Utrecht University

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Data models and modelling environments for field-agent based modelling

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Software for simulation modelling developed at Utrecht University

PCRaster (https://www.pcraster.eu, 1996 -)
- Continuous fields (rasters)

Campo (2021 -)
- Continuous fields and agents
- In development
- https://campo.computationalgeography.org

LUE (2019 -)
- Parallel computation (desktops, cluster computers)
- In development
- https://lue.computationalgeography.org

Schedule

09:00 - 09:05 Welcome and introduction
09:05 - 09:30 Presentation: Geosimulation using fields and agents
09:30 - 10:30 Campo hands-on tutorial and exercises
10:30 - 10:45 Break
10:45 - 11:15 Roundtable
11:15 - 11:35 Discussion
11:35 - 12:25 LUE tutorial and exercises
12:25 - 12:30 Roundup

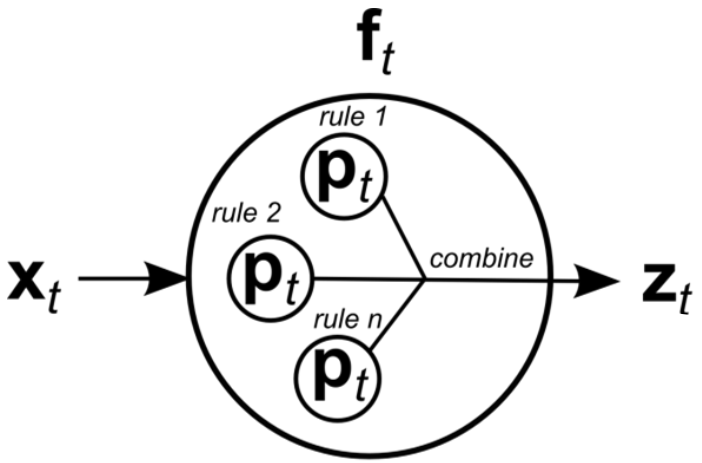
https://campo.computationalgeography.org/workshops/giscience2023/

Motivation

coreymondello.com

Defining Geosimulation

variable	description
t	time step
$\mathbf{z}_t$	system state at t
$\mathbf{f}_t$	transition function
$\mathbf{x}_t$	inputs/drivers at t
$\mathbf{p}_t$	parameters at t

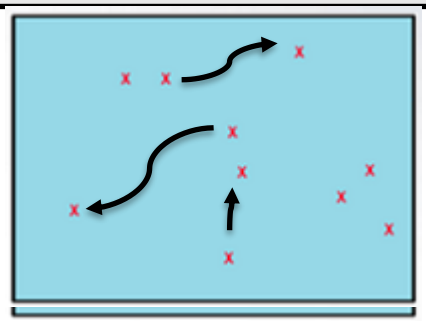


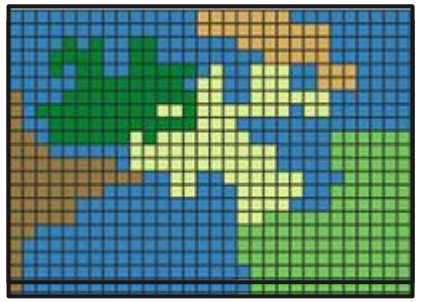
→ impact

Data-driven	Spatio-temporal models	Process-driven
Start with empirical data		Start with a theory (system description)
Based on correlations between drivers and the system state		Based on known/assumed cause-effect relations between drivers and system state
Also called: empirically-based model, statistical model, machine learning model		Also called: process-based model, physically-based model, **geosimulation model**

Modelling paradigms

	Agent-based modelling (multi-agent systems)	Field-based modelling (cellular automata)
system state	Set of discrete objects	Continuous or discrete
attribute(s)	Is linked to the agent	Has a value everywhere
processes	Behavior of a single agent, potentially moving	Behavior of cells that remain in their location

