INTERACTION MAXIMIZATION AND THE OBSERVED DISTRIBUTION OF URBAN POPULATIONS

An agent-based model of humanity's metric condition

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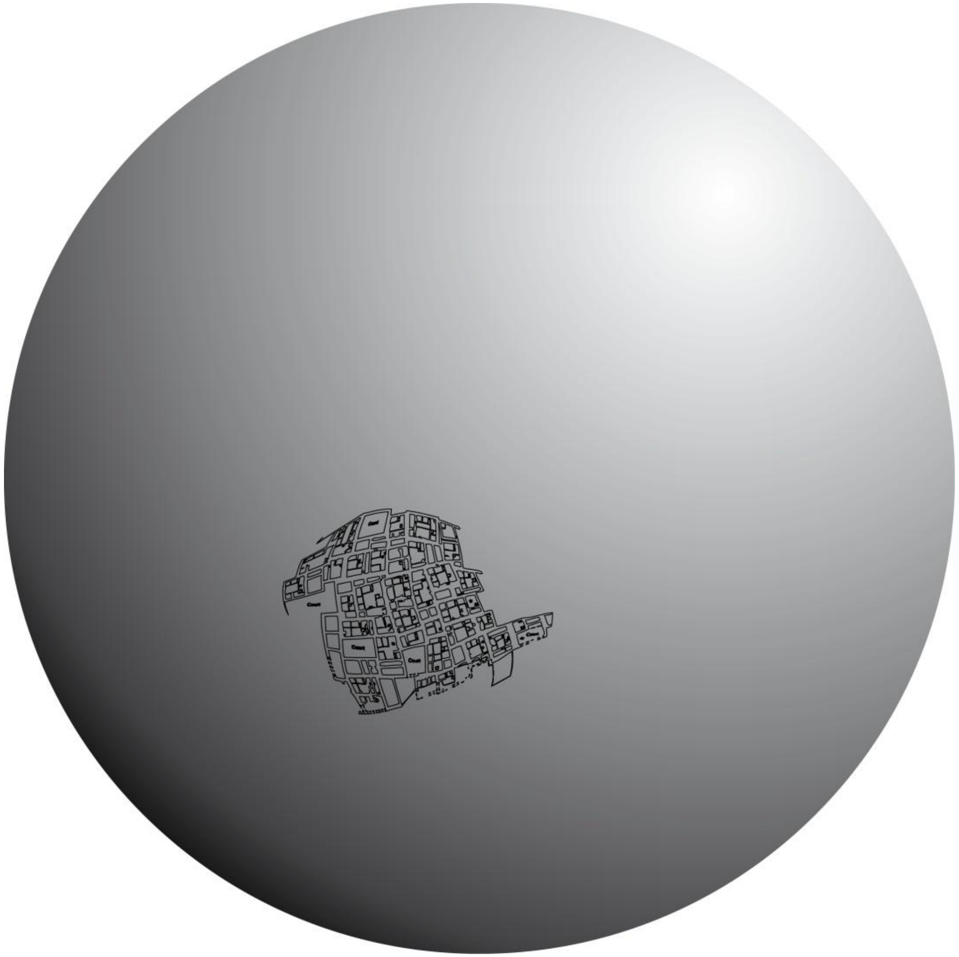
"Why are there cities?" - a classical answer:

- Spatially concentrated populations have a competitive advantage in comparison with more dispersed populations:
  - More efficient use of human capacities
    - Specialization and division of labor
    - Scale economy
  - More efficient use of natural resources
    - Culture-driven innovation
    - Specialization in agriculture
  - Security
    - Mutual help
    - Military defense power
  - More differentiated context for the constitution of individual identity
    - Cultural / spiritual /religious self-awareness
    - Additional degrees of individual freedom

There should be just one city



Why didn't the early stages of world urbanization lead to the emergence of just one city?

