Games, Interactions and Networks

Giorgio Fagiolo

https://mail.sssup.it/~fagiolo

University of Verona, Verona, Italy

and

S.Anna School of Advanced Studies, Pisa, Italy

Outline of the Talk (1/2)

- Macro Order from Micro Disorder
- Examples:
  - How do market prices and interest rates emerge?
  - How do GNP, unemployment, consumption, investment move together along economic cycles?
  - How do some technological standards manage to dominate a market?
- Coordination and Technological Adoption
- Insights from Standard Models

Outline of the Talk (2/2)

- Interactions, Networks and Adoption Choices
- Examples
  - How can networks help us in understanding technological adoption and diffusion?
- Conclusions

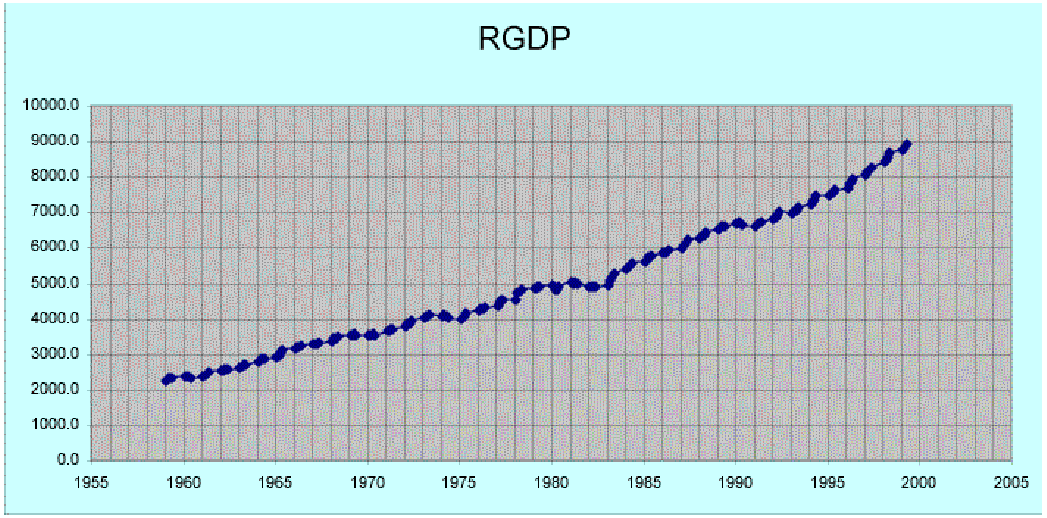
Macro Order from Micro Disorder (1/2)

- Economies and societies as complex systems
  - Micro Level (Firms, Consumers, Households, Individuals…)
  - Macro Level (Aggregate Variables, Macro Patterns, …)

- Micro Level
  - Many entities interacting over time
  - Possibly conflicting interests

- Macro Level
  - Properties emerging from micro level
  - Feedback to micro level

Macro Order from Micro Disorder (2/2)



Feedback to Micro Level

Micro Level

- Firms competing in turbulent markets
- Undertaking strategic decisions (output, investments, marketing, R&D, innovation, etc.)

Macro Order: Coordination

- Coordination among individuals
  - Technological adoption between standards (PC vs. Mac, Unix vs. Windows, Qwerty vs. Dvorak, etc.)
  - Social norms (languages, currencies, etc.)

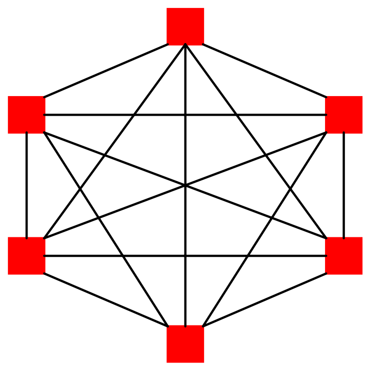
- Micro Level
  - Network externalities: my utility from choosing X increases in the number of agents choosing X
  - Coordination on a single technology in agents' interest

- Macro Level
  - Which technology will be adopted?
  - Why does one observe co-existence of standards?

Standard Answers: Game Theory (1/4)

- Common Setup: Two basic assumptions
  - Economic agents are perfectly rational
    - Maximize expected utility
  - Each agent "interacts" with anyone else
    - Individual utility depends on what every other single player does

- Interaction networks
  - Complete Network: every pair of agents is connected



Standard Answers: Game Theory (2/4)

- Coordination: Strategic complementarities
  - Two standards (Unix vs. Windows, Mac vs. PC)
  - Each individual has interest in doing what the other does

		Opponent	
	Payoff	X	Y
Myself	X	4	0
	Y	0	2

Standard Answers: Game Theory (3/4)

- Coordination: Strategic complementarities
  - Two standards (Unix vs. Windows, Mac vs. PC)
  - Each individual has interest in doing what the other does

		Opponent	
	Payoff	X	Y
Myself	X	4	0
	Y	0	2

Standard Answers: Summary (4/4)

