Complexity

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complex systems

- complex systems
  - unpredictable
  - robust
  - large events
    - magnitude of effect not foreseeable
    - “power law”
  - dynamic
    - neither (static) equilibrium nor chaos
    - somewhere in between “order” and “chaos”
  - emerging phenomena
    - bottum up
    - self-organization
    - novelty
  - complex $\neq$ complicated

complex systems

- entities in a complex system
  - agents
    - diverse
    - interdependent
    - connected
    - adaptive
  - operate within environment

- is the economy getting more complex?
  - yes, on all levels:
    - people are more connected
    - actions become more interdependent and require more coordination
    - work is more diverse
    - companies / strategies / products / … change must faster

complex systems

- what are the interesting aspects?
  - emergence
    - macro level ⇔ micro level
    - differs in kind
    - bottom up, no central control
    - self organization
  - phase transition
    - “tipping points”
    - non-linear
      - marginal responses change
  - innovation
    - adaptation
    - novelty

complex systems

- what is required
  - precise definitions
    - evaluate & compare situations
  - new tools
    - mostly computational
    - e.g., simulation
  - new vocabulary
    - “self organized criticality”, “cellular automata”, “agent-based modelling”, “adaptive systems”, “learning”, …

diversity

- why is it important?
  - innovation
  - robustness

- important aspects
  - positive feedback
    - “diversity begets diversity”
  - harshness of enviroment
    - weak selection pressure
  - situation dependent objectives and requirements
    - strategy must be fit for purpose
  - changing requirements
    - co-evolution

diversity

- how to measure it
  - measures of variation
  - entropy measures
  - distance measures
  - attribute measures

- complex systems in economy ⇔ ecology
  - representation
  - size of leaps
  - interim viability
  - retrievability

emergence

- what it is
  - spontaneous creation of order and / or functionality
  - bottom up, no central planning
  - breaking symmetry
  - “more is different” (Philip Warren Anderson)

- types
  - simple ⇔ complex
  - weak ⇔ strong

emergence

- example: culture
  - shared set of believes, behaviours, routines
  - when people meet
    - action sets, believe systems
    - actions are interdependent
  - model
    - consistency of believes and actions
    - avoid cognitive dissonance
    - "coordination game"
    - ➔ culture is emerging pattern
  - functionalities
    - predictions about other people's behaviour
    - dealing with new situations

networks

- "space matters"
  - connections between agents
    - (not) everybody is connected with everybody
    - influence actions, reactions, adaptations
  - importance of networks can depend on situation
    - e.g., spread of diseases
- properties
  - nodes and edges
    - degree: *number of connections to other agents*
    - path length: *minimum number of edges from A to B*
  - some types
    - random nets
    - hub and spokes
    - small world

networks

- example: www
  - many sites with few links; few sites with many links
  - power law:
    - number of nodes of degree k is proportional to $1/k^2$
- how do networks emerge?
  - examples
    - social networks
      - agents with common attributes, preferences, etc.
    - preferential attachment model
      - links to already highly connected nodes
      - “first mover advantage”
    - alternatively / additionally: quality of nodes
      - example: Google wasn’t the first search engine

feedback

- main types
  - positive feedback
    - "more creates more"
    - examples
      - ants' pheromone trails (reinforcement)
      - fashions (within limits) & trends
      - panic reactions
      - contagion in markets
  - negative feedback
    - "more creates less"
    - examples
      - queues
      - trend followers ⇔ individualists / contrarians
- feedback ⇔ externalities

feedback

- path dependences
  - current decisions affect future outcome and possibilities
  - a few actions can trigger large scale changes
  - tipping point

