

# Modeling Behavioral Changes in Agent-Based Simulations

## PhD Defense (Rigorosum)

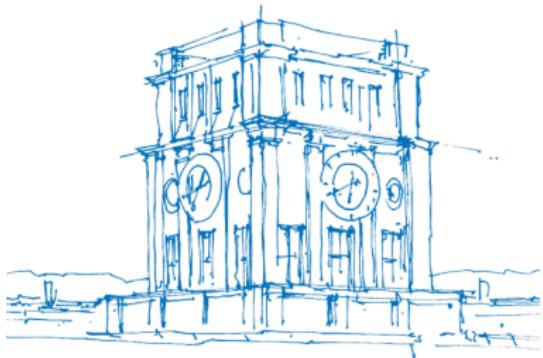
**Benedikt Kleinmeier**

Technische Universität München

Department of Informatics

Chair of Scientific Computing and Computer Science (SCCS)

May 21, 2021



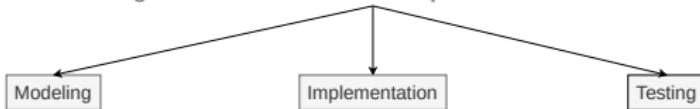
TUM Uhrenturm

1. Motivation and research question
2. Highlights
  - ▶ Modeling: Approaches and my experiment
  - ▶ Implementation: A reusable psychology layer
  - ▶ Validation: 2nd use case — perceived threat
3. Summary

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## Research question:

How can changes in human behavior be operationalized for simulations?



## Why do we need pedestrian dynamics?



Stampede at Love Parade, Duisburg, 2010, photo: Wiffers 2010

**Goal:** Reduce risks for life and limb wherever crowds gather

## An interdisciplinary research community

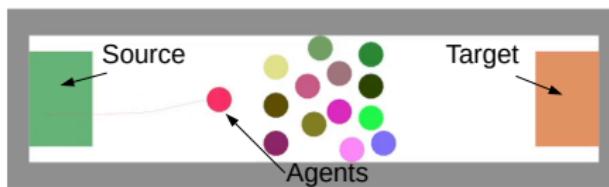


As computer scientist:

- Tool: Computer
- Methods: Modeling and simulation

## The scientific gap

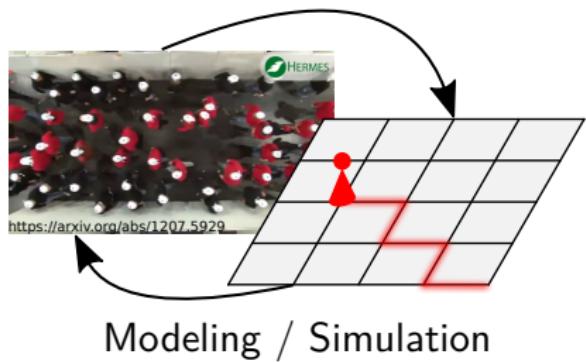
**Default behavior:**



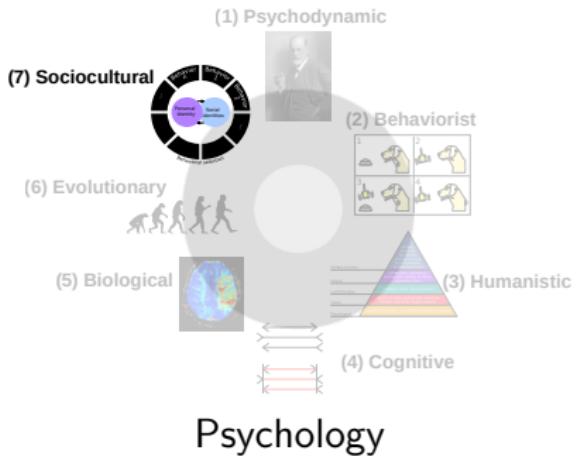
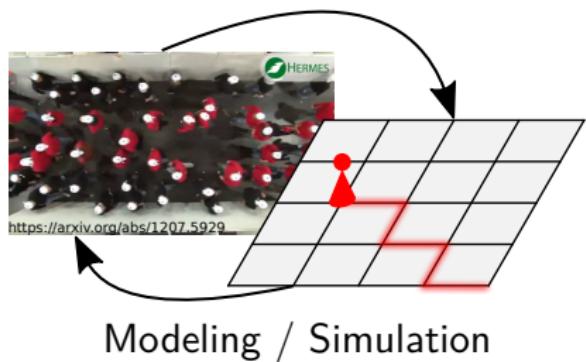
## Research question

How can changes in human behavior be operationalized for simulations?

