what to do when …

Individuals' attributes are heterogeneous

Individuals' interactions are complex, nonlinear, discontinuous, or discrete

Agents exhibit complex behaviour, including learning and adaptation

Topology of the interactions is heterogeneous and complex (social networks are rarely homogeneous, but clustered)

Space is crucial and the agents' positions are not fixed

Analytical approaches often fail at this level of complexity

Agent-based simulations are capable of studying this complexity at the cost of generality that analytical methods provide

BUT: ABM and analytical methods do not oppose but complement each other

what are agent-based simulations?

definition and aim of ABM

Rule-based computational modelling

Based on dynamic interactions among agents/individuals

Goal of Agent-based simulations

Model **components** of a **system** and simulate their **interactions**, which are based on a pre-defined set of rules

Gain insight into **collective behaviour** of agents following simple rules

what are agent-based simulations?

Modularity

Individuals can be added and removed from system

Rules can easily be changed without changing entire model

Complexity

Allows complex low level interactions, and changes to agents and environment

Emergence

Local interactions among agents can lead to higher level patterns

what are examples for agent-based simulations?

Ecosystem and natural-resource management

Land-use and agricultural policy

Control disease outbreaks

Marketing

Private-sector logistics and strategy

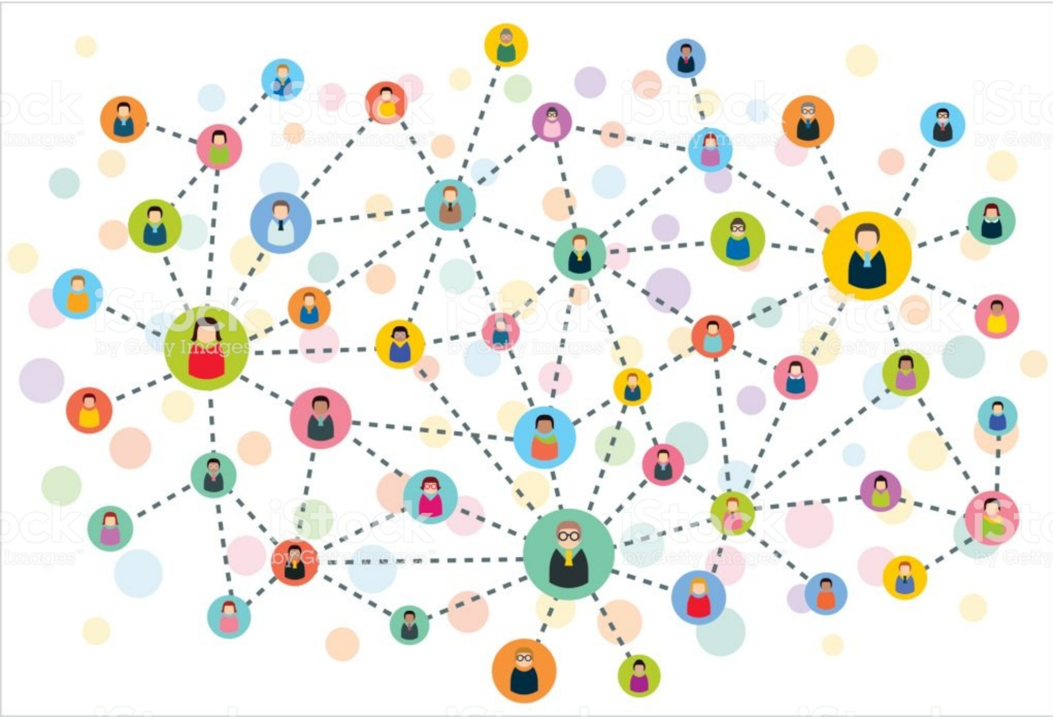
Stock exchange

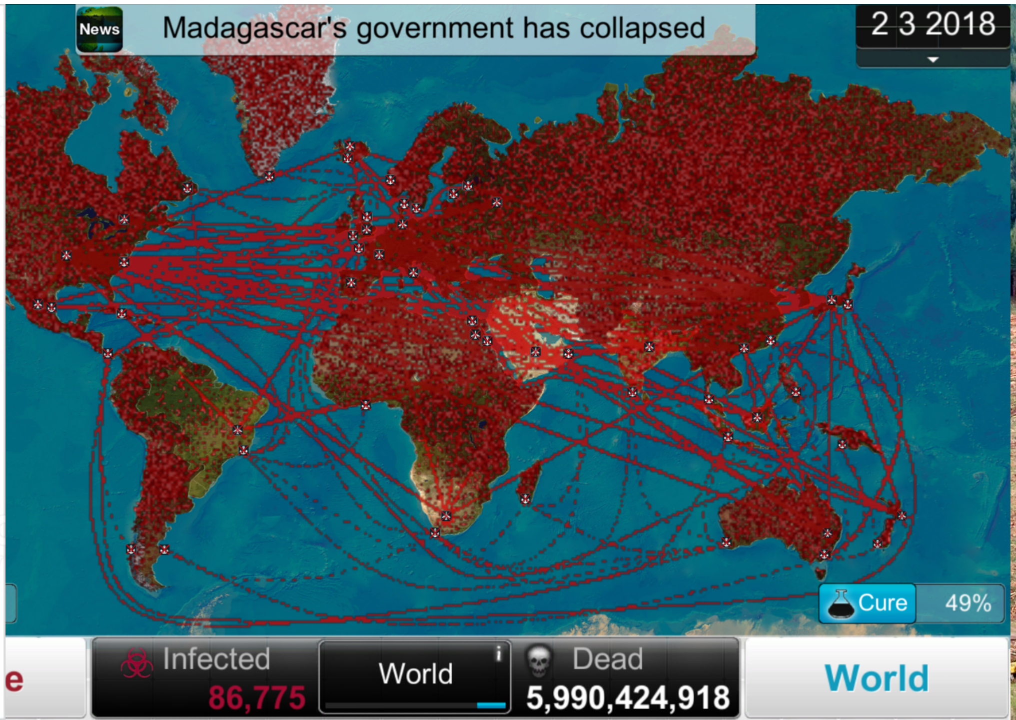
Electoral design

Social media dynamics

Emergency escape planning

Traffic planning





what are examples for agent-based simulations?

- Ecosystem and natural-resource management
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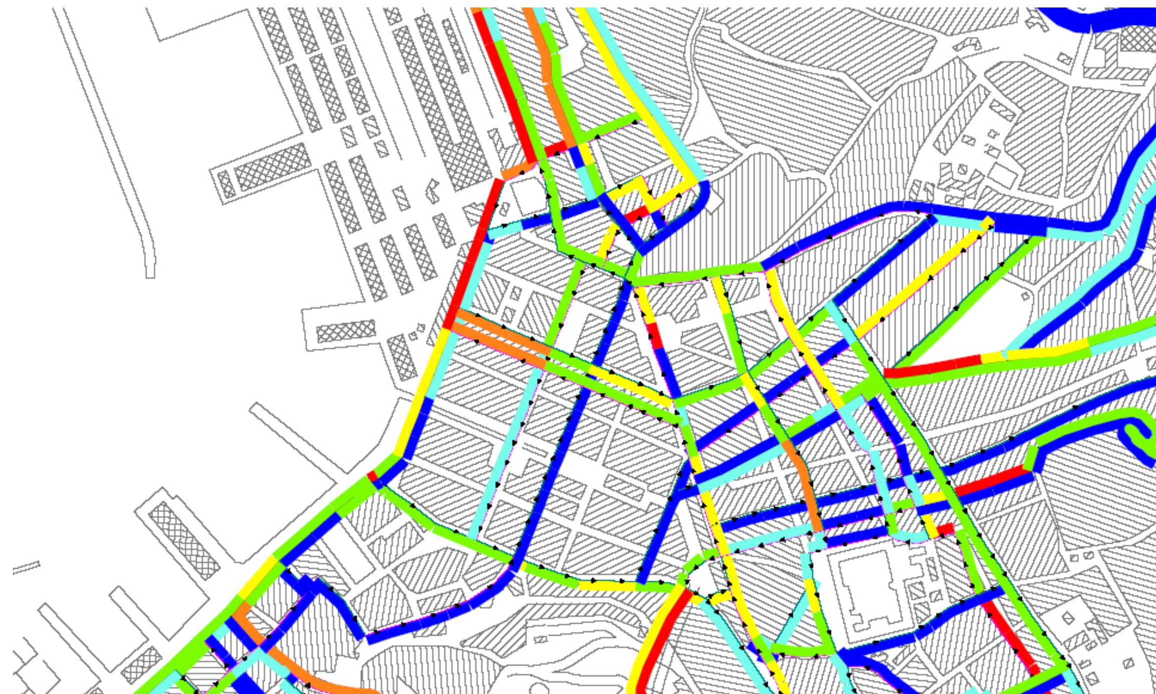

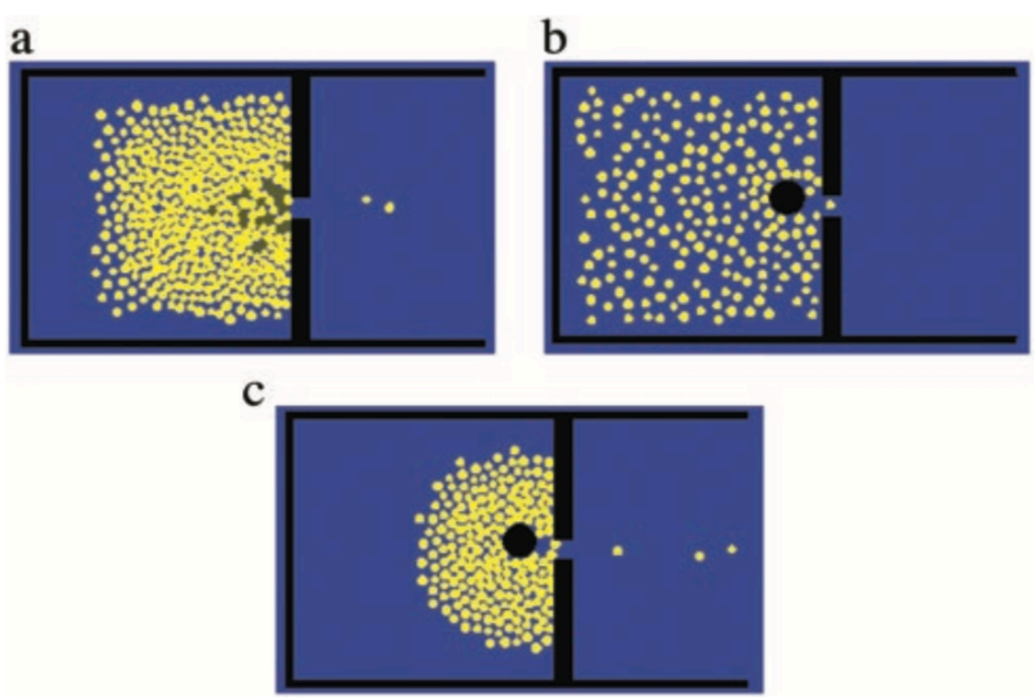

what are the components of an agent-based model?

