Agent-Based Modeling (ABM) and Geo-Simulation Components Summary:

Agents:

- **Definition**: There is no universal definition of an agent, but generally, agents are self-directed entities that operate within an environment, sensing and acting upon it to achieve their goals. Definitions by Franklin and Graesser (1997) and Iglesias et al. (1999) highlight agents as systems or objects with internal goals, decision-making capabilities, and the ability to influence their environment.
- **Characteristics**: According to Macal and North, agents are identifiable, situated in an environment, heterogeneous, goal-directed, autonomous, and flexible. Nigel Gilbert adds that agents perceive their environment, have behaviors (motion, communication, action), memory, and policies (rules governing behavior).

Environments:

- **Definition**: The environment is the space in which agents operate. It supports their interactions with the environment and other agents, acting as the virtual world for their actions.
- **Types**:
    - **Physical Environment**: Includes ecological factors like temperature and food sources.
    - **Communication Environment**: Structures and processes enabling information exchange.
    - **Social Environment**: A type of communication environment where agents interact in a coordinated manner.
- **Dynamic vs. Static**: Dynamic environments change over time due to agent actions or external factors, whereas static environments do not change unless altered by agents.

Time:

- **Ticks**: A standard measure of time in NetLogo models, ensuring consistency across different systems and simulations.
- **Events**: Simulations can be event-driven, reacting to internal or external events. Time advances are specified by the occurrence of these events.
- **Scheduling**: Events can be scheduled at the beginning, during the run, or triggered by other agents.

Elements in NetLogo

Turtles: The agents in NetLogo. **Patches**: Cells in a grid representing the environment, similar to GIS tessellations. **Ticks**: Time steps in the model, ensuring standardized time progression across different models. **Links**: Connections between turtles, forming networks that can be directed or undirected. **Observer**: A unique entity that oversees the simulation and can issue commands affecting turtles.

Agent Behavior and Interaction

- **Goal-Driven**: Agents act to achieve specific goals, following a set of behavioral rules.
- **Communication**: Agents can communicate directly (message passing), indirectly (changing shared variables), or through broadcasting (sending information to all agents).
- **Perception**: Agents perceive their environment to various extents (the cell they occupy, adjacent cells, entire rooms, or the whole environment).

Cellular Automata (CA) Models

- **Attributes**: CA models in geospatial analysis have state variables, spatial frameworks, neighborhood structures, transition rules, and time steps.
- **Interaction**: CA models represent environments as grids where cell values change over time based on neighboring cells, previous states, and external inputs.

Practical Examples

Evacuation Model:

- **Agents**: Different types of agents (officer, leaver, follower) with specific behaviors during evacuation.
- **Environment Interaction**: Agents move based on environmental constraints (e.g., cannot walk through walls).

Wolf-Sheep Model:

- **Environment Dynamics**: The grass is a physical, dynamic environment influenced by the actions of the sheep.

Social Networks

- **Connections**: Agents can form social networks, sharing information and potentially influencing each other's behavior.

Calibration and Temporal Scales

- **Calibration**: Linking simulation time to real time.
- **Temporal Scales**: Different processes might be modeled at various temporal scales, such as hourly for visitors and monthly for vegetation growth.

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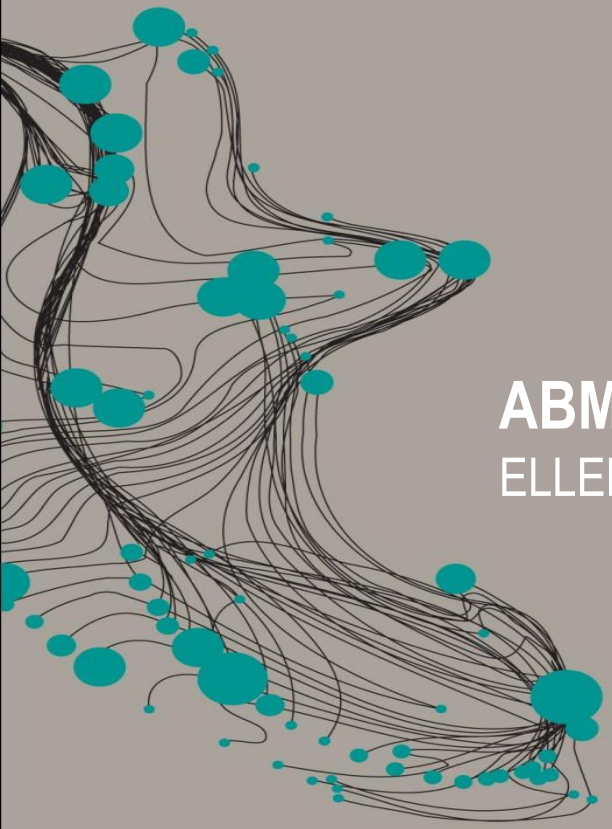

ABM1

ELLEN-WIEN AUGUSTIJN

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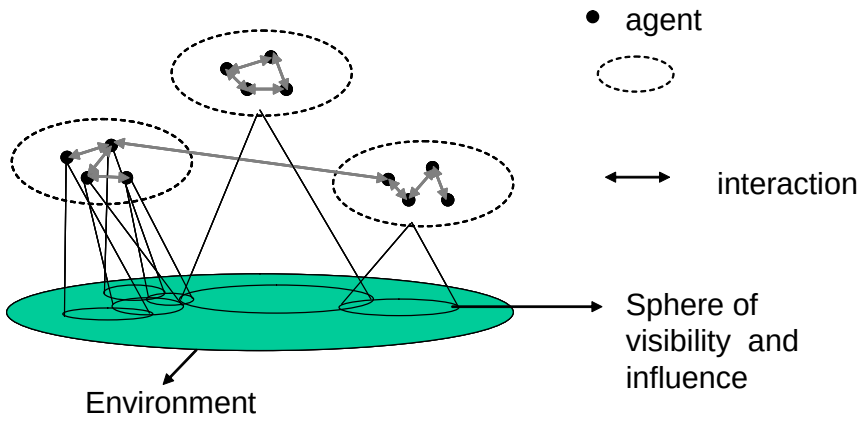
COMPONENTS OF GEO-SIMULATION

