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Change your tags fast! - A necessary condition for cooperation?

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Project funded by the Future and Emerging Technologies arm of the IST Programme

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Talk Overview

- Why study cooperation in agent systems?
- Some previous models of cooperation
- Tags – what are they?
- Tags – how do they work? (Hypothesis)
- Conclusion

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Why study cooperation?

How can agents do tasks involving:

- Coordination & Teamwork
- Specialisation & Self-Repair
- Emergent Functions & Adapting to Change

WITHOUT centralised supervision and in a scalable way when agents are autonomous (worst case: selfish, greedy)

The Prisoner’s Dilemma

Two thieves are taken in. The police have little evidence. They interrogate them separately – each is offered a “deal”: If they give evidence against the other they get a lighter punishment (whatever the other does), otherwise they get some time in jail. But both know that If they both keep quiet they get off lightly, if both talk then they both get put away for longer, but if one talks and the other stays silent then the “grass” walks free while the silent one goes away for an even longer time.

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The Prisoner’s Dilemma

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

Player 1 / Player 2	C	D
C	R (Player 1), R (Player 2)	T (Player 1), S (Player 2)
D	S (Player 1), T (Player 2)	P (Player 1), P (Player 2)

The Prisoner's Dilemma

- This is a "minimal form" of a "Commons Tragedy" (Hardin 1968).
- In Game Theory "Nash" equilibrium is to defect
- Evolution would also tend to Nash
- Desirable for "societies" to maintain some cooperation in such situations and many seem to. But how?

Maintaining Cooperation in the PD

- Binding Agreements (3'rd party enforcement) – expensive, complex (Thomas Hobbes 1660)
- Repeated Interactions can punish defectors – tit-for-tat (Axelrod 1984)
- Spatial relationships – lattice or fixed network (Nowak & May 1992)
- **Tags – scalable, single round, simple (Holland 1993, Riolo 1997, Hales 2000)**

Tags – New and Novel Mechanism for Cooperation

What they are they?

Some previous tag models.

Thoughts on how they work.

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What are “tags”

- Tags are observable labels, markings or social cues
- Agents can observe tags
- Tags evolve like any other trait (or gene)
- Agents may discriminate based on tags
- John Holland (1992) => tags powerful “symmetry breaking” function in “social-like” processes
- In GA-type interpretation, tags = parts of the genotype reflected directly in the phenotype

Recent tag models

- Tags may be bit strings signifying some observable cultural cue
- Tags may be a single real number
- Most show cooperation / altruism between selfish, greedy (boundedly rational) agents
- No worked-out analytical proof
- Nobody really know why it works!
- Necessary or sufficient conditions?

Tags in the literature

Year	*Author(s)*	*Tag Type*	*Model*	*Interp.*	*Task*	*Ref*
1993	Holland	general / real no.	none	socio. / bio	IPD	SFI WP
1997	Riolo	real number	bio.	bio.	IPD	SFI WP
2000	Hales	binary string	socio.	socio.	PD	MABS2000
2001	Riolo et al	real number	socio.	socio.	giving game	Nature
2002	Hales	real number	socio.	socio.	special-isation	MABS2002
2003	Hales & Edmonds	binary string	agents	agents	help giving	AAMAS2003
2003	Hales & Edmonds	various	agents	agents	various	ESOA2003
2004	Hales	network links	p2p	p2p	PD	ESOA2004
2004	Hales	network links	p2p	p2p	file-sharing	IEEE p2p2004

A generic evolutionary algorithm

```
Initialise all agents with randomly selected strategies
LOOP some number of generations
    LOOP for each agent (a) in the population
        Select a game partner (b) from the population
        select a random partner with matching tag
        Agent (a) and (b) invoke their strategies
        receiving the appropriate payoff
    END LOOP
    Reproduce agents in proportion to their average payoff
    with some small probability of mutation (M)
END LOOP
```

Results

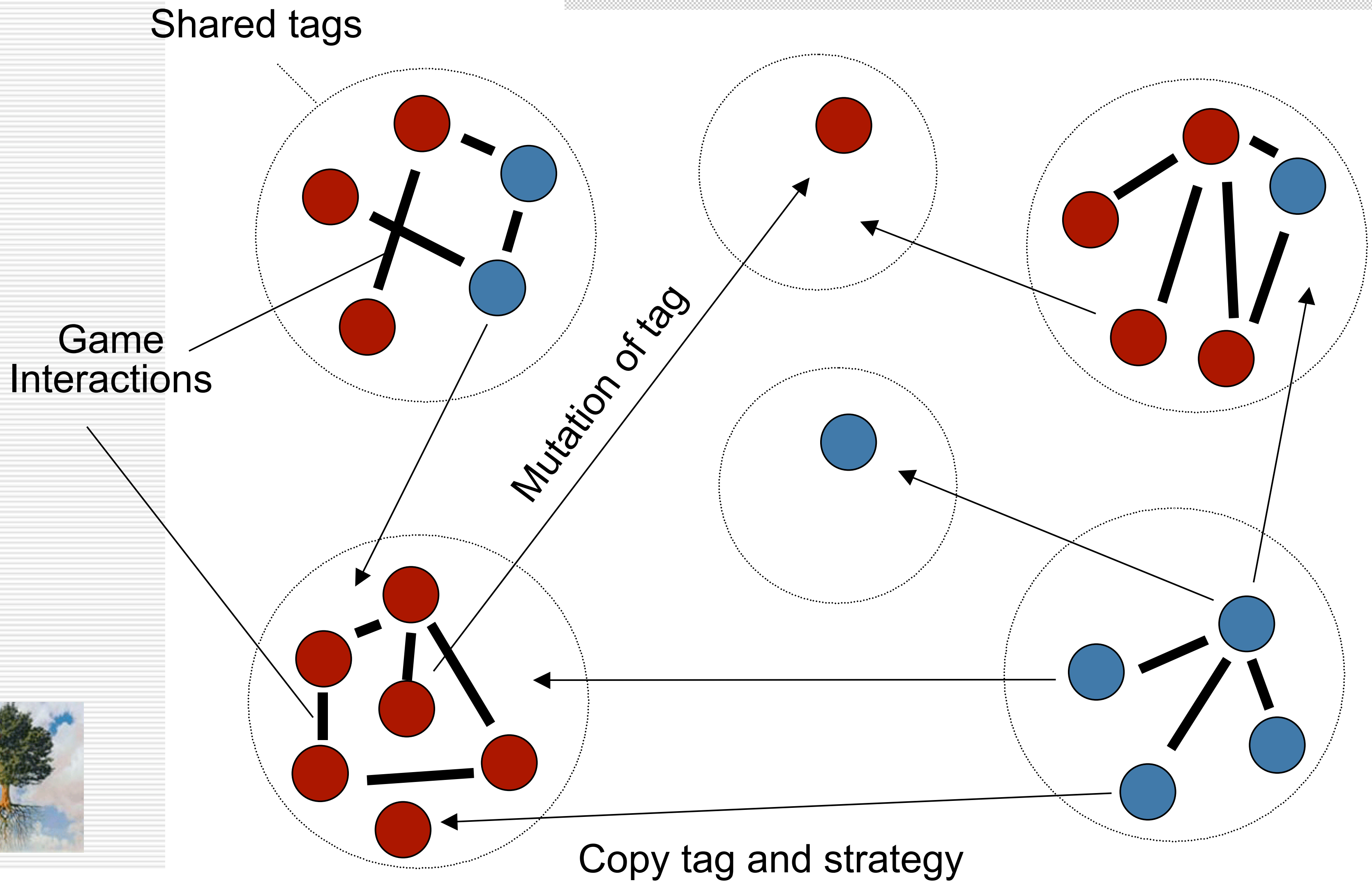
- Very high levels of cooperation
- Even when all agents initialised as defectors
- Over broad range of parameters
- For binary string tags – needed > 8 bits
- Mutation rate needs to be within some range
- What kinds of process appear to be occurring?