- Coordination will occur
  - Full coordination on one single technology should be the case
- Which technology will prevail?
  - We cannot predict
    - which technology will be selected
    - whether the "ex-ante" superior technology will emerge

A Critique: Three Basic Observations

- **Rationality**.
  - People are not fully rational
  - Make persistent mistakes, explore non-optimal options

- **Dynamics.**
  - Behaviors are often revised through time
  - Choices are based on observation of the past or "status quo"

- **Interactions.**
  - Agents do not typically care about any other single behavior
  - Interaction networks are far from being "complete"

Interaction Networks

- **Interactions: Basic Assumption**
  - Agents only care about a small subset of other agents
- **Significant others**
  - Friends, relatives, peers, neighbors, …
  - Competitors, technologically-similar agents
- **Interaction networks are not complete**
  - Graph (links) describing who interacts with whom is sparse

Interaction Networks: Three Types

- **Type 1: Random Graphs**
  - Agents make a few random phone calls in each time period
- **Type 2: Local Interactions**
  - Agents always interact with their close friends
- **Type 3: Interaction Trees**
  - There are hierarchical relationships among agents

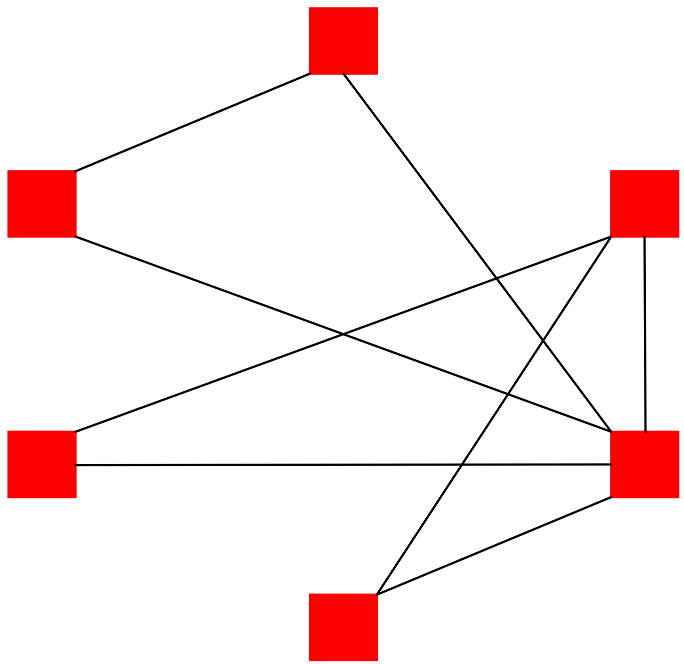
Interaction Networks (1/3)

- **Interaction Networks as Random Graphs**
  - Agents make random phone-calls, search, meet people, etc.
  - No underlying geographical or social structure

- **Dynamics**
  - In each time period
    - any two agents in the population meet at random
    - agents tend to meet different **but few** people

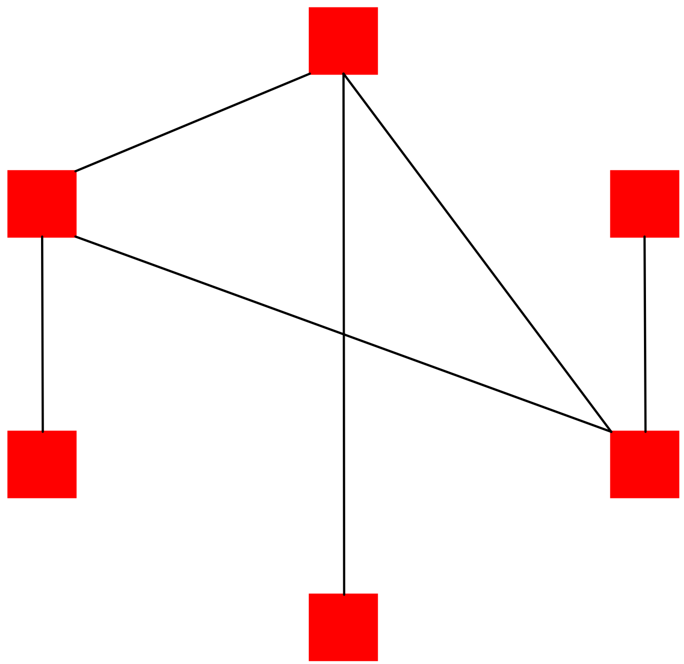
Interaction Networks (1/3)

