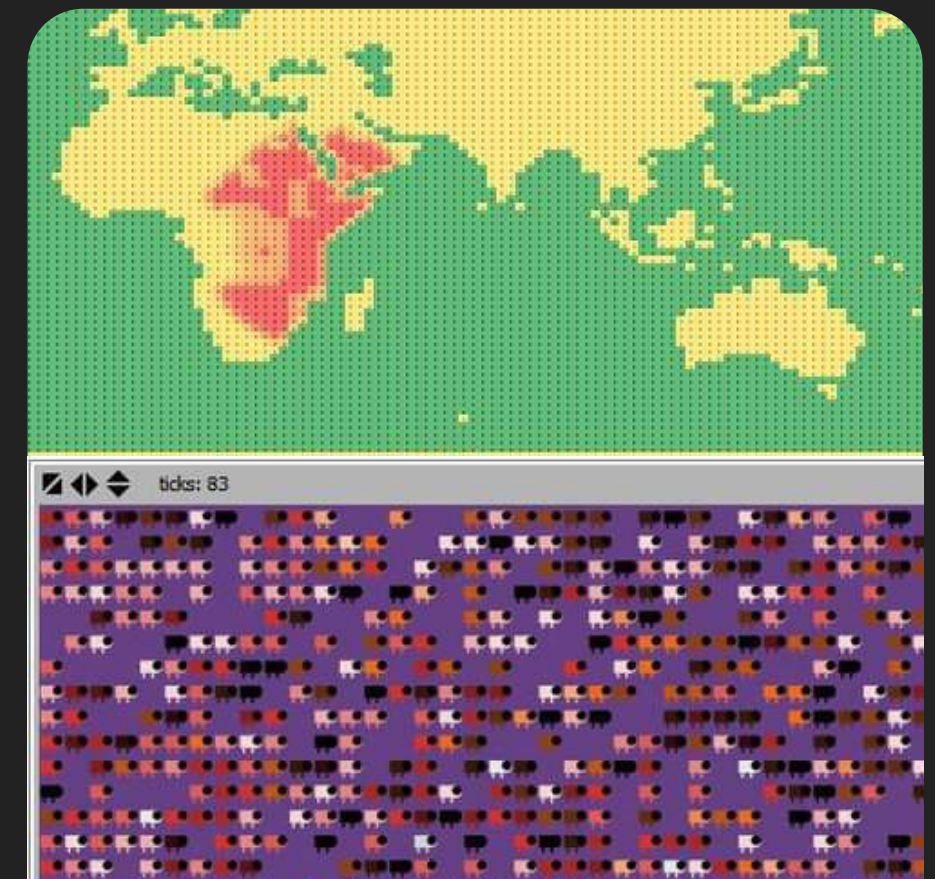
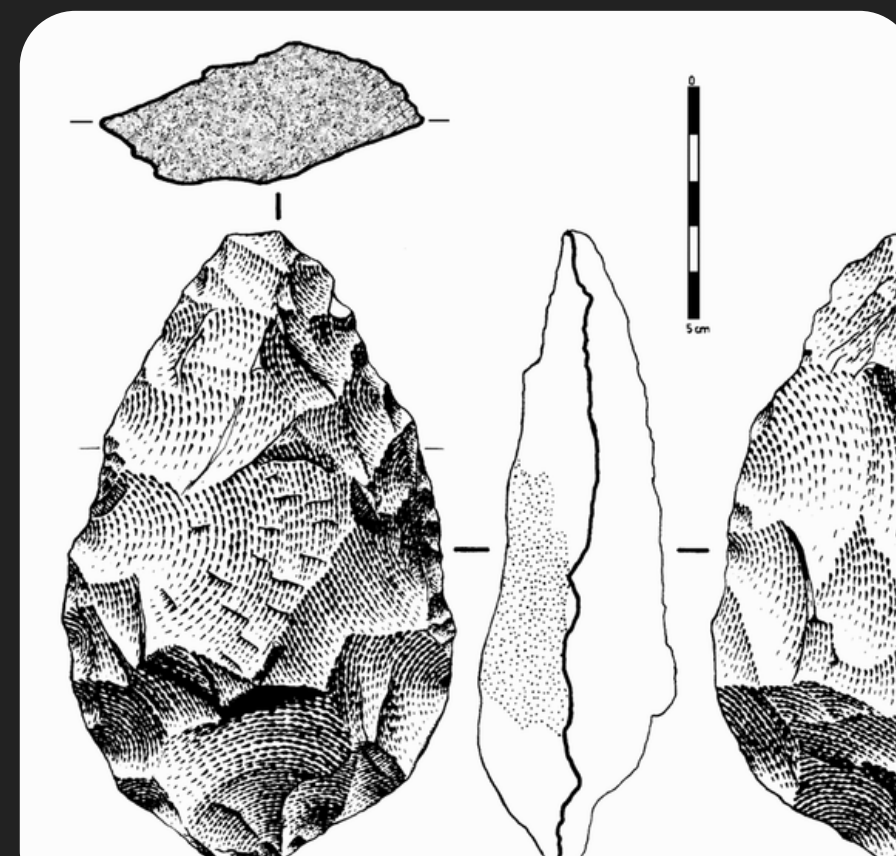
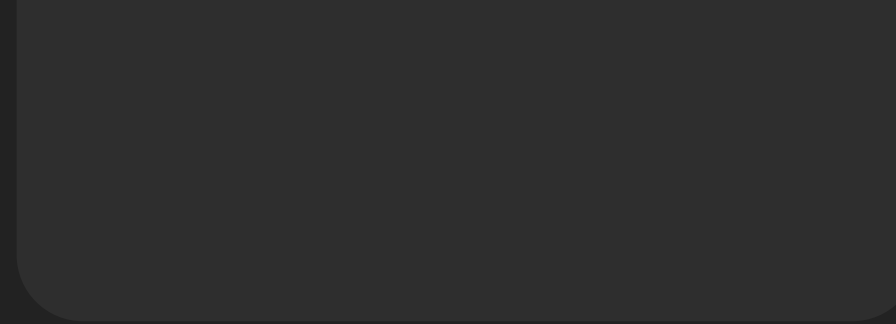
Evolutionary Processes
Human Origins, Roman Archaeology
Lithics and Pottery

