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Modeling of AmI-based socio-technical systems

Hermann de Meer, Richard Holzer

Chair for Computer Networks & Computer Communications
University of Passau
Germany

Overview

1. Modeling Socio-technical systems
2. Quantitative measures
3. Example: Traffic scenario
4. Example: Evacuation scenario

Socio-technical systems

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- For the evaluation of **socio-technical systems** a mathematical model can be used.
- Socio-technical systems may be very **complex.**
  - ⇒ A single model does not suffice to describe all relevant aspects of the system.
  - ⇒ Combination of many different models is necessary.
  - ⇒ **Integrated model**, which contains different aspects from the different models.
- **Ambient Intelligence** (AmI) based smart environments:
  - Ability to **monitor user actions**.
  - Adjust their configuration and functionality accordingly.
  - System **reacts** to human behavior while at the same **influencing** it.
    - ⇒ **Feedback loop**
    - ⇒ **Tight entanglement** between the human and the technical system.

Socio-technical systems

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SOCIONICAL

- **Large scale integrating project** funded by the EU in FP7 (ICT).
- **Duration:** 1.2.2009-31.1.2013
- Development and evaluation of methods and tools for modeling, simulation, and prediction of global properties and emergent phenomena in large scale socio-technical systems.
- Focuses on **AmI** based smart environments.
- Partners:

Universität Passau	Akademia Górniczo-Hutnicza im. Stanis#awa Staszica w Krakowie
Beacon Tech LTD	Julius-Maximilians Universität Würzburg
Universität Linz	Fraunhofer Gesellschaft zur Förderung der angewandten Forschung E.V.
London School of Economics and Political Science	Sociedad Iberica de Construcciones Electricas Sa
Eidgenössische Technische Hochschule Zürich	SmartCare Srl
Vereiniging voor Christelijk Hoger Onderwijs	Technische Universität München
Wetenschappelijk Onderzoek en Patientenzorg	Martin-Luther-Universität Halle-Wittenberg
	Civil Protection Department - Ministry of Home Affairs

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- The partners of SOCIONICAL have brought in their expertise in different modeling methods to build a methodology for the creation of **integrated models**.
- Such an integrated model consists of many models
- Each model may specify different **aspects** of the system.
  - **Individual model**
    - **Aspects:** Physical characteristics of humans (e.g. age, gender) and devices, cognitive characteristics (e.g. trust), …
  - **Social model**
    - **Aspects:** Social identity (e.g. relatives), grouping behavior, …
  - **Population model**
    - **Aspects:** Global properties (e.g. population size, density) of the humans in the system and their macro-behavior

Socio-technical systems

- **Dispersion and collection model**
  - **Aspects:** (Explicit or implicit) spread or collection of information (e.g. sensors on AmI devices, advices given by AmI devices)
- **Space and environment model**
  - **Aspects:** Structure of the space and of the environment
- **Mobility model**
  - **Aspects:** Movement of humans and devices
- **Evolutionary dynamics model**
  - **Aspects:** Global dynamic phenomena (e.g. spreading of fire) and their macro-behavior

Socio-technical systems

- After building the integrated model, **evaluation methods** have to be chosen:
  - Analytical evaluation methods
  - Simulation
- For analyzing self-organizing properties of a socio-technical system, **quantitative measures** have been developed.
- Quantitative measures are defined on the micro level to describe global properties.

Quantitative Measures

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The following **quantitative measures** are based on information entropy H:

Levels of

- emergence
  - Are there any coherent patterns induced by local interactions?
- autonomy
  - How much control data from external entities are needed to keep the system running?
- global state awareness
  - How much information does a single entity have about the global state (averaged over all entities)?

Quantitative Measures

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The following **quantitative measures** are based on fitness functions:

Levels of

- target orientation
  - Is the high-level goal that the system designer had in his mind, reached by the system?
- adaptivity
  - Is the high-level goal also reached after changes in the environment (new control data from external entities)?
- resilience
  - Is the high-level goal still reached after unexpected events in the system (e.g. break down of nodes, attacks by an intruder, …)?

Although quantitative measures are defined analytically on the micro level, it is usually too difficult to calculate them analytically, so they are **approximated** by simulations.

