DELIS
Dynamically Evolving, Large-scale Information Systems

# Socially Inspired Approaches to Evolving Cooperation

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# A note on typology in this presentation

- Because this area is actually vast, covering lots of disciplines and concepts, I have highlighted some key concepts in *red italic*
- This means that there are good overviews on wikipeadia: http://en.wikipedia.org
- You should look these terms up to fully grasp what is being presented here

# Sociologically Inspired Computing

- Many key problems in the engineering of distributed computer systems bear close similarities to puzzles in human societies
- Historically these have been studied in areas such as Economics, Sociology and Political Science
- As computer scientists / engineers we can benefit from an awareness of some of these ideas

# Sociologically Inspired Computing

- Recently an area called "*Computational Sociology*" has emerged
- Social scientists express their ideas using computer simulations (often agent-based)
- This is good news since we can get agent-level algorithmic descriptions of their ideas
- Some of those algorithms can be modified and applied for our purpose (nice self-* properties)

# Sociologically Inspired Computing

- *CAUTION:* when dealing with social theories and talking about human societies it is important to note:
  - Within the social sciences there is no general agreement on basic principles, theories or subject matter
  - Social science tends to be broken into disconnected "factions" with competing assumptions, methods and goals
  - Furthermore ideas are often "political" and hence can cause people to get "excited"

# Sociologically Inspired Computing

- *HOWEVER*: none of this need worry us because:
  - We are only interested in if the “theories” and “ideas” work in computer systems
  - We don’t care if they are true, false or silly
  - Hence we don’t need to get involved in sociological debates but just “steal” good ideas

# Sociologically Inspired Computing

- There are many possible areas from which we could attempt to steal good ideas from social science (e.g.):
  - Formation of organisations and roles
  - The emergence of money / Economy
  - Trust and Reputation / Crime and Deviance
  - Power / Class
  - Cooperation, coordination, and altruism
- We will focus on Cooperation

# Cooperation in Distributed Systems

- Many systems are composed of semi-autonomous units
  - E.g. Agent, P2P, animal and human societies
- It is often the case that individual interests conflict with collective interests
  - E.g. P2P file sharing system - downloading more than uploading
  - E.g. human society - over exploitation of a common resource

# Cooperation in Distributed Systems

- Consider pollution and the environment:
  - It is in the *collective interest* keep the environment clean enough so we don't all die
  - But it is in the *individual interest* of firms (corporations) to save money by not properly disposing of dangerous pollutants
  - This is particularly true if a small set of firms could pollute without this causing a problem but if *all* pollute then this kills us all (say)

# Cooperation in Distributed Systems

- Consider a community fishing an area of sea:
  - It is in the *collective interest* of the community to avoid over-fishing such that there are not enough fish to reproduce
  - But it is in the *individual interests* of the fisherman to catch as much fish as possible

# Cooperation in Distributed Systems

- These kinds of situations have been termed "commons dilemmas" or "collective resource dilemmas"
- G. Hardin (1968) summarized the issue in his famous paper: "The *Tragedy of the Commons*"
- These kinds of situations can occur in distributed systems also

# Cooperation in Distributed Systems

- Consider an open file sharing P2P overlay network:
  - It is in the *collective interests* of the entire network community that each node shares high quality files
  - But it is in the *individual interest* of each node to download files without uploading them

# Cooperation in Distributed Systems

- Consider routing of a message in an ad-hoc mobile network
  - It is in the collective interests of the network community that messages are routed correctly
  - But it is in the individual interests of the each node to save energy by receiving messages but not passing them on

# Cooperation in Distributed Systems

- What kinds solutions have been proposed / identified for these kinds of problems?
- Central enforcement of correct behaviour
  - E.g. EU fishing quotas, “Kyoto carbon taxes”
    - Require centralised agencies and policing
- Decentralised methods
  - E.g. self-policing, emergence of cooperative social norms or behaviours
    - Do not require centralised coordination

# Cooperation in Distributed Systems

- Much economic theory (including *Game Theory*) makes the following assumptions:
  - Individuals can assign a utility to themselves and others for all possible outcomes of behaviours
  - Individuals behave to maximise their utility
  - Individuals know that all others will behave in this way and have infinite computational resources to calculate the best next behaviour
- This is termed “ideally rational” or *Homo Economicus* model

