Endogenous Cooperation Networks

A Complex Systems Approach

Simon Angus

School of Economics, University of NSW, Sydney, Australia

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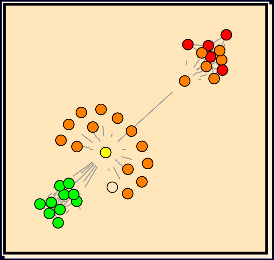


Two General Questions

Question
How do popluations decide between behaviours?

Question
When might 'risky' (but helpful) behaviours become stable in a population?

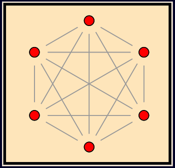
Context of inquiry:

1. Coordination (economic: technology adoption, cultural: 'norms')
2. Cooperation (e.g. trust, corruption *sans* institutions)

A Pathway into Complexity

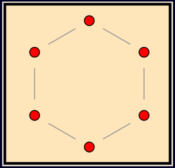
Uniform

- ‘Trembling towards equilibrium’ (best-response with mistake-making)
- Risk-dominant eq.
- e.g. KMR (1993)



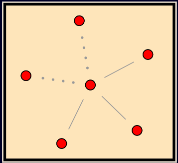
Circle, Line, Grid

- Best-response, with **local** interactions
- Risk-dominant with acceleration
- e.g. Ellison et. al (1993–2000)



Dynamic

- Best-response graph-formation
- Inefficient and non-risk-dominant eq. possible
- e.g. Jackson & Watts (2002)



Modelling Motivation

Limitations of Analytic Work:

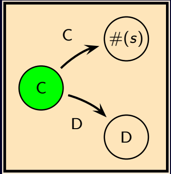
- Strategies other than the Best-response (utility maximizing) hard to model analytically;
- Non-uniform (and non-regular) interaction spaces very challenging;
- Dynamic, interaction spaces, with diverse boundedly rational agents (seemingly) impossible to incorporate analytically...
- But, computational, agent-based approaches well suited!

Desirable Computational Model Qualities:

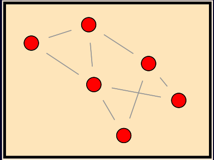
- 'Simple' set-up – relationship to previous literature
- Endogenous (strategy-based, rather than observer based) interaction-space dynamics;
- Allowance for realistic behaviours (inc. irrational play)

Model Overview

1. *Game*: Reward for cooperative, but risky play (modified IPD)
2. *Agents*: Finite State Automata (FSA), GA updating
3. *Mixing*: Uniform initially, but updated based on interactions/strategies (unknown, 'strengthen', 'weaken')



$$\pi[\eth^*] = \begin{array}{c|cccc} & \#_w & C & D & \#_s \\ \hline \#_w & (0,0) & \cdots & & (0,0) \\ C & \vdots & (3,3) & (0,5) & \vdots \\ D & & (5,0) & (1,1) & \\ \#_s & (0,0) & \cdots & & (0,0) \end{array}$$

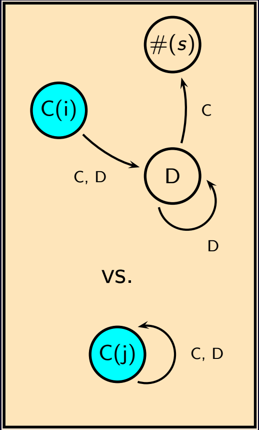


Example Interaction

1. Agent i interaction probabilities determine m opponents in one period;
2. Here, drawn to play agent j;
3. IPD: interaction stopped if $\#(x)$ played, or κ iterations reached;

Iteration	P_i	P_j	π_i	π_j
1	C	C	3	3
2	D	C	5	0
3	$\#(s)$	C	0	0
$\sum \pi_x$			8	3

4. $\sum \pi_x$ added to period payoffs;
5. Interaction structure updated (here, $i \nleftrightarrow j$).



Model Validation: Uniform Interactions

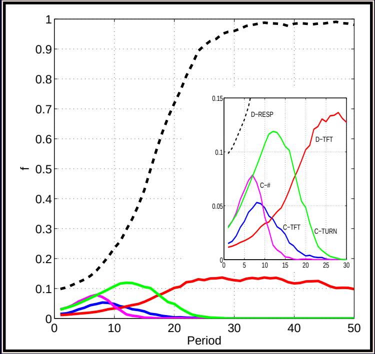
Network 'strength': $\eta \in [0, 1]$

Set $\eta = 0$

- Remark

  For all initial distributions of three-state FSA playing the game Ↄ* under $\kappa = 2$, the strategy triplet $s_D : \{P, R(C, D)\} = \{D, (\{C, D\}, D)\}$ is the only evolutionary stable strategy.

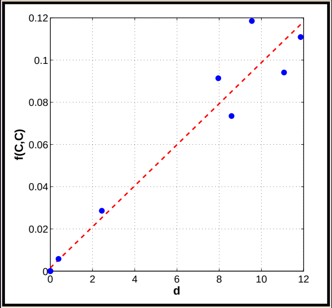
- Computationally, this result is confirmed (20 trials; 100 agents; $m = 20$).



$\eta > 0$: Network formation & Cooperation

'Frequency' & 'Choice'

- Cooperation and average degree strongly related;
- Frequency of interaction AND 'impact' of edges necessary for sustainable cooperation-networks.