Emergence

To measure the **level of emergence**

$\varepsilon \in [0, 1]$

of a system, we consider the values in the communication channels $k \in K$ between the entities and compute the dependencies.

At time t we compare the information contained in all channels with the sum of the information contained in each single channel:

$$\varepsilon_t = 1 - (H(Conf_t|_K) / \sum_{k \in K} H(Conf_t|_k))$$

where $Conf_t$ is the global state containing all local states and all values on the communication channels at time t and $Conf_t|_K$ is the valuation of communication channels at time t and H denotes the information entropy.

Level of emergence of the whole system in the interval [0, T]:

$\varepsilon_{[0, T]} = Avg(t \mapsto \varepsilon_t)$, Time average value of the map $t \mapsto \varepsilon_t$

$\varepsilon_{[0, T]} \approx 1$ high level of emergence (many dependencies)

$\varepsilon_{[0, T]} \approx 0$ low level of emergence (few dependencies)

Global state awareness

To measure the **level of global state awareness**

$\omega \in [0, 1]$

the initial states are partitioned according to the equivalence relation induced by a property of interest.

- Measurement of the information of each node about the initial equivalence class:

$$\omega_t = 1 - \frac{H(\text{equivalence class} \mid \text{local history up to time } t)}{H(\text{equivalence class})}$$

ω_t is a nondecreasing function of the time:
Increasing local history leads to a decreasing entropy.

Level of global state awareness of the whole system in a time interval [0, T]:

$\omega_{[0,\,T]} = \mathrm{Avg}(t \mapsto \omega_t)$ Time average value

$\omega_{[0,\,T]} \approx 1$ means high level of global state awareness
(each node knows much about initial equivalence class)

$\omega_{[0,\,T]} \approx 0$ means low level of global state awareness
(each node knows few about initial equivalence class)

Target orientation

Before a new system is designed, we have a goal of the system in our mind:

The system should fulfil a given purpose.

Fitness function: In the model, the goal can be described by a valuation of configurations (either time dependent or time independent):

$b_t : Conf \to [0, 1]$ (Conf is the set of all global states)

Level of target orientation at time t:

$TO_t = \boldsymbol{E}(b_t(Conf_t))$, where $\boldsymbol{E}(X)$ is the mean value of a random variable X, i.e. TO_t is the average valuation of the global state $Conf_t$ at time t.

Level of target orientation of the whole system in a time interval [0, T]:

$TO_{[0, T]} = Avg(t \mapsto TO_t)$ Time average value

$TO_{[0, T]} \approx 1$ means that the system mostly runs through many good configurations

$\Rightarrow$ high level of target orientation

$TO_{[0, T]} \approx 0$ means that the system mostly runs through many bad configurations