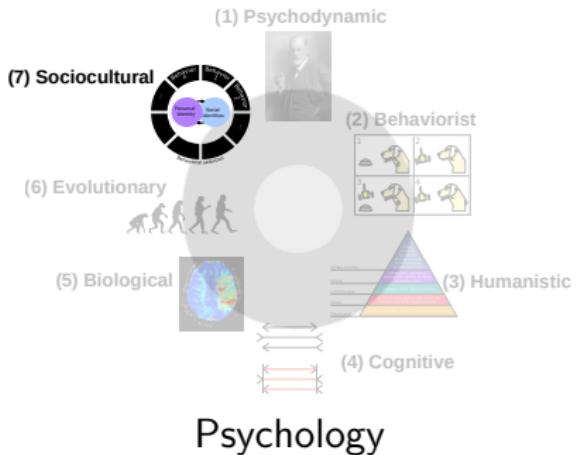
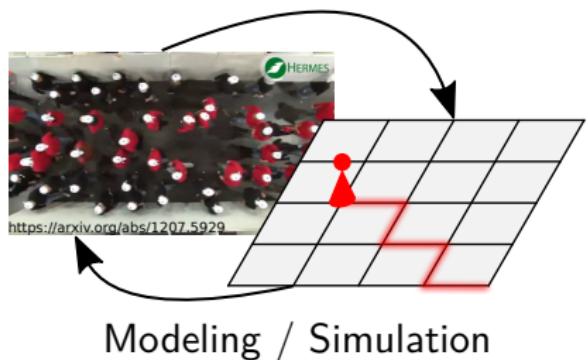
How can changes in human behavior be operationalized for simulations?



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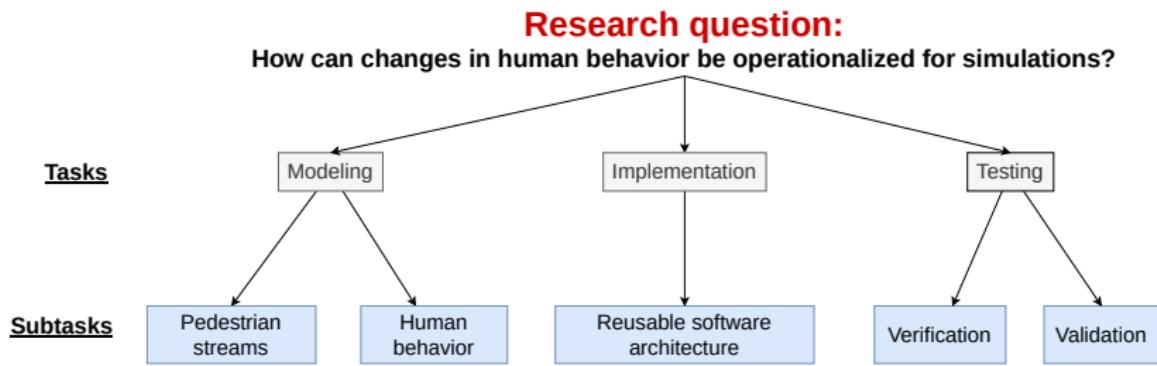


**The challenge:** Bridge the gap between computer science and psychology to obtain a reusable model!

## Research question:

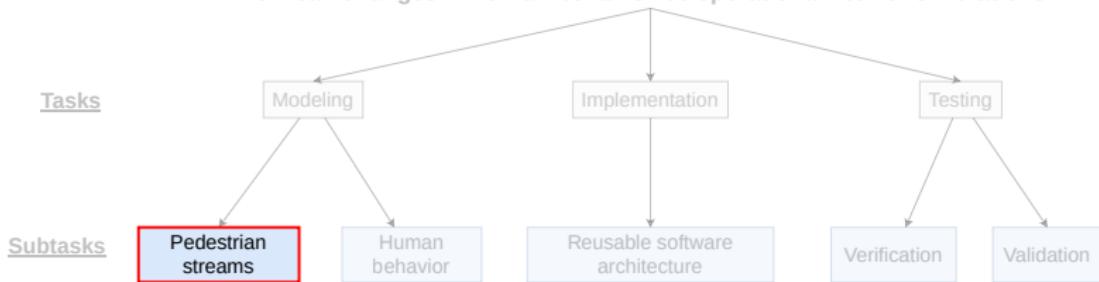
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## Research question:

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1. Motivation and research question
2. Highlights



### Modeling: Approaches and my experiment



Implementation: A reusable psychology layer



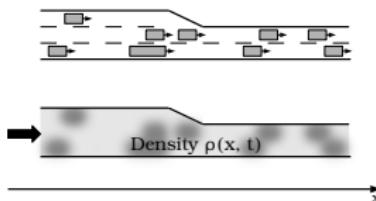
Validation: 2nd use case — perceived threat

3. Summary

## Different approaches exist:

- Macroscopic
- Mesoscopic (multi-scale)
- Microscopic

### Macroscopic

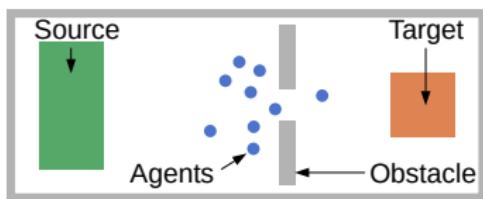


- Individuals are seen as continuum
- Usually, expressed as differential equations, i.e. density or concentration evolution over time

## Different approaches exist:

- Macroscopic
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- Microscopic

### Microscopic

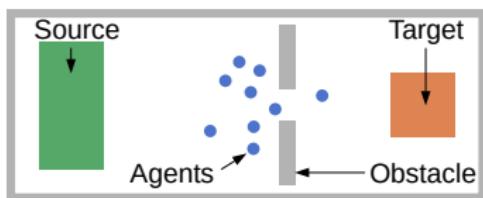


- Each agent has several attributes, e.g. preferred speed etc.
- The agent motion is modeled for each agent individually

## Different approaches exist:

- Macroscopic
- Mesoscopic (multi-scale)
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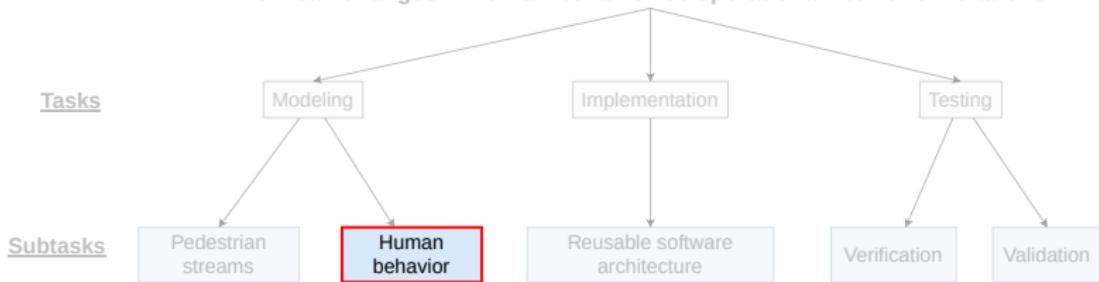
### Microscopic



- I based my work on this model type because:  
*"Crowd behaviour is generated by individuals"*, Wijermans 2011, p. 21
- ⇒ Microscopic approaches serve my purposes best

## Research question:

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## Goal

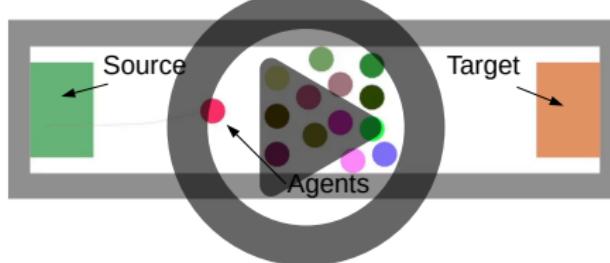
- Observe and document human cooperative behavior.
- Collect quantitative and qualitative data for modeling and validation.



