Economics and Complexity:
Theory and Methods for Economics
or
Undressing the Invisibility Tunic of the Agents

João Basilio Pereima
joaobasilio@ufpr.br

Federal University of Paraná - UFPR
Graduate Program in Economic Development - PPGDE
NeX-Nucleo of Economics and Complexity

Economic Commission for Latin American and Caribean - ECLAC
Santiago, Chile

Summer School 2018

Complexity and Economics

Part 1 - Complexity Science

- Motivations
- Concepts and examples
- How complex science see the world?
- Is there **one** complex science?

Part 2 - Complexity and Economics

- How Complexity is being carried into economic science?
- Agent-Based Economics (ACE) and Agent-Based Model (ABM)
- Two useful software/high level language
  - Laboratory for Simulation and Development (LSD) - Valente (2000)
  - NetLogo - Wilensky (1999)

Complexity and Economics

Part 1 - Complexity Science

- Motivations
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- Is there **one** complex science?

What kind of reality are we dealing with?

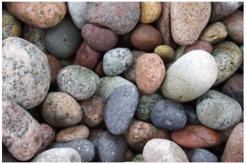
Representative x Heterogeneous Agents

- In the representative agents world the whole is the sum of the parts

$$Y_i = F_i(A_i, K_i, L_i)$$

$$Y = \int_0^n Y_i di \quad \text{or} \quad Y = \int_{L(Y,i)}^{U(Y,i)} Y_i di$$

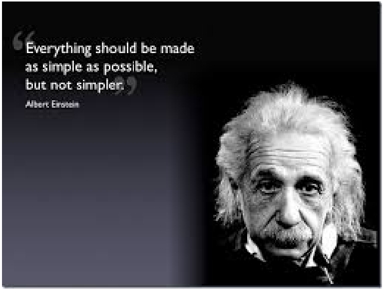
- In the heterogeneous agents world the interactions between agents produce different patterns in the macro level, some of them astonishing

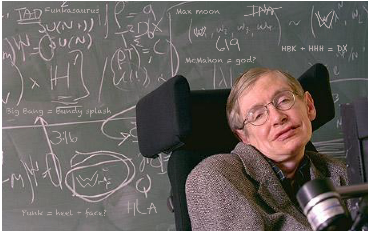


What kind of products, market, institutions, economy, society emerge from the alive gearbox of the interactive agents?

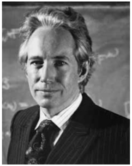
Motivations - (Science with a pinch of emotion)

I think the next century will be the century of complexity.
Stephen Hawking - January 2000





COMPLEXITY - MOTIVATIONS (SCIENCE WITH A PINCH OF EMOTION)

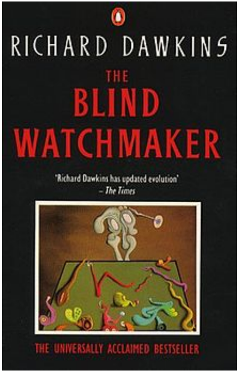


Science has explored the microcosmos and the macrocosmos; we have a good sense of the lay of the land. The great unexplored frontier is ***complexity***
Heinz-Pagels: *The Dreams of Reason*

... but we could say: *Economic science has explored the microeconomics and the macroeconomics; we have a (not so) good sense of the economic system. The great unexplored frontier is* ***complexity***

Why economists do not understand Complexity well, if so?

Our brains were designed to understand hunting and gathering, mating and child-rearing: a world of medium-sized objects moving in three dimensions at moderate speeds.
Dawkins (1987) in The Blind Watchmaker



FROZEN VIEW!

"Economic is not a evolutionary science - by the confession of its spokesman: and the economists turn their eyes with something of envy and some sense of baffled emulation to theses rivals that make broad their phylacteries with the legend, 'Up to date'.

Precisely wherein the social and political sciences, including economics, fall short of being evolutionary sciences, is not so plain."

Veblen (1899, p. 374-5)

The same reasoning applies today to the Complexity Theory context.
Ex.: Arthur (1994, 1999)

Why Complexity?

- Many phenomena in the physic, natural and social dimension of the reality can not be explained with concepts of mechanical physic (e.g.: with analytical solutions of reduced equation system)
- Large structures are assembled from particles or individuals in a way far beyond that the simple aggregation and sum: they interact
- By the first time in science it is possible generate aggregated patterns from micro behaviour and explain at the same time the origins of macrodynamics and structural change
- Structures evolves to an unpredictable future and forms
- The time arrow is not reversible and many traditional scientific methods fails to explain and forecast
- Commonly the systems shows up heterogeneity and produces novelty
- The system (societies) are populated by $\pm$ heterogeneous agent who interacts with the others
- We are far from comprehend the World or the Reality with the Newtonian machine or statistical viewpoint only, mainly in social and economic science
  - **Deterministic** *versus* **Statistical** *versus* **Complex** view of the world

Despite of the progress of science in the XX century, many new questions and answers remains open and can not be thought with traditional viewpoint

So, what is complexity?

