Address by Michael Goodchild

The US based on representation
UK based on ABM

Logistics:
60 to 70 responses
49 participants - a record

Target: agenda setting, open discussion, partly communication

Mike Worboys
Modeling of Complex Spatial Systems
The rules are simple - emergent processes are complex.
Personal interest: Moves in GIS technology
We want an effective model
Focused
Complete
Generic
Deductive and predictive power
Illuminating
Building on existing foundation

Sensor Networks -

Paradigm shifts in the last 20 years
Technology shift essentially

Traffic management scenario:
Is there a vehicle at location x
Is the vehicle at location x moving on a particular street… etc

Challenge:
Overcome the impedance mismatch
Data in
Get information out

Ontology level - what ontology supports these challenges?
Not just static, - time, change, events, processes, and all those dynamic things

Snapshots in time of something that is happening -
A specific moment in time - what do we have and what are their relationships to one another - we have a progression of these snapshots - a series of maps - but we're missing the processes - not seeing the implicit change

SNAP: coninuant entities

What's missing?
SPAN side of the ontology: Occurrent entities, that happen and then are gone
Complex interrelationships
Cars and bridges are snap entities, while gridlock would be a span

…and the 3rd component is missing which is process that describes the transition between snap and span

…focusing on the geoprocesses
Cellular automata -
Space into cells
Cells have states
Cells have neighborhood, modeling flow, diffusion etc
Transition rules
Discrete time

Diversion into the foundations of computer science

Sequential processes
Process meaning = memory → memory
  Function calculus
  Lambda-calculus

Distributed information systems

What we need to understand distributed processes
Name processes
Process Equivalence
Process Composition
Process Choice
Process Reaction
Mobile processes

Processes can be formalized - defined symbolically

Processes can communicate - there are some actions that come in pairs - "if then" situations - called reaction- that can lead to transitions
These processes are a lot like agents
Four way stop example

Sensors responding to a dynamic field

Time and space -
Modeling (linear) time
Construct a collection of tick processes, tick ….$tick_n$

Partition a region, each one being a processes
What is the structure?

Mobile process - modeling the movement of a vehicle via the use of sensors - and movement expressed by channels - changing the positions of channels to change which sensor the vehicle is associated with.

Argument: Process algebras provide richer and more formalized models than cellular automata

Effective models?
- Sufficiently focused?
- Complete?
- Generic?
- Deductive and predictive?
- Illuminating?
- Build on existing knowledge?

Complex models?
- Distributed processes are inherently complex, even if described by simple rules
- There is usually a high degree of uncertainty and non-determinism in the way in which the rules will play out.
- Rule systems are not enough. We need more mathematical principles upon which such systems can be expressed
- Credo: Process algebras and their extensions that handle mobility provide a possible next step from cellular rules.

Desired elements of models of complex spatial systems

Agent-based, focusing on the processes that agents can perform, and their properties.
Event-based,
Distributed
Rich,

Discussion:
Helen:
CA and ABM - have not been brought together effectively

Why are state time and location all represented as processes? What is the purpose of this? (I missed this part)

How do inputs lead to outputs? There is an axiomatic basis which allows deductive reasoning …
How would one decide which model to use? Cells - rules - and interaction is the classic CA model. When more complicated rules and connections are present between the elements - ABM?

Bayne: languages used to describe agents - place to start - scripting language

Engineering the system and understanding the system are two goals that we hope coincide.

Uncertainty about processes and what processes are associated with which object -
What kinds of uncertainty?

Marina Alberti
Modeling Urban Landscapes as Emergent Phenomena of Couples Human-Ecological Systems

Dr Alberti
How urban landscapes evolve over time - interaction between human and natural biophysical processes - and how can these processes explain development in Phoenix and Seattle -

How do coupled human-natural systems generate the emergent patterns that we see in metropolitan regions?

