The Socio-economics of Pervasive Systems

David Hales

The Open University, UK

www.davidhales.com

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Quote:

"The ideas of economists and political philosophers, both when they are right and when they are wrong, are more powerful than is commonly understood. Indeed the world is ruled by little else. Practical men, who believe themselves to be quite exempt from any intellectual influence, are usually the slaves of some defunct economist."

John Maynard Keynes (English economist, journalist, and financier, 1883-1946)

Quote:

"The philosophers have only interpreted the world, in various ways. The point, however, is to change it."

"From each according to his abilities, to each according to his needs."

Karl Heinrich Marx (German political philosopher, political economist, and social theorist, 1818-1883)

Quote:

"It is not from the benevolence of the butcher, the brewer, or the baker that we expect our dinner, but from their regard to their own interest. We address ourselves, not to their humanity, but to their self-love, and never talk to them of our own necessities, but of their advantages."

Adam Smith (Scottish economist and philosopher, 1623-1790)

Quote:

"during the time men live without a common power to keep them all in awe, they are in that condition which is called war; and such a war as is of every man against every man.”

Thomas Hobbes (English philosopher 1588-1679)

Big Picture

- Call it
  - Distributed systems
  - pervasive adaptive technology
  - Peer-to-peer or person-to-person
  - Mobile sensor networks
  - Adhoc networks
  - Self-organsing / Self-adaptive (SASO) systems
  - Socially intelligent systems
- That’s not important!

Big Picture

- What is important?
  - Increasingly these technologies will structure our interactions (transforming society)
  - Designing them requires assumptions that "boil down to" social and economic choices / theories
  - We should be aware of these to inform "good design"
  - Should we design systems for the *common good*?
  - If so then *what* is the common good? Who says?
  - Is there an "ethics" of good design?

Big Picture

- Technology can facilitate new kinds of economic / social organising forces:
  - Commons-based Peer Production (Wealth of Networks – Yochai Benkler)
  - Open source projects
  - Facebook / Twitter revolutions (overhyped?)
  - The P2P dream? (eliminate central control) – Replace the banks – Bitcoin / RipplePay - do you trust banks or open source software?

Designing such systems

- How can we model agents?
- Don’t cleaver people use game theory to prove things?
- Beware!
- tread carefully in this strange world
- Remember the quote by Keynes

Game theory comes with a whole set of assumptions

- Developed as a response to the problem of the cold war within RAND corporation
- Assumes extremely selfish and non-communicating agents
- And extremely intelligent and well informed agents – “rational fools”
- Nice solution concepts elegant mathematics
- Losing credibility in economics (my opinion)

Individualism v. Collectivism

- In socio-economic systems individual interests may conflict with collective interests:
  - e.g. over exploitation of a common resource (a river, a field, the atmosphere etc.)
  - e.g. banks - lending (to those who they know can not repay) to gain a commission by selling on the debt to other banks
  - e.g. P2P file sharing system - downloading more than uploading

Individualism v. Collectivism

- Consider a P2P file sharing system:
  - It is in the *collective interest* for all to upload to others so everyone gets the file quickly
  - But it is in the *individual interest* to save bandwidth by only downloading and hence free-riding on others
  - Free-riding (or free-loading) is a perennial problem in P2P file-sharing systems
  - Any efficient system needs to tackle it in some way

The tragedy of the commons

- These kinds of situations have been termed "commons dilemmas" or "common pool resource dilemmas"
- Called "dilemmas" because we would all be better off if we "did the right thing" but there is an individual incentive to do the wrong thing
- G. Hardin (1968) summarized the issue in his famous paper: "The *Tragedy of the Commons*"
- These kinds of situations occur in P2P file-sharing systems like *BitTorrent*

How to avoid the commons tragedy?

