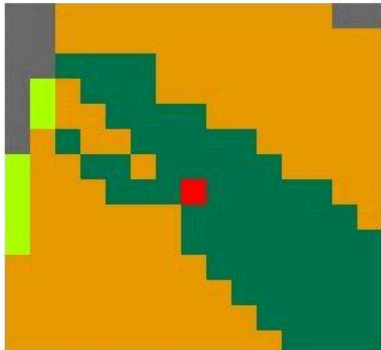


Modelling Landscape Dynamics with Cellular Automata and Agent-Based Models

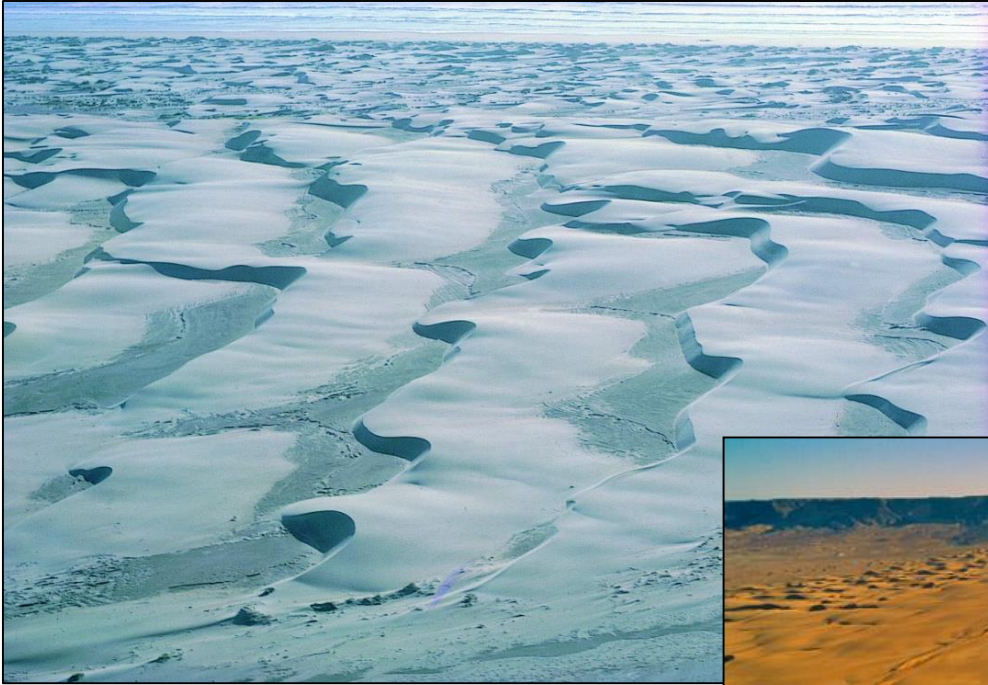
Dr. Andreas Baas & Dr. James Millington



Earth Surface Landscapes



Earth Surface Landscapes



Earth Surface Landscapes



Earth Surface Landscapes



Earth Surface Landscapes



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

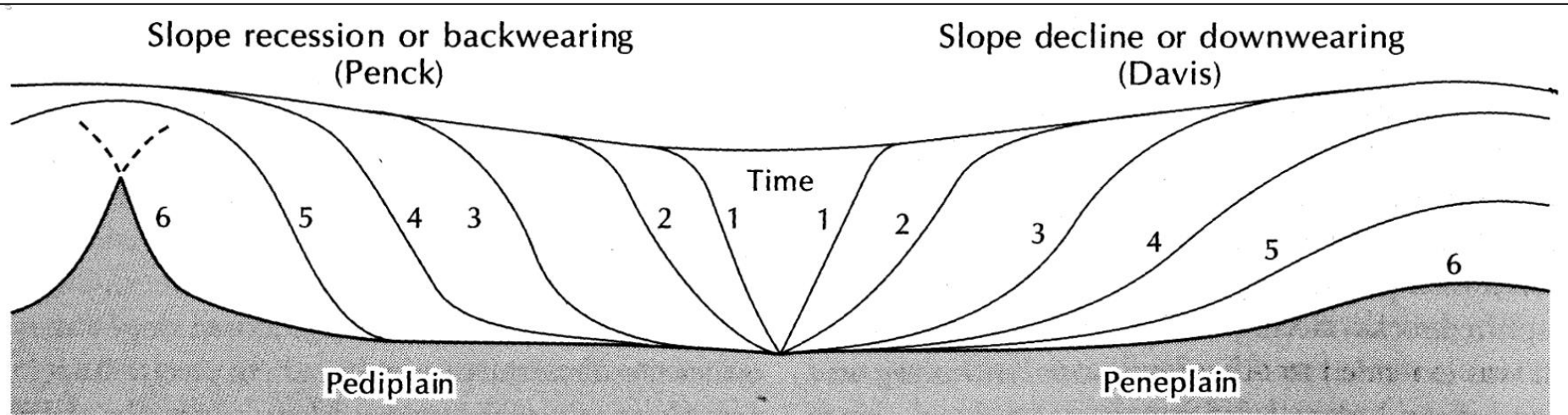


Figure 1.2 Slope recession, which produces a pediplain (p. 315) and slope decline, which produces a peneplain.

Source: Adapted from Gossman (1970)

Scale Models

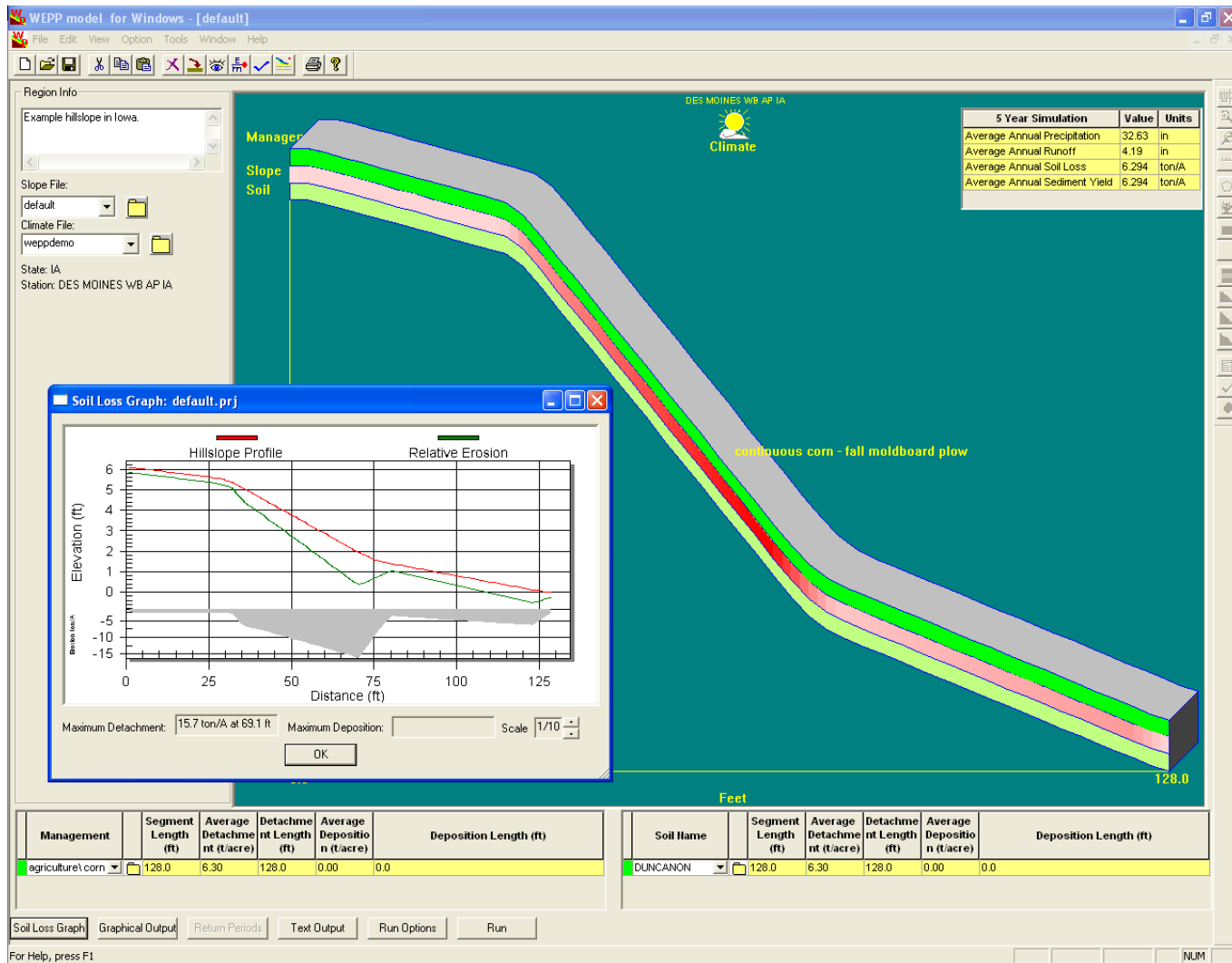


Quantitative Models

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***

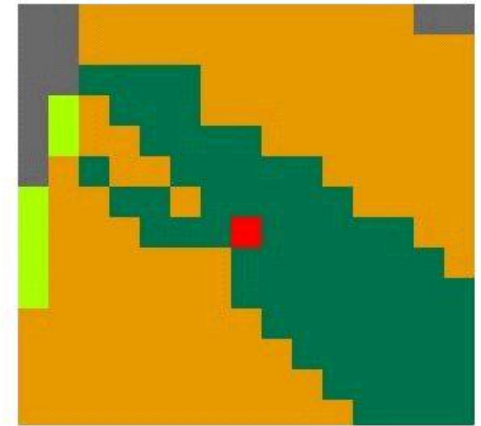
- Ecology
- e.g. foraging animals, forest growth/senescence

