Innovation and Structural Change in Complex Evolutionary Systems

Part II

Complex Economic Systems: Evidence & Basic Principles

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Plan for the next four of days

Part I: discuss some **evidence** and **main properties** of *innovation* (as an evolutionary process)

Part II: discuss some evidence and main properties of *complex systems*

Part III: introduce the use of ABM to study complex economic systems – taster of ACE

Part IV: modelling micro aspects of innovation

- The basic evolutionary process: replicator dynamics
- Search: NK Model
- Path dependency: technological choice

$\Rightarrow$ Part V: model growth and structural change as an evolutionary complex dynamic

Complex economic systems[a]

Part II
Complex economic systems: some properties and empirical evidence

[a] Acknowledgement: partly based on material presented given by Alan Kirman

Plan for Part II

- Introduction
- Basic concepts: some features of the 2008 financial crisis
- Basic properties – empirical evidence

Main references: Complex Economic Systems

- Arthur, W. B. (2013), 'Complexity Economics: A Different Framework for Economic Thought', Working Paper 2013-4-2012, Santa Fe Institute.
- Kirman, A. (2010) Complex Economics: Individual and Collective Rationality Taylor & Francis
- Page, Scott E. 2015. What Sociologists Should Know About Complexity. Working Paper, mimeo.

Some ingredients of the financial crisis

The financial crisis, and the related real crisis, were unpredictable, and are only partially understood, using available economic models

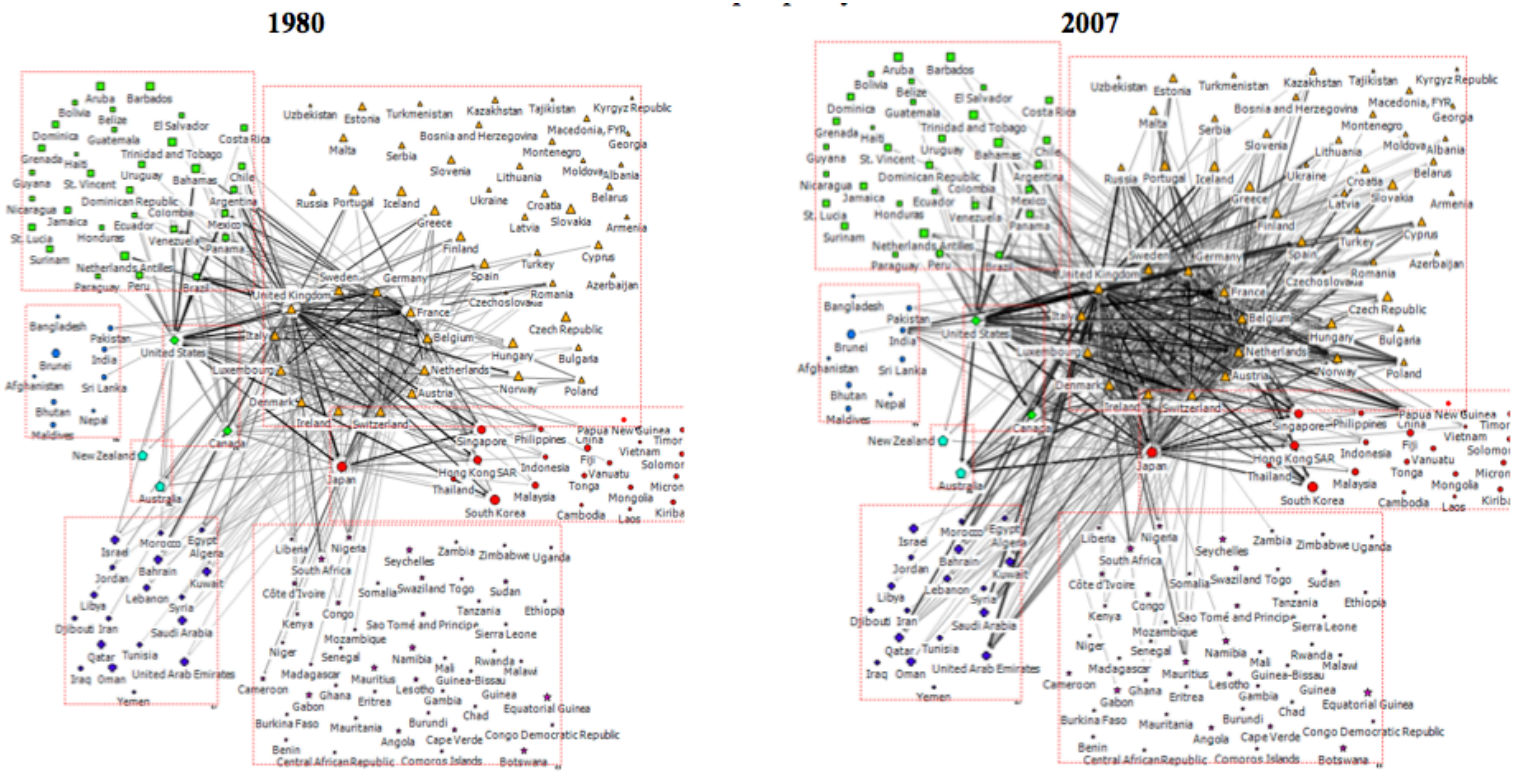
- Where *unpredictable* refers to Knightian uncertainty, where risk cannot be seen, rather than a wrong guess on a probability distribution

Why?