- Central enforcement of correct behaviour
  - require centralised agencies and policing
  - ability to identify and track individuals centrally
  - not suitable for pure P2P (but used with private trackers)
- Decentralised methods
  - self-policing producing incentives for cooperation
  - do not require centralised coordination
  - more suitable for pure P2P
  - can apply ideas from "*game theory*"

What is game theory?

- Way to mathematically analyse games assuming we know:
  - number of players
  - possible moves they can make (strategies)
  - outcome of game based on players moves (pay-off)
  - desirability of game outcomes for each player (utility)
  - the players are “rational”, “homo-economicus” agents

What game are you playing?

- Games can be categorised into two types:

1) Zero-sum games
   - when one player wins another loses
   - summing the final utilities of players = 0
   - e.g. poker, chess, monopoly etc.

2) Non-zero-sum games
   - utilities do not always sum to zero
   - both players may lose or both may win
   - considered to capture social / economic realities
   - e.g. tragedy of the commons examples

Capturing a commons tragedy with a simple game

- Consider a game composed of two players:
  - each player:
    - has choice of one move (C or D)
    - makes a single move then the game ends
    - does not know how the other will move
    - gets a payoff (or utility) based on how they moved and how the other player moved
  - for certain payoff values this game can, minimally, capture a form of commons tragedy (or dilemma)
  - a classic such game is called the *Prisoner's Dilemma*

The Prisoner's Dilemma - "payoff matrix"

Game is a PD when: T > R > P > S and 2R > T + S

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

The Prisoner's Dilemma - example games

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

Game theory says defect!

- Game theory assumes players are:
  - rational - attempt to maximise *their* utility
  - selfish - don't care about the other guy
  - knowledgeable - have complete information
  - clever - have unlimited computational time
- Given these assumptions it can be proved:
  - agents will select equilibria where no player will improve by changing strategy unilaterally
  - many games have such equilibria - by the famous John Nash (so-called *Nash Equilibrium* - NE)
  - the NE for the PD is DD (all defect)

Iterated Prisoner's Dilemma

- Previous example "one-shot" PD but:
  - real world interactions often repeated
  - might meet the guy you just ripped-off in the future
  - allows for more complex sequence of strategies based on past interactions with others
  - can punish someone tomorrow for defecting against you today - "the shadow of the future"
- Iterated PD (IPD) captures this and, as we will see, maps well onto P2P file-sharing protocols like BitTorrent

What is the rational thing to do in the IPD?

- Traditional game theory has trouble here:
  - cooperative equilibria exist in infinitely repeated games but not in finite games of known length
  - many equilibria exist and it is not clear which one would be chosen by rational agents
  - defection on every round is still an equilibrium
- For these reasons *Robert Axelrod* (political scientist), in the late 70's, decided to find out what kinds of strategies worked well in the IPD by using computer simulation

Axelrod’s Tournament - programs as strategies

- Axelrod organised an open IPD tournament:
  - Academics were asked to submit programs (BASIC or FORTRAN) that would play the IPD against each other
  - Nobody knew competitors code
  - The only input would be the on-going past history of the game (a string of C’s and D’s)
  - The aim was to get the highest score (utility) based on round-robin playoffs between all pairs of programs
  - Axelrod’s aim was to see which programs did best against all the others and understand why
  - He wrote-up his results in the famous book “the evolution of cooperation”

Axlerod's Tournament - what happened?

- Basic results were:
  - many strategies were submitted (complex and simple)
  - the one with the highest overall score turned out to be simple: *tit-for-tat* (TFT) or "look back"
  - starts playing C, then "looked back" at the last move made by opponent and copied that move
  - submitted by Psychologist Anatol Rapoport
  - didn't "win" against each strategy but did better overall on average against all strategies
  - TFT mechanism an example of "*reciprocal altruism*" (Robert Trivers)

What has this got to do with BitTorrent?