Complexity Science

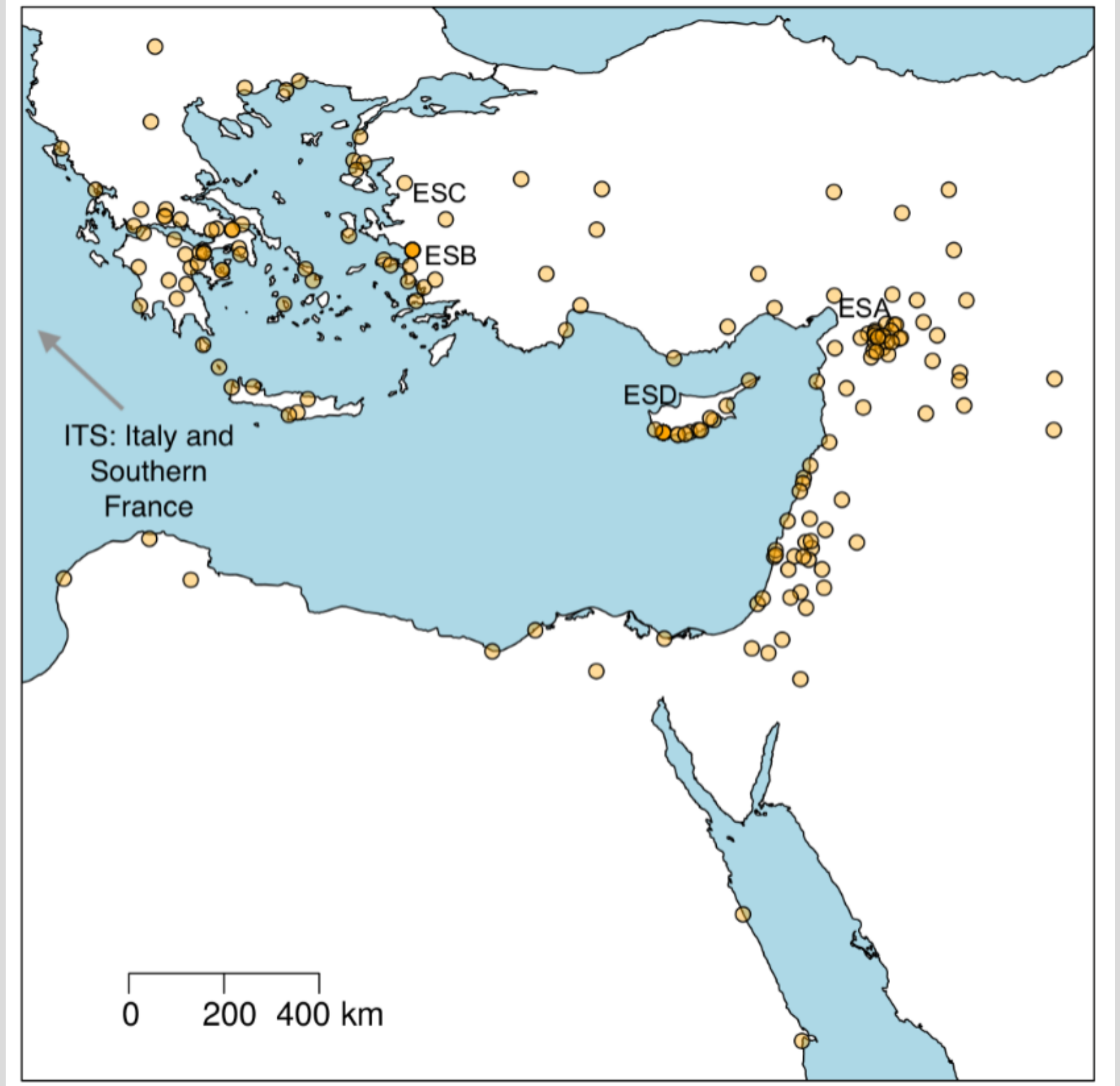
Agent-based Modelling
Long-term Trends in Socio-natural Dynamics
Complex Adaptive Systems

Computer Science

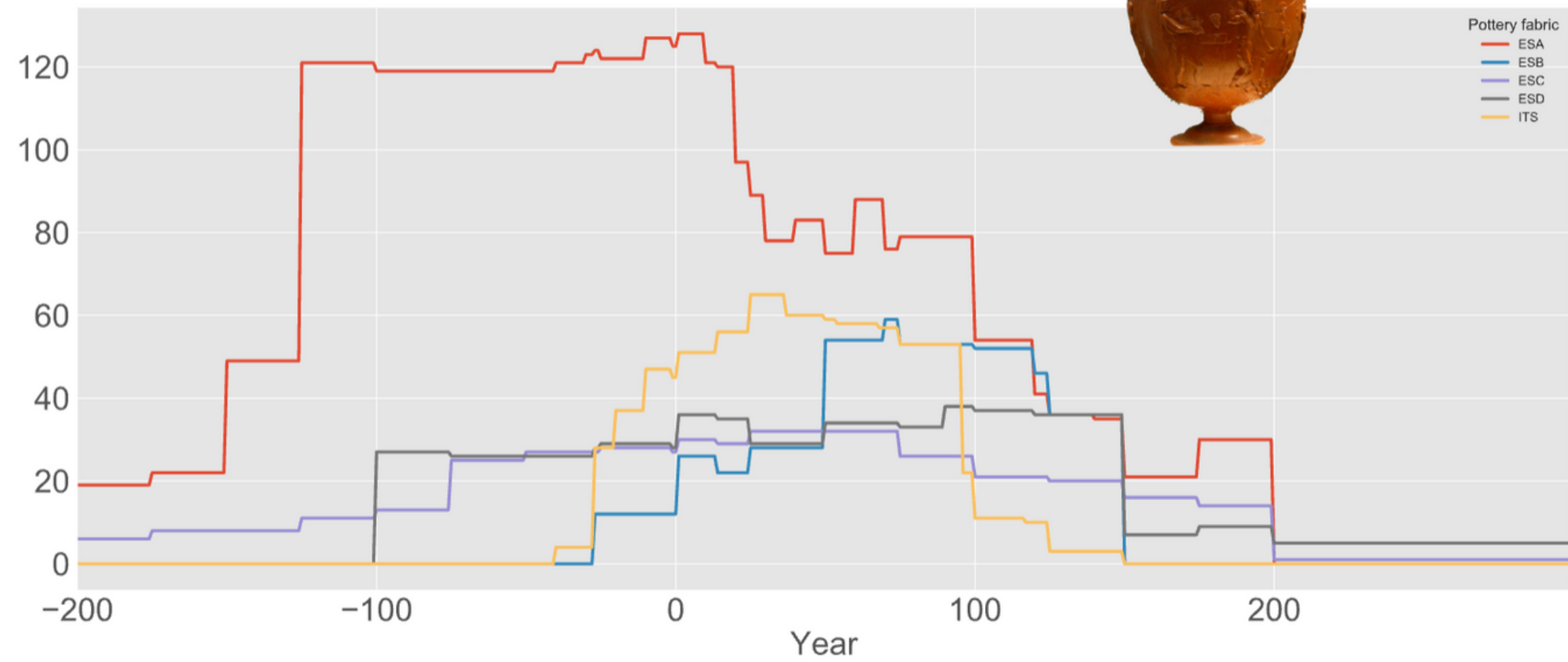
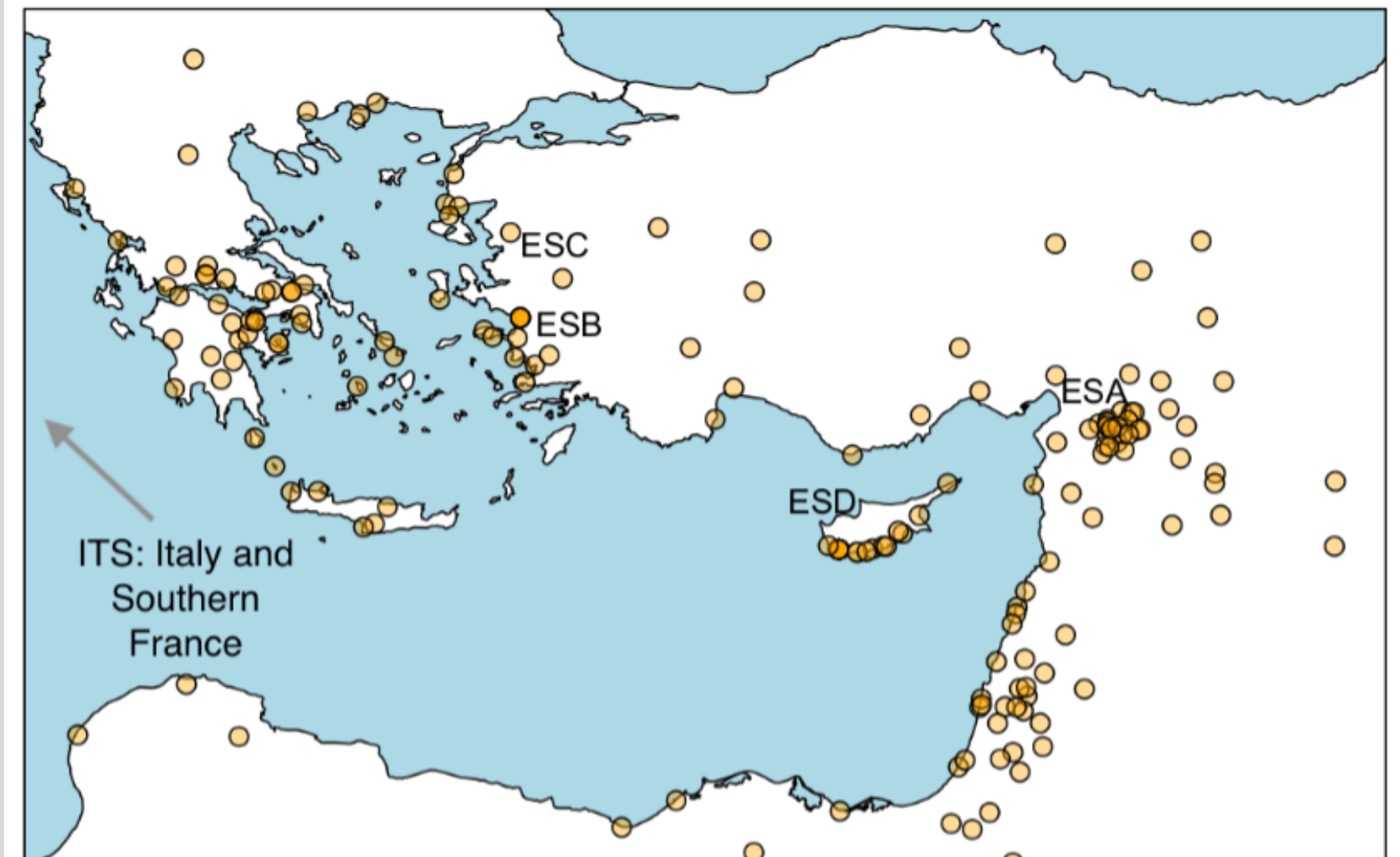
Algorithmics
High Performance Computing
Software Sustainability