Properties, Actions, Rules, Time, and Environment

Agents	Context

Properties
what defines the individual? (age, sex, size, wealth, etc.)
are these properties fixed or can they change throughout simulation?

Actions
what can the individual do? (move, eat, communicate or learn from neighbour)
do activities affect only the individual, or also neighbours and the environment?

Rules
based on environmental input, or time, or others' states or behaviours?

Time
the unit in which rules, actions, and changes in agent properties or the environment occur
can be fixed for all components, or vary e.g. spread of information in a network versus the change in the network topology

Environment
structure of the environment (e.g. lattice, ring, torus, checkerboard)
can change over time (e.g. turnover of quality of resources patches)

(Hammond, 2015)

looking at an example in more detail

(http://anoved.net/2010/05/working-on-a-model-of-flocking-behavior/)

looking at an example in more detail

flocking behaviour

Emergent pattern appears complex, however, it can be explained with relatively simple heuristics as shown in various agent-based models.

looking at an example in more detail

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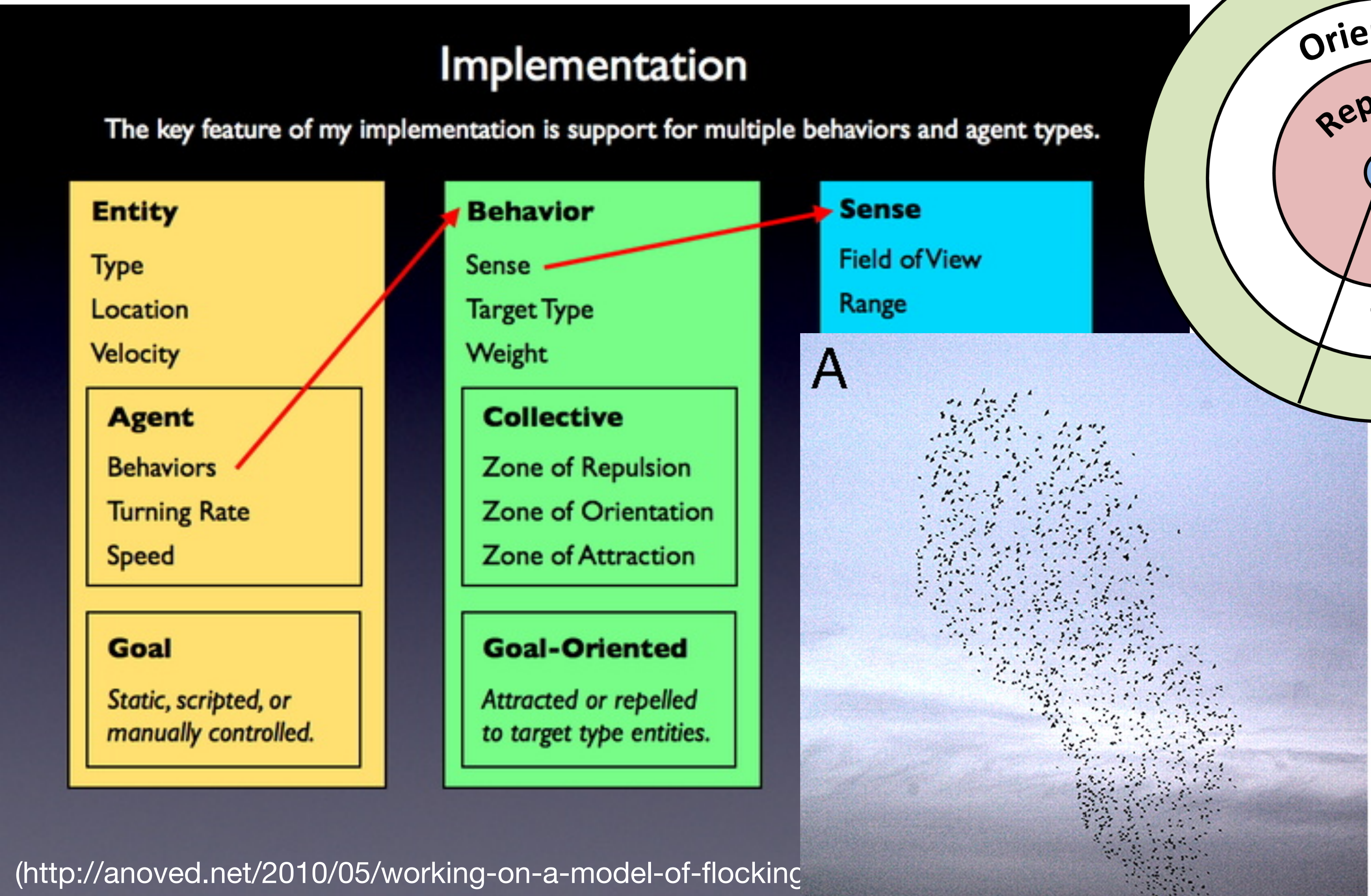
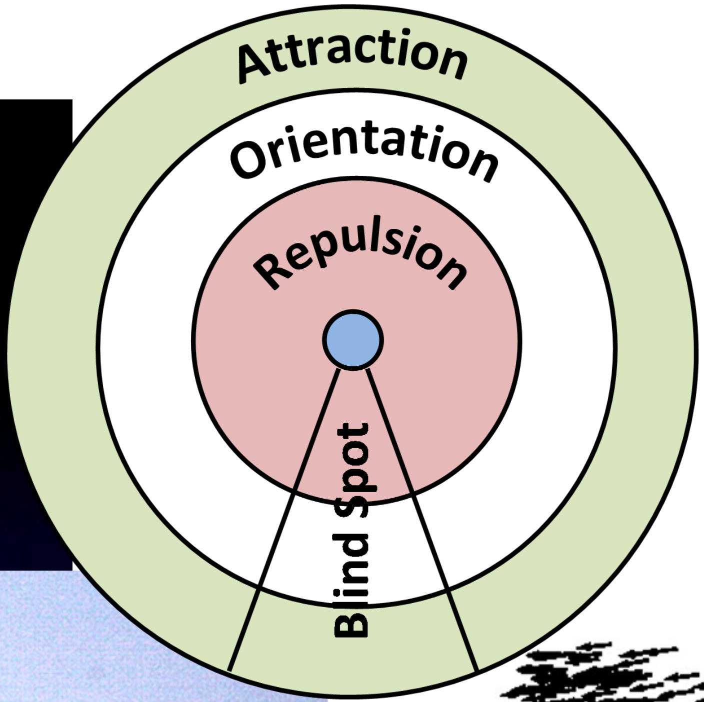
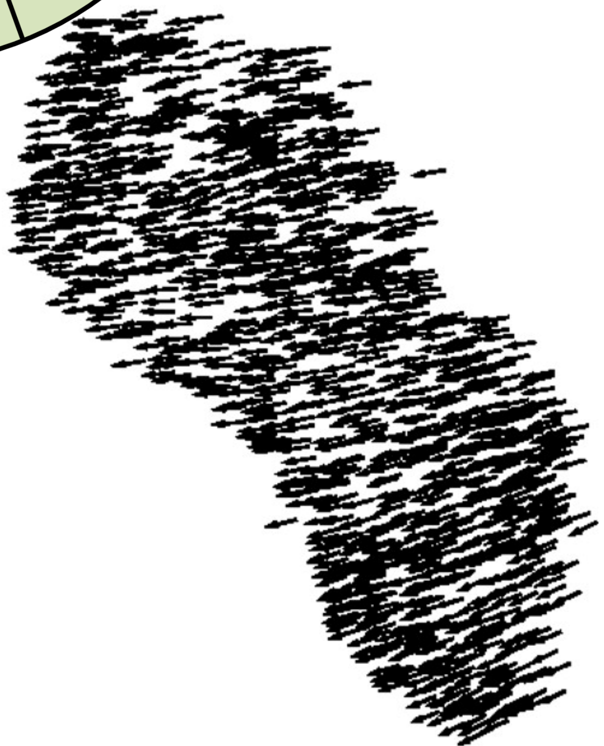






(http://anoved.net/2010/05/working-on-a-model-of-flocking

developing an abm

1. **Define question and goal of the simulation model**
2. **Model scope and conceptual design**
   informed choice of key concepts, structures, relationships (from literature)
3. **Model specification**
   decisions on how to implement components from step 2 in a simulation model
4. **Model implementation**
   translating concepts and components into a executable program and run with test parameters
5. **Analysis**
   1. **Testing, calibration, debugging**
      check whether model behaves as expected and adjust if necessary
   2. **Designing experiments and conducting analysis**
      use model to test hypothesis
   3. **Sensitivity analysis**
      sweep parameter space to identify where small changes in parameter values can cause drastic changes in model outcomes and to test the effect of assumptions that have been made during model design
6. **Synthesis and reporting**
   compile statistical analysis and visualisations

(Hammond, 2015)

exemplary case study on social learning

competition effects on social and individual learning

when is social learning adaptive?