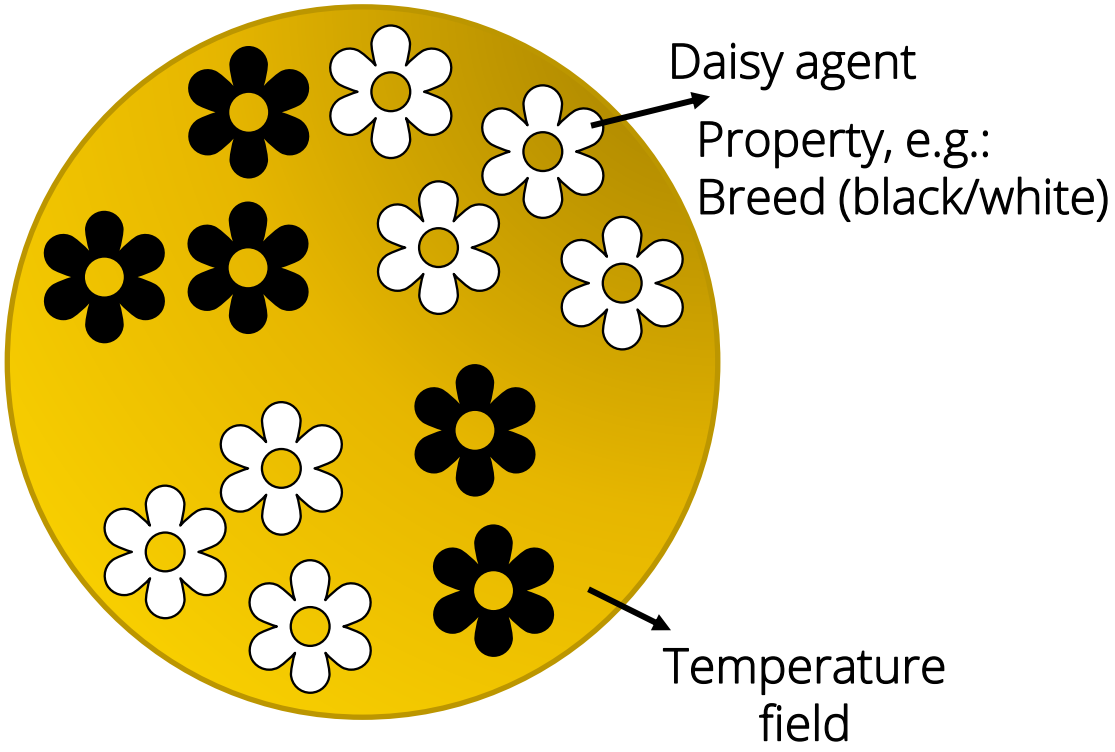




Systems have multiple phenomena that do not fit into one paradigm!

Example: Fields & Agents!

DaisyWorld was introduced by James Lovelock and Andrew Watson (1983), to illustrate the Gaia Hypothesis that organisms interact with their surroundings, creating a self-regulating system.



White daisies - high albedo, reflecting light, cooling the surface temperature.

Black daisies - low albedo, absorbing light, increasing the surface temperature.

Example: Fields & Agents! – model rules & inputs

Daisies can only reproduce in a certain temperature range.

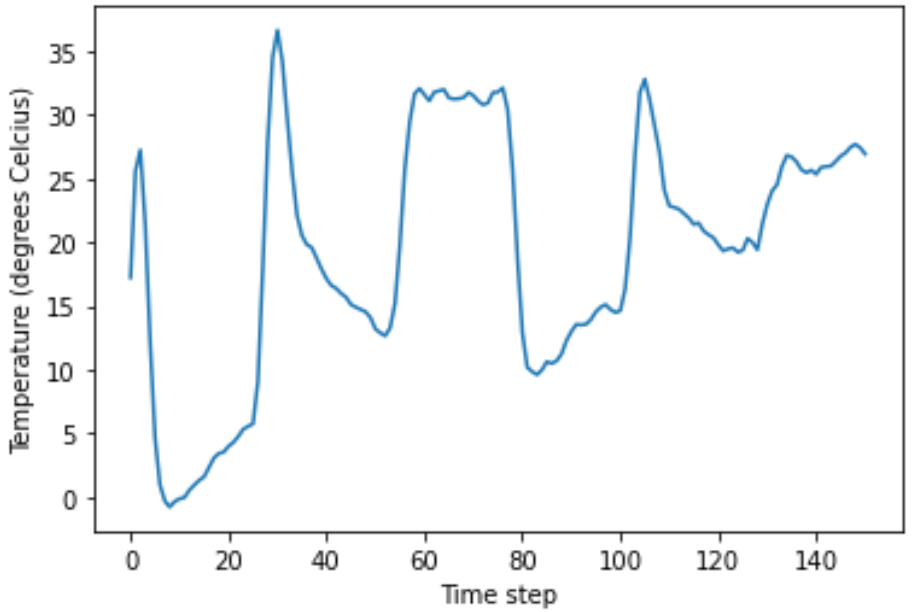
Temperature depends on:
- Daisies (nr and color)
- Luminosity of the sun

