Innovation and Structural Change in Complex Evolutionary Systems

Part III
Agent Based Models

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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

⇒ Part V: model growth and structural change as an evolutionary complex dynamic

Agent based models

Part III
Alternative modelling tools: agent based models

Plan for Part III

- Why ABM: summary of evolutionary complex systems
- Definition and properties
- Implementation and structure of an ABM

Main references

- Haldane, A G, and A E Turrell (2018). An Interdisciplinary Model for Macroeconomics. *Oxford Review of Economic Policy* 34 (1–2). Oxford University Press: 219-51
- Tesfatsion, L. & Judd, K. (ed.) Handbook of Computational Economics: Agent-Based Computational Economics Elsevier, 2006, 2
- http://www2.econ.iastate.edu/tesfatsi/ace.htm

Summary

	Innovation and evolution	*Complex systems*
Dynamics	Evolution	Adaptation
Knowledge	Accumulation & heterogeneity	Learning
Clustering	Accumulation & discrete changes	Local interdependence
Trajectories	Path dependence & non linearity	Routines & interdependence
Uncertainty	Risk / high variance	Routines
Heterogeneity	Evolutionary / sectors	Pareto distributions
Interactions	Diffusion, imitation, selection	Topology: interdependence
Interdependence	Systems	Contagion/cascades
Limited rationality	Heuristics	Heuristics

Wrapping-up

Empirical evidence suggests heterogeneity, skewed distributions (average not useful), cumulation & clustering, uncertainty, limited rationality, evolution, interactions (systems), non linearities, use of routines

Innovation

- is persistent, dynamic (and follows a trajectory), highly uncertain
- uses innovation, knowledge, learning – in non linear way
- generates several responses, heterogeneity (structural change), more innovation, imitation, adaptation
- differs across populations – industries and consumers

⇒ inherent features of evolutionary complex systems (not of standard economic models)

Main problems in standard macroeconomics

Focussed on atomistic behaviour with no interactions

Use of static equilibrium

Little investigation on the evolution towards equilibrium

Information transmission (e.g. contagion) assumed away

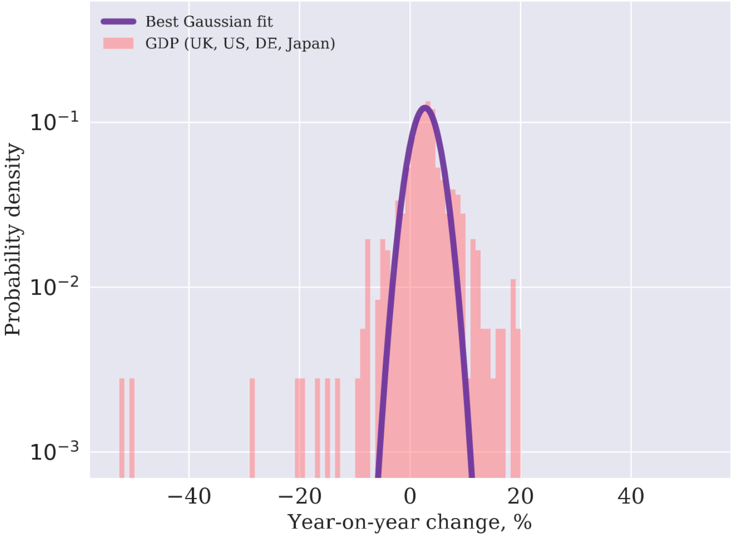
Holds on two crucial assumptions:

- rationality of individuals (widely criticised from Simon onwards)
- aggregate behaving like a "rational individual"