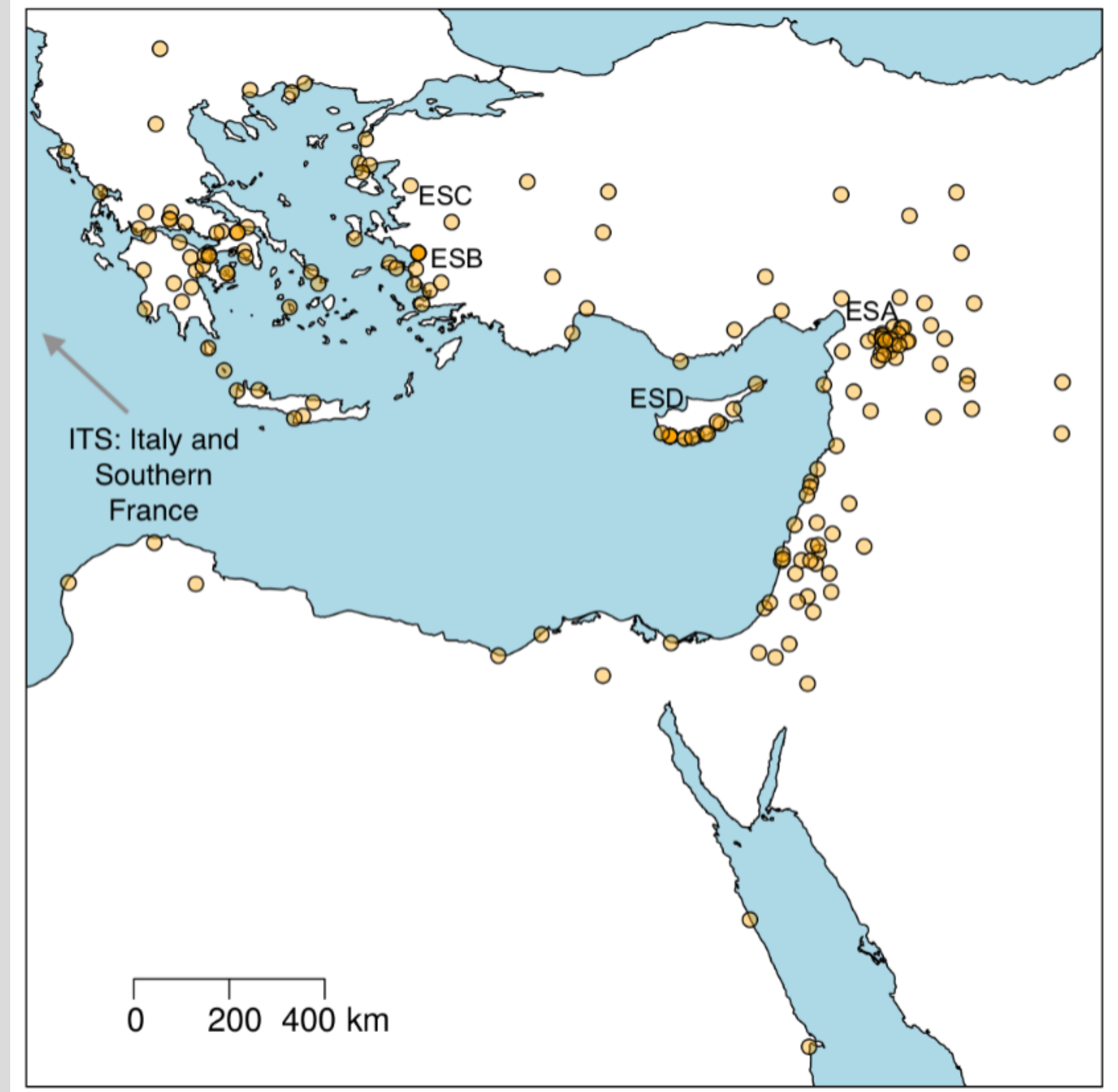
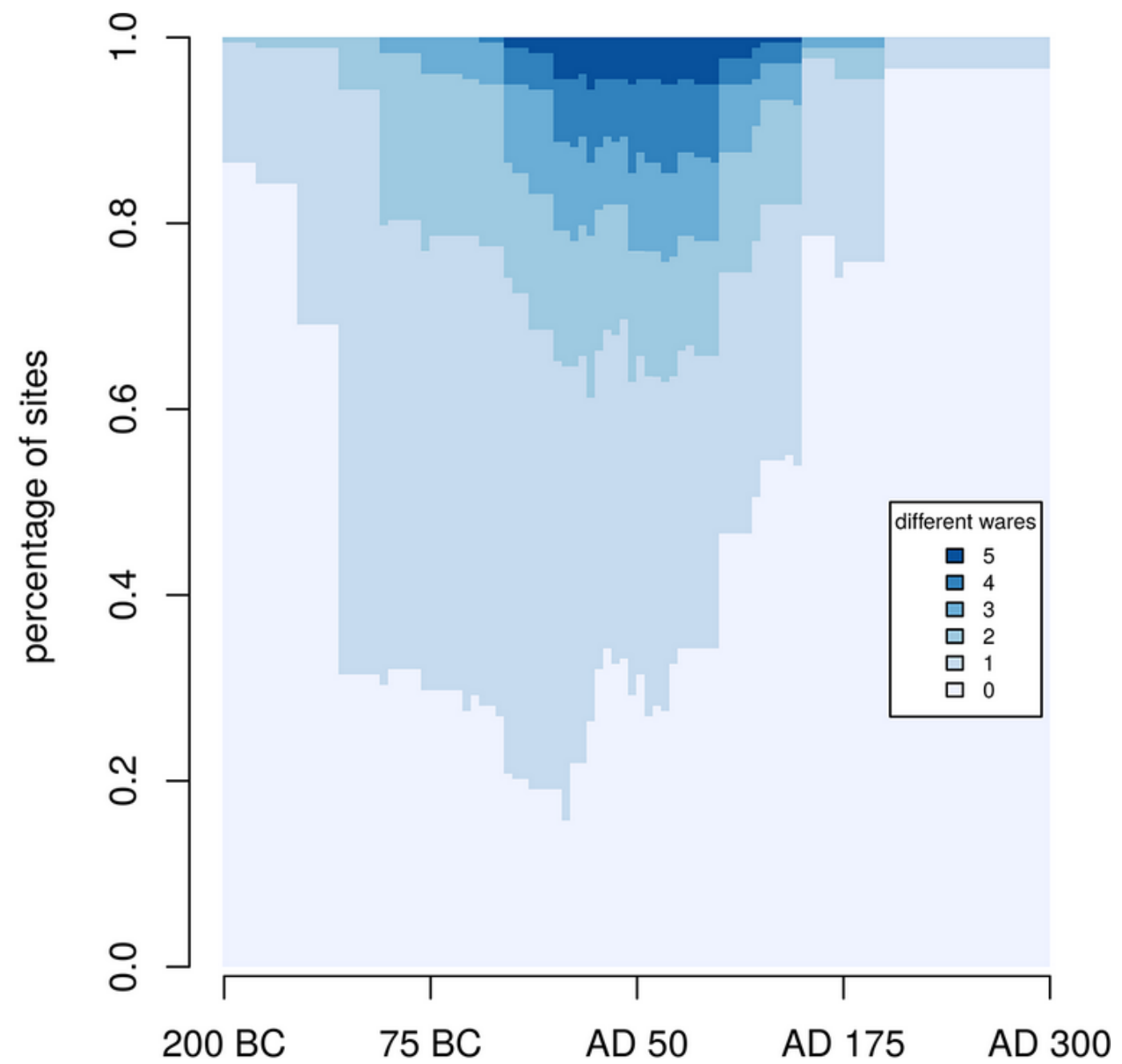
THE ROMAN EAST



