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Vahana.jl Workshop

Part I - Vahana.jl Basics & First Model Implementation

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Introducing Vahana.jl

- Vahana is an open source HPC framework designed for **large-scale ABMs**, particularly those focusing on complex social systems.
- Vahana has a focus on **network-based models**, although it is allowed to include a spatial dimension.
- Vahana simplifies the development phase with its **interactive capabilities**, using Julia's REPL.
- Once developed, a Vahana simulation can be **run parallelized** without additional actions from the developer.
- Models must be formulated as a **Graph Dynamic System** (GDS), which imposes certain constraints.

(Synchronious) Graph Dynamical Systems (GDS)

- A GDS involve a **finite graph** with a state assigned to each vertex and a **vertex function** that update the state of a vertex based on the states of its neighboring vertices.
- In a synchronious GDS (SyGDS), all vertex state updates happen **simultaneously**.
- A SyGDS can be interpreted as a **generalized cellular automata**, where the neighborhood is determined by the network instead of the position of the cell.
- When an ABM is implemented as a GDS, the **vertices represent the individual agents** of the model.

Vahana's SyGDS Extension

We have ...

- A **directed graph** $G_t = (V_t, E_T)$.
- Vertices of **different types** $\delta_v \in \Delta_V$, and a mapping function $\pi_v : V_t \to \Delta_V$.
- Likewise edges of **different types** $\delta_e \in \Delta_E$, and a mapping function $\pi_e : E_t \to \Delta_E$.

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- Likewise edges of **different types** $\delta_e \in \Delta_E$, and a mapping function $\pi_e : E_t \to \Delta_E$.
- For each δ_v and δ_e a different **state space** $\Theta_\delta = X_{\delta,1} \times \ldots \times X_{\delta,n_\delta}$, where each $X_{\delta,i}$ is itself a set (like e.g. $\mathbb{N}$).
- At least one **transition (vertex) function** $f_{\delta_v,i} : G'_{v,t} \to (V'_{v,t+1}, E'_{v,t+1})$, where $G'_{v,t}$ is the 1-neighborhood of vertex $v \in G_t$.
- The source v_s and target v_t of an $e \in E'_{v,t+1}$ must be vertices of $G'_{v,t} \cup V'_{v,t+1}$.

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- The source v_s and target v_t of an $e \in E'_{v,t+1}$ must be vertices of $G'_{v,t} \cup V'_{v,t+1}$ **or a raster vertex**.

Constructing G_{t+1}

To construct G_{t+1}, we take the following actions:

- For each vertex $v \in V_t$ we **apply** $f_{\pi_v(v),i}$.
- **Combine** the results: $G_{t+1} = (\bigcup_{v \in V_t} V'_{v,t+1}, \bigcup_{v \in V_t} E'_{v,t+1})$.
- **Remove** all $e \in E_{t+1}$ with a source v_s or target v_t that is not in V_{t+1}.

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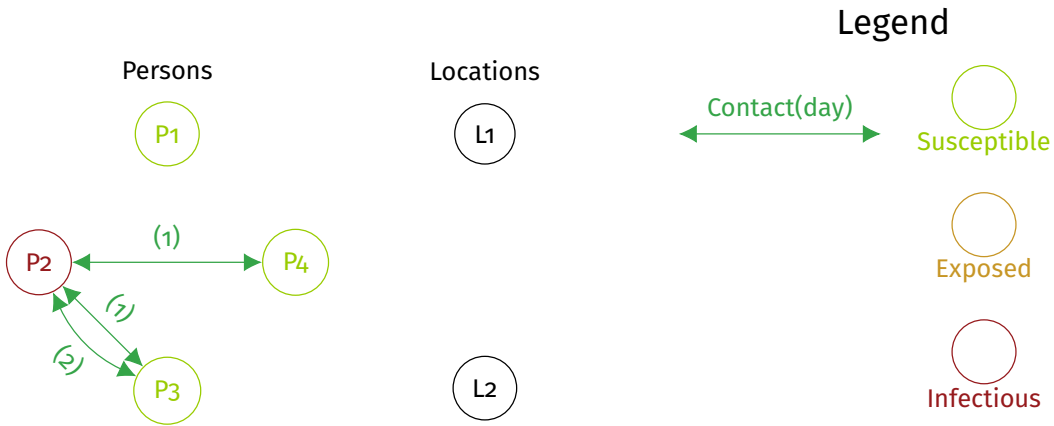
It would be inefficient and cumbersome to require that even **invariant parts of the graph** must be reconstructed, so:

- Users specify which vertex/edge types are **mutable** during transitions.
- There exist an option to retain existing agents/edges of a type, **only adding new ones**.

