Agent-based Modeling: An Overview of Applications and Statistical Aspects

Gelonia L Dent, PhD

Medgar Evers College, The City University of New York

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Outline

- Definition agent-based model
- Dynamic vs. Agent-based simulation
- Overview, Design components, Details
- Application

Definition of ABM

- Agent-based models use information about individuals (agents), their environment and interactions to track behavior
- 'Process of constructing and executing a computer program in which actors are represented by segments' (Gilbert, 2007)
- Simulation models that describe individual organisms or more generally 'agents'; allow for the study of how system level properties emerge from the adaptive behavior of individuals (Railsback, 2001; Strand et al. 2002)

Comparison to Dynamic Models

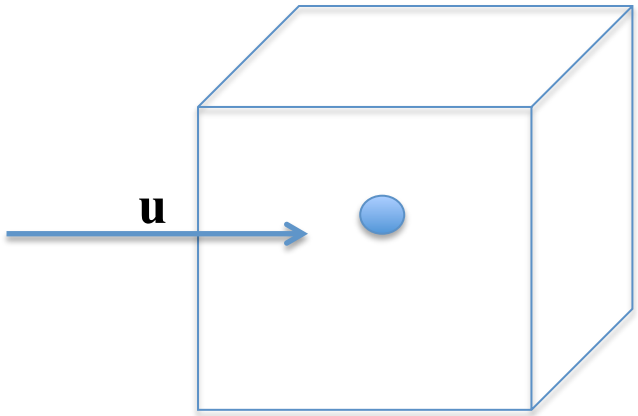
Dynamic

- Governing mathematical equations (ODE's, PDE's)
- System state is defined by initial and boundary conditions
- Choose (or design) an appropriate numerical algorithm
- Goal: ***to model or predict*** known experimental or empirical data

ABM

- Identify discrete entity known as an 'agent'
- Incorporate micro-data to describe behavior of agent
- Goal: ***to identify patterns of behaviors*** that effect the system's overall behavior

e.g. Force-coupling method (FCM)

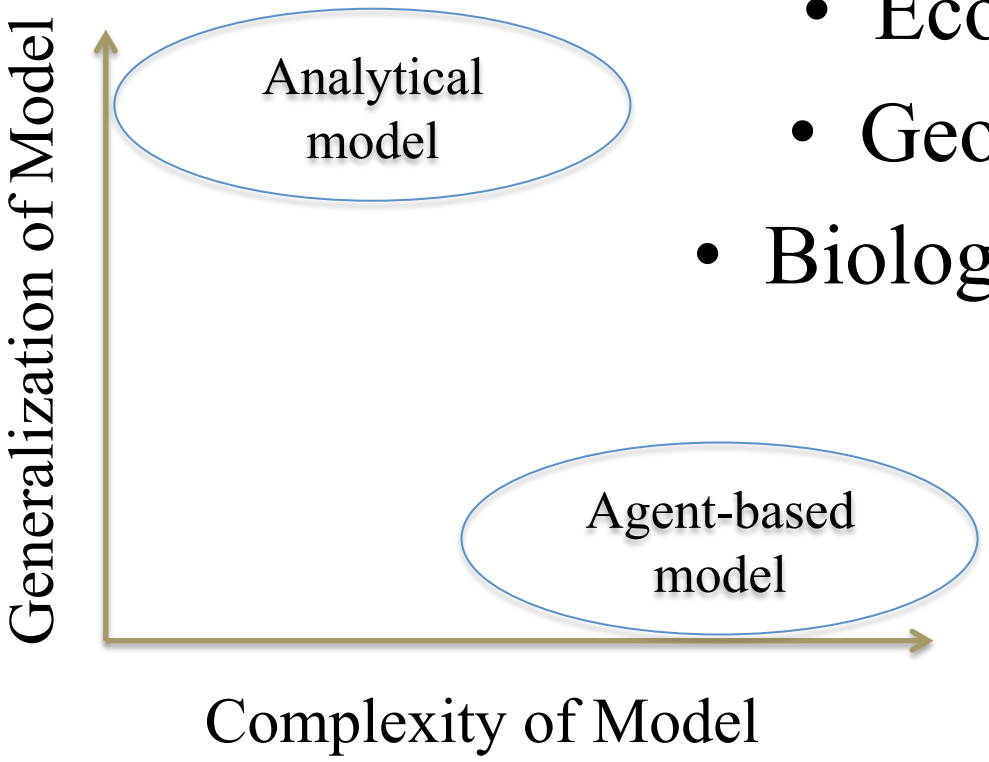


$$\rho \frac{D\mathbf{u}}{Dt} = -\nabla p + \mu \nabla^2 \mathbf{u} + \mathbf{f}(\mathbf{x}, t)$$