- Agents (1)
- Environments (2)
- Time (3)



Canonical View of an Agent based System (Jennings, 2000)

On agent-based software engineering by N.R. Jennings (2)
http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.553.8239&rep=rep1&type=pdf

ELEMENTS IN NETLOGO

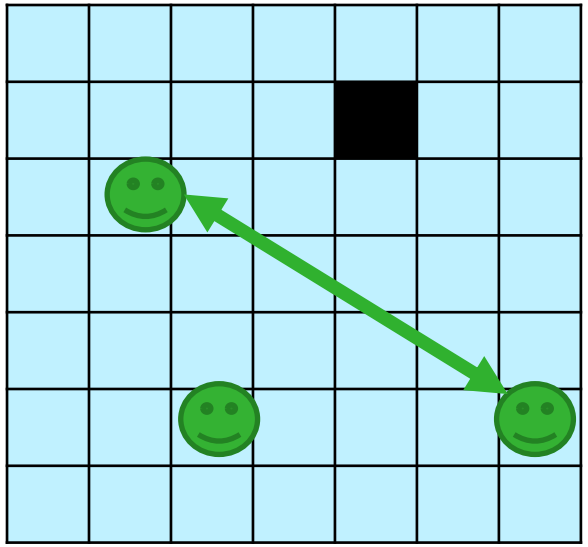
Turtles: agents

Patches: Are comparable to regular tessellations in a GIS. They divide a total map extent into cells of equal size and shape. It is possible to load the values of a GIS layer into the patches.

Ticks: A tick is a measure of time in NetLogo models (like seconds or minutes). Ticks are used instead of seconds, minutes, or hours because ticks are standardized across all models and computers; some models and computers run slower than others, but ticks are always the same!

Links: Links are agents that connect two turtles. They are used to create social networks. Links can be directed (from one turtle to another turtle) or undirected (one turtle with another turtle).

The observer: There is only one observer and it does not have a location. Since, the observer oversees the NetLogo world, it can give commands that affect individual turtles, as well as groups of turtles.



COMPONENTS OF GEO-SIMULATION

- Agents (1)
  - When is something an agent?
  - How do we define agent behavior?
  - Groups of agents
- Environments (2)
- Time (3)

WHAT IS AN AGENT

No universal agreement on a definition of the term ‘agent’

“(…) a system situated within and a part of an environment that senses that environment and acts on it, over time, in pursuit of its own agenda and so as to affect what it senses in the future.”
(Franklin and Graesser 1997)

“An agent is a self-directed object, i.e. it has the ability to satisfy internal goals or objectives through actions and decisions based on a set of internal rules or strategies.”
(Iglesias et al. 1999)

2.2 CHARACTERISTICS OF AGENTS

Characteristics of agents according to Macal and North:

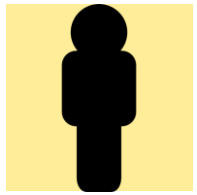
1. An agent is identifiable (discrete)
2. An agent is situated in an environment with which it interacts
3. Agents are heterogeneous
4. An agent is goal-directed
5. an agent is autonomous and self-directed (can function independently)
6. An agent is flexible, can learn, to adapt its behavior.

Characteristics of agents (Nigel Gilbert):

1. Agents perceive their environment
2. Agents have behavior:
   - Motion
   - Communication (other agents)
   - Action (interaction with environment)
3. Memory
4. Policy (rules that determine which behavior to perform)

AGENTS ARE HETEROGENEOUS

- Different agents have different behaviour



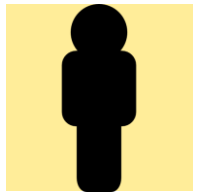
Officer: Check if room empty, move to the next room

Leaver: Check if pre-evacuation time is over. Check exit and evacuate

Follower: Wait for officer to arrive, follow officer

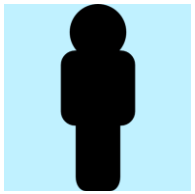
AGENTS ARE HETEROGENEOUS

- Different agents have different behaviour



- Different routes in the building

Officer: Check if room empty, move to the next room



- Pre-evacuation time
- Exit Choice

Leaver: Check if pre-evacuation time is over. Check exit and evacuate

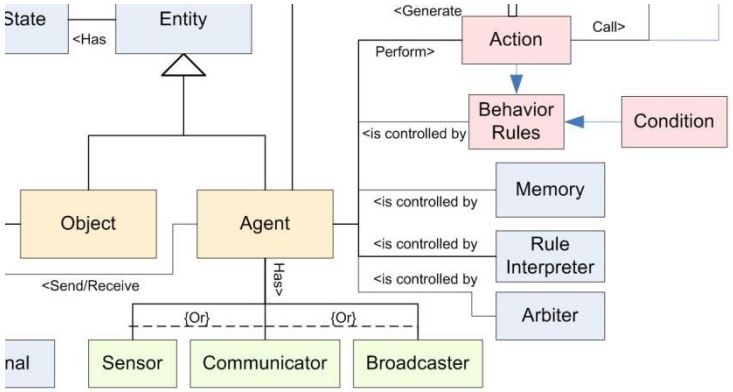
AGENTS COMMUNICATE

- Direct Communication: Agents can communicate directly with each other through message passing. Agents can send messages that contain information or requests, and other agents can receive and respond to those messages.
- Indirect Communication: Agents can also communicate indirectly through the environment or by changing the state of shared variables. For example, an agent might leave a trail of pheromones to signal the presence of a resource.
- Broadcasting: Agents can broadcast information to all other agents in the system, rather than sending targeted messages to specific agents.

