

Linking Landscape Patterns with Ecological and Social Processes

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LUCC as a Human-Environment Framework

Interaction
of land with:

Economics

Policy

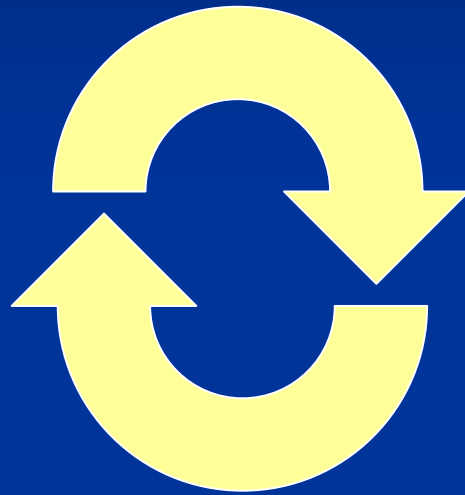
Culture

History

Perception

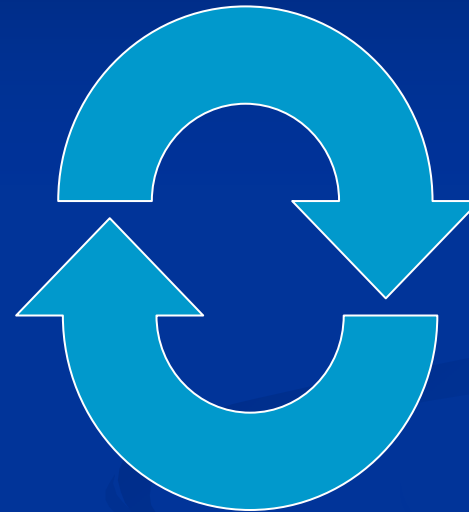
Behavior

Social System



Land Use

Natural System



Land Cover

Interaction of
land with:

Atmosphere

Biota

Hydrology

Soil

State Variables

- Studying spatial and temporal patterns of land use and land cover, and their interactions, is one way to begin understanding interactions of society and environment.

Value of Integrated Modeling

Outcomes of interest:

Adaptive Capacity

Vulnerability

Equity

Well being

Social System



Land Use Change

Natural System



Land Cover Change

Outcomes of Interest:

Water Quantity and Quality

Biodiversity

Ecosystem productivity

- We can simultaneously evaluate outcomes of interest in the social and environmental systems. Only by taking them together can this set of outcomes can help us define *sustainability*.

Outline

- Representing land-cover and land-use dynamics
- Pattern-process linkages of interest
- Operationalizing these linkages
- Challenges

Land Use Change



Hale Lake
Iosco County, MI

Photo Date: Jul, 1973
Plat Map Date: 1970



Photo Date: Aug, 1992
Plat Map Date: 1991

Land Cover Change



August 1966



April 1991

Cass County, MN

Remote Sensing of Land-Use and Land-Cover

- RS most comfortably gives us land cover.
- Attempts at translation and hybridization have not been very successful.
- However, RS is an important tool for standardized wide-area coverage.
 - It will continue to be used in global-change studies.

