# Multi-Agent Systems

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# Course outline

# Agent-Based Modeling

## Definition (Wilensky & Rand, 2015)

Agent-based modeling is a form of computational modeling whereby a phenomenon is modeled in terms of agents and their interactions.

- Agents are entities that have state variables and values (e.g., position, velocity, age, wealth)
  - Gas molecule agent: mass, speed, heading
  - Sheep agent: speed, weight, fleece
- Agents also have rules of behavior
  - Gas molecule: Rule to collide with another molecule
  - Sheep: Rule to eat grass
- Universal clock: At each tick, all agents invoke their rules.

# Wolves and Moose

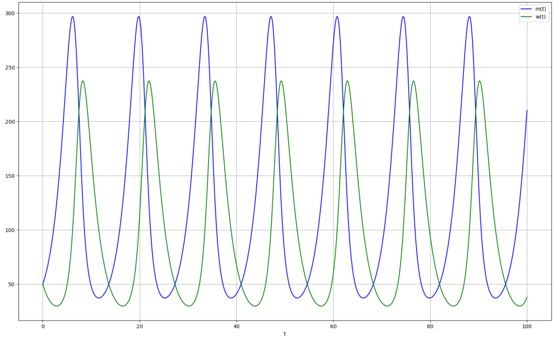
The populations of wolves and moose of Isle Royale have been observed for more than 50 years. Result: Dynamic variation rather than ‘balance of nature’.

- More wolves
- ... leads to less moose
- ... leads to less wolves
- ... leads to more moose.

# Wolves and Moose: Classical Model

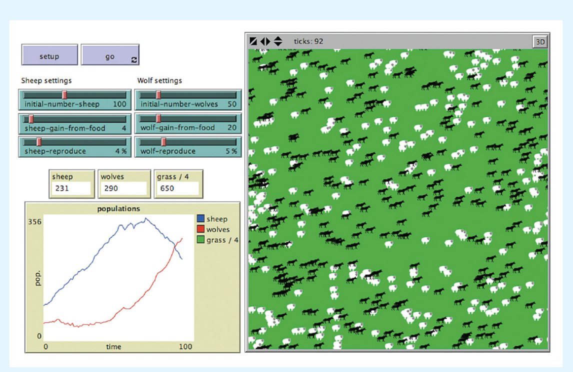
Lotka-Volterra model for wolf (w) and moose (m) populations:

$$\frac{\delta m}{\delta t} = k_1 m - k_2 w m, \frac{\delta w}{\delta t} = -k_3 w + k_4 k_2 w m$$



# Wolves and Moose: Agent-Based Model

- Spawn *m* moose and *w* wolves and invoke each agent's behavior in each loop:
  - ask moose [move death reproduce-sheep]
  - ask wolves [move set energy energy - 1 catch-sheep death reproduce-wolves]



# Discussion: Pros and Cons

Differential Equations

- Pro: Mathematically well understood, analytical inference by using calculus, many tools available (e.g., Matlab)
- Con: Hard to explain, models phenomenon rather than behavior, harder to extend

Agent-Based Model

- Pro: Easy to understand and to explain to stakeholders, models individual beahvior and observes emergent phenomenon, easy to extend
- Con: Tool support improves slowly, no analytical tools comparable to calculus

# Modeling Traffic

- Observation: Traffic on the motorway produces certain patterns.
- Question: Can similar patterns be algorithmically reproduced?
- Agent-Based Simulation approach:
  - Modeling traffic on the motorway as a multi-agent system
  - Cars (drivers) as agents
    - Percepts: Distance to next car in front
    - Internal State: Current Speed
    - Actions: Speeding, braking

# Nagel-Schreckenberg Model: Motivation

- Research Question: How do traffic jams emerge?
- Research Hypothesis: Might be due to the local behaviour of individual agents.
- Approach: Model traffic as a MAS and study the resulting system's behavior. If the systems' behavior matches empirical phenomenon, then the model might be an acceptable explanation.

