Statistical Validation of Spatial Patterns in Agent-Based Models

William Rand

Daniel G. Brown

Scott E. Page

Rick Riolo

Luis E. Fernandez

Moira Zellner

Project Sluce

Modeling Group

http://www.cscs.umich.edu/

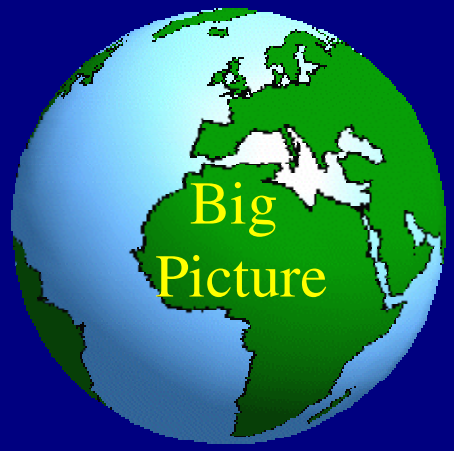
sluce@umich.edu

Center for the Study of Complex Systems

University of MICHIGAN

Overview of Presentation

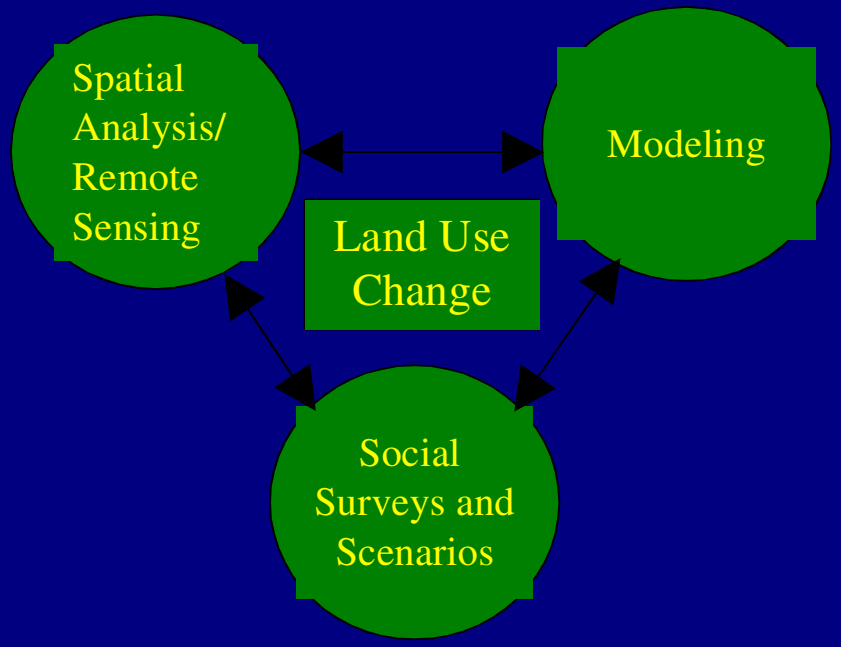
- Project Overview and Urban Modelling
- Validation of ABMs
- SOME
  - Agents
  - Environment
  - Interaction
- Valid Results :)
- Conclusions and Other Work



Project Sluce

(*Spatial Land Use Change and Ecological Effects*)

- Project Sluce focuses on land-use dynamics at the Urban-Rural Fringe
  - Greater Detroit Metropolitan Area
- Uses an ABM in synthesis with other modeling techniques
- Results will be compared with historical data and theoretical models



Modelling of Urban Development

- Understanding the Processes that result in Urban and Exurban Patterns
- Suburban Sprawl = Negative Ecosystem Impacts
  - Habitat Destruction
  - Migration Corridor Destruction
- Make Prescriptive and Descriptive Statements about Processes
- Goal is to Minimize Ecological Damage

Two Types of Models

Physical Analog Models

- Examples - Markov Random Field, Diffuse Limited Aggregation, Correlated Percolation
- Based on well understood formal systems
- Hard to translate into 'real world'

Agent-Based Models

- Examples – Schelling's Tipping model of Segregation, Otter's ABLOoM model, Our model
- Easy to Incorporate New Ideas
- Ontology understood by Policy Planners
- Not well understood