Linking urban landscape pattern to human and ecological function:
Human function: housing, accessibility,
Forest function: nutrient cycling - etc

Modeling Challenges:
Emergent properties -
Adaptive agents- human agents and biophysical agents
Multiple equilibria-
Hierarchies - nested - not just characteristic of agents by
Heterogeneity
Path-dependency

Emerging Patterns of Urban Landscapes
Human agents include households, developers, businesses and governments

Those agents are spatial explicitly and interactions are spatial dynamic

Characterize multiple states -
As urbanization increases, ecosystem functions are replaced by human functions -

Urban landscaping can be described as nested hierarchy
Spatial and temporal scales - at a lower level, you have smaller scale, and faster processes or larger scale and slower processes

There are infrequent interaction between scales

Path dependency scenarios:
We need to think of interaction at different scales

Hybrid modeling approach
Agent based
Patch dynamics
Hierarchical
Discrete choices and DPRM - probabilistic relationship models

Why ABM?
Model emergent phenomena resulting form the interactions of individual entities
Agents are heterogeneous, and their interactions complex, nonlinear, and discontinuous
The topology of the interactions is heterogeneous and complex

Agents also learn

Interest in representing agents and the actual processes across multiple scales -
Hierarchical approach allows us - in contrast to CA - to structure the relationship between agents at multiple scales -

Most Markov models don't have the ability to represent different types of states -
Dynamic probabilistic relational models can - and address high order temporal dependency.

Pattern modeling of AB complex systems -
Bio-complexity model:
Demographic, Markets, and Development Behaviors←→Land use land voer spatial interactions←→

Sources of agreement and errors in predicted landscape

Spatial dependency: spatial autocorrelation among the locations and or the spatial dependency

Modeling spatial pattern: equation
Temporal non-stationarity AI of developed Land

Future directions - build a hierarchical pattern oriented model that can handle small and large scale

Nigel Gilbert

Processes and process algebras:
Can we use process algebra to represent reality? What does that leap of imagination consist of?

The variety of ways of modeling in ABM - abstract models on one hand and facsimile models on the other

We've just heard about a complicated model - what can be said?
We must be clear about what we are trying to do - what choices have to be made?

The idea of emergency - sociology is about emergency - and what does that mean?

Processes and process algebra in terms of emergence -
Activity theory - 1930s Russian researcher -

If you are dealing with human activity - they give rise to intuitions/urban landscapes - but the fact of those institutions exists as a macro that effect the individuals that work within them.

Downward causation: parallels of this in any complex system when individual activities give rise to emergent effects
Emergence: because you working within a social institution - actions and activities change

Discussion:
Things viewed at different level of detail have different characteristics -
Using the past to see if the present can be predicted -
We need to link model building with scenario building there is a certain degree of uncertainty with models that we cannot deal with

Complexity theory- we can potential identify where those bifurcations occur - this can help us with decision making

Temporal issues - time between cause and effect are shortening
Coherent models can be useful - cannot be proven

Problem with modeling: if we don't go into the real world, the models we build cannot evolve

In defense of formal theories - complexity is in the eye of the beholder - no way to determine if the simple or complex model is better
Ant example: is the complexity in the ant itself? Or the terrain?

2 questions: what did you do and why did you do it? Why our agents do what they do is not clearly understood

It may be that all systems are complex
Why invariance instead of probability? Invariance is what's left when probability is taken out - H.C.
Outputs of these models are typically probabilities

The factors that make places they way they are are often a result of earth-shattering events like the dust bowl - the great depression - etc

What are the endogenous forces?
They can't be anticipated

How do you deal with the interaction of drives that are uncertain?
Scenario building is an option because it sets the assumptions for alternative models - i.e. a dust bowl, a pandemic, a depression….

Models are built for specific purposes - a general "model" discussion cannot encompass the range of models we build

By building models and scenarios - we're building ***projections***

Post Lunch - Dave Bennett - elk example

Complex (adaptive spatial) systems
My interests in ABM for CASS lie primarily in the representation of intelligent, mobile, contextually aware, and adaptive decision-making.

How do social networks evolve or emerge - how landscape structure emerges from individual and localized actions and how feedback mechanisms link multiple social or spatial scales.