Example: A epidemiological model



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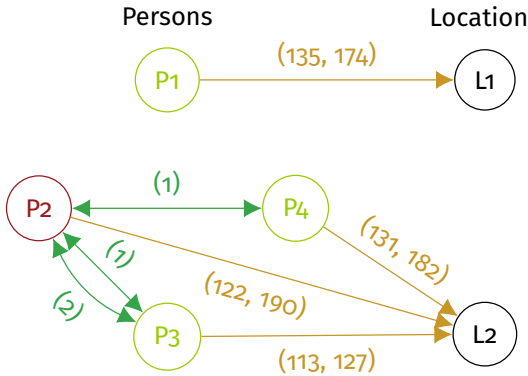
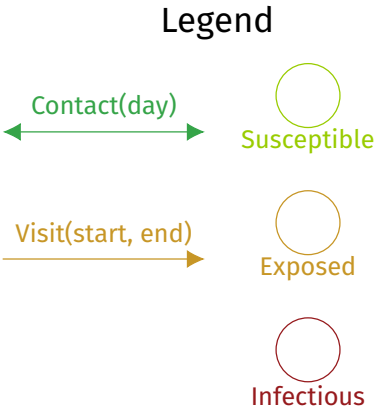
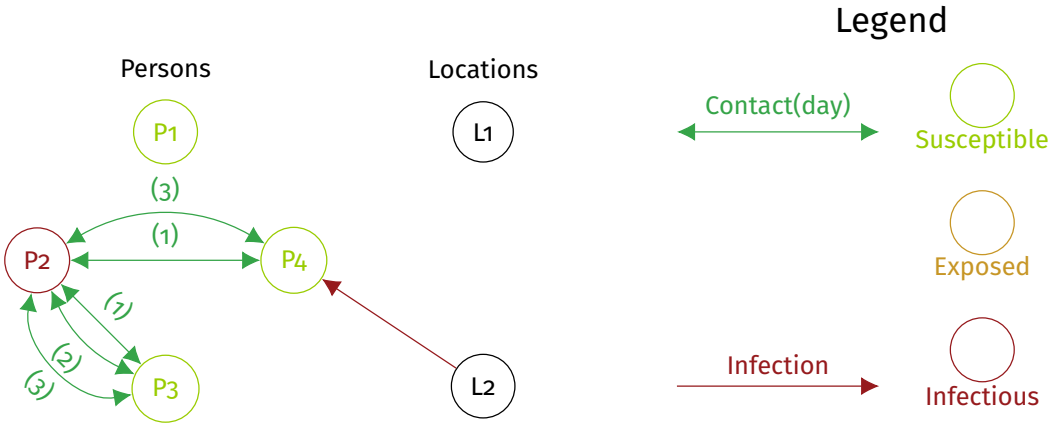




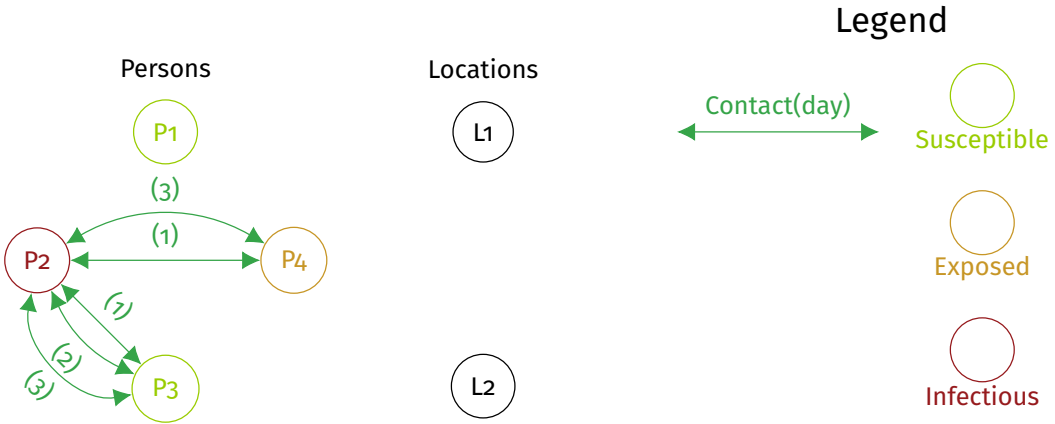
Persons: Plan day

Example: A epidemiological model



Locations: Infect persons & add contacts

Example: A epidemiological model



Persons: Update health status

REPL example

```
julia> show_agent(sim, Person; neighborstate = true)
Id / Local Nr: 0x0100000000085e35 / 548405
State:
    health=susceptible
    age=41
    quarantine=Quarantine(false, -1, -1)
Edge(s):
    MaybeEvent
        from:               edge.state:
        0x020000000007691a MaybeEvent(0, ACTSTART, HOME)
        0x020000000007691a MaybeEvent(32520, ACTEND, HOME)
        ... (16 not shown)
    Home
        from:
        0x020000000007691a
    Knows
        from:               neighborstate:
        0x0400000000000001 capacity=0, traced=0, reported_infections=0,
```