- **Dynamics of Random Graphs : t=0**



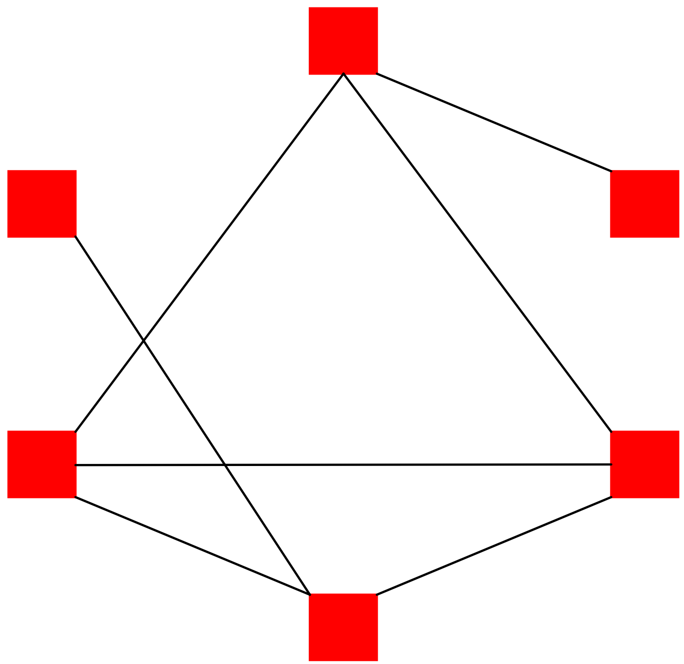
Interaction Networks (1/3)

- **Dynamics of Random Graphs : t=1**



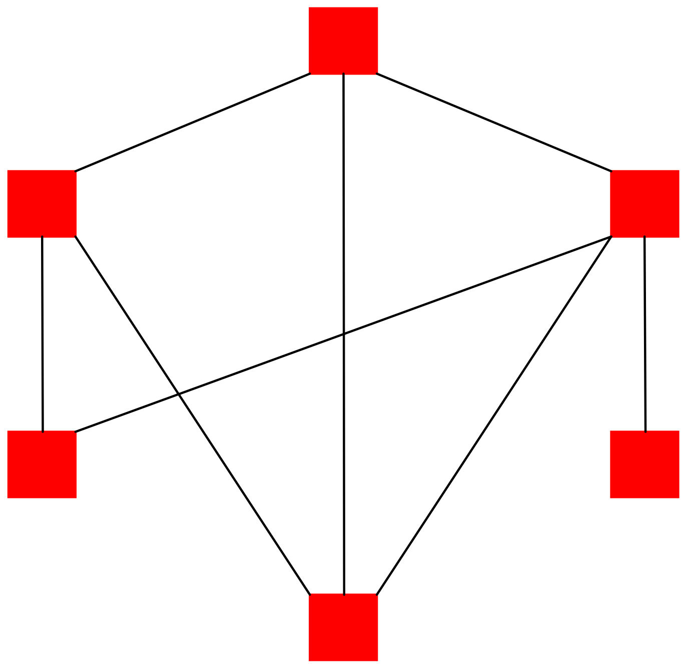
Interaction Networks (1/3)

- **Dynamics of Random Graphs : t=2**



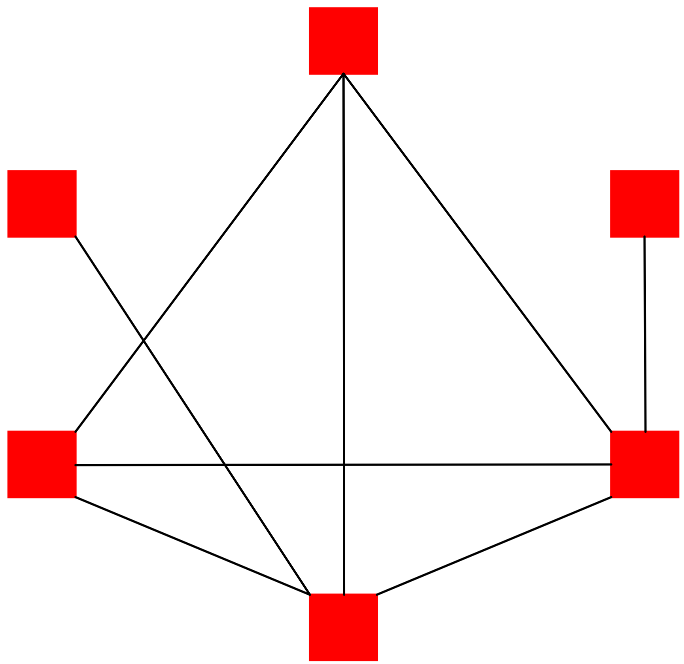
Interaction Networks (1/3)