© The experiment setup, image: Kleinmeier, Köster, and Drury 2020

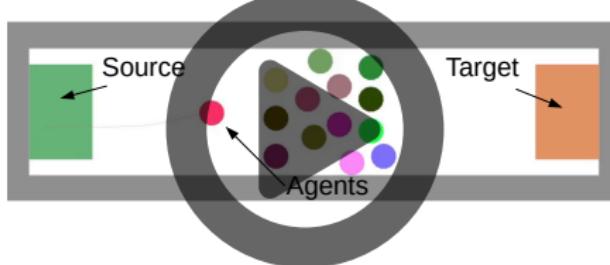
## Cooperative behavior instead of deadlock

**After experiment:**



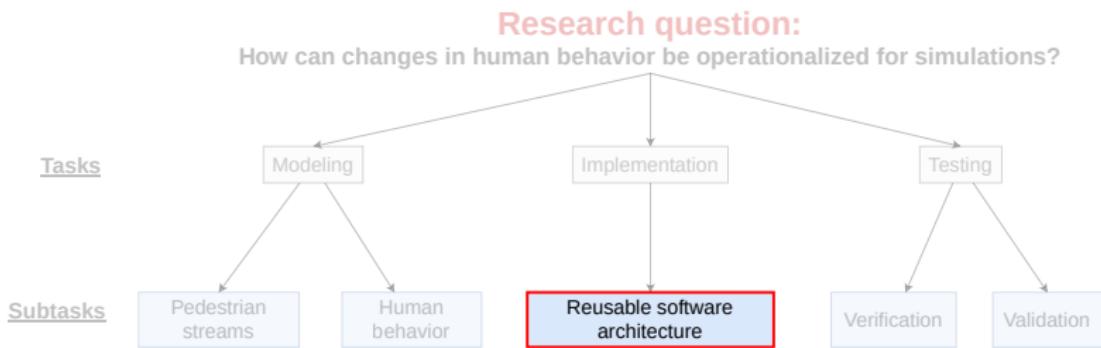
## Cooperative behavior instead of deadlock

After experiment:



But...

the goal is a **reusable software architecture** to allow behavioral changes for a wide range of scenarios.



## 1. Motivation and research question

## 2. Highlights



Modeling: Approaches and my experiment



Implementation: A reusable psychology layer



Validation: 2nd use case — perceived threat

## 3. Summary

- Research stay at University of Sussex.
  - ▶ Working with social psychology professor Dr. John Drury.
  - ▶ Operationalization of psychological findings seen at numerous crowd events.
- Goals:
  - ▶ A reusable software architecture that covers different situations.
  - ▶ Use the Vadere framework as tool to test psychological hypotheses.

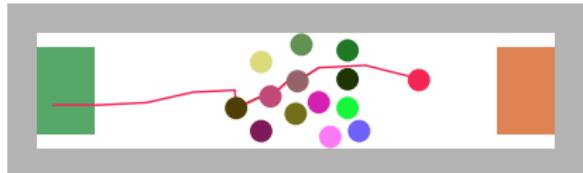
### Bird's eye view onto a simulator:

```
while (simulationIsRunning) {  
    ...  
    // For each agent, search next agent  
    // position that is closer to target  
    locomotionModel.update(agents, time);  
    ...  
    time++;  
}
```

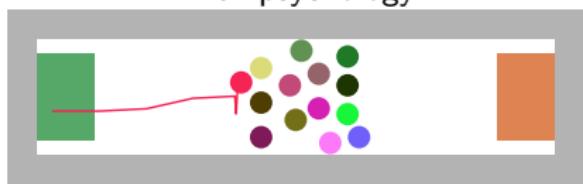
Psychology Layer

Locomotion Layer

Operationalization

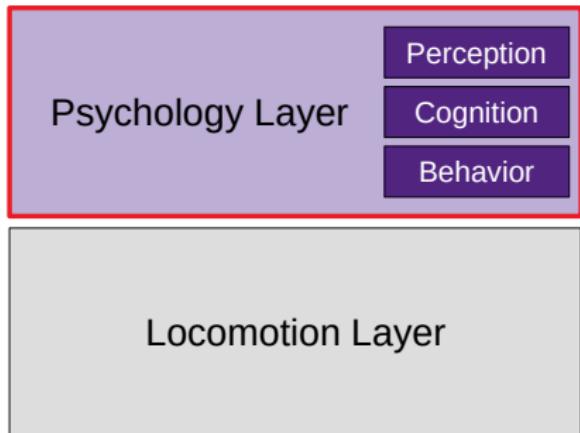


With psychology



Without psychology

Simulator (Vadere)