$\Rightarrow$ low level of target orientation

Example: Traffic scenario

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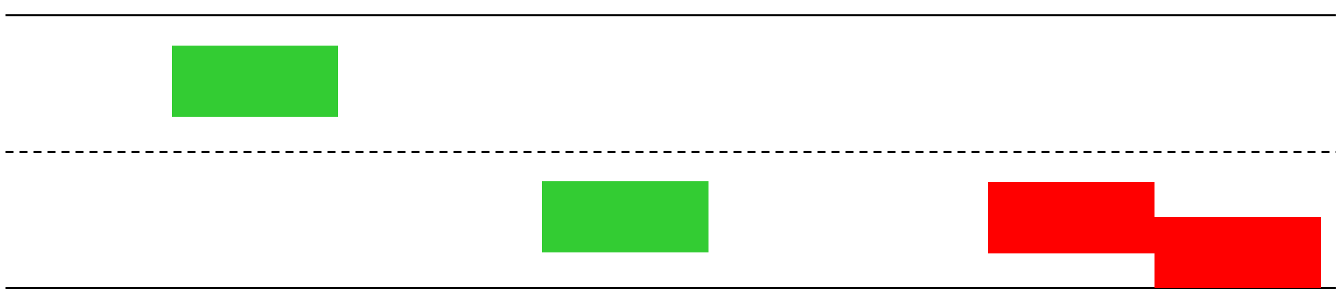
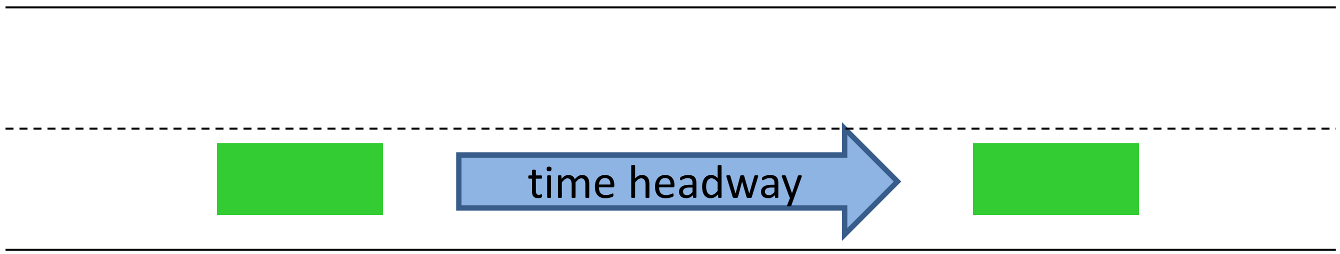
- **Scenario:**
  - There was an **accident** on a highway
  - Other cars **slow down**, when they are approaching the scene of accident.
  - Possibility for **AmI device**:
    - Some cars may contain a device, which **send information** (e.g., current position) to other cars to improve safety.
    - The device can give **advice to the driver** (e.g., slow down) before he reaches the scene of accident
  - Which rules for the AmI device leads to a high level of target orientation?



Example: Traffic scenario

- **Proposed system:**
  - If speed of a car is below a threshold v_0, AmI device sends an **alert** to inform the cars behind.
  - Alerts are **forwarded** backwards by other cars together with the position of the sender.
  - If the distance to the sender is smaller than a **threshold** s_r (relevance distance), the adaptive-cruise-control (ACC) is activated:
    - **Time headway** is changed to 1.8s
    - **Speed** is changed to 60km/h
    - Car stays in **current lane** until the merging point is reached.

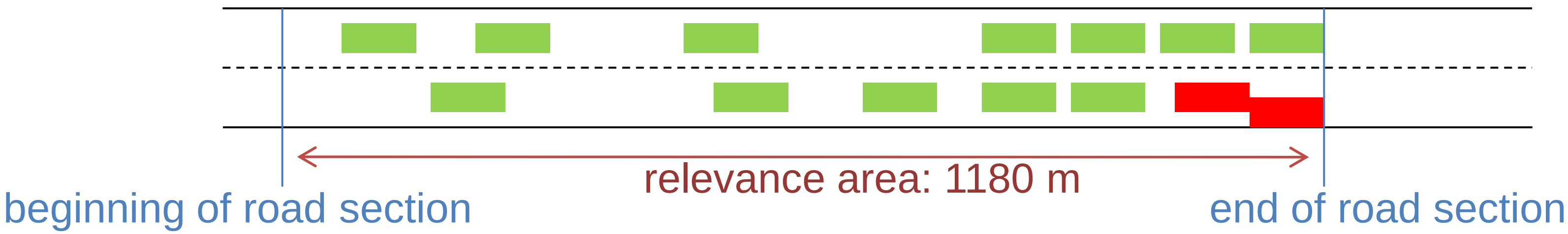


Example: Traffic scenario

- The specification of the whole **integrated traffic model** includes
  - an **individual model** for the car (physical properties of cars and devices),
  - the **population model** (e.g. number of cars per hour),
  - a **dispersion** and **collection model** (information spread),
  - a **space** and **environment model** (structure of the environment),
  - a **mobility model** (movement of cars).
- **Note:** ACC is only a part of the mobility model. The whole integrated model consists of many other rules and parameters.

Example: Traffic scenario

- For the analysis, we consider only a short road section (**communication area** for AmI alerts):
  - Outside of the communication area, the distance to traffic jam is larger than the threshold s_r during the whole run of the simulation, so the alert signals would have no effect on the behavior.
  - The number of cars in this communication area varies from 15 to 40.