Agents - a Tag and a PD strategy

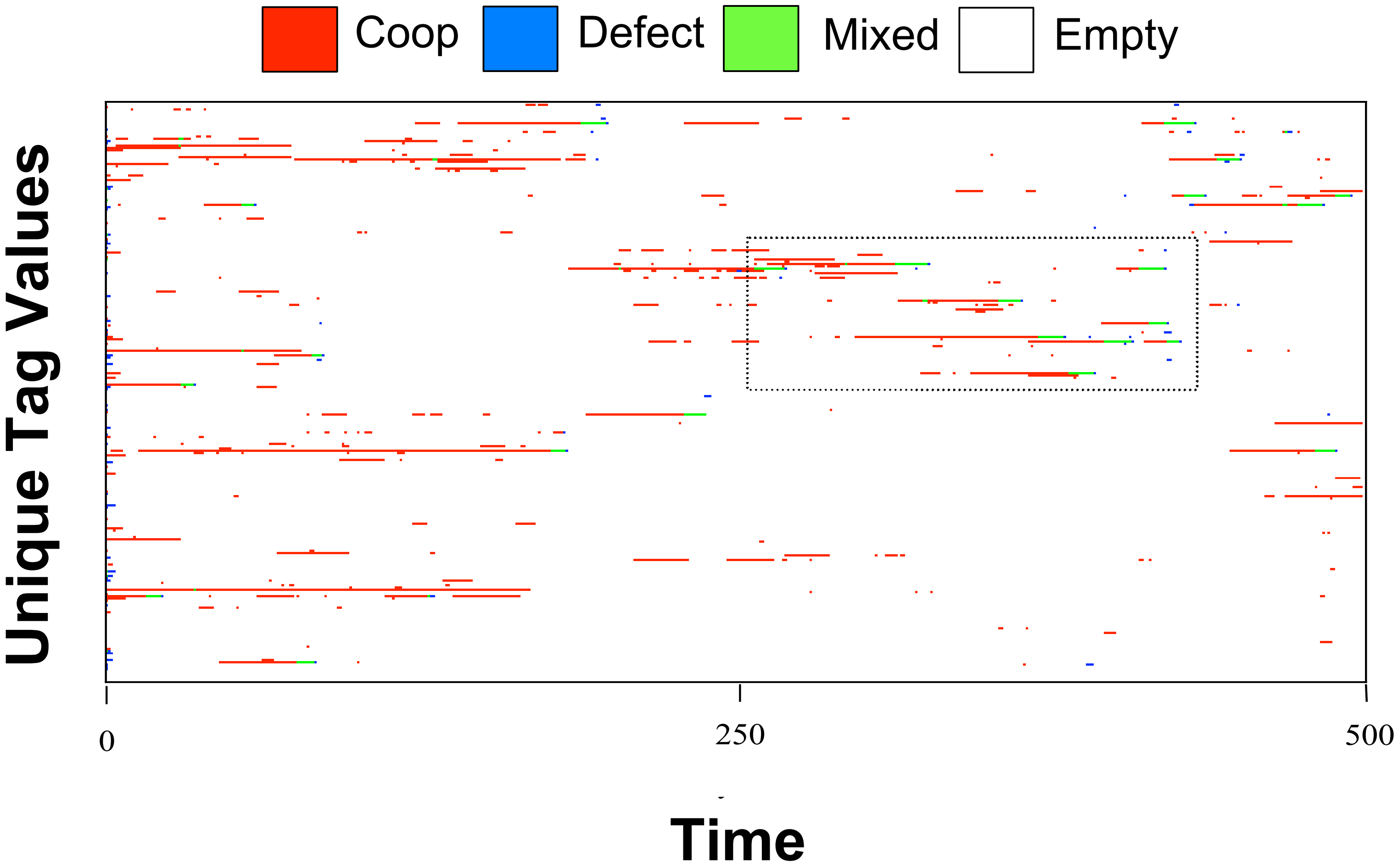
Tag = (say) Some Integer

Game interaction between those with same tag
(if possible)

