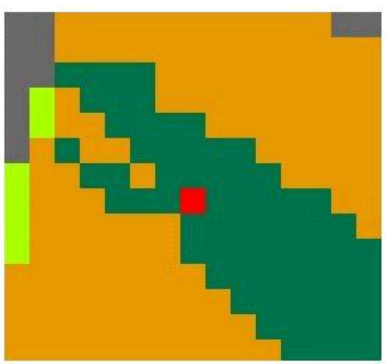
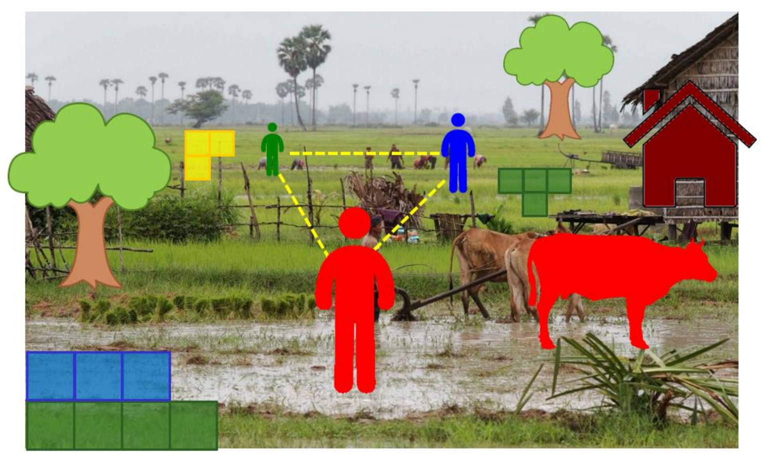
Modelling Landscape Dynamics with Cellular Automata and Agent-Based Models

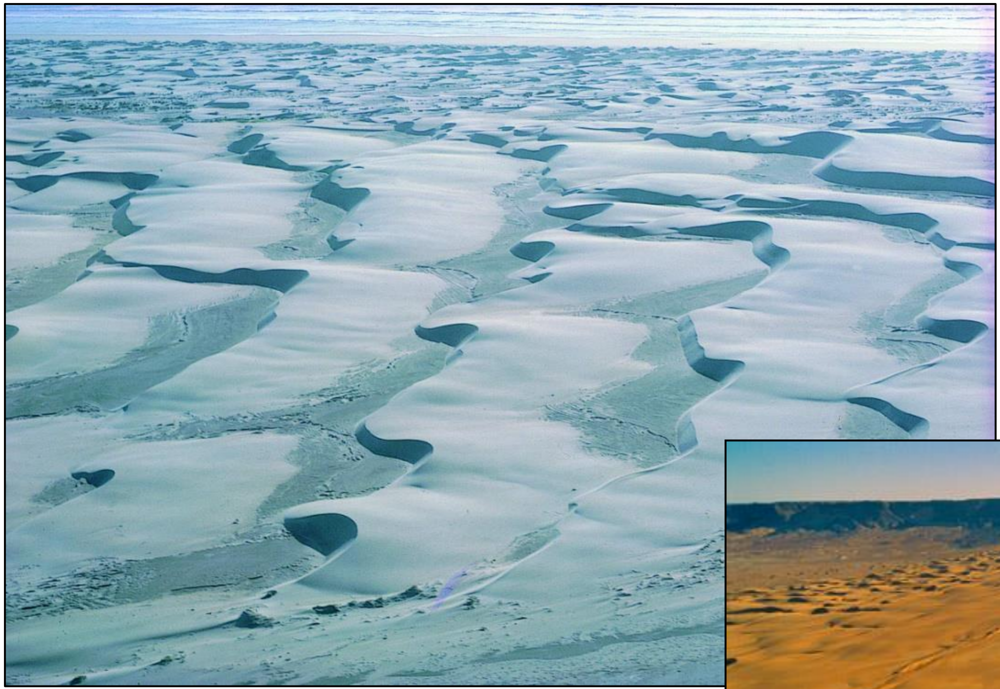
Dr. Andreas Baas & Dr. James Millington





Earth Surface Landscapes

Earth Surface Landscapes



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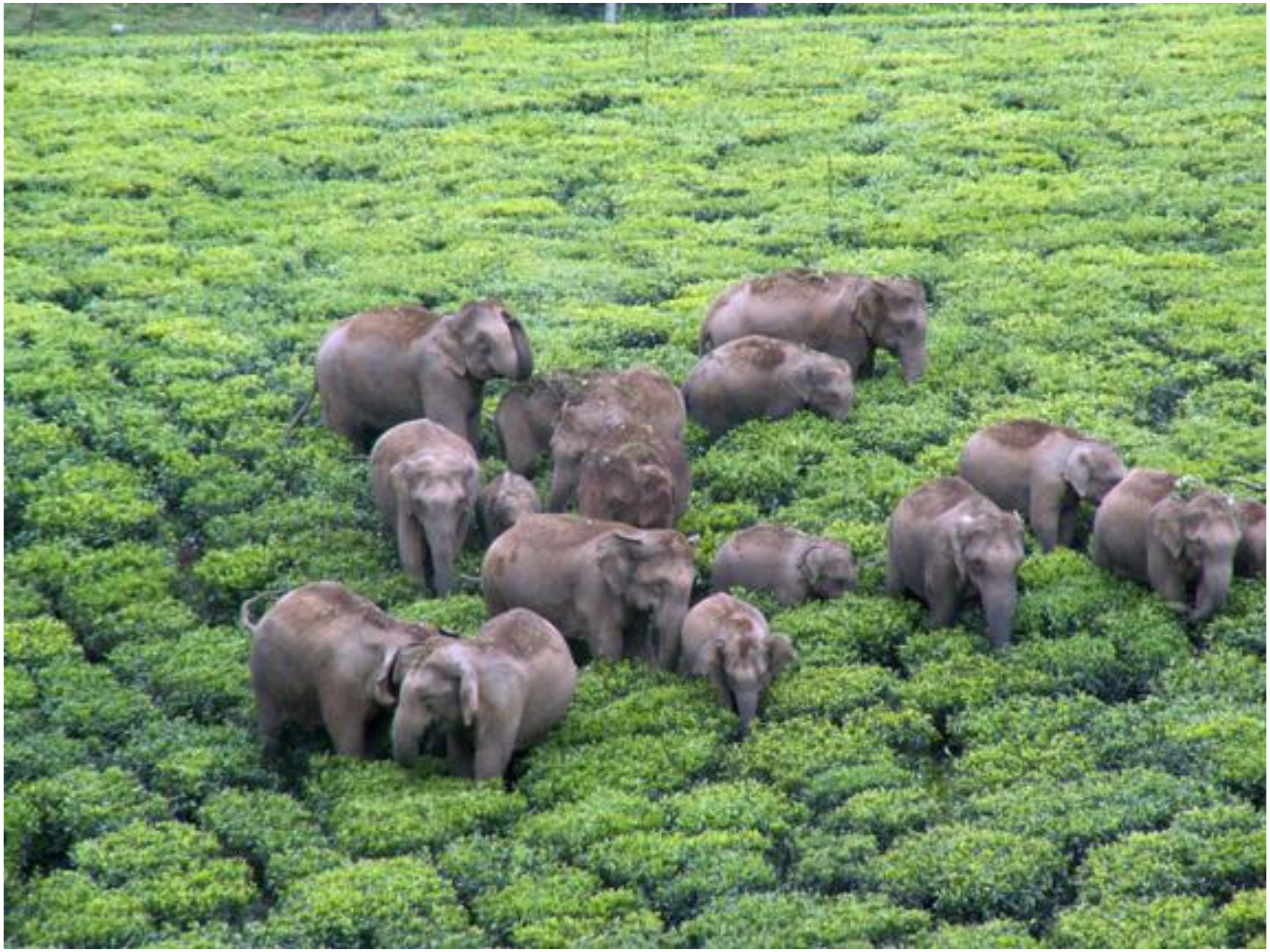


Modelling Context

Primary distinction:

i) conceptual models

ii) scale models or analogues

iii) quantitative models

iv) physically-based models

v) ‘Reduced complexity’ models

Conceptual Models

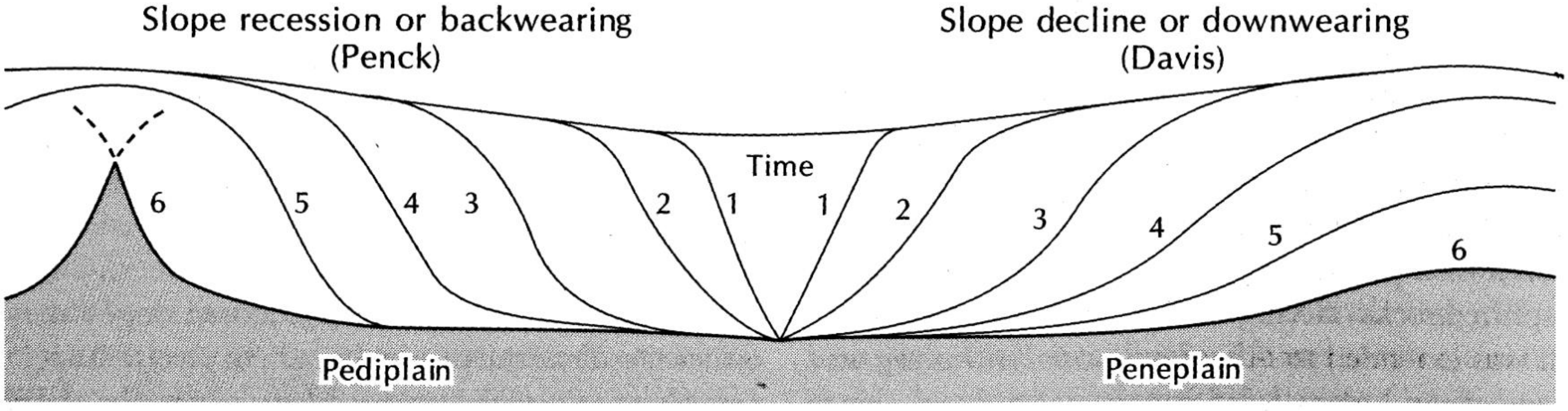


Figure 1.2 Slope recession, which produces a pediplain (p. 315) and slope decline, which produces a peneplain.
Source: Adapted from Gossman (1970)