Some fundamental features of economic systems

- network structure – banks, users and countries
- people beliefs and expectations – satisficing, partly adaptive, and heterogeneous
- interdependent behaviour – contagion

Network: Cross border banking network: core-periphery



Source: Minoiu and Reyes (2011)

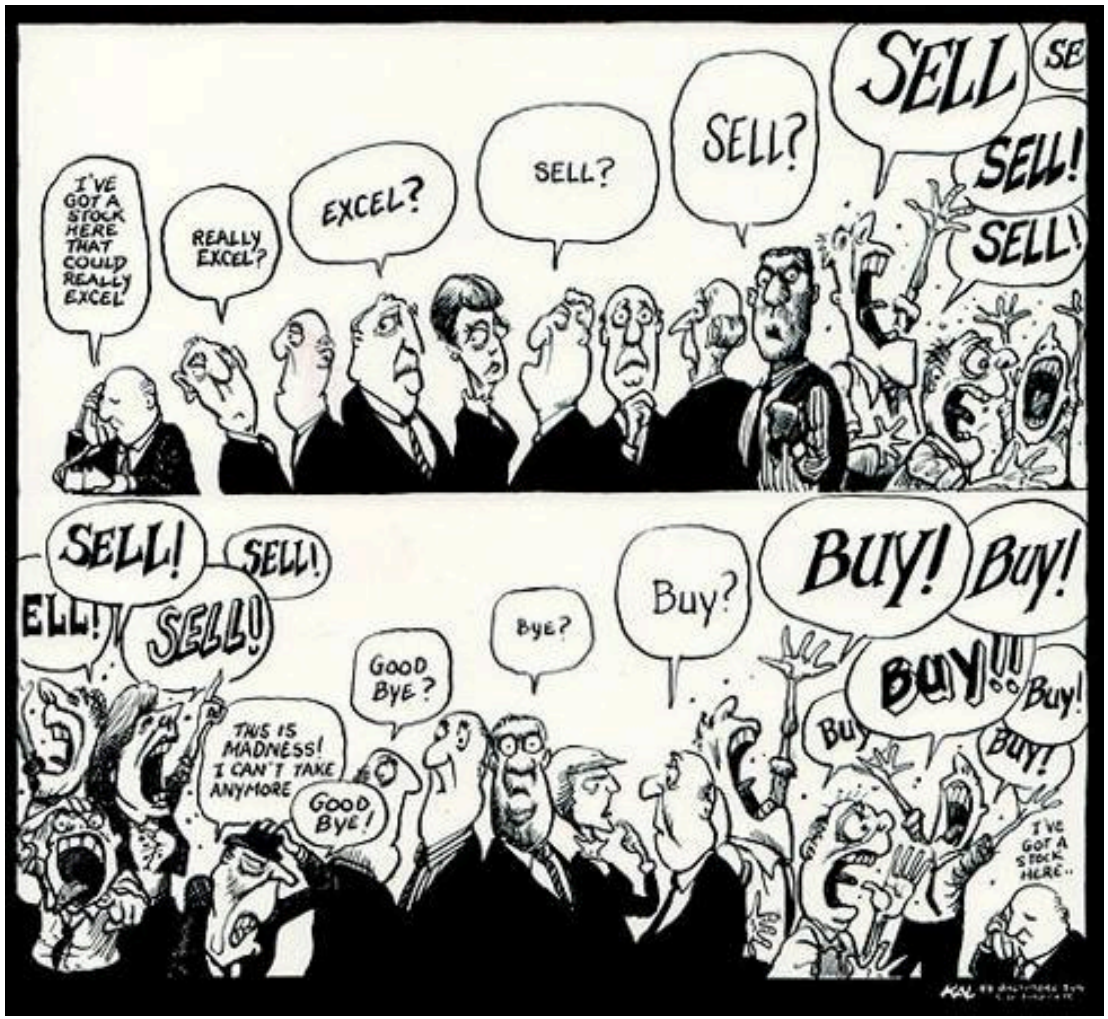
People behaviour: Markets are not made up of rational individuals optimising in isolation

Source: Kirman slides

Contagion: herding behaviour

Source: Kirman (2010)

Contagion: information cascade



Source: The Economist, Nov 1, 1997

Contagion: information cascade

Decision are taken sequentially: market signals adjust through time

- We do not jump from one equilibrium to another

Information is mediated locally by other actors (people), not only centrally by prices