Our hypothesis

There is an upper limit to urban growth:

*This limit is due to a phenomenon of **spatial friction**, acting upon the very interactions that make urban configurations auspicious*

*The interaction most sensitive to this phenomena is the one existing between **food producers** and **urban specialists**.*

Purpose and method

- Hypothesis extensively supported by literature (ex.: van der Woude/ Hayami / Vries 1995; Falk 2005)

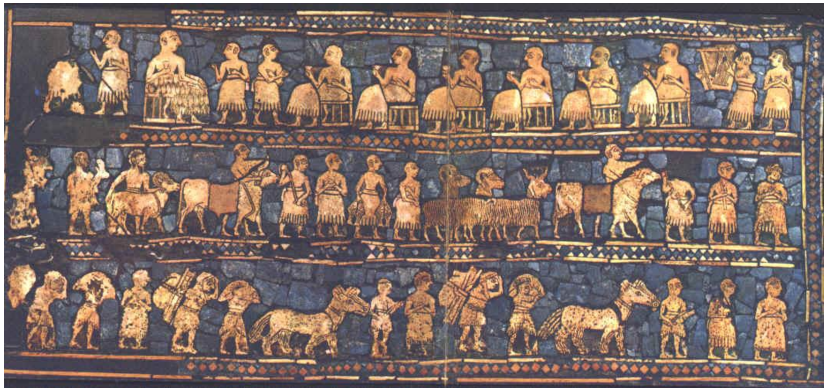
- Objective: Make the hypothesis explicit by articulating **macrophenomena** (total or partial spatiodemographic concentration) to **micro-motives and –behaviors** (individual settlement strategies)

- Method:

1. Setting up an agent-based model of an early urban settlement system (proto-neolithic period).
2. Simulating the effects of spatial friction on population concentration/scattering, under diverse levels of interaction-induced benefits

An agent-based model: 3 elements

- Resource fields
- City centers
- Agents
  - A - food producers
  - S - urban specialists