Land Cover to Use Translation

Land Covers

Land Uses

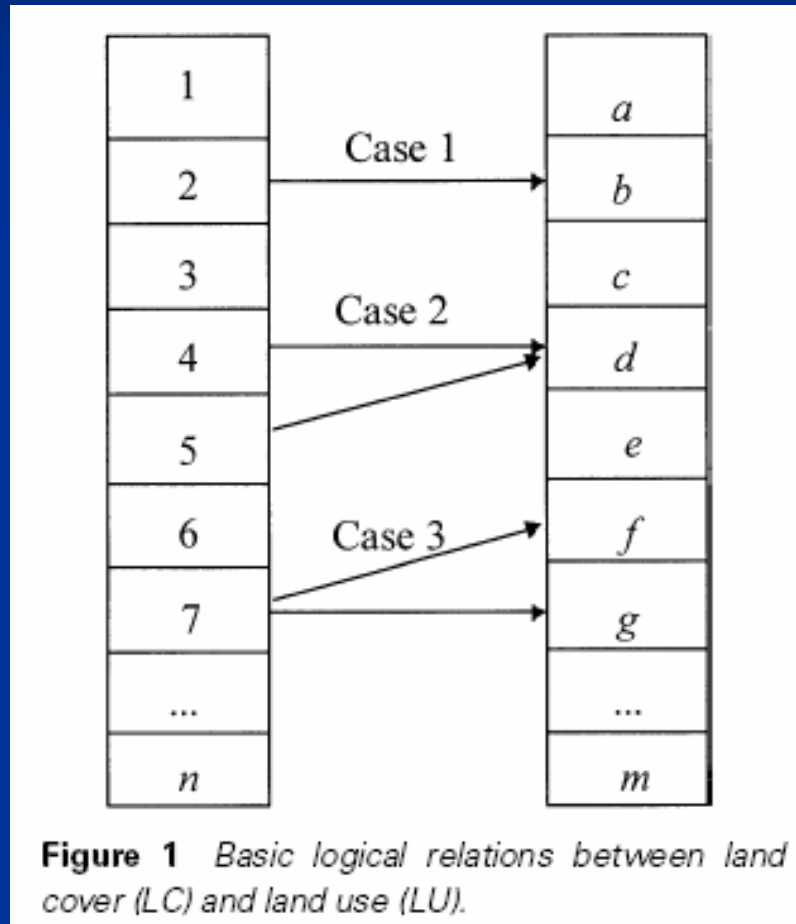


Figure 1 Basic logical relations between land cover (LC) and land use (LU).

Standardized Classifications

- Anderson et al. (1975) – land use and land cover
- LCCS – land-cover classification
- Land Use Classification Standard (2003) - American Planning Association, based on
 - Activity (e.g., residential, shopping, leisure)
 - Function (e.g., residence, manufacturing, transport)
 - Structure (e.g., commercial bldgs, public assembly structures)
 - Site Development Character (e.g., natural, developing, developed)
 - Ownership (e.g., private, public, easements, leased)
- Are these efforts at standardization worth pursuing?

So...

- Land use and land cover and their changes are the **patterns** of interest.
- What are the **processes**?

Linking Pattern and Process

Example

Processes:

Social System

Birth, labor,
death, migration

Information
exchange

Livelihood
strategies



Natural System

Water dynamics

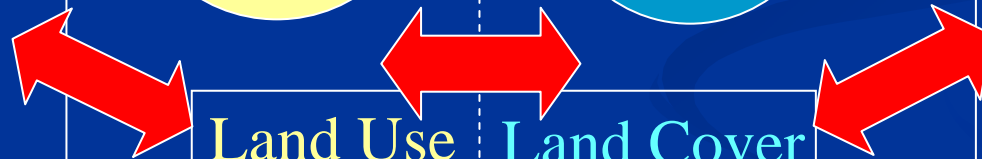
Plant and animal
growth and
dispersal

Soil erosion and
deposition



Land Use
Change

Land Cover
Change



- It might be profitable to think about three key process linkages:
 - social processes interacting with land-use change,
 - biophysical processes interacting with land-cover change, and
 - land-use change processes interacting with land-cover change processes.

Land Use ↔ Socioeconomic Process

Example questions

- Socioeconomic Process → Land Use
 - How do economic and policy initiatives aimed at mitigation of climate change (e.g., biofuels) affect land area devoted to agricultural production and its distribution?
- Land Use → Socioeconomic Process
 - How might existing land-use patterns constrain options for adaptation and affect vulnerability of social systems to impacts from climate change?

Land Cover ↔ Biophysical Process

Example questions

- Land Cover → Biophysical Process
 - How does fragmentation of habitat interact with the matrix to produce changes in faunal fecundity and survival that are important for biodiversity?
- Biophysical Process → Land Cover
 - How might changes in the hydrologic cycle (e.g., increasing duration of drought) affect land-cover resources?