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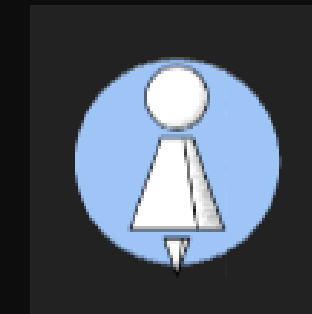




HOW INTEGRATED WAS THE
ROMAN EAST?



FLOW OF GOODS



FLOW OF COMMERCIAL
INFORMATION

Economy meets Culture

(04)

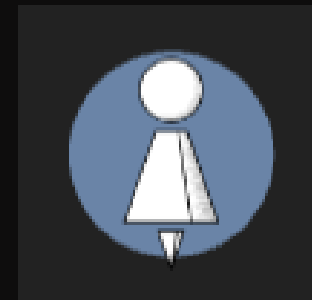
RESEARCH QUESTION



INDEPENDENT LEARNING

Traders independently change their tableware buying strategy

NO ACCESS TO COMMERCIAL INFORMATION



UNBIASED SOCIAL LEARNING

Traders randomly copy the tableware buying strategy of another trader

LIMITED ACCESS TO COMMERCIAL INFORMATION



SUCCESS-BIASED LEARNING

Traders copy the tableware buying strategy of the most successful trader

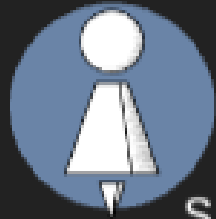
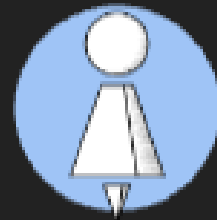
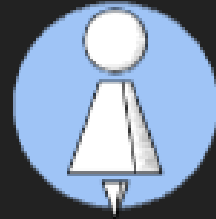
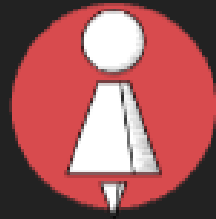
FULL ACCESS TO COMMERCIAL INFORMATION

Economy meets Culture

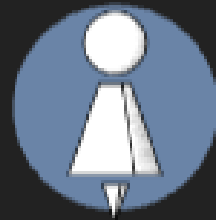
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HYPOTHESES

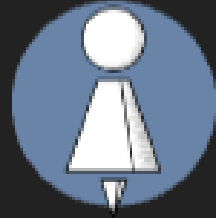
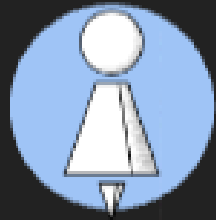
Gintis H. The emergence of a price system from decentralized bilateral exchange. Contributions in Theoretical Economics. 2006;6(1):1-15.



Strategy
Goods: abf
Value: 956



Strategy
Goods: efg
Value: 159



strategy CCB

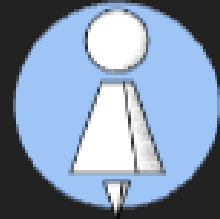
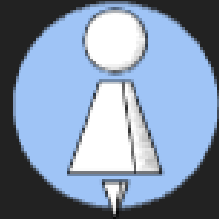
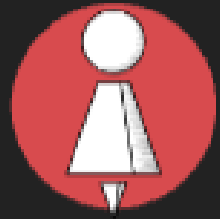
Economy meets Culture

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ECONOMIC EXCHANGE

1. TRADE with other traders based on your strategy
 - 1.a Score for "success"

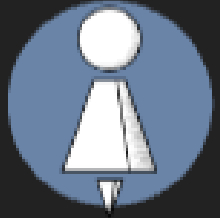
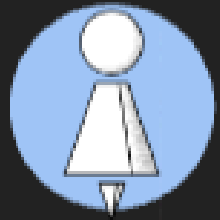
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Economy meets Culture

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CULTURAL EXCHANGE

2. Learn/update strategy

- adapt your strategy independently (innovation)
- learn from the best (social learning -biased transm.)
- learn at random (social learning -unbiased transm.)