- **Dynamics of Random Graphs : t=3**



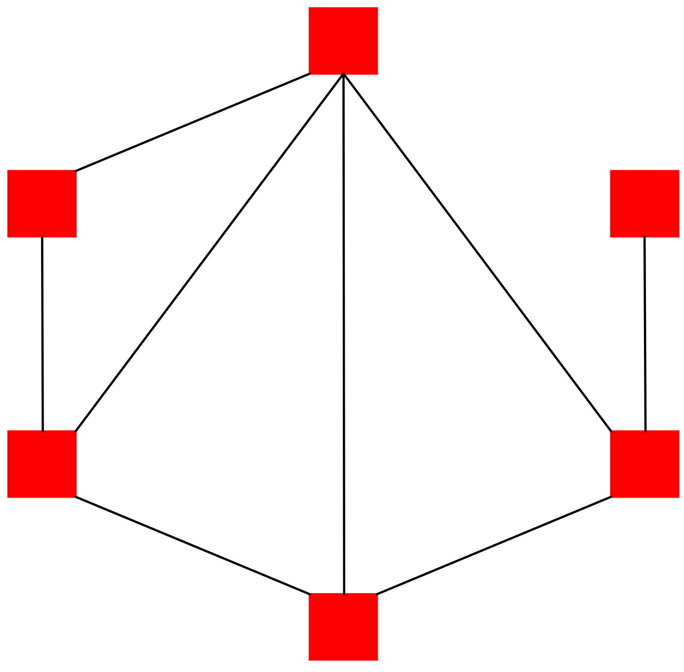
Interaction Networks (1/3)

- **Dynamics of Random Graphs : t=4**



Interaction Networks (1/3)

- **Dynamics of Random Graphs : t=5 … and so on …**



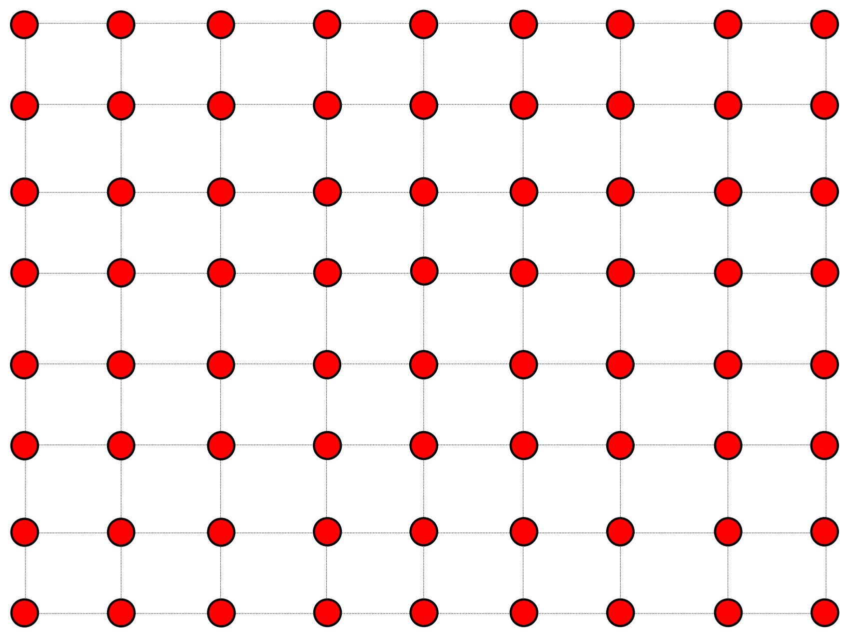
Interaction Networks (2/3)

- **Random Graphs**
  - Agents always switch interacting people
  - Ok if switching (search) costs are small and there is no underlying spatial or social structure

- **Alternative: Local Interactions**
  - Friendships, neighboring relations, etc. can be sticky
  - There is some underlying geographical (spatial) structure
  - Agents always interact with their “nearest neighbors”

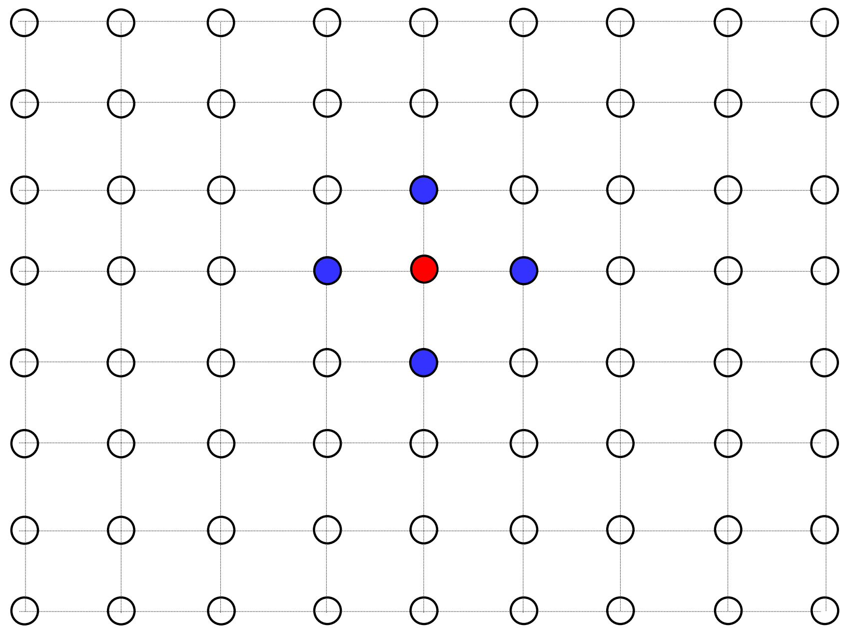
Interaction Networks (2/3)