Land Use ↔ Land Cover Change

Example questions

■ Land Use → Land Cover

- How are land-cover-management options constrained by land tenure and land-use regime?

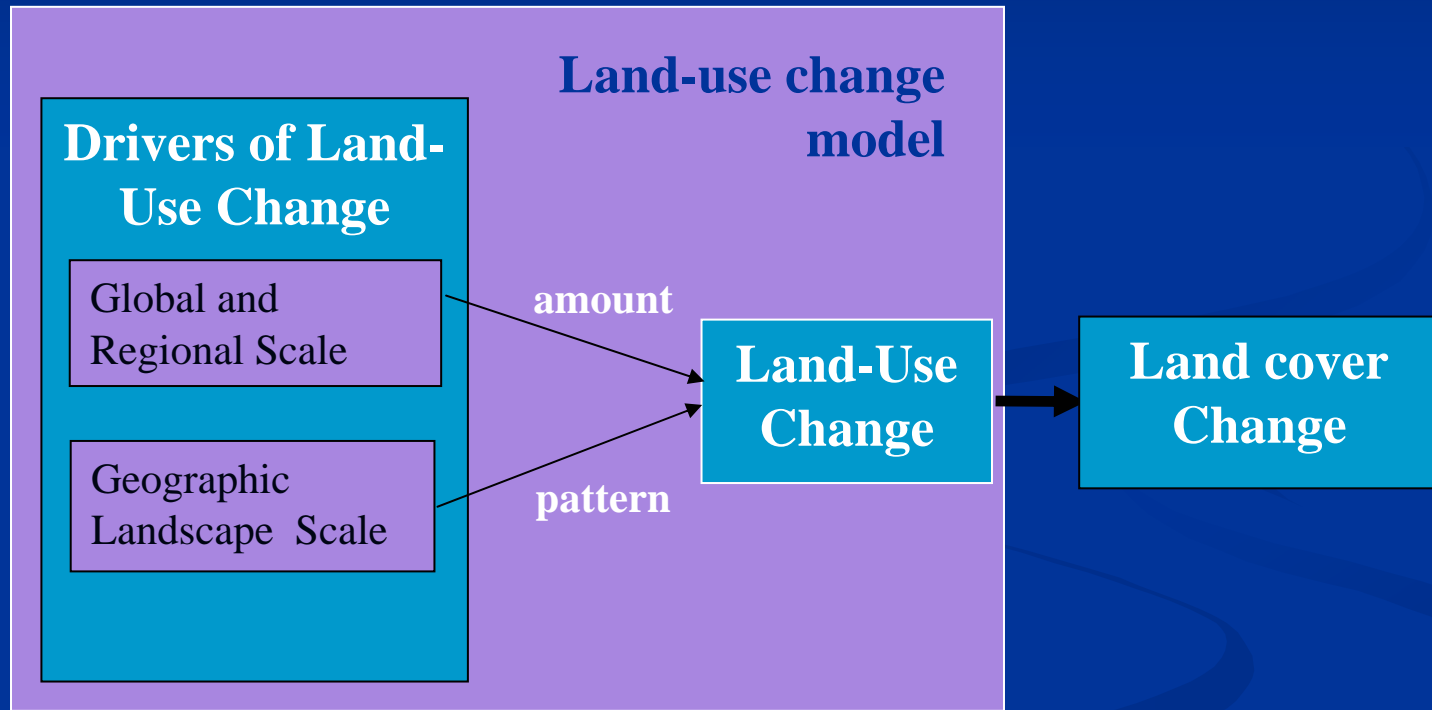
■ Land Cover → Land Use

- How do land-cover choices on one piece of land influence the economic, aesthetic, and social value, and consequent land-uses, of nearby land?

What's all this mean for modeling?

- Integrated modeling is important.
- Models that are explicit about linking land-use and land-cover might be helpful.
- A variety of modeling approaches will be useful, moving towards models of process.