"After a sufficient time the cumulated actions of other actors contain so much information that an individual will have an incentive to ignore his or her own information and a 'cascade' will start" (Kirman, 2010)

- Choice of a restaurant comparing public and private information
- Adoption of technologies, diffusion and lock-in (e.g. Arthur, 1989; Cowan and Gunby, 1996)

Characteristics of a complex system (Page, 2015)

Interaction structure (facebook)

Interdependent: people influence each other (contagion, fads)

Learning and adaptation: change agents and populations (modify fitness), change behaviour (beliefs)

- Selection (and variation)

Heterogeneity: initial, and as a process of adaptation, or *innovation*

$\Rightarrow$ Full rationality is not useful/adequate/optimal

Summary

	Complex systems
Dynamics	Adaptation
Heterogeneity	Non-normal distributions
Interactions	Topology: interdependence
Interdependence	Contagion/cascades
Limited rationality	Heuristics

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Heterogeneity

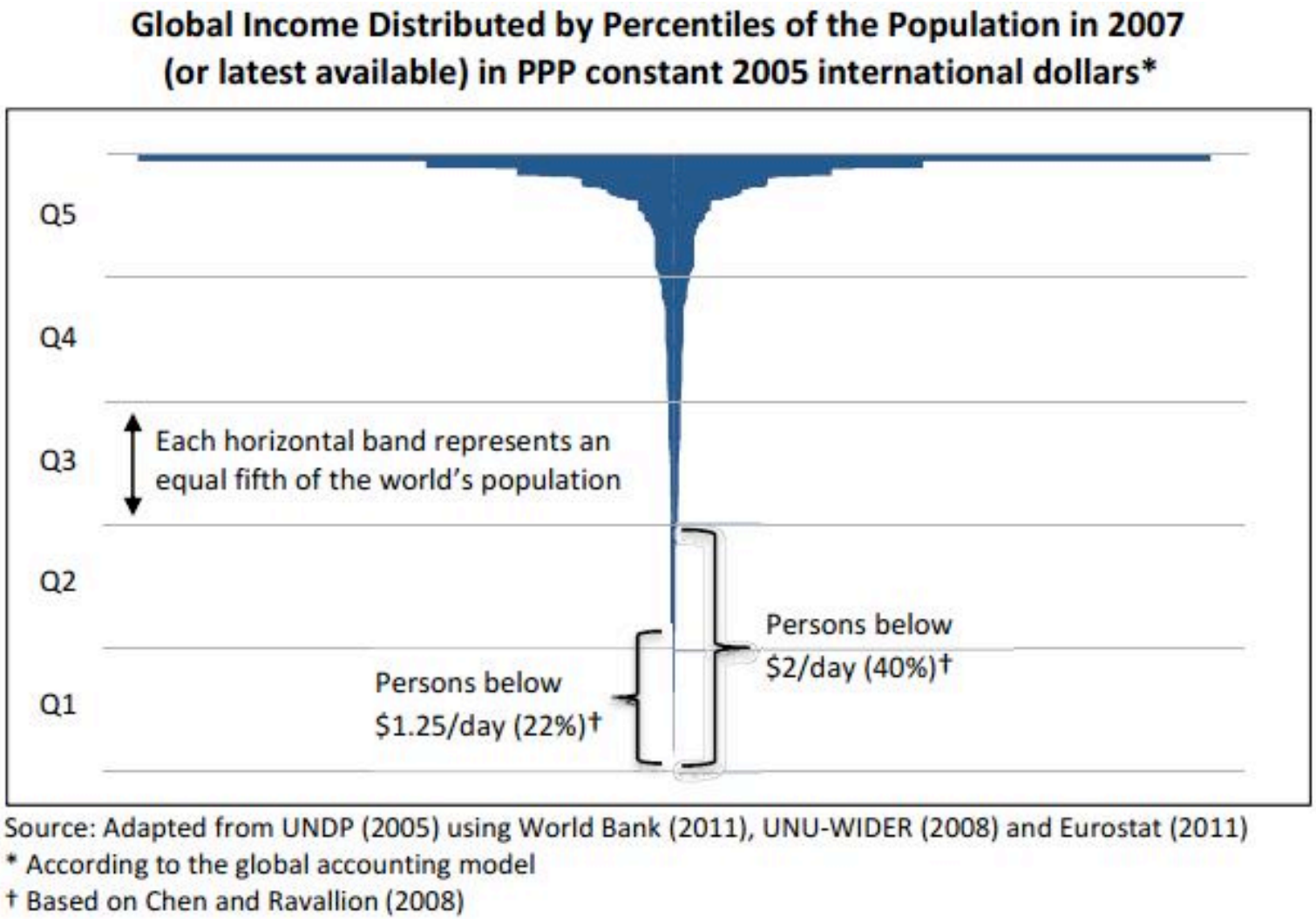
Distribution of

- Consumers: wealth, income, wages, preferences
- Firms: size, growth rates, productivity
- Markets: prices, institutions, organisation, peers