■ ***Agent-Based Models***

- Social Science
- e.g. subsistence farming, urban populations

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

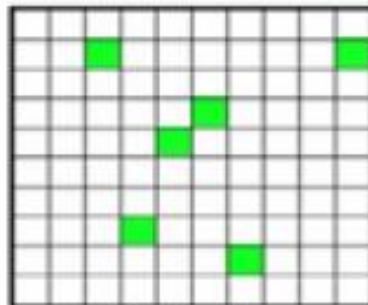
What is a Cellular Automaton?



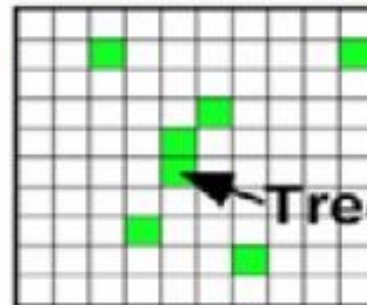
Grids of cells (pixels) that change state dependent on rules about their neighbours

00	01	02	03	04	05	06	07	08	09
10	11	12	13	14	15	16	17	18	19
20	21	22	23	24	25	26	27	28	29
30	31	32	33	34	35	36	37	38	39
40	41	42	43	44	45	46	47	48	49
50	51	52	53	54	55	56	57	58	59
60	61	62	63	64	65	66	67	68	69
70	71	72	73	74	75	76	77	78	79
80	81	82	83	84	85	86	87	88	89
90	91	92	93	94	95	96	97	98	99

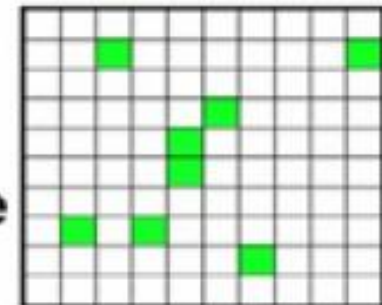
10 x 10 grid



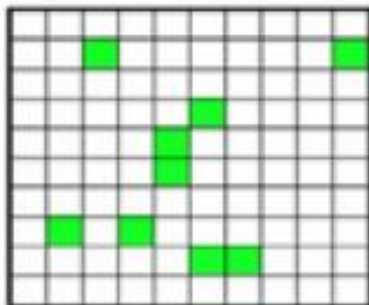
Beginning Configuration



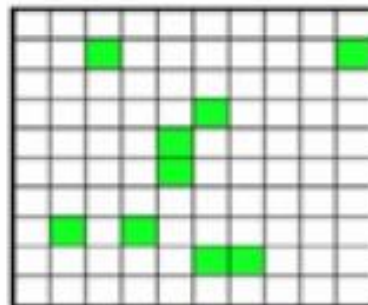
step 1
(tree on cell 54)



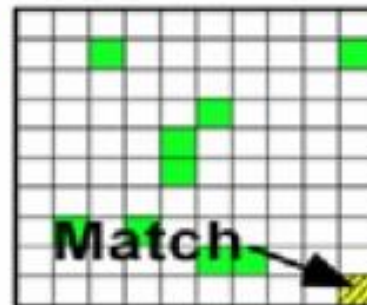
step 2
(tree on cell 71)



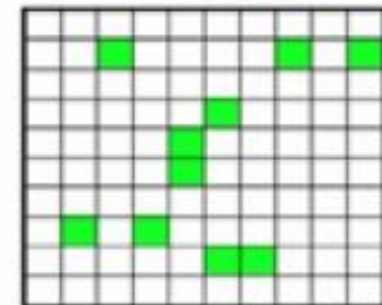
step 3
(tree on cell 85)



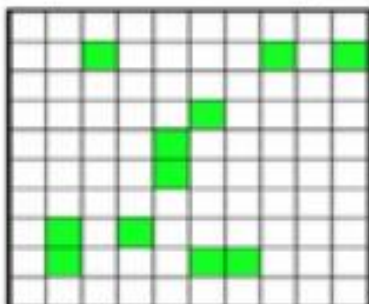
step 4
(tree on cell 19)



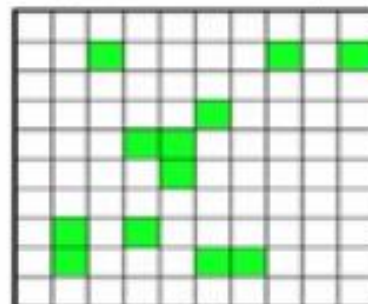
step 5
(match on cell 99, $A_F = 0$)



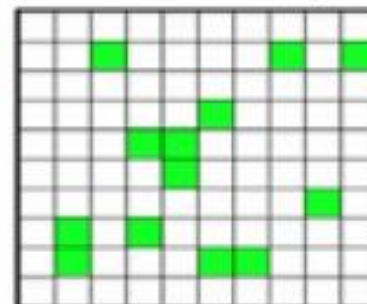
step 6
(tree on cell 17)



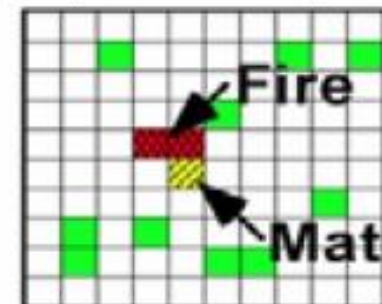
step 7
(tree on cell 81)



step 8
(tree on cell 43)



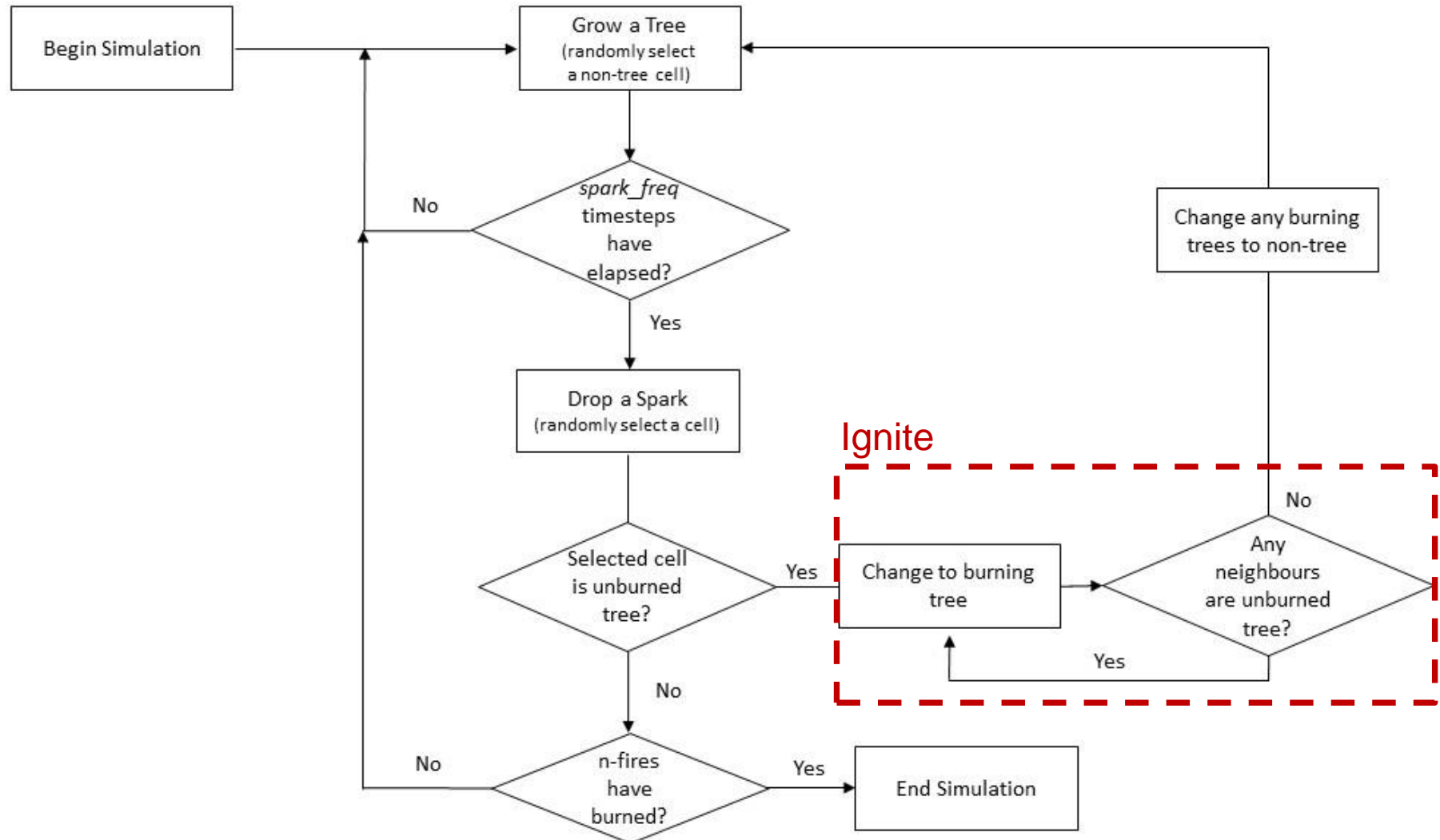
step 9
(tree on cell 68)



step 10
(match on cell 54, $A_F = 3$)