An interdisciplinary field of research that seeks to explain how large number of relatively simple entities organize themselves, without the benefit of any central controller into a collective whole that creates patterns, uses information, and, in some cases, evolves and learns.

Mitchell (2009, p.4)

Complex systems consist of units interacting in a hierarchy of levels, including subsystems composed of even more intricate sub-subsystems.

Complex systems exhibit emergent properties due to the interaction of their subsystems when certain unspecific environmental conditions are met, and they show temporal and/or spatial patterns on a scale that is orders of magnitude bigger than the scale on which the subsystems interact.

Fuchs (2013, p.4)

A complex thing is something whose constituent parts are arranged in a way that is unlikely to have arisen by chance alone.

Dawkins (1987, p.7)

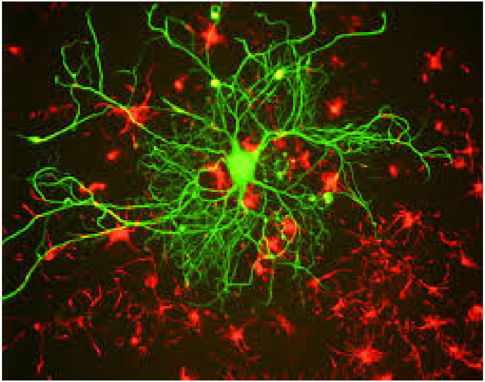
Complex and Army Ants

Army Ants: A Collective Intelligence - Franks (1989)

An example of individual simplicity with collective sophistication

Complex and Neurons

Human Neuron, artificially illuminated

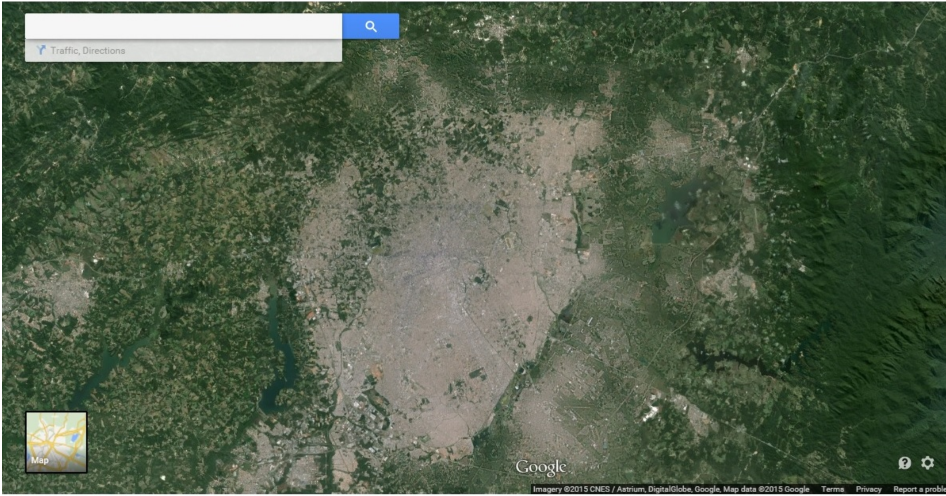


Complex and Crowd

A Crowd on street - India

Complex and Spatial Urban Growth

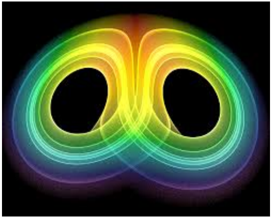
Curitiba-Brazil from the space

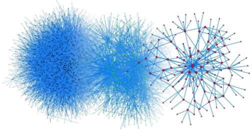


Complexity Approaches

Important concepts

- High Non-linearity
- Hierarchy
- Non-Predictability
- Interactions (at micro and macro level)
- Network
- Learning and information computation
- Diversity/variety
- Adaptive system
- Evolution
- Self organization
- Emergence

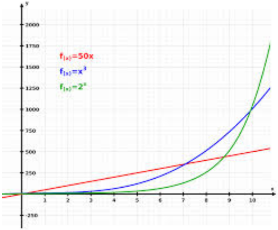




Complexity Approaches

- A - Non-linear system of differential equations (at macro level)
  - Instability
  - Multiple equilibrium
  - Dynamic replicator or Lotka-Voltera system
  - Bifurcation
  - Deterministic Chaos
  - Fractal structures
- B - Agent-based models with interactions - connecting micro and macro
  - Networks
  - Auto-organization (from chaos to order)
  - Spatially oriented models (e.g. using Netlogo)
  - Hierarchic Micro-macro models in difference (e.g. using LSD in economic models)
- C - Evolution, Adaptive System and Computation
  - Cellular automata
  - Genetic algorithms and evolutionary computation
  - Computation of information
  - Fitnnes Landscape