- In the *BitTorrent protocol*:
  - TFT-like method used for sharing files
  - nodes form groups interested in a particular file (swarms) and swap or "barter" pieces with each other
  - if a node does not upload data then this can be compared to playing defection
  - it is punished in the future by being "choked" - not getting upload from others
  - even if you hack your client to be selfish the chances are the standard TFT-like protocol will do better overall
  - *Bram Cohen* - original BT designer - inspired by Axelrod's tournaments

The Global Ecology of BitTorrent Clients

- Many *bittorrent clients* exist in "the wild"
  - Bittorrent 6 (from Bittorrent.com, formally utorrent)
  - Others: Azureus, ABC, Transmission, many others…
  - bad guy clients: BitThief, BitTyrant
- Hence:
  - The current bittorrent ecosystem is a ***global on-going experiment***, like Axelrod's, but with huge user base and rich interactions (not just TFT) incredible strategy sophistication
  - This is unprecedented and could lead to new economic theory - in general!

BitTorrent Clients

BitTorrent client	FOSS	Linux/Unix	Windows	Mac OS X	IPv6[1]	Programming language	Based on	Interface	Spyware/Adware/Malware-free
ABC	Yes	Partial	Yes	No	buggy[2]	Python	BitTornado	GUI and web	Yes
Acquisition	No	No	No	Yes	?	Objective-C and Cocoa	Limewire	GUI	Yes
Anatomic P2P	Yes	Yes	Yes	Yes	No	Python	BitTornado	GUI and old CLI	Yes
Arctic Torrent	Yes	No	Yes	No	No	C++	libtorrent	GUI	Yes
aria2	Yes	Yes	Yes	Yes	?	C++	-	CLI	Yes
Azureus	Yes	Yes	Yes	Yes	Partial[3]	Java and SWT	-	GUI, CLI, Telnet, Web, XML over HTTP remote control API	Yes
BitComet	No	No	Yes	No	No	C++	?	GUI	Yes[4]
BitFlu	Yes	Yes	No	Yes	Yes	Perl	-	Telnet and Web	Yes
BitLet	Planned	Yes	Yes	Yes	?	Java and JavaScript	-	Web XHTML	Yes
BitLord	No	No	Yes	No	No	C++	BitComet	GUI	Adware
BitPump	No	No	Yes	No	No	C++	-	GUI	Yes
Bits on Wheels	No	No	No	Yes	No	Objective-C and Cocoa	-	GUI	Yes
BitSpirit	No	No	Yes	No	No	C++	BitComet	GUI	Yes
BitThief	No	Yes	Yes	Yes	?	Java	?	GUI	Yes
BitTornado	Yes	Yes	Yes	Yes	Yes	Python	BitTorrent	GUI and CLI	Yes
BitTorrent 5 / Mainline	Yes	Yes	Yes	Old version	No	Python	-	GUI and CLI	Yes
BitTorrent 6	No	No	Yes	No	Yes	C++	µTorrent	GUI and CLI	Yes
BitTyrant	Yes	Yes	Yes	Yes	Partial[3]	Java and SWT	Azureus	GUI, CLI, Telnet, Web, XML over HTTP remote control API	Yes
Blizzard Downloader	No	No	Yes	Yes	?	?	BitTorrent client for early version	GUI	Yes
Blog Torrent	Yes	No	Yes	Yes	?	?	BitTorrent client for early version	GUI	Malware-Status: unknown
BTG	Yes	Yes	Partial[5]	Yes	No	C++	libtorrent	CLI, GUI and web	Yes

Take home message

- Previous work in social / economic science (Axelrod's IPD) has provided a basis for protocol design in a P2P system
- Deployed variants of the protocol are creating a massive global economic experiment
- Measurements can be made and these could inform new theory and new protocols

References

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work using socio-economic ideas