Economy meets Culture

parameter	description	initial value
t	Total number of economic interactions	\mathcal{S}
ω	number of economic interactions per cultural interaction	\mathcal{S}
CI	total number of cultural interactions	\mathcal{S}^*
μ	rate of innovation	\mathcal{S}
λ	rate of social learning	\mathcal{S}
N	total number of agents	500
μ_{max}	variance of innovation	\mathcal{S}
λ_{str}	strength of bias (when social learning is biased)	\mathcal{S}
n_{good}	number of types of goods (e.g. ESA, ESB, . . .) produced and exchanged	3-6

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EXPERIMENT DESIGN

Vast parameter space

Limited input data

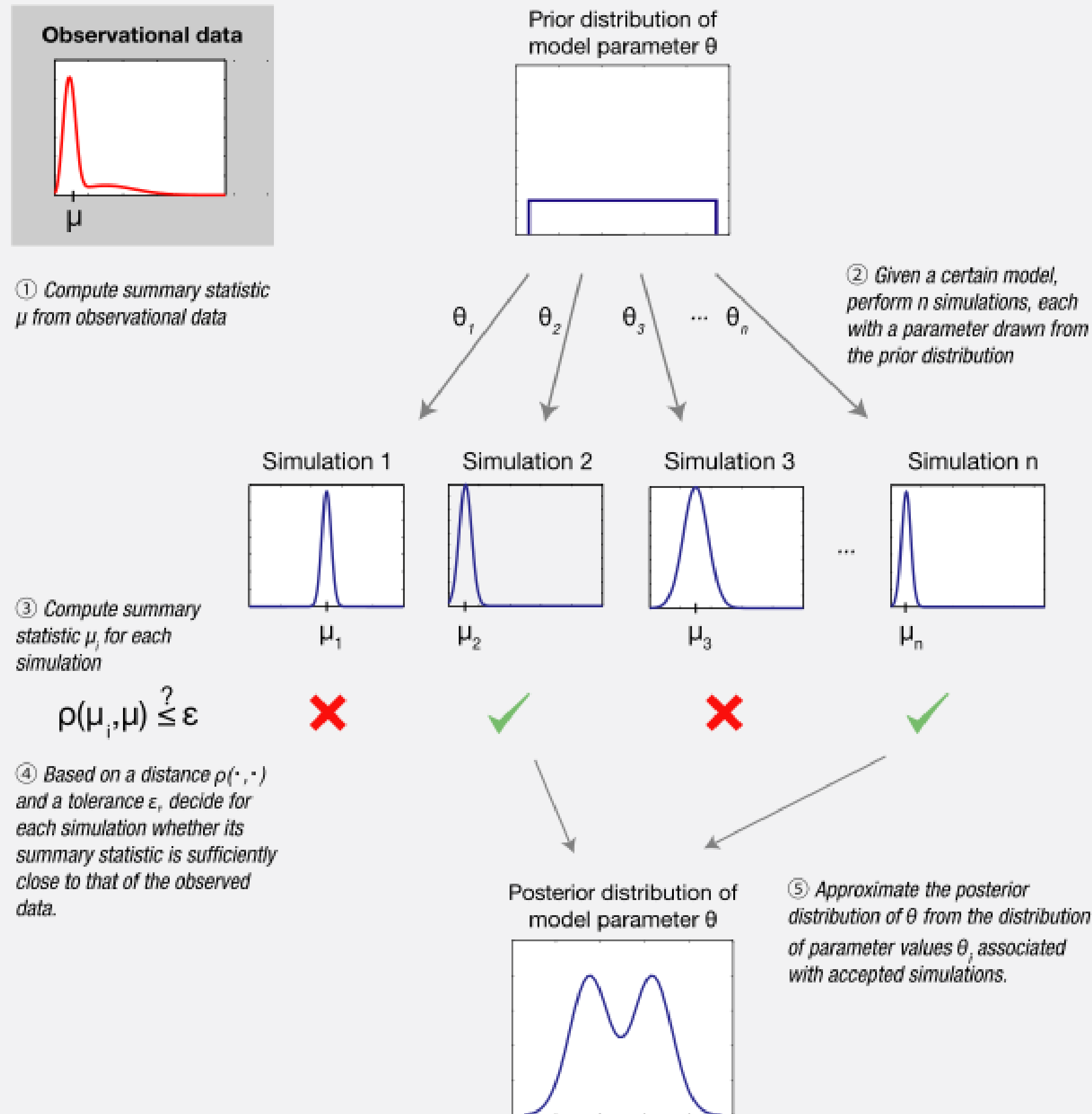
No calibration dataset

Economy meets Culture

(06)

APPROXIMATE BAYESIAN COMPUTATION

Runs the model until parameter values produce output that is similar to the data pattern
The distribution of these parameter values is the posterior



Economy meets Culture

(06)

EXPERIMENT DESIGN

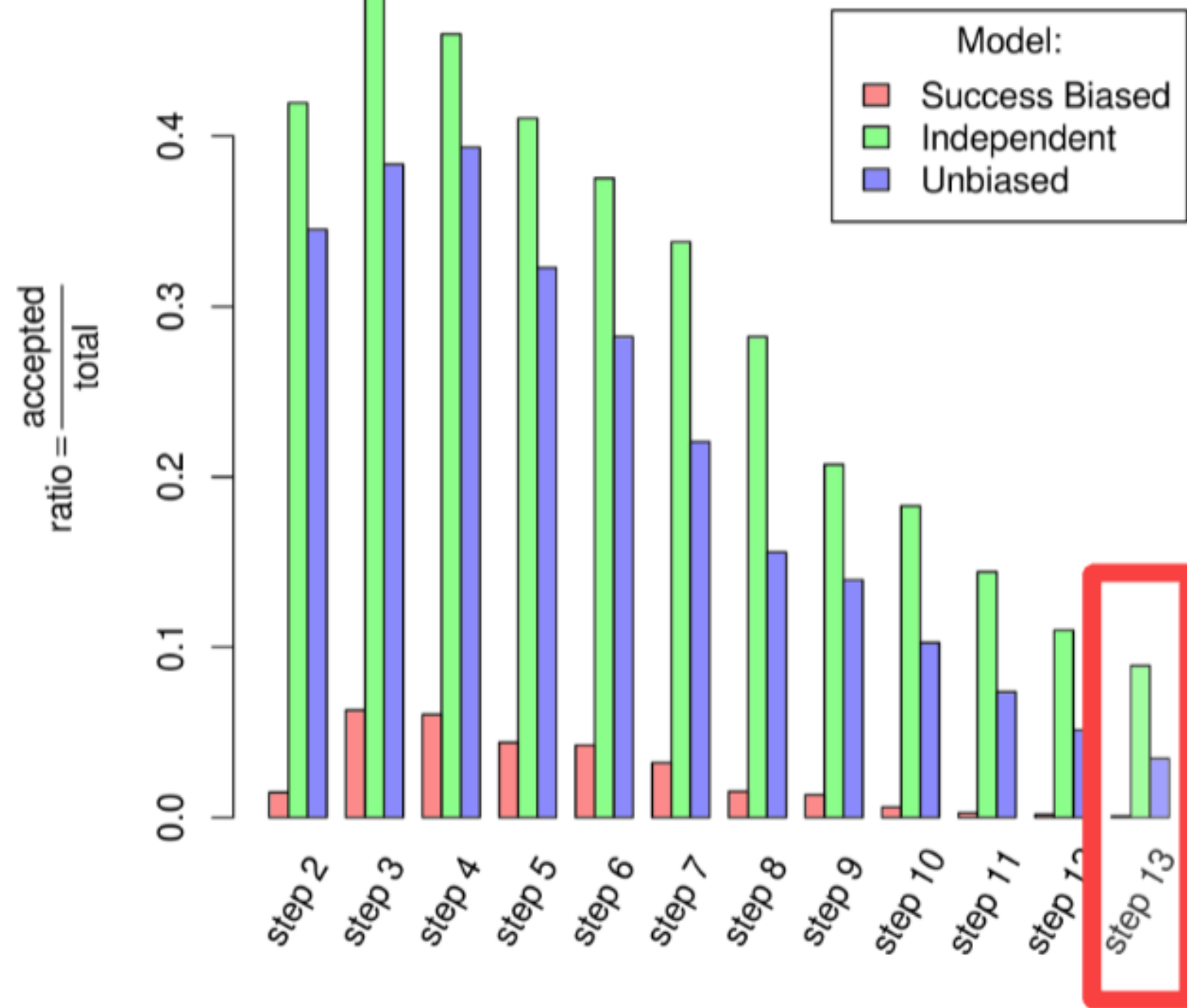
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Parameters	Priors	Description
μ	$U(0, 1)$	rate of innovation
μ_{max}	$U(0, 10)$	variance of innovation
λ	$U(0, 1)$	rate of social learning
λ_{str}	$U(0, 10)$	strength of social learning bias
t	$U^*(50, 1000)$	total number of economic interactions
ω	$U^*(1, 50)$	number of economic interactions per cultural interaction