Economic structure is lost under aggregation

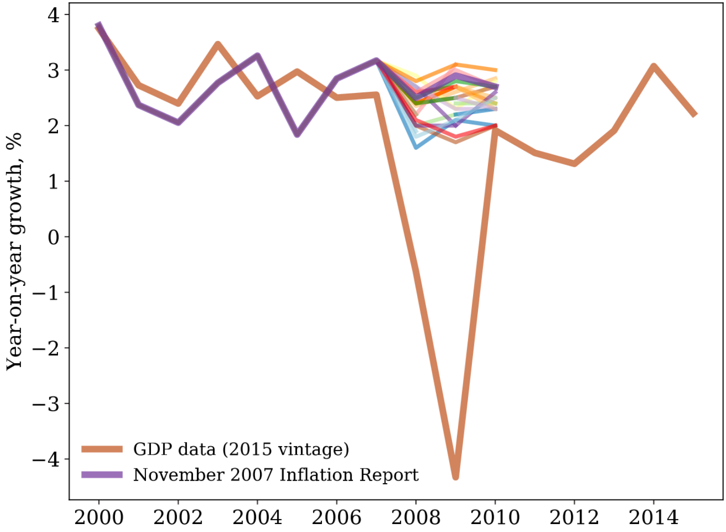
Most relevant stylised facts cannot be reproduced (Fagiolo and Roventini, 2012, 2017; Haldane and Turrell, 2018)

The distribution of year-on-year growth in GDP, 1871–2015



Source: Haldane and Turrell (2018)

Range of GDP forecasts (27 forecasters) in 2007Q4 – UK



Source: https://www.bis.org/review/r161115a.pdf

The role of models in the crisis

'[T]here is also a strong belief, which I share, that *bad or rather over-simplistic and overconfident economics helped create the crisis*. There was a dominant conventional wisdom that markets were always rational and self-equilibrating, that market completion by itself could ensure economic efficiency and stability, and that financial innovation and increased trading activity were therefore axiomatically beneficial"
Adair Turner, Ex Chairman of the Financial Services Authority, U.K

Comparing Economic models and Complex Systems (G. Fagiolo)

	Standard Economic models	*Complex Evolving Systems*
Individuals	1,2 or infinite, fully rational, sophisticated learning	N large but finite, simple entities, adaptive, routine behaviour
Interactions	Extreme cases, trivial patterns (full or empty/star graphs)	Non trivial patterns, local interactions with subset of other agents
Diversity	Possibly heterogeneous, but diversity does not matter for aggregate dynamics	Persistently heterogeneous, diversity matters for aggregate dynamics
Time and Aggregate Dynamics	Static (not truly dynamic) models, only equilibrium states count	Truly dynamic systems, equilibria possibly irrelevant, meta-stable states and emergent (self-organized) properties

Why simulations?

In order to analyse complex social problems (e.g. development and environmental sustainability) we need a different class of models that can

- Embed realistic assumptions into micro and macro models: uncertainty, procedural decision, heterogeneity, local interactions, non-equilibrium
- Replicate some of the empirical evidence discussed
- Include innovation and structural changes
- Do not assume macro dynamics

"Agent-based models [...] are suited to answering macroeconomic questions where complexity, heterogeneity, networks, and heuristics play an important role" (Haldane and Turrell, 2018, p. 219)

Why simulations?

Interaction of objects (agents) as a *complex* problem $\mapsto$ no analytical solution

Social interaction as a complex problem with individual behaviour (less straightforward then physical behaviour)

- No closed system
- Interaction of heuristics and reaction heuristics

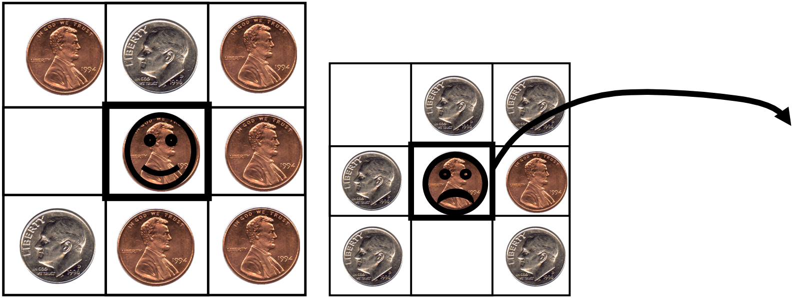
"I can calculate the motion of heavenly bodies, but not the madness of people" (I. Newton)

Simple interactions can lead to complex outcomes (Arthur, 1994; Schelling, 1971)

- Minority games, urban segregation, choice of a technology/good
- The place where you are sitting now

Schelling segregation model: explaining segregation

Micromotives and Macrobehaviour (Schelling, 1978): segregation can be explained by the interaction of simple individual choices (no racism...)