A Spatial Land-Use Modeling Framework



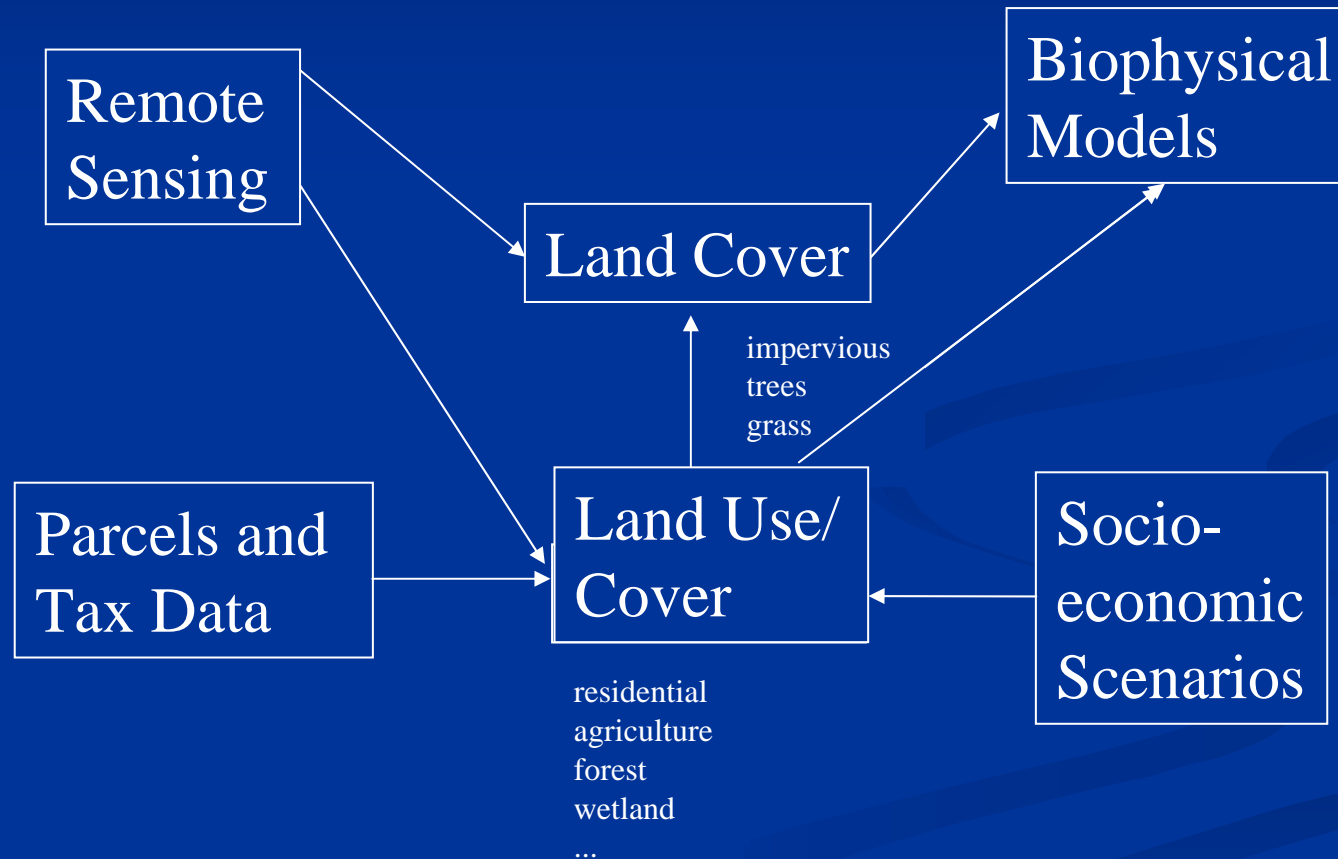
Brown et al. 2000. *Journal of Environmental Management*, 59: 247-263.

Integrating LU and LC Models

Data Sources

Semantics

Models



What about modeling LC directly?