AGENT BEHAVIOR

Agent behavior is driven by:

- A certain goal
- Which lies in performing actions
- Following a set of behavioral rules



The goal of the agent in the evacuation model is to reach the exit and evacuate

The actions the agent can perform are:

- Select an exit (stored in memory)
- Retrieve an earlier selected exit
- Check if pre-evacuation time is over
- Move (in the direction of the preferred exit)
- …….

The agent has a set of behaviour rules that tell the agent which actions to perform:

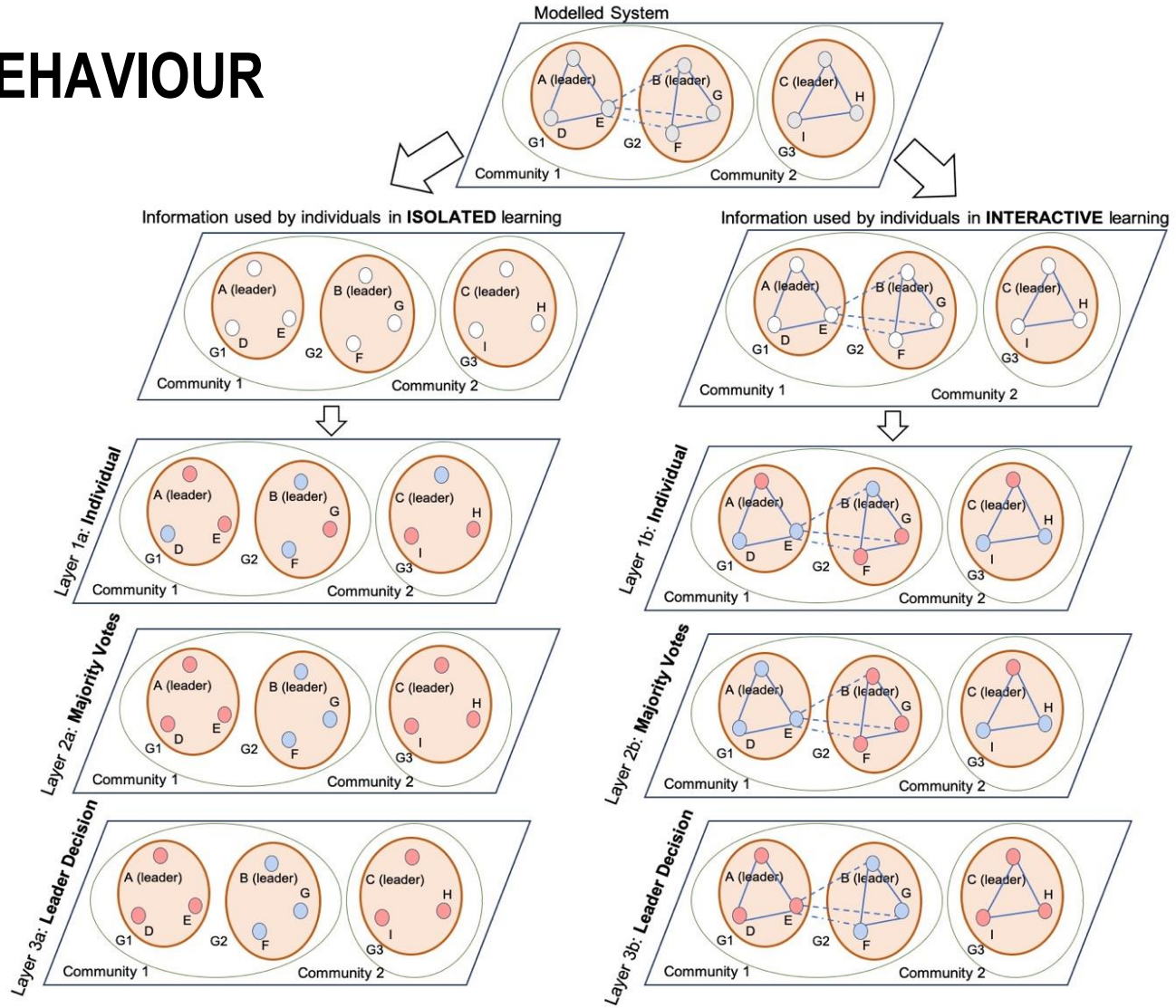
- When pre-evacuation time is over
- And, you already have an exit stored
- Determine your next location and move

AGENT CAN PERCEIVE AN ENVIRONMENT

- How much of the environment does the agent perceive?
  - The cell the agent is standing on
  - The 8 cells adjacent to the cell the agent is standing on
  - The room (defined by the walls) that the agent is in
  - The complete environment, even when it is not within sight

INDIVIDUAL VERSUS GROUP BEHAVIOUR

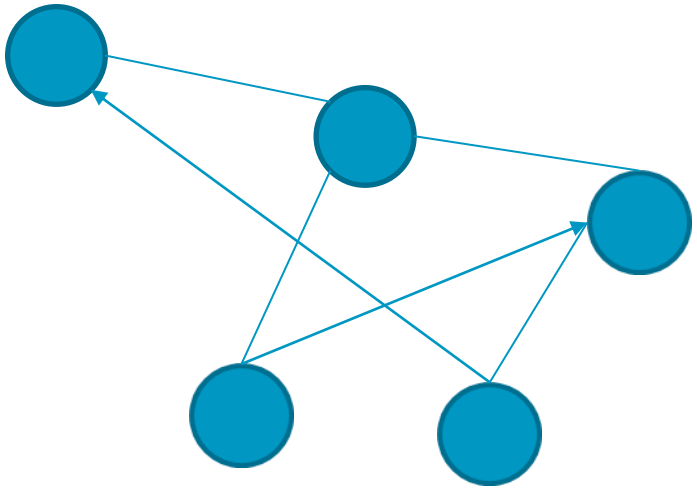
- Agents can form groups and both the individual agent and the group can have behaviour.
- Knowledge can be shared within the group (type of communication)
- Behaviour of the group can be synchronised.