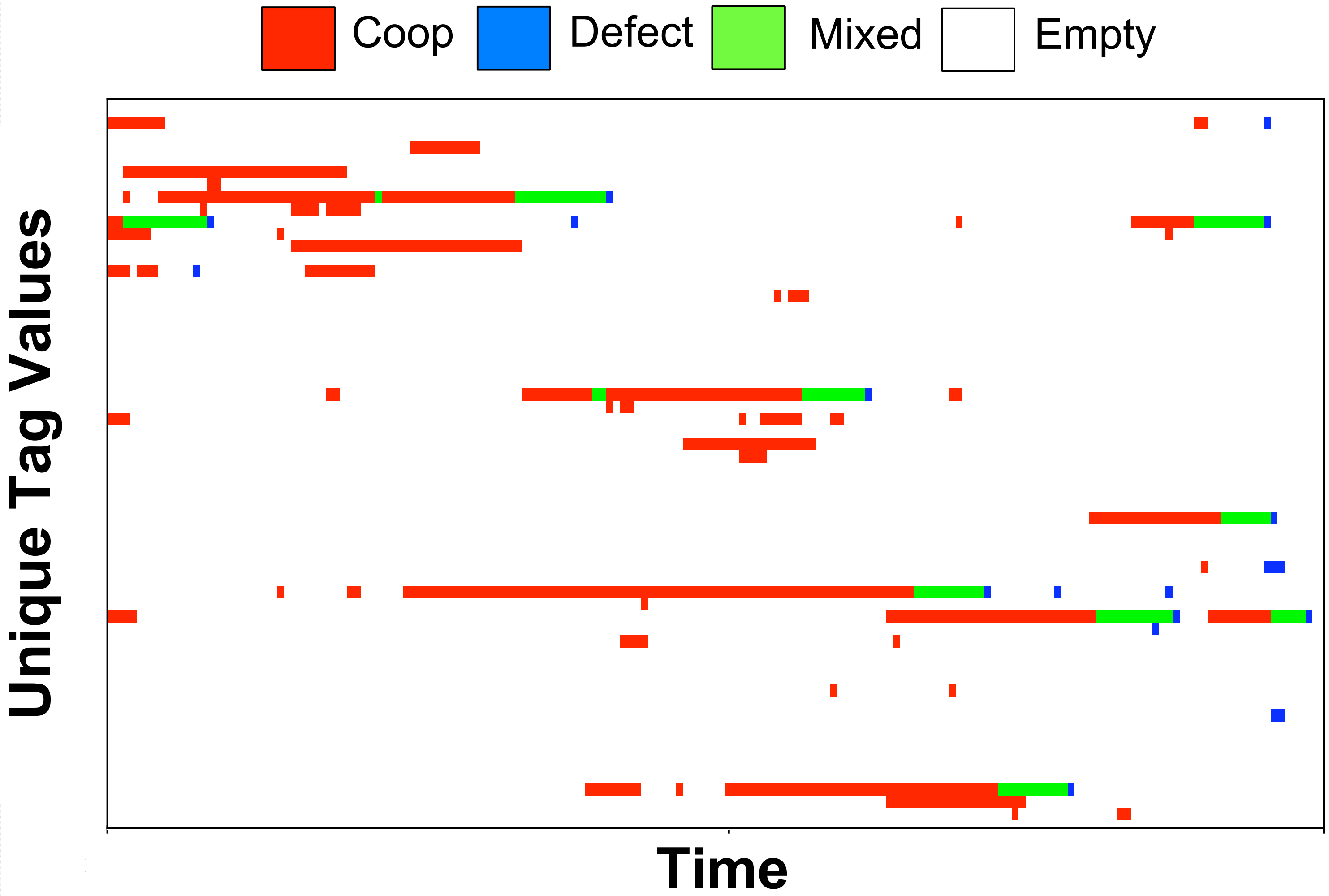
Thinking about how tags work



Visualising the Process



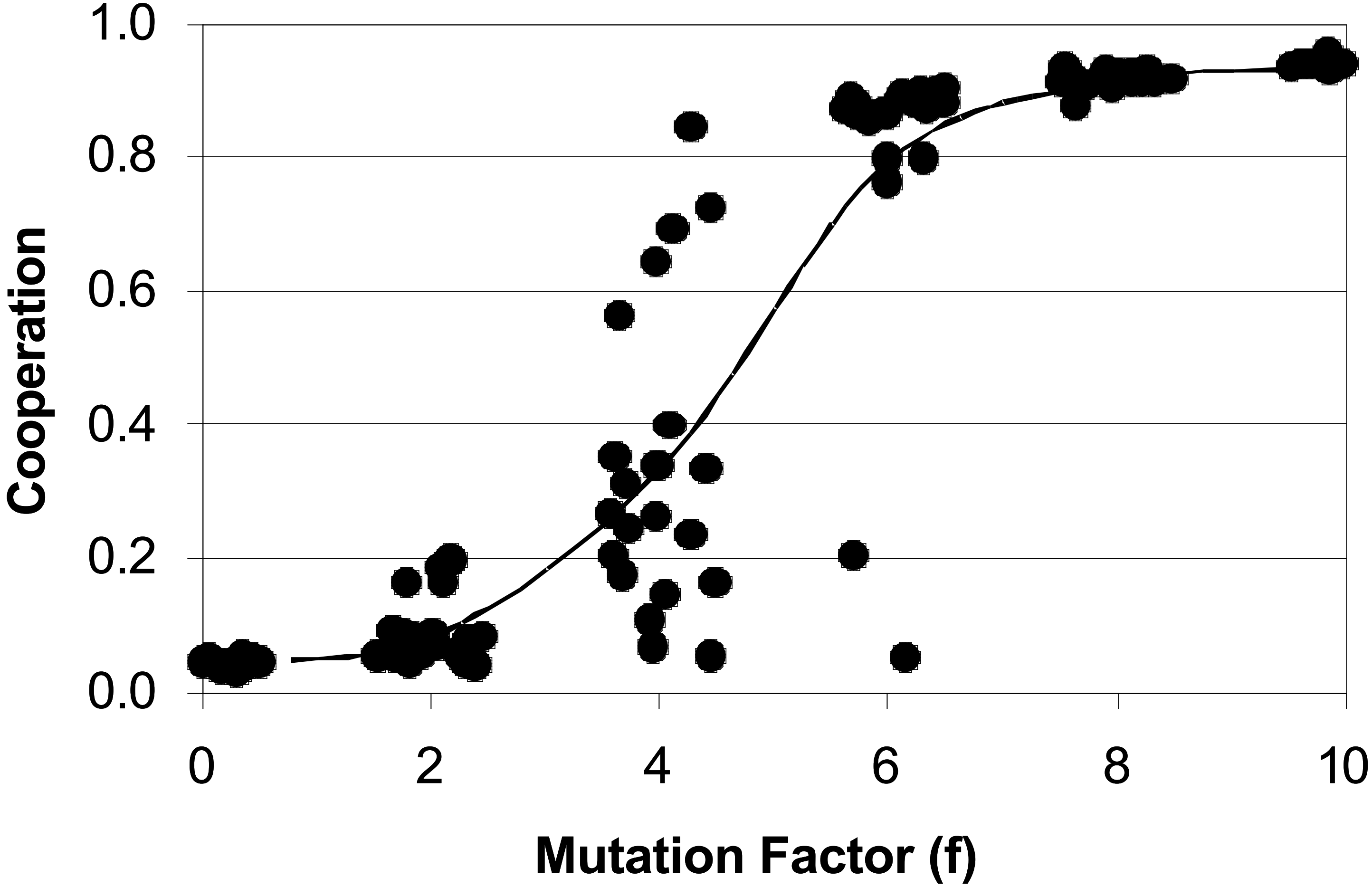
Visualising the Process



Hypothesis

- Groups have to be formed more quickly than they invaded and killed
- New groups are formed by mutation on the tag
- Old groups are killed by mutation on the strategy
- So if tag mutation > strategy mutation this should promote cooperation?
- Test it by looking at the existing models and implementing a new one

Varying tag mutation rate relative to strategy mutation rate



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Conclusions

- Hypothesis – high mutation required on the tag than the strategy to produce high cooperation
- Appears to hold (in some form) in ***all previous models*** – often obscured by model details
- But without formal analysis how can we know this is necessary?
- Could show it's necessary for existing results by reproducing models and changing assumption
- Has helped in translating to new domains – P2P network model (tomorrow @ ESOA workshop)

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Translating Tags into a P2P Scenario

All well and good, but can these previous results be applied to something like looks more like: unstructured overlay networks with limited degree and open to free riders

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A P2P Scenario

Consider a P2P:

- Assume nodes maintain some max. no. of links
- 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 RND 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.

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Initial thoughts and questions

- For tag-like dynamics high clustering would appear to be required (groups required)
- Will dynamic nature of the scenario support this?
- Can cooperation be maintained without it?
- We might start simulations of the model with high clustering initially (say small world or lattice) and compare that to random networks
- Many schemes of “neighbourhood copying and mutation” are possible which to use?
- What kind of topologies emerge over time?

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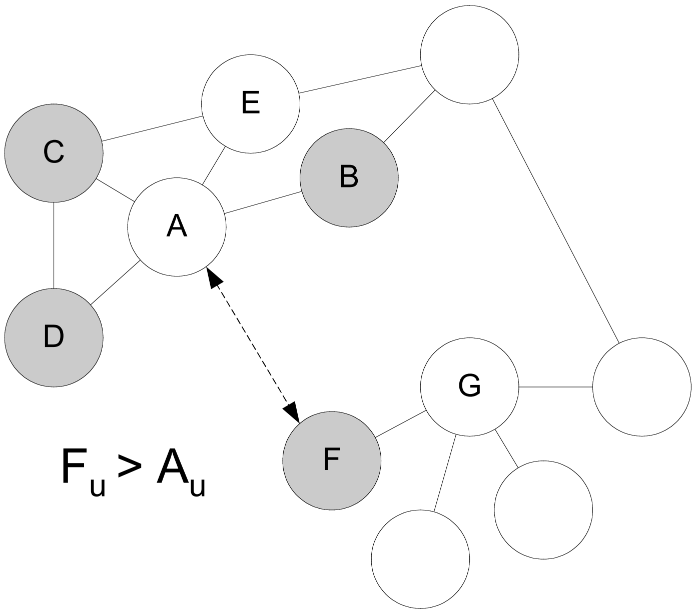
Design Decisions

- Mutation of neighbourhood = replace all neighbours with a single neighbour chosen at random from the population
- Mutation on strategy = flip the strategy
- Node j copying a more successful node i = replace i neighbourhood with j’s U j itself
- When maximum degree of node is exceeded throw away a randomly chosen link
- Payoffs as before: T=1.9, R=1, P=d, S=d