(a) Stay if at least 1/3 of neighbours are 'kin'

(b) Move to random location otherwise

Source: L-E Cederman

Schelling segregation model: set-up

N agents located on a 2-dimensional grid (torus) of LxL cells.

Types: Each agent can be either RED or GREEN

Only a percentage p of cells is occupied: $N < LxL$

Agents are initially located on the grid at random

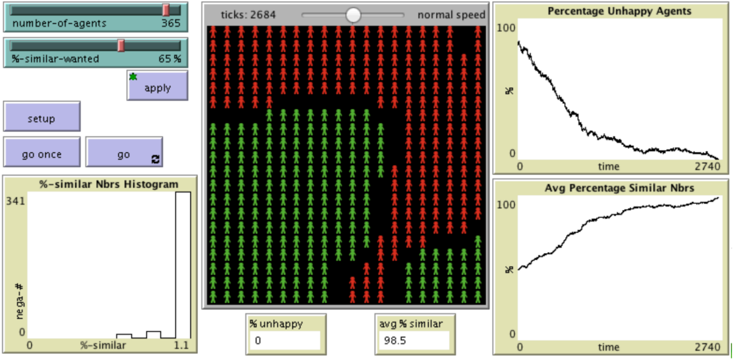
In each time period, agents may be happy or unhappy

Agent cares about the proportion q of other agents of same colour in its Moore neighbourhood of radius 1

Agents are unhappy if q is below a certain critical threshold (parameter of the model) and happy otherwise

In each iteration of the model one unhappy agent is randomly selected to move to a random empty cell in the lattice

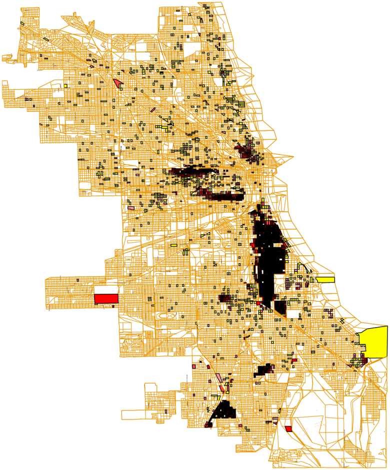
Schelling segregation model: experiments



Source: Izquierdo et al. (2009)

http://jasss.soc.surrey.ac.uk/12/1/6.html

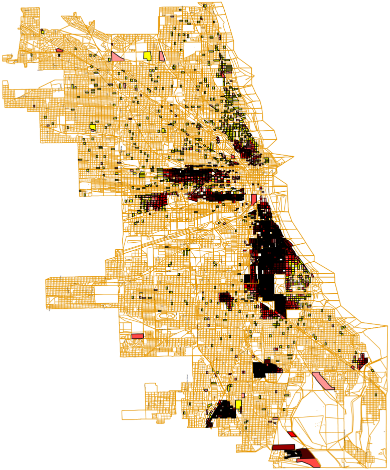
Schelling segregation: Chicago 1940



Source: Möbius and Rosenblat (2001)

Percentage of blacks: 1-5% yellow; 5-10% pink; 10-25% orange; 25-50% red; 50-75% dark red; 75-95% brown; > 95% black