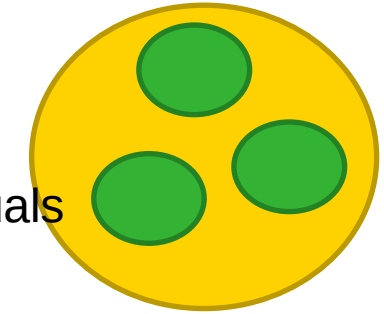
https://journals.plos.org/plosone/article/authors?id=10.1371/journal.pone.0226483

Ref: Shaheen Abdulkarreem

SOCIAL NETWORKS



Family

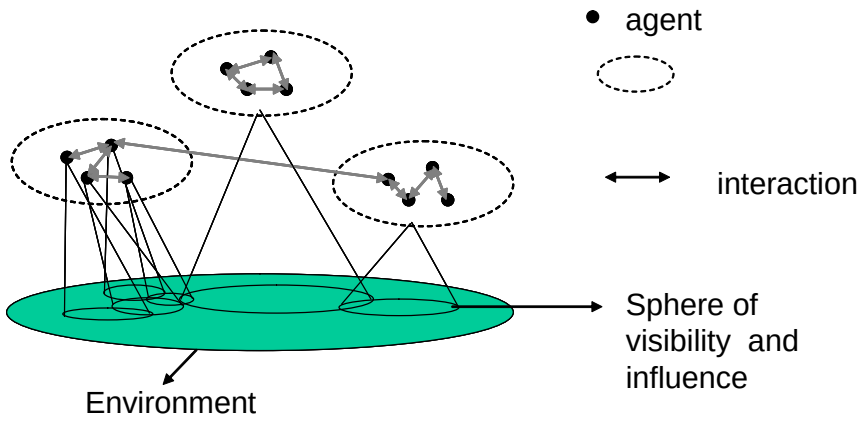


Individuals

- Agents can be connected to other agents via social networks. Networks can be directed (information in one direction) or undirected (information in both directions) – in this case, agents share information but do not necessarily have the same behaviour.

COMPONENTS OF GEO-SIMULATION

- Agents (1)
- Environments (2)
- Time (3)



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COMPONENTS OF GEO-SIMULATION

- Agents (1)
  - When is something an agent?
  - How do we define agent behavior?
  - Groups of agents
- Environments (2)
  1. What is an environment?
  2. Different types of environments
  3. Static versus dynamic environments
- Time (3)

ENVIRONMENT

"Environments define the space in which agents operate, serving to support their interaction with the environment and other agents"

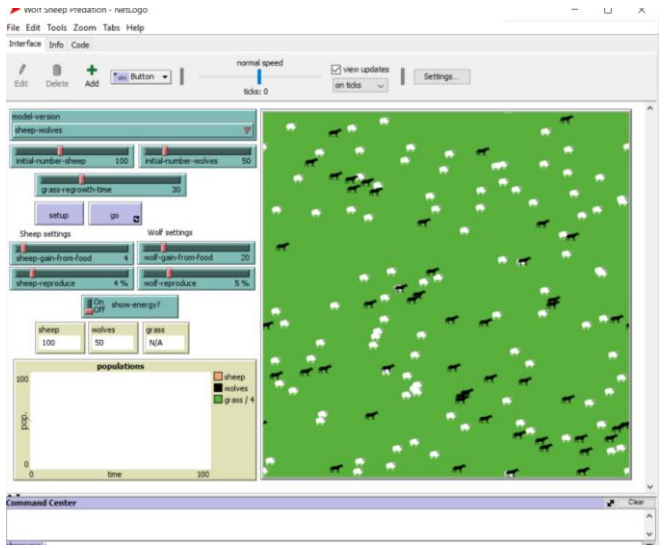
Castle and Crooks

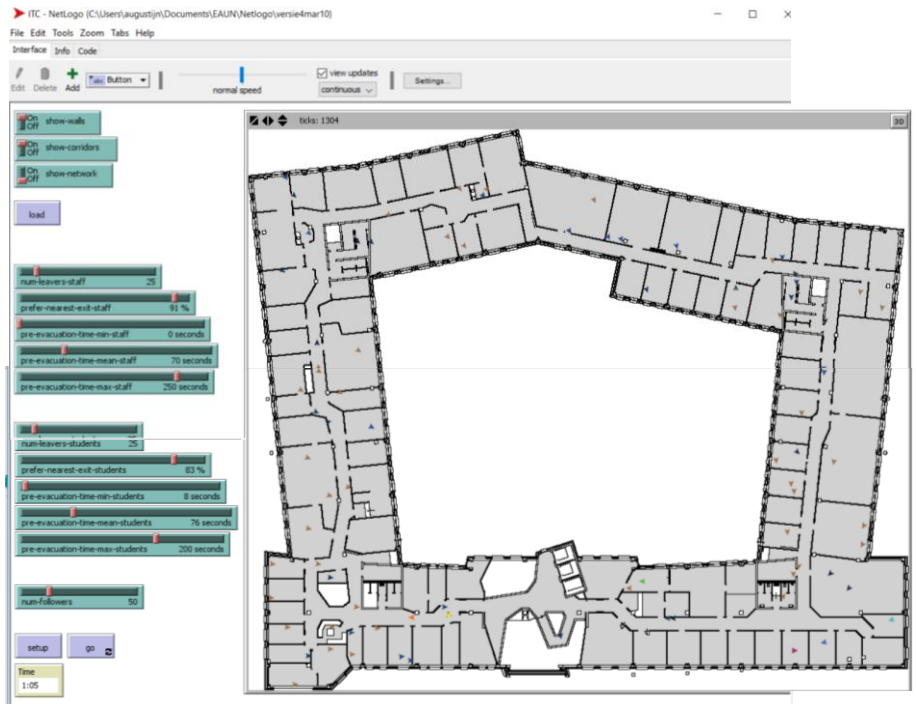
"The environment is the virtual world in which the agents act"