Challenges for ABM of CASS
Representation
    Cognition and context

Representing cognition
    Individual-level
    Perceive
    Plan
    Act
    Learn
    Adapt

Context: Individual state becomes important - does the farmer have the economic means to survive the upcoming difficulties…

To what degree does social networks affect decision making?

Bounded heterogeneous decision making -

Representing cognition
Individual state
Motives
Knowledge
Capabilities
Beliefs
Certainty
Social network

Building ABM - focusing on link between learning algorithms and environment
Mobile, Adaptive, Intelligent Agents (MAIA)

Learning movement patterns - Patch scale cognition map based on a graph representation and learned experientially.

The way in which learning algorithms are implemented is significant - spatiotemporal variability may affect the model

Some things may change thru time - representations have to balance space and time

Within systems with complex behavior we have representation issues, bifurcation issues….
How can we represent the path that got us to the result?

If we accept the idea that small changes dictate a system - how do we show this?

The challenges are great, but "…we don't know enough about rational actors and equilibrium conditions to address issues of bounded rationality

Discussion:
Have the learning methods been validated? No

Ecosystem dynamic - the wolf comes in, elk population goes down which in turn affects the willow…

Cognitive -
Difference between knowledge and belief to be further developed. The term belief has more to do with emotional beliefs

Georgios Theodoropoulos

How can we deal with issues of adaptation, equifinality, bifurcation, divergence?
Can we determine a priori what an important event in an ABM simulation looks like?
How do we prove that an emergent behavior produced by the system is, in fact, generative evidence of real complex behavior and not an unintended artifact?

Integration of temporal GIS and ABM:
Need to have hierarchical data sets to provide multi-scalar spatial structures for the investigation of geographic dynamics and for the incorporation of local , regional, and global constraints and agent's behavior rules

Such an approach can empower ABM in two ways:
Rules applicable to different levels of geographic dynamics can be incorporated into different levels of the ABM (find and course grain).
What is the relationship between the emergent behavior of the fine grain model and the course level rules obtained…

DDDAS: Dynamic Data Driven Application Systems/Simulations

A simulation co-exists and runs in parallel with the real system
Data from the system ("sensors") is absorbed by the simulation so that the simulation is adjusted "online" according to developments in the real system to enhance model reliability
Simulation predictions are "fed back" to the real system (e.g. for optimization)
DDDAS a major NSF program

DDDAS: the simplest case
Data is absorbed by simulation to bring it up to date with reality.

Predicted state points to a need for more information of a certain type

DDDAS: A Fully Symbiotic Scenario

How to apply DDDAS to social sciences?
Data not usually real-time, but sequences of transactions are available (e.g. history of new tenancies in social housing)
Model may be about a typical system (e.g. a typical housing estate.) In this case no direct correspondence between simulation and data
Automated interpretation of simulations is required in order to determine whether predictions are consistent with available data
It is essential to have a semantic description not just of static entities, but one that can encapsulate the dynamic changes a simulation to enable the representation and interpretation of the content and the emergent properties of the simulation components

How to apply continued:

To achieve automated interpretation of simulation predictions, if necessary to
-have machine readable descriptions of what is happening in the simulation

AIMSS: Adaptive intelligent modeling for the social sciences
U: The user-defined model
D: Representation of the main concepts in U - a machine readable description of the simulation content which contains
-An ontology ; entities and relations in the model
A behavior

AIMSS prototype:
Case study: Housing policy
Agents are households in a “housing space”
They will want to move house if their needs are not satisfied
Needs are prioritized: affordability, safety
Entites in the simulation can change dynamically
Households (agents): income and household size can change
Homes can change: building, demolition

Agent Emergent Behavior in repast

AIMSS Prototype : Data
CORE continuous recording data
A sequence of records, each one describing a new tenancy with a Housing Association
Each record is interpreted as a move from a source

Interpretation using data mining:
Two datasets: simulation-generated and CORE data