# Cooperation in Distributed Systems

- With classical assumptions - often possible to calculate *Nash Equilibria* - sets of behaviours (or strategies) such that no individual can improve their utility by changing strategy
- Under "ideally rational" assumptions individuals would behave selfishly in all our previous examples
- But studies show humans don't behave in an ideally rational way - more cooperation, heuristics, learning (Herbert Simon - *Bounded Rationality*)

# Cooperation in Distributed Systems

- More recently the “evolutionary approach” relaxes the classical assumptions:
  - Individuals follow simple learning rules based on how well they do relative to others
  - Copy the behaviours of better performing others
  - Modify their behaviour from time-to-time (innovate)
- Cultural evolution *not* biological evolution (although will often produce similar results)

# The Prisoner's Dilemma

- This is a kind of minimal two-player form of a *Commons Tragedy*
- The "rational" game theoretic solution (the *Nash Equilibrium*) is the worst outcome for all
- Selfish adaptive / evolutionary units would also tend to Nash because this is also the *Evolutionary Stable Strategy* (ESS)
- It is desirable for societies to cooperation in such situations and many seem to. But how?

# The Prisoner's Dilemma Game

Given: $T > R > P > S$ and $2R > T + S$

| Player 2 \ Player 1 | C | D |
|---|---|---|
| C | R (3) / (3) R | S (0) / (5) T |
| D | T (5) / (0) S | P (1) / (1) P |

# The Prisoner’s Dilemma

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Players => | P1 | P2 | P1 | P2 | P1 | P2 | P1 | P2 |
| Moves => | C | C | C | D | D | C | D | D |
| Payoffs => | R | R | S | T | T | S | P | P |
| Values => | (3) | (3) | (0) | (5) | (5) | (0) | (1) | (1) |
| Total => | (6) | | (5) | | (5) | | (2) | |

A contradiction between collective and individual interests: *Nash Equilibrium* = DD

# Ways to get Cooperation in the PD

- 3'rd party enforcement – requires trusted authority
- *Tit-for-Tat* – requires repeated interactions (IPD) with same agents (Axelrod 1984)
- Interaction & copying on lattice – not possible in many environments (Nowak & May 1992)
- Image Scoring - requires others to observe game interactions (Sigmund & Nowak 1998)
- Tags – scalable, single round, simple, applicable to P2P (Holland 1993, Riolo 2001, Hales 2004)

# What are “tags”

- Tags are observable labels, markings, cues
- They are attached to agents
- Can be observed by other agents
- Agents interact preferentially with those sharing the same tag – no other function
- In cultural interpretation, tags = clothing styles (fashions) or other overt signals (make-up or mannerisms)