Nigel Gilbert

GEO-SIMULATION (ENVIRONMENT)

- Models in which the environment represents a geographic space are called: *Geographically explicit*
- Environment can be explicit but not geography but some other type (‘knowledge space’ – designed) *spatially explicit*
- Not spatial (agents have no coordinates)





3.2. TYPES OF ENVIRONMENTS

1. The ***physical environment*** *provides those principles and processes that govern* and support a population of entities.
   - *ecological niche:* temperature, humidity, and food items, diffusion and evaporation,
2. The ***communication environment*** *provides those principles, processes, and* structures that **enable an infrastructure for agents** to convey information
   - a satellite could periodically send one bit to inform ground control, government, newspaper, television
3. A ***social environment*** *is a* ***communication environment*** *in which agents interact* in a coordinated manner
   - requesting the price of a product, contract bidding activities

Odell 2001

DYNAMIC ENVIRONMENTS

Static versus dynamic environments:

In ABMs, a dynamic environment refers to an environment that changes over time in response to the actions of agents or external factors.

- What triggers the change in the environments?
  - Agents
  - The environment itself
  - both?

- The sheep will eat the grass – but the grass will grow back?
- The smoke will diffuse through the corridors of the burning building?
- ……..

DETERMINISTIC/STOCHASTIC ENVIRONMENTS

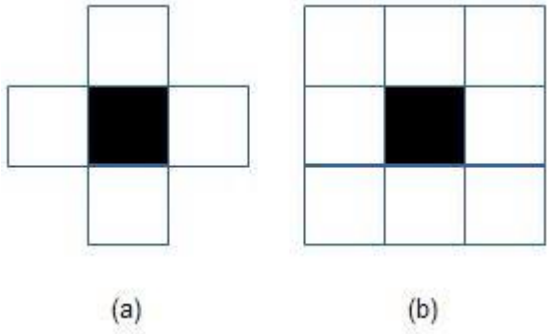
- An *environment* that is fully **deterministic** is one in which the subsequent state of the environment is wholly dependent on the preceding state and the actions of the agent.
- If an element of interference or uncertainty occurs, then the environment is **stochastic**. Note that a deterministic yet partially observable environment will *appear* to be stochastic to the agent.
- Environments can be composed of a **finite** or **infinite** number of possible states (they can be discrete or continuous)

TYPES OF SIMULATION MODELS

Cellular automata (CA) as applied in geospatial analysis, may be characterized by the following key attributes:

- *State variable*
- *Spatial framework*
- *Neighborhood structure*
- *Transition rules*
- *Time*

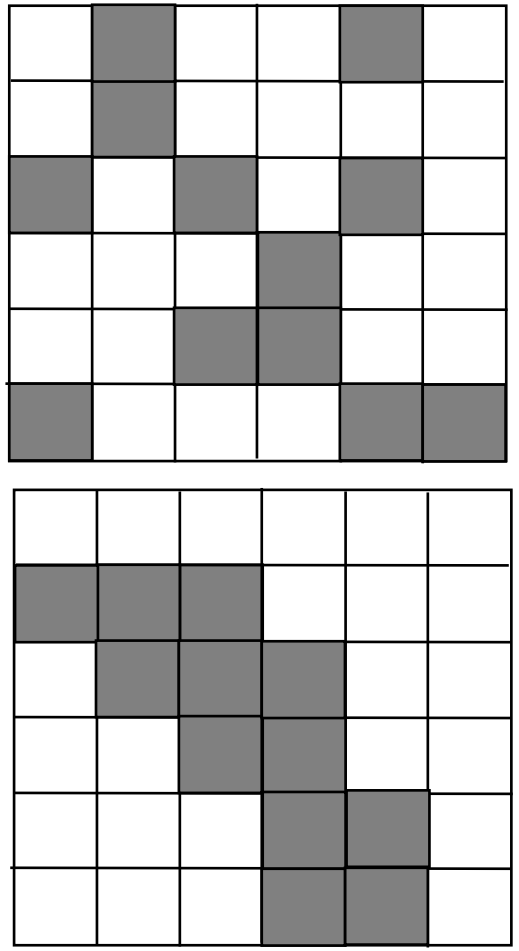
- **State variable** are a set of attributes that describe the automaton at a particular point in time
- **Spatial framework**: lattice of cells
- **Neighborhood structure**: 'Moore' (cell plus 8 surrounding cells) or 'Von Neumann' (cell and four cardinal neighbours)
- **Transition rules**: rules that determine the state change
- **Time**: discrete steps



Ref: Geospatial analysis (reader)

CA MODELS

- A cellular model represents the environment. It is based on a generalized cellular automata, a two-dimensional grid where cell values change over time according to rules based on the value of adjacent cells, previous states and external inputs



