GEOG 413/613

LECTURE 13

1

Complex Systems

- Geography: people, places and environments.
  - Spatial and temporal dimensions
  - Relationships and interactions
  - Patterns and processes
- Complex Systems: the collective behaviors of the parts gives rise to properties that can hardly be inferred from the properties of the constituent parts.
  - Complexity Science as a field of study

"The whole is more than the sum of its parts" – Aristotle

2

Complex Systems

- Examples of complex systems
  - A colony of ants
  - A transportation system
  - The economy
  - The human body

- How about a Chevy truck? A school of fish? Space shuttling? Raising a family? A rolling ball?

3

Complex Systems

- Modeling Complex Systems

Reductionism	**Holism**
The properties of the system could be explained in terms of its parts.	The whole system cannot be determined or explained by its component parts alone.
The understanding of the parts leads to the understanding of the whole	To understand the whole, we must understand the relationships between the parts in the system.
Parts	Relationships

4

Complex Systems

- Modeling approaches take on combination of both the *Parts* and the *Relationships*

- Consideration of feedback loops
  - Positive feed-back (Reinforcing)
  - Negative feed-back (Regulative)
    - Examples: A rolling ball, predator-prey dynamics

  - Feed-back loops can make systems counter-intuitive or unclear
    - New highways into cities tend to lead to more traffic jams. Initially it decreases the waiting times but this in turn increases the desirability of driving a car.

5

Modeling

- Modeling Complex Systems
  - Cause and effect are not always clear, e.g. ecosystem
  - Non-linear relationships, emergence, self-organization, bifurcations

- Global coherent patterns emerge out of local interactions.
  - Examples: flocking behavior of birds, swarming behavior of fish
  - Simple local rules
    - '*separation*' (avoidance of crowding, or short-range repulsion)
    - '*alignment*' (steering towards the average heading of neighbors)
    - '*cohesion*' (steering towards the average position of neighbors)

6

Modeling

- Modeling as in the application of GIS-based techniques to represent the real world
- A **model** is a simplified representation of reality
  - A map is an example of a model
    - It's ***a*** representation of the real world
    - It's ***a*** simplification of the real world
    - It serves a purpose (objective)
- Modeling should be considered as a procedure

7

7

Modeling

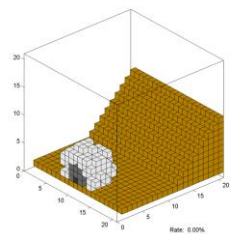
- Some Types of GIS Models
  - Static/Dynamic
  - Descriptive/Predictive/Prescriptive
  - Deterministic/Stochastic
  - Inductive/Deductive

8

8

Types of GIS Models

- Static/Dynamic
  - A static model represents a temporal snapshot of a phenomenon (state of the phenomenon is stable).
  - A dynamic model emphasizes the spatiotemporal changes of a phenomenon (changes over time).



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9

Types of GIS Models

- Descriptive/Predictive/Prescriptive
  - <u>Descriptive models</u> provide insights about a study area. E.g. Thematic map of land cover
  - <u>Predictive models</u> offer a forecast of what could happen in the future. Models use past and present data in addition to statistical models and predictive algorithms to generate what-if (alternative) scenarios
    - E.g. Prediction of future land use patterns
  - <u>Prescriptive models</u> use optimization techniques to provide the best solution.
    - E.g. Best route from A to B

10

10

Types of GIS Models

- Deterministic/Stochastic
  - Both deterministic and stochastic models are mathematical models.
    - Deterministic models the process is fully described by the parameter values and the initial conditions.
    - Stochastic models consider the presence of some randomness in one or more of its parameters or variables.
      - Although the real world is characterized by stochasticity, there are times when deterministic models are sufficient

11

11

Types of GIS Models

- Inductive/Deductive
  - A deductive model presents outcomes derived from established theories, physical laws or relationships.
    - E.g. Model is based on established laws of climatology
  - An inductive model represents the conclusion derived from data.
    - E.g. model based on past climatology observations can be relied upon