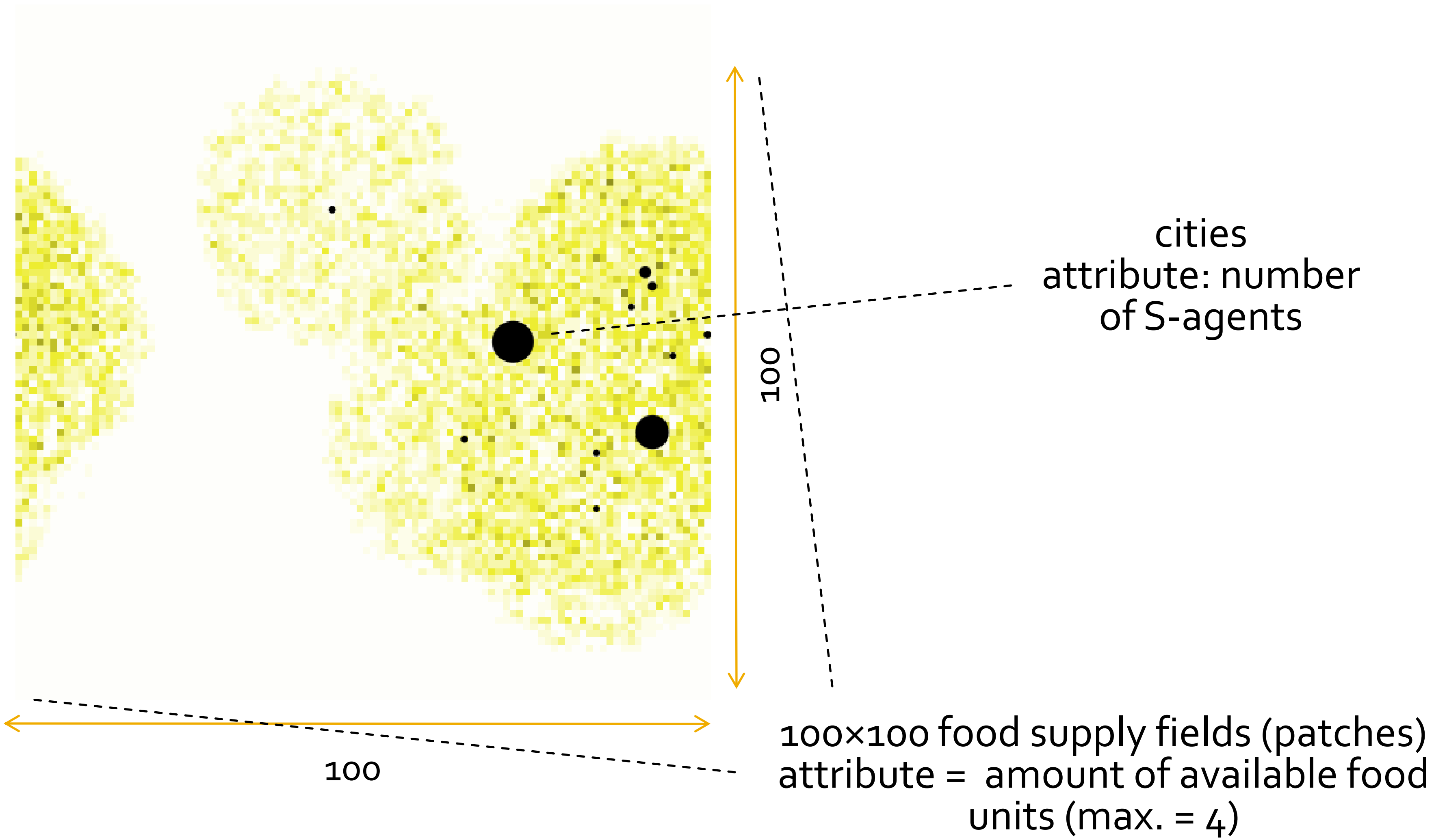
The A-agents: food producers

- Agents whose interest lies in **maximum dispersion**, i.e., in the occupation of a maximum amount of land.
- Not advantaged by demographic concentration *per se*, but advantaged by the **contact with urban specialists**, whose technical knowledge allows for an increased land-use return
- Eventually **stimulated by the city** as a source of consumption goods and services

The S-agents: urban specialists

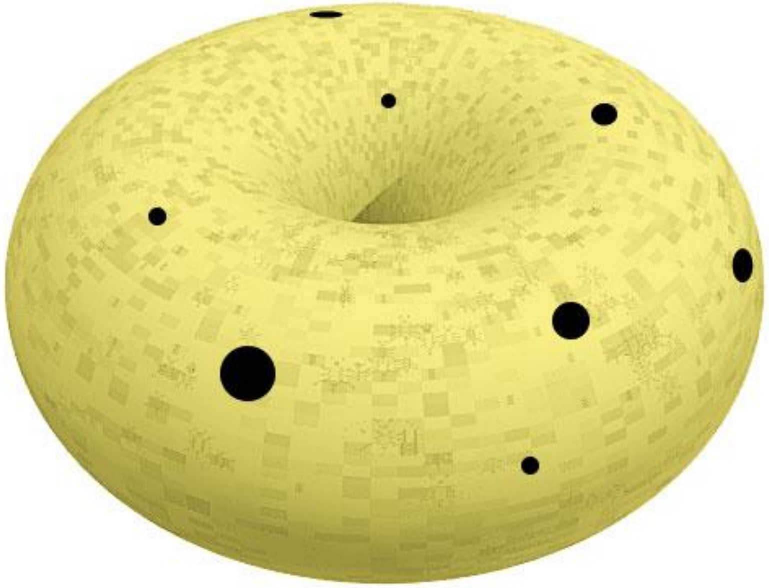
- They live in cities, because directly interested in a population concentration, allowing them to
  - share resources
  - share knowledge pertaining to their activities
  - take advantage of the market efficiency of a centralized position
- They depend on food producers
- They increase agricultural production by
  - providing more efficient production tools and techniques
  - producing consumption goods, stimulating the agricultural production

Model space: cities and resources



Model space: cities and resources

- **wrapped topology** to avoid border effects



Global variables (user-set parameters)

- **global reach** (R)
  (btw. 0 and 40 patch-widths):
  - How far away from a city are resources still accessible to the city dwellers
  - Simulates the ability to overcome spatial friction. It is inversely proportional to costs of transport of raw materials to town and of manufactured goods to the country
- **a grow-back rate** (G)
  (btw. 0 and 4 food-units / time-unit)
  - Rate, per time iteration, by which food resources are renewed
  - G is equal for all food-supply fields
  - Simulates land-use return
    - Agent productivity
    - Resource type: G(hunting and gathering) < G(wheat) < G(potatoes) < G(rice)