Validation of ABMs

- A model is valid if it can correctly answer questions it was designed to answer (Casti, 97)
- Two Methods of Validation
  - Matching model outputs to measured variables
    - Micro-details
    - Macro-level patterns
  - Matching component structures and interactions

Difficulties in Validation

- Validation is Hard
  - Positive Feedbacks
  - Path Dependence
  - Extreme Sensitivity to Initial Conditions
  - Unpredictability of Agent Adaptation
- Micro-details often impossible to match

Sluce's Solution

- Our goal is not to match micro-level detail
- We build our model from “first principles”
  - Heterogeneity
  - Bounded Rationality
  - Correspondence between virtual agents and real agents
- Matching of Macro-Level Patterns
  - Zipf's Law
  - Clark's Law

Zipf's Law

- Zipf (49) showed that there is a power law relationship between city populations and their rank
- Contemporary research has shown this also is true between frequency of developed clusters and size

$$N(A) \approx A^{-r}$$

- Universally r≈2, A is the size of a cluster, N(A) is the frequency of that size

Clark's Law

- Clark (51) showed that as the radius of a circle around a city increases the density of development decreases exponentially

$$y \approx Ae^{-bx}$$

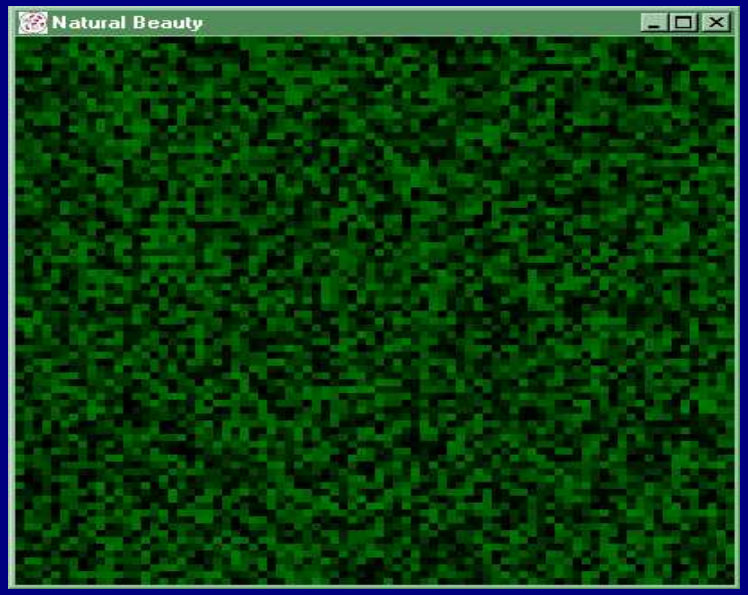
- y is the density, x is miles from city center, b and A are constants
- The constants vary for different areas and times,

Overview of SOME

(Sluce's Original Model for Exploration)

- Three Main Components
  - Environment
  - Agents
  - Agent Interaction
- Modular Structure
- Landscapes are archetypal and GIS-based
- Implemented in Swarm

Environment



- Lattice (Variable; 301x301)
- Initial Distribution of Service Centers (1)
- Standard Characteristics (5-10 underlying maps)
  - Natural Beauty (exogenous; normal distribution from [0,1]; spatially autocorrelated)
  - Distance to Service Centers, nearest 8 service centers are used (endogenous)
  - And others...
- Many Output Variables (30-50 outputs per step)
  - Clustering Statistics
  - Radius vs. Density Statistics
  - And many more....