A - Non-linear system of differential equation



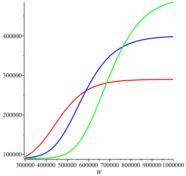
Thomas Malthus - 1766-1839

The Malthusian exponenctial equation is (Malthus, 1798)

$$\frac{dN(t)}{dt} = rN(t) \longrightarrow N(t) = N(0)e^{rt}$$

It is a one dimensional equation

A - Non-linear system of 1 differential equation



Pierre François Verhulst - 1804-1849

The logistic equation was coined by Verhulst (1838)

$$\frac{dN(t)}{dt} = rN(t)\left(1 - \frac{N(t)}{K}\right) \longrightarrow N(t) = \frac{K}{1 + CKe^{-rt}}$$

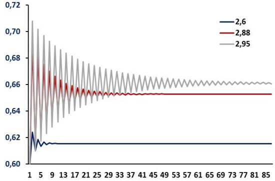
where $C = \frac{1}{N(0)} - \frac{1}{K}$ is the constant of integration and initial condition. It is a one dimensional quadratic equation and K is the carry capacity.

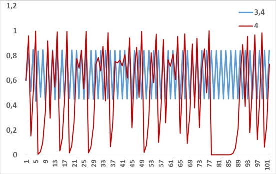
A - Non-linear system of 1 differential equation

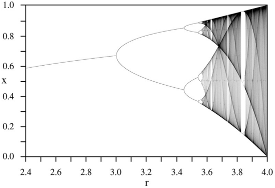
Logistic function: from linear behavior to deterministic chaos

$$\frac{dN(t)}{dt} = rN(t-1)\left(1 - \frac{N(t-1)}{K}\right)$$

This happens in the discrete case.





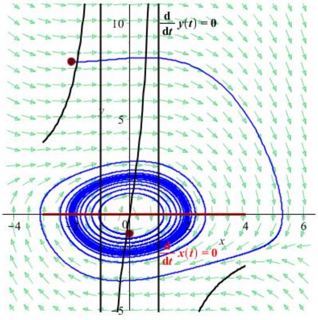


A - Non-linear system of 2 differential equation

The van der Pol (1926) model

$$\dot{x}(t) = y(t)$$

$$\dot{y}(t) = \alpha \left(1 - x(t)^2\right) y(t) - x(t)$$



Phase Diagram

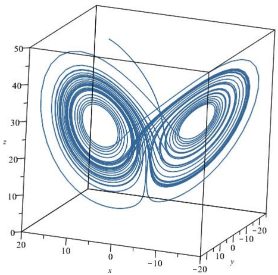
View it in Maple...

A - Non-linear system of 3 differential equation

The Lorenz (1963) Attractor model

$$\dot{x}(t) = \sigma \left(y(t) - x(t)\right)$$
$$\dot{y}(t) = x(t) \left(-\rho - z(t)\right) - y(t)$$
$$\dot{z}(t) = -\beta z(t) + x(t)y(t)$$

Lorenz attractor



Show example with Maple... and on the Wikipedia:
http://en.wikipedia.org/wiki/Lorenz_system

B - Agent-based models with interactions - connecting micro and macro

The World of Interacting Agents

All the preceding examples were based in evolution of aggregated, summed up or average quantities. No heterogeneity or interactions was present. In the Agent-based-world, the behavior of an agents have an effect on the others, and individual following a simple and particular rule, can produce surprising aggregated effects. Stem cell can divide yourself and generate different organs. One initial cell generate a complete and different body within the same species. Individuals following his particular or collective simple rule generate a social or economic reality, observed and analysed by the traditional methods: econometrics and structural models.

The aggregated researcher can not answer suitably the question: Where does this aggregated pattern came from?

In order to answer this you need a agent-based-world (model) inhabited by heterogeneous agents more than representative one.

An important starting point is Schelling (1978), Granovetter (1978), Arthur (1989)

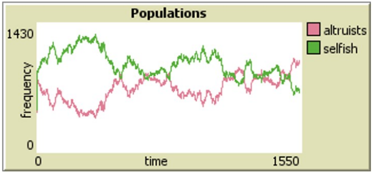
B - Agent-based models with interactions - An example

To the Social Science and Economics in particular, an important idea is the possibility of **interactions**, which can manifest in many levels:

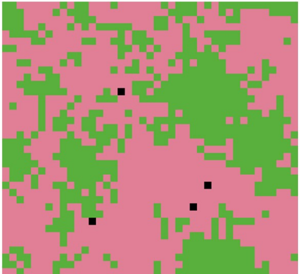
- Agent $\rightleftharpoons$ Agent
- Agent $\rightleftharpoons$ Environment

An example of interaction in a social model:

```
if Agent = “A” (altruist) then
   fitness = 1 - cost + (Number Altruists in Neigh / 5 * benefit
                       from Altruists)
else Agent = “S”
  fitness =  1 + (Number Altruists in Neigh / 5 * benefit from
                 Altruists)
end if
```



Ver NetLogo: social science / altruism model



B - Agent-based models with interactions or adaptive behaviour

Not exhaustive examples using Netlogo

- NetLogo Library: Computer Science/Cellular Automata/Life (Game of Life)
- NetLogo Library: Social Science/El Farol
- NetLogo Library: Social Science/SugarSpace3
- Einloft & Pereima (2017) - The Bandwagon Effect and innovation
- Einloft & Pereima (2017) - Wealth Inequality and the Pattern of Innovation