- **Local interactions: example**
  - Agents are thought to be arranged on a 2-dim lattice



Interaction Networks (2/3)

- **Local interactions: example**
  - Each interacts with his 4 nearest-neighbors



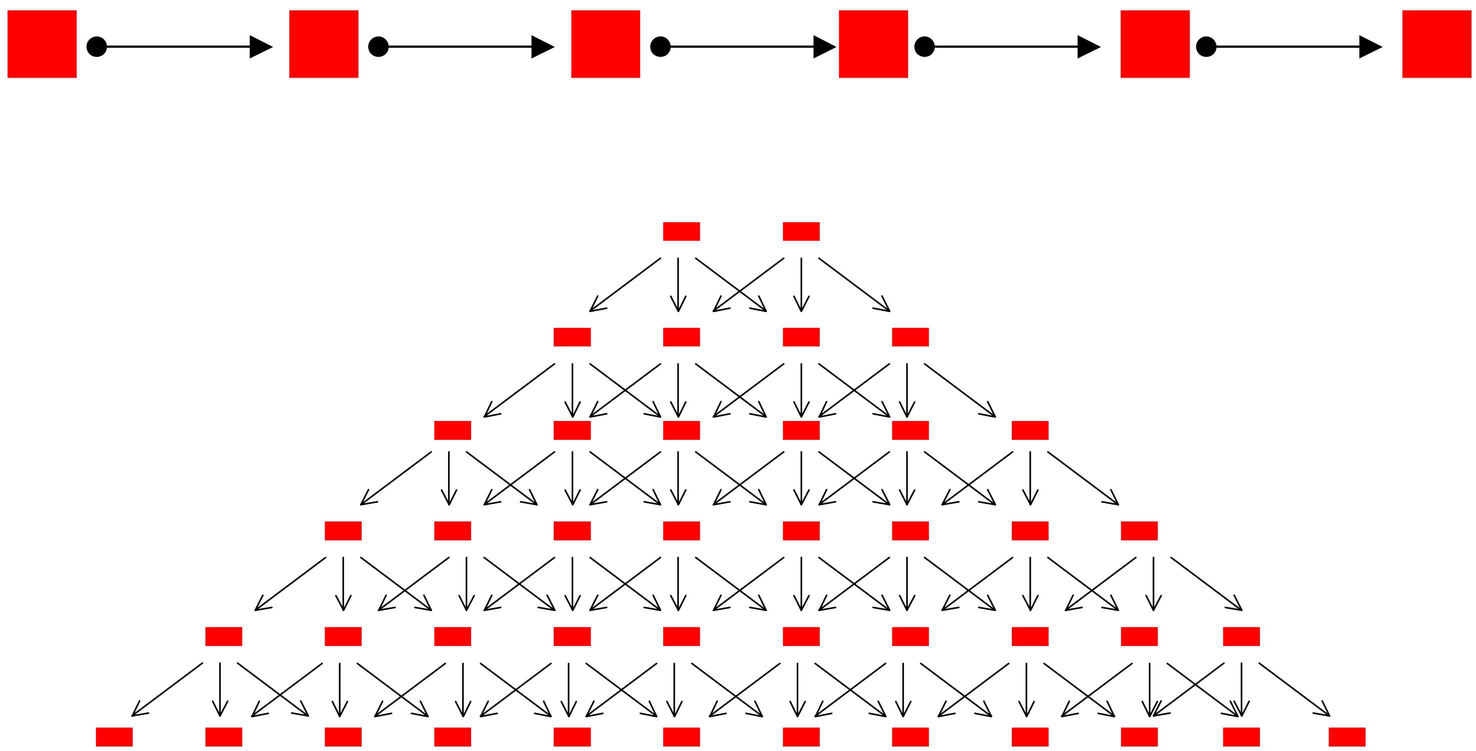
Interaction Networks (4/4)

- **Random graphs and local interactions**
  - No hierarchy whatsoever
  - Ok there is no information or role asymmetry among agents

- **Alternative: Interaction Networks as Trees**
  - Agents are not all the same as to their influence on others
    - Large firms can have advantages, upstream firms can move first
    - "Gurus" and "leaders" can force "followers" choices
  - There is some order in the way agents choose
  - Agents choosing
    - **first** face a higher uncertainty but are not influenced by others
    - **later** know what happened but are not free to choose

Interaction Networks (4/4)

- **Interaction networks as trees**



Our New Questions

- **What happens when**
  - Real-world agents are not fully rational (mistakes, exploration)
  - They are dynamically allowed to revise their choice through time
  - They do so by taking into account only their "relevant others"
- **What do these new insights add to our understanding of**
  - Aggregate coordination patterns generated out of micro level ?
  - Prediction of:
    - Which technology (if any) will get the whole market (full coordination) ?
    - If and when "technological niches" will emerge (coexistence of techniques) ?