12

12

The Modeling Process

- The development of a model follows a series of steps.
  - Define the goals of the model (objectives of the study)
    - Phenomenon to be modeled
    - Required data
    - Appropriate spatial and temporal scales
  - Model Specification
    - Determine the elements in the model, their properties,
    - Design the interrelations and interactions between the elements
    - Specify the parameters of the model (properties of the elements)
    - Specify the mathematical/statistical models

13

13

The Modeling Process

- The development of a model follows a series of steps:
  - Model Verification
    - Model is tested to check that it is correctly implemented with respect to the conceptual model (implementation matches the literature)
  - Model Calibration
    - Adjust parameter values so that the model's output appropriately represent the phenomenon

14

14

The Modeling Process

- The development of a model follows a series of steps.
  - Sensitivity Analysis
    - Determine how the different variables impact the model's output
  - Model Validation
    - Evaluate the correctness of the model's output. Comparison is made to an existing dataset.

Integrating GIS with Models

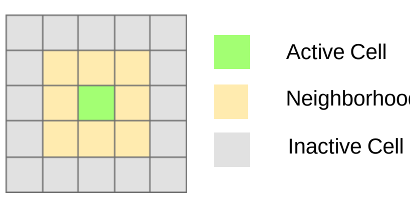
- There are three ways of linking a GIS to a model
  - **Loose coupling:** The model and GIS are not directly connected. Generally data files are transferred between the GIS and the model through each application's independent import and export functions.
  - **Tight coupling:** The GIS and the model software are linked and are dependent on each other.
  - **Embedded system:** The GIS and the model share memory and a common interface.

Modeling Complex Systems

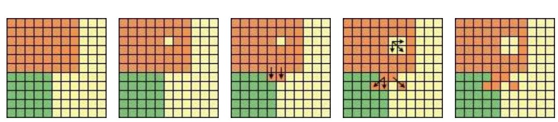
- Bottom-up modeling approaches
  - Cellular Automata
    - Grid of cells
    - Cell states
    - Neighborhood
    - Transition rules
    - Time steps
  - Agent-based modeling
    - Neighborhoods of influence
    - Individual actions and interactions
- Differ from spatial interaction models (gravity, location allocation)
  - Static, zone aggregate

17

Cellular Automata



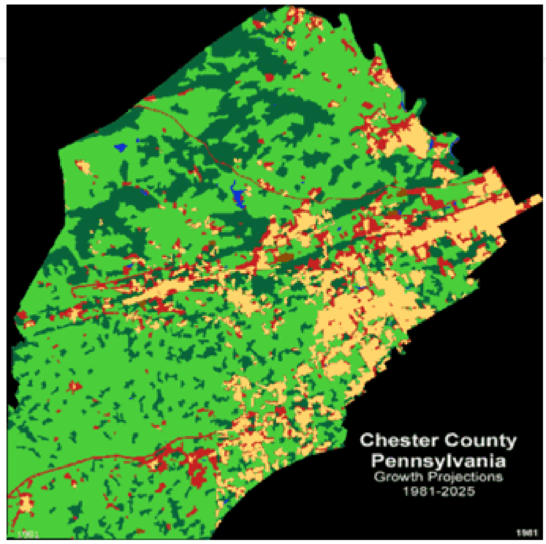
$$S_{xy}^{T_{i+1}} = f(S_{xy}^{T_i}, N_{xy}^{T_i})$$