Not exhaustive examples using LSD

- Brian Arthur
- Nelson & Winter
- Ciarli (2012) - Structural interactions and long run growth
- Ciarli e Valente (2016) - The complex interactions between economic growth and market concentration in a model of structural change
- Dosi et al (2017) - Micro and macro policies in the Keynes+Schumpeter evolutionary models
- Lorentz et al (2016) - The effect of demand-driven structural transformations
- Higachi, Lima & Pereima (2016) - Crescimento, Ciclo Econômico e Inovação
- Pereima & Gabardo (2016) - The complex dynamics of growth and structural change: the role of consumption, innovation and finance

More about this in the 2rd part!

C - Adaptive System, Evolution and Computation

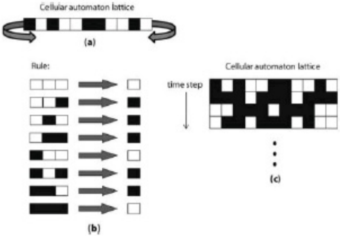
- Cellular automata
- Genetic algorithms and evolutionary computation
- Computation of information
- Fitnnes Landscape

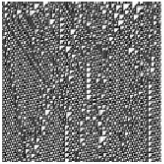
C - Adaptive System, Evolution and Computation
Cellular Automata-CA

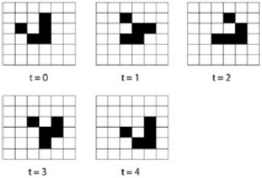
At a very general level, one might say that computation is what a complex system does with information in order to succeed or adapt in its environment. Mitchell (2009, cap. 10, p. 146)

The CA are discrete, abstract computational system that have proved useful to study complex and non linear behaviour of some systems where the agents (cell) can change its status or move to another place according to a set of disposal simple rule and depending of the status of its neighborhood. The CA generally is represented in a Lattice (grid) of cells. [John von Neuman (1940s)]

Wolfram Cellular Automata (1D-CA) and Conway (1970) Game of Life (2D-CA)







C - Adaptive System, Evolution and Computation
1D - Cellular Automata-CA

Starting point:

- von Neumann (1966): *Theory of Self-Reproducing Automata*
- Langton (1984, 1986): *Self-reproduction in cellular automata*
- Wolfram (1984a,b, 2002): *A New Kind of Science*
- Miller and Page (2007, Chap 8): *Complexity Adaptive Social Systems in One Dimension*

Examples of 1-Dimension Cellular Automata in NetLogo

- **CA 1D Elementary** - a model that shows all 256 possible simple 1D cellular automata
- **CA 1D Totalistic** - a model that shows all 2,187 possible 1D 3-color totalistic cellular automata
- **CA 1D Rule 30** - the basic rule 30 model
- **CA 1D Rule 30 Turtle** - the basic rule 30 model implemented using turtles
- **CA 1D Rule 90** - the basic rule 90 model
- **CA 1D Rule 110** - the basic rule 110 model
- **CA 1D Rule 250** - the basic rule 250 model

C - Adaptive System, Evolution and Computation
2D Cellular Automata-CA

The Game of Life, also known simply as Life, is a cellular automaton devised by the British mathematician John Horton Conway in 1970.

The "game" is a zero-player game, meaning that its evolution is determined by its initial state and a rule, requiring no further input. One interacts with the Game of Life by creating an initial configuration and observing how it evolves, or, for advanced "players", by creating patterns with particular properties.

Conway was interested in a problem presented in the 1940s by mathematician John von Neumann, who attempted to find a hypothetical machine that could build copies of itself and succeeded when he found a mathematical model for such a machine with very complicated rules on a rectangular grid. The Game of Life emerged as Conway's successful attempt to drastically simplify von Neumann's ideas.

Theoretically, Conway's Life has the power of a universal Turing machine: anything that can be computed algorithmically can be computed within Life.

- https://en.wikipedia.org/wiki/Conway%27s_Game_of_Life

C - Adaptive System, Evolution and Computation
Genetic Algorithms

In his famous book *Theory of Self-Reproducing Automata*, von Neumann (1966) answered affirmatively an astonishing question: *"Can a machine reproduce itself?"* and after that he start working to take the next logical step and have computers (or computer programs) reproduce themselves with mutations and compete for resources to survive in some environment. This would counter the "survival instinct" and "evolution and adaptation". However, von Neumann died before he was able to work on the evolution problem.

Others quickly took up where he left off. By the early 1960s, several groups of researchers were experimenting with evolution in computers. Such work has come to be known collectively as **bb**. The most widely known of these efforts today is the work on genetic algorithms done by John Holland and his students and colleagues at the University of Michigan.