# An Evolutionary PD Scenario

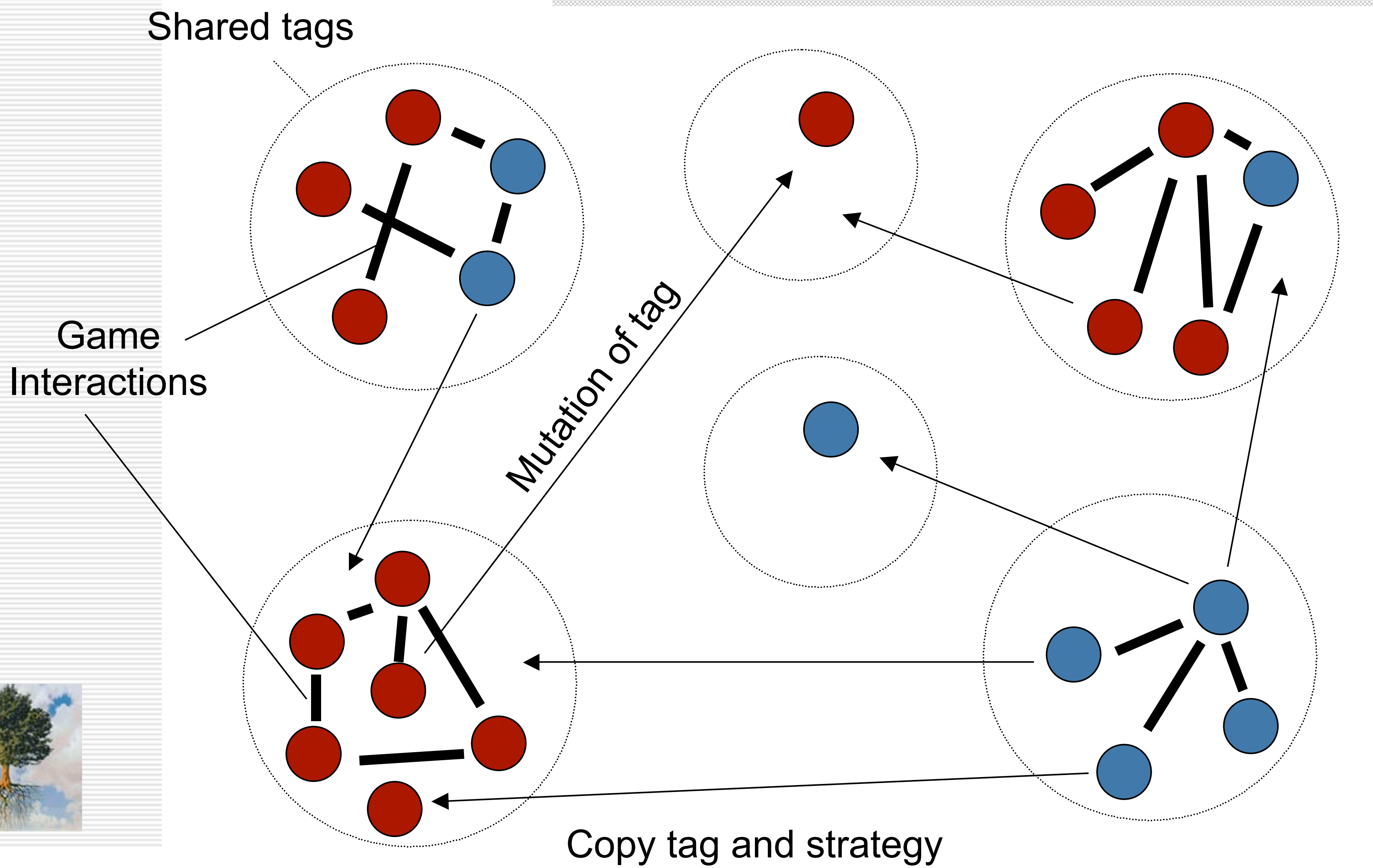
- Agents are selfish and greedy
- Copy behaviors and tags of more successful
- Randomly mutate strategies and tags
- No population structure but….
- *Agents preferentially interact with those sharing the same tag*
- When agents interact they play the PD