Social Learning Strategies Tournament

Rendell et al., 2010

winning strategy: almost only social learning

?

sometimes individuals rely less on social information even when available

honeybees

Grüter et al. 2008

goats

Baciadonna et al. 2003

guppies

Kendal et al. 2004

can resource competition explain the pattern?

Smolla M, Gilman RT, Galla T, Shultz S. 2015 **Competition for resources can explain patterns of social and individual learning in nature.** *Proc. R. Soc. B* 282: 20151405. http://dx.doi.org/10.1098/rspb.2015.1405

producer-scrounger game

learning in a foraging context

Patches with different payoffs Q

Individual learner

Information producer

Social learner

Information scrounger

10,000 rounds
100 individuals
100 patches
0.01 turnover rate

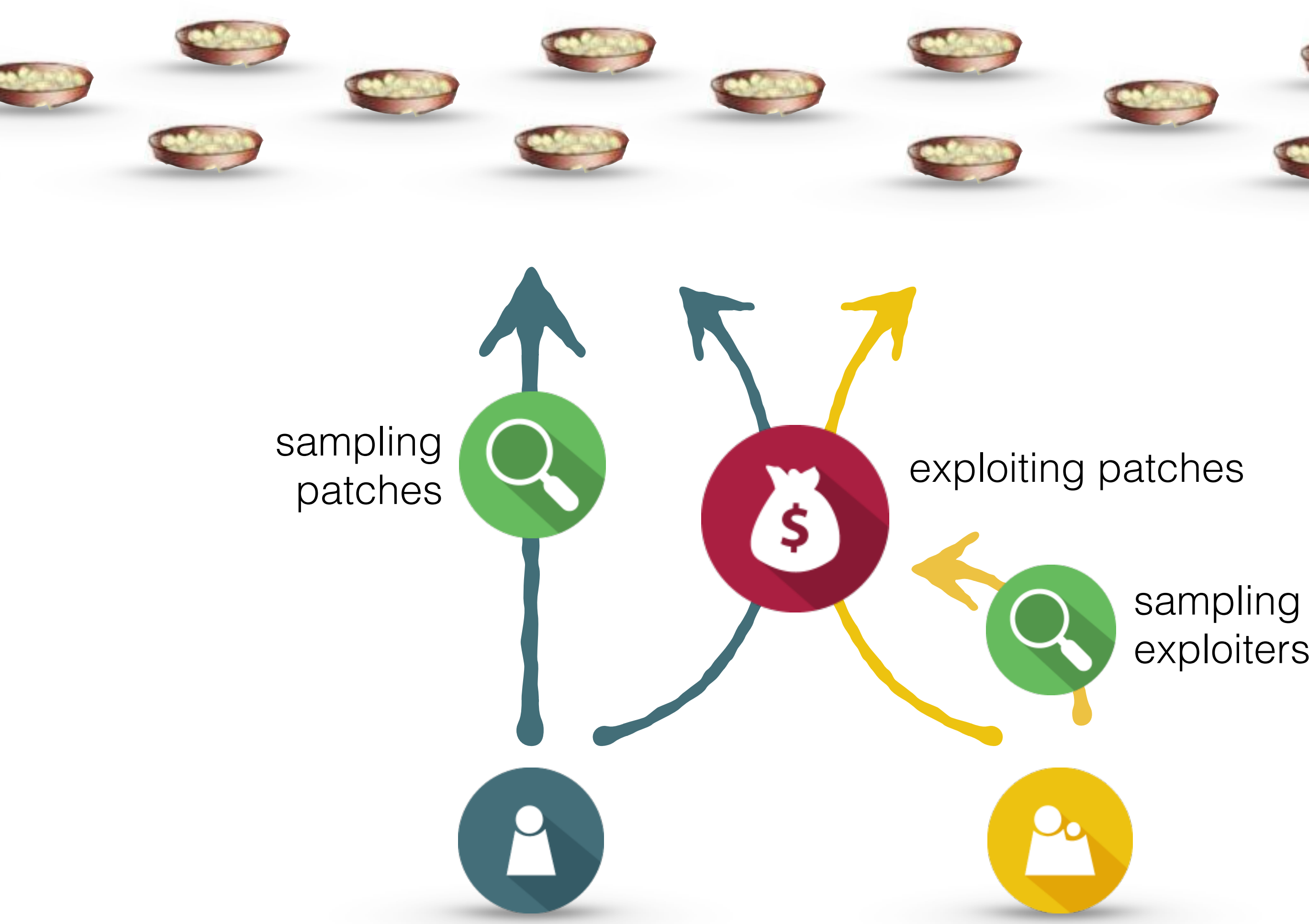
Why use an ABM approach?

- Learning (innovation & imitation)
- Memory
- Local interactions

producer-scrounger game

learning in a foraging context

Patches with different payoffs Q

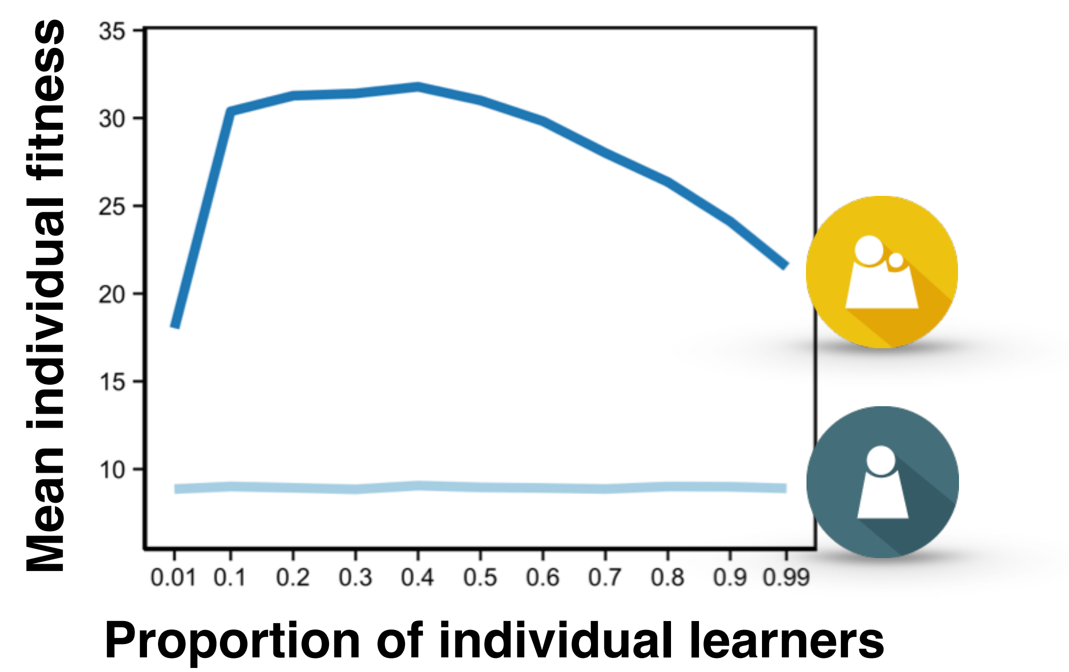


Individual learner

Information producer

Social learner

Information scrounger



free-riding social learners always dominate individual learners

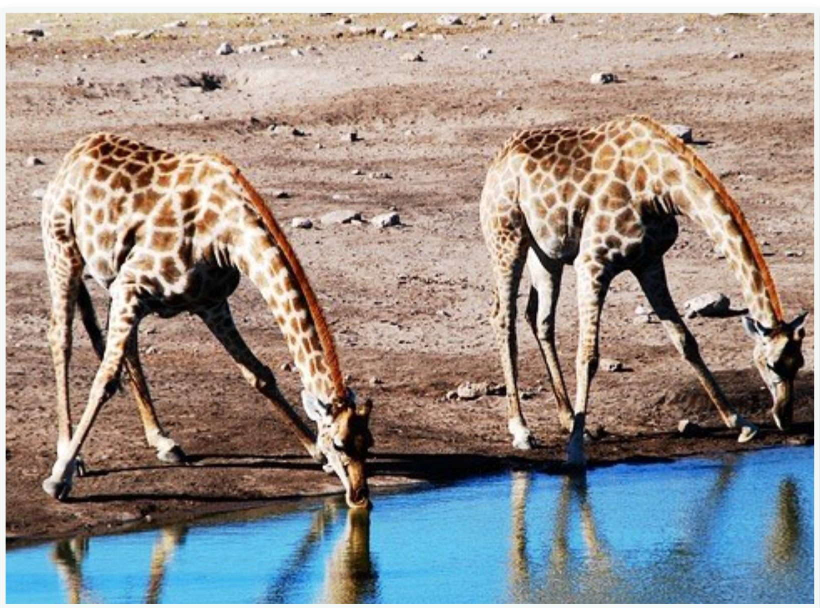
10,000 rounds
100 individuals
100 patches
0.01 turnover rate

resource competition

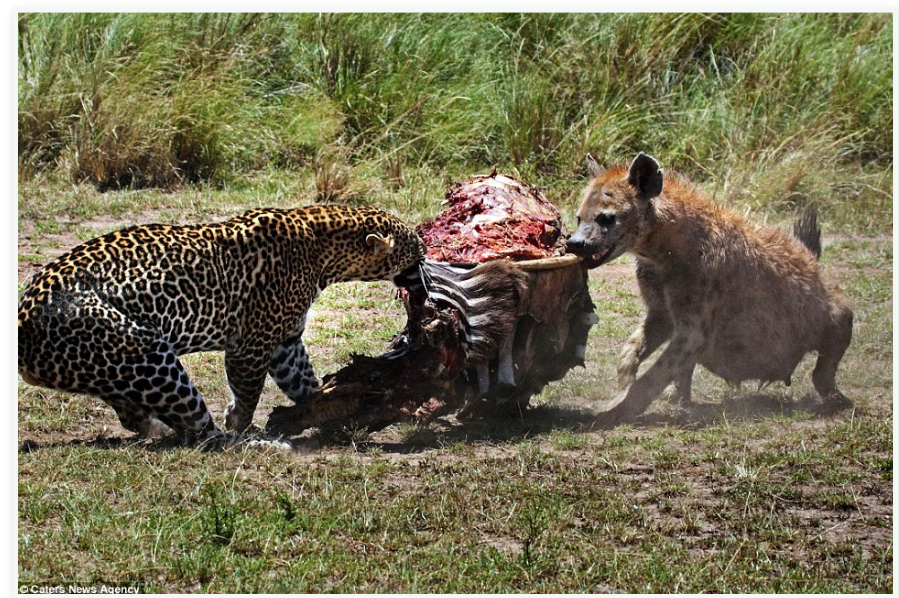
how to formalise competition?