Millington *et al.* (2006)

FFCA flowchart



Power-Law Frequency-Area

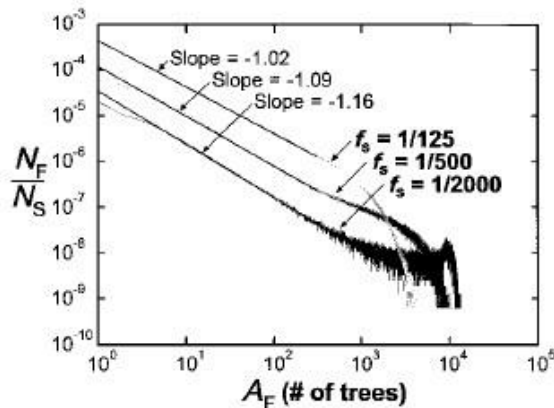


Fig. 1. Noncumulative frequency-area distributions of model forest fires for a grid size of 128 by 128 squares at three sparking frequencies. $f_s = 1/125$, $1/500$, and $1/2000$. The number of fires per time step (N_F/N_S) with area (A_F) is given as a function of A_F , the number of trees that were 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)

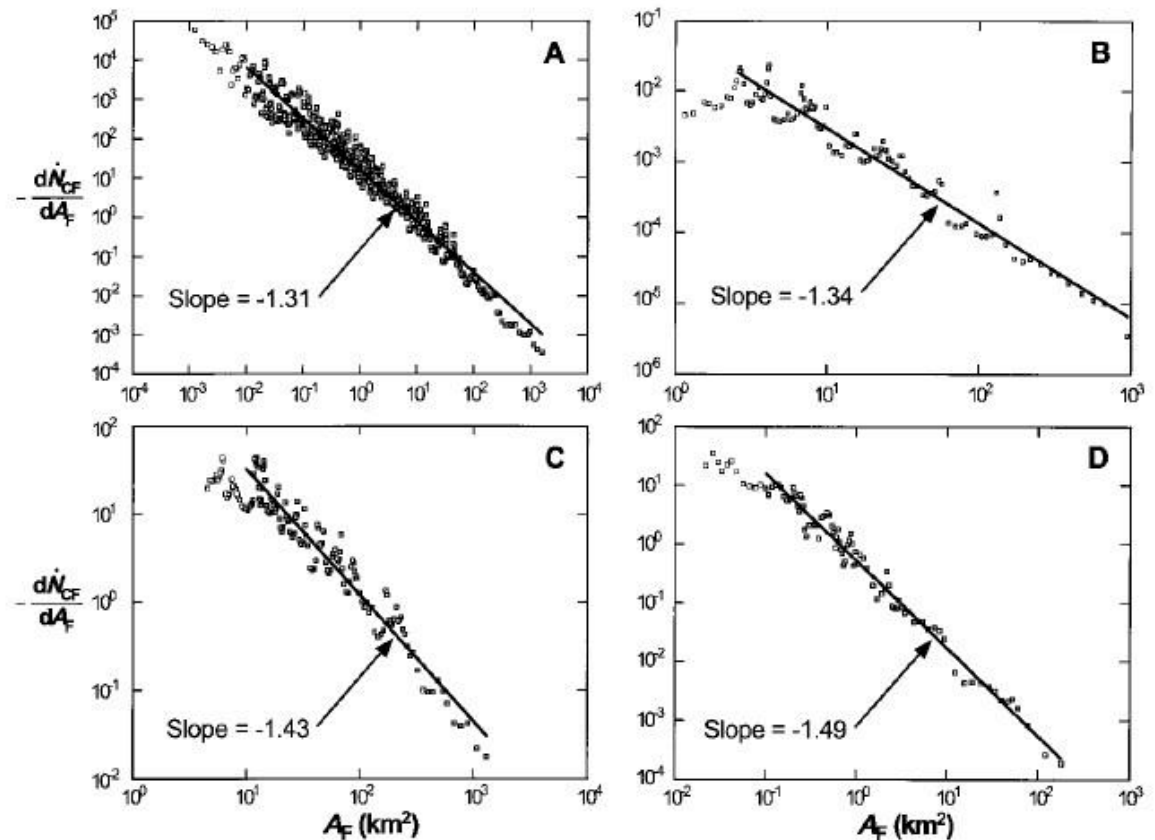
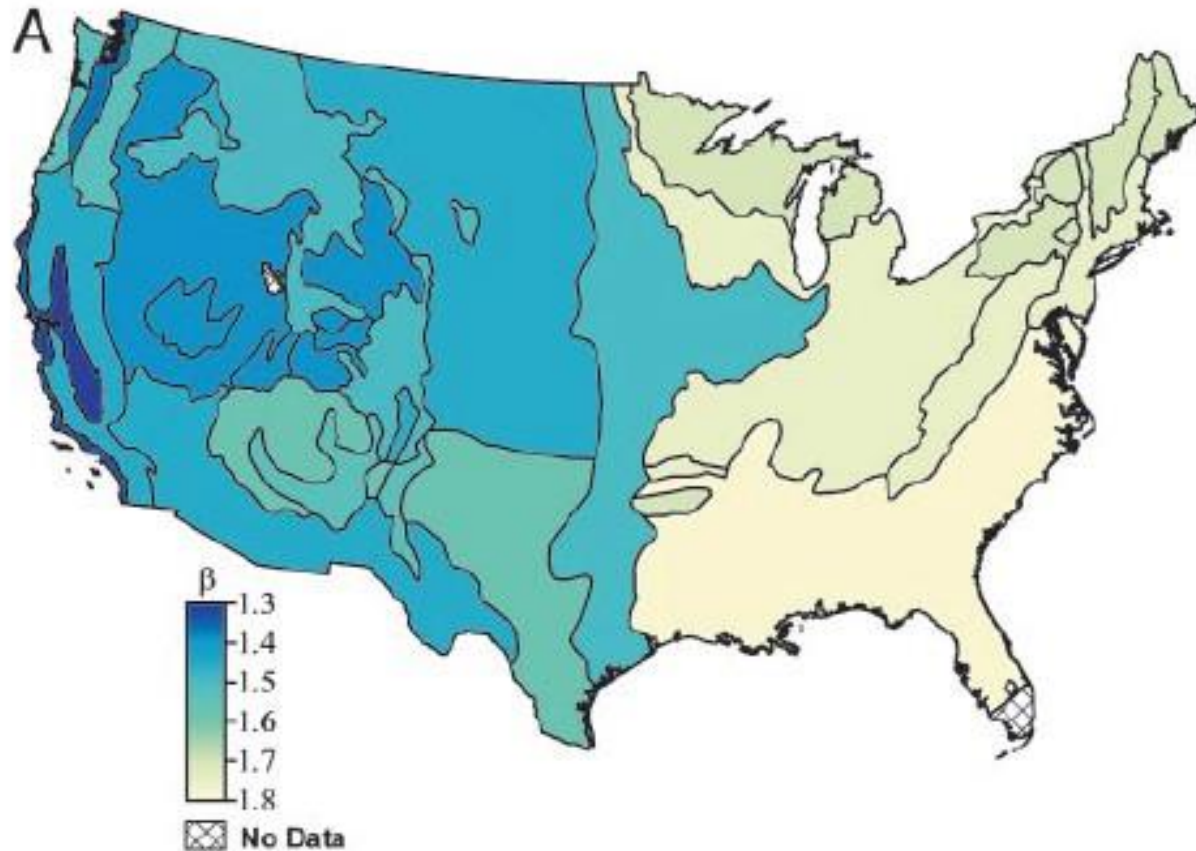


Fig. 2. Noncumulative frequency-area distributions for actual forest fires and wildfires in the United States and Australia: (A) 4284 fires on U.S. Fish and Wildlife Service lands (1986–1995) (9), (B) 120 fires in the western United States (1150–1960) (10), (C) 164 fires in Alaskan boreal forests (1990–1991) (11), and (D) 298 fires in the ACT (1926–1991) (12). For each data set, the noncumulative number of fires per year ($-dN_{CF}/dA_F$) 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 $\alpha = 1.31$ to 1.49 ; $-\alpha$ is the slope of the best-fit line in log-log space and is shown for each data set.

