ThinkSpatial
The UCSB Brown-Bag Forum in Spatial Thinking

22 October 2008

Polyplexity
A complexity science for the social and policy sciences

Helen Couclelis
University of California
Santa Barbara, USA
An ant, viewed as a behaving system, is quite simple. The apparent complexity of its behavior over time is largely a reflection of the complexity of the environment in which it finds itself.

Herbert Simon
Some background

• The Institute **Para Limes** in the NL
  – Meant to become a European version of the US **Santa Fe Institute**
  – Inaugural workshops in 2007, e.g.
    • **Complexity, Evolution and Learning: in Search of Simplicity**
      – Only workshop in the social sciences so far
      – “Give us your boldest, craziest ideas”

• Latest IPL **Newsletter**
  – The abbey is almost ready!
Outline

1. Why?
2. What?
3. How?
1. **Why Polyplexity?**
Complexity research in the social and policy sciences is flourishing!

- Plenty of wonderful work using
  - agent-based models
  - cellular automata models
  - artificial neural networks
  - synergetics
  - bifurcation theory, etc. etc.

- But none of these were developed for the social sciences
Are we going from this....

Spatial interaction:

\[ P_{ij} = \frac{a_i P_j}{D^2} \]

The Gravity model in geography
Are we going from this…. to this?

Spatial interaction:

\[ P_{ij} = aP_iP_j / D^2 \]

The Gravity model in geography

Self-organized criticality: the sand pile model

http://www.adit.co.uk/assets/images/Sandpile.gif
Wrong metaphors!

• Things we have trouble with (e.g.):
  – The description of social processes and events, which involve reasons (telic considerations) as well as causes;
  – The coherent representation of multiple perspectives on – and interpretations of – the same social process or event;
  – The emergence of institutional structures that are not simply the result of bottom-up interactions;
  – The representation of individual decision and choice under fast changing conditions;
  – The support of decision making in planning and policy under ‘deep uncertainty’ and conflict.
Let’s suppose…

(a) Complexity is (largely) in the eye of the beholder

- How much complexity
- What kind of complexity
Let’s suppose…

(b) Social systems are different in kind from natural systems

  Consciousness
  Intentionality
  Purpose

Social systems are governed by reasons (‘in order to –’) as well as by causes (‘because –’).
Let’s suppose…

(c) “Complexity theory is preternaturally spatial”

Nigel Thrift *

(a) + (b) + (c) → Polyplexity

(a) We should feel free to explore novel frameworks for complex systems
(b) Complex system frameworks for the social sciences should reflect the differences between natural and social systems
(c) Alternative representations of space & time may be worth exploring
Instead of…
perhaps...
What do we gain?...

idiosyncratic  more systematic
2. What complex time and space?
Complex time
Some examples

1 Time in geographic information science
   Over 15 years of efforts

2 ‘Real’ time

3 Historical time
   The TimeMap project ([www.timemap.net/timelines](http://www.timemap.net/timelines)) by I. Johnston, R. Mostern et al.
1. Models of time in geographic information science

There is a **practical** need for more complex models of time

- Cyclic time
- Partially-ordered time
- Valid & transaction time
- Clock- vs. event-driven time
- Branching time
- ....

*Better, but still not complex enough...*
2. ‘Real’ time

Newtonian time has 3 basic properties:

– Homogeneity
– Continuous divisibility
– Causal inertness

“The future is merely the unfolding of a tapestry that exists now.”
Newtonian time vs. ‘Real’ time (2)

Real time is the opposite. It is characterized by:

– Dynamic continuity
– Heterogeneity
– Causal efficacy

“The nature of a phenomenon depends to some extent on its place within a process of historical development”

→ Path-dependence
Real time precludes prediction

• Dynamic continuity:
  – The value of each moment depends on memory and anticipation

• Heterogeneity:
  – No two instants can be the same
    • Every instant depends on a different nexus of past and anticipated instants

• Causal efficacy:
  – The timing of an action or event affects its nature
“In this world, there are two times. There is mechanical time and there is body time. The first is rigid and metallic as a massive pendulum of iron that swings back and forth, back and forth, back and forth. The second squirms and wiggles like a bluefish in a bay.
(continued)
The first is unyielding, predetermined. The second makes up its mind as it goes along... Where the two times meet, desperation. Where the two times go their separate ways, contentment... Each time is true, but the truths are not the same.”

Alan Lighthman, *Einstein’s Dreams*
3. Historical time

“Modeling time as a fourth dimension downgrades it into being only a facet of space whereas, in fact, time operates according to very particular principles”.

The TimeMap project

• At the core of historical understanding is the event.
• There are intimate causal and telic linkages among time, events, choices, and their ever-changing contexts.
• To represent events, multiple streams of real time are needed.