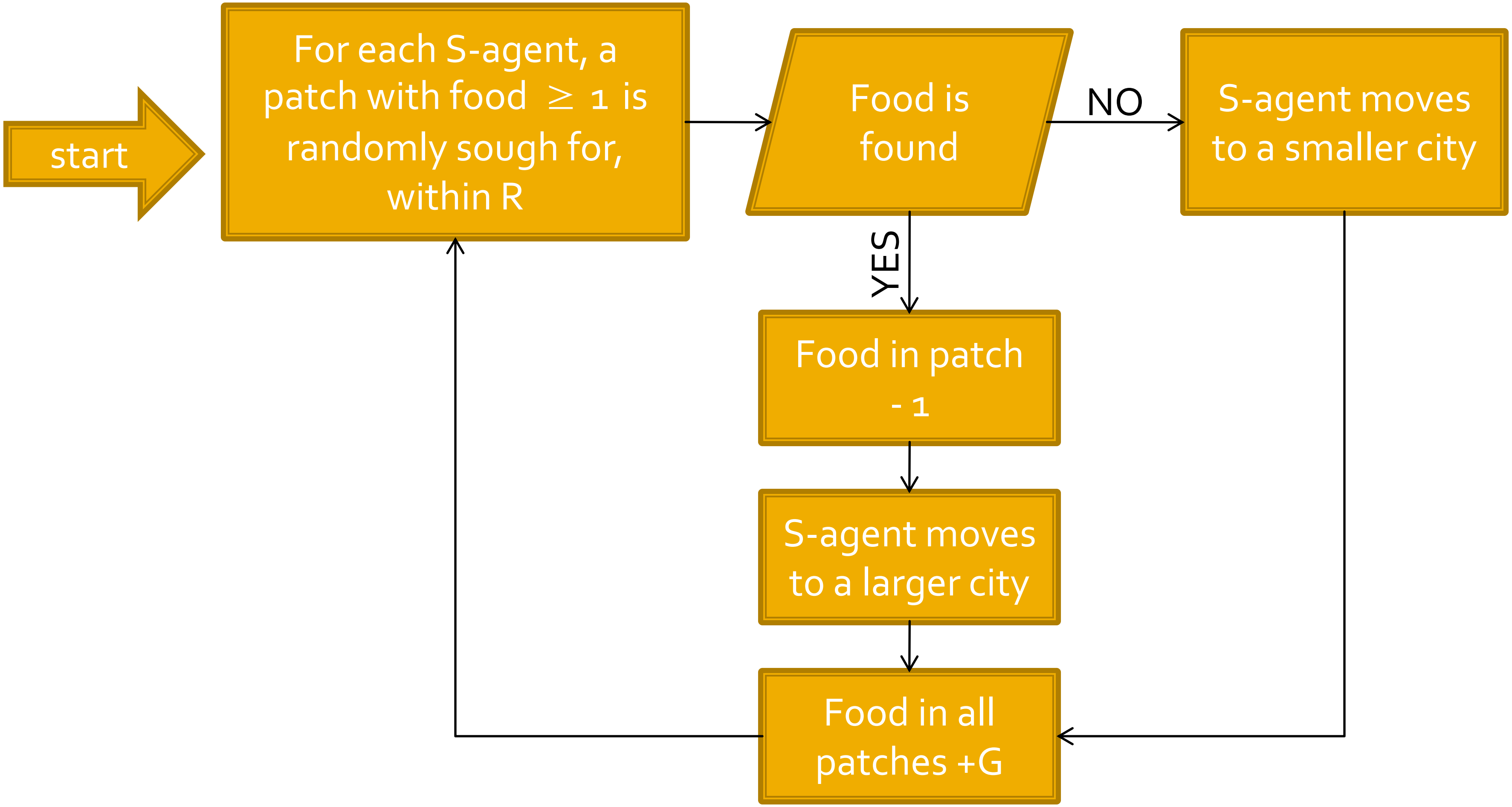
Model dynamics (1st version)