All scale free distributions (Pareto): highly skewed, fat tailed, large variance

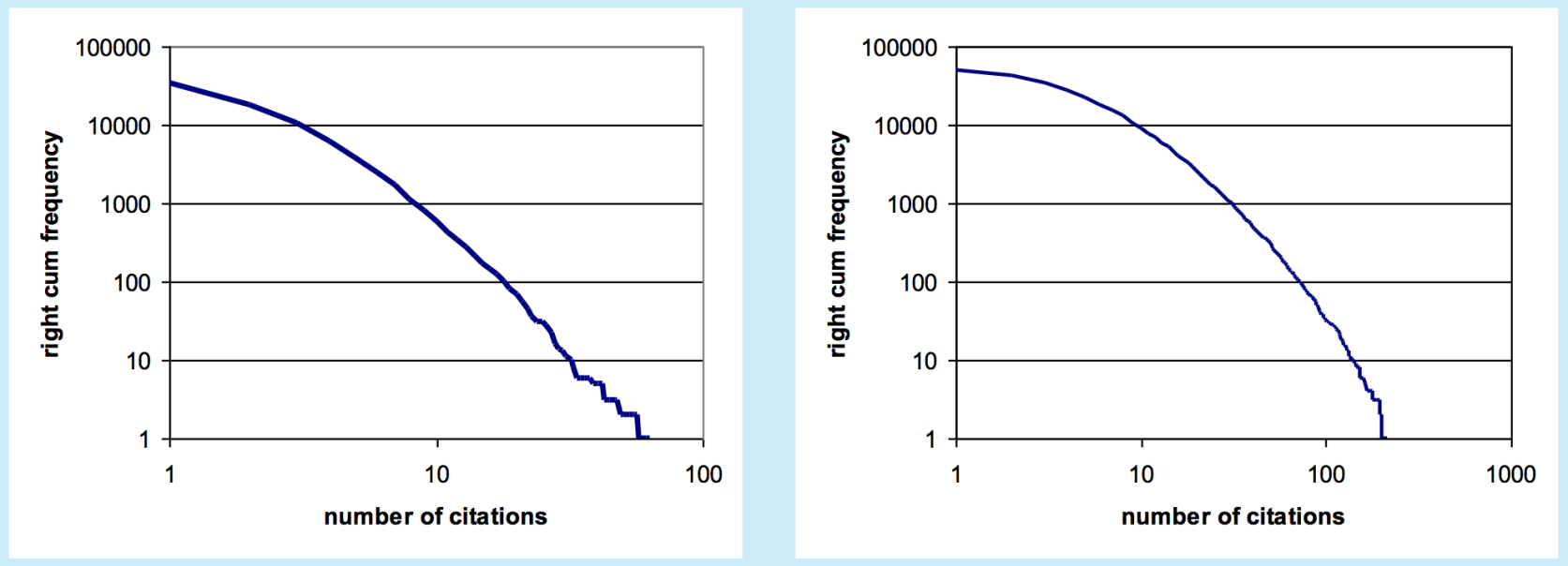
- Meaning of an average?

World income distribution



Source: Ortiz and Cummins (2011)

Innovation size distributions (Pareto Plots) based on patent citations



Source: Gerry Silverberg

EPO 1989 patent citations (left) and USPTO 1989 patent citations (right)