K. Clarke

18

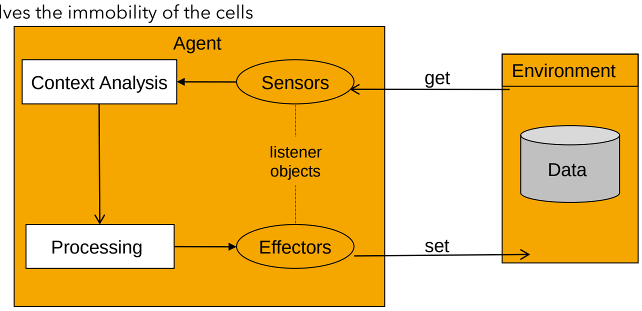
Cellular Automata



19

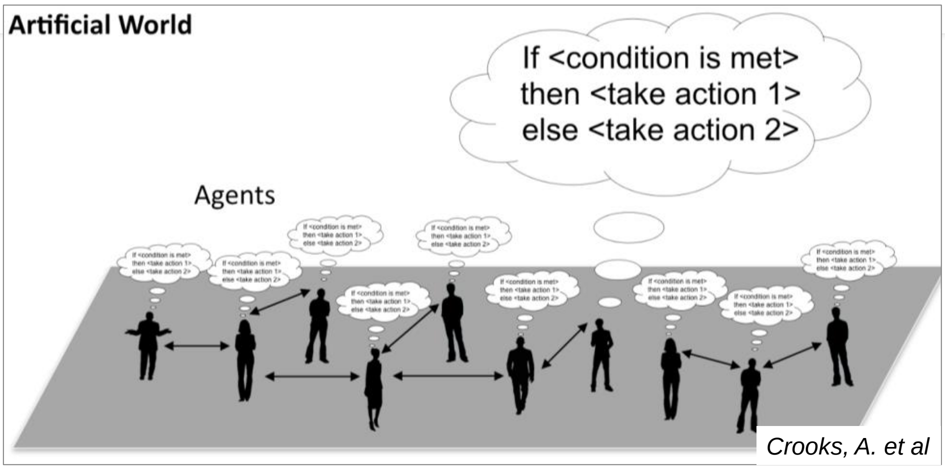
Agent Based Modeling

- Complex Systems Modeling
  - Agent-based Modeling
    - Focused on decisions and actions of individuals
      - Adds behavioral realism
      - Solves the immobility of the cells