Consistency-checking
Interpretation and consistency checking

Why not data mining only?
Data mining may be used to generate predictive models: however
Such models are developed without domain expert knowledge (i.e. social science knowledge
Agent-based simulations can help explain why some events occur
Consequences of a model’s rules are often not know in advance
Running the model as a simulation can show some unexpected dimensions
Why not simulation only?
Discovery assistance to automate the model building and testing process
Automated assistance enables wider search
-simulation cold b adapted by running many simulations in parallel and applying an evolutionary algorithm to find the best fit for the data
-allows more exploration. Even for one simulation

Can the use of the system be used to explain the real world?
These are difficult things to do -

May Yuan
University of Oklahoma

Temporal GIS for Agent Based Modeling of Complex Spatial Systems
In the past we have data and cases, and in for the future we have simulations

If we can somehow feed back and forth to help develop agents, it can improve ABM - link between temporal GIS and ABM ABM
How to represent agent, landscape, and their interactiosn
Discretization
Disaggregation and aggregation
Mathematical functions, probability, and decision models

Temporal GIS

Agents:
Simple behavior rules
Autonomous and adaptive nature
Individual decisions
Randomness

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

Emergence
Patterns that emerge

Temporal GIS:
What, When, How
Snapshots
Spatiotemporal object model
Spatiotemporal event-based model
Process model
Event model
Lifelines model
Helixes models

Most of the TG do not catch the complexity
When we try to represent TG we're interested in more than the time frame, but what is happening in that time frame.

Geographic dynamics
-drivers: activities, events, and processes
-observables: change and movement
Forms and patterns in space and time
Works of activities, events and time
Works of activities, events, and processes
Observable through means of change and movement

Activity, event, sand processes are drivers that transform space

For GIS approaches, we need cohesive conceptual models

The three independent dimensions that something can change are geometry, internal structure, and movement. Each one of these can be dynamic or static. Internal structure is the spatial variability

Kwan(2004)
Stefanidis, Agouris, Partsinevelos (2003)
Spatiotemporal helixes

Pequet and Duan (1995) Spatiotemporal event-based data model

Change and movement are the observable to give us a sense that something dynamic is happening

Weinberg (1976) General Systems Theory
Three different systems
Small number, large number, and middle number complex systems

Middle-number complex systems in which elements are…
-few enough to be self-assertive and noticeably unique in their behavior

Ecological systems
Hierarchy Theory:
Reality may or many not be hierarchical

Hierarchical structures facilitate observations

Grain (resolution)
Scale (extent)
Identification of entities
Hierarchy
Dynamic

2 kinds of entities:
Definitional entities and empirical entities

ABM connected with definitional entities, and temporal GIS associated with empirical entities.

Empirical objects define objects

Establish the distinction of what an event is in a GIS
The agent can represent objects, events, or processes -

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

Is anything missing from the conceptual model?
Integrate ABM and TGIS
Hierarchy theory serves the conceptual framework
Levels of aggregations, levels of geographic dynamics

Dynamic Modeling w/ geo-agents
ESRI - David Maguire

Goal is to provide a generic product (ArcGIS)
Agent Analyst

Why ABM with ArcGIS? It can manage large datasets, gives access too data conversion, transformation, and integration tools, mapping and visualization environment, scripting and customization, and finally - integration

Fire modeling: concepts - interaction with landscape, position matters, interaction with global factors - wind - temperature, and there are characteristics

ModelBuilder: input data, a process, output
Functions are strung together.

Model has feedback loop:
Adding complexity:
Adding several random variables to the model - stochastic events
First demo of fire spread without random element, second model adds random variable - and both show how the new looping option can be used to do iterations, and animations.

Agent Analyst - links REPAST to ArcGIS.
Create, edit, and run models in ArcGIS geoprocessing environment
Call using java api
Display results in ArcMap in 2D, or ArcGlobe in 3D

Sample Application: Cougars -
Cougar is an agent - what does it do?