# Agents - a Tag and a PD strategy

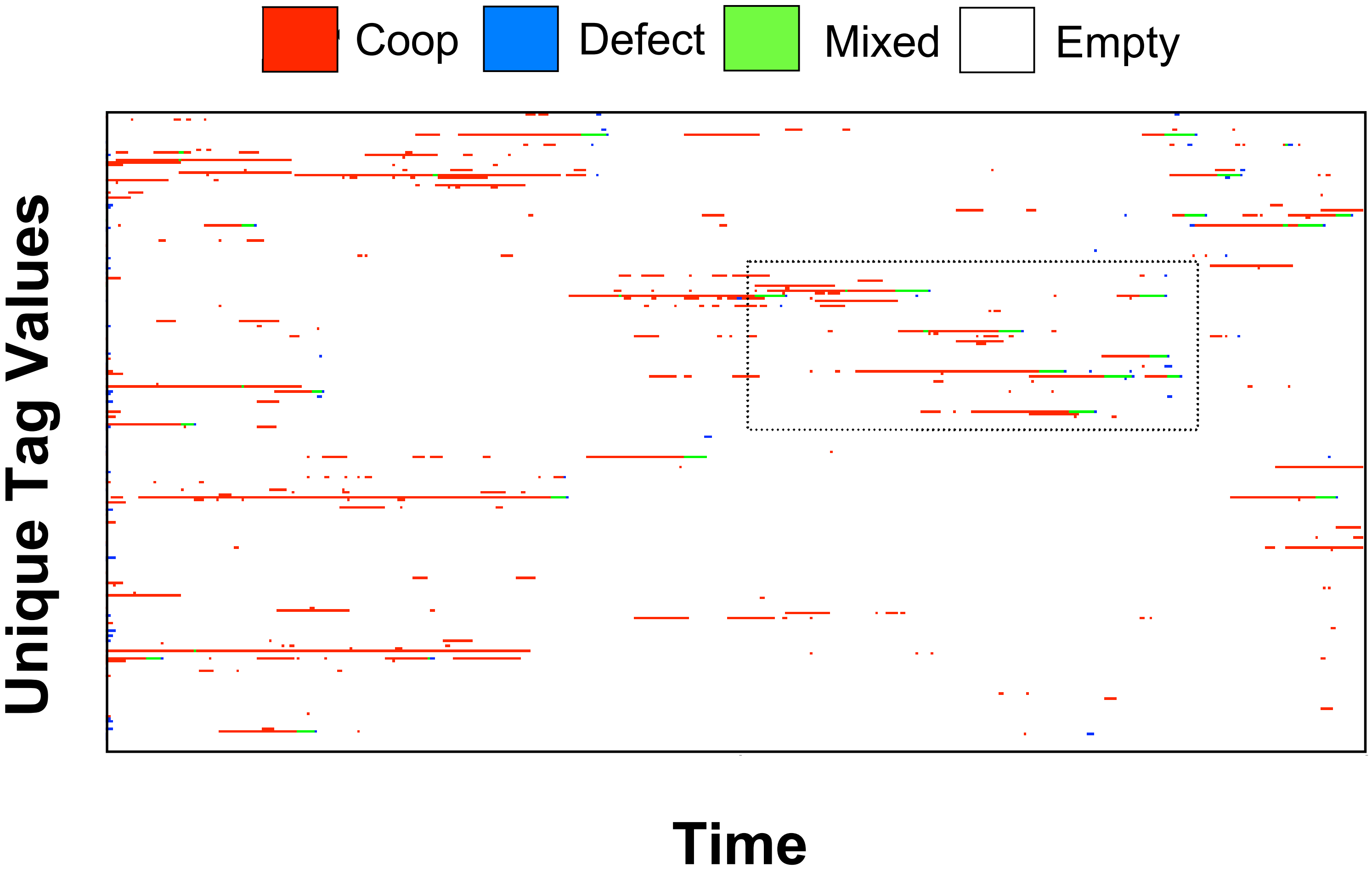

Tag = (say) Some Integer

Game interaction between those with same tag
(if possible)

# How Tags Work



# Visualising the Process

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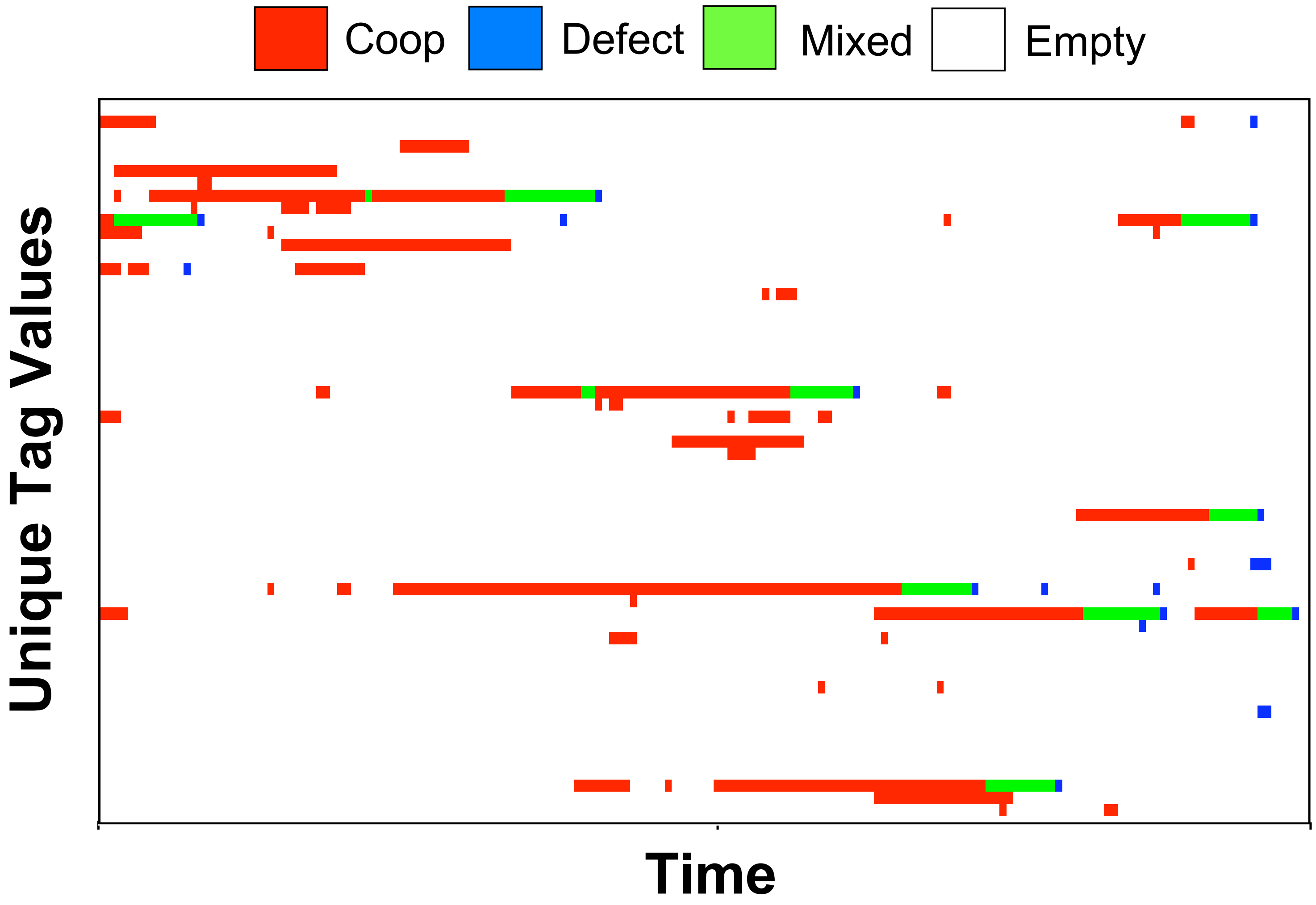
# Visualising the Process