20

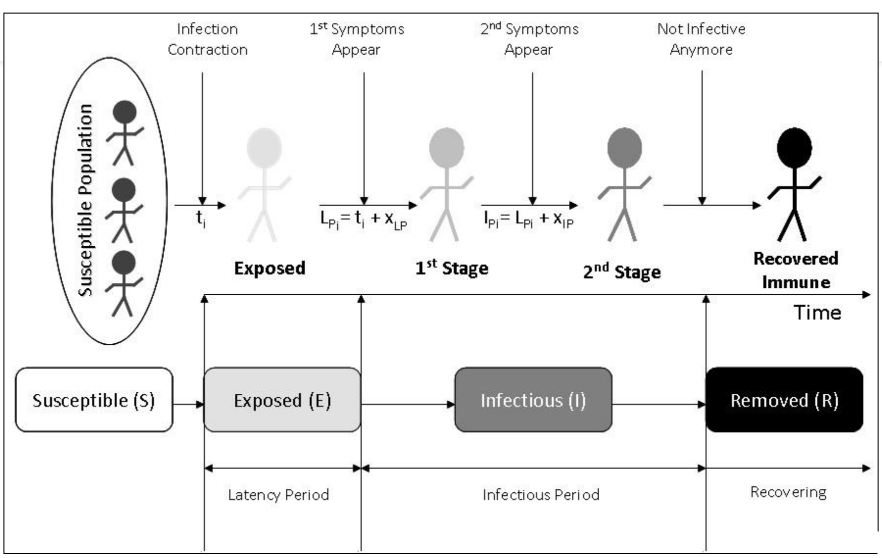
Agent Based Modeling



Crooks, A. et al

21

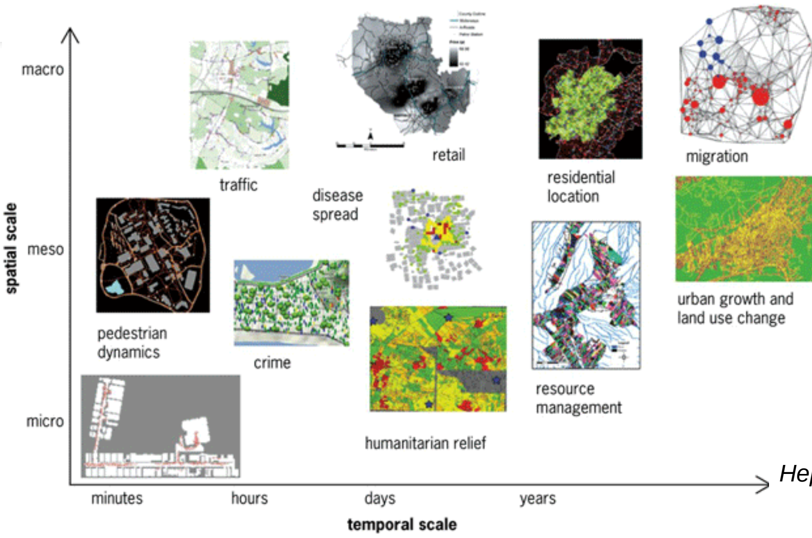
Agent Based Modeling



Perez, L. et al

22

Agent Based Modeling

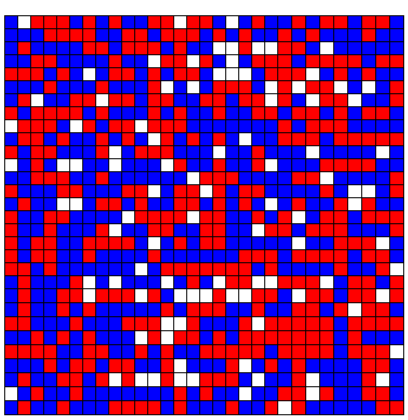


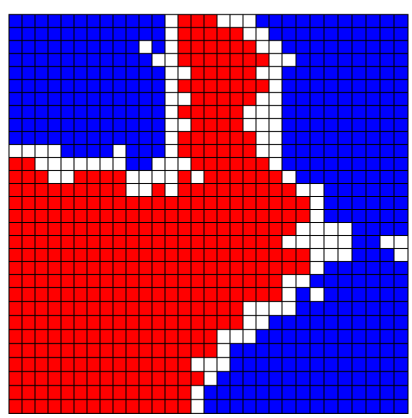
Heppenstall, A. et al

23

Agent Based Modeling

- Schelling's Model

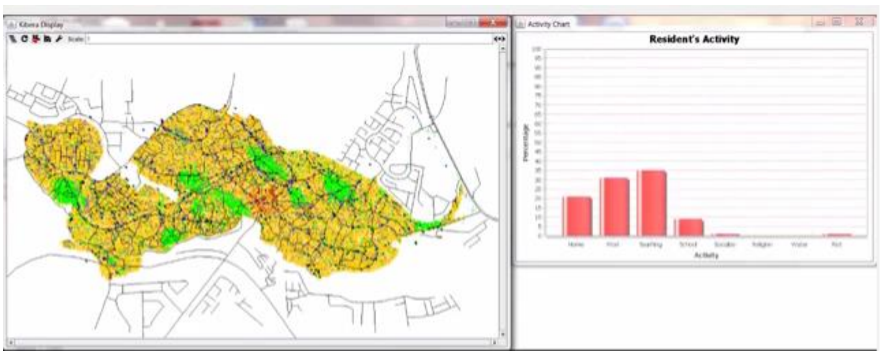




24

Agent Based Modeling

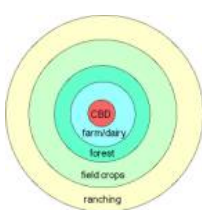
- [Riots in Kibera Slum]

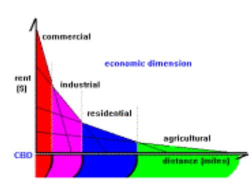


Crooks, A. et al

ABM – Urban Systems

- Modeling land use patterns in the city
  - Von Thunen's regional land use model (1826)
  - The Burgess concentric model (1925)





- Urban Dynamics (Forrester, 1969) is used in reference to the multiplicity of interacting systems in a city: land use, transport system, employment, housing

ABM – Urban Systems

"Cities [are] problems in organized complexity, like the life sciences. They present situations in which half a dozen or several dozen quantities are all varying simultaneously and subtly interconnected ways …The variables are many but they are not helter skelter; they are interrelated into an organic whole."