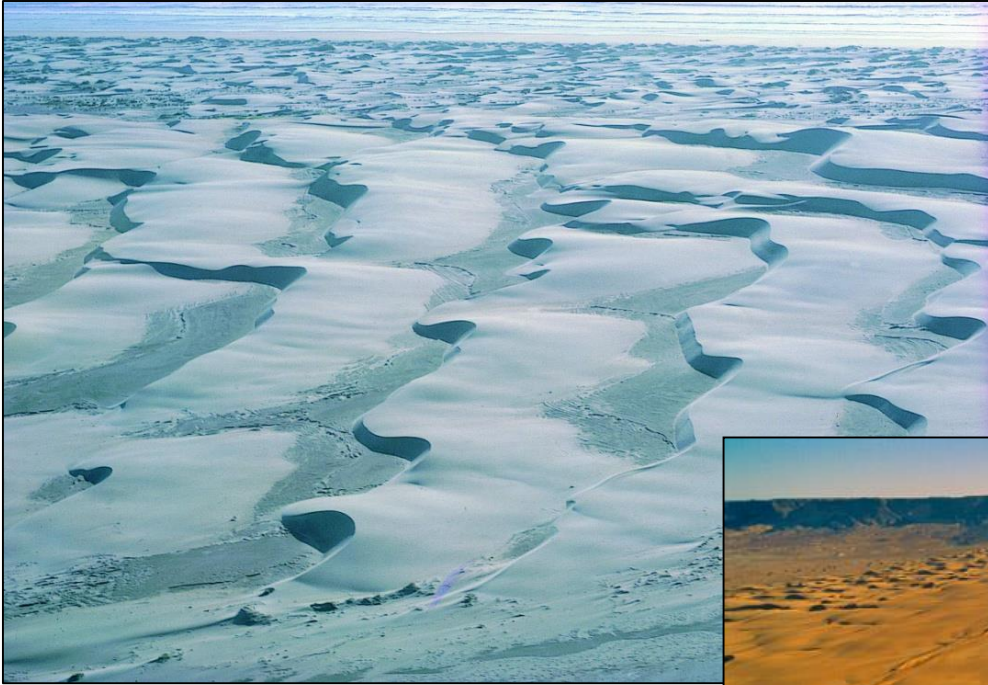
Spatial Patterns of Statistics

Variation in frequency-area distributions across USA

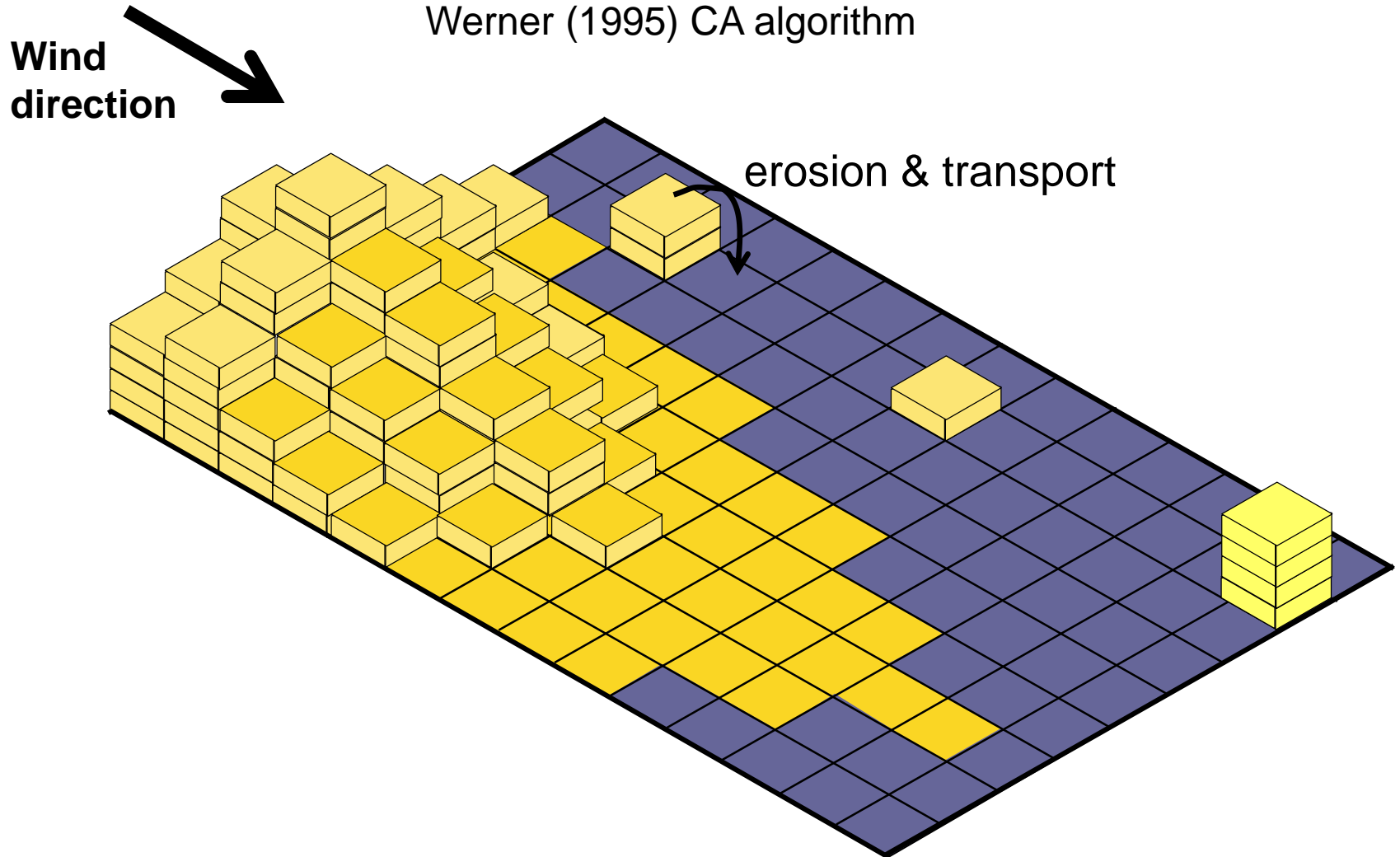


Malamud et al. (2005)