# A P2P Scenario

**Consider a P2P:**

- Assume nodes maintain some max. degree
- Node neighbours can be thought of as a group
- Nodes may be good guys, share resources with neighbours, or free-ride, using neighbours resources but not sharing theirs (PD)
- Sharing / free-riding is a Strategy
- The neighbour links (as a whole) a kind of “tag” (if clustering high enough)

# A P2P Scenario

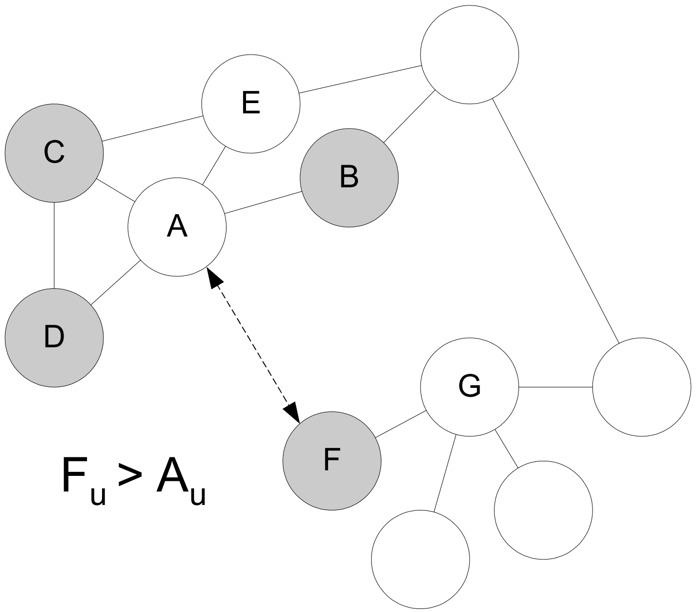
- Represent the P2P as a undirected graph
- Assume nodes are selfish and periodically:
  - Play PD with randomly selected neighbour
  - Compare performance to some randomly selected other node
  - If other node is doing better copy its neighbourhood and strategy
  - Mutate strategies and neighbourhood.

