Temporal GIS for Agent-Based Modeling of Complex Spatial Systems

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The great divide and the opportunity for bridging

Temporal GIS | Agent-Based Modeling

Data and Cases | Simulation and Prediction

Now
All about representation

• **ABM:**
  - How to represent agent, landscape, and their interactions
  - Discretization
  - Disaggregation and aggregation
  - Mathematical functions, probability, and decision models

• **Temporal GIS:**
  - How to represent facts and knowledge
  - Philosophical
  - Cognitive
  - Ontological
  - Data modeling, logic, and calculus
ABM Representation Complex Spatial Systems

• Agents
  – Simple behavior rules
  – Autonomous and adaptive nature
  – Individual decisions
  – Randomness

• Landscape
  – Simple cellular structures
  – Variations, changing, and modifiable nature
  – Multiple themes

• Emergence
  – Meaningful orderly patterns from the non-linear interactions among autonomous disaggregated parts (agents) and the landscape
TGIS Representation of Complex Spatial Systems

• What, When, How
• Snapshots
• Spatiotemporal object model
• Spatiotemporal event-based model
• Process model
• Event model
• Lifelines
• Helixes
Time in DBMS and GIS

- **1993**
  - Nixon: 17,000, 20,000
  - Cleveland: 35,000, 32,000
  - Oklahoma: 86,000, 28,000

- **1994**
  - Nixon: 17,000, 21,000
  - Cleveland: 35,000, 32,000
  - Oklahoma: 86,000, 28,000

- **1995**
  - Nixon: 20,000, 19,800
  - Cleveland: 35,000, 32,000

**a. Time-stamped tables**
(Gadia and Vaishnav 1985)

**b. Time-stamped tuples (rows):**
an ungrouped relation
(Snodgrass and Ahn 1985)

**c. Time-stamp values (cells):**

**d. Time-stamped space-time objects:**
the spatiotemporal object model
(Worboys 1992)

**Space-Time Composites**
(Langran and Chrisman 1988)
From Space-Time to Geographic Dynamics

- Space-time is the reference frame
- Geographic dynamics
  - Drivers: activities, events, and processes
  - Observables: change and movement
- Forms and patterns in space and time
- Works of activities, events, and processes
- Observable through means of change and movement
Geographic dynamics and GIS data

Activity, event, process

spatiotemporal data

Transform

Object/State in (S,T)
captured by

GIS approaches:
- ontology and conceptualization
- representation and data modeling
- algorithm development for query, analysis and modeling
Goodchild, Yuan, and Cova (2007): all possible changes
Kwan (2004): Activities
SpatioTemporal Helixes for Event Modeling
Pequet and Duan (1995)
SpatioTemporal Event-based Data Model
A severe weather case

- **A severe weather event**: 1999 May 3 OKC tornado outbreaks
- **Severe weather processes**: development of convective storms, supercell thunderstorms, tornadoes
- **Severe weather states**: spatial distributions of storms, supercells, and tornadoes at a given time
- **Spatiotemporal data**: radar data, GEOS data, sounding data, photos, etc.
Weinberg (1975) General Systems Theory
- Small-number simple systems: individuals’ behaviors
- Large-number simple systems: averages
- Middle-number complex systems
Hierarchy Theory is for...

- Middle-number complex systems in which elements are...
  - Few enough to be self-assertive and noticeably unique in their behavior.
  - Too numerous to be modeled one at a time with any economy and understanding.
- Koestler (1967) Duality of a holon:
  - **Self-assertive tendency**: preserve and assert its individuality as a quasi autonomous whole;
  - **Integrative tendency**: function as an integrated part of an existing or evolving larger whole.
Examples of Middle-number Complex Systems

- Ecological systems (Allen and Ahl, 1982).
- Geographic systems.
Hierarchy Theory

• Reality may or may not be hierarchical.
• Hierarchical structures facilitate observations and understanding.
• Processes operate at different levels of scale
• Higher levels constrain lower levels.
• Fine details are related to large outcomes across levels.
• Scale is the function that relates holons and behavior interconnections across levels.
Zones

Levels of Spatiotemporal Aggregation

Zone
Sequence
Process
Event
Sequences
• **Information**
  - **Event**: an incidence of rain
  - **Process**: the development of rain (e.g. rain storms, squall lines, orographic effects, etc.)
  - **State**: the distribution of rain at a given time

• **Data**
  - Images
  - In-situ observations
Key Elements in Hierarchy Theory

• Grain (resolution)
• Scale (extent)
• Identification of entities
• Hierarchy of levels
• Dynamics across levels
• Incorporation of disturbances
Two kinds of entities in HT

• Definitional entities:  << Agents
  – Observer- generated to outline what is expected to examine.
  – Fixed the level of observation at the outset.

• Empirical entities:  << Data objects
  – Observed and measured in the field.
Identification of Entities

- Definitional entities vs. Empirical Entities
- Agents vs. data objects
- Agents can represent any kinds of autonomous entities (including drivers of geographic dynamics)
- Data objects, same, but in databases
Bridge Agents and Data Objects

- Data objects >> empirical objects >> inform definitional objects >> agents
- Agents >> definitional objects >> inform observations >> data objects
- Inform agents: refine behavior rules, interaction and relationship
- Inform observations: where to look, what patterns to look, and when patterns may emerge or converge
• ABM: control factors at local, regional, and global scales

• ABM: Local optimal vs. global optimal solutions

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From Strout and Li
Intro Agent Analyst

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• ABM: Local optimal vs. global optimal solutions
Hierarchy of Geographic Dynamics

• Levels of agents:
  – Fine grain agents: drivers
  – Coarse grain agents: conveys

• Levels of landscape situations
  – Fine grain: traffic lights, distance between vehicles
  – Coarse grain: highway types, traffic flows

• Agent-based modeling needs to incorporate the hierarchical nature of geographic dynamics

• Temporal GIS needs to support the necessary data in forms that enable the simulation of agent actions within and across levels of geographic dynamics.
Similarity

- Pattern transitions from ABM
- Pattern recorded in TGIS
- Similarity
- Comparison and calibration
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Comparison

- Dynamic time warping: the simulated ABM pattern transitions and observed patterns transitions are stretched so that imperfectly aligned common features align.
Find matching storms ...

Query

Return:
storm systems with similar behaviors
Organize data based on processes and similarity

Figure 8. Test set of processes with durations between 3 and 5 hours.
Summative Remarks

- Integrate ABM and TGIS
- Hierarchy Theory serves the conceptual framework
- Levels of aggregations > Levels of geographic dynamics
- Geographic dynamics
  - Drivers: activities, events, and processes
  - Observables: change and movement
  - Possible changes: attributes, geometry, internal structure, movement
- ABM and TGIS for all ranges of geographic dynamics
  - Definitional entities vs empirical entities
  - Levels of dynamics and complexity
- TGIS supports ABM: behavior rules, landscape situations and comparison
- ABM benefits TGIS: what, when, and where to look or take observations
- Cross-fertilization
  - Comparison and calibration
  - Patterns, behavior, landscape effects, and outcome
  - The past is the key to the future
  - The future promotes the rethinking and a deeper understanding of the past