- Effort based incentive approaches from participatory economics applied in BT
  - Rahman, R., Meulpolder, M., Hales, D., Pouwelse, J. and Sips, H. (2010) Improving Efficiency and Fairness in P2P Systems with Effort-Based Incentives. Proceedings of the IEEE International Conference on Communications, 23-27th May 2010, Cape Town, South Africa
- Analysis of credit shortages and “monetary policy” in private BT communities
  - Hales, D., Rahman, R., Zhang, B., Meulpolder M., and Pouwelse, J. (2009) BitTorrent or BitCrunch: Evidence of a credit squeeze in BitTorrent? Proceedings of the 5th Collaborative Peer-to-Peer Systems (COPS) Workshop, in conjunction with 18th IEEE International Workshops on Enabling Technologies: Infrastructures for Collaborative Enterprises, June 29 - July 1, 2009, Groningen, the Netherlands.
  - Rahman, R. and Hales, D., Vinko, T., Pouwelse, J. and Sips, H. (2010). No more crash or crunch: sustainable credit dynamics in a P2P community. International Conference on High Performance Computing & Simulation (HPCS 2010), Caen, France, 2010.
- Apply Axelrod-like tournaments to realistic BT protocol
  - Joint work with Rameez Rahman, Tamás Vinko, David Hales, Johan Pouwelse, Henk Sips (2011) Design Space Analysis for Modeling Incentives in Distributed Systems, to be presented at Sigcomm August 2011, Toronto.

Design Space Analysis for Modelling Incentives in Distributed Systems

- Mainly thesis work of Rameez Rahman
- Apply Axelrod-like tournament approach to evaluate *realistic* P2P protocol variants
- Interesting bit is:
  - break down of P2P protocols into a design space
  - Evaluation of protocol variants (PRA)
- Specific application to BitTorrent protocol variants

PRA characterisation of a protocol

- ***Performance*** - the overall performance of the system when all peers execute Π (where performance is determined by the designer);
- ***Robustness*** - the ability of a majority of the population executing Π to outperform a minority executing a protocol other than Π;
- ***Aggressiveness*** - the ability of a minority of the population executing Π to outperform a majority executing a protocol other than Π.

More detail on PRA

- P = average download time
- R = number of "wins" in round robin tournaments against all other protocol variants
- A = number of "wins" in round robin tournaments against all other protocol variants
- P,R,A values normalised over the space

Parameterising a P2P protocol

- **Peer Discovery**: In order to perform productive peer interactions, it is necessary to find other partners. For example, when a peer is new in the system, looking for better matching partners or existing partners are unresponsive. The timing and nature of the peer discovery policy are the important aspects of this dimension.
- **Stranger Policy**: When interacting with an unknown peer (stranger), past history cannot be used to inform actions. It is therefore necessary to apply a policy to deal with strangers. The way peers allocate resources to strangers is an important aspect of this dimension.
- **Selection Function**: When a peer requires interaction with others this function determines which of the known peers should be selected. This could include, for example, past behaviour (through direct experience or reputation system), service availability and liveness criteria.
- **Resource Allocation**: During peer interactions resources must be allocated to the selected peers (given by the selection function). The way a peer divides its resources among the selected peers, defines the resource allocation policy.

Parameterising BT

- Stranger policy (10 variants)
- Selection function:
  - Candidate list - peers to consider (2 variants)
  - Ranking function - order list (6 variants)
  - Selection - number of peers to select (9 variants)
- Resource allocation (3 variants)
- Gives a space of 3270 unique protocols