# Design Decisions

- Mutation of view => replace all with single randomly chosen node
- Mutation of strategy = flip the strategy
- Node j copying a more successful node i => replace i view with j's plus j itself
- When maximum degree of a node is exceeded throw away a randomly chosen link

# Copying a more successful node

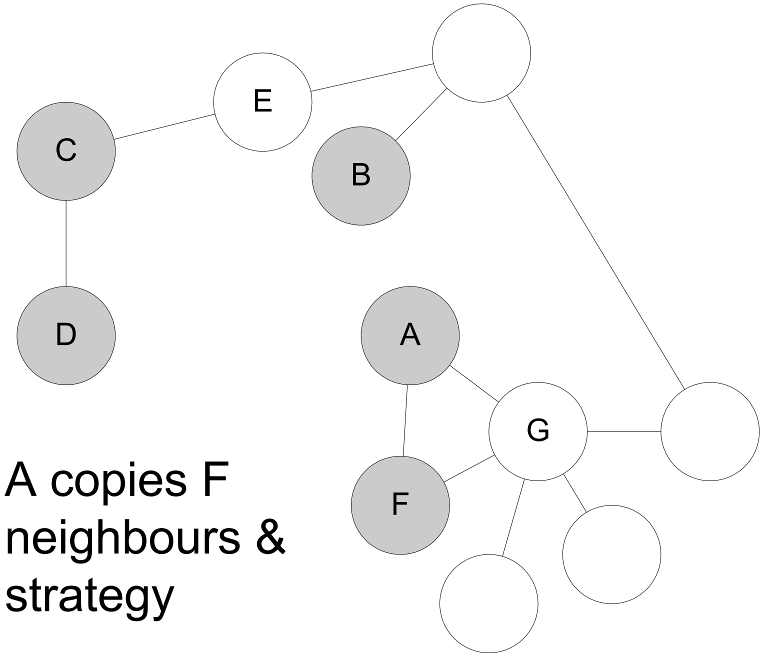
## Before




$F_u > A_u$