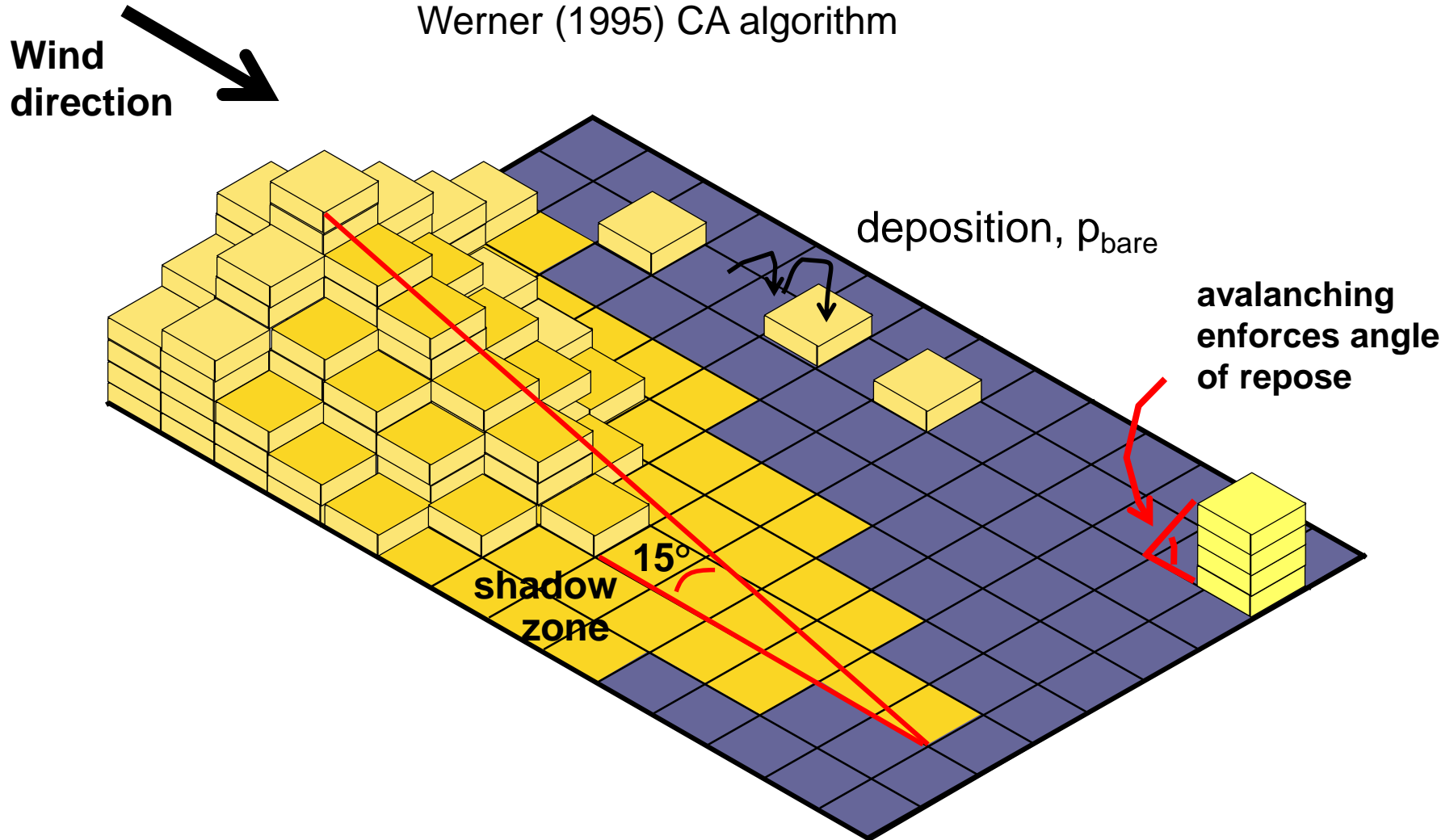
Earth Surface Landscapes



Dune 3-D Cellular Automaton



Dune 3-D Cellular Automaton



What is an Agent-Based Model?

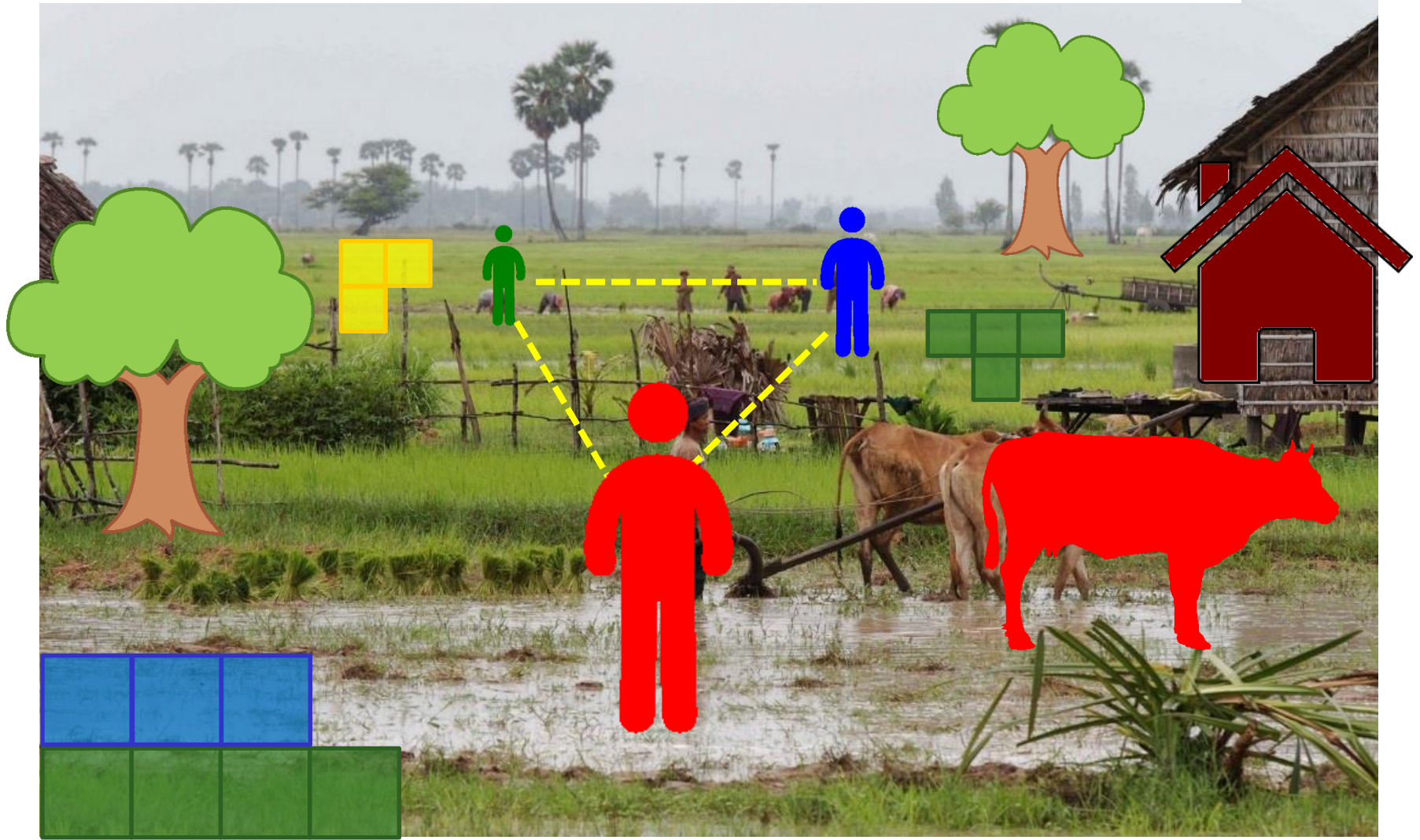
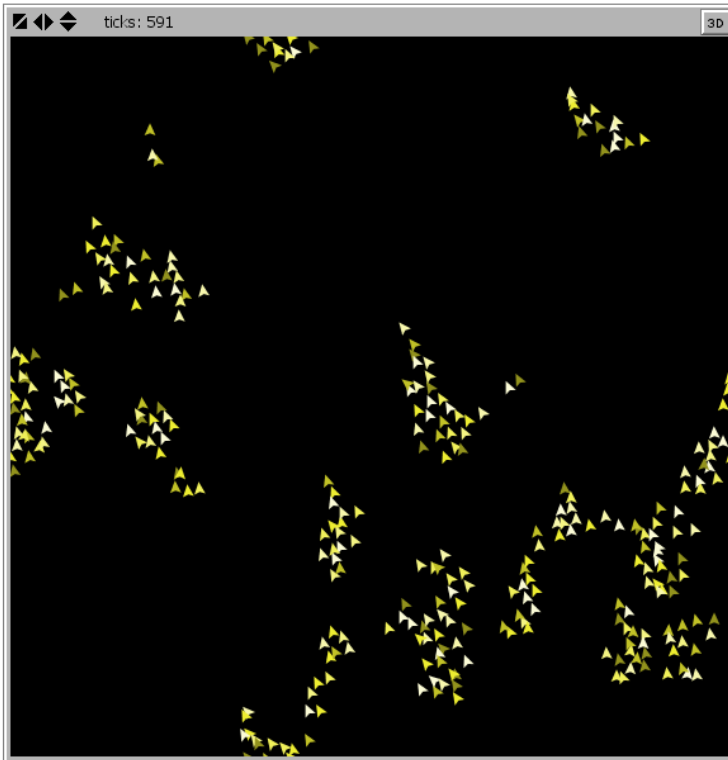