Social Climbing, Ostracism, Replication

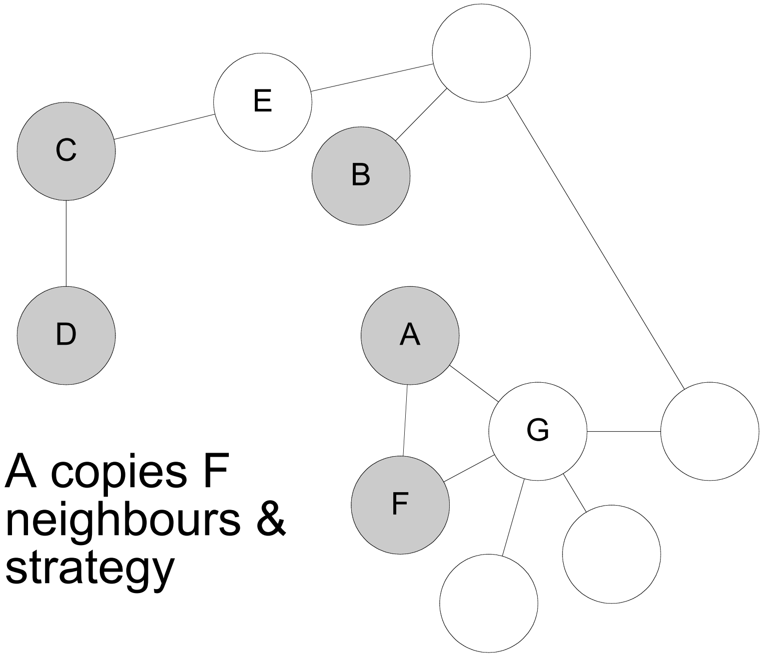
Before



$F_u > A_u$

Where A_u = average utility of node A

After

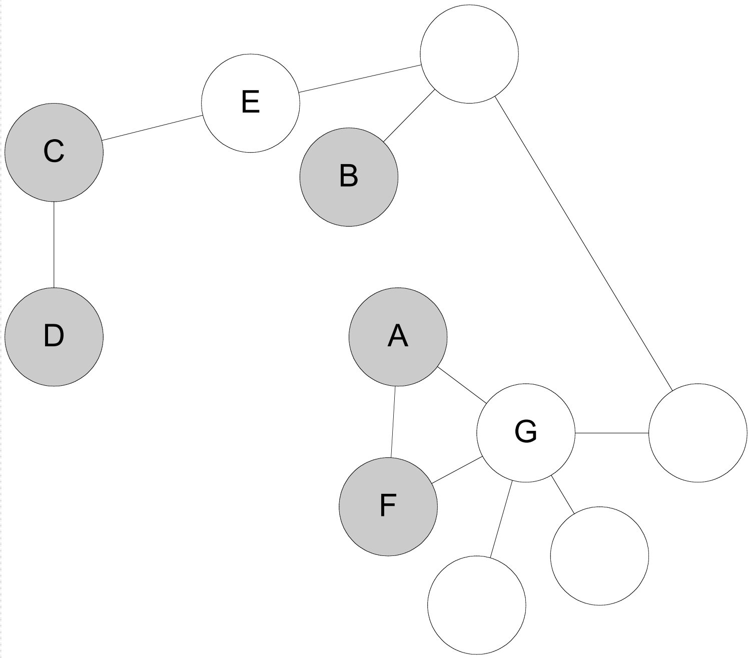


A copies F neighbours & strategy

In his case mutation has not changed anything

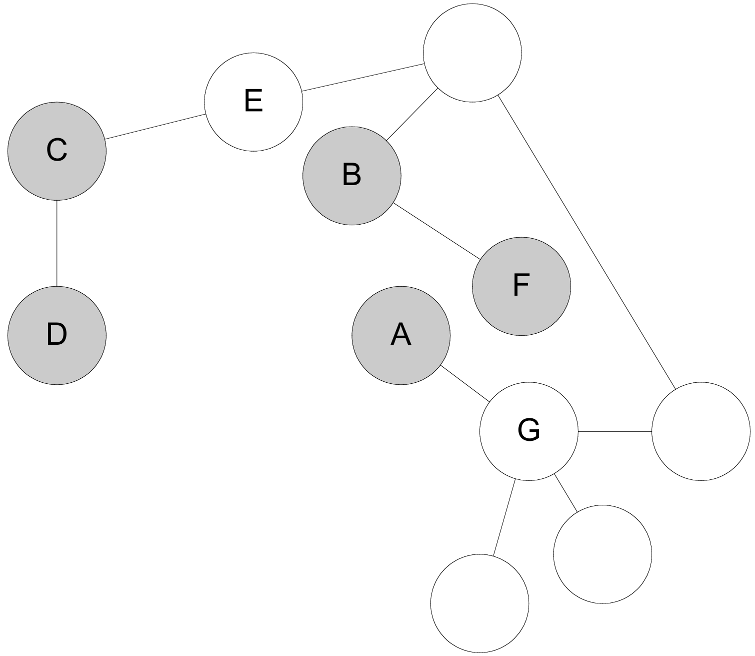
Mutation on the Neighbourhood

Before



Mutation applied to F's neighbourhood

After



F is wired to a randomly selected node (B)

The Simulation Cycle

LOOP some number of generations

  LOOP for each node (i) in the population N

    Select a game partner node (j) randomly from neighbour list

    Agent (i) and (j) invoke their strategies and get appropriate payoff

  END LOOP

  Select N/2 random pairs of agents (i, j) reproduce higher scoring agent

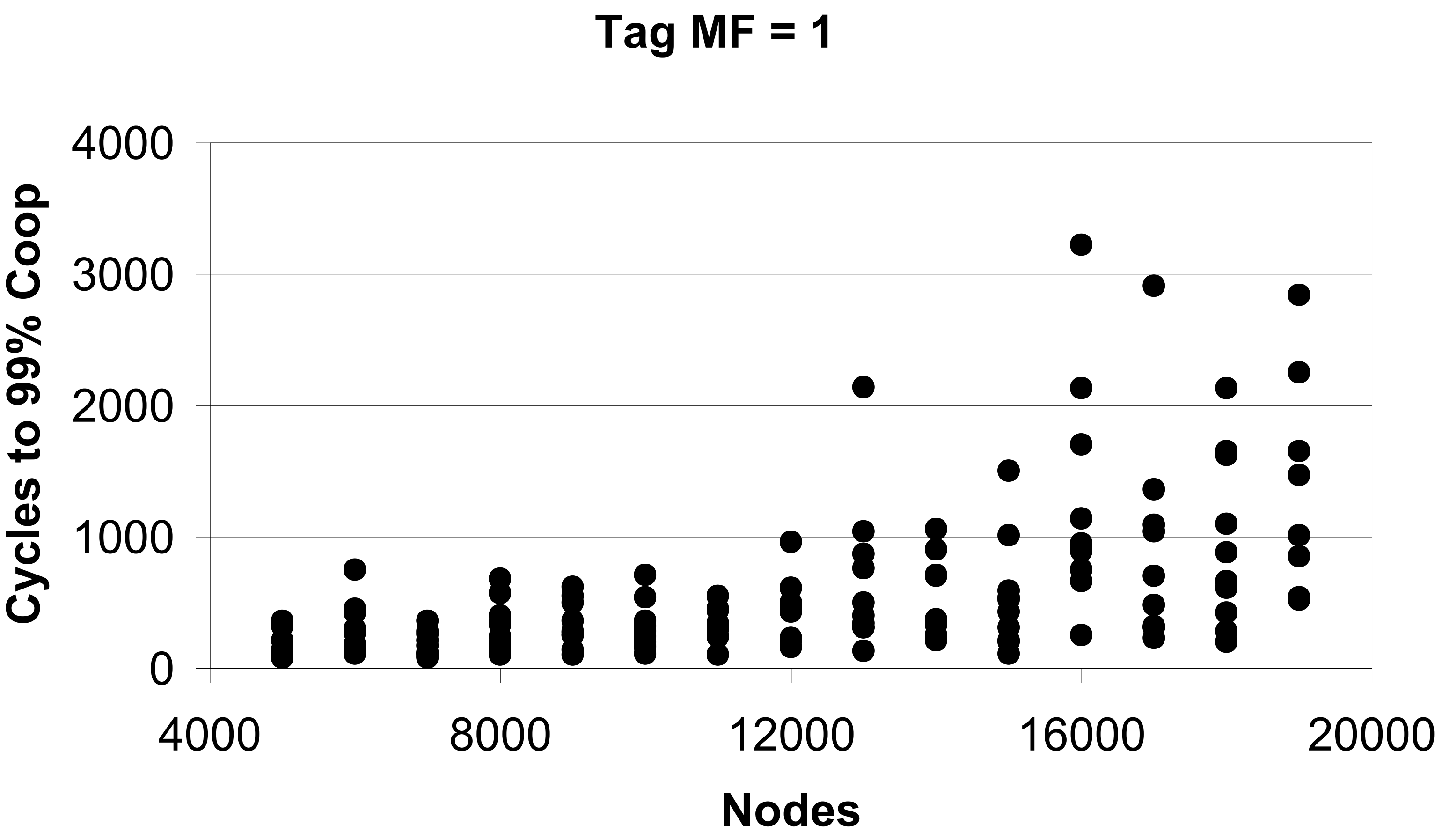
  Apply mutation to neighbour list and strategy of each reproduced agent with probability m