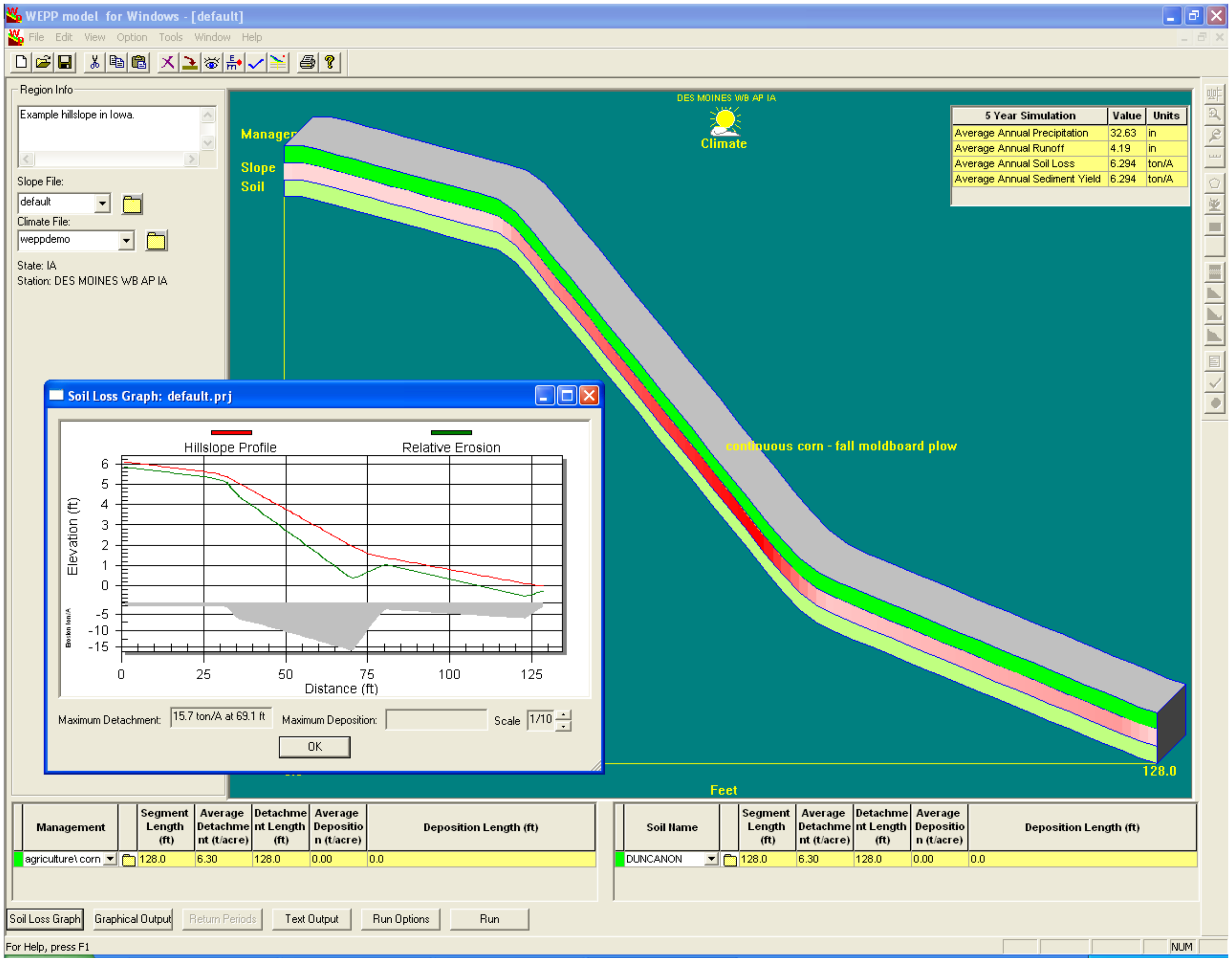
Scale Models

Quantitative Models

Manning equation (1890s):

$$\bar{u} = \frac{R^{2/3}\, S^{1/2}}{n}$$

Physically-Based Models



Physically-Based Models

Advantages:

- physical processes complete
- ‘real’ parameters

Disadvantages:

- computationally ‘expensive’
- many parameters and coefficients

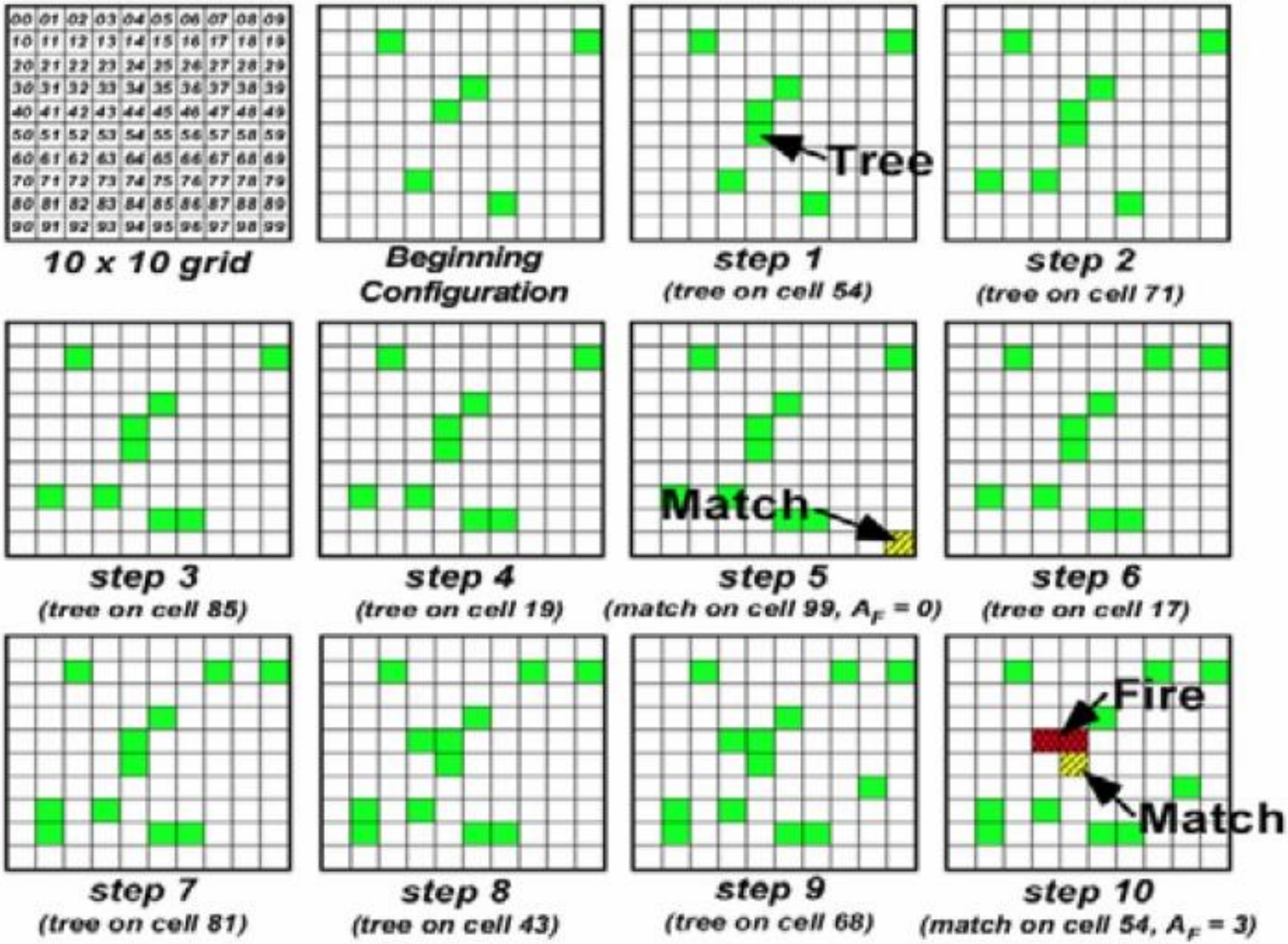
‘Bottom Up’ Simulation

- ***Discrete Element Models***
  - Geomorphology
  - e.g. gravel-bed rivers, avalanches, debris flows
- ***Individual-Based Models***
  - Ecology
  - e.g. foraging animals, forest growth/senescence
- ***Agent-Based Models***
  - Social Science
  - e.g. subsistence farming, urban populations