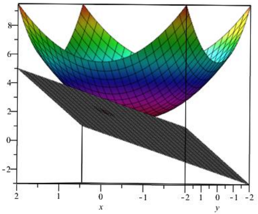
John Holland is, in some sense, the academic grandchild of John von Neumann. Holland's own Ph.D. advisor was Arthur Burks, the philosopher, logician, and computer engineer who assisted von Neumann on the EDVAC computer and who completed von Neumann's unfinished work on self-reproducing automata.

This introduction was slightly adapted from Mitchell (2009, chap. 9)

C - Adaptive System, Evolution and Computation
Genetic Algorithms

Genetic Algorithm (GA) is a computational (artificial) procedure which evolve replicating the natural evolution. The GA algorithm use search heuristics and optimization techniques based on variation and selection.

In the traditional optimization under restriction problem the analytical solutions of an given $V = F(y, u, t)$ subject to a set of restrictions is reached by solving an Hamiltonian function:



$$\max \quad V = \int_0^T F(y, u, t)dt$$

$$\text{subject to} \quad \dot{y} = f(y, u, t)$$

$$y(0) = A, \quad y(T) = \text{free}, \quad (A, T)\,\text{given}$$

$$\text{and} \quad u(t) \in \mathcal{U} \quad \text{for all} \quad t \in [0, T]$$

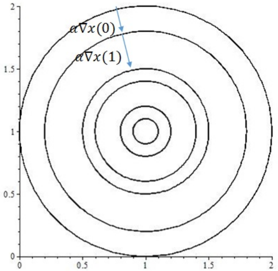
If you can do this, you can jump directly into the optimal point and the history finishes!

C - Adaptive System, Evolution and Computation
Genetic Algorithms

Genetic Algorithm (GA) technique

In the Genetic Algorithm, the agent "walk" on the landscape comparing the actual fitness with the past, changing randomly some propriety, adapting to environment and interacting with other agents.
Gradient based, or hill climbing: given a continuous function $y = f(x)$

- Pick a point $x(0)$ on *landscape*
- Compute the gradient $\nabla f[x(0)]$
- Evaluate if the *Fitness* has increased
- Give one step ahead with size α: $x(1) = x(0) + \alpha \nabla f[x(0)]$
- Repeat, repeat and repeat again, until reach the top



This procedure, again, depends on the function $f(x)$ be differentiable. Easily reach the local maximum, when the gradient $\nabla f[x(t)] = 0$

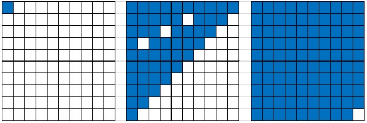
See Holland (1975, 1998), Kauffman and Levin (1987) and Valente (2013) for an economic application

C - Adaptive System, Evolution and Computation
Computation of information

Evolution has been processed by computation. How the evolution process manipulates the information? Dawkins (1987): by a Blinded Watchmaker. Evolution goes on by small and located random mutation towards a long and slow and cumulative selection.

Consider a system composed by "***n***" constituents (agents) or a space-state with "***n***" configuration whom or which presents only two characteristics or attribute $a = \{0, 1\}$ which can means black and white, optimistic and pessimistic, altruist or selfish, or anything else. If we arrange this "***n***" components in a one-dimensional sequence we get an array or a landscape with many different results or configuration at instant t:

N=2 A=$\{0,0\}, \{0,1\}, \{1,0\}, \{1,1\}$ A = $2^2 = 4$	**N=3** A=$\{0,0,0\}, \{0,0,1\}, \ldots, \{1,1,1\}$ A = $2^3 = 8$
N=100 A = $2^{100} = 1.267.650.600.228.229.401.496.703.205.376 = 1,267E^{30}$	



The size of Universe: 1.2 to $3.0E10^{23}$ stars $\rightarrow 10^{78}$ to 10^{82} atoms

C - Adaptive System, Evolution and Computation
Fitness landscape

A Simple Genetic Algorithm

Given a clearly defined problem to be solved and a bit-string representation for candidate solutions

[0010101110]
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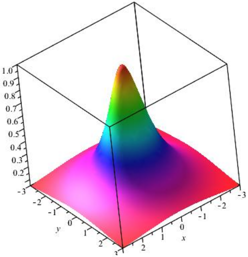
The simple GA works as follows:

- Start with a randomly generated population of N L-bit (candidate solutions to a problem).
- Calculate the fitness $F(x)$ of each x in the population.
- Repeat the following steps (a)-(c) until N offspring have been created:
  - Select a pair of parent from the current population, with the probability of selection being an increasing function of fitness. Selection is done with replacement, meaning that the same bit can be selected more than once to become a parent.
  - With probability p_c (the crossover probability), cross over the pair at a randomly chosen point (chosen with uniform probability) to form two offspring. If no crossover takes place, form two offspring that are exact copies of their respective parents.
  - Mutate the two spring at each locus with probability p_m (the mutation probability), and place the resulting in the new population.
- Replace the current population with the new population.
- Go to step 2.