$$\nabla \cdot \mathbf{u} = 0$$

- Flow past particles or particles moving through a still fluid (sedimentation)
- Specify fluid parameters (density, pressure, viscosity), particle size
- *This analytical problem is formulated to be solved by numerical simulation*

When is ABM Appropriate?



- Economics and Finance
- Geography and Ecology
- Biology and Epidemiology

Fig. 1 Rand & Rust (2011)

Types of Models

- **Discrete-element (DEM)** – the particulate flow where the particles are identifiable discrete particles that interact due to the force of the fluid

- **Individual-based (IBM)** – used to model the interactions between many individuals (of varying type)

- **Agent-based** (ABM) – used to model individuals who also have the ability to make decisions

ABM: Overview, Design, Details

- A standard protocol of developing ABM models should include:
  - A general structure for describing ABMSs making the model *independent* of its specific structure, purpose and form of implementation (Grimm, 2002)
  - Language of mathematics, i.e. separate verbal descriptions from mathematical equations rules and schedules.

(ODD) Overview of Model, Design concepts, Details

ABM: Overview & Design

- Overview of Model
  - Purpose
  - State Variables and Scales
    - Identify low-level variables, elementary properties of model entities
    - High-level variables
    - Time scales
  - Process overview and scheduling

Concise information about the purpose of the model

Ecological Process Representations

- Static representation – not spatially dependent, changes over longer timescale than the temporal model

- Dynamic representation- one of the following applies
  - *Transition rules* – changes in ordinal or nominal reversible manner, reversible, explanatory variables unavailable
  - *Regression*-generate empirical estimates
  - *Individual-based*- depends upon population dynamics, response to environment, long time scale
  - *Equilibrium-based*- long term effects dominate

Luus et al. 2011

Design & Details

- Design concepts
  - Communication framework
- Details
  - Initialization
  - Input
  - Sub-models