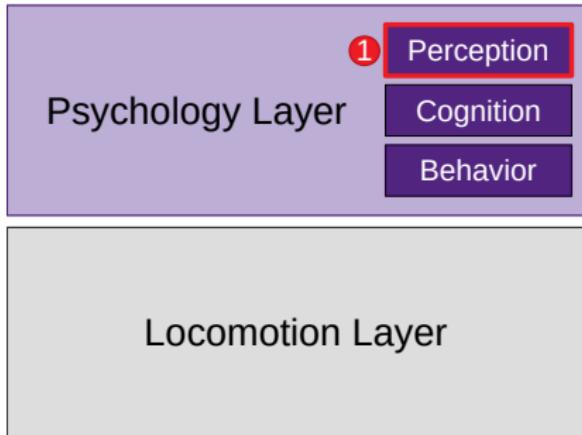


Operationalization

A screenshot of the Vadere simulator interface. The top navigation bar includes tabs for "Simulation", "Model", "Psychology", "Topography", and "Perception". The "Psychology" tab is currently selected and highlighted in blue. Below the tabs, there is a code editor window displaying the following JSON configuration:

```
1曰 [  
2   "usePsychologyLayer" : true,  
3   "psychologyLayer" : {  
4     "perception" : "SimplePerceptionModel",  
5     "cognition" : "CooperativeCognitionModel"  
6   }  
7 ]
```

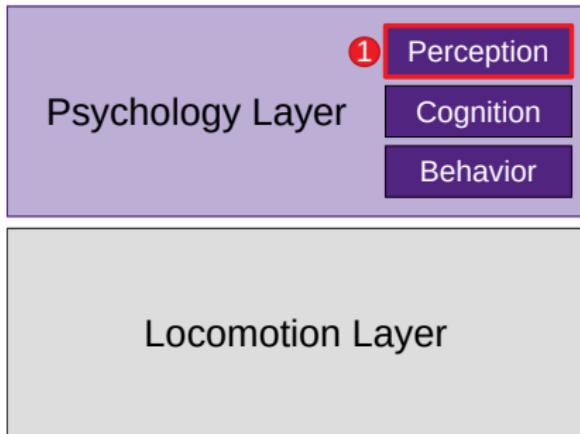
Simulator (Vadere)



```
1曰 "stimulusInfos" : [ {
2曰   "timeframe" : {
3曰     "startTime" : 15.0,
4曰     "endTime" : 17.0,
5曰     "repeat" : false,
6曰     "waitTimeBetweenRepetition" : 0.0
7曰   },
8曰
9曰   "stimuli" : [ {
10曰     "type" : "Threat",
11曰     "originAsTargetId" : 0,
12曰     "loudness" : 1.0,
13曰     "radius" : 10.0
14曰   } ] }
```

Operationalization

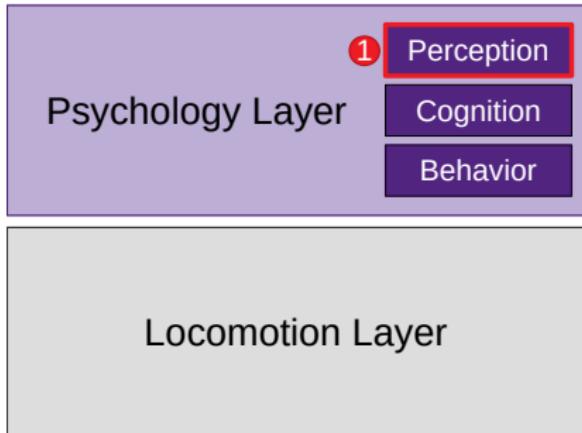
Simulator (Vadere)



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Simulator (Vadere)

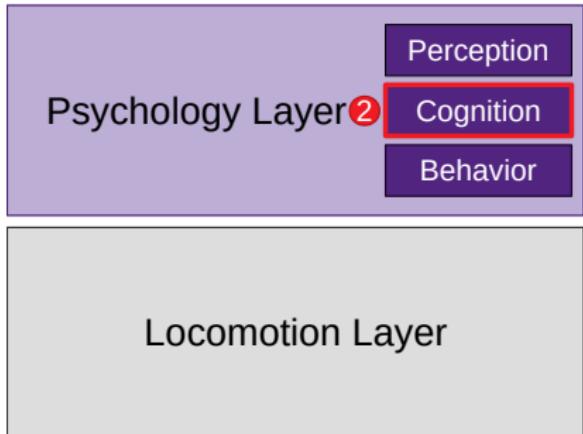


```
class SimplePerceptionModel
...
void update(List<Agent> agents, List<Stimulus>
stimuli) {

    for (Agent agent : agent) {
        mostImportantStimulus = prioritizeStimuli(
            stimuli, agent);
        agent.setMostImportantStimulus(
            mostImportantStimulus);
    }
}
```