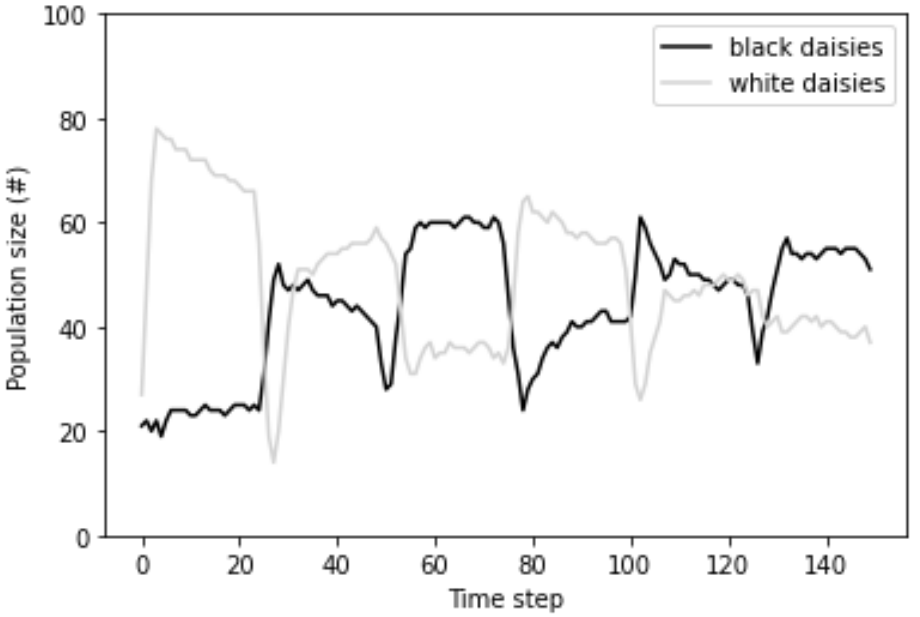
This leads to an equilibrium between black and white daisies under a relatively wide range of luminosity conditions.

Example: Fields & Agents! - output

Field properties over time

Population statistics over time





Example: Fields & Agents! - scenarios

We can look at various luminosities:

- Low
- High
- Our
- Ramp

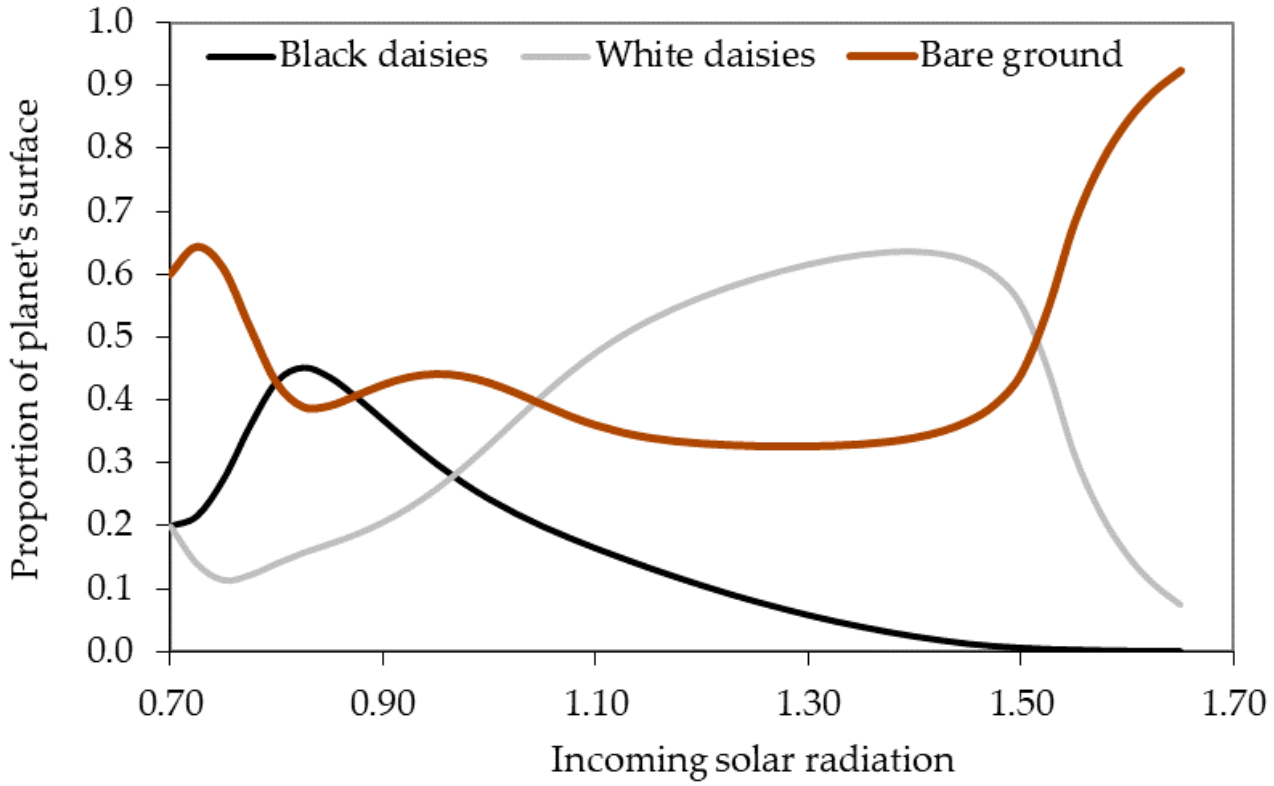


Figure: Wilby 2020, Water

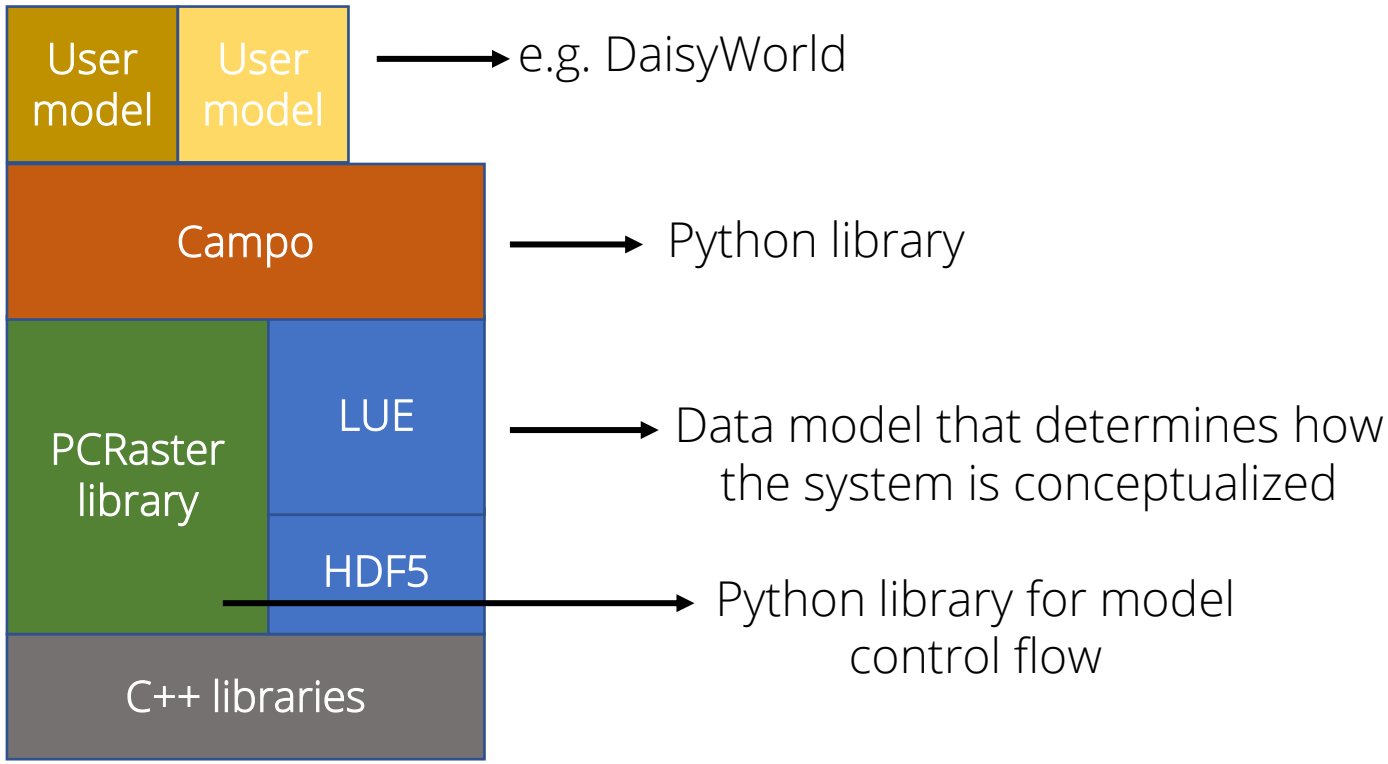
Problem statement

Current software:

- Often departs from ABM, and approaches fields as sets of square objects → computationally sub-optimal
- Has separate sets of functions for fields and agents

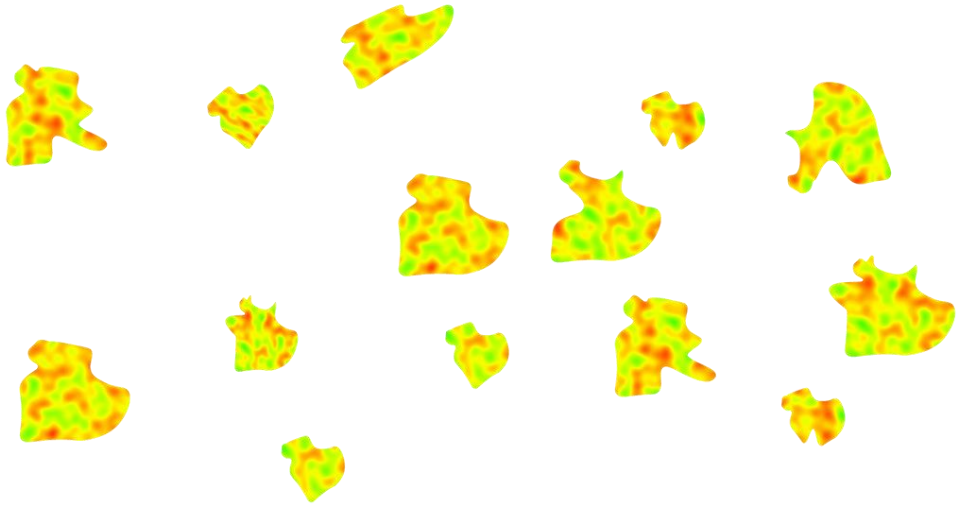
→ No full integration between fields and agents