Pareto distributions are found everywhere

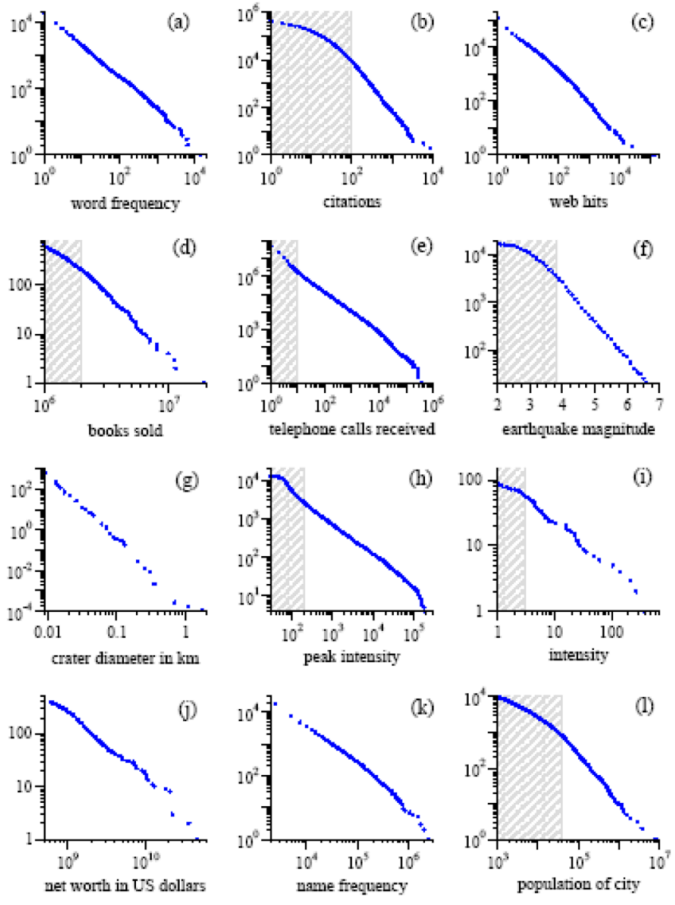


FIG. 4 Cumulative distributions or "rank/frequency plots" of twelve quantities reputed to follow power laws. The distributions were computed as described in Appendix A. Data in the shaded regions were excluded from the calculations of the exponents in Table I. Source references for the data are given in the text. (a) Numbers of occurrences of words in the novel *Moby Dick* by Hermann Melville. (b) Numbers of citations to scientific papers published in 1981, from time of publication until June 1997. (c) Numbers of hits on web sites by 60 000 users of the America Online Internet service for the day of 1 December 1997. (d) Numbers of copies of bestselling books sold in the US between 1895 and 1965. (e) Number of calls received by AT&T telephone customers in the US for a single day. (f) Magnitude of earthquakes in California between January 1910 and May 1992. Magnitude is proportional to the logarithm of the maximum amplitude of the earthquake, and hence the distribution obeys a power law even though the horizontal axis is linear. (g) Diameter of craters on the moon. Vertical axis is measured per square kilometre. (h) Peak gamma-ray intensity of solar flares in counts per second, measured from Earth orbit between February 1980 and November 1989. (i) Intensity of wars from 1816 to 1980, measured as battle deaths per 10 000 of the population of the participating countries. (j) Aggregate net worth in dollars of the richest individuals in the US in October 2003. (k) Frequency of occurrence of family names in the US in the year 1990. (l) Populations of US cities in the year 2000.

Source: Mitzenmacher (2004)

Heterogeneity is a relevant property

Many economic phenomena are driven by heterogeneity: diffusion curves, business fluctuations, pricing

Innovation!

Heterogeneity in the aggregate?

Heterogeneity does not cancel out in the aggregate, unless characteristics are normally distributed.

- Some components dominate (e.g. the financial crisis does not occur because a couple of small firms fail)
- Imitation and avalanches in networks

$\Rightarrow$ Structural change
$\Rightarrow$ Changing shares of populations

Aggregate properties likely to differ from individual properties

The aggregate is many times impossible to predict from individual behaviour

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Interactions and networks

Most of the phenomena that we study in social sciences are about interactions

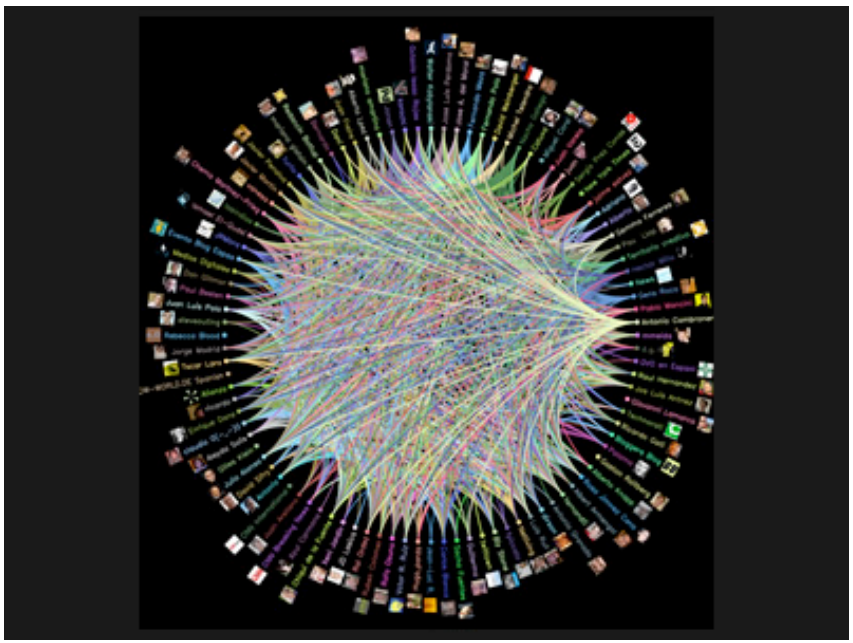
- Trade
- Information and knowledge
- Expectations
- Social relations: e.g. six degrees of separation
- Neighbourhoods

Most natural, technological, and social interactions can be described as networks