Black: If less than 2 neighbors black turn white

White: if more than 2 neighbors black turn black

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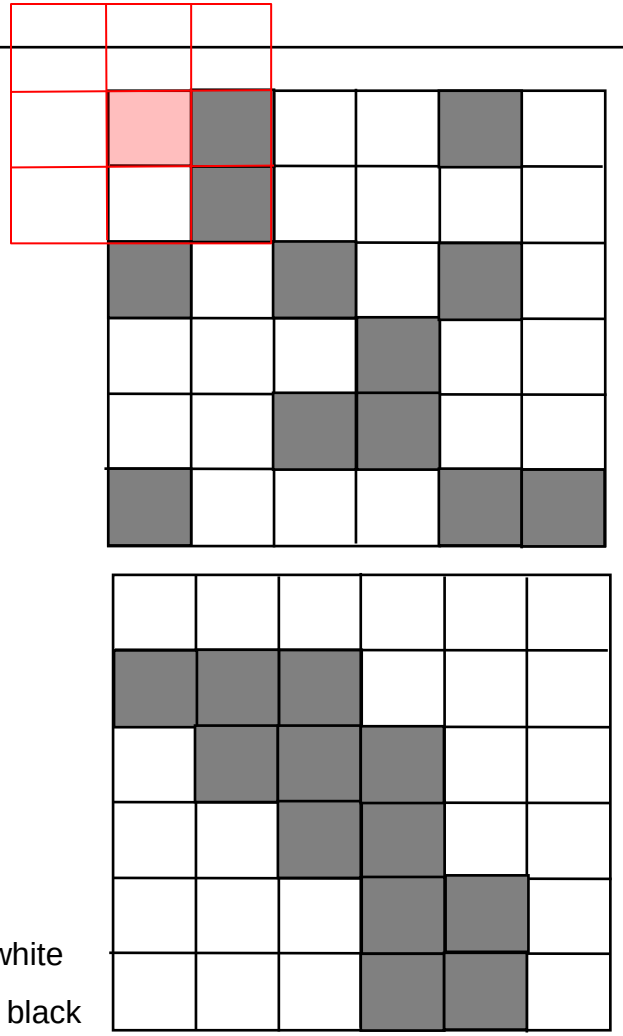

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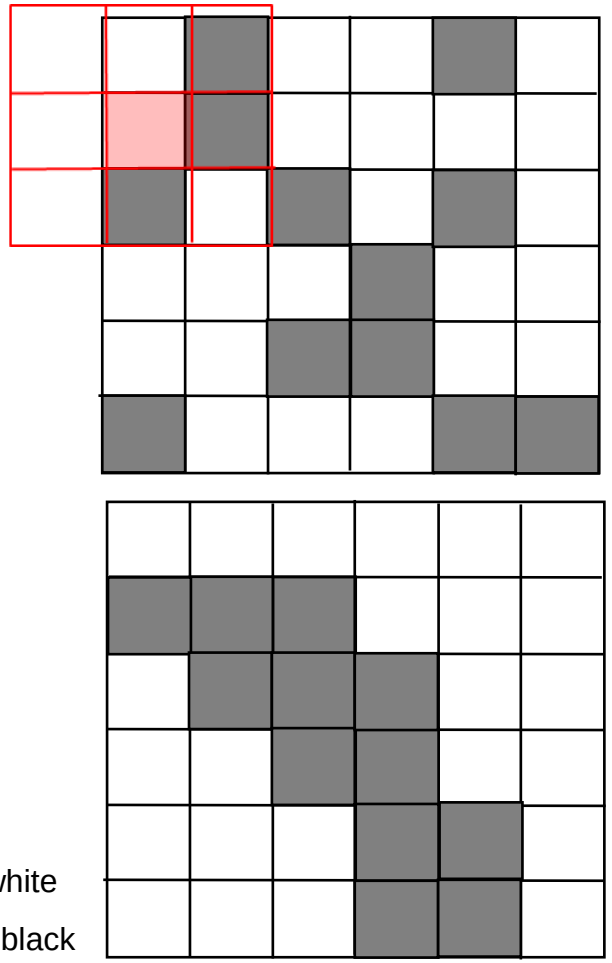

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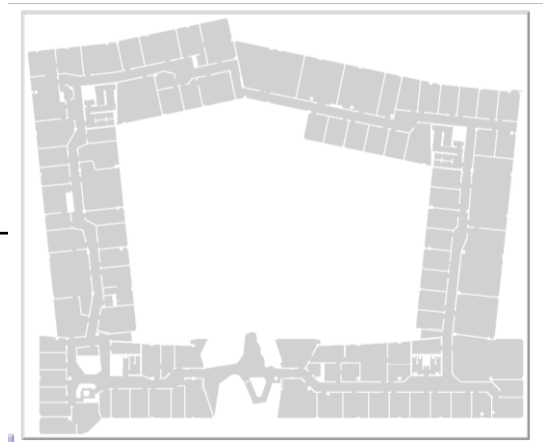
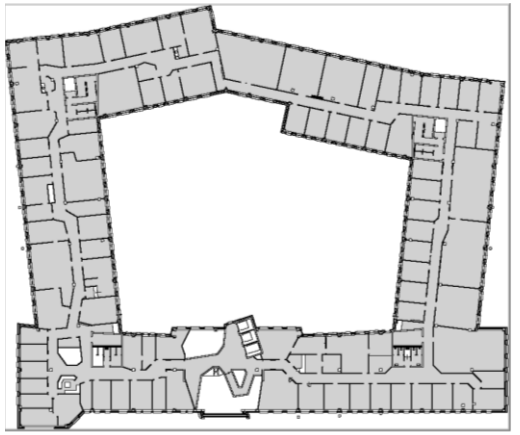
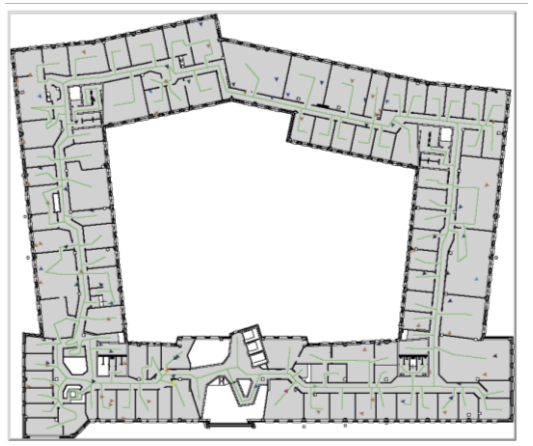
HOW DO AGENTS INTERACT WITH ENVIRONMENTS?