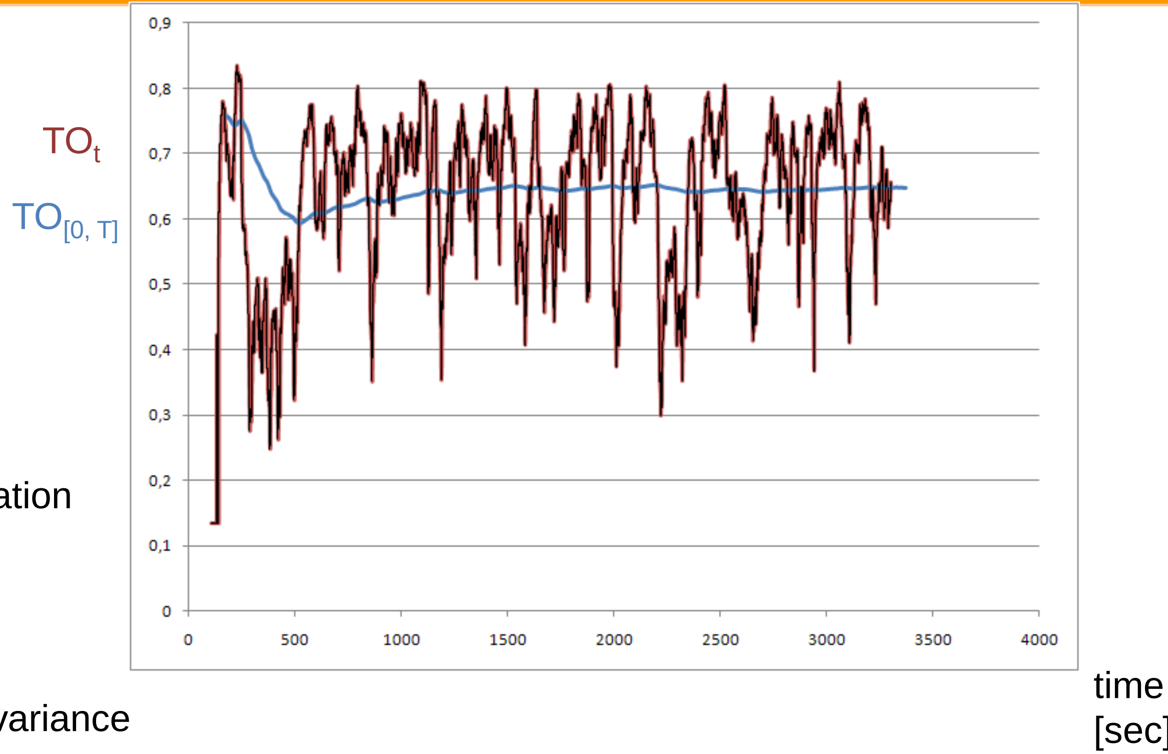


Example: Traffic scenario

- For the **level of target orientation**, we have different possibilities to define a **"fitness function"** $b : \mathrm{Conf} \rightarrow [0, 1]$ for the current state:
  - Based on the **variance of the velocities** of the cars.
  - Based on the **variance of the time headways** of the cars.
  - Based on the **relative velocities** from one car to the next car.
  - …

Example: Traffic scenario

- TO using variance of velocity v_i of each car i



$$TO_t = 1 - K \cdot \frac{\sigma_t}{\mu_t}$$ level of target orientation

$$\mu_t = \frac{1}{n_t} \cdot \sum_{i=1}^{n_t} v_i(t)$$ mean velocity

$$\sigma_t^2 = \frac{1}{n_t - 1} \sum_{i=1}^{n_t} (v_i(t) - \mu_t)^2$$ empirical variance