# Cellular Automaton

- A cellular automaton is a quad-tuple $A = < R, Q, N, \delta >$
- A cell space $R$
- A set $Q$ of states each cell can be in
- A neighborhood $N : R \rightarrow 2^R$
- A transition function $\delta : Q^{|N|} \rightarrow Q$
  - For a probabilistic cellular automaton, $\delta$ is a probability distribution $P(r = q | N(r))$
- The configuration of $A$ can be written as $x_1 x_2 \ldots x_n$ with $x_i$ being the state of the cell $r_i$.

# Nagel-Schreckenberg Model: Representation

- Traffic is modeled as $A =< R, Q, N, \delta >$
- Entities of $R = \{c_1, c_2, \ldots\}$ stand for parts of the lane
  - Each cell corresponds to a discrete part of the lane (roughly the space needed by a car)
- $Q = \{0, \ldots, v_{max}, free\}$: Each cell is either occupied by one car with velocity $v \leq v_{max}$, or it is empty.
- $N(c_i) = \{c_{i-v_{max}}, \ldots, c_{i+1}\}$
- $\delta$ is realized by a set of four rules executed by each driver

# Nagel-Schreckenberg Model: Rules

- Each car at cell $c_i$ with velocity $v$ performs four consecutive steps:
  - Acceleration: If $v < v_{max}$ and gap to next car is larger than $v+1$, then increment speed by 1.
  - Slowing down: If the next car is at cell $i+j$ with $j \leq v$, then reduce speed to $j-1$.
  - Randomization: If $v > 0$, then decrement $v$ by 1 with probability $p$.
    - Car does not accelerate although it could (takes back Acceleration)
    - Car reached maximal velocity but slows down again
    - Overreaction when braking
  - Car motion: Move forward $v$ cells.

# Nagel-Schreckenberg: Example

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# Nagel-Schreckenberg: Example

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# Nagel-Schreckenberg: Example

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# Nagel-Schreckenberg: Example

2 _ _ 2 _ _ 2 _ _

_ _ 2 _ _ 2 _ _ 2

_ 2 _ _ 2 _ 1 _ _

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# Nagel-Schreckenberg: Density and Flow

- Assume constant system density: $\rho = \frac{|Ag|}{|R|}$
- For a fixed cell $c_i$, time-averaged density over time interval $T$:

$$\bar{\rho}^T = \frac{1}{T} \sum_{t=t_0+1}^{t_0+T} n_i(t)$$

- ...with $n_i(t) = 1$ if $i$ is occupied, else $n_i(t) = 0$
- Time-averaged flow $\bar{q}$ between $i$ and $i+1$:

$$\bar{q}^T = \frac{1}{T} \sum_{t=t_0+1}^{t_0+T} n_{i,i+1}(t)$$

- ...with $n_{i,i+1}(t) = 1$ if some car moved between $i$ and $i+1$ at $t$, else $n_{i,i+1}(t) = 0$

# Nagel-Schreckenberg: Fundamental Diagram

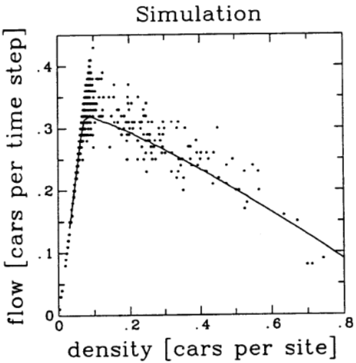


Fig. : Source: [2]

# Outlook

- Exercises: You will implement the Nagel-Schreckenberg Simulation by yourself and thereby become familiar with our multi-agent simulation framework.
- Next Week: On the diversity of agent architectures

# Literature I


U. Wilensky, W. Rand, An Introduction to Agent-Based Modeling, MIT Press, ISBN: 9780262731898, 2015.

K. Nagel, M. Schreckenberg (1992), A cellular automaton model for freeway traffic, J. Phys. I France 2, pp. 2221–2229.