- The agent can collect the state of the environment (e.g. the patch/cell they occupy) and use this information in their decision making.
- The agent can scan the environment to select the best locations.
- The agent can move based on the environment.
  - The agents cannot walk through walls in the evacuation model
  - There is an environment that defines walkable space
  - The officers move via a network environment that guides them via all rooms on one side of the corridor.







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- Environments (2)
  1. What is an environment?
  2. Different types of environments
  3. Static versus dynamic environments
- Time (3)
  - Ticks
  - Calibration of ticks
  - Events
  - Multiple timelines

TICKS

- A tick is a measure of time in NetLogo models (like seconds or minutes). Ticks are used instead of seconds, minutes, or hours because ticks are standardized across all models and computers;
- In many NetLogo models, time passes in discrete steps, called “ticks”.

- Discrete time steps means, that the same code is repeated each tick. At each time step the agents evaluate their current state of fitness, sense the environment, take a decision and act. Each time step the model iterates through these processes.

TIME - EVENTS

Event-driven simulations react to *events* that take place.
Events can be caused by the environment (external event) or be scheduled (internal event)

A time advance is specified as the time it takes until the next internal event.

Upon expiration of the time advance, the system will be updated, however, when an external event occurs, the system will update itself immediately

TIME - EVENTS

Scheduled events may be implemented in three ways:

- Events may be sequenced in a synchronous step wise fashion.
- An event may be scheduled to occur only once at some time step *n.*
- The model may encapsulate ‘event-driven’ processes whereby model agents may trigger events to occur or may add events to the schedule or queue of events to take place

Ropella, G., et al. (2002). "Software engineering considerations for individual-based models." Natural Resource Modeling **15**: 5-22.

TIME - EVENTS

Three types scheduling:

- Events can be scheduled directly (at the beginning)
- Events can be scheduled during the run of a simulation
- Events can be scheduled with Watcher (watcher informs an agent of the state change in another agent)

Disease simulation:

- Every weekday go to school at 8.00 hours
- When a child reaches the age of 4, schedule the child to go to school
- When the child becomes ill, change the schedule of the parent to return home and care for the child.

MODELS WITH VARIOUS TIMELINES

- You may have sub models that contain processes that you want to model at different temporal scales:
  - Visitors of the beach with a time step of hours
  - Vegetation growth in the dunes at a monthly time step