See Bithell *et al.* (2008) for review

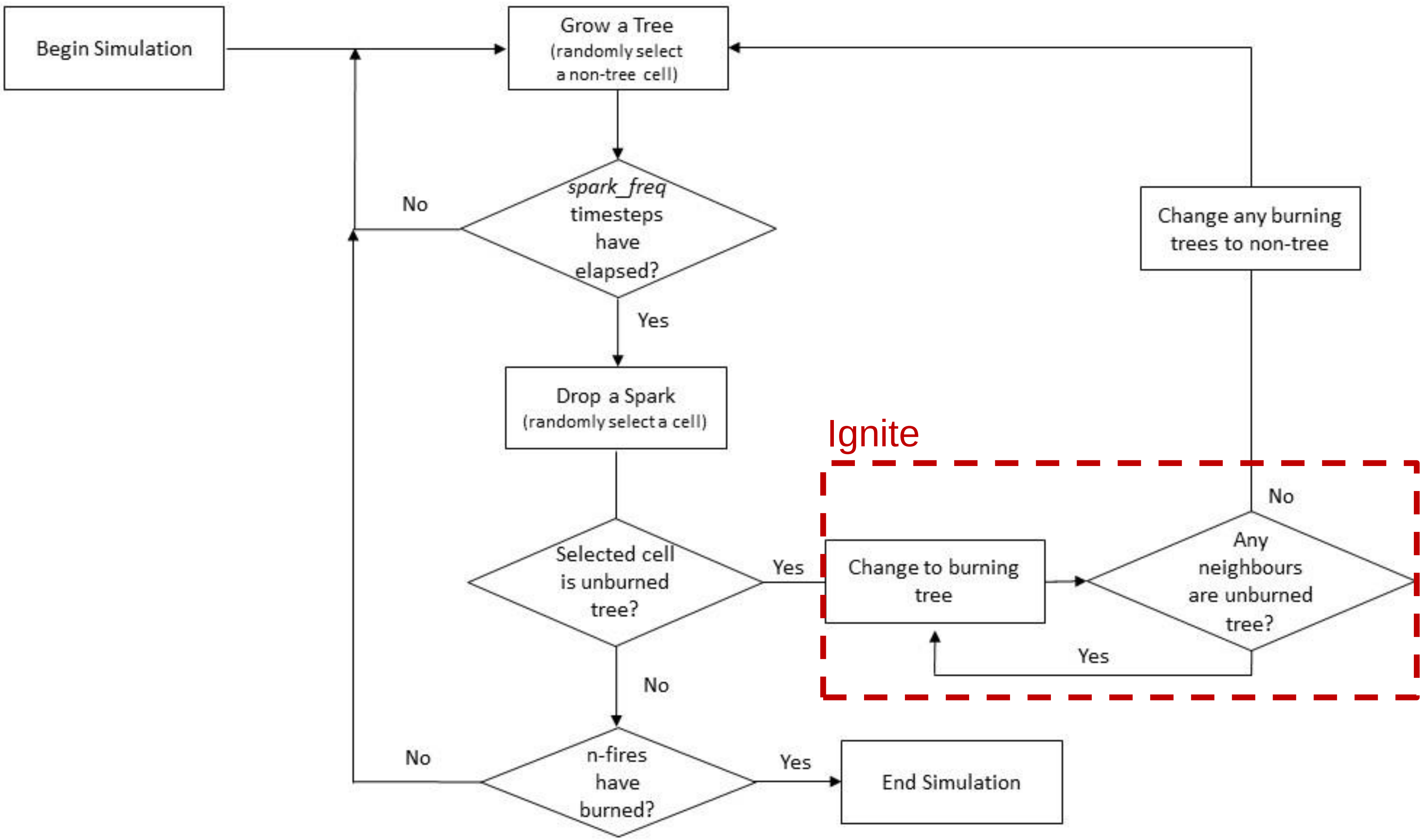
What is a Cellular Automaton?

Grids of cells (pixels) that change state dependent on rules about their neighbours



Millington *et al.* (2006)

FFCA flowchart



Power-Law Frequency-Area

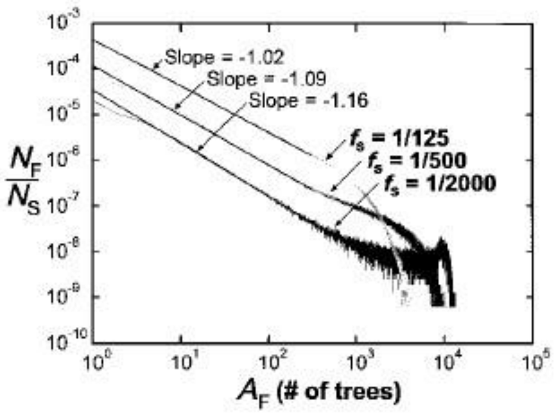


Fig. 1. Noncumulative frequency-area distributions of model forest fires for a grid size of 128 by 128 squares at three sparking frequencies. f_S = 1/125, 1/500, and 1/2000. The number of fires per time step (N_F/N_S) with area (A_F) is given as a function of A_F, the number of trees that were burned in each fire. For each sparking frequency, the model is run for $N_S = 1.638 \times 10^9$ time steps. The small and medium fires correlate well with the power-law relation (Eq. 1) with $\alpha = 1.02$ to 1.18; $-\alpha$ is the slope of the best-fit line in log-log space and is shown for each sparking frequency. The finite grid-size effect can be seen at the smallest sparking frequency, f_S = 1/2000. At about A_F = 2000, fires begin to span the entire grid.

Malamud *et al.* (1998)

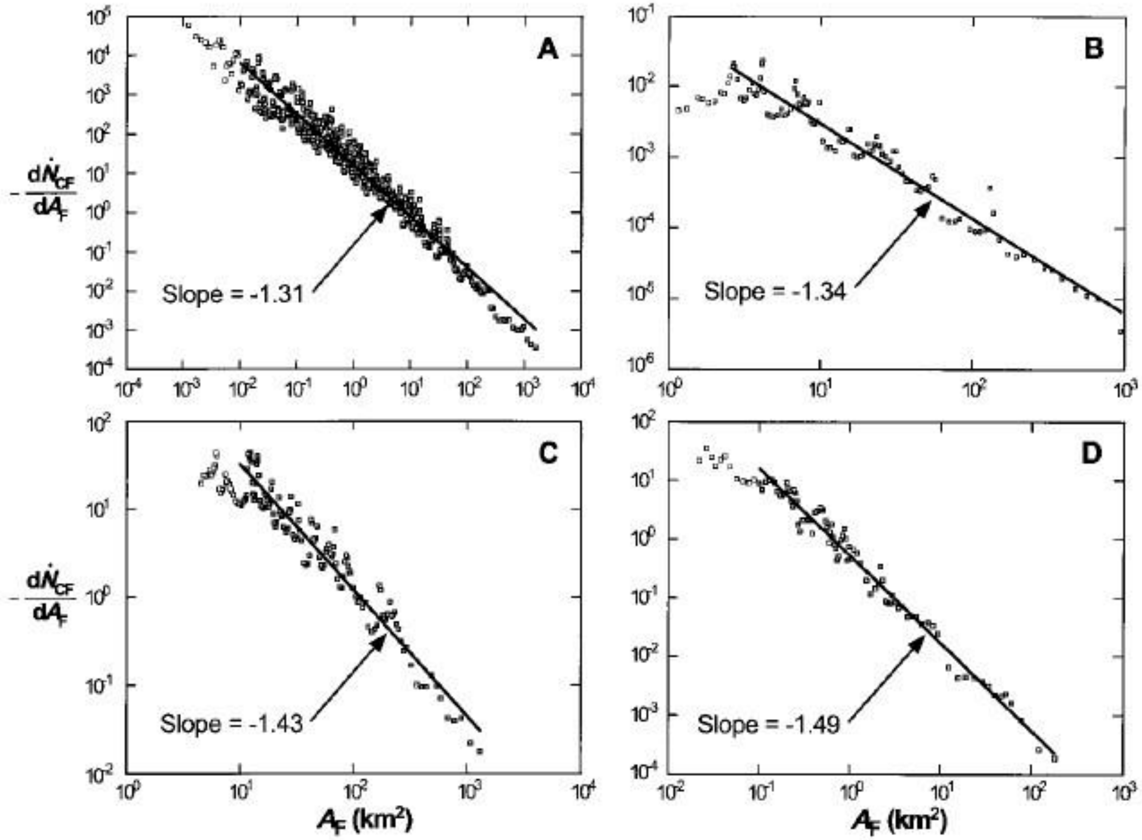
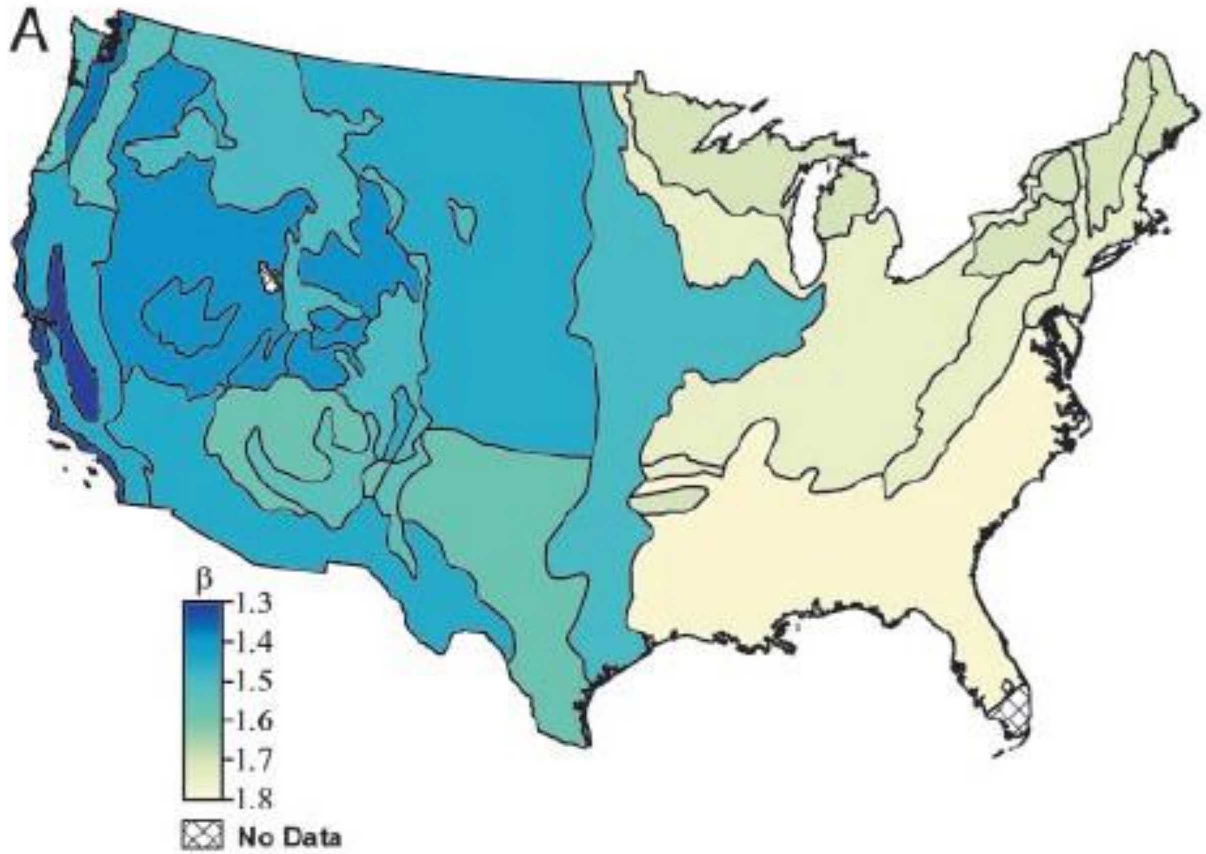