- For example, why don't we just model the socioeconomic drivers of deforestation?
- There is a long history of this kind of work, especially in the tropics.
- Unless there is a one-to-one mapping between the observed land-cover change and the land-use processes giving rise to that change, this skips a step in process chain.
 - I believe this condition holds in many tropical frontier situations.

Types of Land Models in One Review

- *Empirically Fitted Models* – emphasis is on fitting a statistical model to observations.
- *Dynamic Process Models* – emphasis is on describing system processes and encoding it in a simulation.

These are not mutually exclusive categories, they describe differences in emphasis

Brown, et al. 2004. In Gutman et al., Eds. *Land Change Science: Observing, Monitoring and Understanding Trajectories of Change on the Earth's Surface*. New York: Springer.

I: Empirically Fitted Models

- Focus is on accounting for spatial and temporal *patterns* in data or empirically testing hypotheses
- Theory informs selection of explanatory variables and structure of relationships
- Predictions outside the range of observed conditions are problematic

Estimation Challenges

- Temporal non-stationarity
- Spatial autocorrelation and non-stationarity
- Non-linearity in relationships
- Heterogeneity in household/agent characteristics
- Aggregate vs. disaggregate data
- Endogenous interactions and feedbacks

II: Dynamic Process Models

- Iterative – including systems dynamics, cellular automata and ABM
- Focus is on describing the processes of change rather than data on the outcomes of process
- Should lend generative insights to dynamics and possible effects of shocks and unobserved variation.
- Predictions can be difficult to interpret in presence of non-linear dynamics.

Examples of Pseudo-Process Models

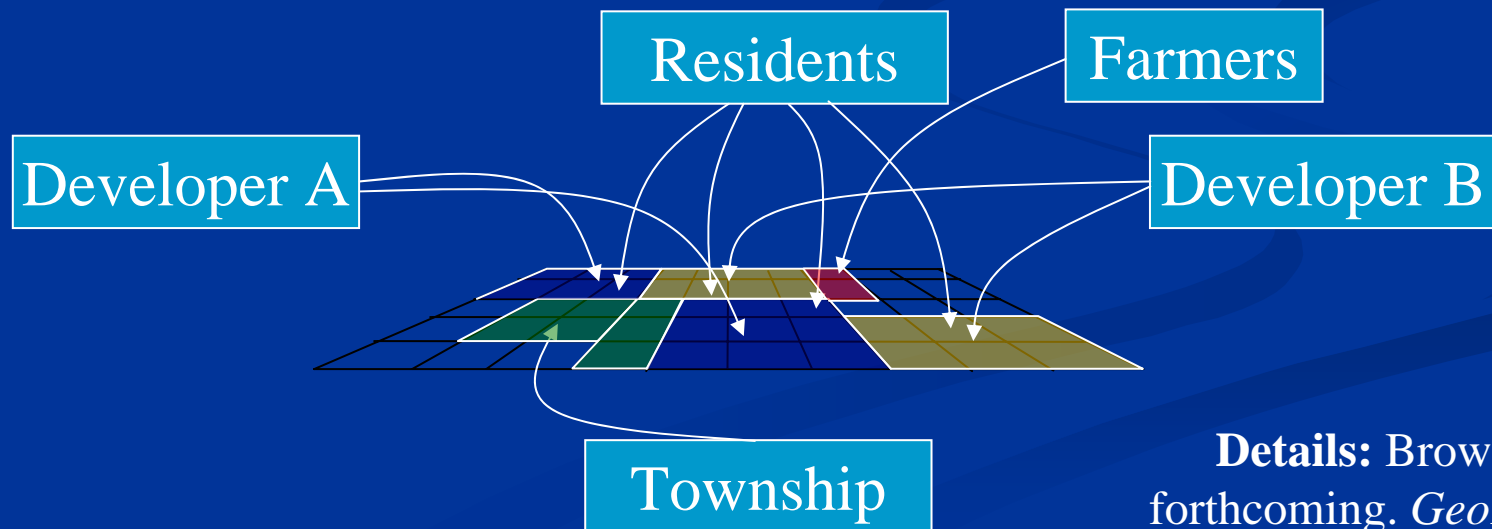
- Markov process
 - A useful mathematical formulation with too many simplifications (esp. stationarity).
- Cellular automata
 - Rules governing transitions or transition probabilities are useful, but aren't a natural outcome of our theory about the way land users, managers, or natural systems behave. Focus is on patterns.
- Test of useful process representation should be:
can we implement multiple types of interventions and evaluate outcomes?