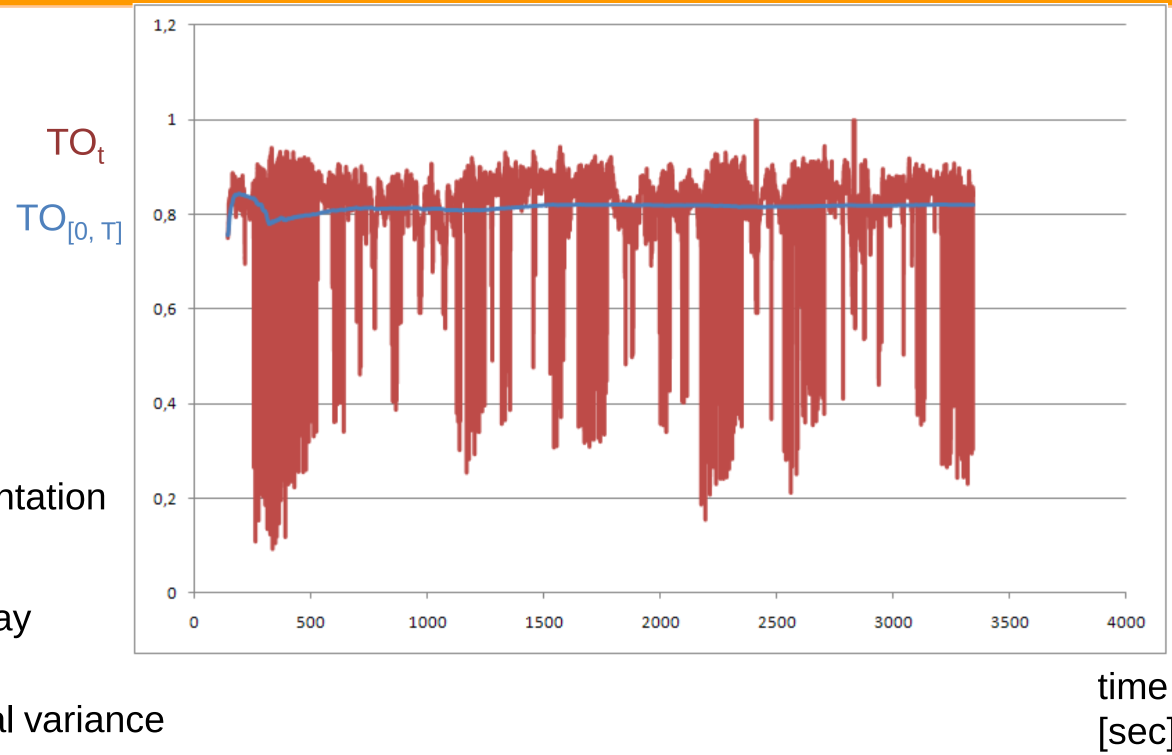
$\frac{\sigma_t}{\mu_t}$ variance coefficient

n_t number of cars in the system at time t

K normalizing constant for the variance coefficient

Example: Traffic scenario

- TO using variance of time headway thw_i of each car i



$TO_t = 1 - K \cdot \frac{\sigma_t}{\mu_t}$ level of target orientation

$\mu_t = \frac{1}{n_t} \cdot \sum_{i=1}^{n_t} thw_i(t)$ mean time headway

$\sigma_t^2 = \frac{1}{n_t - 1} \sum_{i=1}^{n_t} (thw_i(t) - \mu_t)^2$ empirical variance

$\frac{\sigma_t}{\mu_t}$ variance coefficient

n_t number of cars in the system at time t

K normalizing constant for the variance coefficient

Example: Traffic scenario

Quantitative measures can be used to **optimize** the system parameters and the local rules.

- Level of **target orientation**:
  - For each setting, **simulation runs** lead to an approximation of the level of target orientation.
  - The highest level of target orientation indicates the **optimal values** for the system parameters.
- Measure of **global state awareness**
  - Some drivers already know about the **traffic jam** near the accident.
  - Other drivers are not aware of the situation.
  - The measure for **global state awareness** can be applied to analyze the influence of different settings for system parameters:
    - Which system parameters can increase the **global state awareness**?
    - Safety can be increased, if all drivers have **maximal information** about the global state.