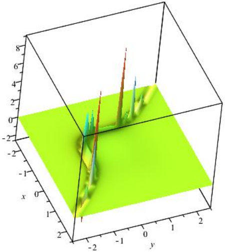
C - Adaptive System, Evolution and Computation
Fitness landscape

Agents look for best fitness searching randomly or according to a simple rule around the neighbourhood and decide to move or not to another site. Without maximize, they reach the ridge after some time. See: Wright (1932), Kauffman and Levin (1987), Valente (2008, 2013)

$$z = \frac{1}{1 + x^2 + y^2}$$

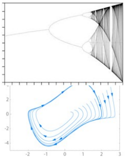


$$z = \frac{1}{1 + x^3 + y^3}$$



A more alluring example: https://en.wikipedia.org/wiki/Fitness_landscape

HOW MUCH COMPLEXITY



Complexity Degree

Low

High

Complexity and Economics

Part 2 - Complexity and Economics

- How Complexity is being carried into economic science?
- Agent-Based Economics (ACE) and Agent-Based Model (ABM)
- Two useful software/high level language
  - Laboratory for Simulation and Development (LSD) - Valente (2000)
  - NetLogo - Wilensky (1999)

How Complexity is being carried into Economics

Not exhaustive list

- Schelling (1978), Granovetter (1978) introduce the idea of “Micromotives and macrobehavior”, an approach of the type of bottom-up systems: aggregated results emerging from interactions and subject to thresholds effects
- Nelson and Winter (1982) interact firms competing through innovation as microfoundations of evolutionary theory of growth. (Frontal attack tone!)
- Arthur (1989, 1992, 1999, 2013) - Competing Technology, Increasing return and Lock-in events
- Simon (1996) in The Science of Artificial introduces the idea of the complexity as hierarchy
- Foster (1997) - The analytical foundations of evolutionary economics
- Beinhocker (2006) in The Origins of Wealth defends a vision of the economic as a *complex adaptive system*. (Frontal attack tone!)
- Tesfatsion and Judd (2006) - Handbook of Agent Computational Economics (ACE)
- Hommes and LeBaron (2018) - Handbook of Agent Computational Economics: Heterogeneous Agent Modeling
- Jackson (2008, 2014) - Networks Analysis
- Delli Gatti and et al (2011) - Macroeconomic from Bottom-up, with evolutionary microfoundations
- Ciarli et al. (2010a,b) - ABM of Growth and Structural Change
- Valente (2013) - Fitness in the Rugged Landscapes: *An NK-like model of complexity*, adapted the idea from Kauffman et al. (2000)
- Guerini et al. (2016) - About heterogeneity, local interactions and macroeconomic dynamics

How Complexity is being carried into Economics

Three paradigms in formal economic science

- **Theory without agents**
  - Macro without micro-foundations (ex: Keynesian)
  - No behaviour concern
  - Simple equation systems with analytical solutions
  - Explains ***how*** the economic system works
  - Mainly, but not only, used for forecasting - A good theory is the one that works (Friedman)
  - Based on empirical correlations, validated by econometric
- **Theory with representative agent**
  - Macro with micro-foundations - Traditional view: optimizing agents
  - Hypothesis about the behaviour of agents, but no interactions
  - “Simple” equation systems with analytical solutions
  - As before explains ***how*** the economic system works
  - Explains where the economic systems came from, but wearing the agents with the straitjacket of the full rationality, and because of this, assume representative agent
  - Assumes the system starts and ends at a dynamic equilibrium. No structural change and long-run transformations.
- **Theory with heterogeneous agents**
  - Macro with micro-foundation - Decision rule, heuristics, searching, learning, ...
  - Hypothesis about the behaviour of agents
  - Strong Interaction - Schelling (1978)
  - No analytical solutions, no reversibility
  - Based on computing models - Tesfatsion and Judd (2006), Tesfatsion (2006)
  - Explain how the economic system works
  - Explain where the economic systems comes from, depending on a collection of distinct behaviour
  - Explain how the economic systems change and evolve - Metcalfe and Foster (2003)
- More arguments for microfoundation: Cimoli and Porcile (2015)-*What Kind of Microfoundation: Notes on the evolutionary approach*
- Comparison DGSE x ABM: Fagiolo and Roventini (2017)-*Macroeconomic policy in DSGE and agent-based models redux: New developments and challenges ahead*

Moving to Economy: Example with technology

Representative x Heterogeneous Agents (as shown at the beginning

- In the representative agents world the whole is the sum of the parts
- In the heterogeneous agents world the interactions between agents produce different patterns in the macro level, some of them astonishing

$$Y_i = F_i(A_i, K_i, L_i)$$

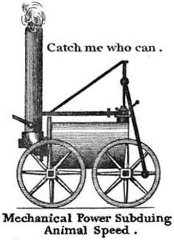
$$Y = \int_0^n Y_i di \quad \text{or} \quad Y = \int_{L(Y,i)}^{U(Y,i)} Y_i di$$

Moving to Economy: Example with technology

Invention & Invention as complex phenomena

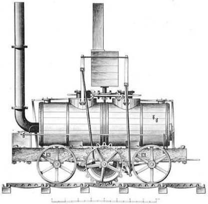
Steam-engine Case

Grazebrook Engine
This is a Boulton & Watt beam blowing engine re-erected on the Dartmouth Circus roundabout, on the A38(M) in Birmingham, UK.
It was built in 1817 and used in Netherton at the ironworks of M W Grazebrook.