Q amount of accessible resources in a patch

no competition



competition

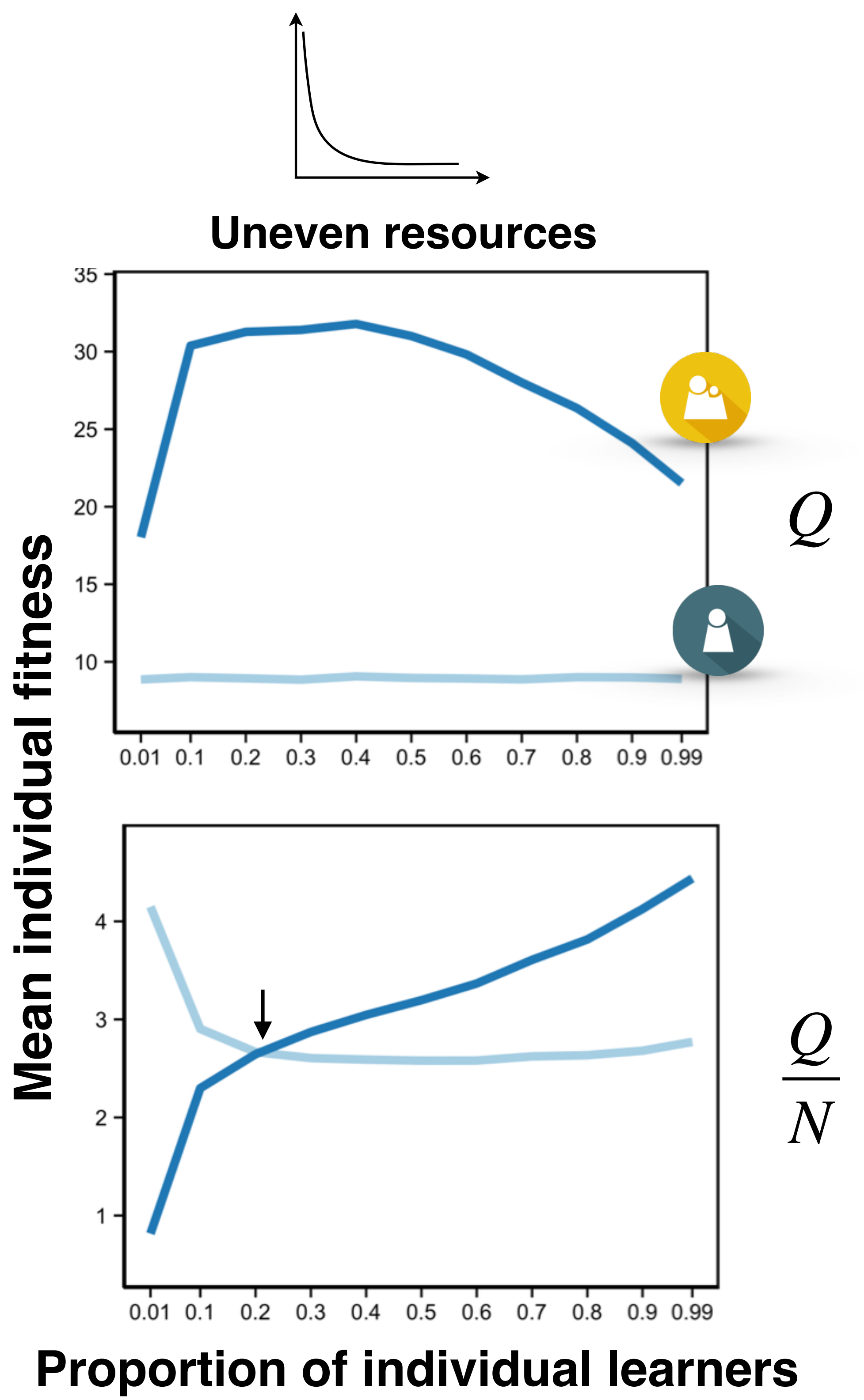


a single individual receives

Q

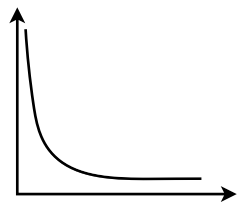
$\frac{Q}{N}$ (number of individuals in patch)

effect of competition

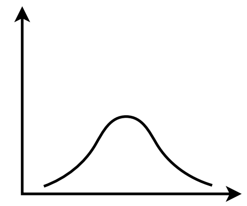


finding the stable state between two strategies

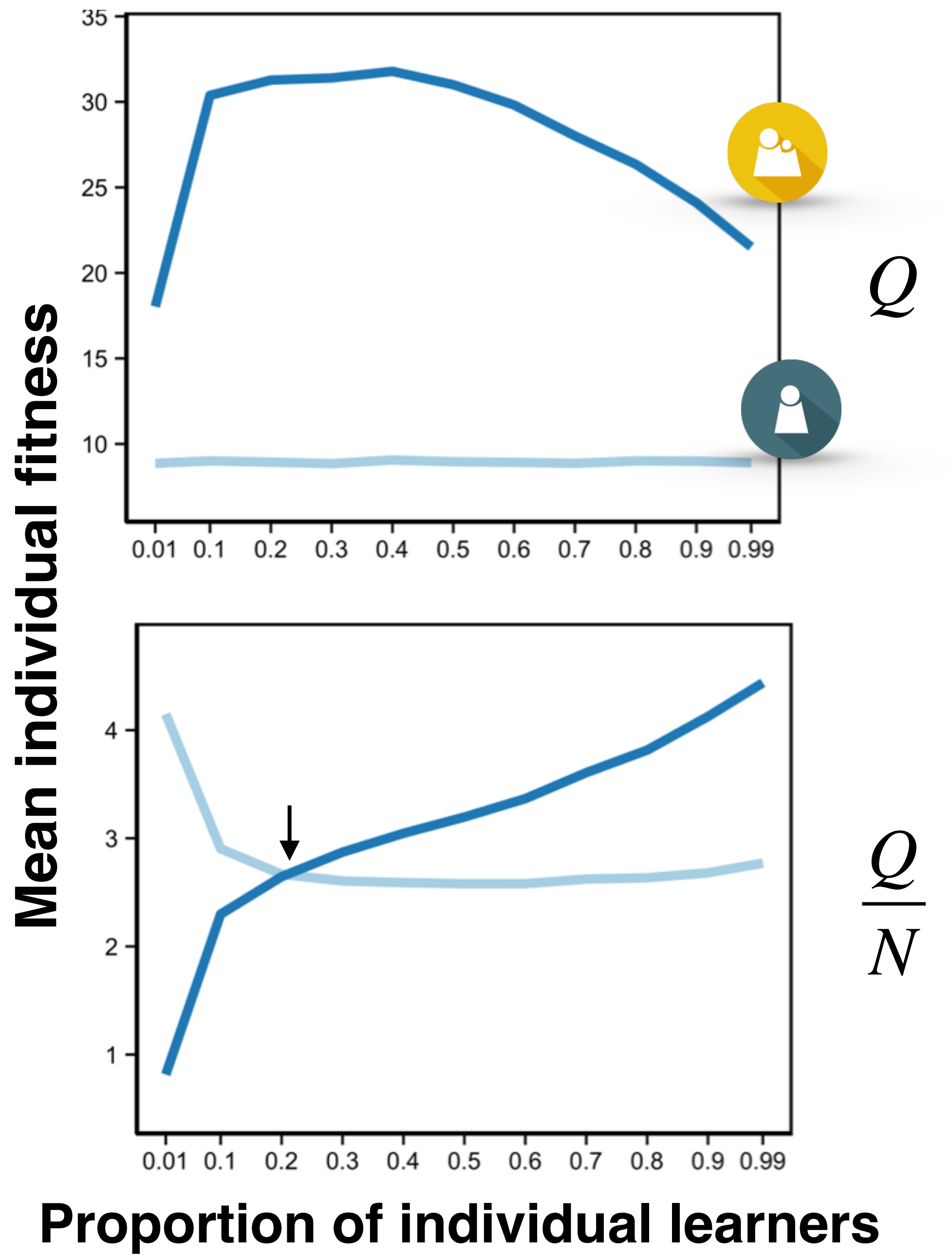
effect of competition



Uneven resources

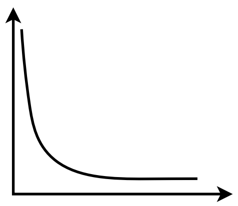


Even resources



finding the stable state between two strategies

effect of competition



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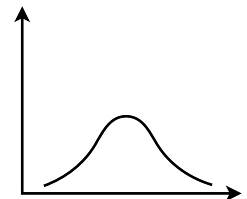
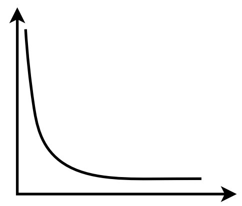