END LOOP

Parameters

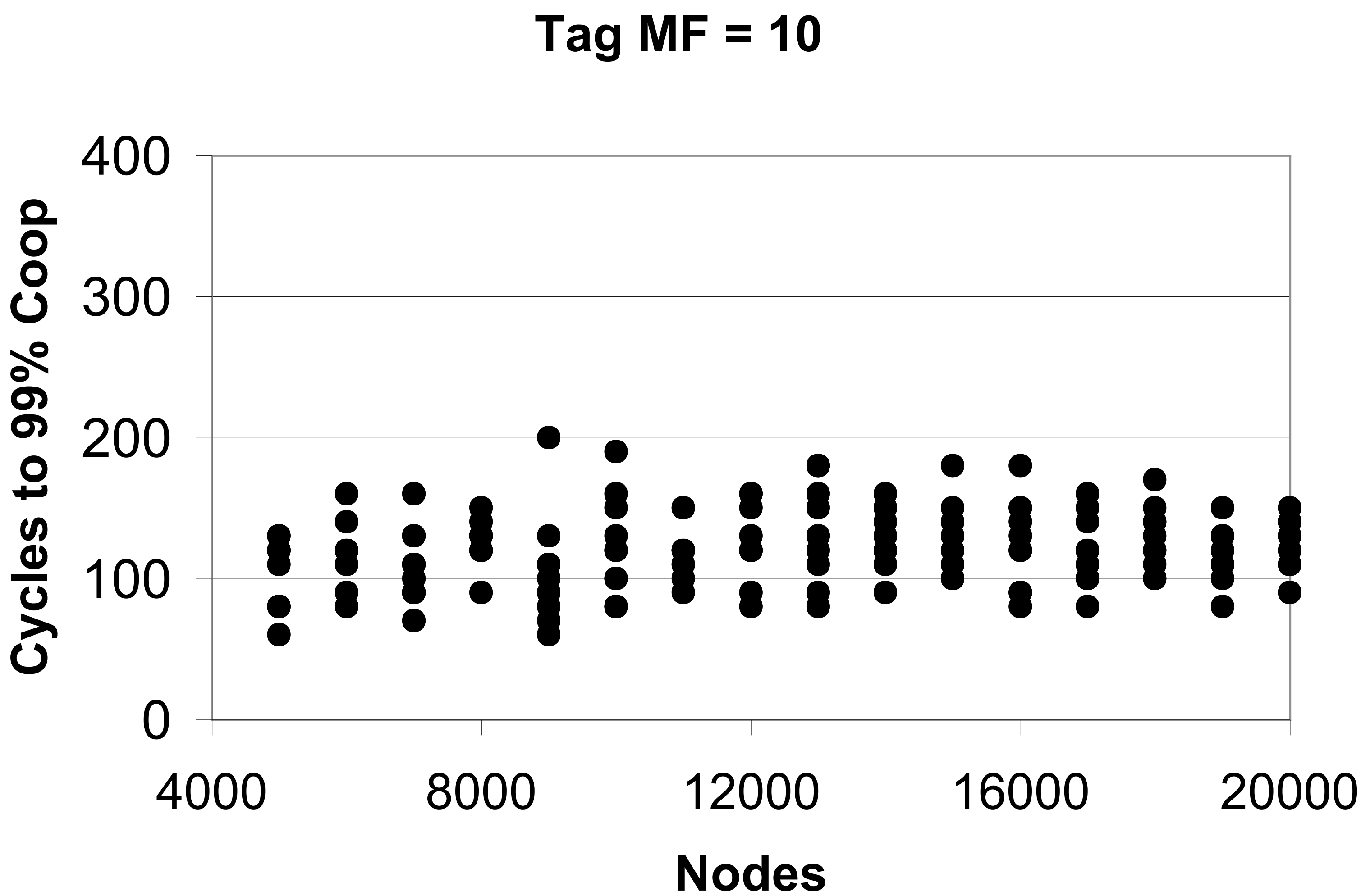
- Vary N between 4,000..120,000
- Maximum degree 20
- Initial topology random graph
- Initial strategies all defection (not random)
- Mutation rate m = 0.001 (small) a previous
- Payoffs as before: T=1.9, R=1, P=d, S=d (where d is a small value)

Results

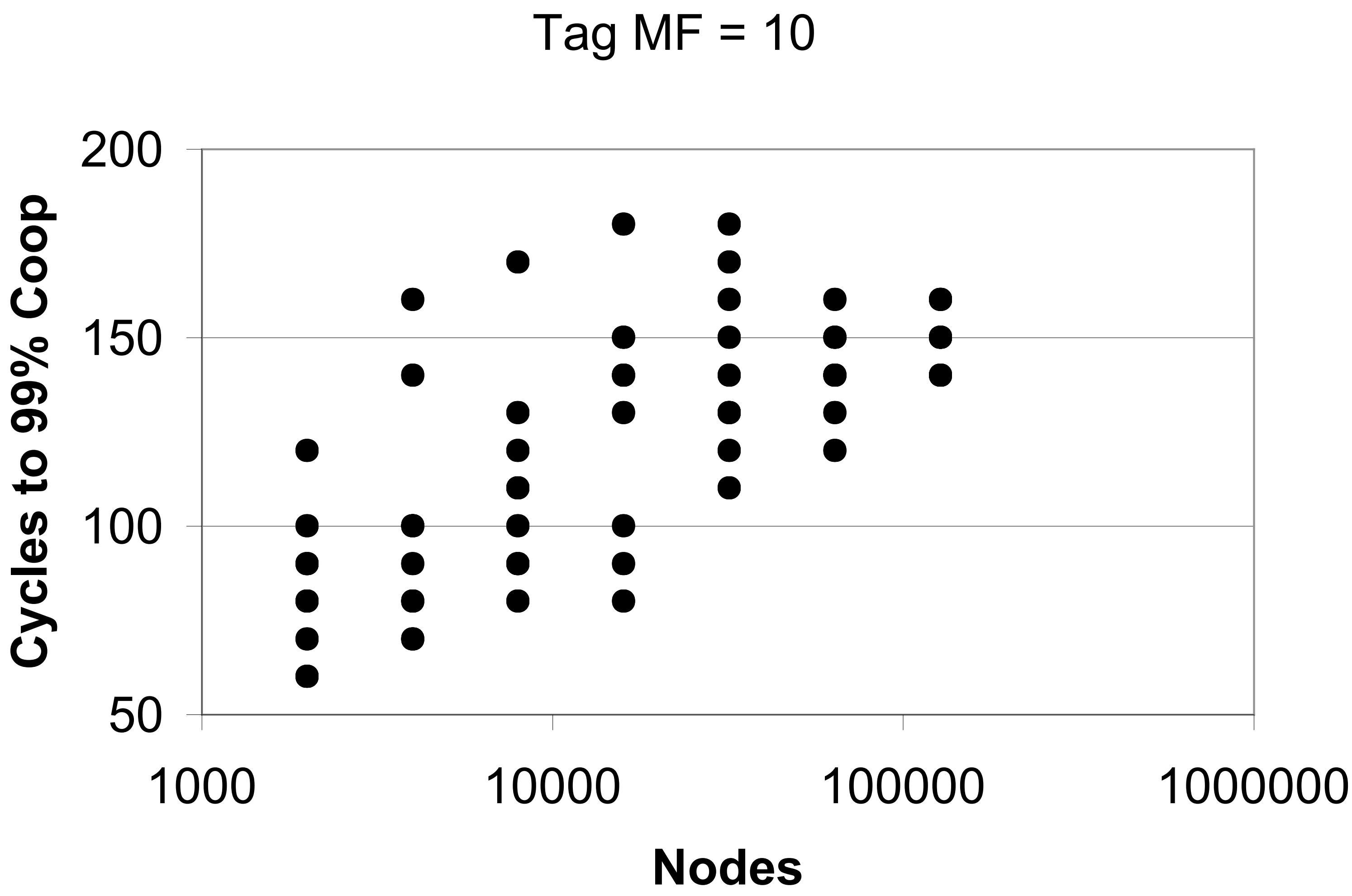


Tag MF = 1
Cycles to 99% Coop
4000
3000
2000
1000
0
4000
8000
12000
16000
20000
Nodes