The Basic Setup

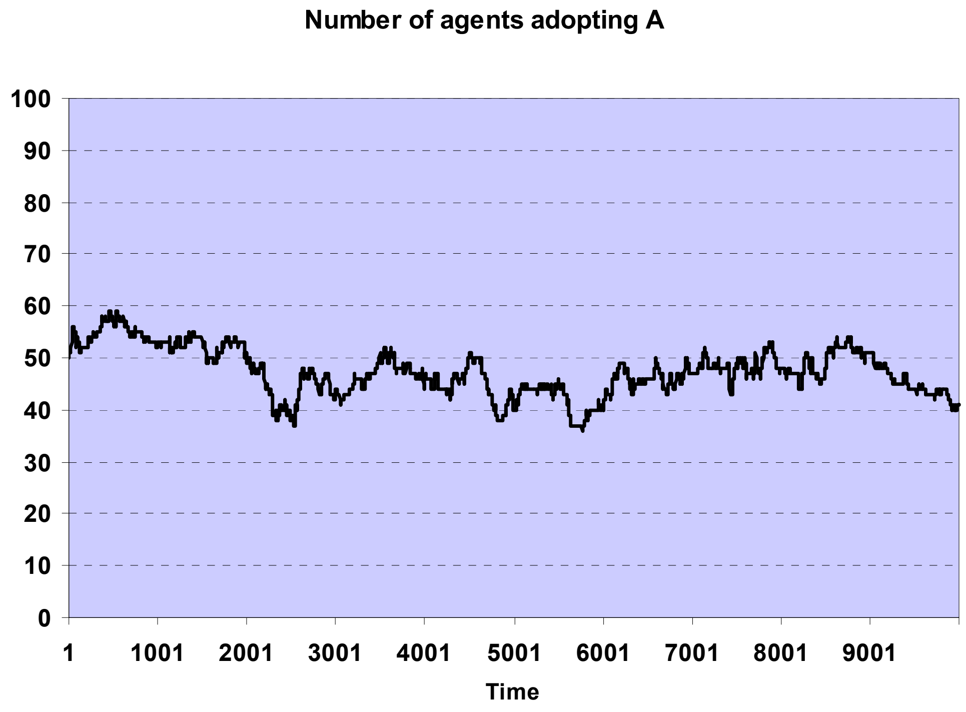
- **Agents**
  - i = 1, 2, …, 100
- **Time**
  - t = 0,1, 2, …
- **Technologies**
  - S = {A,B}
  - s(i,t) : technology adopted by agent *i* at time *t*

Example I: Random Meetings (1/2)

- **Initial Conditions**
  - 50 agents choosing A, 50 agents choosing B
- **Dynamics**
  - At each t, two agents meet at random (only 1 phone call)
  - The first agent asks the second which technology he uses
  - Then the first agent:
    - With probability p: sticks to his previous choice
    - With probability 1-p: adopts the technology suggested by the second
- **Remarks**
  - Interaction networks are random
  - The smaller p, the more agents are sensible to others' opinions

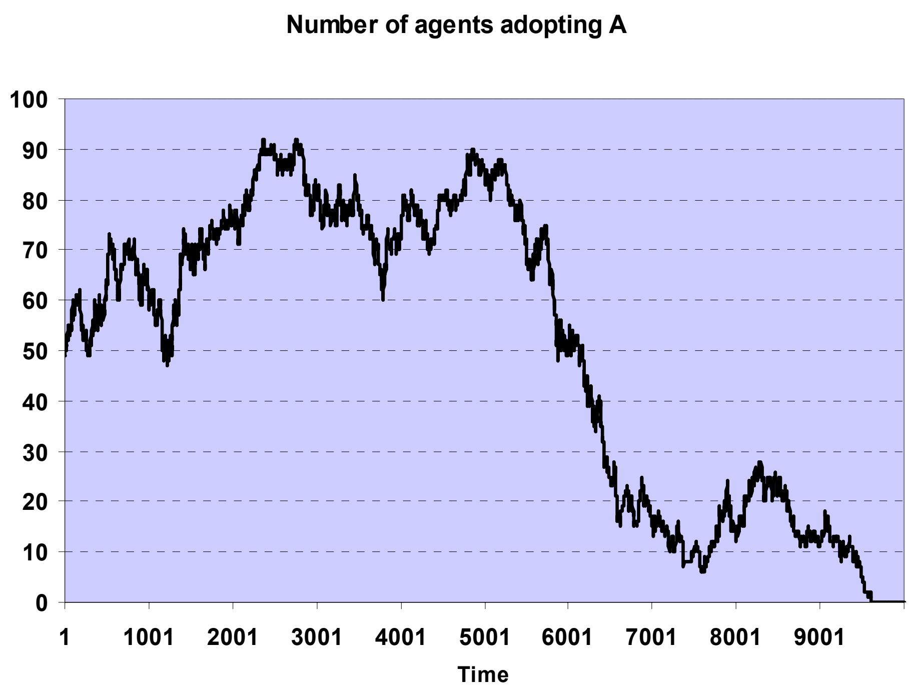
Example I: Random Meetings (2/2)