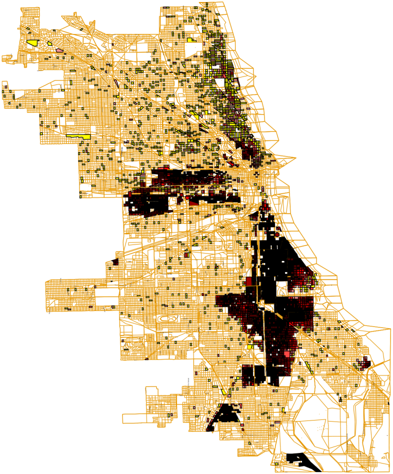
Schelling segregation: Chicago 1950



Source: Möbius and Rosenblat (2001)

Percentage of blacks: 1-5% yellow; 5-10% pink; 10-25% orange; 25-50% red; 50-75% dark red; 75-95% brown; > 95% black

Schelling segregation: Chicago 1960



Source: Möbius and Rosenblat (2001)

Percentage of blacks: 1-5% yellow; 5-10% pink; 10-25% orange; 25-50% red; 50-75% dark red; 75-95% brown; $>$ 95% black

ACE: Definition

ACE

Agent–Based Computational Economics: “the computational study of economic processes modelled as dynamic systems of interacting agents” (L. Tesfatsion)

Modeller constructs a virtual economic world populated by various agent types (economic, institutional, social, biological, physical)

Modeller sets initial world conditions

Modeller then steps back to observe how the world develops over time (no further intervention by the modeller is permitted)

World events are driven by agent interactions

Main properties of ACE

Population of *heterogeneous* (economic) 'agents'

Agents live in complex systems evolving through time (Kirman, 1998). True dynamics: non reversible

No 'hyper-rationality' (Dosi et al., 1996): internal states, rules of behaviour, and adaptive expectations

Agents are autonomous or semi–autonomous

Agents interact with one another and possibly with an environment (local/social interactions)

Endogenous and persistent novelty (technological change): open-ended system

Aggregate structure emerges from agent interactions (Tesfatsion, 1997)

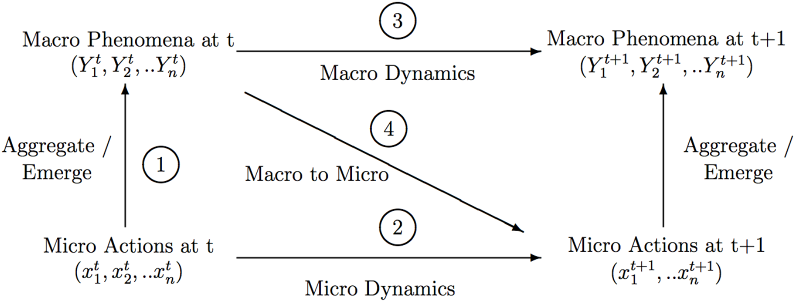
Generations of agents emerge from the interactions of their ancestors (selection, retention, innovation $\mapsto$ evolution) (Nelson and Winter, 1982)

Structure of ABM

Time	$t = 0, 1, 2, \ldots, (T)$	Discrete
Sets of Agents	$I_t = 1, 2, \ldots, N_t$	Often $N_t = N$
Sets of Micro States	$i \rightarrow \underline{x}_{i,t}$	Firm's output
Vectors of Micro-Parameters	$i \rightarrow \theta_i$	Res. Wage
Vector of Macro-Parameters	$\Theta \in \Re^m$	Min. Wage
Interaction Structures	$G_t \in \wp(I_t)$	Networks
Micro Decision Rules	$R_{i,t}(\cdot\|\cdot)$	Innovation rule
Aggregate variables	$\underline{Y}_t = f({}_{1,t}, \ldots, \underline{x}_{N_t,t}, \underline{Y}_{t-1})$	GNP

Source: by courtesy of Giorgio Fagiolo

Evo complex approach builds from bottom up (interacting agents)



Source: Page (2015)