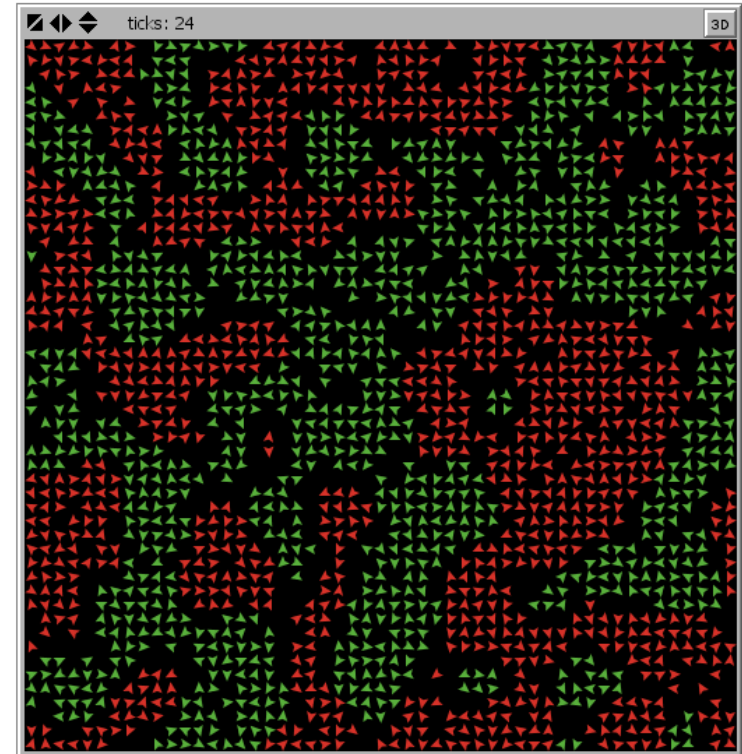
Image: [Sophie et Fred](#), flickr

Roots in Complexity Theory

Flocking



Segregation



Agent-Based Models

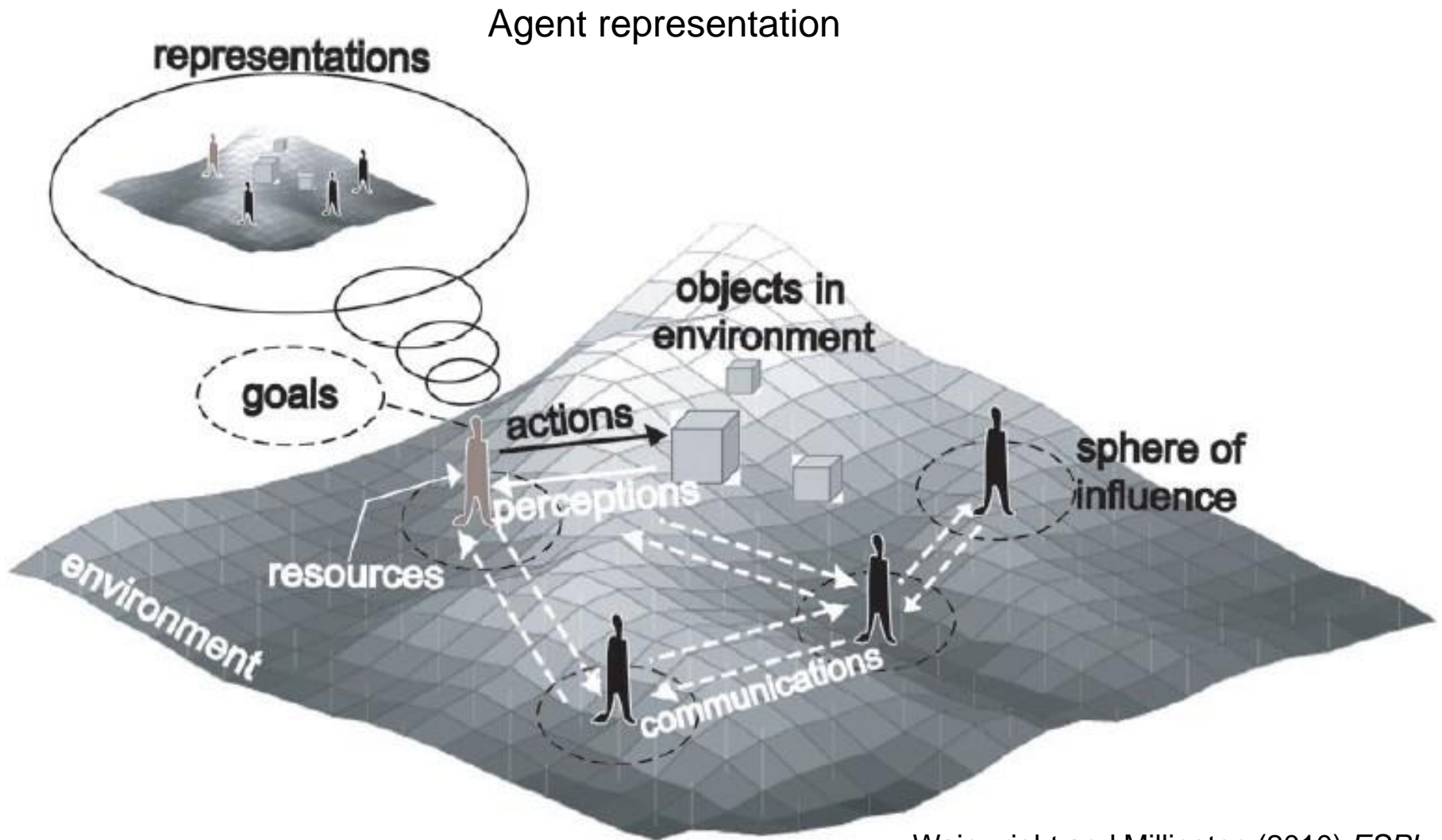
Discrete, **heterogeneous** 'agents':

- ❖ 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-Based Models

Investigating human-environment interactions

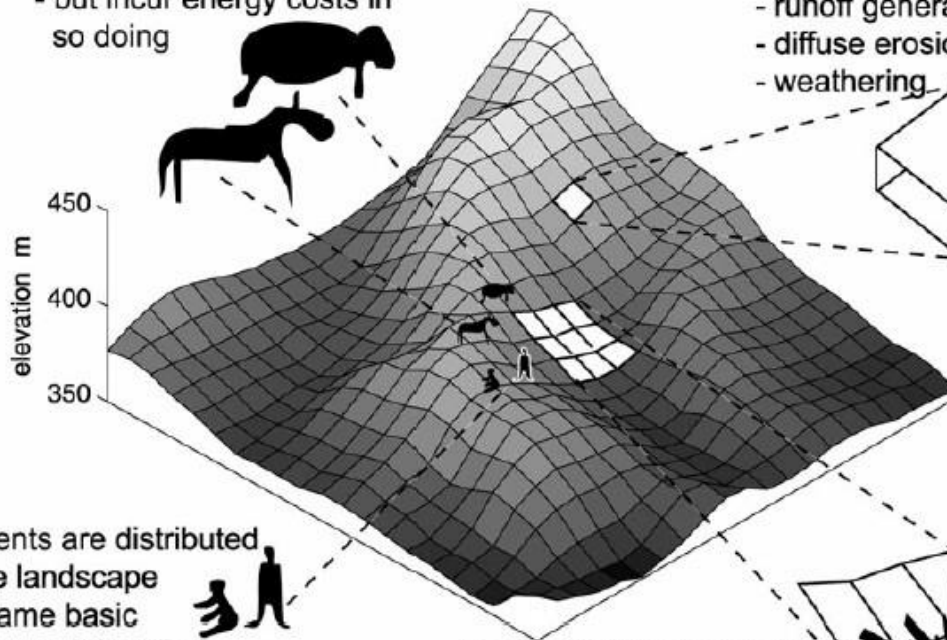
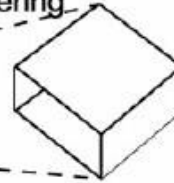
Animal agents are distributed through the landscape

- have energy requirements to be met by eating vegetation
- can move through the landscape to find food
- but incur energy costs in so doing



Cells define local characteristics:

- vegetation type and amount
- soil texture and nutrients
- soil-moisture content
- runoff generation
- diffuse erosion
- weathering



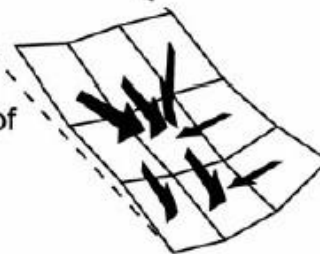
Human agents are distributed through the landscape

- use the same basic energetics model as the animal agents
- but can move to hunt, gather or clear vegetation from the landscape



Local neighbourhoods of cells define:

- flow routing
- concentrated erosion
- sediment routing



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:

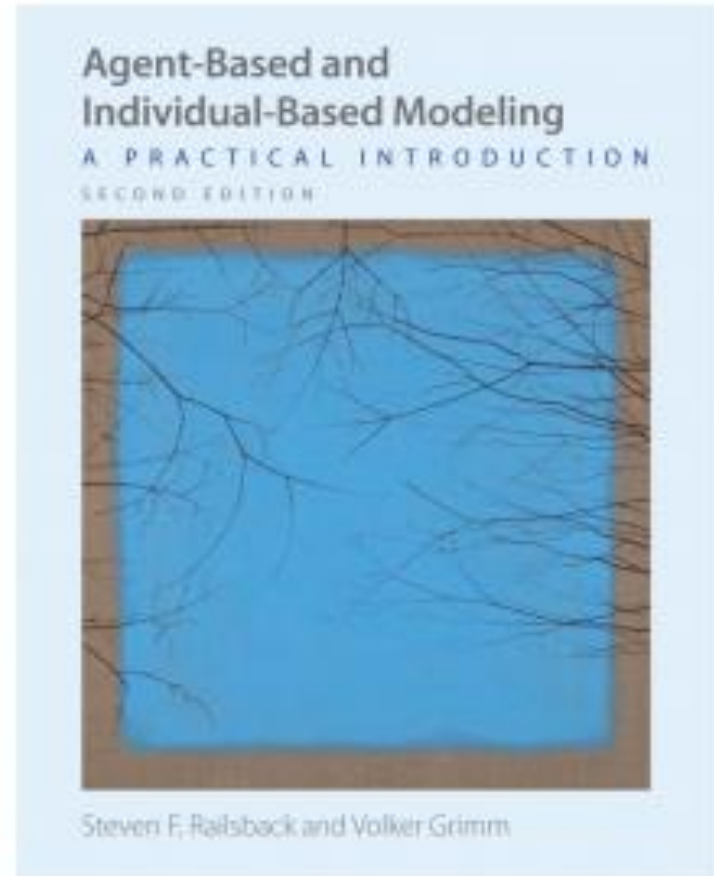
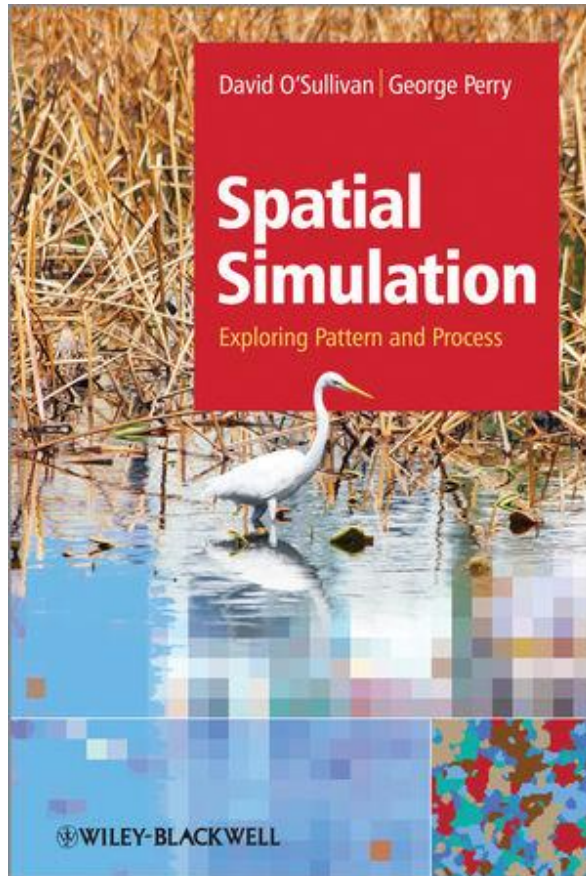
- 5) sensitivity analysis
- 6) calibration
- 7) data exploration
- 8) uncertainty assessment
- 9) consider alternatives

Each of these steps can lead to new insights!

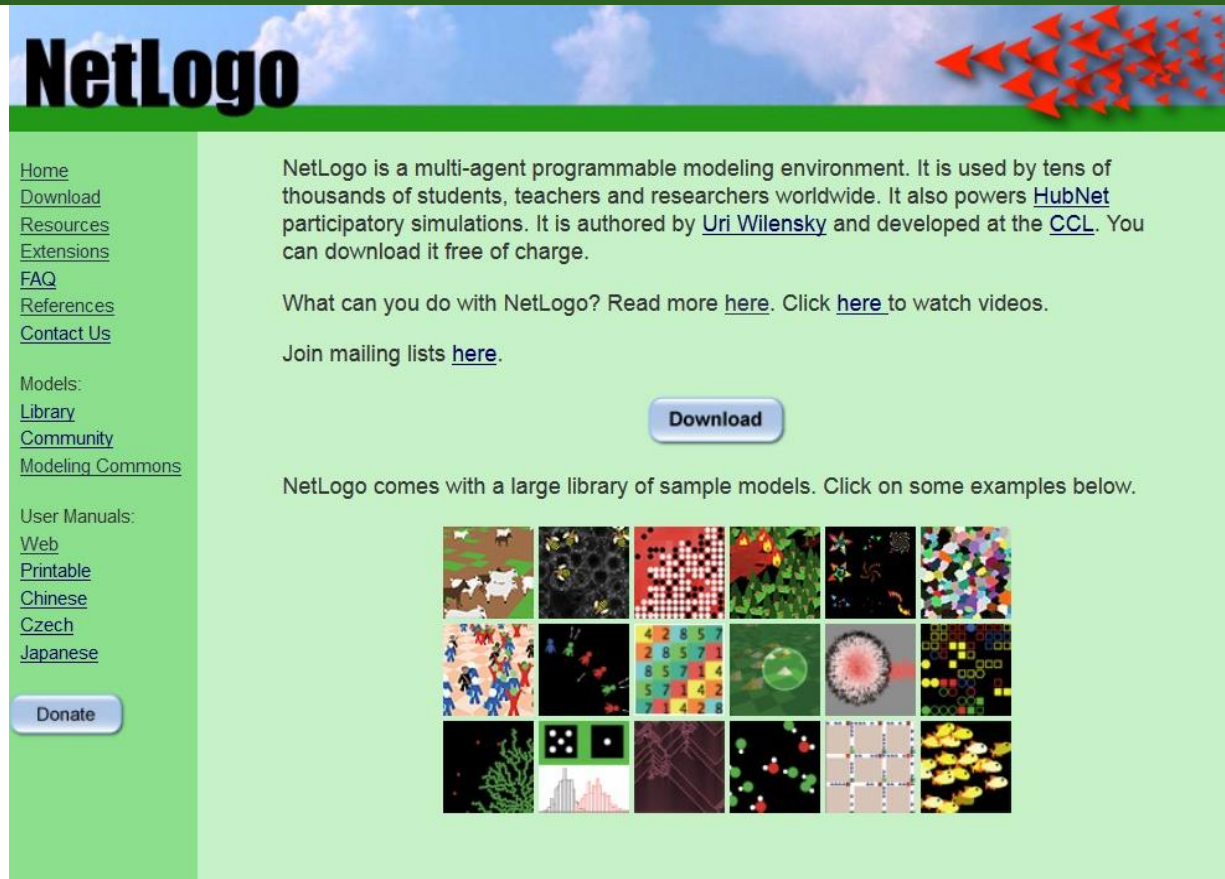
Modelling Thoughts

- 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 during model development,
 - The journey is often more fruitful than the destination!
-

Resources



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

A screenshot of the NetLogo website. The header features the "NetLogo" logo in large black letters on a blue sky background with clouds. To the right of the logo is a decorative graphic of red arrows pointing left. Below the header, the page is divided into a green sidebar on the left and a white main content area on the right. The sidebar contains a list of links: Home, Download, Resources, Extensions, FAQ, References, Contact Us, Models: Library, Community, Modeling Commons, User Manuals: Web, Printable, Chinese, Czech, Japanese, and a blue "Donate" button. The main content area has a paragraph describing NetLogo as a multi-agent programmable modeling environment, followed by a "Download" button. Below this is a grid of 15 small thumbnail images showing various simulations, including a flock of birds, a forest fire, a city skyline, and a game of Go.

NetLogo

Home
[Download](#)
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[Extensions](#)
[FAQ](#)
[References](#)
[Contact Us](#)

Models:
[Library](#)
[Community](#)
[Modeling Commons](#)

User Manuals:
[Web](#)
[Printable](#)
[Chinese](#)
[Czech](#)
[Japanese](#)

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NetLogo is a multi-agent programmable modeling environment. It is used by tens of thousands of students, teachers and researchers worldwide. It also powers [HubNet](#) participatory simulations. It is authored by [Uri Wilensky](#) and developed at the [CCL](#). You can download it free of charge.

What can you do with NetLogo? Read more [here](#). Click [here](#) to watch videos.

Join mailing lists [here](#).

[Download](#)

NetLogo comes with a large library of sample models. Click on some examples below.

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

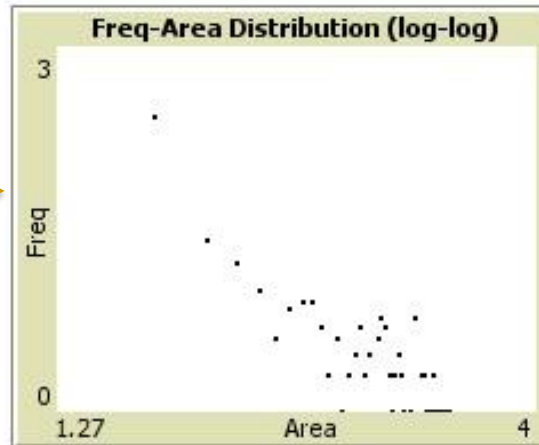
Buttons



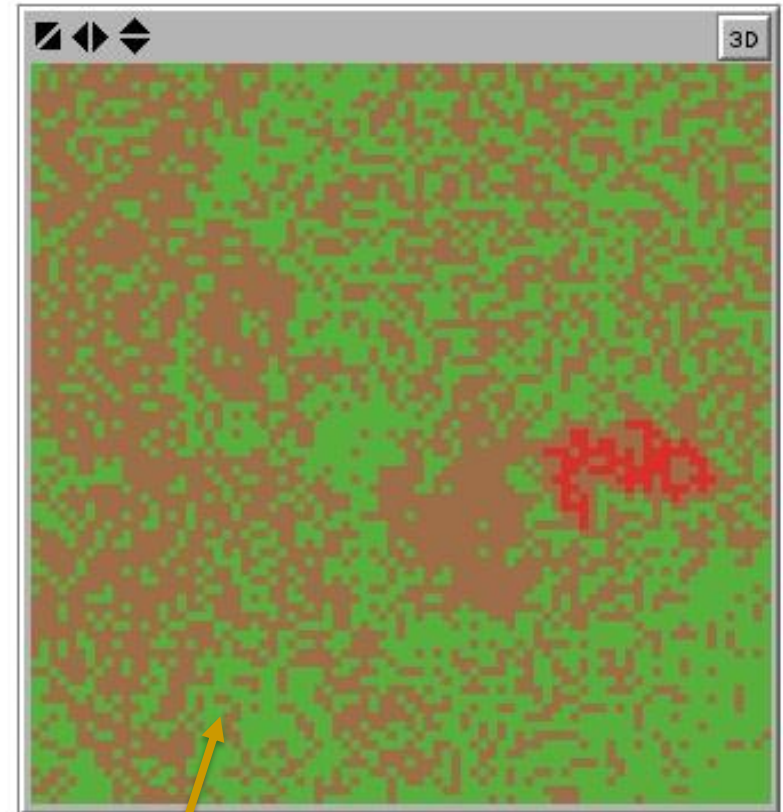
Parameter
(‘slider’)