Even resources

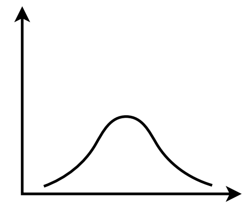
Proportion of individual learners

finding the stable state between two strategies

effect of competition

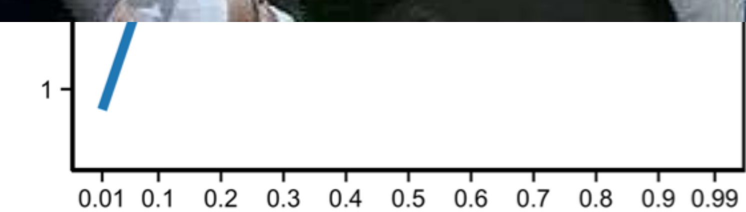


Uneven resources



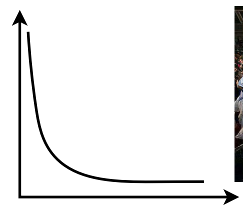
Even resources

finding the

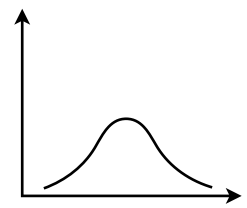


Proportion of individual learners

effect of competition



Uneven resources



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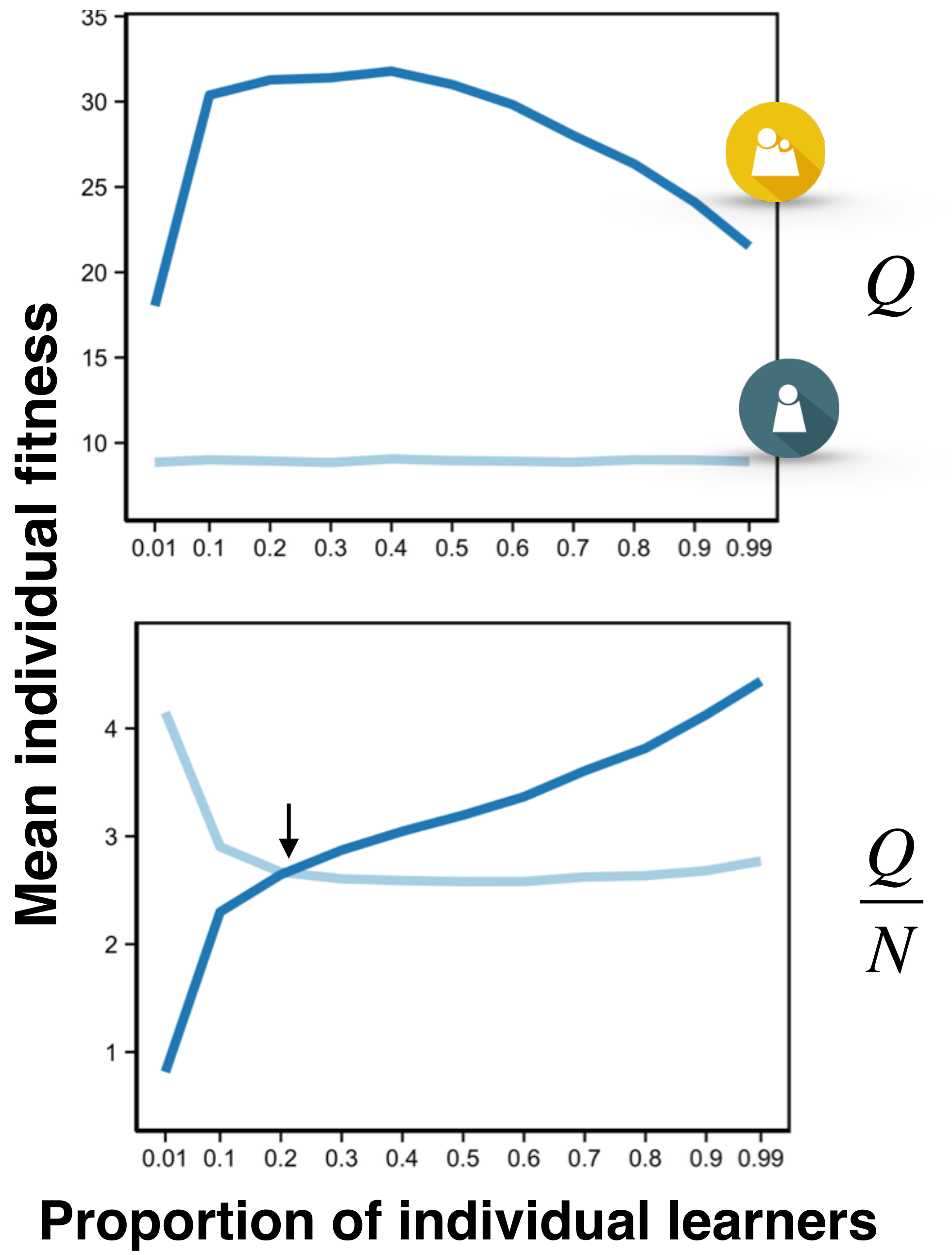
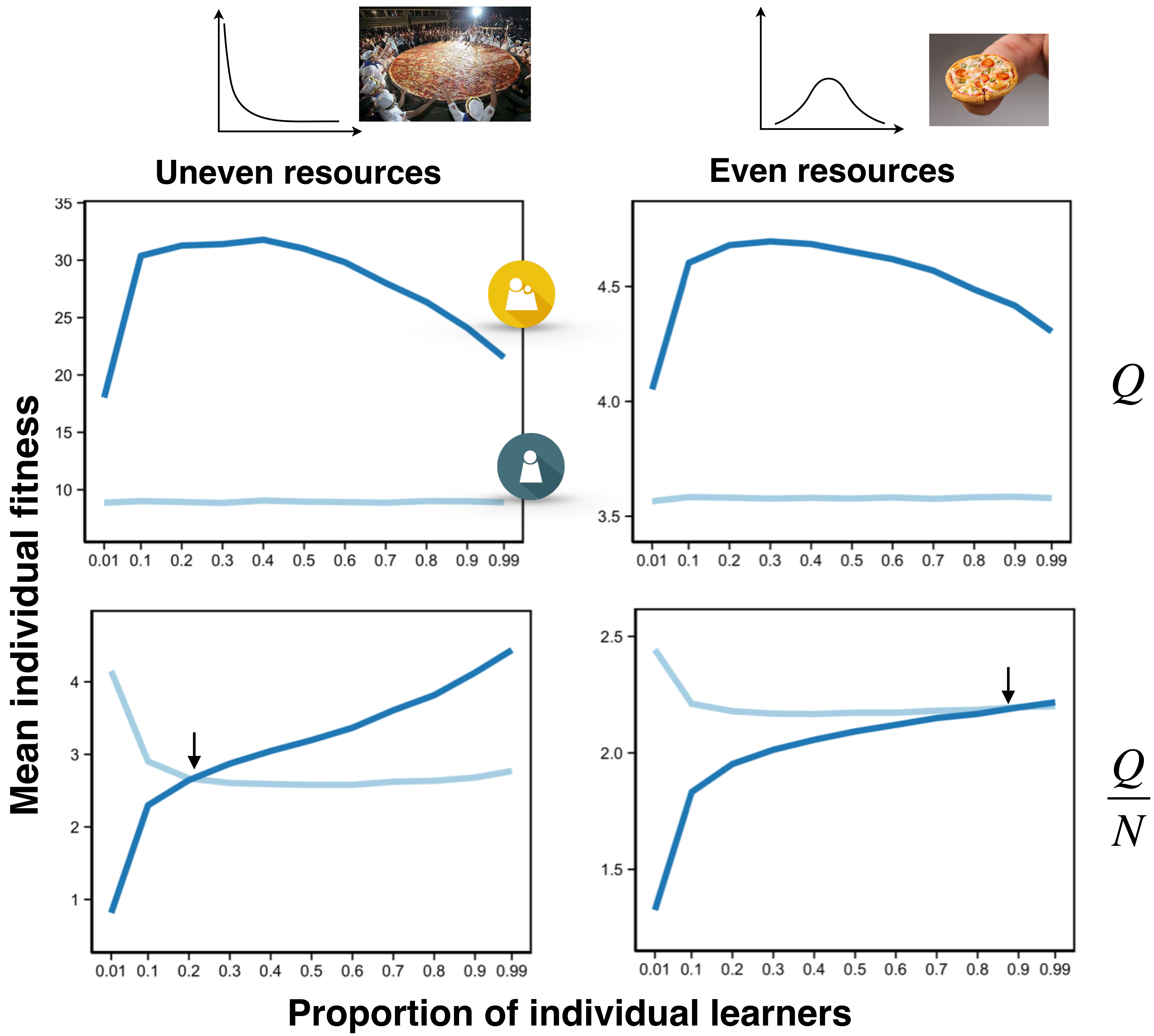