Operationalization

Simulator (Vadere)



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```

Operationalization

Simulator (Vadere)

## Psychology Layer②

Perception

Cognition

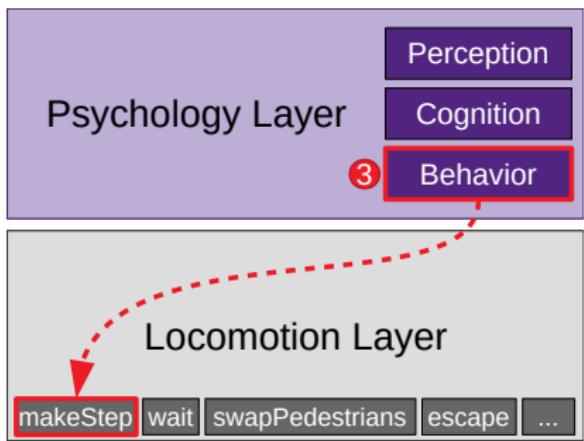
Behavior

## Locomotion Layer

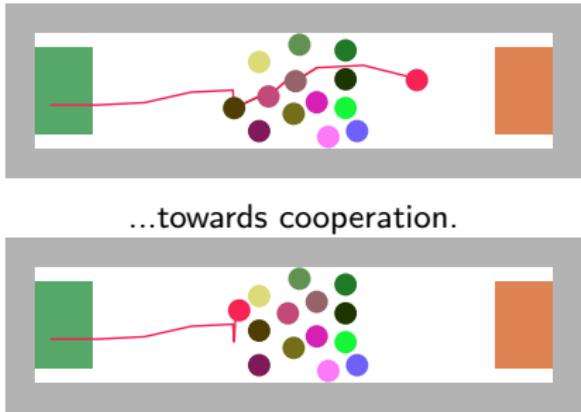
## Operationalization

```
public class CooperativeCognitionModel {  
    ...  
    for (Agent agent : agents) {  
        boolean cannotMove = agent.getSpeed(  
            lastSteps) <= threshold;  
  
        if (cannotMove) {  
            agent.setSelfCategory(COOPERATIVE);  
        } else {  
            agent.setSelfCategory(TARGET_ORIENTED);  
        }  
    }  
}
```

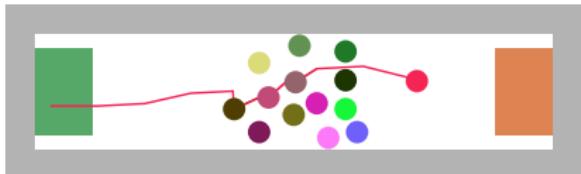
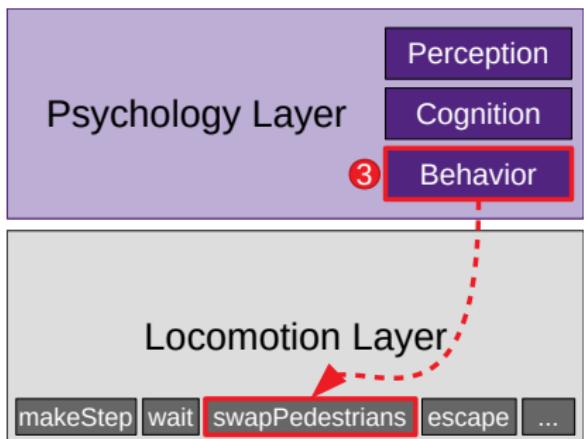
## Simulator (Vadere)



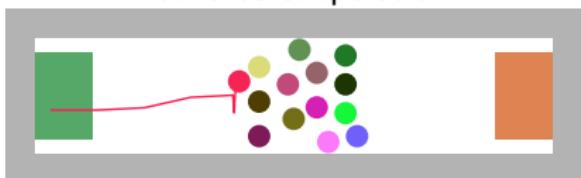
Operationalization



Simulator (Vadere)



...towards cooperation.



Behavioral change...