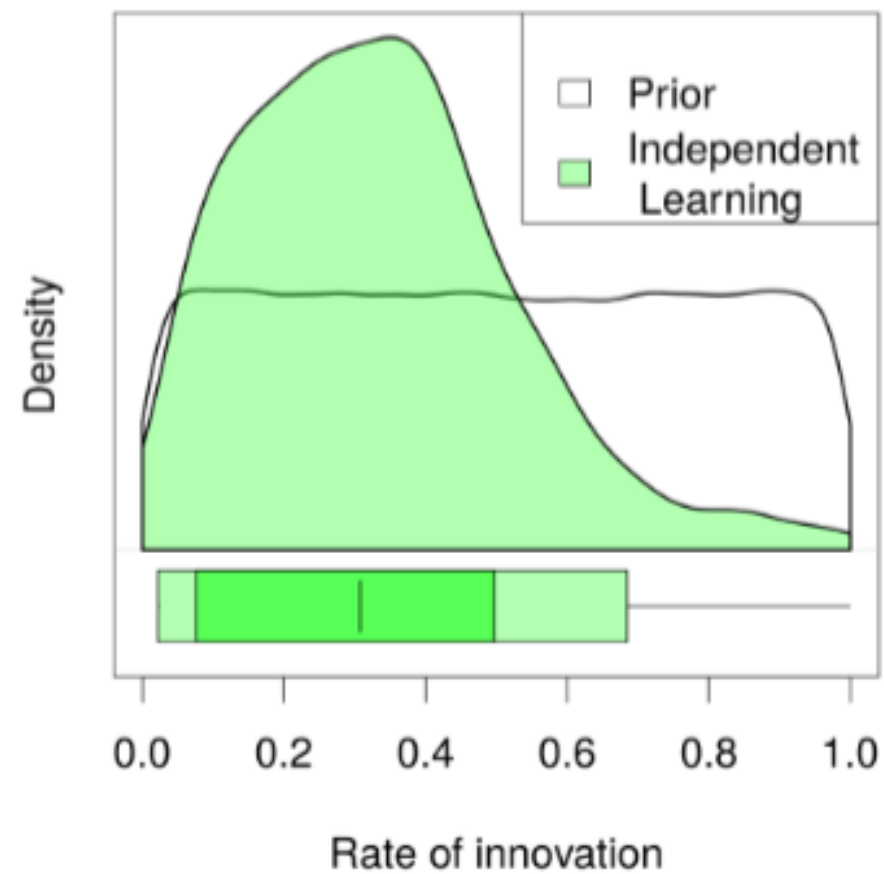
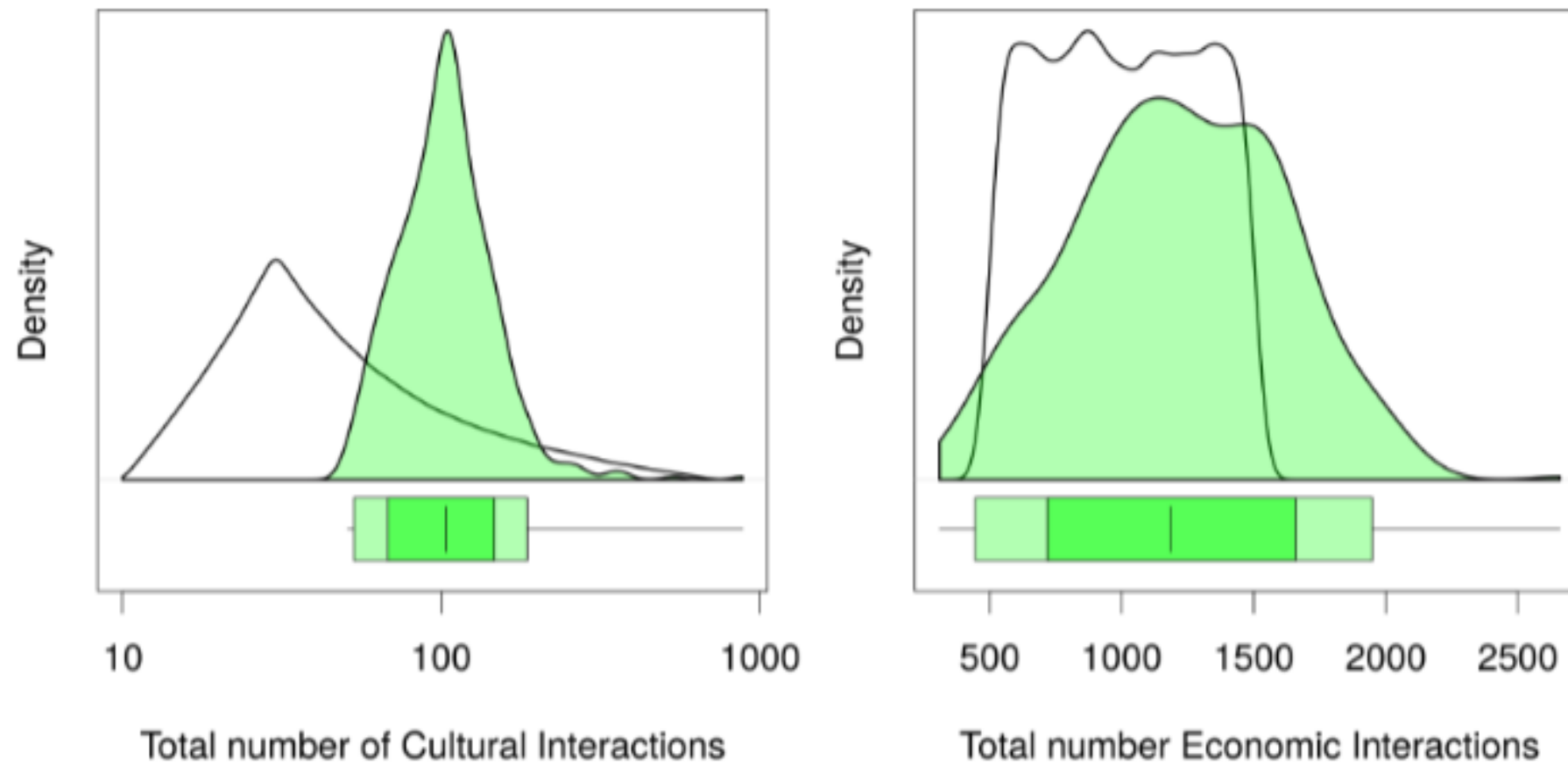
Economy meets Culture

(07)

INDEPENDENT LEARNING

Suggests limited contact and economic integration.