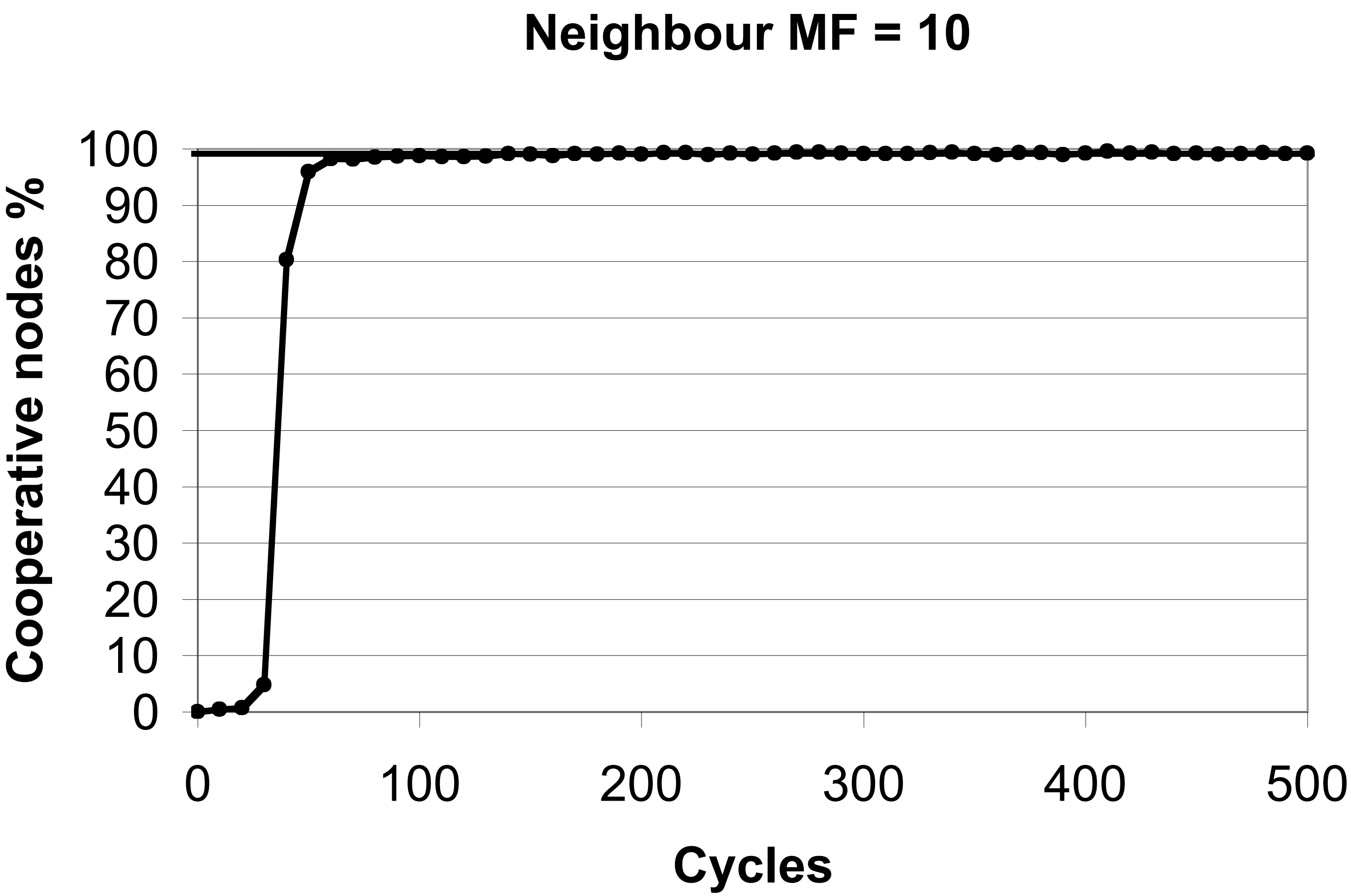
Results – increased mf=10



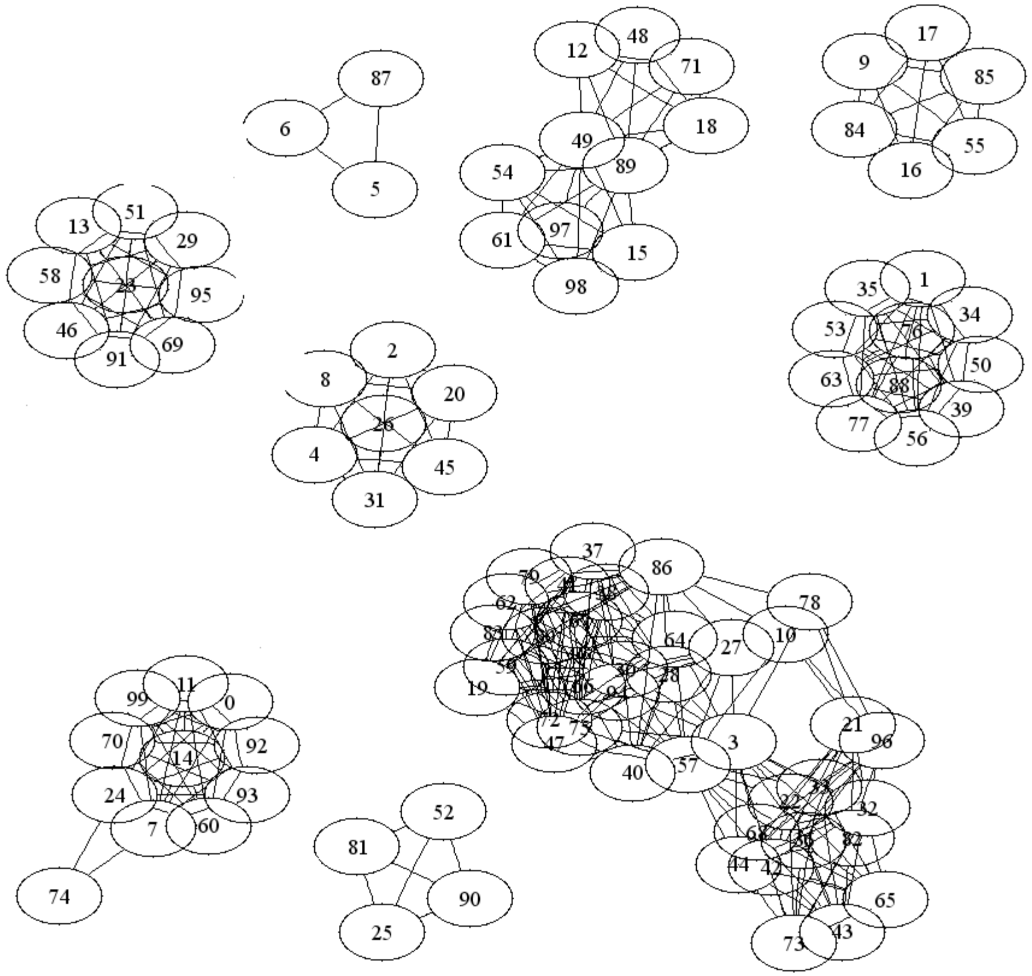
A few more nodes



A typical run (10,000 nodes)