Drawing of the locomotive *Catch Me Who Can*, from a card or admission ticket to Trevithick's "Steam Circus", summer 1808.

Richard Trevithick



Blenkinsop's rack locomotive **Salamanca**, Middleton to Leeds (UK) coal tramway, 1812

Moving to Economy: Example with technology

Invention & Invention as complex phenomena

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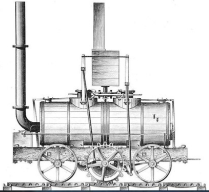
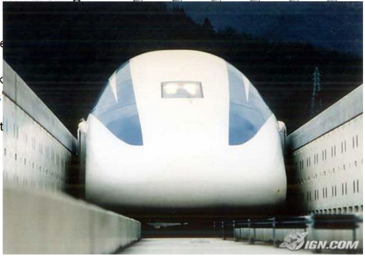
Drawing of the
Me Who Can,
admission tick
"Steam Circus"

Richard Trevit



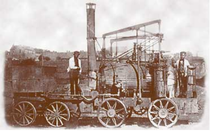


Das locomotivas aos supercondutores

HOW SALAMANCA BROKE AWAY THE WALRASIAN WORLD

Sellers and buyers meeting at the same location. Small market. Small World. Every one knows every one. An omniscient market, with perfect coordination.

$\Rightarrow$



For the first time in the history human could move in a speed higher than horses. Local industries expand their market, destroying another local industries creating a oligopolistic production system.

$\Rightarrow$

Market became global. Internet, AI, Complex Computation and disruptive technology are bringing society back to a Walrasian society, but in planetary scale?

A comparison

Five "Big Ideas" That Distinguish Complexity Economics from Traditional Economics

	Complexity Economics	Traditional Economics
Dynamics	Open, dynamic, nonlinear systems, far from equilibrium	Closed, static, linear systems in equilibrium
Agents	Modeled individually; use inductive rules of thumb to make decisions; have incomplete information; are subject to errors and biases; learn and adapt over time	Modeled collectively; use complex deductive calculations to make decisions; have complete information; make no errors and have no biases; have no need for learning or adaptation (are already perfect)
Networks	Explicitly model interactions between individual agents; networks of relationships change over time	Assume agents only interact indirectly through market mechanisms (e.g., auctions)
Emergence	No distinction between micro- and macroeconomics; macro patterns are emergent result of micro-level behaviors and interactions	Micro- and macroeconomics remain separate disciplines
Evolution	The evolutionary process of differentiation, selection, and amplification provides the system with novelty and is responsible for its growth in order and complexity	No mechanism for endogenously creating novelty, or growth in order and complexity

Source: Beinhocker (2006)

Quick Cases of ABM or What we can do with ABMs

Some models of interacting agents in NetLogo

- NetLogo: Ants
- NetLogo: Hotelling Location
- NetLogo: Urban Development (1)
- NetLogo: More Real Urban Development (2)
- The Echoes of Bandwagon on Innovation in a Complex Small World Live Network

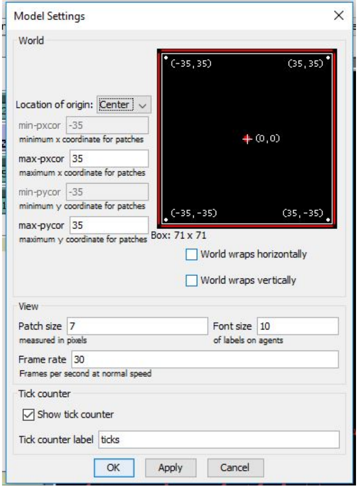
Some models of interacting agents in LSD

- On the determinants of structural change an exploratory model
- Growth, Business Cycle, Technological Change and Financing–an entwined innovation and finance approach

NetLogo Environment

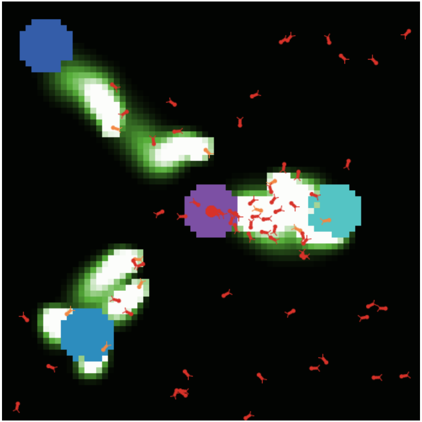
NetLogo Concepts:

- **Patch**: 2 or 3 dimensional space where agents live
- **Turtles**: agent
- **Links**: network connections
- Both patches and can have living proprieties