– Jane Jacobs (1961)

- The city is a complex system
  - Relationships and interactions between different components
  - Continuous change makes the city a dynamic environment

27

ABM – Urban Systems

- Urban growth is characterised by <u>population increase, redevelopment, expansion, densification</u>
- One concern for urban planners is to forecast future population growth and plan for possible changes in land use patterns
- Often urban planning is top-down and sector based housing, transportation, land-use

28

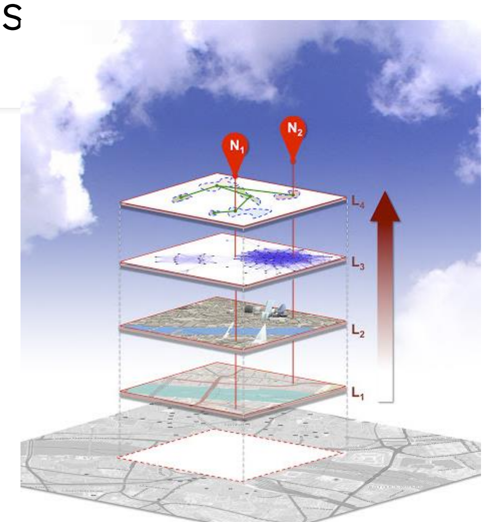
ABM – Urban Systems

- Significant components in a city
  - Urban Population
    - Housing development
    - Infrastructure for services
  - Planning Regulations
    - Expression of the city's vision and priorities
      - Land use, Sustainability
  - Transportation
    - Accessibility
    - Mobility
  - Urban Economy
    - Employment and Income

29

ABM – Urban Systems

- Representing the city
  - Conceptualization
    - Geographic Space
    - Key Actors/Stakeholders
  - Fusion of data
    - Physical (L1, L2),
    - Social, Perceptual (L3) Spaces to
    - Derive Place Abstractions (L4)
    - for Different Locations (N1, N2).



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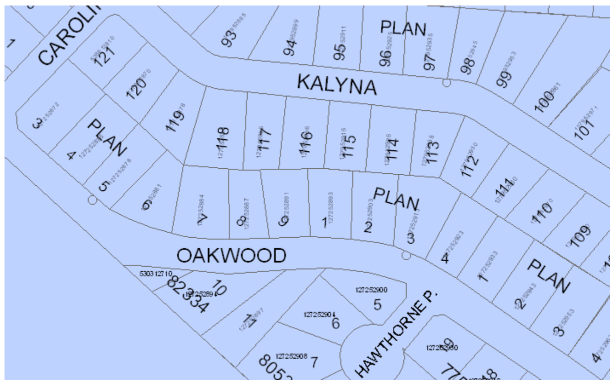
30

ABM – Urban Systems

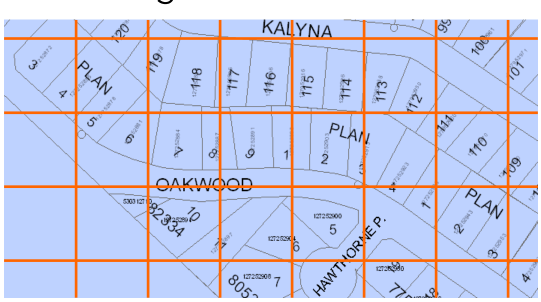
- Urban landscape is composed of irregular spatial units



31

ABM – Urban Systems

- A regular grid is inappropriate for high resolution modeling



- Building on work by Stevens and Dragicevic (2007)
  - Agent-based modeling using irregular spatial tessellations

32

ABM – Urban Systems

- Understanding the city for
  - Transportation modeling
  - Household mobility
  - Forecast of future urban land use patterns
  - Tools that support planning

References

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34