- feedback & diversity
  - combination can make systems robust / instable

	positive feedback	negative feedback
no / little diversity		
much diversity		

positive feedback

- example: Thomas Schelling's "Segregation model"
  - grid; each cell represents one household
  - two types of households: red / blue
  - households don't want all neighbors to be different from themselves
    - if minimum level of similarity is exceeded, households are happy
    - if not, they move
  - effects
    - increase similarity in new neighborhood
    - decrease similarity in old neighborhood (old neighbors likely to follow)
  - results
    - fairly tolerant on micro level, strong segregation on macro level
    - once beyond tipping point, system will not "de-segregate"
  - extensions
    - households have different thresholds for minimum similarity

negative feedback

- examples
  - increasing (decreasing) tourist numbers will decrease (increase) attractiveness of resort
  - price increases will lower demand

- in combination with …
  - externalities
    - example: air fares for short-hall trips ⇔ train ticket prices
  - positive feedback
    - example: increased prices ➔ increased supply & decreased demand
  - network structures
    - example: local / global players in locally regulated markets

self-organised criticality

- self organisation …
  - emergence phenomenon
  - aggregate exhibits patterns & structure not present in indivuals
- + criticality …
  - small events trigger large cascades of events
  - tipping point
- = self-organized criticality
  - self-organisation towards critical states
  - big events *can* results
    - often: no big events => false sense of security
    - power law

self-organised criticality

- power laws
  - probability of event of size k is proportional to $1/(k^b)$
  - important properties:
    - fat tails
    - scale invariant
  - general examples
    - sandpile models
    - traffic jams
    - certain contagion / herding models
    - network effects
  - actual outcome depends on
    - network structure
    - type of feedback
    - adaption within system

randomness

- potential sources of randomness in models
  - by definition / engineering
    - e.g., Monte Carlo approach
  - error terms
    - e.g., (external) randomness causes (further) randomness
  - fundamental randomness
    - e.g., quantum mechanics
  - complexity
    - e.g., cellular automata
    - interdependence & interactions

randomness

- randomness due to complexity
  - main characteristics
    - interdependent rules create changing events and responses
    - adaptiveness system
  - distributions are not necessarily stationary
- learning in complex systems
  - co-evolution
  - learning assumes (some sort of) stationary (within limits)
  - lessons learned might have a “sell-by” date

randomness

- examples in economics & finance
  - collapse of LCTM (Long Term Capital Management)
    - "bets" on long term equilibria ➔ problems if bubbles persist too long
    - pricing models assume stationary distributions ➔ problems if violated
  - subprime crisis
    - flawed assumptions (ex post)
      - mark to model
      - bundles of loans ➔ central limit theorem should hold
      - stationary distributions
      - little inter-connectedness
    - positive feedback
      - necessary down-payments lowered
        ➔ subprime market reacts first to economic problems
      - insurance via CDO (pay off when bundles go bad)
        ➔ insufficient deposits

complex systems

- the ingredients revisited
  - agents are
    - diverse
    - interdependent
    - connected
    - adaptive
    - ➔ influence everything, control nothing
  - systems
    - exhibit emergence & self organisation
    - become unpredictable (i.e., random)
    - can be robust ⇔ collapse

complex systems

- dealing with complexity
  - traditional decision theory rational choice models of limited use in CS
  - change of attributes
    - modification of network structures
    - diversity (distribution; tail events) & innovation
    - adaptation rate, learning, etc.
    - selection & fitness criteria
  - control ⇔ efficiency
  - example: institutions that have existed for more than 500 years
    - ca. 40 universities
    - ca. 125 businesses
      - approx. 2/3: recreational / leisure / etc. (restaurants, breweries, etc.)
      - rest: pharmacies, jewellery makers, cheese makers, knife makers
    - NOT: banks, construction businesses etc.

literature

- background reading, additional material
  - Thomas C Schelling, *Micromotives and Macrobehaviour,*
    Norton & Company, New York 1978.
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    Princeton University Press 2007
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    Oxford University Press, Oxford 2009.
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    Back Bay Books, Little, Brown and Company, New York 2000.
  - John H. Holland, *Hidden Order. How Adaptation Builds Complexity*,
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  - Nigel Gilbert and Klaus G Troitzsch, *Simulation for the Social Scientist*,
    Open University Press 2005