Campo


User model
User model
e.g. DaisyWorld
Campo
Python library
PCRaster library
LUE
Data model that determines how the system is conceptualized
HDF5
Python library for model control flow
C++ libraries

Phenomenon: agents or field

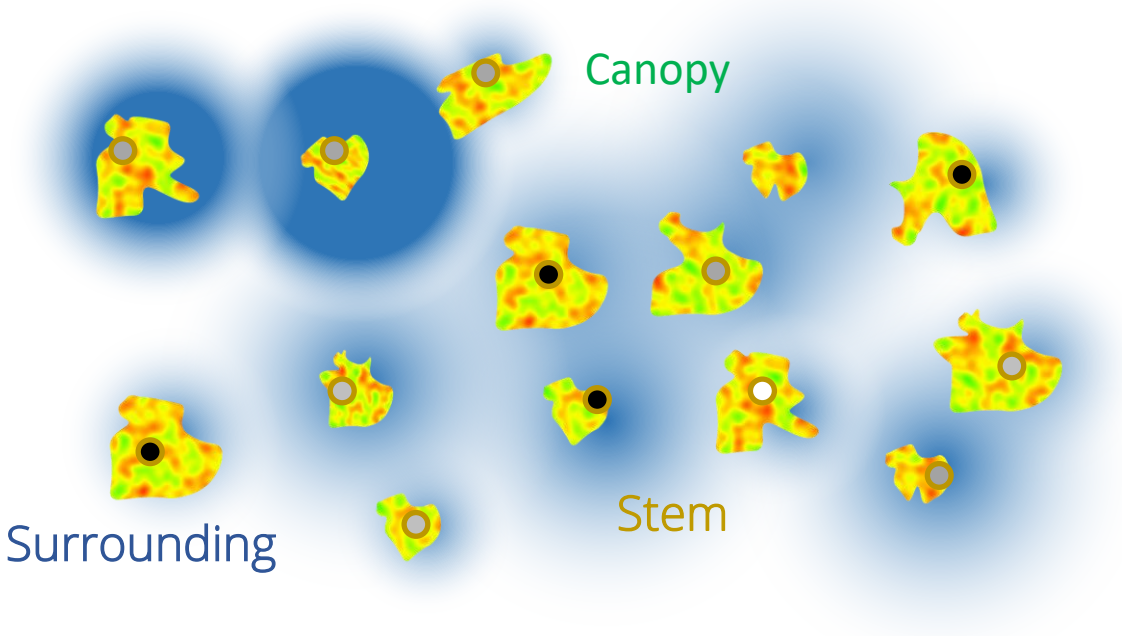
‘Agents’: Phenomenon containing >1 **Objects**, areal coverage of each Object is where it has a value