Most networks have very similar properties: complex systems

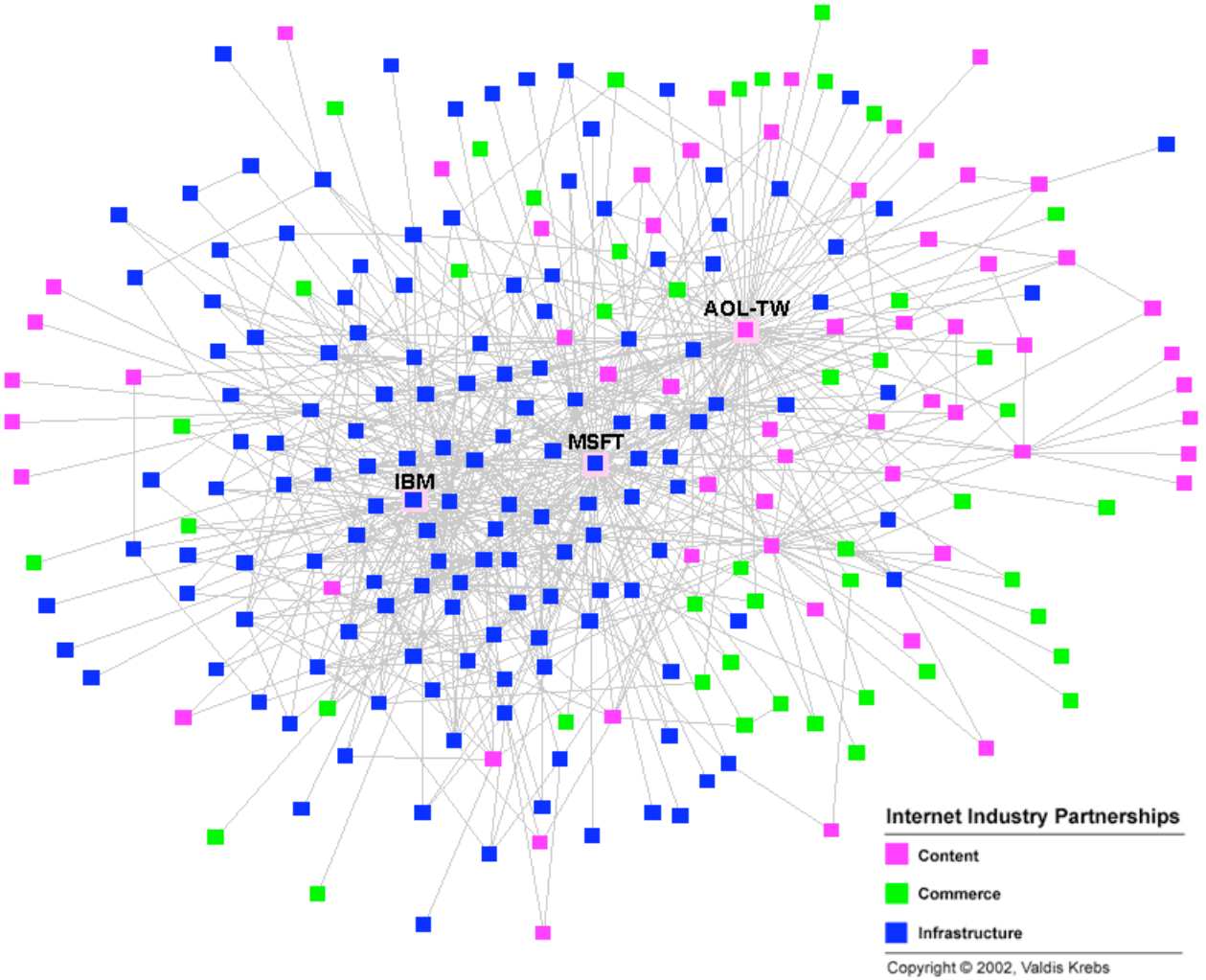
Social networks

(a) Facebook connections



(b) Twitter followers

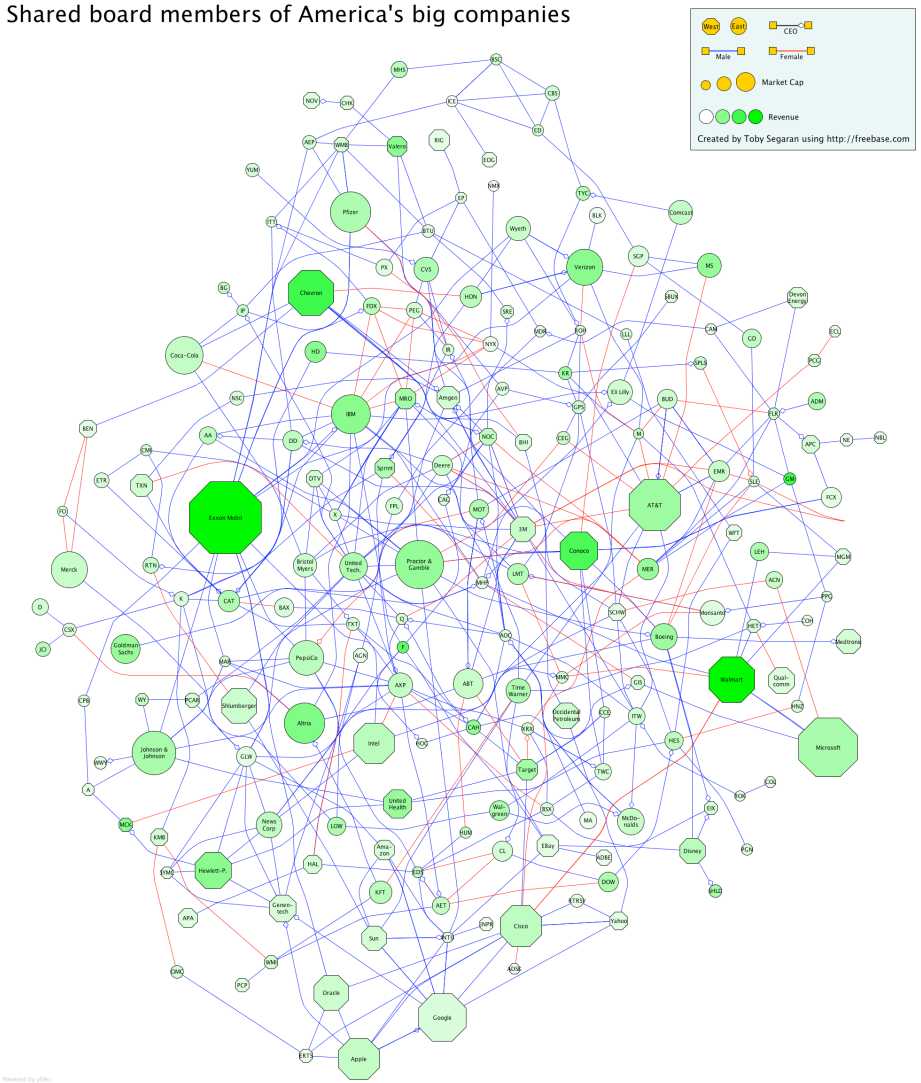
Business collaborations: internet industry



Source: http://www.orgnet.com/netindustry.html