Economy meets Culture

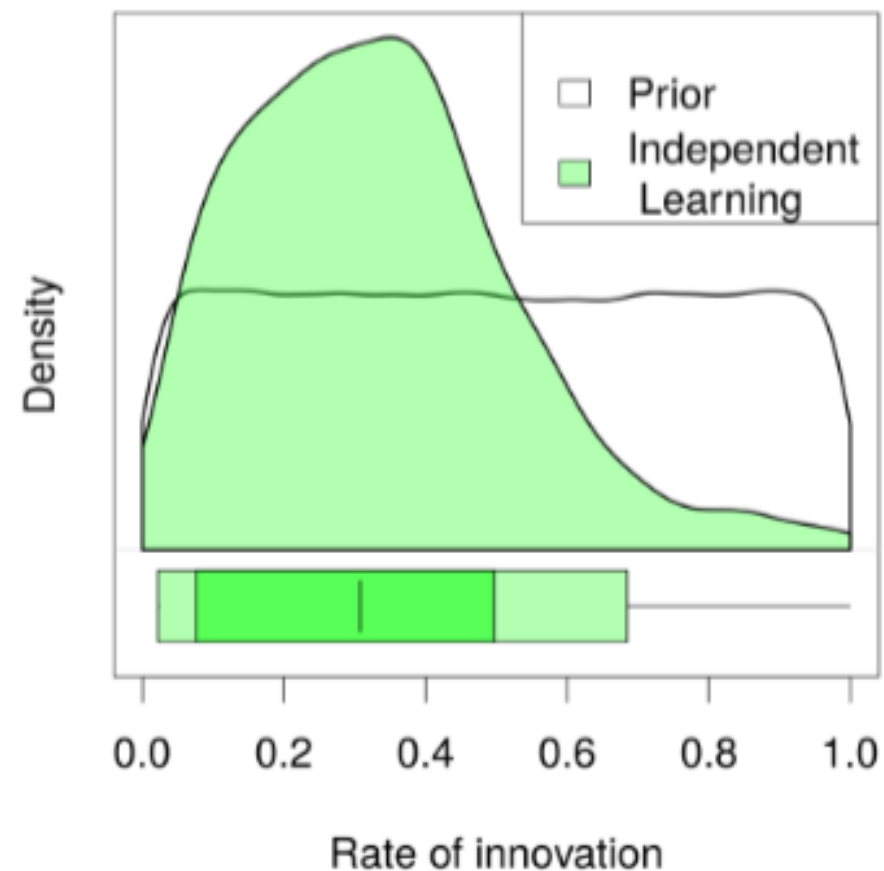
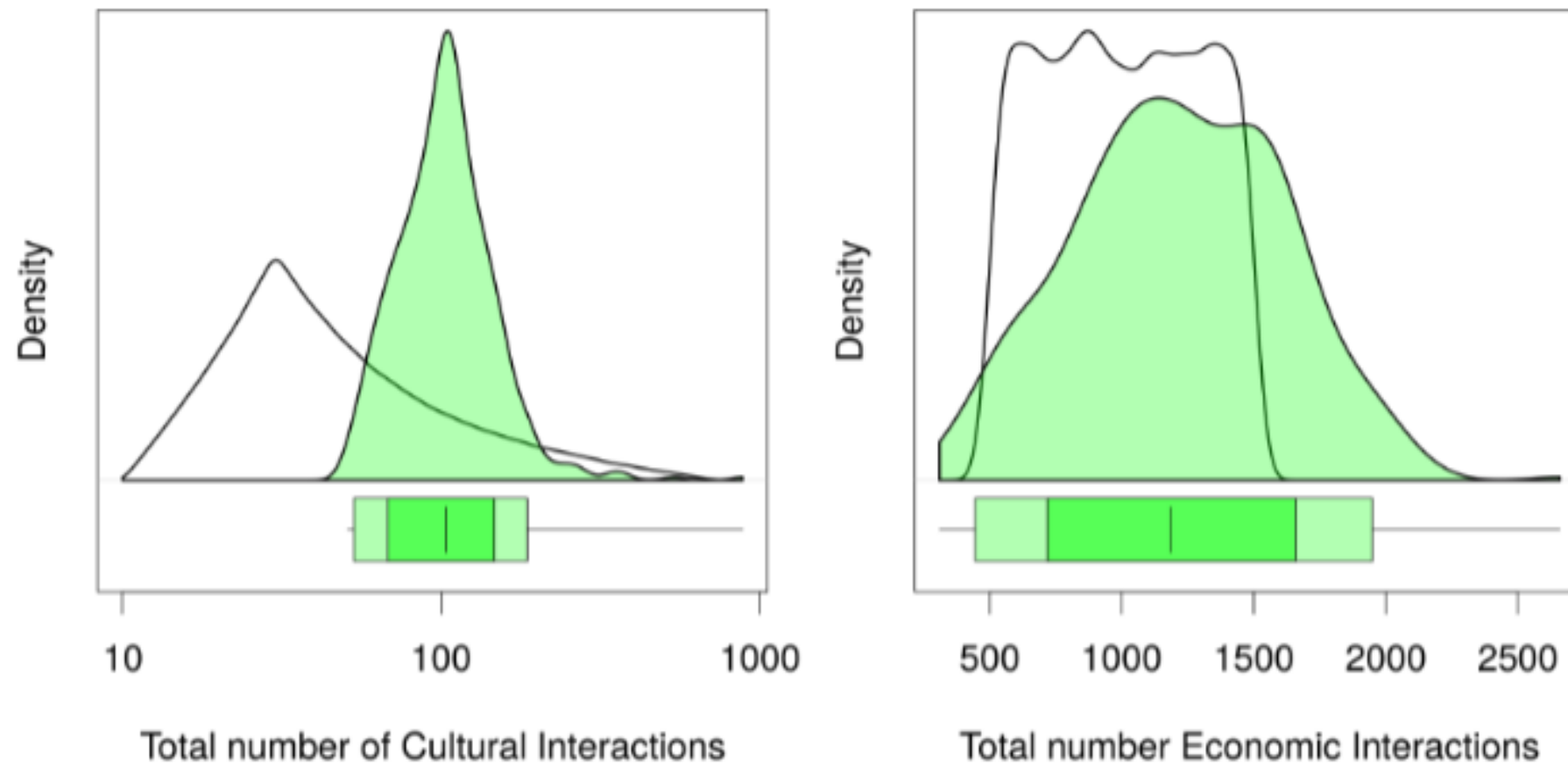


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INDEPENDENT LEARNING

Relatively low rate of innovation, wide range of for the frequency of economic interactions