finding the stable state between two strategies

effect of competition

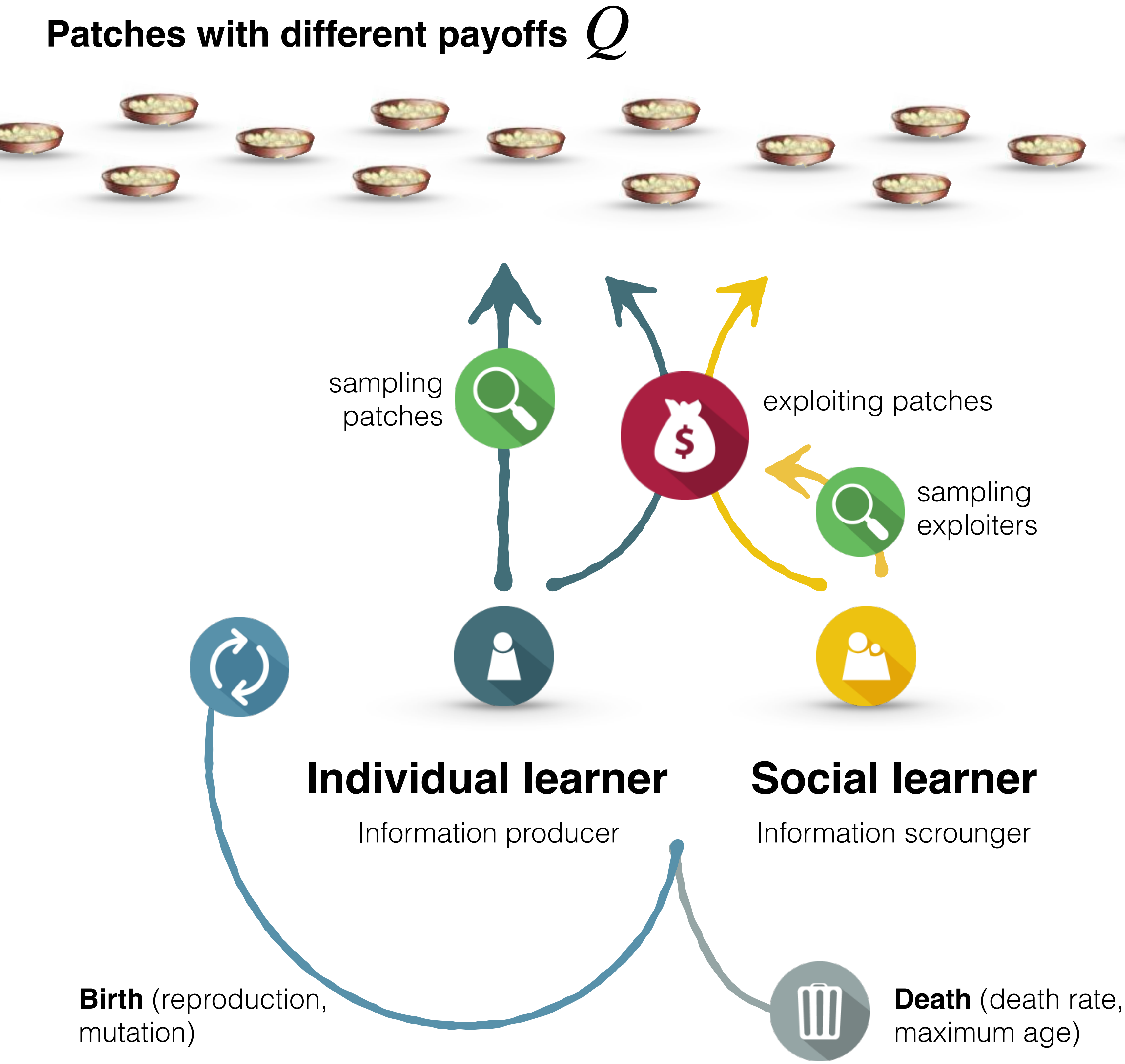


finding the stable state between two strategies

the stable state is affected by the **payoff distribution**

evolving producer-scrounger game

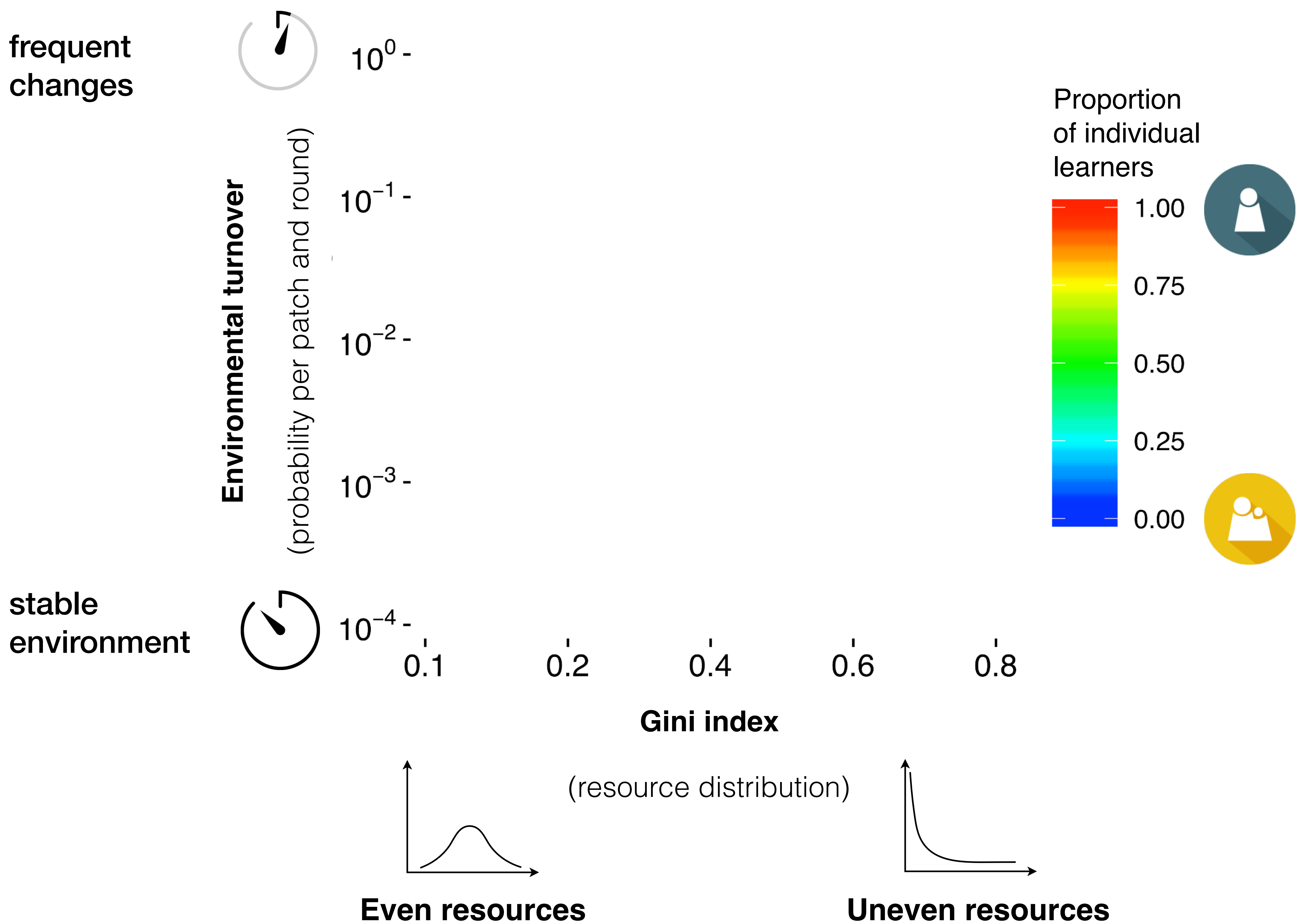
evolutionary model to find strategy equilibrium



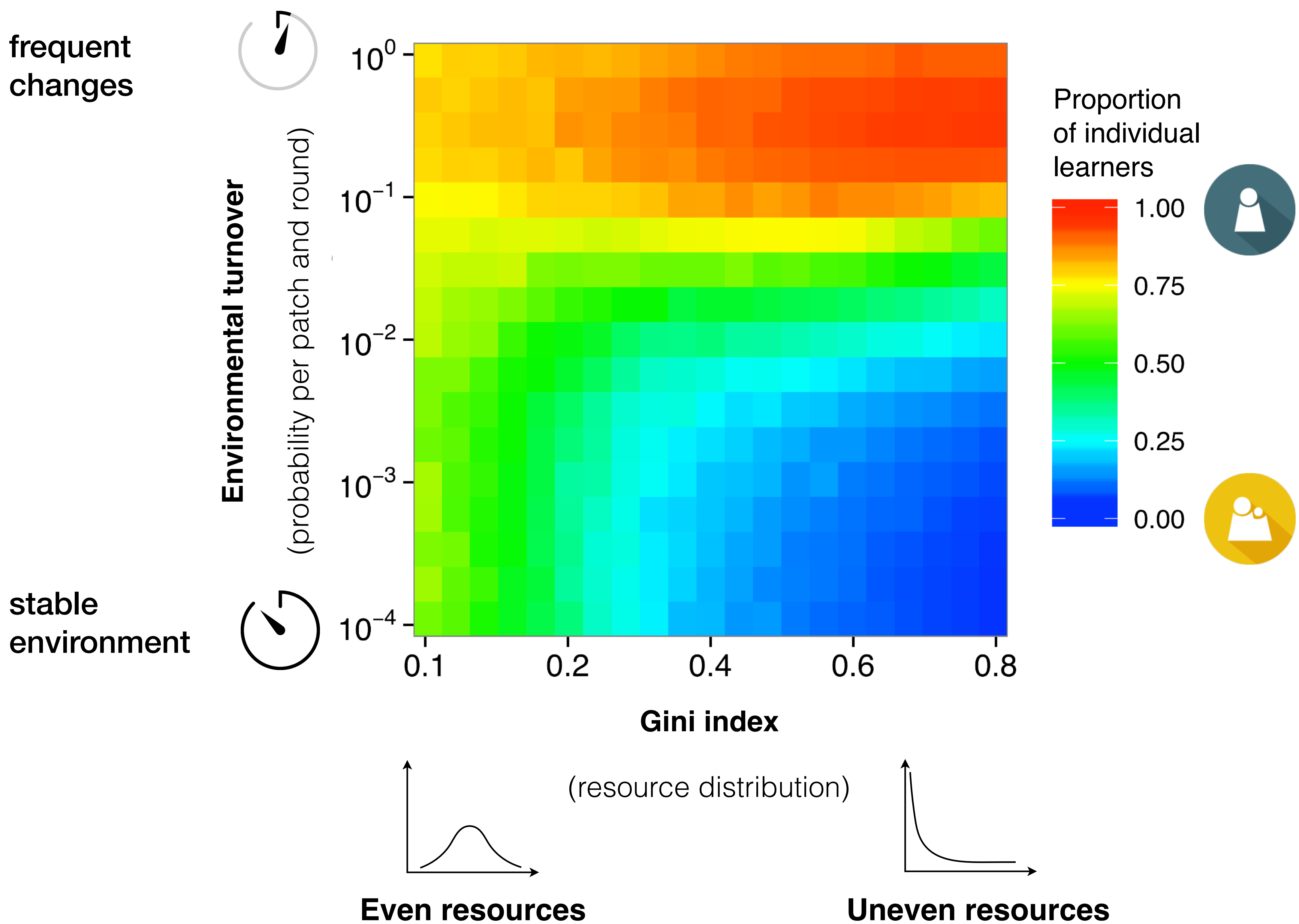
10,000 rounds
100 individuals
100 patches
0.01 turnover rate
0.02 death rate
0.01 mutation rate