Agent-Based Modeling

- Uses object-oriented programming ...
- to represent and simulate the attributes, decisions, and behaviors of multiple interacting actors...
- and their collective impacts on landscape condition and pattern.
- Can be coupled with GIS, which can provide a data modeling counterpart.

Dynamic Ecological Exurban Development (DEED) Model

- *Townships* — purchase land to **preserve**
- *Farmers* — can sell **rural lot** from part of farm field
- *Developers* — convert farms to **subdivisions** of different types
- *Residents* — select residential lots based on preferences



Details: Brown et al.,
forthcoming. *GeoForum*.

Challenges of Process Modeling

- Building models and linking to spatial data is hard work.
 - ...and to be effective it needs to be done again and again.
- Bottom-up models are notoriously difficult to calibrate, in the sense that we do for empirically fitted models.
- Land-change community still has work to do on expressing standards of evidence for land-change models.

Linking Models and GIS

GIS represent **pattern** and have

- ...domain-specific ontology
 - expressed formally in data model
- ...spatial and (sometimes) temporal reference
- ...object-oriented structure

Models represent **process** and have

- a *clock* and
- a *schedule* – for when (on the clock) events should occur.
 - Events may be sequenced in a synchronous step-wise fashion.
 - Events may be scheduled to occur only once at some time step n .
 - Processes may be ‘event-driven,’ using if...then statements.

What can GIS provide to ABMs?

GIS as data

- Need spatial data input for models
- Models produce spatial data as output

GIS as software

- Model needs to calculate distances, adjacencies, slope, visibility, etc.
- Want a model to take advantage of visualization capabilities of GIS

DEED in ArcGIS

The screenshot displays the ArcGIS interface with the following components:

- DEEDS Simulation Parameter Window:**
 - Parameter File: deeds.prm
 - Parameters:
 - Number of Residents Per Turn: 10
 - Number of Developers: 3
 - Stop Time: 20
 - Probability of Farm For Sale: 0.02
 - Number of Res Test Sites: 15
 - Debug Level: 0
 - Minimum Lot Size: 9
 - Subdivision Full Threshold: 0.75
 - Preserve Mode: 1
 - Proportion in Preserve: 0.1
 - Operation Mode:
 - Probability Develop Farm: 0.5
 - Random (unchecked) / Batch mode (unchecked)
 - SLUCE (checked) / Seed: 9999
 - File Information:
- Identify Results Dialog:**
 - Layers: <Top-most layer>
 - agentWorld1
 - 99
 - Location: [263661.349789 4683256.311889]
 - Table:

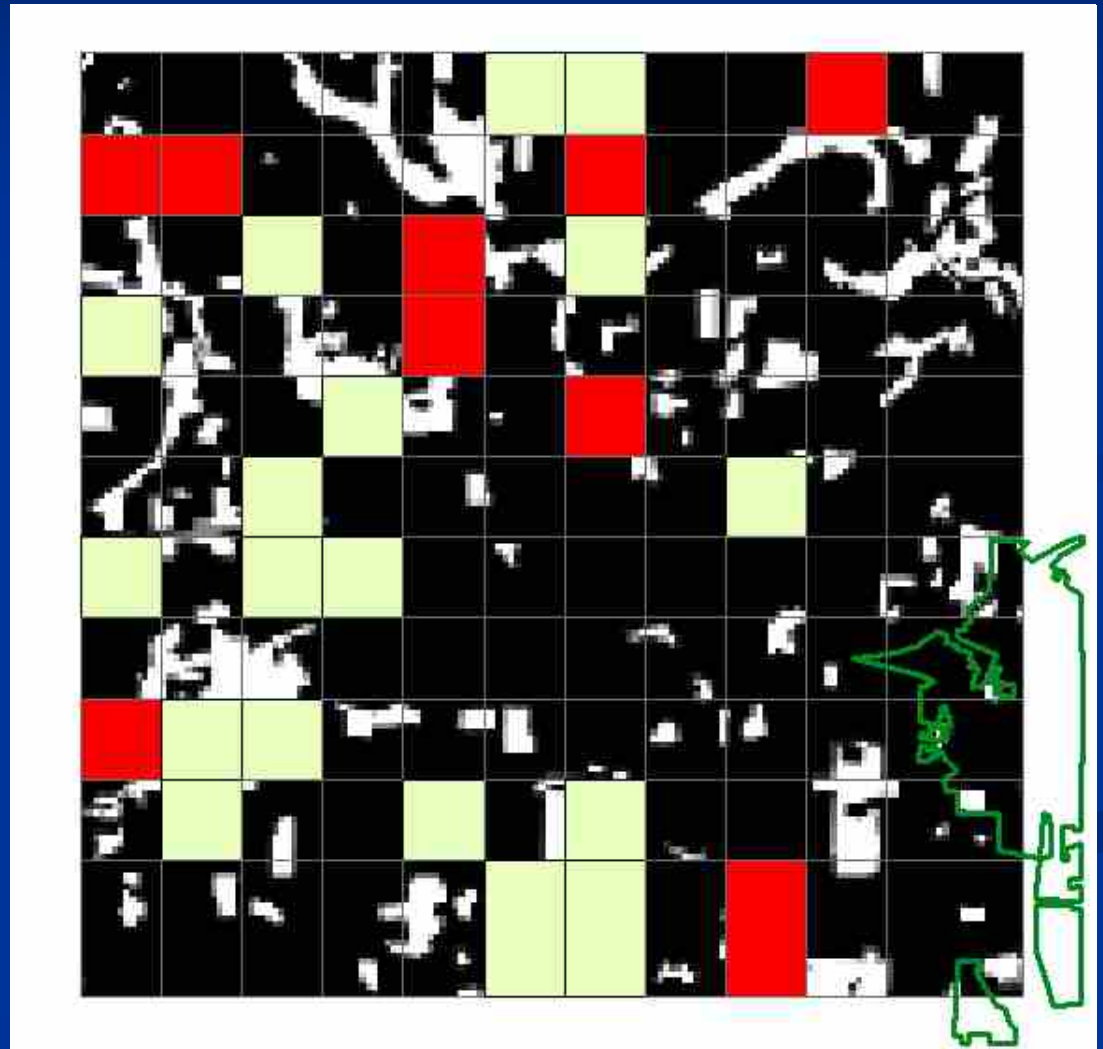
Field	Value
FID	99
Shape	Point
ID	99
Ini_util	0.604707
X	263664.001122
Y	4683255.10341
oAlphaA	0.559601
oAlphaS	0.211997
oAlphaT	0.632538
sAlphaA	0.398538
sAlphaS	0.150980
sAlphaT	0.450482

Developed by Derek Robinson (Robinson and Brown, in review)

Graphics from Example Model Run

- Subdivisions for sale in tan.
- Sold subdivisions in red.
- Gray tone in background indicates % tree cover at the beginning of the model run (Scio Township, MI)
- Model runs in ArcGIS.

Time Step = 00



Community Land-Use/Cover Model

- Might we, as a community, contribute to global change research through development of a model or modeling framework for land use and cover change that couples to and interacts with general circulation models and ecosystem process models?
- Such models should build on the experience of this community.

Challenges

- Learn more about linkages between land use and land cover change.
- Synthesizing lessons learned from modeling projects all over the world and with many different approaches.
- Scaling process models to regional scales. ABMs are still notorious for localized application. Maybe requires linking model types.
- Developing metrics of and improving “skill” in forecasts that are still process based.

The End