- Initial conditions:
  - a regular 10x10 grid of 100 cities
  - ~ 42 S-agents / city
  - A-agents merged with food-production patches
  - each patch set to maximum of resources (=max.)
  - user-set G and R

start

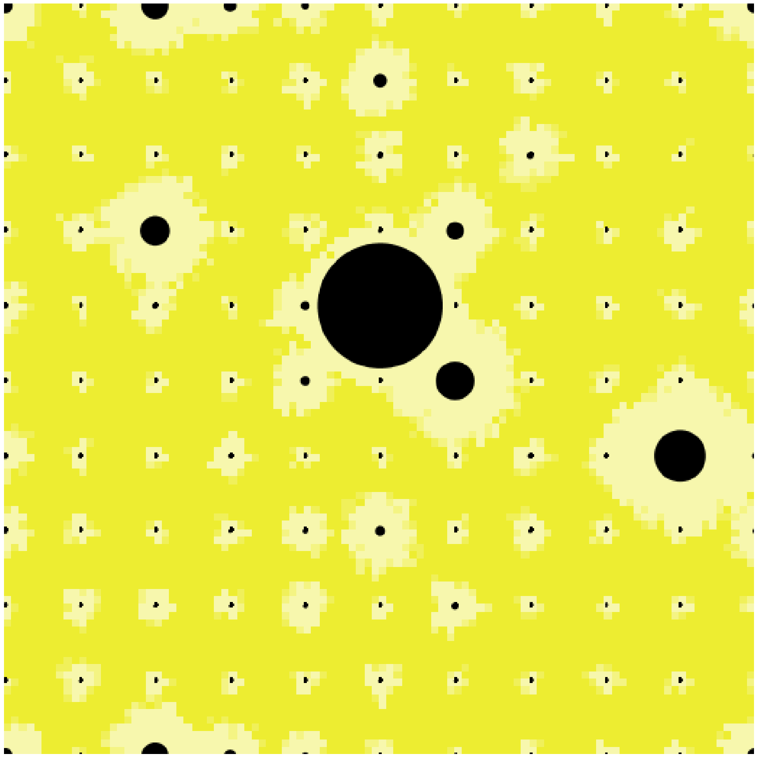
Model dynamics (1^{st} version)

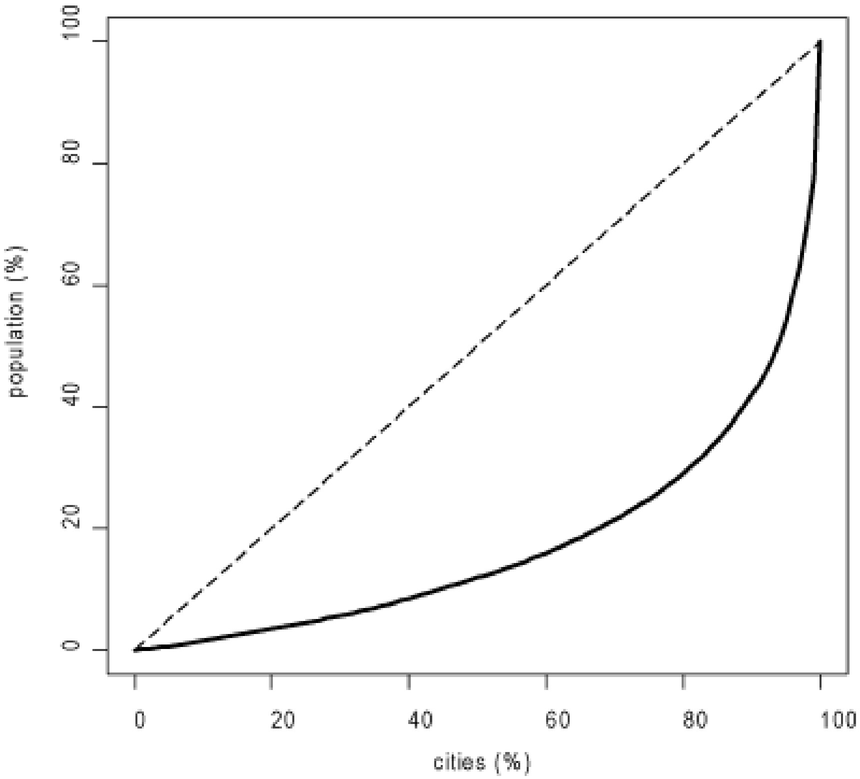
Constrained maximization of spatial concentration