A 100 node example – after 500 generations



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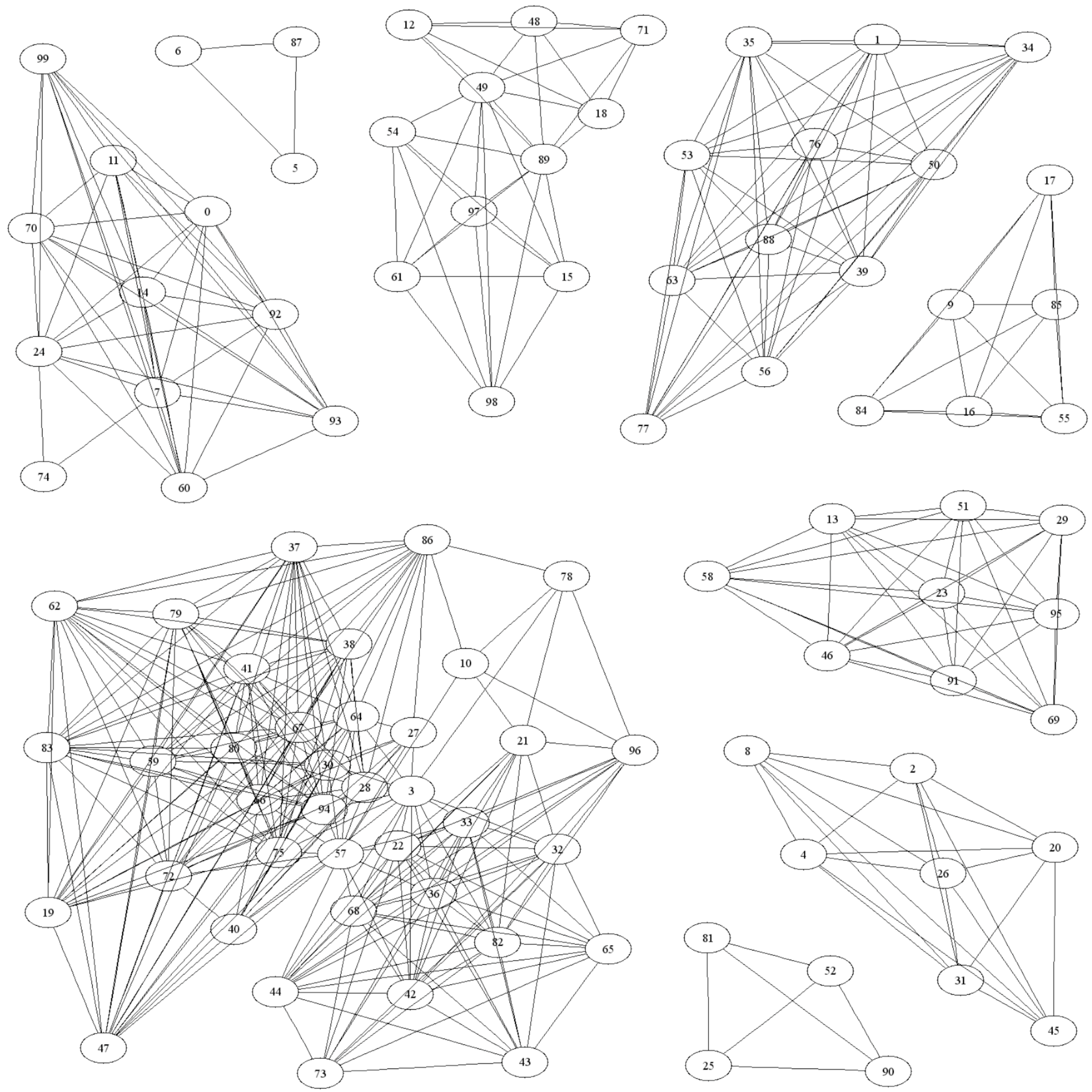
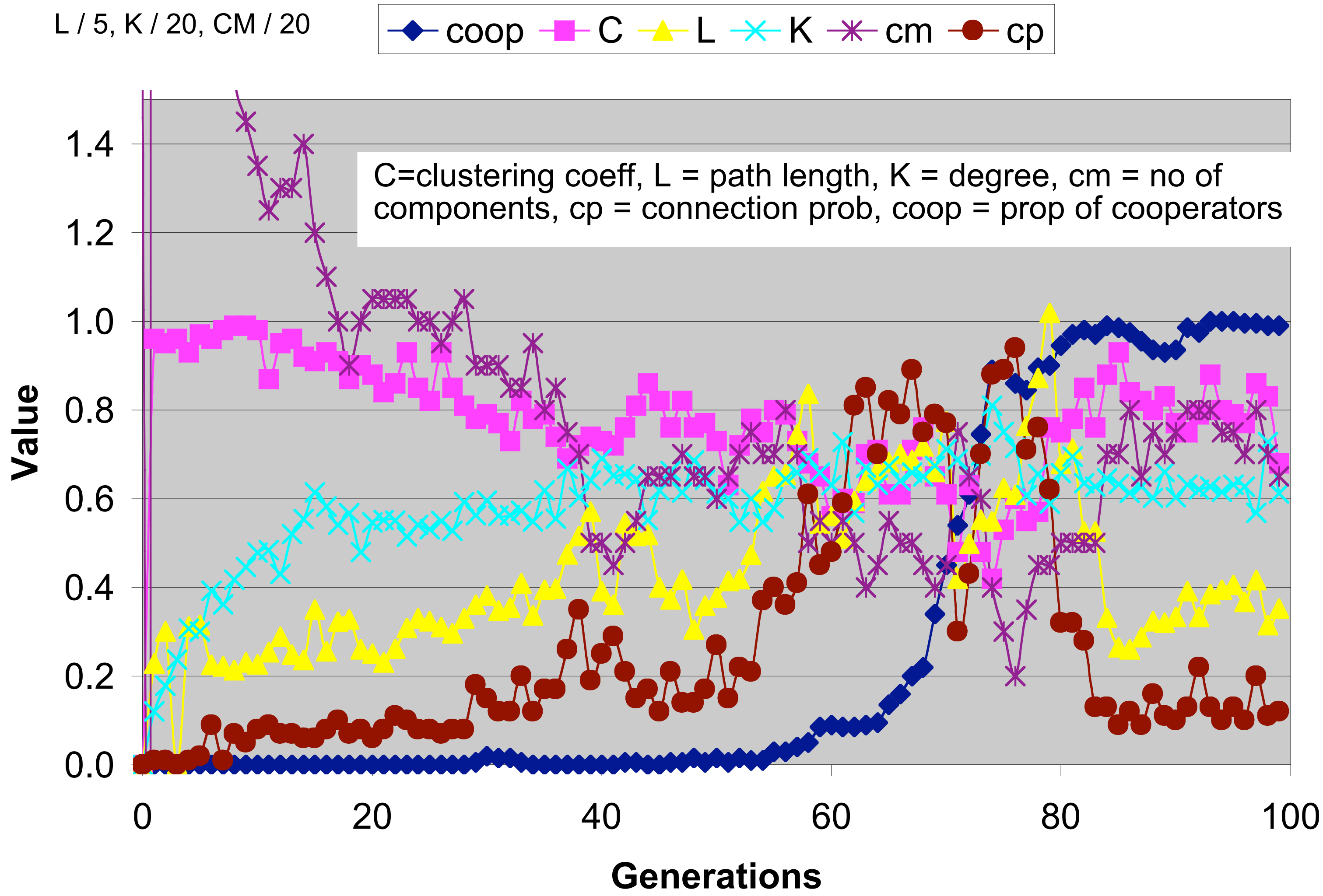

99 6 87 5 11 0 70 14 92 24 7 93 74 60
12 48 71 49 18 54 89 97 61 15 98
35 1 34 53 76 50 88 63 39 56 77
17 9 85 84 16 55
37 86 78 62 79 38 41 10 64 67 27 83 59 80 30 21 96 28 3 66 94 33 75 57 22 32 72 36 19 68 40 82 65 44 42 47 73 43
13 51 29 58 23 95 46 91 69
8 2 20 4 26 31 45
81 52 25 90

Topology Evolution – so far it seems….