Where $A_u$ = average utility of node A

## After

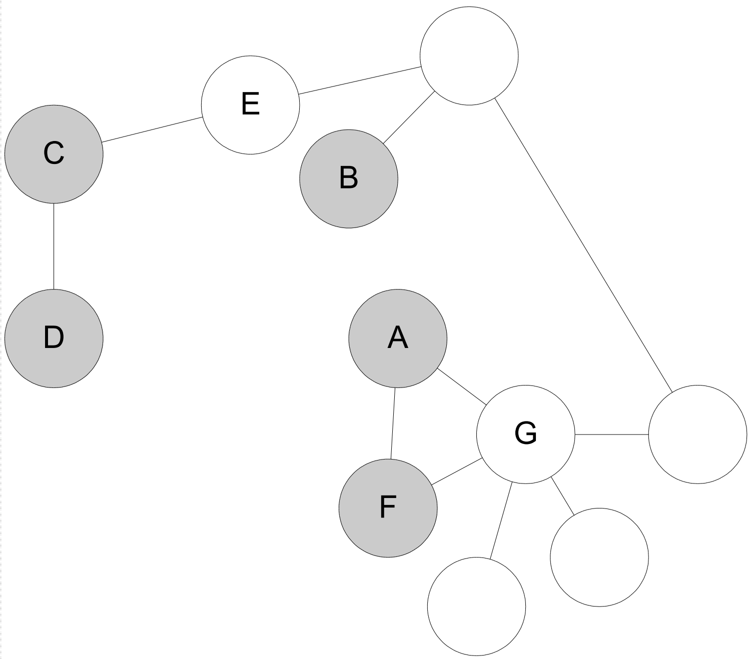



A copies F neighbours & strategy

In his case mutation has not changed anything

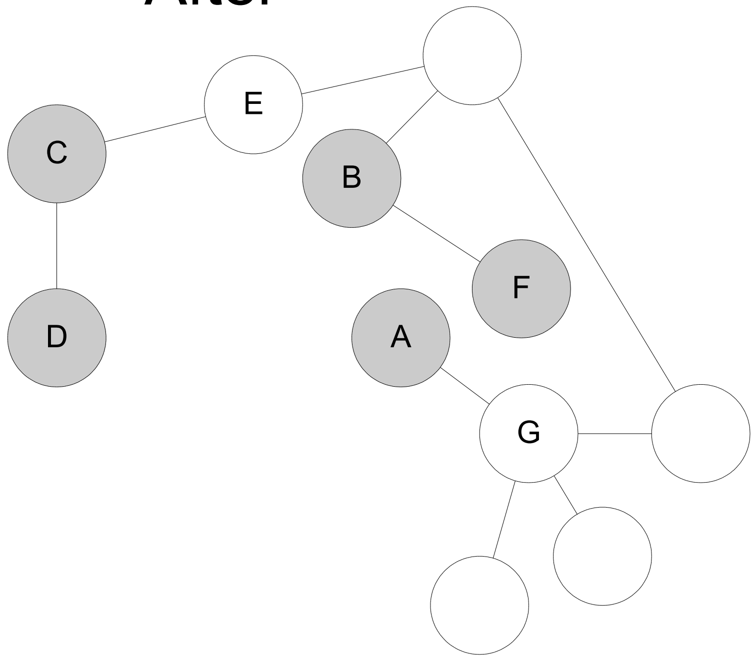
# Random movement in the net

## Before




Mutation applied to F's neighbourhood

## After

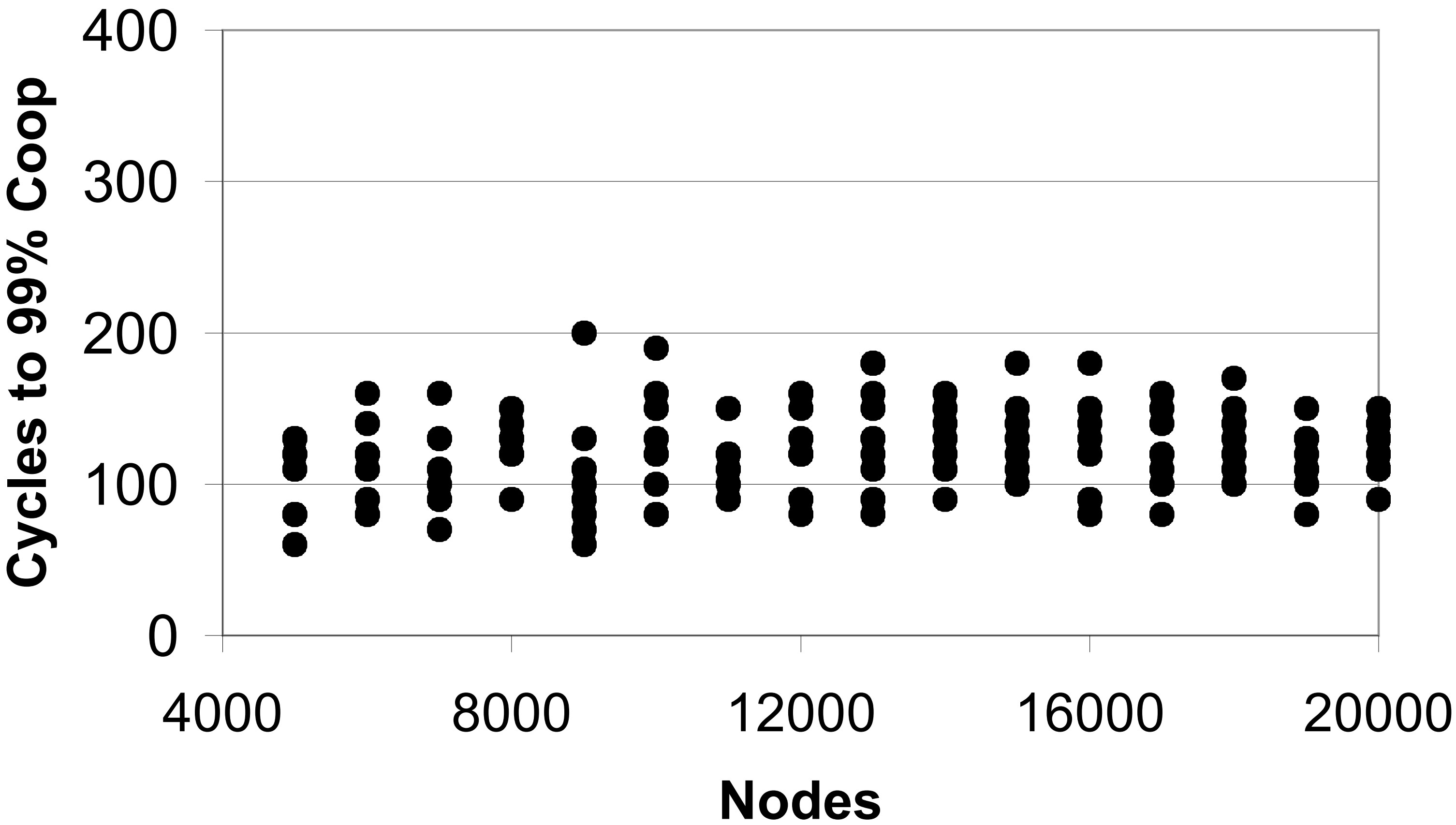



F is wired to a randomly selected node (B)