Model built on energetics - how hungry the animal is, and whether a female is around
Home range needs to be establish
Home range
-makes sure the cougar stays within the home range

Rules are written in “not quite python”

Final example: Niacong Li's urban growth model:
Showing how different paths of development result when different parameters are emphasized - setting up scenarios -

Changing the geometry is technically possibly, just computationally expensive
Discussion about whether or not both Niacong's and Kevin's model could have both been built in ModelBuilder.
Heterogeneity of agents distinguishes the two methods though the urban growth model could be built in ModelBuilder not that looping is available.

Visualize outputs of agent analyst with tracking analyst (bird migration)

Next example - line of sight example

Key Issues
Management of multiple outputs
Modeling time explicitly
Synchronizing different time inputs/intervals
Tools to analyze results - visual interpretation is all at this point
Metrics to compare scenarios

Future research work
Extend existing dynamic GP framework and tools
Explicitly model time
Multi-dimensional data structure
Build robust, scalable implementations for large data sets
Identify and build generic dynamic modeling components - building a toolkit for several different senarios
Create analytical tools to quantify results of simulations

Day 2
David O'Sullivan and Mark Gahegan's presentation

Issues around verification, validation, calibration, and confirmation of agent-based models of complex spatial systems

The nature of complex systems -
Medium-large numbers of interacting elements
 Not trillions or more
 Not just a few
Interactions are generally localized but may scale up in 'unexpected' ways
Interactions vary widely in nature
Elements range from simple-reactive -

No compact model of a complex system is possible
A complex system is its own model

A complex system that is spatial embedded
 Multiple interacting complex systems
 Hierarchical
Interesting in the spatial location of outcomes
 Patterns Processes Relationships between them
Local prediction is impossible

Where does that leave us in terms of validation?
Verification of any model of an open system is impossible and validation is not the same thing
On verification: "Model results are always underdetermined by the available data"

Calibration and confirmation are also not the same thing (as verification, or as one another)
On calibration: "..if a model result is consistent with … observational data, there is no guarantee the model will […] the future"
On confirmation: "If a model fails to reproduce observed data, then we know [it] is faulty in some way, but the reverse is never the case

-Oreskes, Shrader-Frechette, Beltiz (1994) Verification, Validation, and Calibration of Numerical Models in the Earth Sciences 263 641-5

Models are often fit to the past, but we don't know that the past fits the present or the future.

Difficulties analyzing ABM-CSS
Many interacting agents
    Keeping track of individuals is a challenge
    Aggregate measures may hide the spatial variation we are interested in
Spatial variation
    Localized differences may be key drivers of change (e.g., tipping points)
Interactions between spatial patterns and processes

The end product is difficult to analyze. We have clear expectations of what we will see or what we hope to see

Keith Beven has a proposal for a "coherent philosophy for modeling the environment
Steve Bankes advocates working with model ensembles

The traditional GIS/quantitative geography S-T-A cube of Berry
-the model space consists of many cubes
-space itself is also a dimension of this space

Outline framework for thinking about appropriate tools
-tracking progress in this complex space;
Projection pursuit in scientific visualization is a similar problem
Use multivariate visualization to make individual cubes a set of cubes comprehensible
Automatically track where they've been

Where ABMs sits in science

Exploration - data in
Synthesis -
Analysis - model in
Evaluation -
Presentation - map out

Abstract models
What are the different kinds of ABMs
Exploratory models - simple models - aiming to represent some theoretical framework or system

Large-scale models that aim at realism where trust in results is paramount
Important decisions will be made based on the results of such models

Issues for further discussion
- What types of science is ABM-ing?
- Are others more optimistic about the prospects for (technical post hoc) V^2C^2 than I am?
- Are tools making the problem worse
- Can they be part of the solution?
- How must difference does it make that we are interested here in spatial models?
- Does it make it harder, or just different?
- Does GIS have a role to play (Or are generalized data models too hard?)
- …others?

Discussion:
Climate modeling questions-

Dawn Parker - George Mason - bias is land use modeling
Grounding the debate about calibration and validation of spatial agent-based models: Simple questions about complex models

Verburg's definition of calibration -

Structural validation vs outcome validation
What are we looking for?
Define process
Develop interdisciplinary models
Understand how local cases-specific conditions shape local outcomes
Ability to project

Are the goals competing or complimentary?