Realisations

Highly parametrised: analysis

- Parameters of interest: functional analysis
- Whole space / reasonable space

Stochastic processes

- Uncertainty: sequence of stochastic events can have a strong effect on the outcome (e.g. percolation)
- Analyse distribution of each output variable

Each realisation a scenario (consistent with the model and in probability)
Analysis of plausible scenarios

Robustness

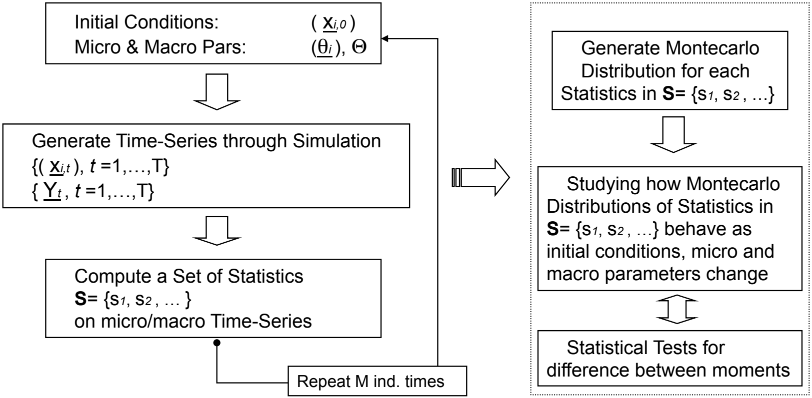
Calibration

- Abstract model vs explanation of a phenomenon vs foresight

Reproducing empirical evidence, under given parameter values (validation)

Robust assumptions: based on empirical evidence

Procedure of ABM



Source: G. Silverberg

Some applications in economics and business

- Evolutionary-Games: P. Young, Kandori et al., Blume, Ellison
- (Local) Interaction Models: Kirman, Weisbuch, Lux
- Endogenous Network Formation: Vega-Redondo, Cowan, Goyal, Jackson-Watts...)
- Innovation (Polya-Urn Schemes): Arthur, Dosi, Kaniovski, Lane, Marengo
- Complexity: Frenken, Valente, Marengo
- Strategy and organisations: Carley and Pietrula, Lomi and Larsen
- Technological modularity, firm and industry organisation: Ethiraj et al. (2007); Frenken et al. (1999); Kauffman et al. (2000); Marengo and Dosi (2005); Ciarli et al. (2008)

Some applications in economics and business

- Growth: Nelson and Winter (1982), Silverberg, Verspagen, Dosi, Howitt, Llerena and Lorentz (2004); Dawid and Fagiolo (2008); Dosi et al. (2010); Ciarli et al. (2010); Ciarli (2012); Ciarli et al. (2012); Fagiolo and Roventini (2012)
- Firms location: David et al. (1998)
- Firms and technological change: Dawid (2006); Teitelbaum and Dowlatabadi (2000); Yildizoglu (2002)
- Markets: Axtell, Epstein, Tesfatsion, Kirman and Vriend (2000)
- Electricity markets: Tesfatsion
- Sectoral studies: Malerba et al
- Environmental economics: van den Bergh, Safarzynska, Windrum et al. (2009a,b)

Some applications in economics and business

- Industrial life cycle cycles: Windrum and Birchenhall (2005), Malerba et al
- Labour market: Tesfatsion, Fagiolo et al. (2004), Richiardi and Leombruni
- Financial markets (a huge number): Delli Gatti et al. (2004), Delli Gatti and Stiglitz, Cont, econophisycs
- Macro instability: Bak et al. (1993); Dosi et al. (2006), Weisbuch and Battiston, Ciarli and Valente (2007)
- Macro: Howitt, Duffy, Arifovic
- Firms coalition and network formation: Cowan and Jonard, Ozman, Page, Huberman, Axtell, Vega-Redondo, Jackson, Watts
- Foresight: Lempert
- Other social sciences: Politics (state cooperation, conflict), Sociology, Anthropology, ...

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