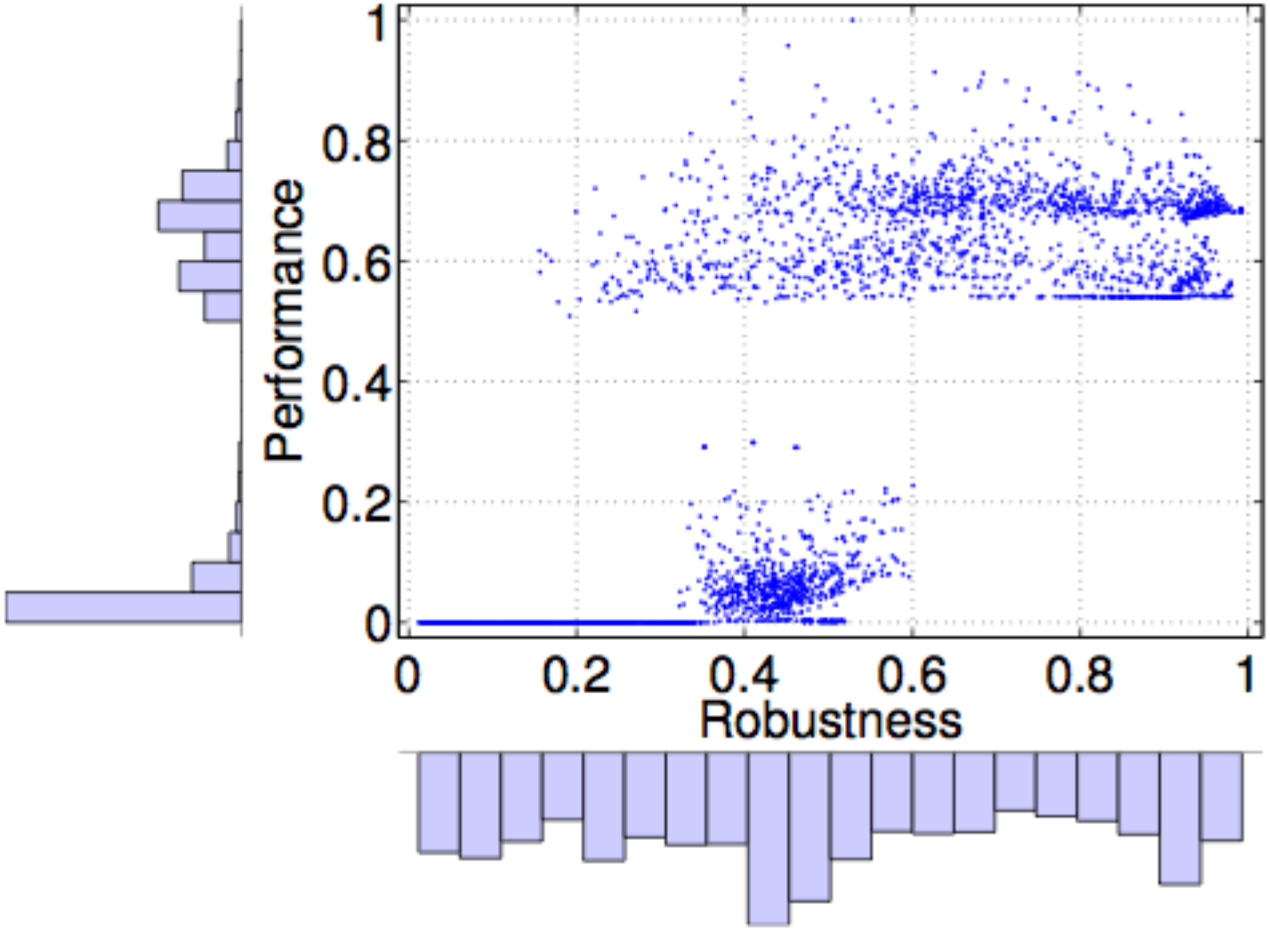

Figure 3: Scatter plot of all 3270 protocols in the design space with Robustness against Performance. The results presented here are a synthesis of over 107 million individual simulation runs. Histograms are also shown.