Economy meets Culture

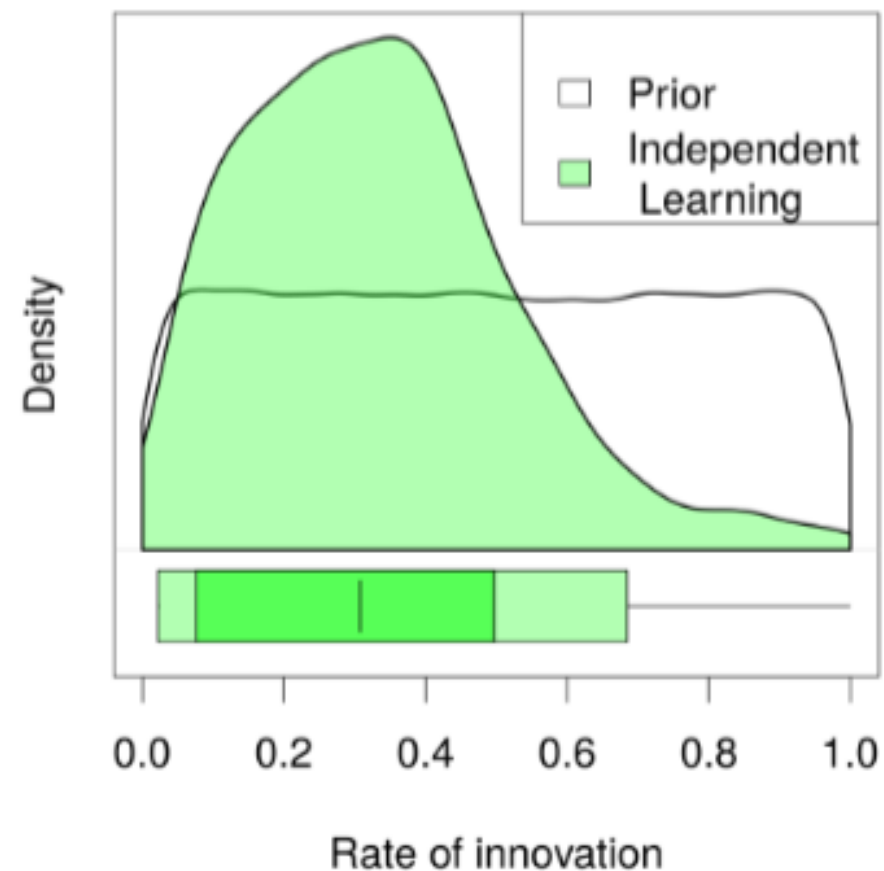
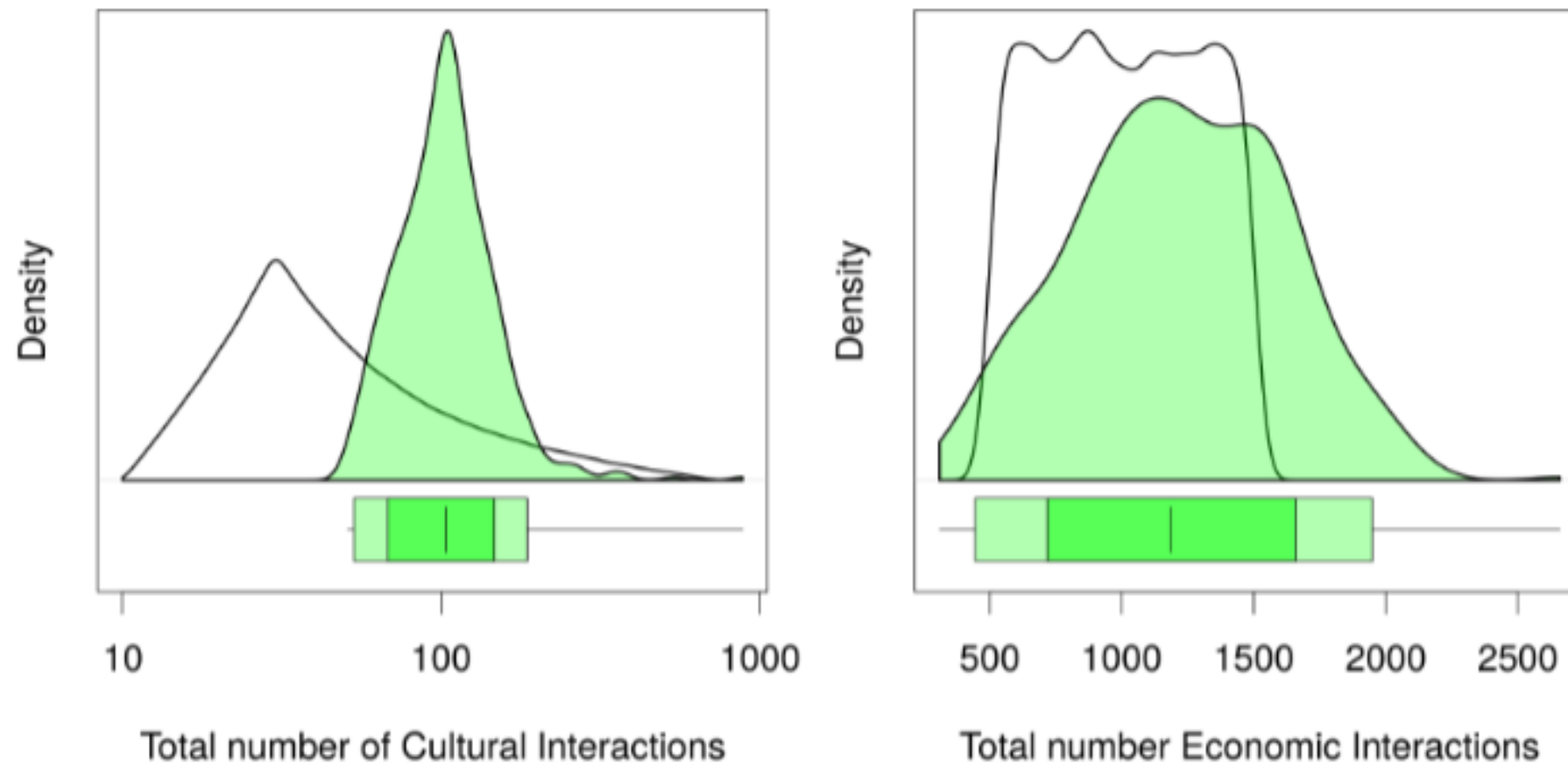


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NUMBER OF ECONOMIC INTERACTIONS

The number of times agents go to the market to buy tableware during the whole simulation. The 75% HDR falls between 750 and 1700 economic interactions, i.e. 1.5 to 3.4 times per year.

Economy meets Culture



(07)

NUMBER OF CULTURAL INTERACTIONS

The number of times agents had the opportunity to copy strategies from other agents. The 75% HDR falls between 63 and 140 cultural interactions, i.e. once every 7.9 to 3.6 years.

OPEN ACCESS PEER-REVIEWED

RESEARCH ARTICLE

Tableware trade in the Roman East: Exploring cultural and economic transmission with agent-based modelling and approximate Bayesian computation

Simon Carrignon , Tom Brughmans, Iza Romanowska

Published: November 25, 2020 • <https://doi.org/10.1371/journal.pone.0240414>



Economy meets Culture

(08)

HIGH PERFORMANCE COMPUTING



Three super- powers of ABM

(08)

**THE PRICE:
EXTREMELY HIGH
COMPUTATIONAL COST**

1

Model definition is intuitive:

- easy to understand dynamics
- familiar entities - important for multidisciplinary projects

2

Enables us to capture emergent phenomena:

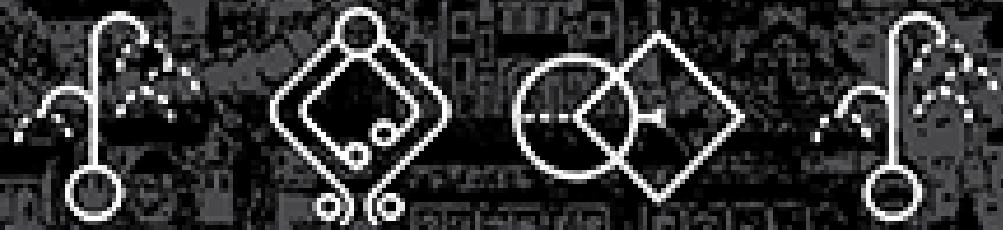
- weakening of standard axioms (full rationality, global knowledge, etc)
- communication, adaptation, evolution

3

Individual agency at the heart:

- heterogeneous population
- local circumstances

ABM how to



[AGENT-BASED MODELING FOR ARCHAEOLOGY]

Simulating the Complexity of Societies

IZA ROMANOWSKA
COLIN D. WREN
STEFANIA CRABTREE

(09)

AGENT-BASED MODELLING FOR ARCHAEOLOGY:
SIMULATING THE COMPLEXITY OF SOCIETIES.
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Get in touch

@IZA_ROMANOWSKA

IROMANOWSKA@AIAS.AU.DK

GOOGLE SCHOLAR
ACADEMIA.EDU
RESAERCHGATE



AIAS
aias.au.dk/aias-fellows/iza-romanowska/

