Economic complexity: A minimalistic model of fisheries

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Economy as a complex adaptive system (CAS)

What is in common between:

- the immune system of an individual
- a friends network or a criminal network
- an industry composed by innovating firms
- a financial market
- a megapolis
- evolution of an ecosystem (eg. fisheries)

→ John Holland (1996) : They are all an instance of *Complex adaptive systems* (**CAS**).

Five general properties of the CAS

Santa Fe Institute on Complexity: (Arthur *et al.* , 1997):

1. Dispersed interaction
2. No global controller
3. Continual adaptation
4. Perpetual novelty
5. Out-of-equilibrium dynamics

In Red Queen's country...

-Now, HERE, you see, it takes all the running YOU can do, to keep in the same place. If you want to get somewhere else, you must run at least twice as fast as that !

(The Red Queen, in Through the Looking Glass, by Lewis Carrol, p.20)

- Dynamics and aggregate properties of a CAS
- $\leftarrow$ Interactions and learning of agents.
- $\rightarrow$ Necessity of developing new tools for analysis and modeling

Micro motives and Macro outcomes?

- Can we predict final states or aggregate dynamics of such a system?
- Can we influence its evolution (policy?)?
- Why and how this evolution can exhibit a very special configuration of the system (a standing ovation, or first two rows always empty in an amphitheater)?
- How the interaction of individual desires can yield aggregate results perfectly in contradiction with these motives (Schelling, 2006)?
- $\rightarrow$ **Emerging properties** of the system
- Subsidiary question for the economist: quid of the *Invisible hand?*

Properties of complex dynamics

- Difficulty to predict aggregate properties from individual behaviors (emergence);
- Difficulty to predict final states of the system (open dynamics);
- Importance of small historical events (path dependency);
- Importance of small components of the system (strong interaction).

- A spatial modeling of fish school movements and of fishing boats, as well as their fishing activities
- allowing the study of different regulation mechanisms (PMA, quotas, etc.)
- and incorporation of economic dimensions (market price, taxes, etc.)
- Reference article for the base model:
  A. Moustakas, W. Silvert, A. Dimitromanolakis, , 2006, A spatially explicit learning model of migratory fish and fishers for evaluating closed areas, *Ecological Modelling*, 192, 245-258.

Principal components

- **The environment:** a rectangular zone representing the (North)sea, composed of a lattice of patches
- **Agents:**
  - **Fish schools** who move in the sea, guided by the nutritive value of different patches, and seasonally, between the food zone and the recruitment zone
  - **Fishing boats** who move on the sea, guided by their past experience (before the fishing has been invented), about the monthly average fish stock (*valPeche*) observed on different patches for a given number of years

How do the boats move?

- Each boat,
  - checks every day the quantity of fish present on its location (patch) and around (the 8 neighboring patches) and
  - fishes on-place if there is at least *minPeche* fish schools on its location,
  - or moves to a new location, with a probability increasing with the value *valPeche* of the neighboring patches, but potentially with some inertia
  - She would also choose to move if there are more than *maxNbBateaux* boats on a patch (*too crowded!*)
- When fishing, the boat can only take a proportion α of the fish population located on its patch (this parameter representing the efficiency of its technology).

Creation of fish schools

- The initial fish population (the number of fish schools and their initial size) is fixed at the beginning of the simulation ($biomasse_0$).
- Fish school increase their size in each period, following a growth rate ($tauxCroissance$) and a maximal biomass corresponding to the carrying capacity of this sea:

$$maxBiomasse \equiv 10 \times biomasse_0$$

- The initial biomass is the sum of the population of all fish schools initially created ($nbInitBancs$).
- Each school initially includes a random number of members $\in [1, 5]$.
- and it is placed at a random location in the sea

Dynamics of fish schools

- The growth rate (*tauxCroissance*) determines the percentage of the distance to the carrying capacity that can be covered in each period:

$$popBanc_{t+1} = popBanc_t \times (1 + \gamma)$$

$$\gamma = tauxCroissance \times \frac{maxBiomasse - biomasse_t}{maxBiomasse}$$

- School's population decreases when they are fished during that period
- If there is no fish left in, the school dies
- Id the school becomes too big ($size > 10$), it divides to two schools that become independent
- In each period, each school moves to a neighboring patch, selected with a probability increasing with the value *valPoisson* of the patches.

Determination of *valPecheur* of the patches

- This is a monthly value computed for each patch, and gives **the expected value of this patch for the fishing boats**
- It corresponds to the average relative quantity of fish observed on each patch, for each month, during a given number T of years, before the start of the fishing activity:

$$valPecheur(p,m) = \frac{1}{T}\sum_{y=1}^{y=T}\left(\frac{1}{30}\sum_{d=1}^{j=30} 100 \times \frac{nbPoissons(p,m,d)}{biomasse_d}\right),$$

  $y = 1...T$ represents the years of observation, $m = 1 \ldots 12$, the months, $d = 1 \ldots 30$, the days of the month, and p, the patch
- To simplify, we will consider that each year has exactly 360 days.

Determination of *valPoisson* of the patches

- This is the resource value of the patches for fish schools
- It is distributed around a summit S, where it has the maximal value of 100
- And then, for each patch, it decreases when the distance of the patch to S increases:

$$valPoisson\,(patch \neq S) = \Gamma - 0.5 + \varepsilon, \text{ with } \Gamma \equiv 100 \frac{1}{1+\sqrt{\Delta}}$$

  where $\Delta > 1$ is the distance of the patch to S, and $\varepsilon \rightsquigarrow \aleph\,(0,1)$, a random noise

- Consequently, $\Gamma \in [8, 100]\,, \forall S$ and patch in this sea

Movements and recruitment of fishes

- This summit S, which is hence an attraction point, changes in a seasonal manner:
  - for the first 4 months, the summit becomes $S = P = (20, 25)$
  - for the following 8 months, $S = Q = (60, 70)$
  - $\rightarrow$ Hence fishes migrate seasonally between these two summits
- And, during the first half the year, schools that are at a distance smaller than *distPonte* to the summit P can reproduce (as seen above)

An ABM for this very simple spatial ecosystem

- We want to study the dynamics, in time and in space, of the population of these two types of agents
- We create a computationa agent-based model (ABM) of this ecosystem with NetLogo
  https://ccl.northwestern.edu/netlogo/
- An open source, cross-OS and free platform, supported by the Northwestern University, and the NSF
- Providing a complete programming meta-language dedicated to ABM, easy to learn
- and a very practical graphical user interface (GUI)
- Allowing to easily interact with the system and the agents

NetLogo: Talking to the agents

```
ask bancs [
    set taille taille * (1 + tauxCroissance *

        (( maxBiomasse - bioMasse ) / maxBiomasse ))
    if taille > 10 [
        let tailleParent taille
        hatch 1 [
         set taille ( tailleParent / 2 )
        set tailleParent ( tailleParent - taille )
        ]
        set taille tailleParent
        ]
    ]
```

Arthur, W. Brian, Durlauf, Steven, & Lane, David A. 1997. *The Economy as an Evolving Complex System II*. Reading: MA: Addison-Wesley.

Holland, John H. 1996. *Hidden Order. How Adaptation Builds Complexity.* Reading (MA): Addison-Wesley.

Schelling, Thomas C. 2006. *Micromotives and Macrobehavior*. W.W. Norton.