Plot



Monitors



Model ‘Environment’

Walking Agents (Ungulates)

setup go step

go-length 10000

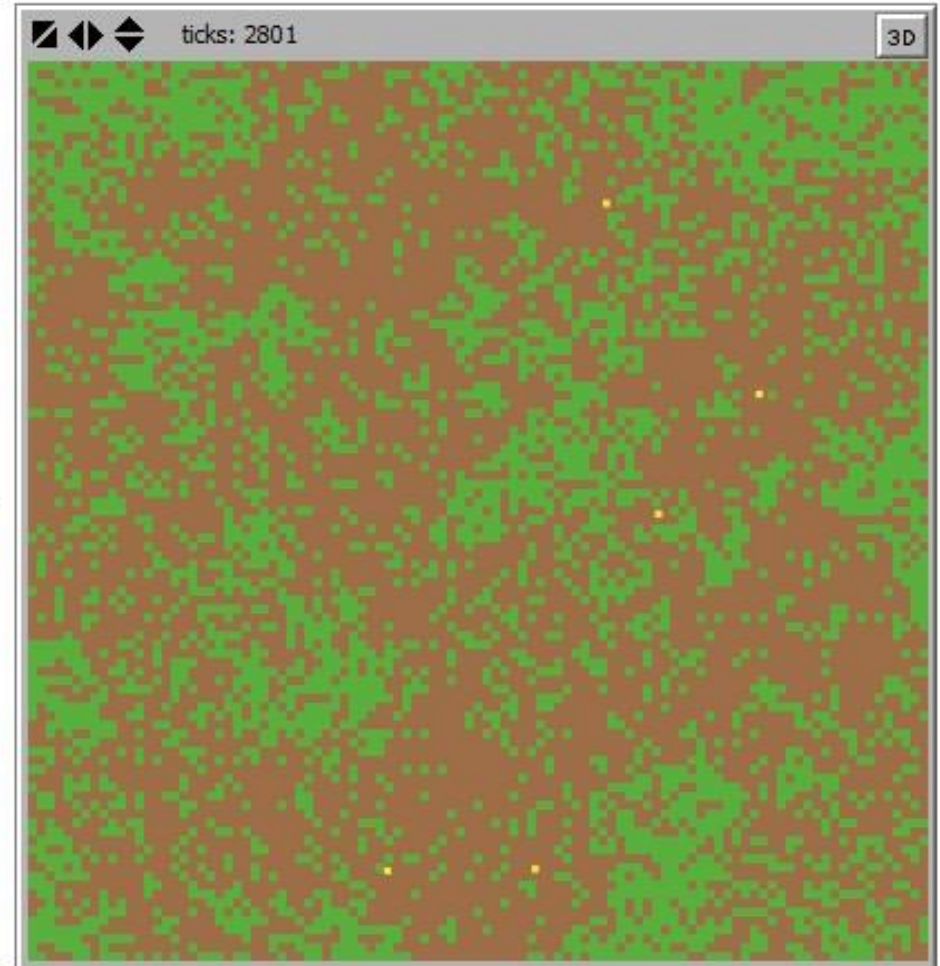
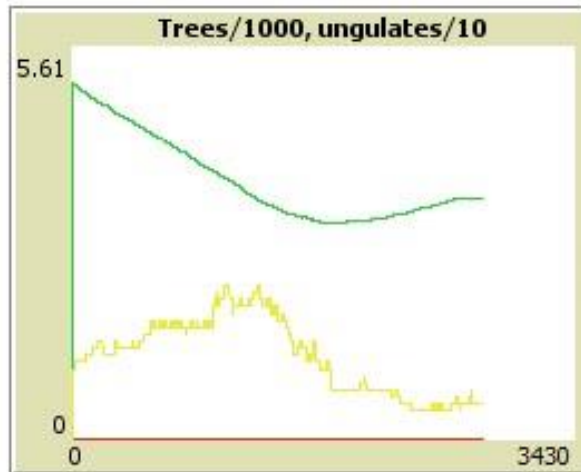
initial-ungulates 10 initial-trees 50 %

energy-from-food 10 reproduction-rate 0.2

walk
random

trees 3451 ungulates 5

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.

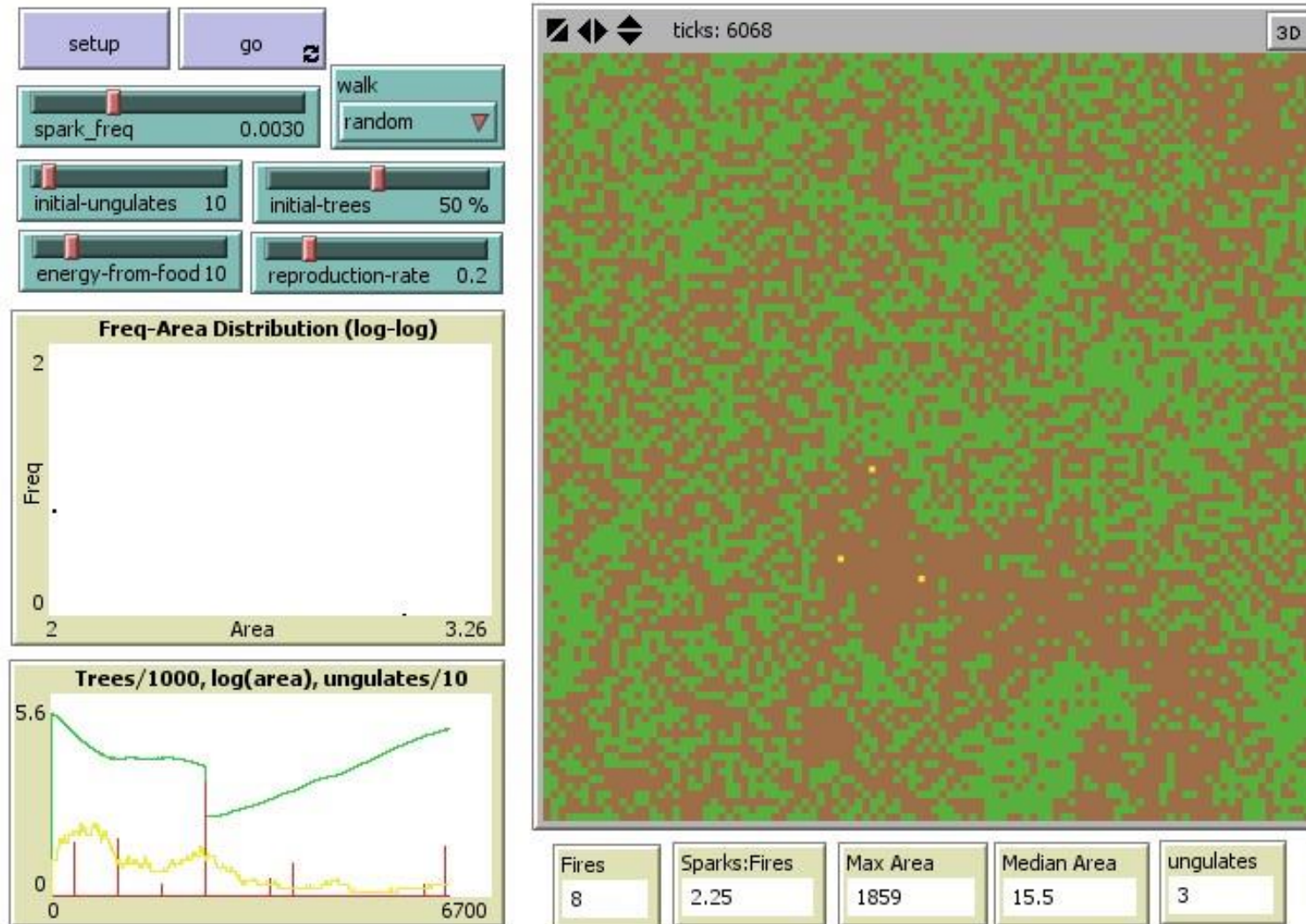
Ungulate Browsing Model

- 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