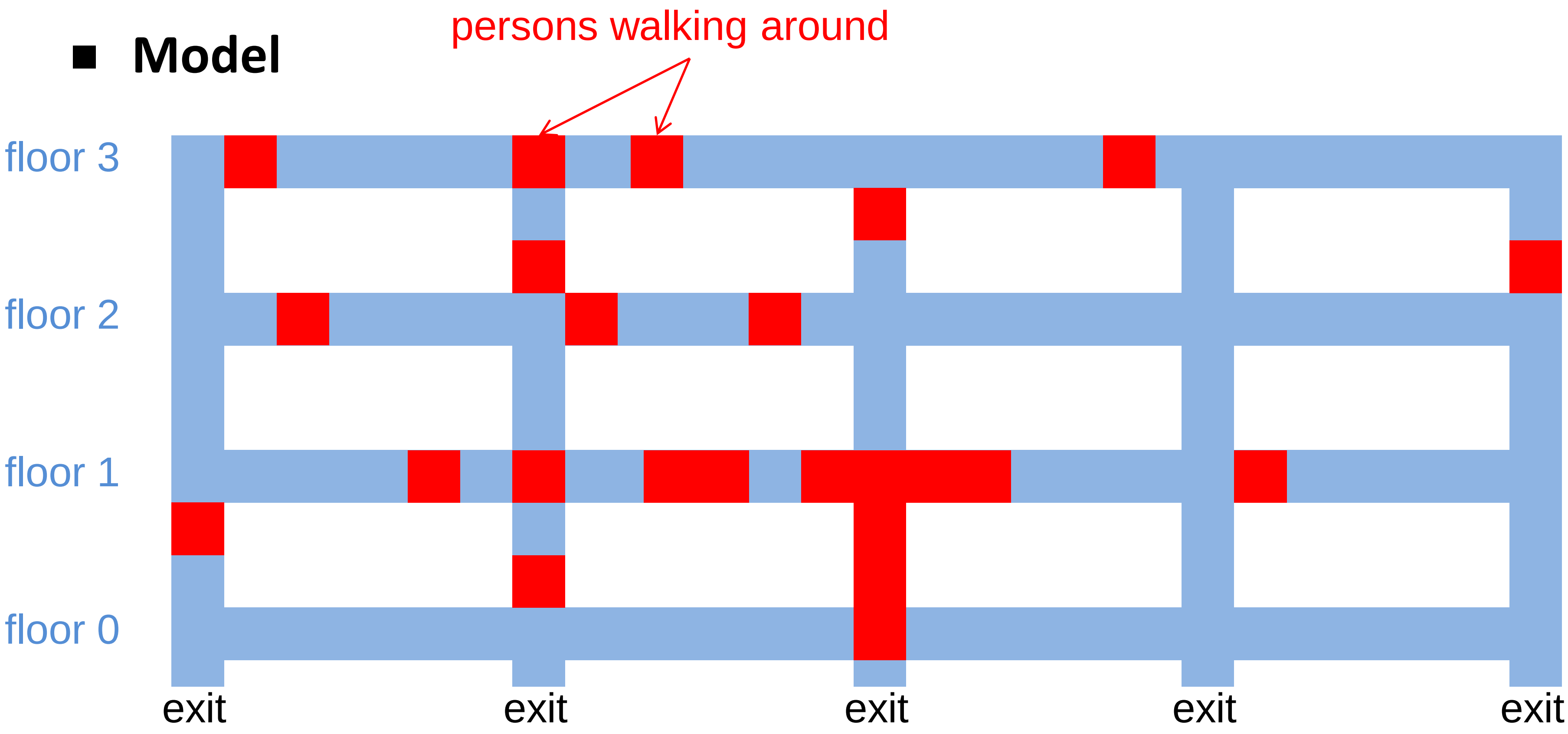
$\Rightarrow$ Improved **safety** in traffic

Example: Evacuation scenario

- **Scenario:** Evacuation in a building
  - Each person wears an AmI device, which is able to communicate with the other AmI devices to improve the evacuation.