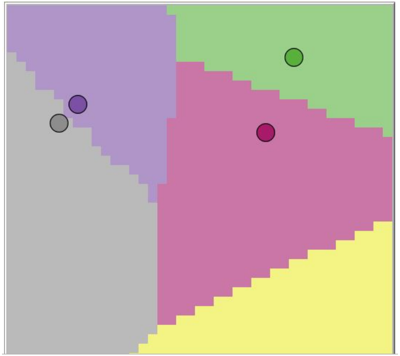
NetLogo: Ants Model

- A colony of ants forages for food. Though each ant follows a set of simple rules, the colony as a whole acts in a sophisticated way
- When an ant finds a piece of food, it carries it back to the nest, dropping a chemical as it moves. Other ants "sniff". They send and collect local information
- Ants spread Pheronoma according to the parameter *Diffusion Rate*
- Pheronoma evaporate
- Ants move around by changing direction until 40° ahead
- Ants follow and uphill-chemical procedure-three direction it find chemical



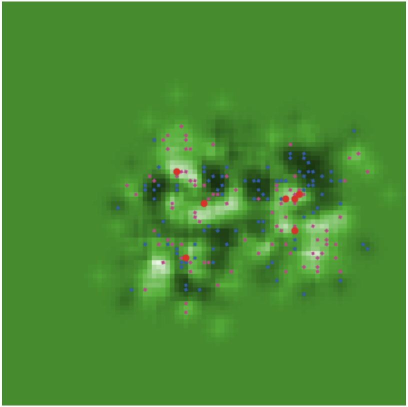
NetLogo: Hotelling Model

- This model represents the Hotelling's law (1929), which examines the optimal placement of stores and pricing of their goods in order to maximize profit. In Hotelling's original paper, the stores were confined to a single dimension.
- This model replicates and extends Hotelling's law, by allowing the stores to move freely on a plane.
- In this model, several stores attempt to maximize their profits by moving and changing their prices.
- Each consumer chooses their store of preference based on the distance to the store and the price of the goods it offers.



NetLogo: Urban Development Model (1)

- The model explores residential land-usage patterns from an economic perspective, using the socio-economic status of the agents to determine their preferences for choosing a location to live.
- It models the growth of rich (pink) and poor(blue), who settle based on three properties of the landscape: the perceived quality, the cost of living, and the proximity to services (large red dots). These properties then change based on where the different populations settle.
- The model shows the segregation of populations based on income, the clustering of services in more affluent areas, and how people's attitude can lead either to a cluster condition (emphasis on proximity), or a condition of sprawl (emphasis on cost or quality).
- At each tick, some number of new poor people (POOR-PER-STEP) and new rich people (RICH-PER-STEP) enter into the world. Then they randomly sample some number of locations, and choose to inhabit



NetLogo: Urban Development Model (2)

- This model simulates various socio-economic realities of low-income residents of the City of Tijuana for the purpose of creating propositional design interventions.
- The Tijuana Bordertowns model allows input of migration rates and border crossing rates relative to employment and service centers in order to define population types (i.e. migrants or full-time residents).
- Population densities relative to block sizes are adjustable via the interface in order to steer the simulation toward specific land-uses such as urban centers or peripheral (rural) development.
- The rate of residential building is adjustable based upon relative community size, land value (approximate), required (per-capita) capital and the carrying capacity of (potentially) existing infrastructure.
- Agent cab be traced: current income, savings, living expenses, job, origin, time living in Tijuana.
- Patches can also be inspected: infrastructural features such as water, electricity and roads.
- In all cases, information about agents and patches continually changes during the simulation based upon interrelated feedback.
- A CITYSCAPE is generated, spreading out from a city center.
- An initial set of migrants are created at the edge of the city on“irregular” patches, meaning those patches with a low land-value, near water and away from maquiladoras.
- A second set of migrants is created in the neighboring patches. This establishes the base population of the irregular settlements.
- Then each migrant is assigned a living-expanses values: value of the land they occupy, food and utilities costs, electrical, water, and transportation.

The Echoes of Bandwagon on Innovation in a Complex Small World Live Network

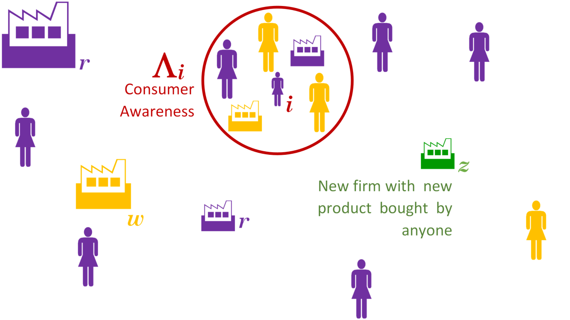
Γ Euclidean space

$\Omega = \{1.....10\}$ - Population

$\Omega_i = \{j \mid (j, i) \in \Lambda_i\} = \{1,2,3\}$ – All consumers *j* into the radius of agent *i**

$\Phi_w = \{1,2\}$ - Consumers into the radius that bought product *w*

$\Xi_i = \{x \mid (x, i) \in \Lambda_i\} = \{1,2\}$ – Firms into the radius of agent *i**



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