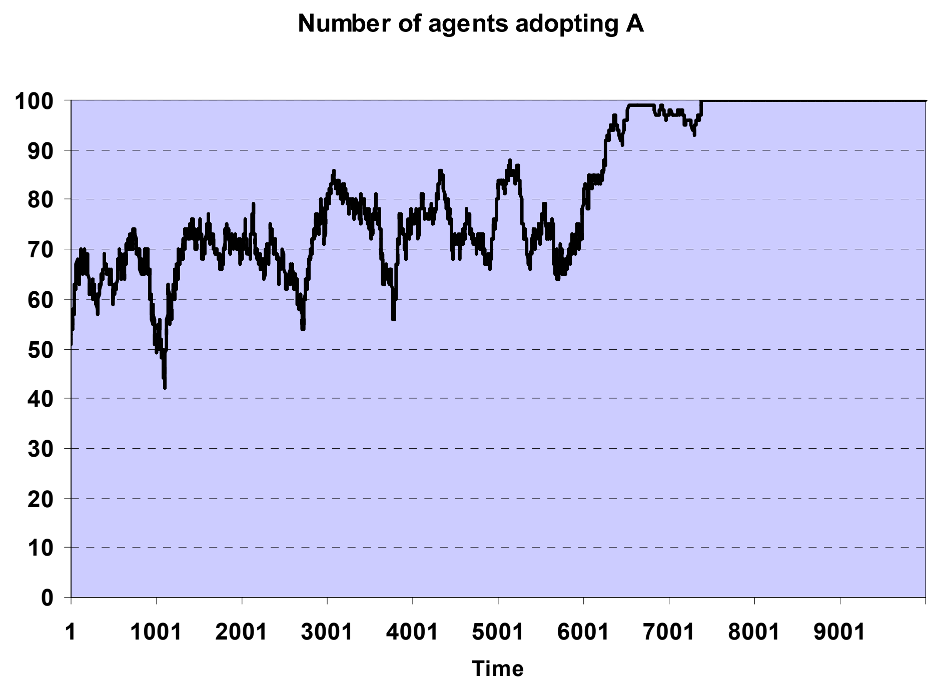
- **Results: Two cases**
  - Large p (agents are "idiosyncratic"): **almost exact coexistence**



Example I: Random Meetings (2/2)

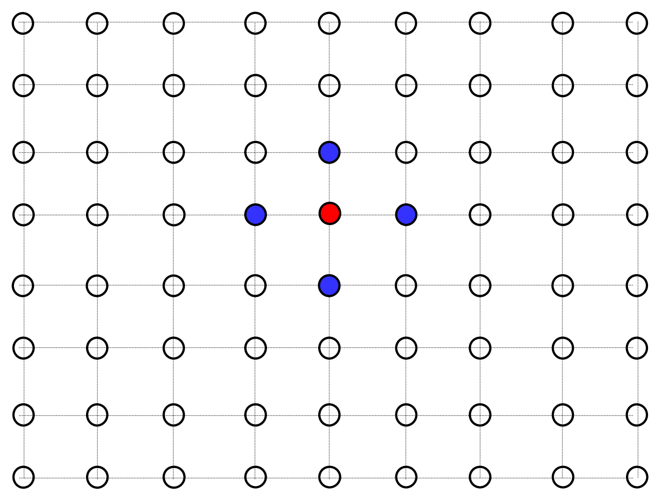
- **Results: Two cases**
  - Small p (agents are sensible): **one technology wins**





Example II: Local Interactions (1/3)

- **Initial Conditions**
  - 50 agents choosing A, 50 agents choosing B
- **Interaction Networks**
  - Agents are spatially located on a 2-dim lattice
  - They only care about their 4 nearest-neighbors



Example II: Local Interactions (2/3)

- **Dynamics**
  - At each t, one agent chosen at random is allowed to revise
  - The agent looks at which technology prevails in his neighborhood
  - He chooses the locally prevailing technology
  - With some probability p he changes his mind and chooses the other technology (mistake or experimentation)