Determine types of agents, agent objectives & agent interactions

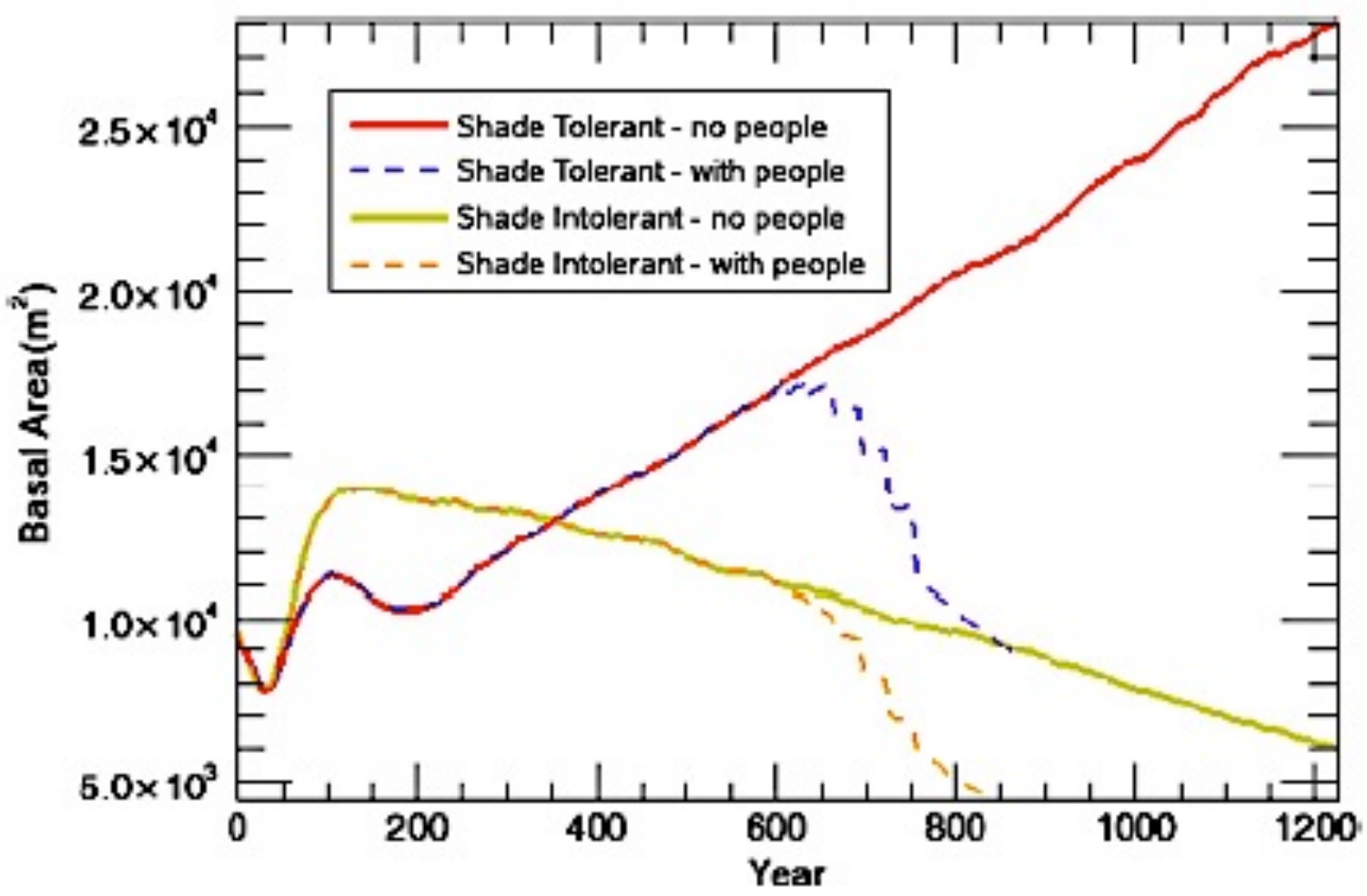
Initial conditions
External inputs

Description of parameters, governing equations, algorithms

e.g. Forest Model ODD

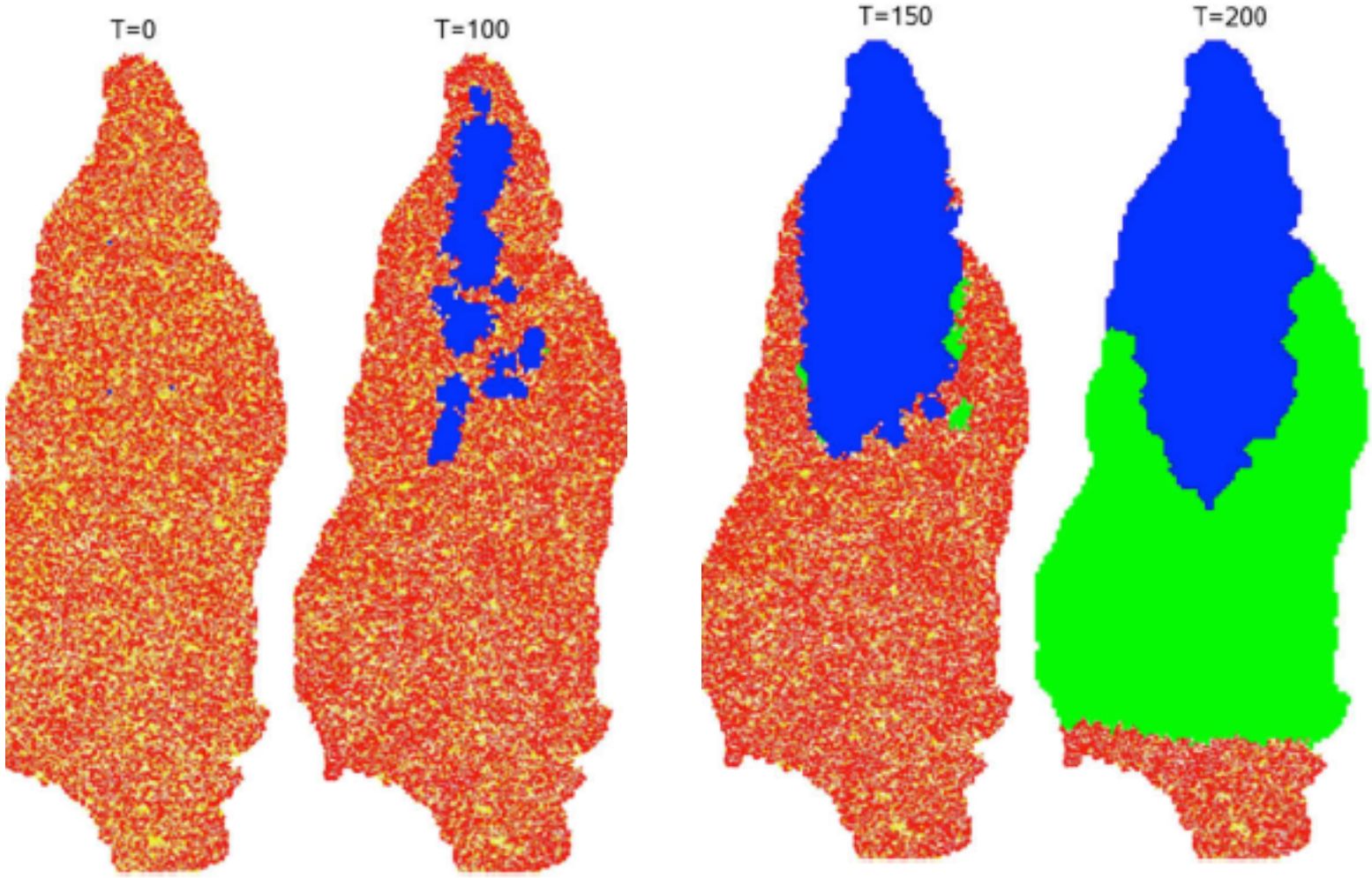
- Purpose – understand the interaction between farmers, trees and hydrology (Bithell, 2009)
- Design Components
  - IBM – represent 2 types of trees (shade tolerant, shade intolerant)
  - ABM- represent the human population
- Details
  - Sub-model is dynamic hydrological model is grid-based
  - Mixed Mode Coupling
    - Trees and people share same spatial scale
    - ABM provides information to hydrology model about land-use changes – *one-way coupling*

Time Evolution of Shade Trees- Tolerant and Intolerant



M. Bithell *et al.* 2008

Progression of land cultivation: tree canopy (red filled), rice (blue) and maize (green)



Bithell, 2009

Coupling

- *Compatibility*- need to establish feedback between models at the correct temporal scales
- *Directional coupling*- output of one sub-model is the input of another; should produce feedback, but this is often not the case
- Computational costs increase due to re-organization of model components, changes in grid size, etc.

Validation

- ABMs at present are insufficient in this area due to the lack of protocol in model development
- No uniform consistency in reporting input parameters (or how they may be manipulated)