Fig. 2. Noncumulative frequency-area distributions for actual forest fires and wildfires in the United States and Australia: (**A**) 4284 fires on U.S. Fish and Wildlife Service lands (1986–1995) (9), (**B**) 120 fires in the western United States (1150–1960) (*10*), (**C**) 164 fires in Alaskan boreal forests (1990–1991) (*11*), and (**D**) 298 fires in the ACT (1926–1991) (*12*). For each data set, the noncumulative number of fires per year ($-d\dot{N}_{CF}/dA_F$) with area (A_F) is given as a function of A_F (*13*). In each case, a reasonably good correlation over many decades of A_F is obtained by using the power-law relation (Eq. 1) with α = 1.31 to 1.49; $-\alpha$ is the slope of the best-fit line in log-log space and is shown for each data set.

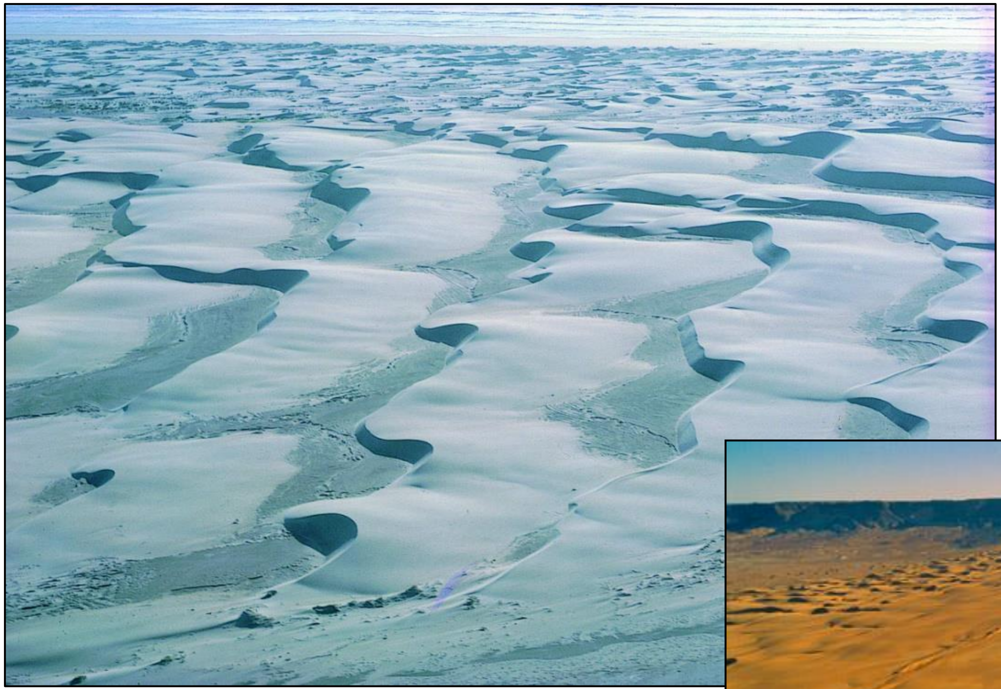
Spatial Patterns of Statistics

Variation in frequency-area distributions across USA



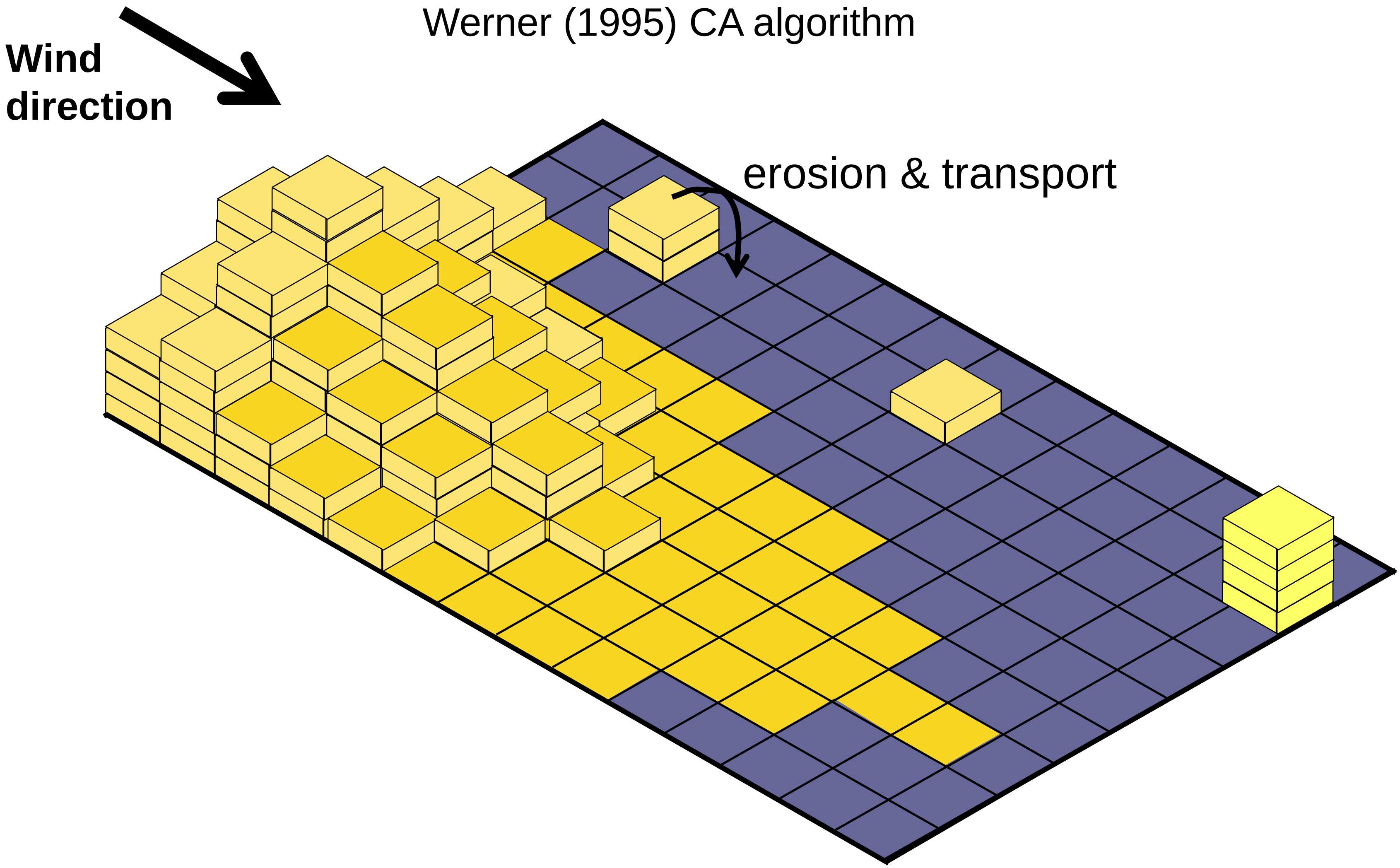
Malamud et al. (2005)