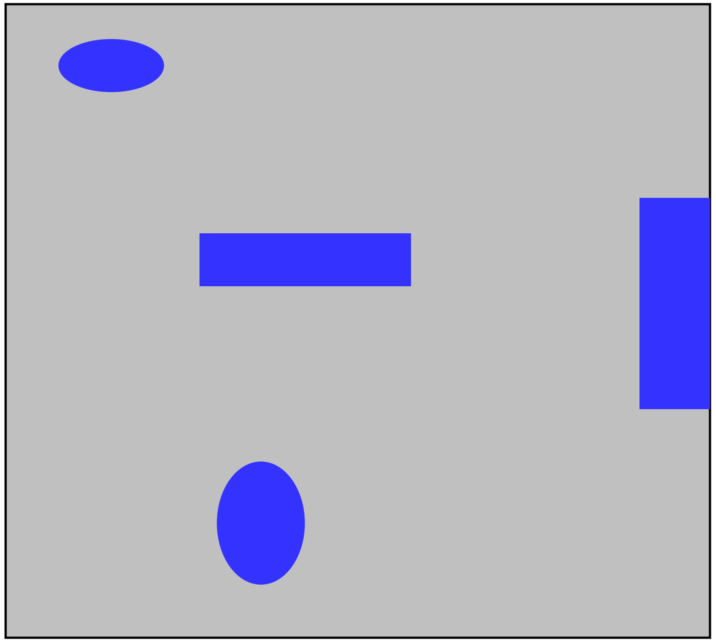
- **Remarks**
  - Interaction networks are fixed
  - The smaller p, the more agents are sensible to others’ opinions

Example II: Local Interactions (3/3)

- **Result I**
  - Similar to before as to how p affects dynamics
  - For small p, technological niches remain in the system
  - **No technology gets the whole market**

Blue: Tech A

Grey: Tech B



Example II: Local Interactions (3/3)

- **Result II**
  - Can we predict winning technology? No answers so far
    - Here: The one associated to highest **average** payoffs will prevail
  - **This is not necessarily the Pareto-efficient one !**

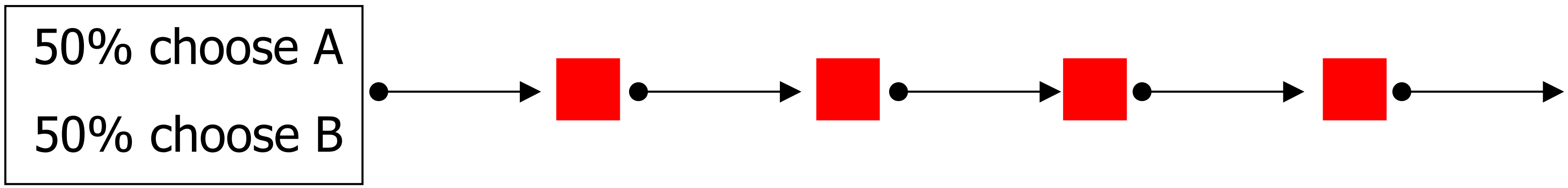
Myself \ Neighbor	A	B
A	4	0
B	0	2

Myself \ Neighbor	A	B
A	4	-3
B	0	2

Example III: Tree Networks (1/4)

- **Initial Conditions**
  - Small number of agents
  - 50% agents choosing A, 50% agents choosing B

- **Interaction Networks**
  - Agents choose sequentially
  - They stick to their choices once they have chosen
  - When choosing, they look at current number of adopters of A,B



Example III: Tree Networks (2/4)

- **Dynamics**
  - At each t, one agent enters the economy
  - He acquires information about prevailing technology
  - He chooses prevailing technology
  - With some probability p he changes his mind and chooses the other technology

- **Remarks**
  - Interaction networks are fixed and sequential
  - The smaller p, the more agents are sensible to others' opinions
  - Agents choosing late are not able to change relative frequencies of adopters

Example III: Tree Networks (3/4)

- **Early choices (leaders)**
  - Agents choosing first face higher uncertainty
    - They do not know which technology will prevail
    - Choices are partly random and idiosyncratic
  - Their early choices make one technology better than the other
    - The gap between adopters increases in the early stages
    - They “build” the gap and “set the trend” to be followed afterwards

- **Late choices (followers)**
  - Agents choosing late face low uncertainty
    - They can see which technology is prevailing
  - Their choices **cannot** displace the “status quo”
    - The gap between adopters is already large
  - They will tend to **follow the herd**

Example III: Tree Networks (4/4)

- **Result 1**
  - One technology will (almost) get the whole market
  - Which one will be is unpredictable
- **Result 2**
  - Which technology will prevail is determined by "leaders" choices, which are partly random
- **Result 3**
  - Followers choices are almost completely predetermined by leaders
  - Informational cascade: followers do not use their information or freedom (fundamentals may not count)

Summary

- **Interaction, Networks and Adoption Choices**
- **Question**
  - How can networks help us in understanding technological adoption and diffusion?
- **Answers**
  - Non-trivial interaction networks help us in addressing issues as:
    - Can one technology get the whole market?
    - Can one explain coexistence of techniques and niches?
    - Which technology will tend to prevail?
    - What is the role of information asymmetries (leaders/followers)

Concluding Remarks

- **Interaction Networks: Additional Applications**
  - Cooperation
  - Financial bubbles
  - Credit market, systemic risk
  - […]

- **Interaction Networks: Current research topics**
  - This lecture: agents cannot choose whom to interact with
  - What if agents can choose their interaction networks?
  - Interesting questions:
    - Can we explain observed real-world interaction networks
    - Small-world, scale-free, etc. ?