- Comparison to real-world phenomena patterns are not always possible

Future models

1. Parameterized to represent realistic agents and environments
2. Establish stability criteria for spatial and temporal scales
3. Establish benchmarks based on empirical, numerical and experimental data that are comparable in a meaningful way to real-world scenarios.

References

- Bithell, M., Brasington, J., Richards, K., *et al*.(2008) Discrete-element, individual-based and agent-based models: Tools for interdisciplinary enquiry in geology, Geoforum 39, 625-642
- Bithell, M. and Brasington, J. (2009). Coupling agent-based models of subsistence farming with individual-based forest models and dynamic models of water distribution. Environmental Modeling and Software 24, 173-190
- Dent, G., "Aspects of particle sedimentation in dilute flows at finite Reynolds numbers." Thesis Brown University 1999
- Grimm, V., *et al*., (2006) A standard protocol for describing individual-based and agent-based models, Journal of Ecological Modeling 198 115-126
- Luus, K.A., Robinson, D.T., Deadman, P.J., (2011). Representing ecological processes in agent-based models of land use and cover change. Journal of Land Use Science, DOI:10.1080/1747423X.2011.640357
- Rand, W., Rust, R.T., (2011) Agent-based modeling in marketing: Guidelines for Rigor, Intern J. of Research Marketing

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