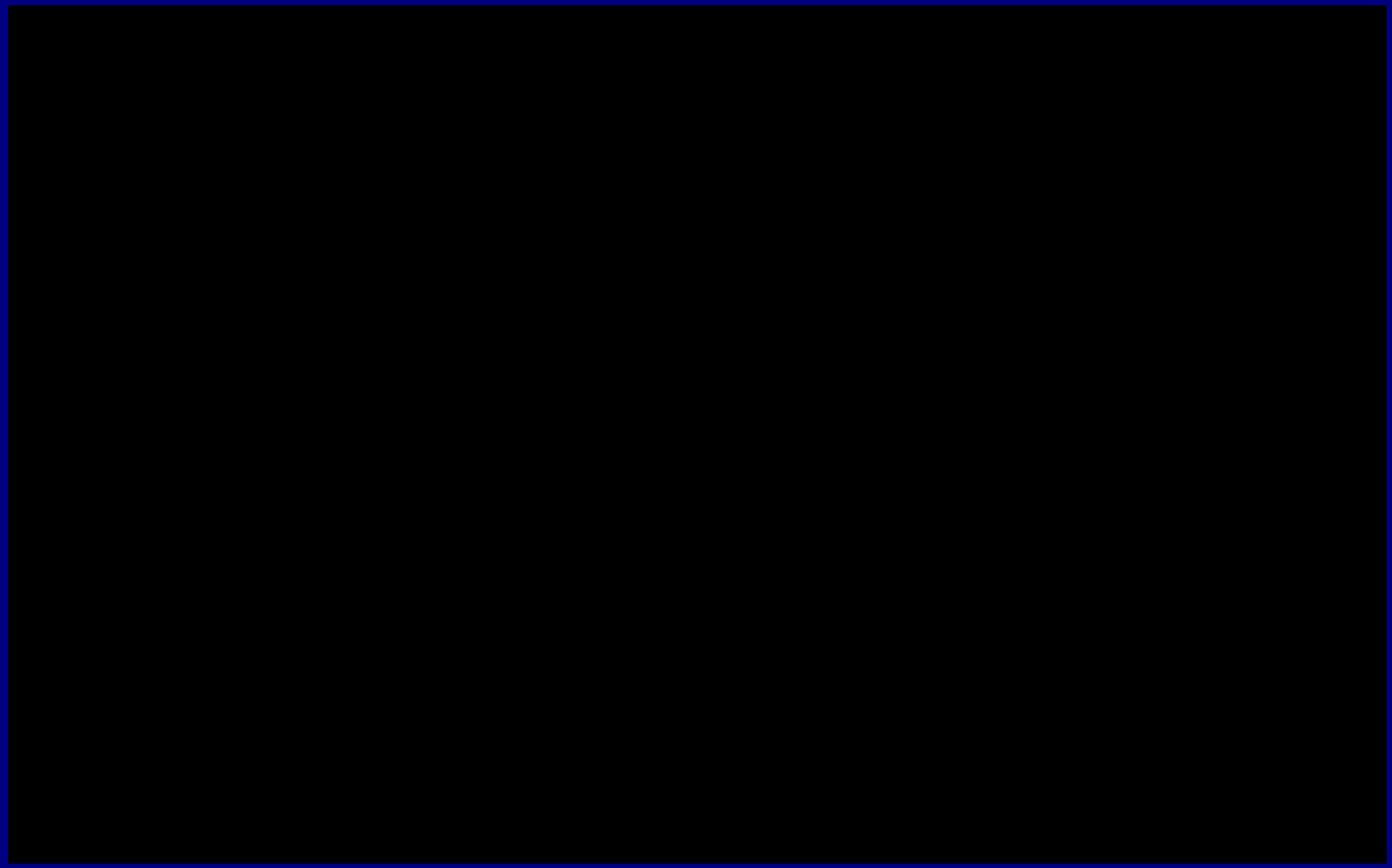
Agents

- Residents
  - Several Preferences (Ideal and Weight)
    - Natural Beauty (0.5)
    - Distance to Service Centers (0.5)
  - Multiplicative utility model
- Service Centers
  - Follow Last Resident in
  - Every 100 Residents, 1 Service Center enters

Agent Interaction

- Residents enter every time step (10)
- Look at random locations (10)
- Choose the location with the highest utility for their preferences
- Corresponding endogenous variables are updated

Valid Results: Zipf's Law



r of 2.067 is within the bounds found in empirical data

Valid Results: Clark's Law

Empirical data shows b to vary quite a bit,
but is usually much larger than .0069

Results of Validation

- Model matches closely with empirical Zipf's Law data
  - Our results through are only over a few decades
- Model matches Clark's Law relationally
  - However slope is different than empirical models
- Further validation is warranted

Future Work

- Validation on a Real Landscape
  - Scio Township and Washtenaw County
  - Satellite Data from 1978, Parcel Data from 1950s
  - Examine Relationship between amount of Information and Predictability (Graceful Decay)
- Other Pattern Analysis Metrics
  - Variant versus Invariant Regions, Certainty of Development
  - Kappa Statistics and Information Gain
  - Cross-Correlation of Development

Any Questions?

sluce@umich.edu