‘Field’: Phenomenon containing 1 **Object**, areal coverage is ‘modelling area’

Phenomenon has Property Sets, Property sets have properties

Forest system: trees, stems, tree canopy, seed dispersal..



Phenomenon **Trees**
- Property Set **Stem**
- Property Set **Surrounding**
- Property Set **Canopy**
  - Property **NDVI**

Spatial *domain of each **Object***:
point at stem
circular centered at stem
crown

Single Algebra for Agents & Fields

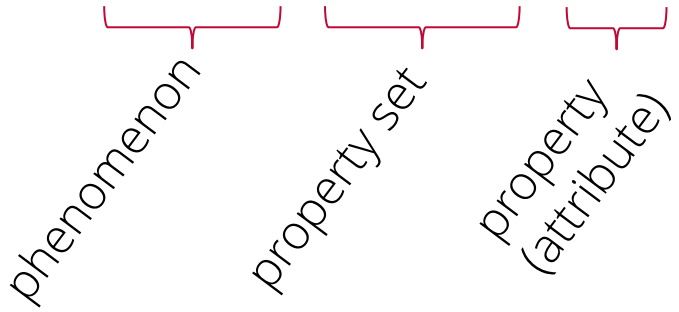
Syntax:

`a = a_function(b)`

Calculates for each Object its property `a` as a function of property `b`

Referring to phenomena, property set, for instance:

`trees.canopy.lai = a_function(trees.canopy.ndvi)`



Framework for control flow

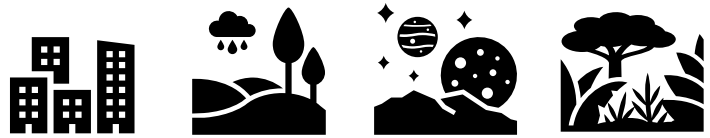
```
class MyFirstModel(DynamicModel):
   ...

   def initial(self):
      # functions here are run once at start
      # create/modify Phenomena for initial state of system
      # I/O using framework functions

   def dynamic(self):
      # functions are run for each time step
      # program time transition function
      # I/O using framework functions
```

Hands-on Campo

https://github.com/computationalgeography/giscience2023

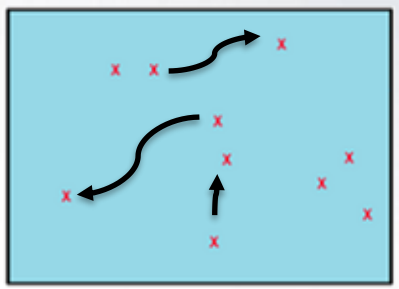
Roundtable

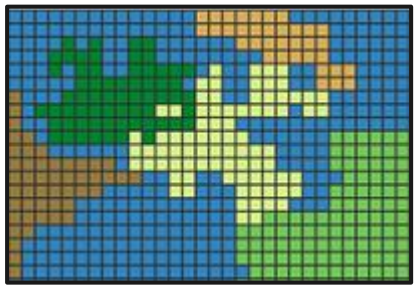
1. What is/are the application domains of your model(s)?
2. Do your models typically contain agents, fields, or both?
3. Which software do you use for your simulation models?
4. Which limitations do you experience with this software?




Discussion

1. What are your most-desired simulation software features?
2. Examples of field-agent problems to demonstrate this?
3. How could we parallelize a field-agent based model?





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