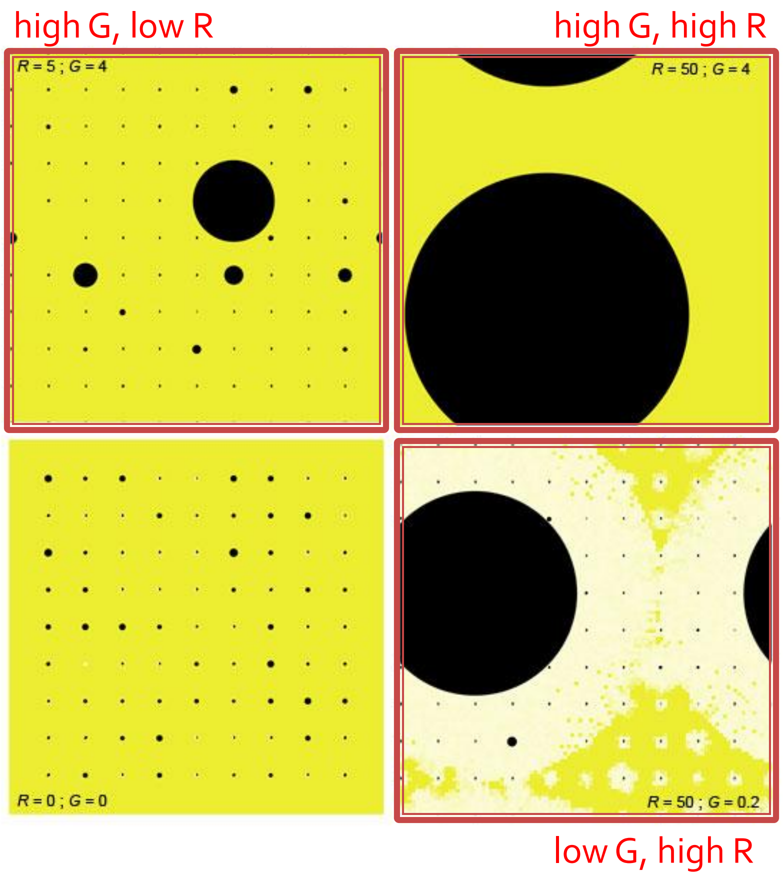
The 1st experiment: results

Urban network hierarchy with R=10; G=1; 200th iteration

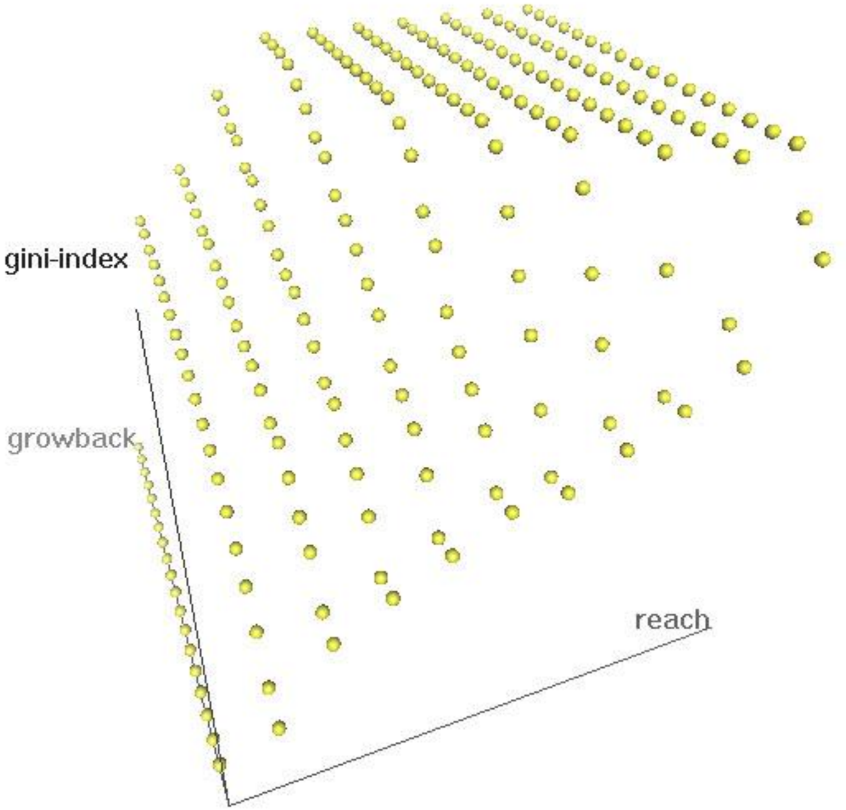




The 1st experiment: results



Clear impact of G (food production) and R (capacity to overcome spatial friction) on spatiodemographic concentration with a **predominance of the R parameter**