250 companies: announced joint ventures, strategic alliances, other partnership

Business informal relations



Source: http://blog.kiwitobes.com

400 largest US companies: shared board members

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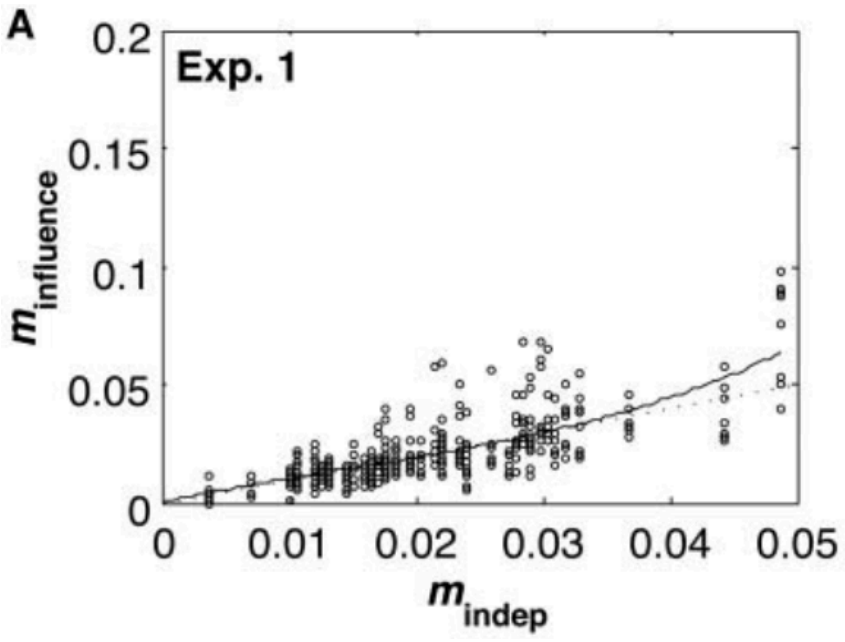
Network and complexity