Earth Surface Landscapes

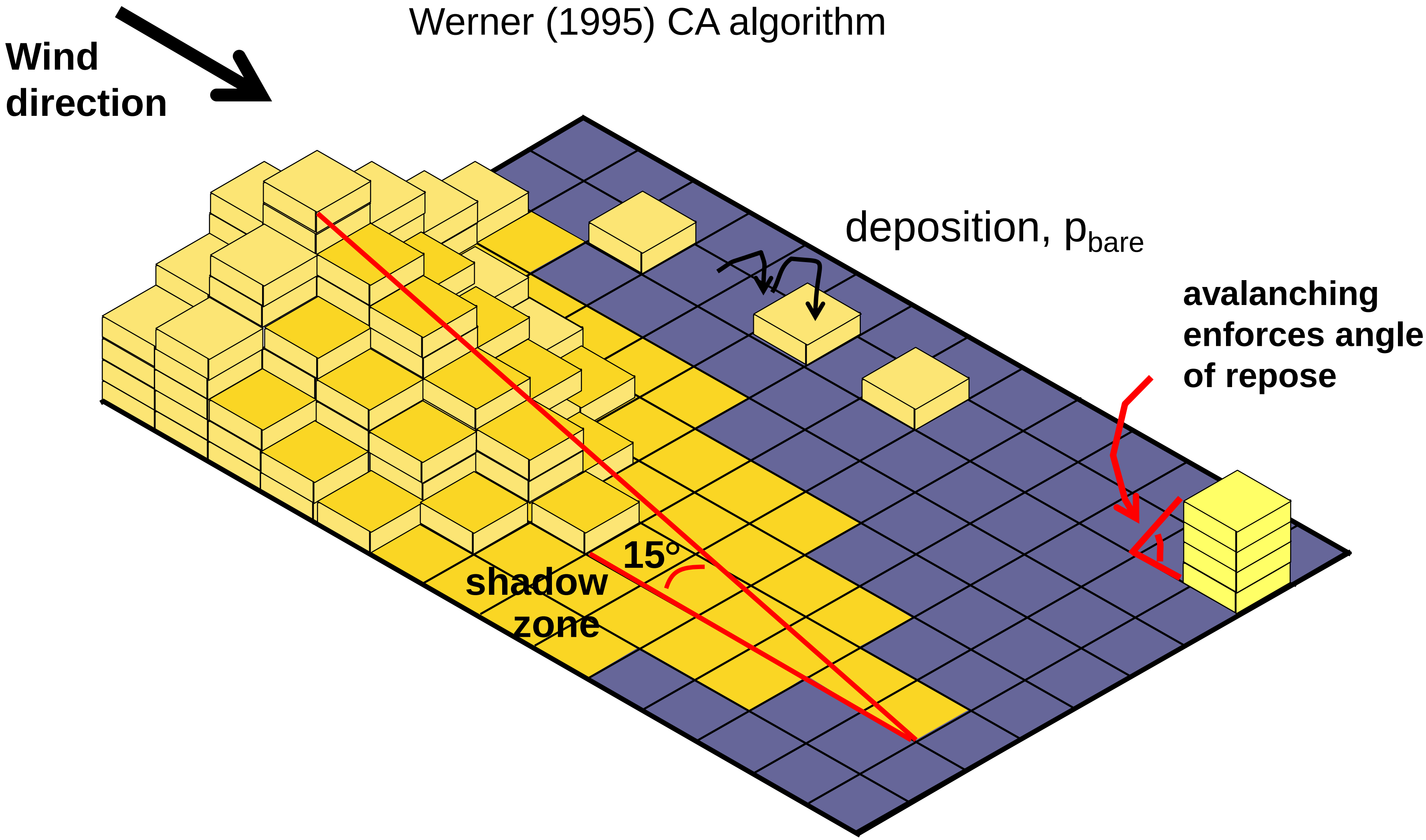


Dune 3-D Cellular Automaton

Werner (1995) CA algorithm



Dune 3-D Cellular Automaton



What is an Agent-Based Model?

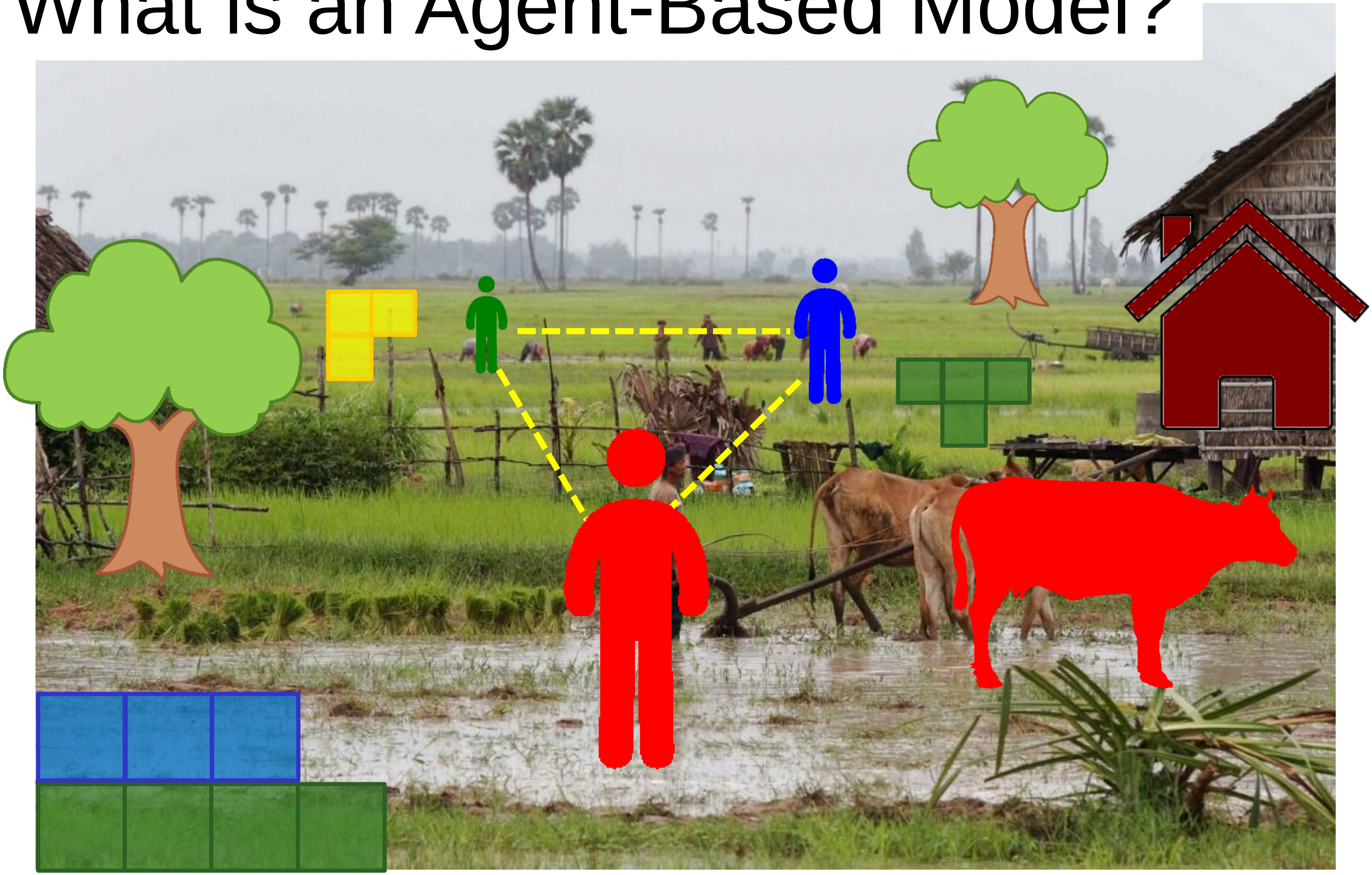
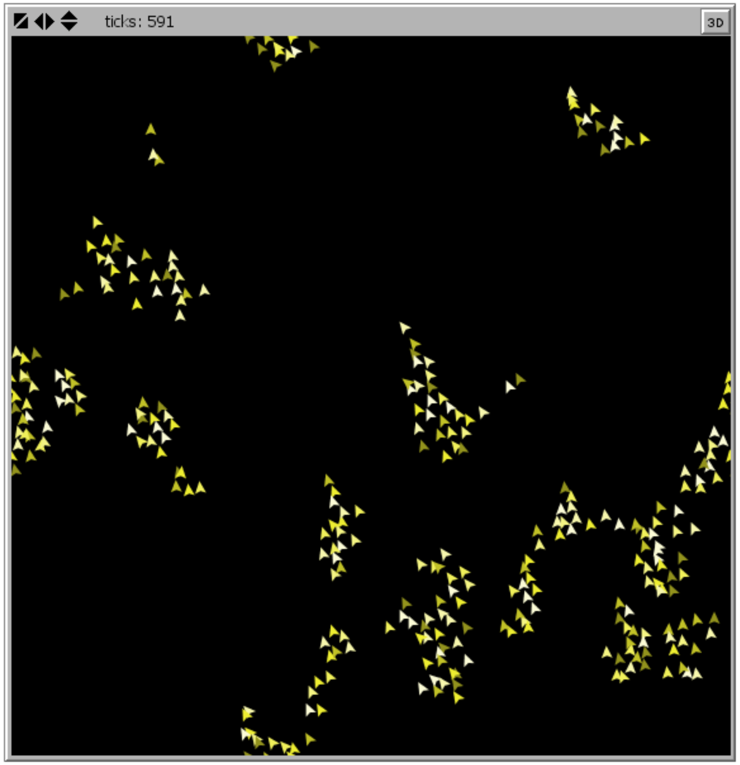


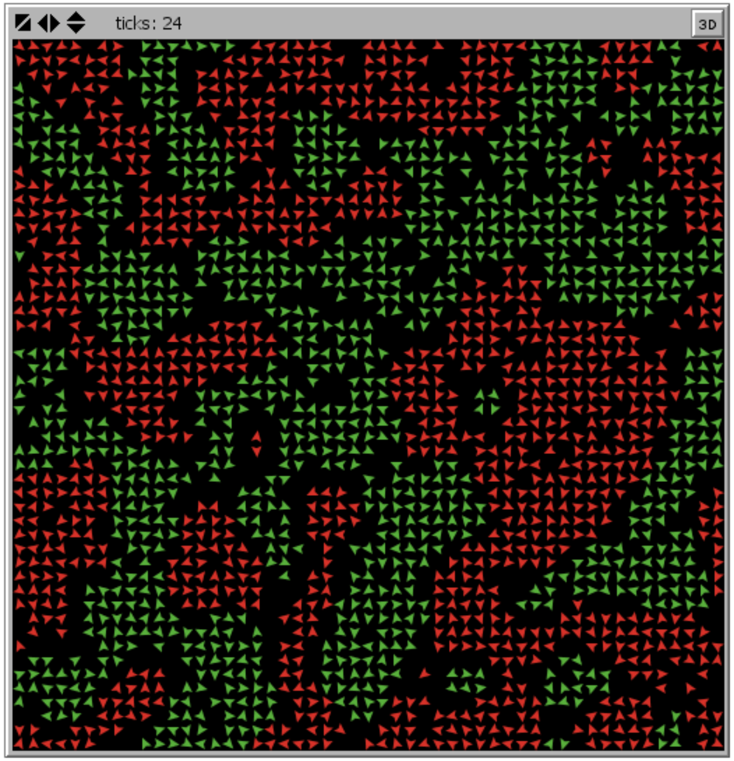
Image: Sophie et Fred, flickr

Roots in Complexity Theory

Flocking



Segregation



Agent-Based Models

Discrete, **heterogeneous** ‘agents’:

- Goals & Behaviours
- Attributes
- Interacting

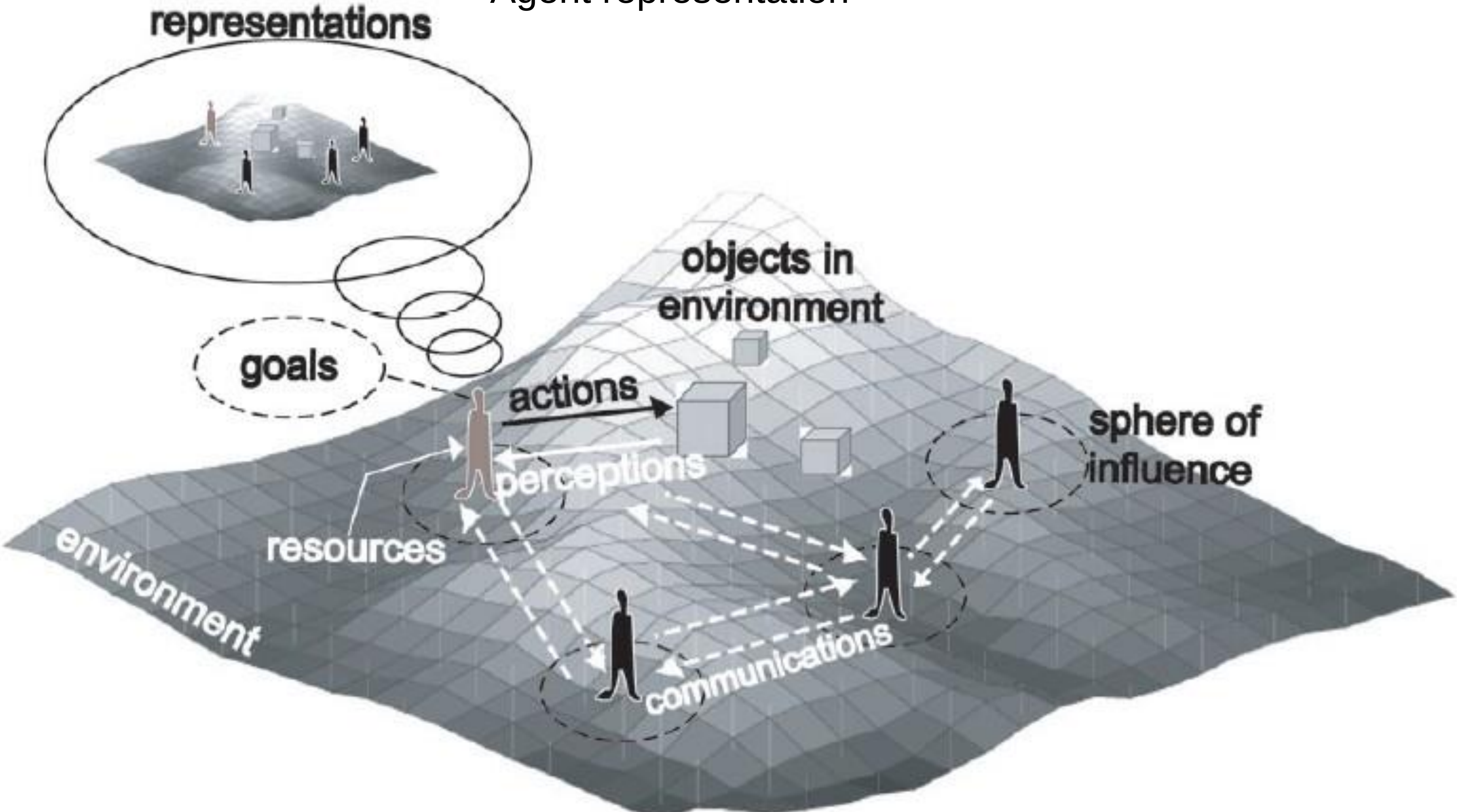
Useful when the system has ‘organised complexity’:

- iterative or hierarchical organisation of actors

- middle-numbered – not many many, not very few

Agent-Based Models

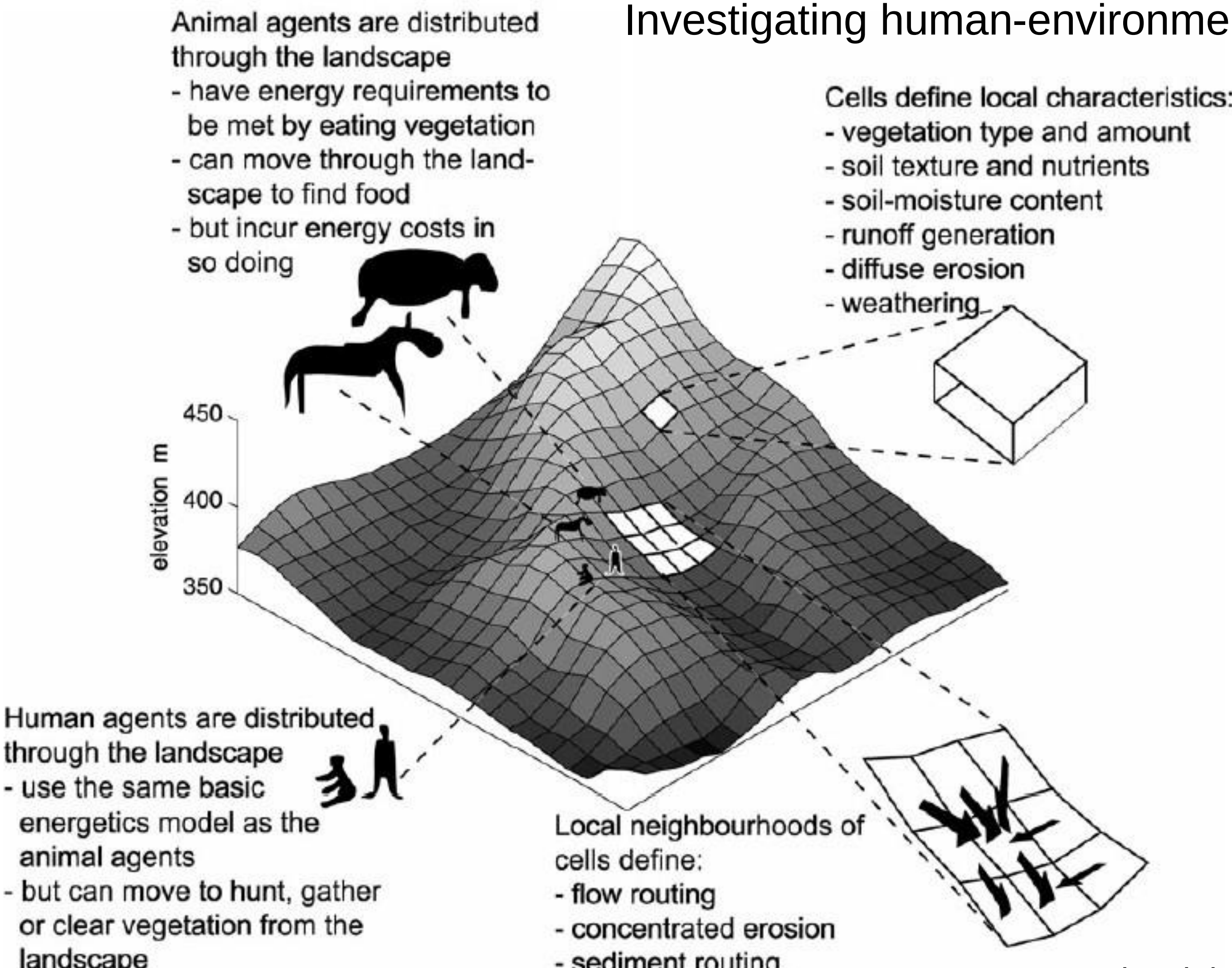
Agent representation



Wainwright and Millington (2010) *ESPL*

Agent-Based Models

Investigating human-environment interactions



Wainwright (2008) *Geoforum*

Good Modelling Practices

Nine Good Practices (Malamud and Baas, 2012):

Model construction:
1) select appropriate model type/strategy
2) parsimony ('Occam's Razor')
3) dimensional analysis
4) benchmark testing

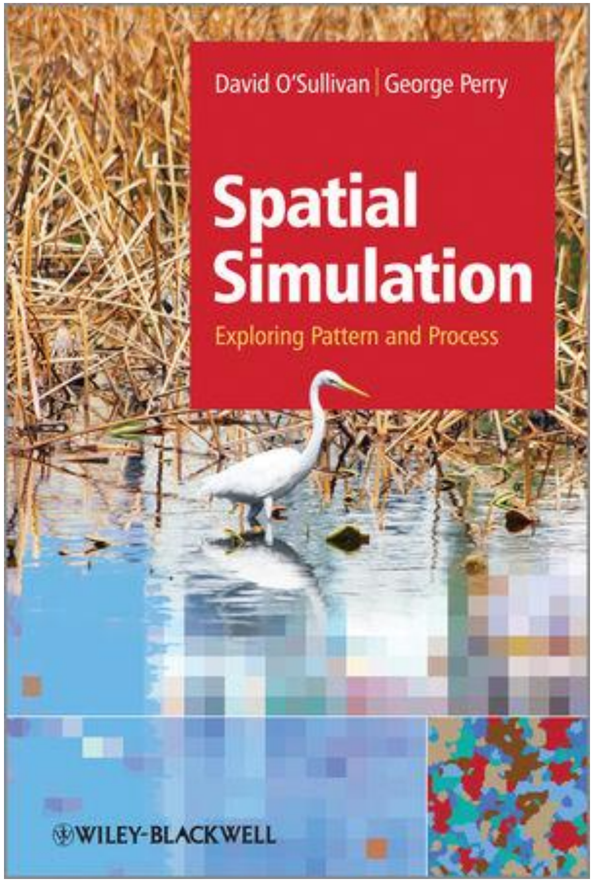
Model running:
5) sensitivity analysis
6) calibration
7) data exploration
8) uncertainty assessment
9) consider alternatives