• Is this the macro-perspective complementing the micro notion of real time?
Complex space

The Ebsdorfer Map of the World (ca. 11th century)
Many kinds of complex spaces:

• Space transforms, e.g.:
  – Cartographic projections
  – Cartograms
  – Logarithmic spaces
  – Velocity fields
  – Cognitive maps

• Relational spaces, e.g.:
  – Self-organizing maps (SOM)
  – Q-analysis
1. Cartograms

The 2004 U.S. Presidential election results, by State

See also Indy Hurst’s http://www.geog.ucsb.edu/~indy/gis/eVote.html
The 2004 U.S. Presidential election results, by County

Source: http://www.research.att.com/~suresh/cartogram/
2. Cognitive maps

by R.G. Golledge
and W. Tobler
Three cognitive maps from Columbus, Ohio

by R.G. Golledge
and W. Tobler
3. Proximal space

• The set of all locations that have some functional or other kind of non-spatial relation with every location of interest at each time.
• A generalization of the notion of neighborhood as used in cellular automata
  – e.g: the set of all locations of my physical and virtual social contacts form the proximal social space of my home location.
• A network space, but one that is rooted in geographical space
• Supports a generalization of cellular automata called geo-algebra

(Takeyama and Couclelis 1999)
4. A hierarchy of experiential spaces

• Six nested levels:
  – A sequence of increasingly complex levels of individual spatial awareness

• The levels are differentiated using
  – Group theory
    • Operands: spatial ‘atoms’ (points, locations, positions,…)
    • Operators: ‘moves’ (links between atoms)
  – Selective operators (from spectral theory)
    • A filter for selecting entities with specific properties

(Couclelis and Gale 1986)
## Spaces of individual experience (??)

<table>
<thead>
<tr>
<th>Concept of space</th>
<th>Axioms</th>
<th>Structure</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$G1$</td>
<td>$G2$</td>
</tr>
<tr>
<td>Symbolic space</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Cognitive space</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Perceptual space</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Sensorimotor space</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Physical space</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Pure Euclidean space</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>
4. A hierarchy of experiential spaces

- Six nested levels:
  - A sequence of increasingly complex individual experiences of space
- The levels are differentiated using
  - Group theory
  - Selective operators (from spectral theory)
- First hints of real time at level 3
- Rejoins ongoing major efforts
  - Hierarchical spatial ontologies in GI science
3. How do we get from all that to Polyplexity?
Some leads

1. **Semantic hierarchies** of complex times and spaces
   - Built from the perspective of *increasing complexity* rather than spatial or temporal scale
   - Another way of looking at this (…): *increasing information content*

2. The notion of **prior structure** in models
   - *Envelope of constraints* limiting the range of observable system states at different levels of analysis
Some spatio-temporal ontologies

- Mathematical, physical, socio-economic, behavioral, experiential space

  (Couclelis 1992)

- Physical, functional, biological, intentional, social level

  (Guarino 1999)

- Physical reality, observable reality, object world, social reality, cognitive agents

  (Frank 2003)
Complexity of spatial decision making

The CIPEC/FS spatial model hierarchy

(Agarwal et al. 2002)

0  No decision making (DM) - biophysical only
1  DM (indirectly) as a variable
2  DM as a probability function without feedback
3  DM as a probability function with feedback
4  DM by one type of agent
5  DM by multiple interacting agent types
Complexity of spatial decision making

A hierarchy of system specifications:

after Zeigler et al. 2001

<table>
<thead>
<tr>
<th>Decision model type</th>
<th>System specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>0  Stimulus-response</td>
<td>I/O relation observation</td>
</tr>
<tr>
<td>basic observation</td>
<td>IORO = (&lt;T, X, \Omega, Y, R&gt;)</td>
</tr>
<tr>
<td>1  Stimulus-response</td>
<td>I/O function observation</td>
</tr>
<tr>
<td>controlled experiment</td>
<td>IOFO = (&lt;T, X, \Omega, Y, F&gt;)</td>
</tr>
<tr>
<td>2  Rational decision</td>
<td>Discrete event system</td>
</tr>
<tr>
<td>..........</td>
<td>DEVS= (&lt;T, X, Q, Y, \delta, \lambda, t&gt;)</td>
</tr>
<tr>
<td>5  Production systems</td>
<td>Discrete event network</td>
</tr>
<tr>
<td></td>
<td>DEVN= (D, {M_\alpha}, {I_\alpha}, {Z_{\alpha,\beta}}), SELECT</td>
</tr>
</tbody>
</table>

(Couclelis 1986)
Bottom line:

• These are all **semantic** hierarchies
  – not of nested spatio-temporal scales
• Many are **formal**
• The last two are openly **informational**, not empirical
  – They model the **same system** of interest at different **levels of complexity**
Some leads

1. Semantic hierarchies of complex times and spaces
   - Built from the perspective of information content rather than spatial or temporal scale

2. The notion of prior structure in models
   - Envelope of constraints limiting the range of observable system states at different levels of analysis
The notion of prior structure

• Two kinds of a priori knowable sets of constraints limit the range of possibly observable outcomes:
  – Historical (empirical) prior information
  – Structural (logical) prior information

• Within that envelope, all allowable microstates are equiprobable
  – Wilson’s entropy maximizing methodology pulls out the most likely system macrostates
Three types of system as distinguished by prior structure:

<table>
<thead>
<tr>
<th>Selected Aspects</th>
<th>Type</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
</tr>
<tr>
<td><strong>Control</strong></td>
<td>No regulator</td>
</tr>
<tr>
<td>Designation</td>
<td>Classical system</td>
</tr>
<tr>
<td>Predict-ability</td>
<td>Predictable</td>
</tr>
<tr>
<td>Time</td>
<td>Newtonian time</td>
</tr>
</tbody>
</table>
In-conclusion: many questions!!!

- Does polyplexity make sense?
- Can the frameworks mentioned in the last section help systematize complex space and time?
- Can polyplexity help simplify problems in the social and policy sciences?
- Can it be integrated with more familiar approaches to modeling complex systems?
- What may be the computational implications? …etc. etc. …
The End Beginning