Network as constraints

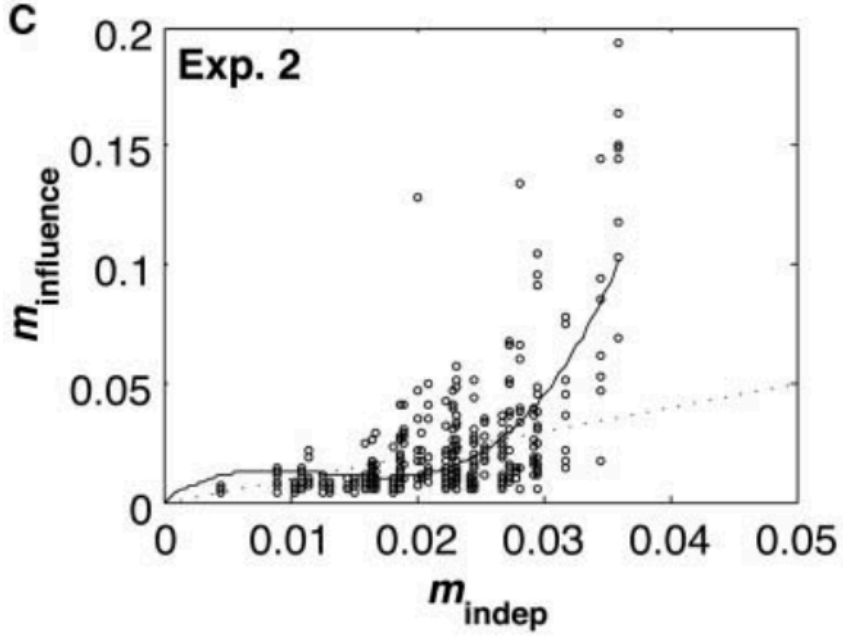
- Behaviour of a node depends on all others
- Examples: diffusion of goods, product modularity, technological trajectories, etc

Networks define the order of a complex system: see the NK model of technology exploration

Example: How can success in cultural markets be strikingly distinct from average performance?



Songs ordered randomly



Songs ranked by download

Source: Salganik et al. (2006)

"Social influence contributes both to inequality and unpredictability in cultural markets"

Example: Business Fluctuations (Ciarli and Valente, 2007)

Heterogeneity in network persist and does not cancel out in the aggregate – see also Weisbuch and Battiston (2005) and Carvalho (2014).

- How do micro shocks affect the system fluctuation
- Production: Input-Output structure
- Identical firms with iid shocks
- Consecutive decisions in adjusting a small shock in the final demand generates fluctuations
  - $\Rightarrow$ Attempts to smooth business cycles generate business cycles
    - Fast adjustments in the demand for inputs create hysteresis
    - Micro volatility is always smaller than aggregate volatility

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Micro behaviour as a source of complexity and heterogeneity

We have discussed the relevance and cumulativeness of knowledge, the uncertainty of innovation (the need for guessing and animal spirits), heterogeneity (lack of average behaviour), interactions and interdependencies (local relations)

How do individuals take decisions in such normally complex environments?

$\Rightarrow$ Simplify

Markets are not made up of rational individuals optimising in isolation

Source: Kirman slides

Agent use simple and routinised behaviour

Experimental evidence from cognitive Psychology: Kahneman, Tversky, Gigerenzer, and others

- Inherent difficulty in dealing with uncertainty and probability
  - Different risk aversion for gains and losses
  - Bayesian VS frequentist approaches
- Cognitive biases
  - People take decisions in a relative way, comparing local options

Risk aversion

Problem A (win): an individual is given $1,000

- A1: Win $1,000 with 50% probability (0 otherwise)
- A2: Win $500 with certainty

Problem B (loss): an individual is given $2,000

- B1: Loose $1,000 with 50% probability (0 otherwise)
- B2: Loose $500 with certainty

Rational choice

- In both cases the expected outcome is $1500
- Depending on risk aversion, if the **rational** individual chooses A1(A2), she should also choose B1(B2)

Risk aversion

Lab experiment:

- A statistically significant majority of individuals choose A2 and B1

$\Rightarrow$ Individuals are risk lovers for losses and risk averse for gains

$\Rightarrow$ The structure of the problem (decision making) affects the choice

Relative decision making

Economist.com subscription: Dan Ariely experiment

Consumers have the following choices

1. Internet only option: $59
2. Print only option: $125
3. Print and Internet option: $125

Result: 16% (1), 0% (2), 84% (3)

Consumers have the following choices

1. Internet only option: $59
2. Print and Internet option: $125

Result: 68% (1), 32% (2)

Micro entities with simple and routinised behaviour

$\Rightarrow$ Difficult to maximise (problem structure and cognitive biases): individuals are not able to make all necessary calculations leading to the optimal choice (under all possible scenarios), even if they had all the required information.

Adaptive trial and error behavioural rules: Gigerenzer heuristics (ecological rationality): simple heuristics more efficient to resolve complex problems

Individuals/firms tend to use known **routines**, and if these are not successful they will revise them.

- "Repetitive, recognizable patterns of interdependent actions, carried out by multiple actors" (Feldman and Pentland, 2003)
  - Stable through time (inheritance)
  - Mutate (variation)
  - Object of selection

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