Parallel Simulations

- Vahana.jl uses the **Message Passing Interface** (MPI) for communication across processes.
- But it **shields users** from complexities of MPI.
- At the end of the initialization phase, the actual graph is **automatically partitioned** and distributed to the processes.
- Each **process only knows a subset** of the graph representing simulation state.
- Vahana.jl uses **MPI-3 shared memory** to avoid copies of agent state on same node.

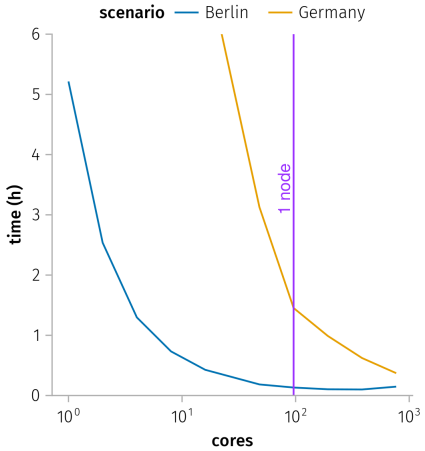
MATSim Episim

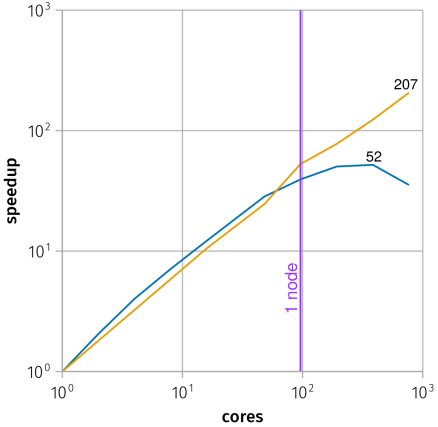
- MATSim Episim is an **epidemiological model** designed to predict the spread of infectious diseases within a population.
- It simulates individual agents moving between various **locations** such as their homes, workplaces, or schools.
- During the COVID-19 pandemic, this model was regularly used to **advise the German federal government** by providing reports containing evaluations of the **impact of various interventions**.
- Each report required **thousands of simulations** based on mobile-phone data for Berlin and Cologne, considering the activities of 25% of a city's population.

MATSim Episim Scenarios

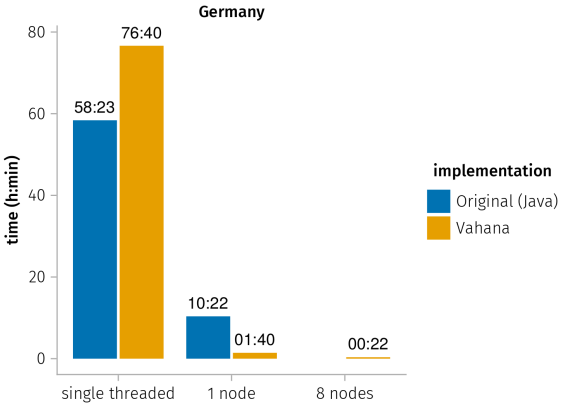
	Berlin	Germany
Persons	1,013,973	16,334,073
Locations	889,958	11,538,167
Location Visits	6,814,215	91,534,255

Parallelization Performance of Vahana's Episim Implementation





Parallelization Performance Compared to Original Implementation



With Vahana, simulations for the whole of Germany becomes practical.

Hegselmann-Krause (HK) Opinion Model

- Finite number n of agents
- Time is **discrete**: $t = 0, 1, \ldots$
- Real number $x_i(t)$ represents the **opinion** of agent i
- There is a **confidence bound** $\epsilon > 0$, opinions with a difference greater then ϵ are ignored.
- Opinions are updated **synchronously** according to

$$x_i(t+1) = \frac{1}{|\mathcal{N}_i(t)|} \sum_{j \in \mathcal{N}_i(t)} x_j(t)$$

$$\text{where} \quad \mathcal{N}_i(t) = \{j : \|x_j(t) - x_i(t)\| \leq \epsilon\}$$