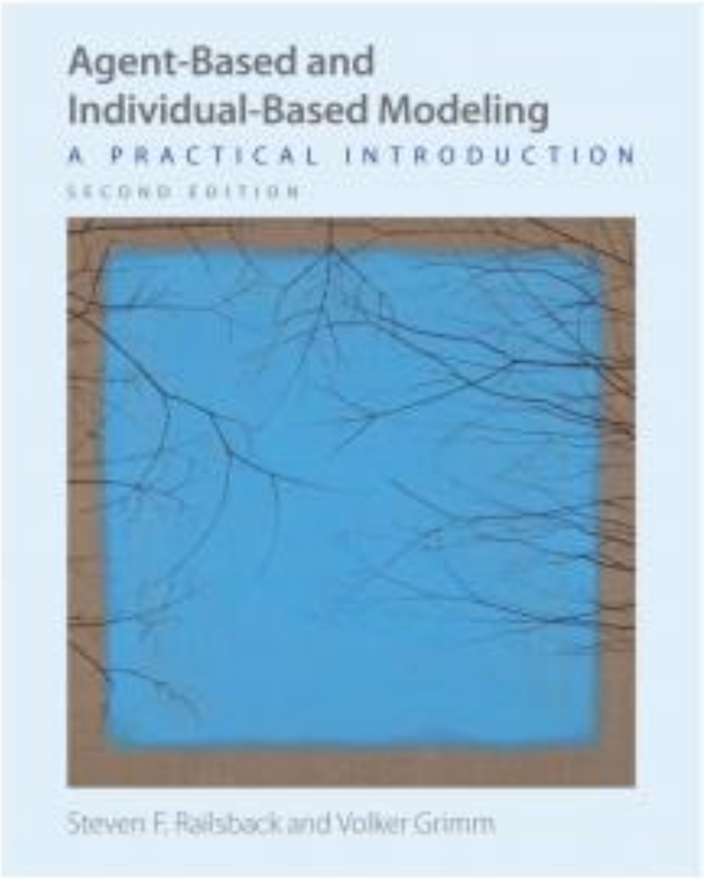
Each of these steps can lead to new insights!

Modelling Thoughts

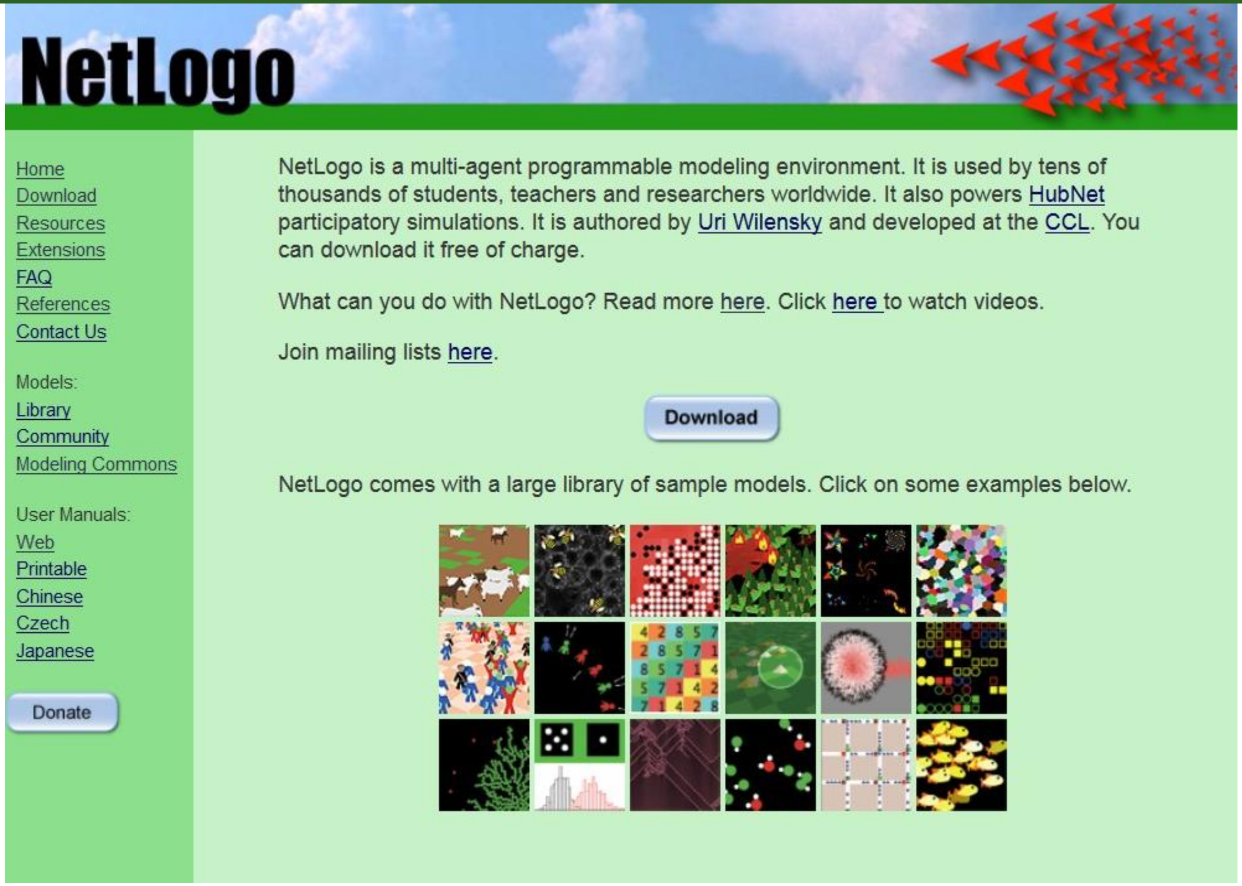
- Parameters and algorithm details need to be investigated thoroughly,
- These inquiries can lead to fundamental questions and insights,
- Many interesting science and application questions arise <u>during</u> model development,
- The journey is often more fruitful than the destination!

Resources


David O'Sullivan | George Perry
Spatial Simulation
Exploring Pattern and Process
WILEY-BLACKWELL


Agent-Based and Individual-Based Modeling
A PRACTICAL INTRODUCTION
SECOND EDITION
Steven F. Railsback and Volker Grimm

http://ccl.northwestern.edu/netlogo/



Download *NetLogo* yourself for free and try it at home. There's lot's of other resources online to help you get your own models going…

Landscapes ‘Tutorial’

https://bit.ly/CA-ABM-20

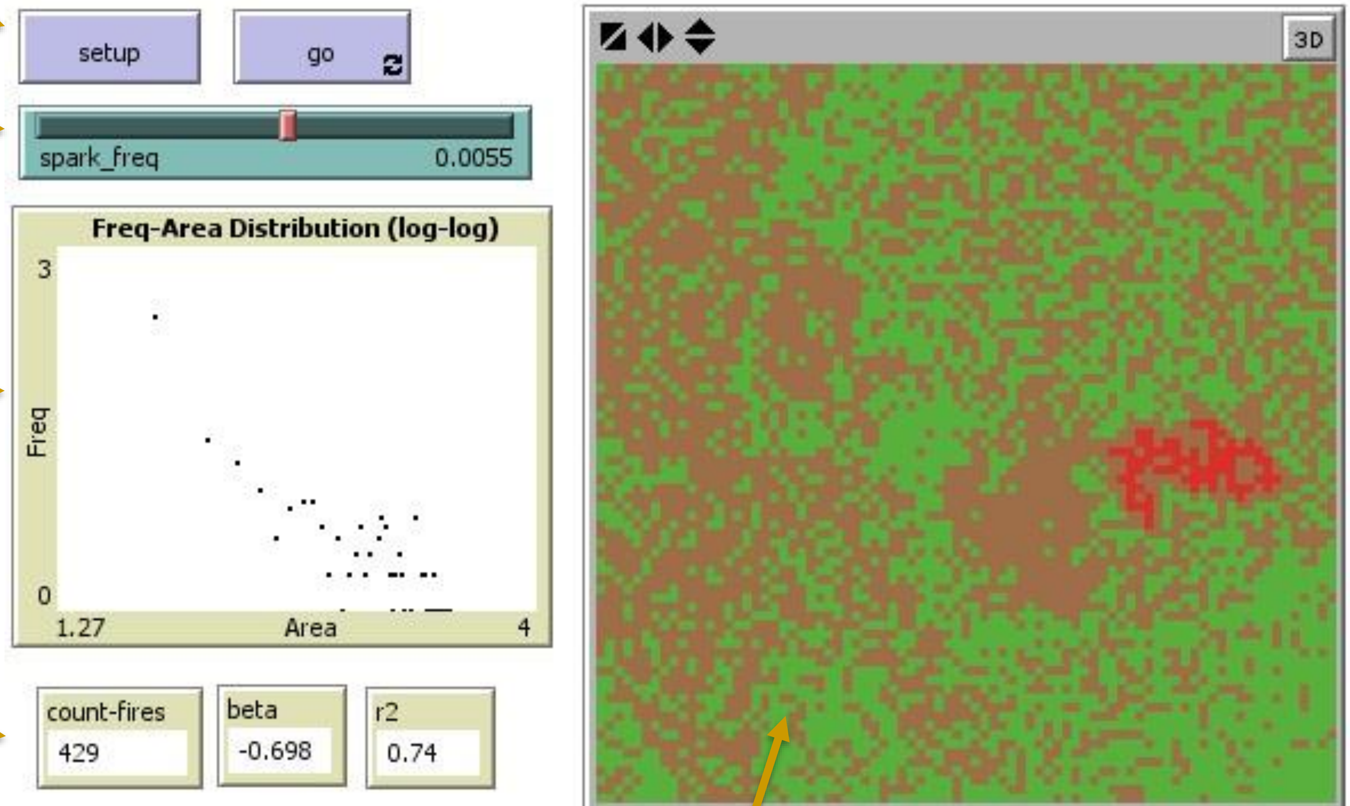
Forest Fire Cellular Automata

Buttons

Parameter
('slider')