- From ANY initial starting topology / strategy mix same outcome (tried random, lattice, small world, all nodes disconnected, all defect, random, all coop)
- Typically (very approx.) a max of n/10 unstable components exist at any one time which are highly internally connected (L not much more than 1 and C very high)
- But they are not of equal size
- Constantly reforming and changing due to mutation and replication
- Rough characterisation of disconnectedness = prob. that two random nodes are connected

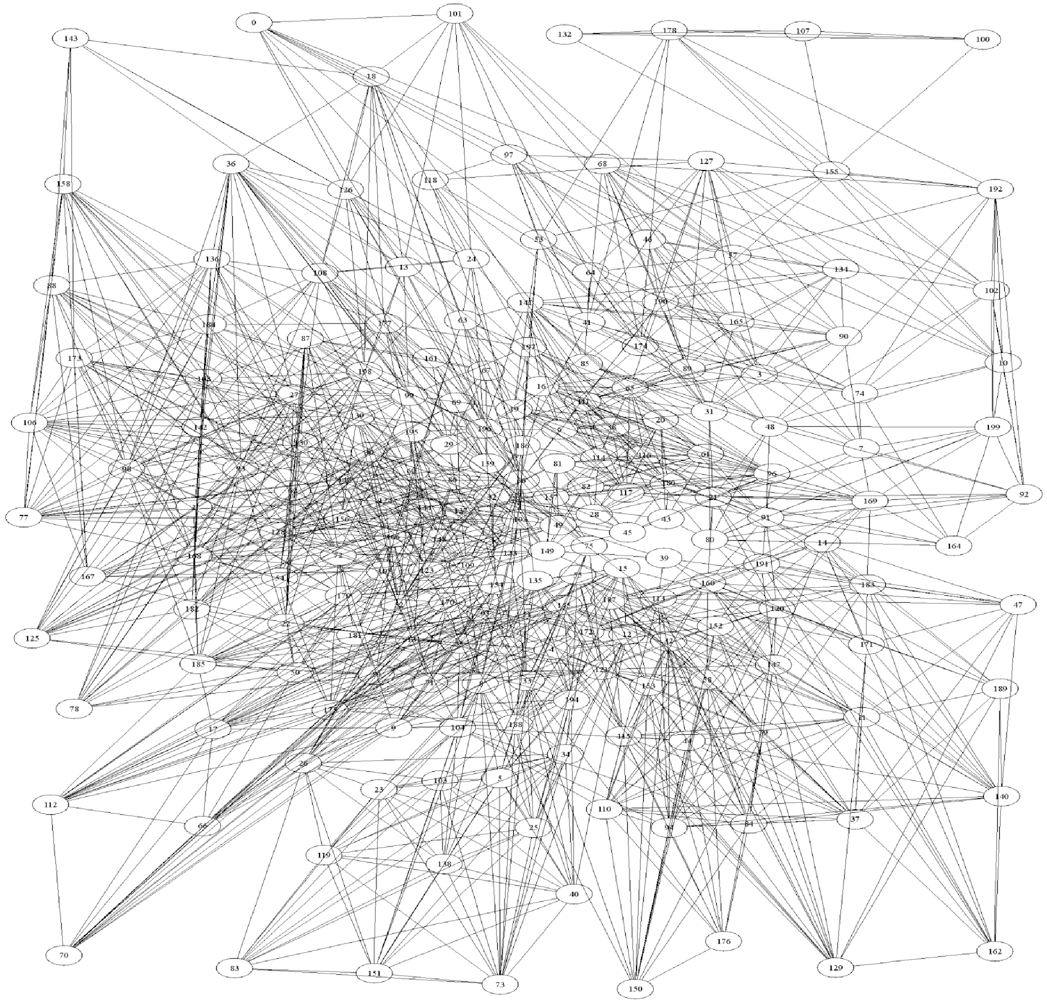
Typical run, 200 nodes



A message passing game

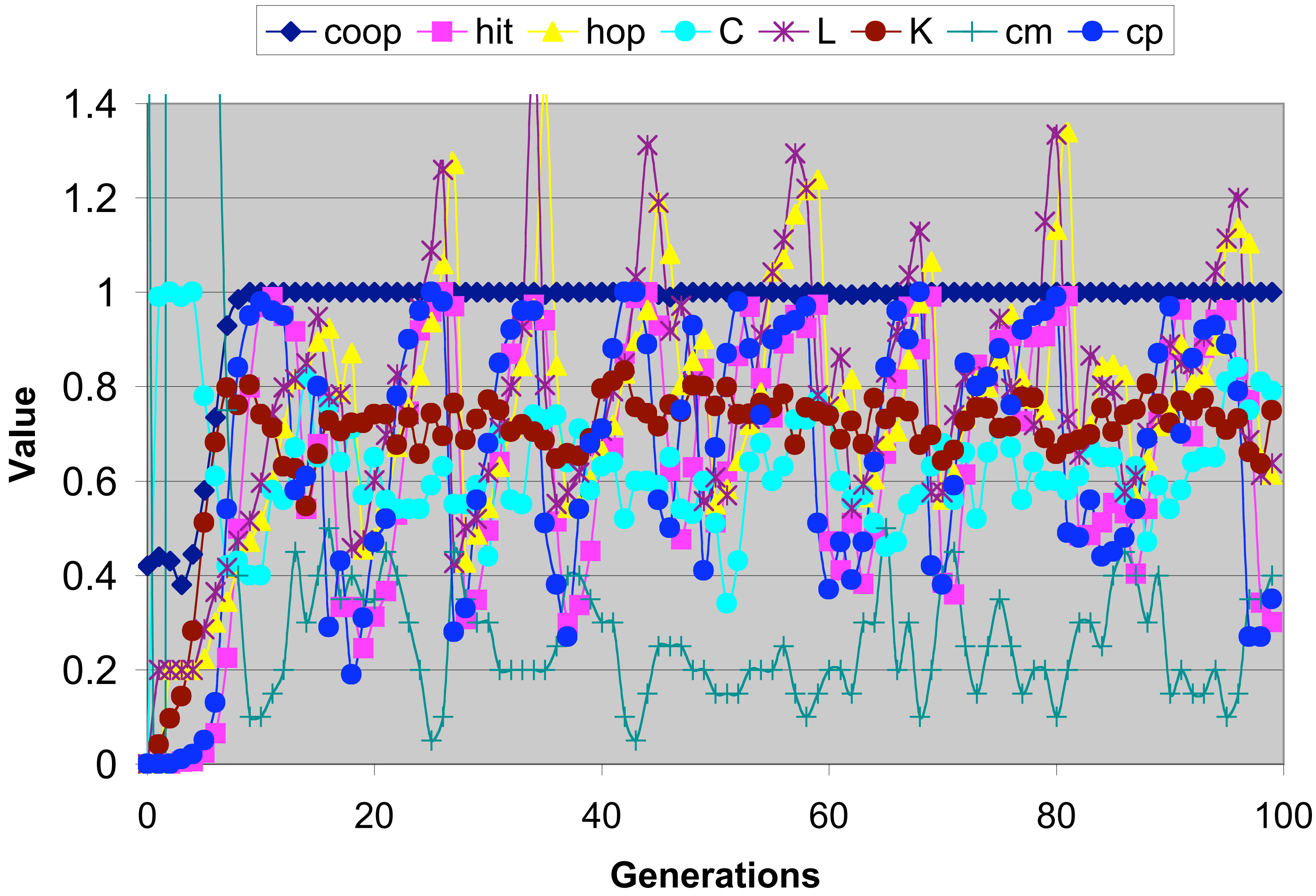
- Keep everything the same but change “game”
- A message passing game – select two nodes (i,j) randomly from G. i tries to send a message to j.
- Do a flood fill query from i to j.
- If a route of *cooperators* is found from i to j then i gets a “hit” (one point added to score)
- Only cooperators pass on a messages incurring a small cost for doing so, reducing score
- Hence defectors will do better than cooperators getting the same proportion of hits
- Tough task since need a route between specific nodes via a chain of coops only

Message Passing game - 200 nodes after 500 generations



Message passing game - 200 nodes to 100 generations

L / 5, K / 20, CM / 20



But its not as good as it seems...

- Increased games to 25n per generation
- Start with random strategies (all def. no good)
- Does not appear to scale well (oscillations)
- More work needs to be done (only a few runs)
- A very tough test for scaling on this mechanism
- On reflection - surprising it did this well
- Try “easier” and more realistic “game”

Next steps

- Assume random selections from the population (will it work with network generated selections?)
- Realistic task (file sharing) (Qixiang Sun & Hector Garcia-Molina 2004 – see Hales 2004 IEEE P2P2004)
- So far robustness tested as effect of mutation – static pop size – try drop or introduce lots of nodes at once
- Simplistically treats all neighbour links as “one chunk” rather than selectively removing links (eliminate comparison also?) various schemes possible
- Modified form might enhance BitTorrent?

Conclusion

- Tag-like dynamics can be put into a network using simple rewiring rules
- Even simple rules appear flexible, able to create and maintain different topologies for different tasks
- Free-riding is minimised, even though node behaviour selfishly and have no knowledge of past interaction
- At least for close neighbour interaction the method scales well
- But much more analysis needs to be done and more realistic kinds of p2p task domain need to be tested