Goal: Modeling to fill in process
Drivers→agent behavior→agent interactions→emergent patterns

Questions?
How do we preserve the scientific method?
    Focus on putting in the appropriate amount of complexity
    The model needs to be at least as complex as those patterns you hope to analyze

What is the role of statistical analysis?
What about calibration?

Sources of complexity:
Heterogeneity
Interdependencies
Linkages across hierarchies
Emergence

Quilting examples of emergence

POM rationale (Grimm et al. 2005)

What could be gained by greater formality/rigor?

What about statistical validation?
Create decision/behavioral rules at the agent level (Many nice recent examples. Can be viewed as micro-scale calibration)

Pseudo-inductive analysis for theoretical models
Build hypothetical causal rules/mechanisms into ABM;
Generate database of outcomes by sweeping model parameter space;

Traditional scientific method:
SLUDGE model summary
Model explores relationships between land use payoffs, transportation costs, spatial externatlities, and fragmented urban forms

Why didn't she just build a linear programming model?

Regression-based modle validation for empirical models
Parameterize ABM using real-world derived rules and data
If estimated model coefficients are statistically significantly similar, you have quantitative agreement with the real world - and probably too good luck

Spatial hedonic model goals
Use combined data from multiple sources

Calibrate parameters of micro-level rules using macro-level data

Pattern-oriented modeling and calibration (Grimm et al 2005)

Goals of validation (Verburg et al 2005; Manson 2003)
How much trust can we put into any model?

How can theory and empirics work together?
Theoretical frameworks may be used to develop conceptual 'meta-models"

Questions:
What's the worst that can happen if someone picks up our models and uses them? - depends on what it is used for…

Parameters represent our ignorance about something….
To what degree can guest get ride of parameters

ABM is a hybrid methodology -

Post break discussion:

Mike Batty:
4 main points;
Complexity leading to so many relationships that it's difficult to know what is really happening
Many variables, many parameters -
Notion of the space of plausible models
In the 60's dynamic models weren't built

Calibration meant fine tuning

Book: Urban dynamics - J Forester -
Second Book: World dynamics - books that created tension in the field

Once the model is chosen, the calibration is routine
If you build a model on a particular system, you cannot validate it on the same system -
Think about plausible space when we model
….Heated debate on the differences between verification and validation ensures….
What are the distinctions that need to be sorted out?

Model assumptions have not been brought up enough in this workshop - what are assumptions in this context needs attention.

Notion of parsimony: how should we use these types of used or specified

Comments --

Complexity suggests that we might be able to learn something new about how the system works
How do we navigate through that solution space?
The idea that a novel result doesn't necessarily mean it's wrong….

Is parsimony the simplicity of the model, simplicity of the outcome, or a combination of the two?
The rules governing the movements can be simple - the complexity lies elsewhere -

What are the most important research topics in this field?
What might be the most useful contribution to research infrastructure
Are there other mechanisms that might advance work in the field
Can we reach consensus on the methodology questions?

Important point: ABM is meant to model simple movements to explain complex systems but what we really might have is complex individual movements to begin with

2:30 Plenary reports from groups -

Breakout Group1

Space -time data structures and representations to support ABM
Distributed systems applied to reality
Extent to which ABM are different from everything else we know about models

Sources of funding:
Nationally: NSF, EPSRC in Britain - building a transatlantic partnership
We should build a national center -

Links with programmers from the gaming industry
Links with climate modelers
Practical applications

Breakout Group2
Areas of growth and gaps:
Growth - social networks, and different notion of space - what does it mean to be connected? Sociology has always been interested in social networks-
Decision making:

Measuring agent characteristics - often we are using canned data - is there something different about the questions we ask for ABM
How do we deal with time?
Emergence that isn't pre-programmed -
Are we engaging with others building complex systems (gaming industry)

Breakout Group3
What defines the core of the field?

Coming up with a master synthetic dataset - would be difficult, but running your dataset thru other models to see if the results are comparable could be interesting