effect of the environment

a wide range of environmental parameters in an evolving system



effect of the environment



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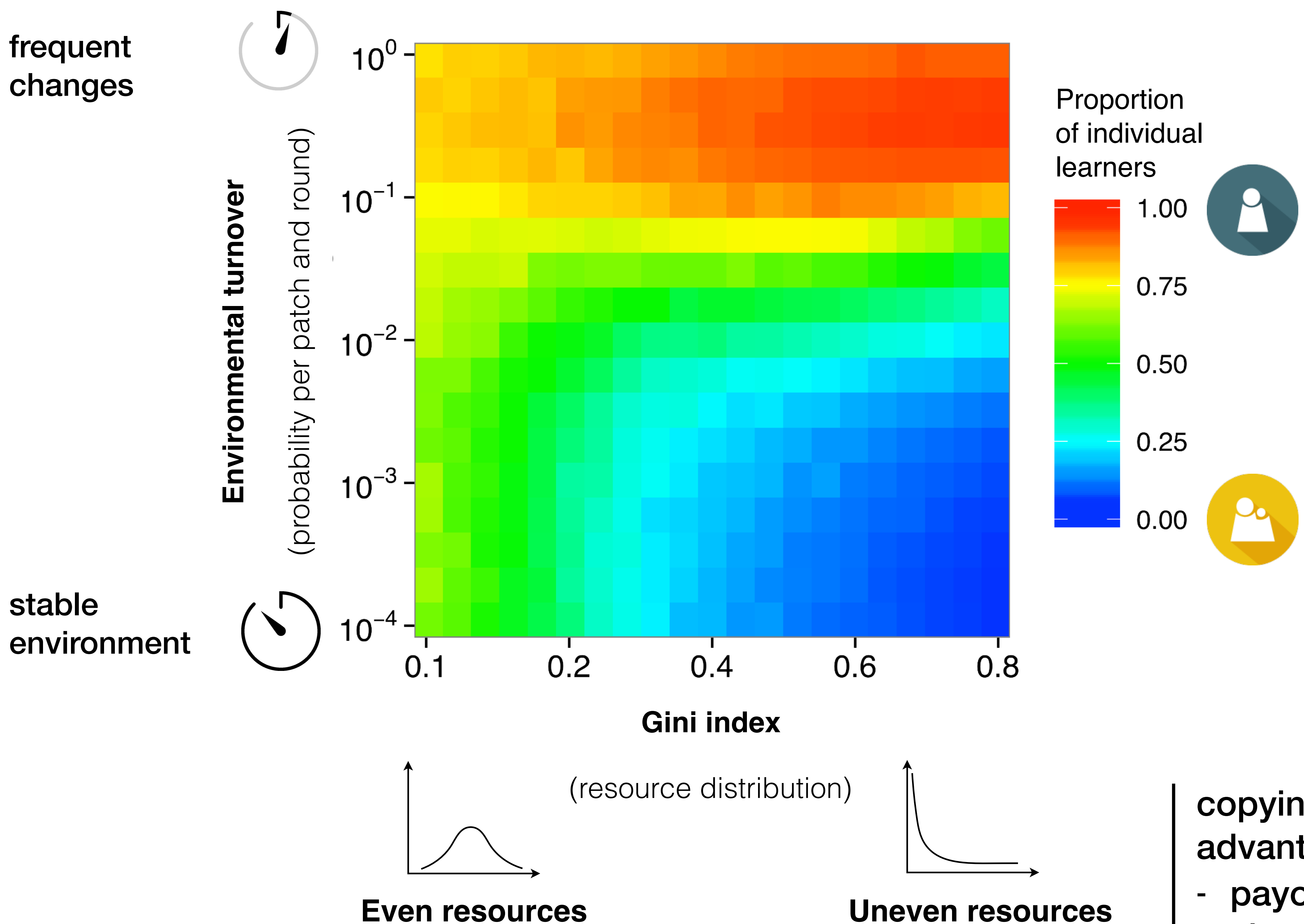
effect of the environment



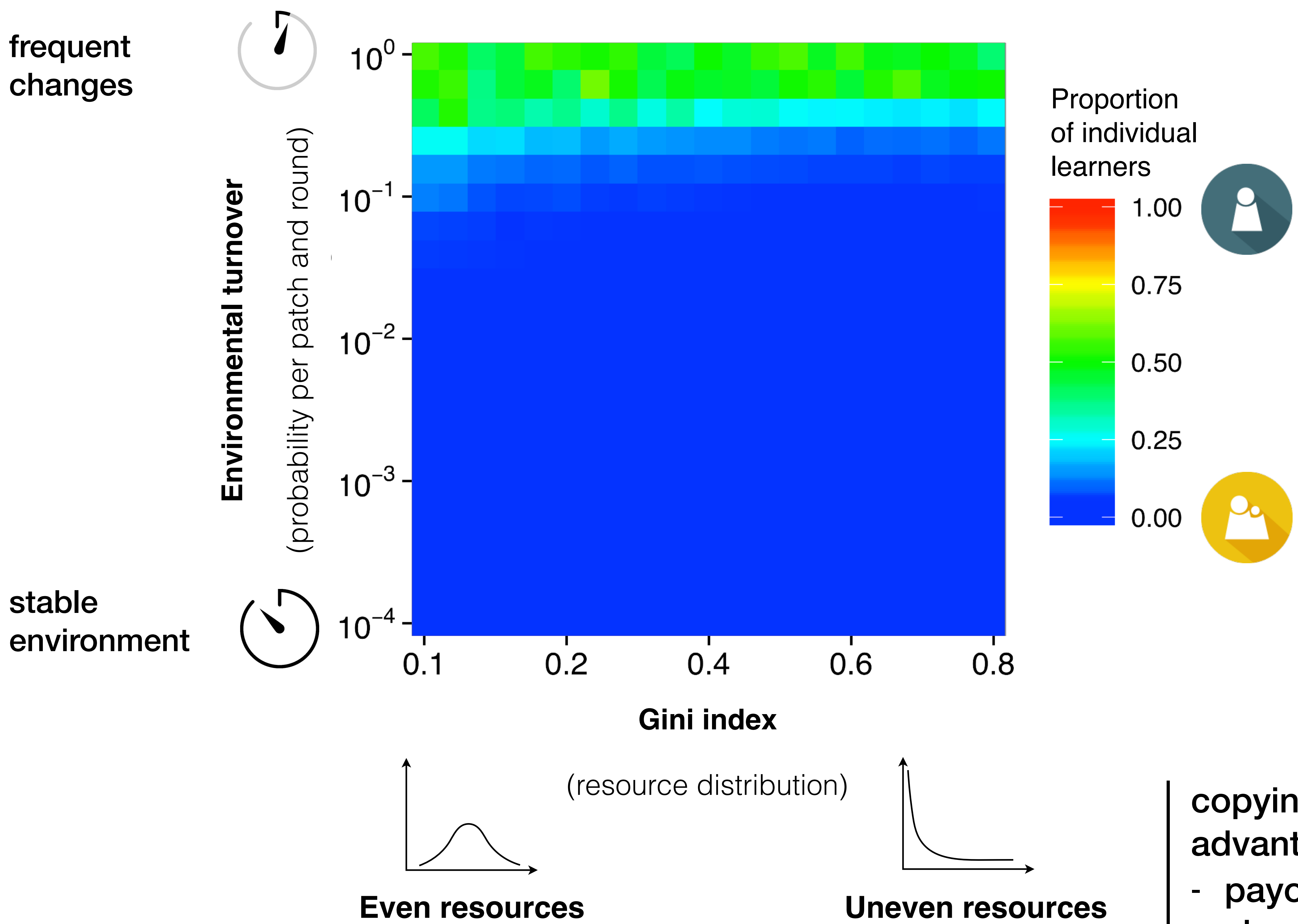
a wide range of environmental parameters in an evolving system

copying others is advantageous if:

- payoffs are highly skewed
- payoffs are stable

effect of the environment

a wide range of environmental parameters in an evolving system



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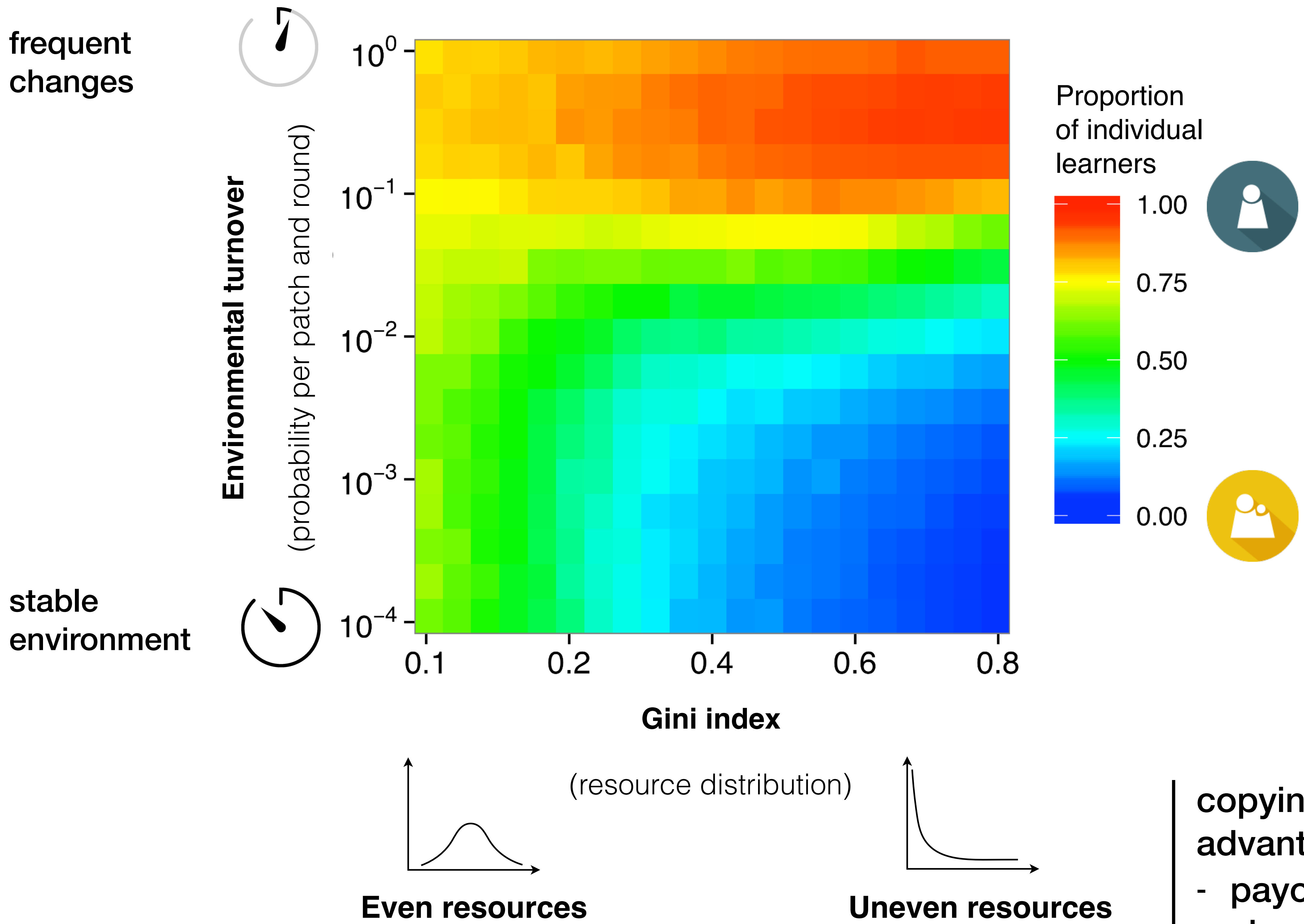


a wide range of environmental parameters in an evolving system

copying others is advantageous if:

- payoffs are highly skewed
- payoffs are stable

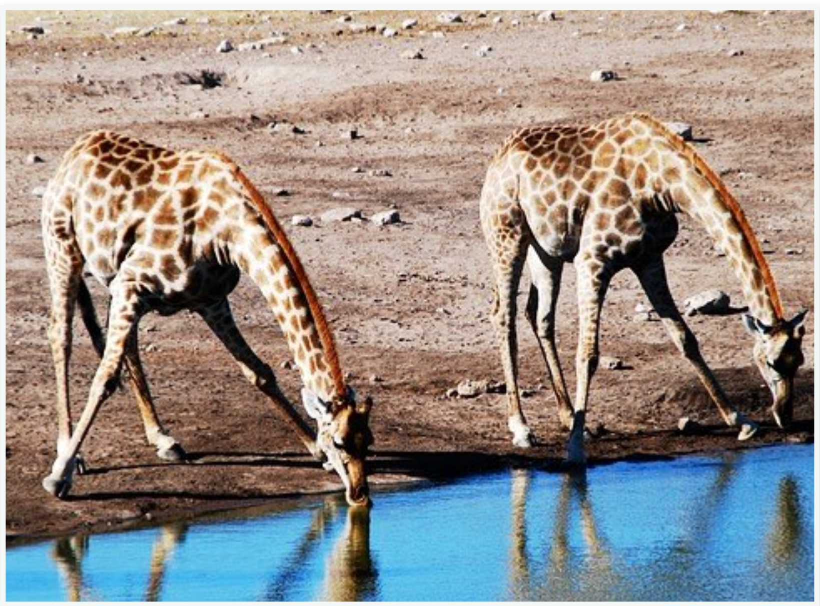
resource competition

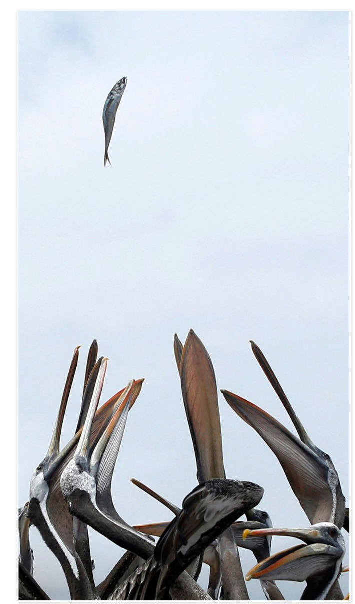
Q amount of resources in a patch accessible for a single individual

no competition | exploit competition | stronger interference

competition strength c

how to formalise competition?





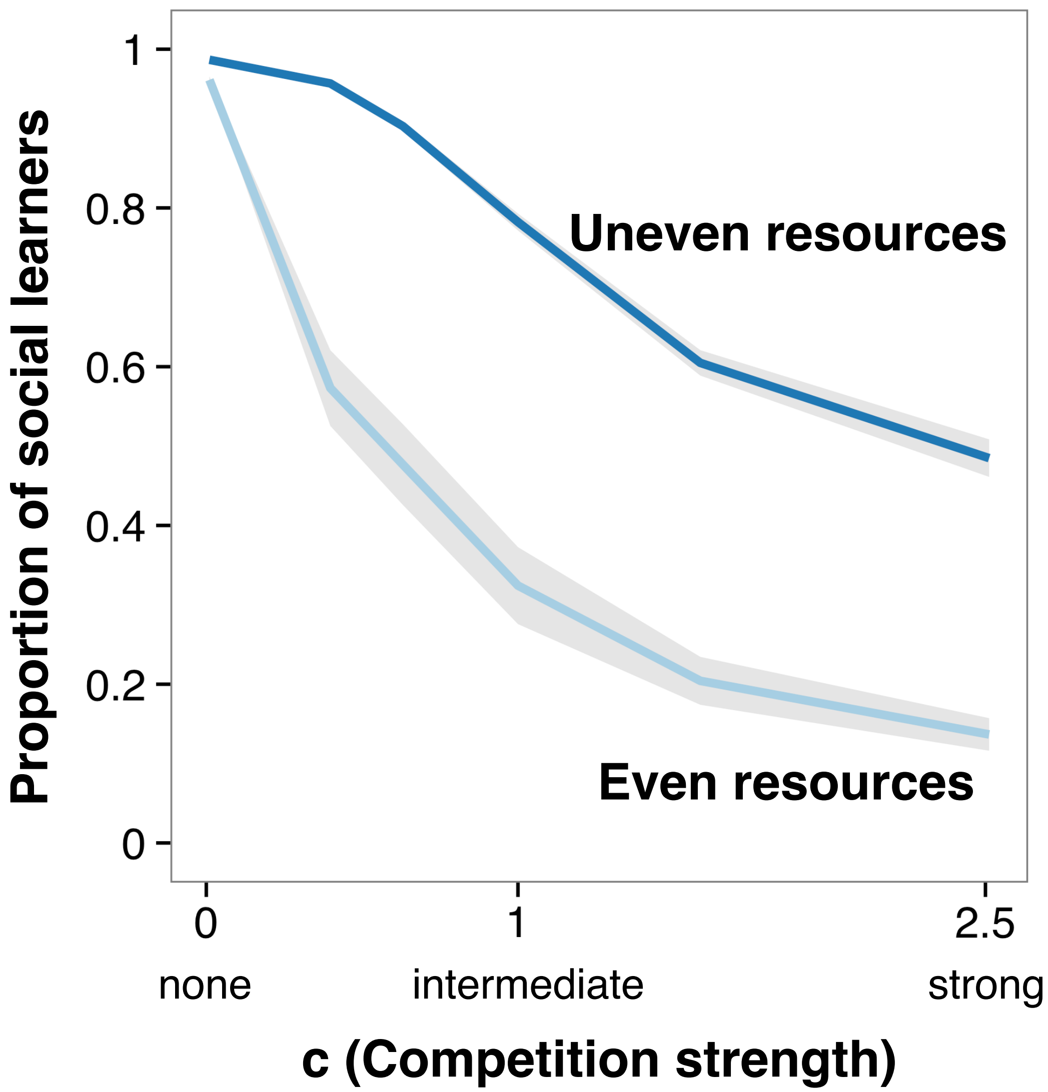
q amount of resources collected by a single individual

$$q = \frac{Q}{N^0}$$

$$q = \frac{Q}{N^1}$$

$$q = \frac{Q}{N^c}$$

effect of different competition strength



Grand and Dill, 1998

with increasing competition social learning decreases

programming our own agent based model
(jupyter notebook)

when are ABMs useful?

Conditional behaviour changes

Learning

Imitation

Evolution

Geographical representation

Social network structures

Emergence (bottom-up)

In-silico experiments

Asses effect of interventions and policies

Help plan data collection

Communication

ABM best practice

1. **Start with a clear question or goal** and let this drive early modelling decisions
2. **Take an "agent" perspective** in initial design, identifying key actors in the system that will be the focus of the model
3. **Start with (relatively) simple models** and build up complexity iteratively, one step at a time
4. **Assumptions should be well grounded** and have a strong **motivation**
5. **Use care in translation** of an ABM design into computational code
6. Conduct **error-checking** and **partial testing** as models are implemented
7. **Retrieve a known, neutral case** with the model (e.g. ideal-free distribution)
8. Fully **document model specification and implementation**, and maintain up-to-date documentation throughout the process
9. Conduct thorough and appropriate **sensitivity analysis**
10. **Design clear experiments** to yield clear insights
11. **Always investigate surprising results**, and make sure that you understand how they arise
12. Draw **appropriate conclusions** from the model analysis

Verification

debugging model code so that model behaves as intended

Validation

making sure right model has been build

(Hammond, 2015)

challenges in ABM

Generalisations are often not possible

Statements only hold for those parameter(s/ sets) that have been simulated

Defining rules, agents, and the environment

Important to choose, motivate, and justify behavioural rules, agent and environmental characteristics

Pitfall: programming results into the model mechanics

References

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