Example: Evacuation scenario

- **Model**



Example: Evacuation scenario

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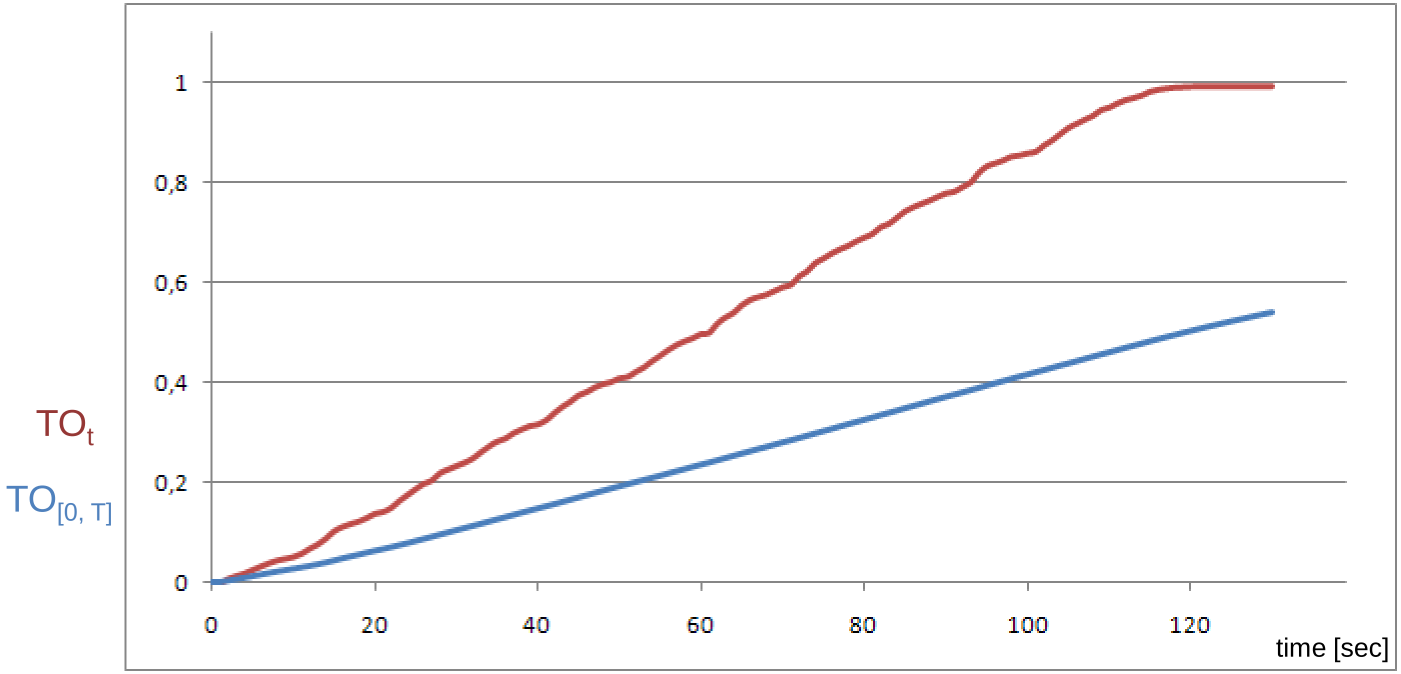
For the **target orientation** we need a valuation of configurations:

$b_t : \text{Conf} \to [0, 1]$

- In the evacuation scenario the good configurations are those where many people have already escaped:
  - $b_t(c) = \#\text{escaped}/N$ $c \in \text{Conf}$, N = number of persons

- Consider a run of the system starting at time t = 0 ending at t = T.
- $TO_t = \boldsymbol{E}(b(\text{Conf}_t))$ is a nondecreasing function
- **Goal:** Try to maximize $TO_{[0, T]}$

Example: Evacuation scenario



Evaluation of different evacuation strategies:

- Which local rules should be used based on the information given by the AmI device?
  - Goal: Optimization of the evacuation

Evaluation of the scenarios

- **Evacuation scenario**:
  - University of Halle-Wittenberg is currently adapting a simulation software to produce the necessary time series.
- **Traffic scenario**:
  - University of Munich is currently producing the necessary time series.
- University of Passau has developed a software for the **evaluation of the quantitative measures** for the time series of simulation runs.
- **Goals:**
  - Analysis and evaluation of the systems
  - Optimization of system parameters and local rules

Conclusion

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For the evaluation of **socio-technical systems** we need

- a methodology for building an **integrated model**, which is rich enough to represent all relevant aspects,
- **evaluation methods**, which allow either an analytical analysis of the model or the usage of time series received from simulation runs.

Quantitative measures provide a link from the micro level to the macro level:

- They describe **global properties of the system**
- They can be used for the **analysis** of complex systems.
- They can be used for **optimization** of existing systems and for the **design** and **engineering** and of new systems.

Thank you for your attention

Hermann de Meer

Chair for Computer Networks & Computer Communications
University of Passau
Germany

demeer@fim.uni-passau.de

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