Network hierarchy measured my the Gini-index. and its dependence on R and G ; 200th iteration

The 1st experiment: results

- Meaning: the multiplication of urban settlements can be explained by an insufficient food supply in larger urban areas, due to spatial friction and leading to a migration to less populated cities

The limits of the 1st version

- **Influence of S-agents on land-use return** not simulated
- ➢ we want to see this influence

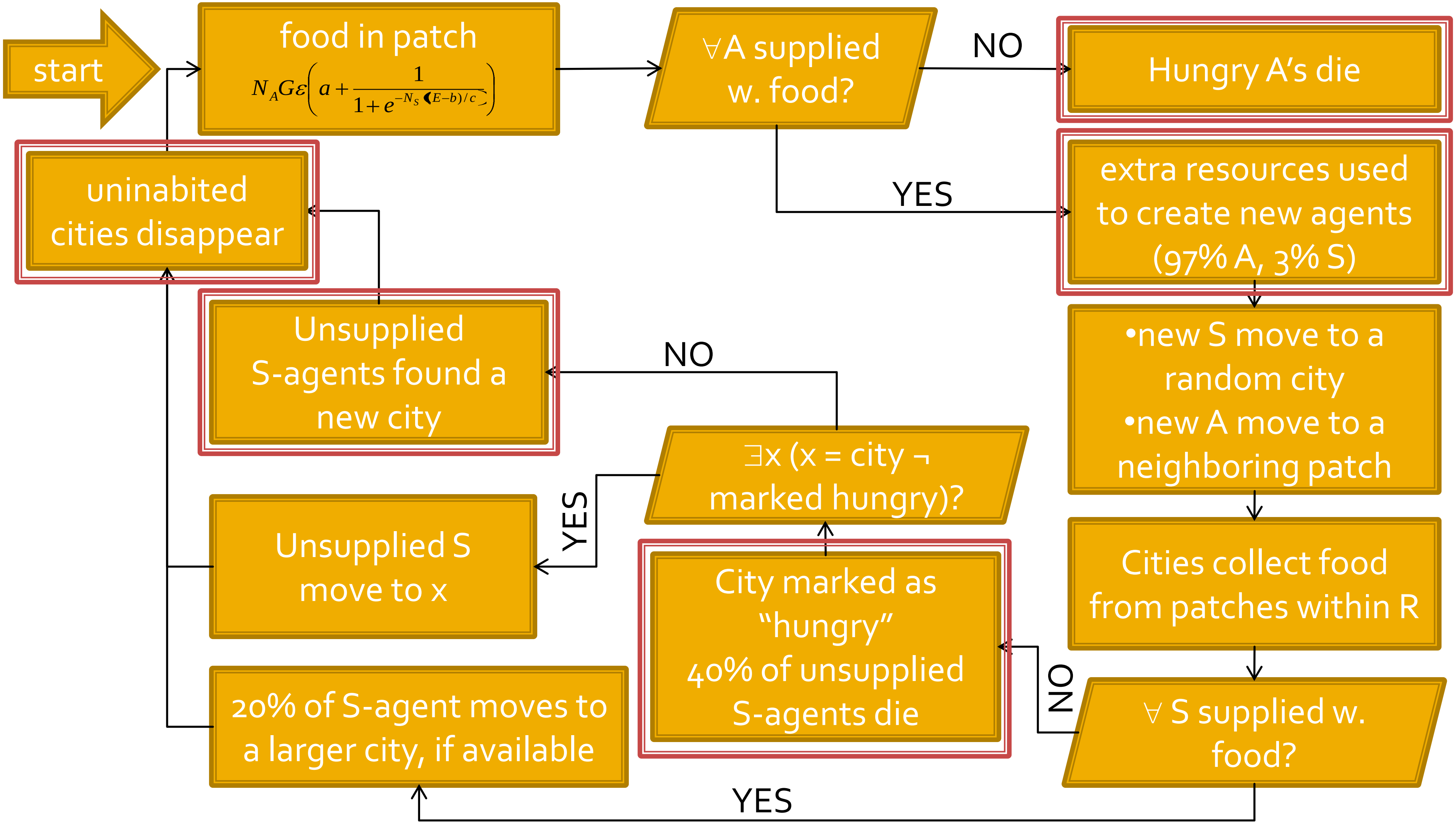
- Non-spontaneous determination of potential city locations & constant number of cities
  - 100 cities at all times
  - in the most concentrated cases, there are cities with zero dwellers
- ➢ we want to observe the **emergence of a city network** from a totally non-urbanized situation