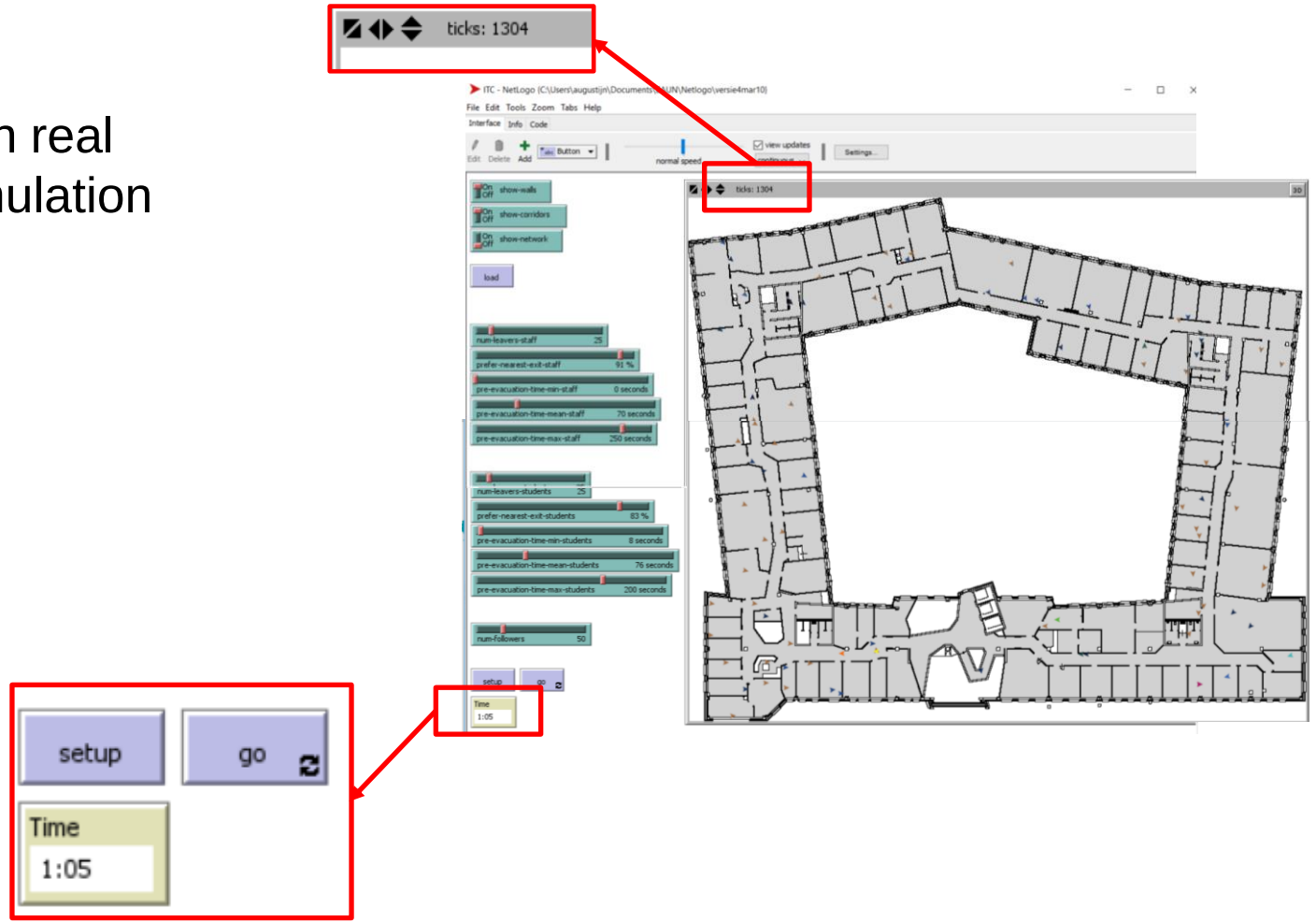
TIME - CALIBRATION

Calibrating time

- Link between real time and simulation time

```
to-report get-time
  let seconds ticks / ticks_per_sec
  let minutes floor (seconds / 60)
  set seconds round (seconds mod 60)

  ifelse seconds < 10
  [
    report (word minutes ":0" seconds)
  ]
  [
    report (word minutes ":" seconds)
  ]
end
```



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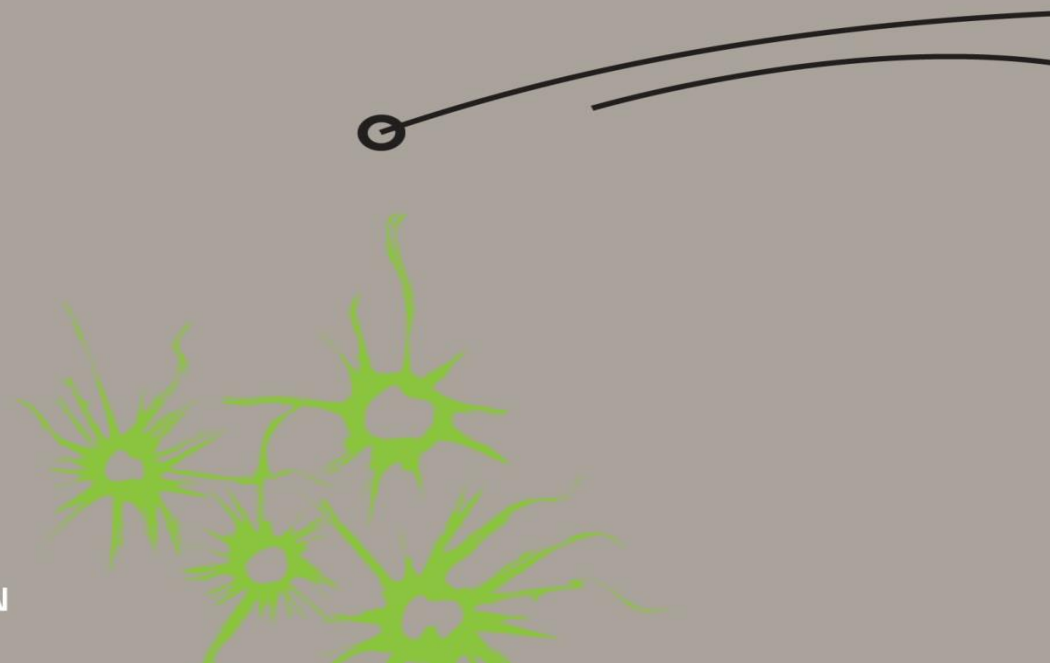
TEAM BASED LEARNING



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WHICH AGENT CHARACTERISTICS DO THE WOLF AND SHEEP HAVE?

Use the wolf – sheep model. Define which characteristics the wolf/sheep have. Select **all** correct answers.

a) Both the wolf and the sheep have a goal.

b) Both the wolf and the sheep are discrete entities positioned in an environment.

c) The wolf and sheep communicate

d) The wolf and sheep have a memory

CA MODELS

Q1: Below you see a picture of a CA model. This CA model simulates the spread of fire. At time step 1 (shown below) one patch (cell = 100) is changed to fire (indicated in red). The patch (cell) values represent the tree density of the area.

The model has the following transitions rules:

- Not currently on fire and not burned: if neighbor of fire and **density >=50%** become fire (value 100).
- Currently on fire (value 100): turn to the value 0 (burned)

The model uses a so called 5 cell von Neumann neighborhood.

49	25	55	50
33	54	34	45
100	55	43	61
51	47	67	39

What is the value of the green cells in the next timestep?

a. Both have a Value of 100

b. Both have a Value of 0

c. The top one has a value of 100 and the lower cell has a value of 47

d. The top cell has a value of 54 and the lower cell 47

IN THE WOLF SHEEP EXAMPLE, IS THE ENVIRONMENT DYNAMIC?

In the wolf-sheep example, which statement about the environment is correct?

a) The grass is a physical, deterministic and dynamic environment in which change is induced by agents.

b) The grass is a social, stochastic and physical environment because the wolf and sheep meet at the same patch/cell.

c) The grass is a physical environment that is deterministic and static, because the change in the environment only takes place when sheep eat the grass, and not because of the grass itself.

d) The grass is static, as the grass environment does not have any behaviour of its own

TIME

Time is the wolf sheep model is:

a) Calibrated

b) Event-based

c) Continuous

d) Divided in discrete time steps