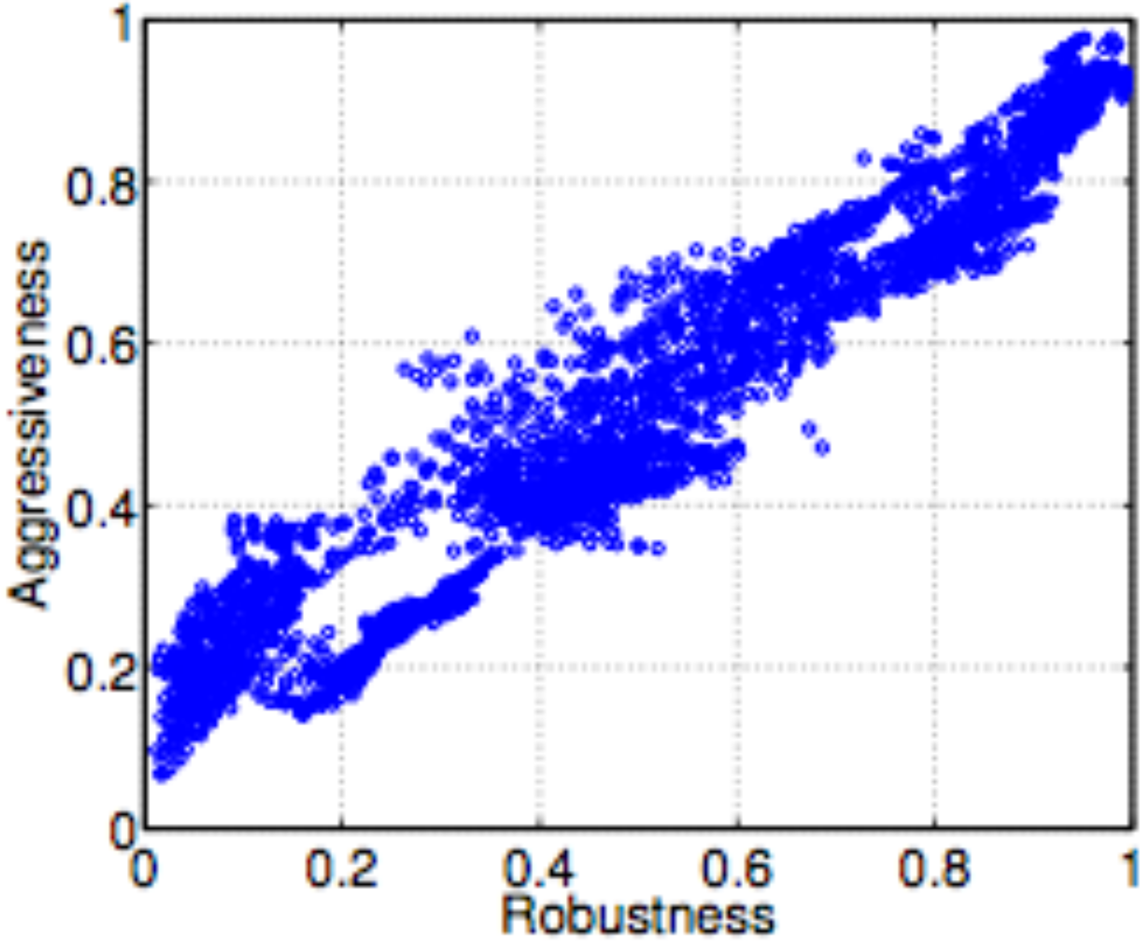

Figure 9: Scatter plot of robustness and aggressiveness values of the protocols. The Pearson's correlation coefficient is 0.96.

Broad Summary

- Lower cluster (low P) all free rider variants who do not reciprocate with partners
- Upper cluster (high P) do reciprocate with partners but some defect with strangers
- Top P, low number of partners (1,2), Sort Loyal, When Needed
- Top R, high number of partners (6-9), Sort Fastest, When Needed, Prop. Share
- Sweet spot (P,R>0.8): Sort Loyal

Interesting link to some economic work?

- ***Compare empirical / modelling work***: Kirman AP and Vriend NJ (2000) "Learning to be loyal: A study of the Marseille fish market" In: Gatti DD, Gallegati G and Kirman AP, Interaction and market structure: essays on heterogeneity in economics, Volume 484. Springer,