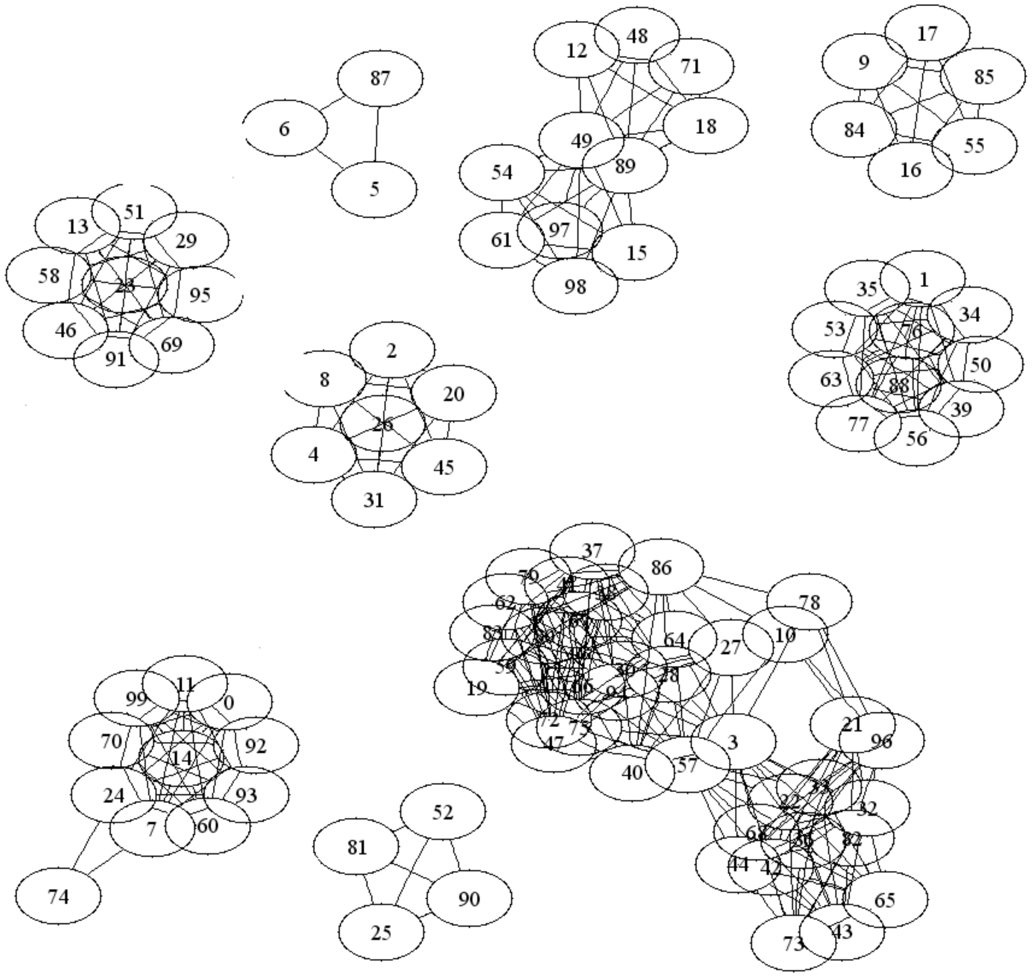
# Parameters

- Vary N between 4,000..120,000
- Maximum degree 20
- Initial topology random graph (not important)
- Initial strategies all defection (not random)
- Mutation rate m = 0.001 (small)
- PD payoffs: T=1.9, R=1, P=d, S=d
  (where d is a small value)

# Results


Cycles to 99% Coop
0
100
200
300
400
4000
8000
12000
16000
20000
Nodes

# A 100 node example – after 500 generations



# General Conclusions
# Socially Inspired Methods

- An awareness of sociological approaches can inspire novel approaches to self-* engineering
- However the process is not simple:
  - need to be aware of the assumptions being imported - make sense in new context?
  - much modification and testing is required
- The emerging area of computational sociology seems to be particularly relevant
- Evolutionary approaches appear more relevant than classical approaches in GT and Econ.

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