- Demographic events reduced to migration
  - Invariant number of S-agents
  - Invariant proportion S-agents/ A-agents
- ➢ We want to see agents **appear and disappear**
- ➢ We want to observe the **variations urban% / rural% of total population**

The 2nd model version

- actual crop yield per patch $:= N_A G\varepsilon\left(a+\frac{1}{1+e^{-N_S(E-b)/c}}\right)$
  - N_A : population of food producers
  - **N_S : population of urban specialists within *R***
  - ***E*: the specialist-effect**
  - ε : stochastic effect.
  - $\{a, b, c\}$: "constants" stochastically varying around an average
- agents can die (hunger) or be born (when there is food overproduction)
- cities can disappear and be spontaneously generated
- initial conditions: purely agricultural societies, S-agent can only be "born" in the context of an agricultural surplus

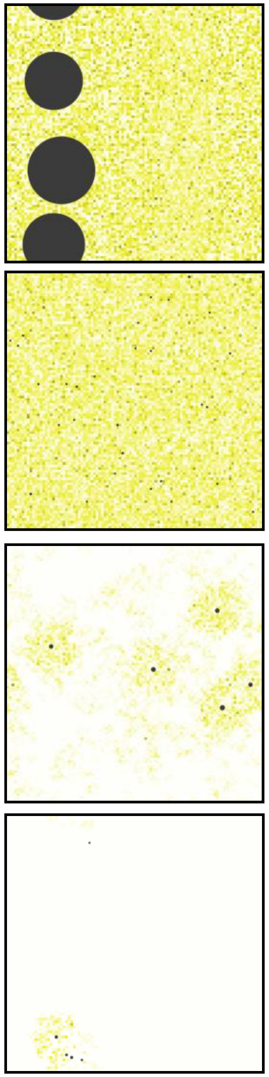
Model dynamics (2^{nd} version)



The 2nd model version: testing 3 parameters

- fertility (G)
  - extreme aridity to extreme productivity
- reach (R)
  - from sessility to unrestrained motility
- specialist effect (E)
  - from no effect to major gains in yield
    major influence of urban populations on crop yields

The 2nd experiment: results



- Fertile land & long reach
  - large population
  - highly stable system
  - apparition of large towns (~3) Urban pop: 33%
- Fertile land & short reach
  - large population
  - highly stables system
  - 25 to 30 small towns. Urban pop.: 2%
- Infertile land & average reach & average specialist-effect
  - more chaotic system, greater amplitude of network hierarchy var.
  - 5 to 10 small towns, urban pop: ~15%
- Arid land & average reach & high specialist-effect
  - very chaotic behavior
  - a society unable to survive without urban specialists
  - very small towns
  - In some cases, the society does not survive.

The 2nd experiment: results

High G and R, but no specialist-effect

Web site

- http://www.ourednik.info/urbanization_mc

The 2^{nd} experiment: results

- Observation: there is an extreme diversity in outcomes according to varying initial parameters. The system is chaotic.
  - Many scenarios of early urban development can be simulated by our simple 3-par. model.

- The model shows…
  - why some societies emerge cities while other do not.
  - that urban development in limit situations is highly sensitive to stochastic conditions in comparison with fertile conditions.
  - why the global urban network does not consist of just one city

Perspectives

- More explicitly defined units (km, kJ, kg, etc.)
- Take more phenomena into account :
  - The effects of specialization diversity
    - more types and levels of spetialization
  - The effects of economic cycles:
    - bumper crop years vs dust bowl years to replace « dumb » stochasticity
  - The advent of economic exchange and market effects.
  - Parasitic agent strategies (plundering) & emergence of state and military power
  - The advent scientific and technical progress

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