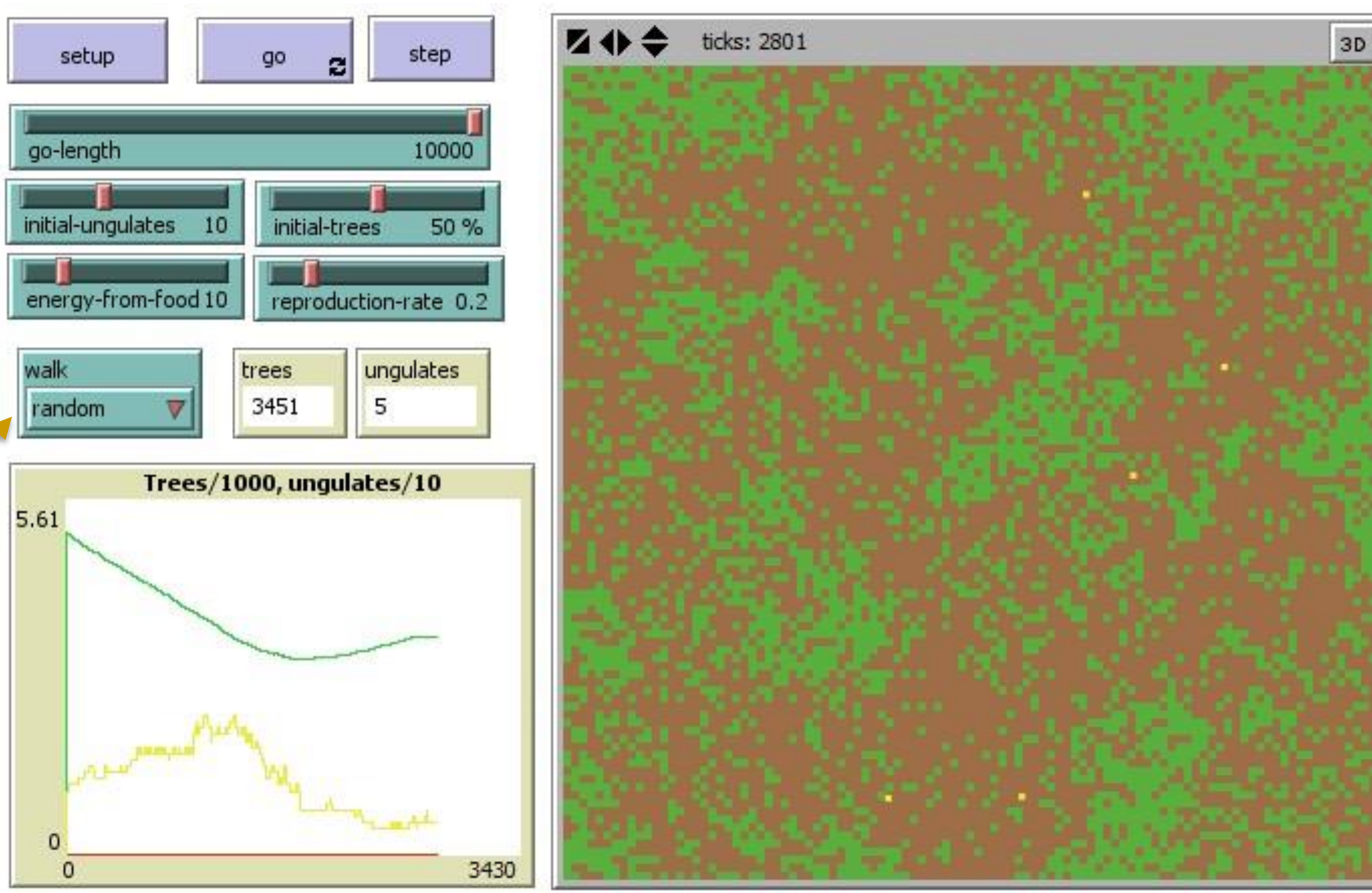
Plot

Monitors



Model 'Environment'

Walking Agents (Ungulates)



Chooser

Ungulate Browsing Model

- *Random Walk*: A fundamental stochastic model used to investigate movements of individuals through space and time
- Can be truly random, correlated or directed.

- *Directed:* ungulates turn to face any vegetation in Moore neighbourhood, otherwise they turn to a random direction.
- In both cases, after turning ungulates move forward a distance of one patch.

Ungulate Browsing Model

- Each time they move ungulates use up (subtract) one unit of energy.

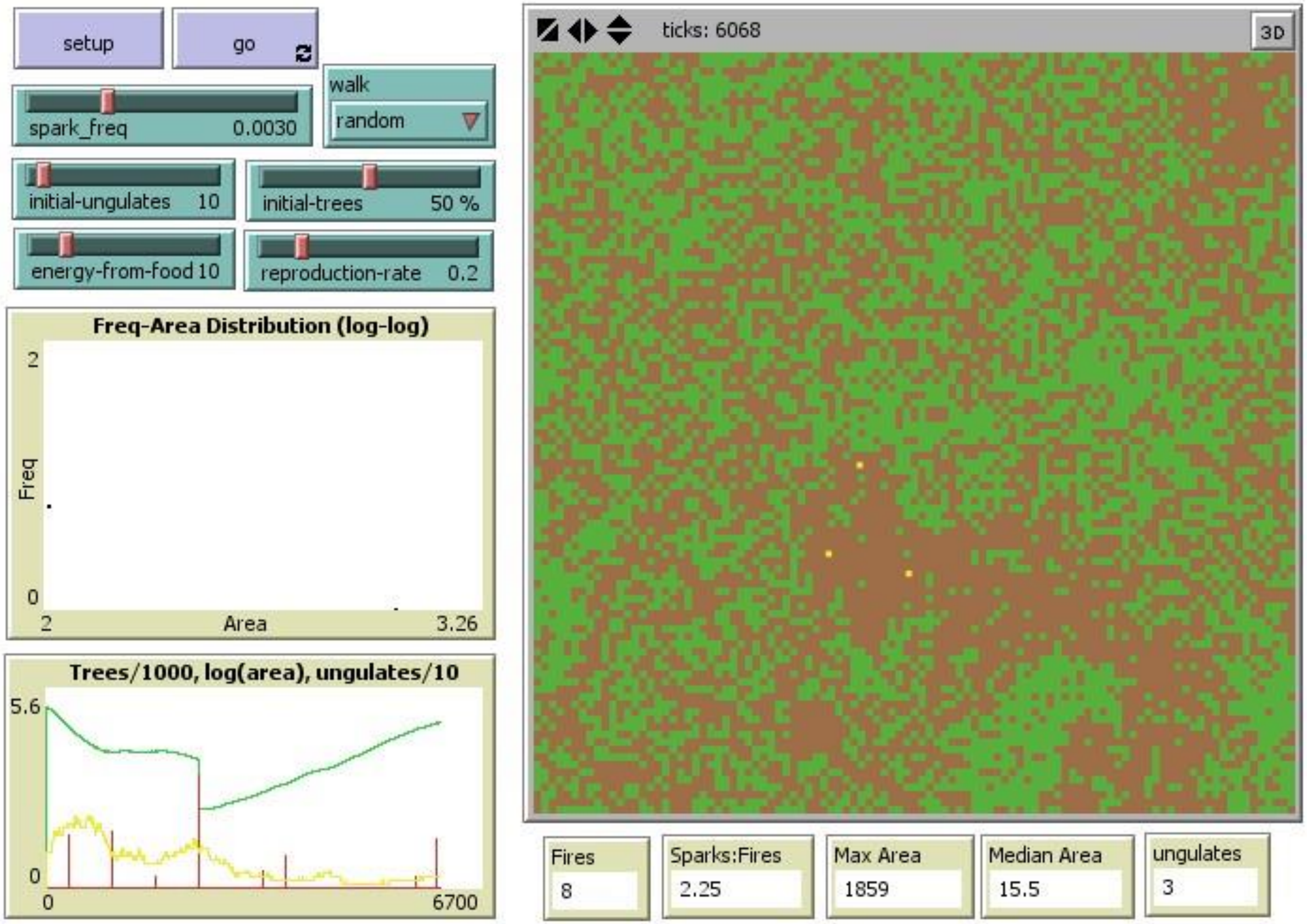
- After moving, if vegetation is present in the patch the ungulate is at, the ungulate eats the vegetation, removing it from the landscape and gaining an amount of energy specified by energy-from-food.

Ungulate Browsing Model

- First, play with the model to understand properly how each type of walk operates:
  - How ‘efficient’ are the two different walking strategies?

- Second, examine system dynamics more systematically
  - Run for ‘directed’ and ‘random’ walking
  - Run each for 5, 10, 15 *energy-from-food*
  - Create a spreadsheet for results: mean trees, mean ungulates and others

Combining Models



Contagion and Memory