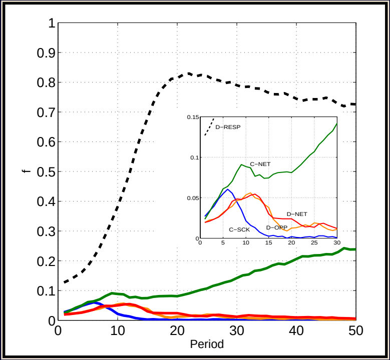


$m \diagdown \eta$	$\bar{d}$ 0.80	$\bar{d}$ 0.90	$\bar{d}$ 0.95	$f(C,C)$ 0.80	$f(C,C)$ 0.90	$f(C,C)$ 0.95
10	0.000	0.000	0.000	0.000	0.000	0.000
14	0.004	0.001	0.391	0.000	0.000	0.006
18	2.441	11.859	8.587	0.029	0.111	0.074
20	7.959	11.073	9.548	0.091	0.094	0.119

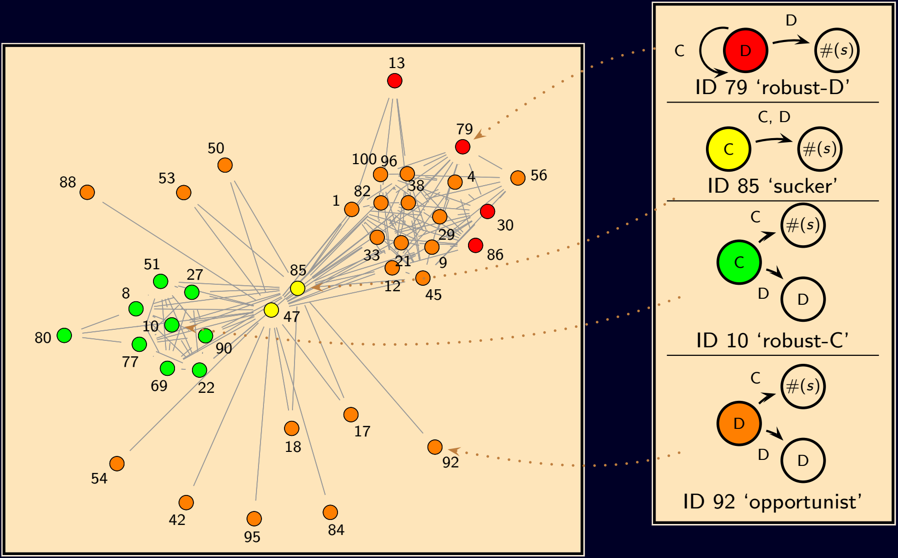
$\eta > 0$: Mean Population Behaviours

Establishing the Network ($m = 20, \eta = 0.8$)

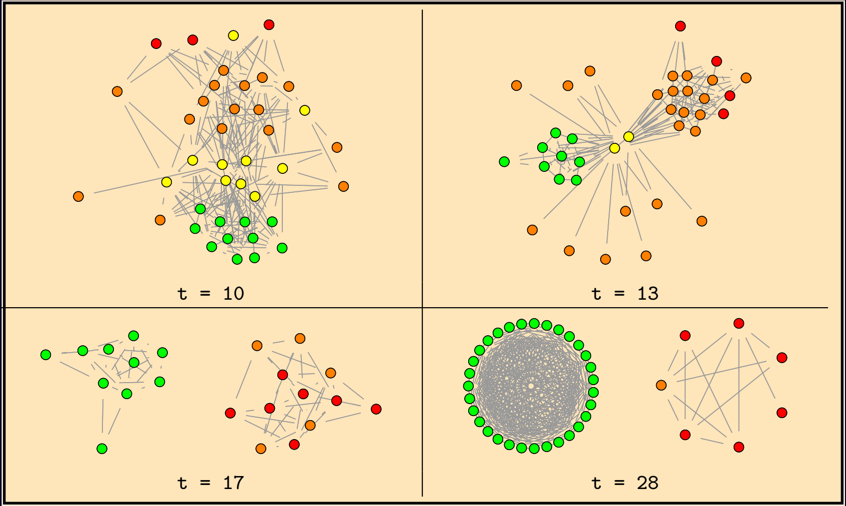
- Periodic behaviours observed: 'sucker' types; 'opportunists'; cooperation network builders; and defection network builders;
- 'Shake-out' period as before, but cooperation network resiliant;
- In network forming trials, cooperative network grows to encompass $\sim 60\%$ of population



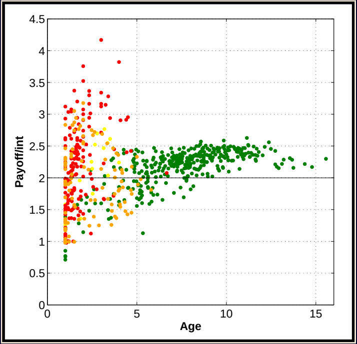
Unmasking the Dynamics



A Dynamic Tour ...



Results Summary



Payoff per interaction vs. Connected component average agent 'age'

Important Factors in Robust Network Formation

- Richness of recognition strategy – selects **assortatively**; protects against exploiting behaviours;
- Strength of edge formation – link creation must have sufficient impact on mixing probabilities;
- Frequencies of interaction – beneficial relationships must be sufficiently revisited;
- Topological effects (Logit) – $L(G)$ significant ($\ominus$) in connected component survival (rôle of hubs?)

Current/Future

- Longer-run effects – behavioural epoch formation?
- Extension of agent 'intelligence' (↑ states) – stable heterogenous behavioural network creation?
- Network breaking in a dynamic behavioural and network responding environment – law-enforcement implications for corruption?

Simon Angus, UNSW
s.angus@student.unsw.edu.au

(MATLAB–LaTeX software: graph-, FSA-, visualisation, &c.)