Operationalization

Simulator (Vadere)

## Bird's eye view onto a simulator:

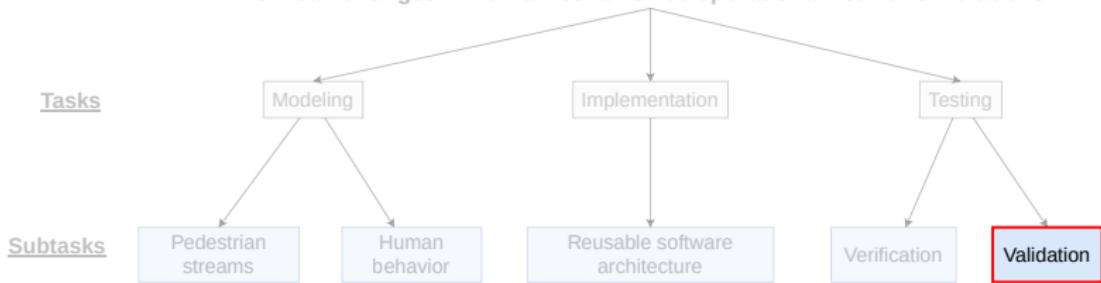
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    ...  
    // For each agent, search next agent  
    // position that is closer to target  
    locomotionModel.update(agents, time);  
    ...  
    time++;  
}
```

```
while (simulationIsRunning) {  
    ...  
    if (usePsychologyLayer()) {  
        // Strategy pattern  
        perceptionModel.update(agents, stimuli);  
        cognitionModel.update(agents);  
    }  
  
    locomotionModel.update(agents, time);  
    time++;  
}
```

- A minimally invasive psychology layer
- that can easily be integrated in other crowd simulators

## Research question:

How can changes in human behavior be operationalized for simulations?



### 1. Motivation and research question

### 2. Highlights



Modeling: Approaches and my experiment



Implementation: A reusable psychology layer



Validation: 2nd use case — perceived threat

### 3. Summary

I used three real-world use cases for validation:

1. Experiment: Cooperative behavior
2. Perceived threat: Fleeing and imitation behavior
3. Counterflowing agents: Evasion behavior

## Motivation

- More and more false alarms after terrorist attacks in the UK
- Stampedes can lead to casualties: Physical and mental

News > London  
**Oxford Circus: Terror alert on London's busiest shopping street declared false alarm**  
[PA] | PATRICK GRAFTON-GREEN | Friday 24 November 2017 09:30 | 0 comments

# The Guardian

This article is more than 2 years old.  
Oxford Street panic began with fight at tube station, suggest police  
Visitors to London West End ran and hid, two tube stations were closed and armed police raced to scene after incident  
Patrick Greenfield, Ian Cobain and Vikram Dodd

Sat 25 Nov 2017 10:07 GMT  
The Telegraph  
Oxford Circus: Met Police end operation after thousands flee in panic over reports of 'gunshots'  
By Robert Hardwick, DEFENCE REPORTER and Harry Yorke  
24 NOVEMBER 2017 • 10:03 GMT



PA



Reuters



EPA

Research question  
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Modeling and my experiment  
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Implementation  
oooooooooooo

Validation  
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18/22

- Real-world incident: Stampede after false alarm
  1. People left underground station target-oriented
  2. After bang, people were fleeing
  3. Then, they were searching for a safe zone
  4. In-group members imitated fleeing behavior  
→ Self-categorization theory (social psychology)

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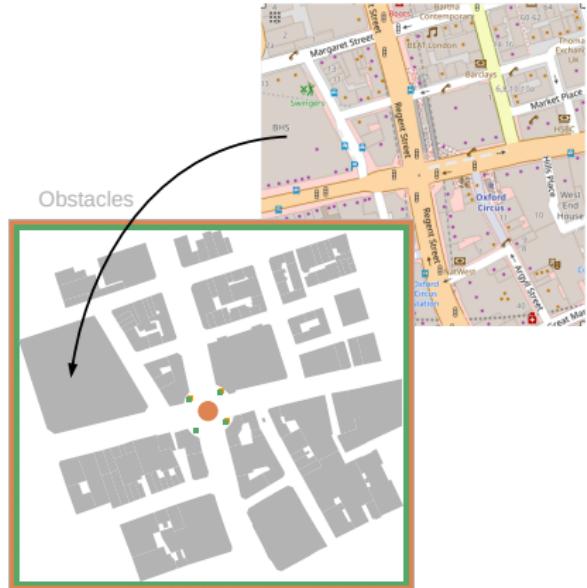
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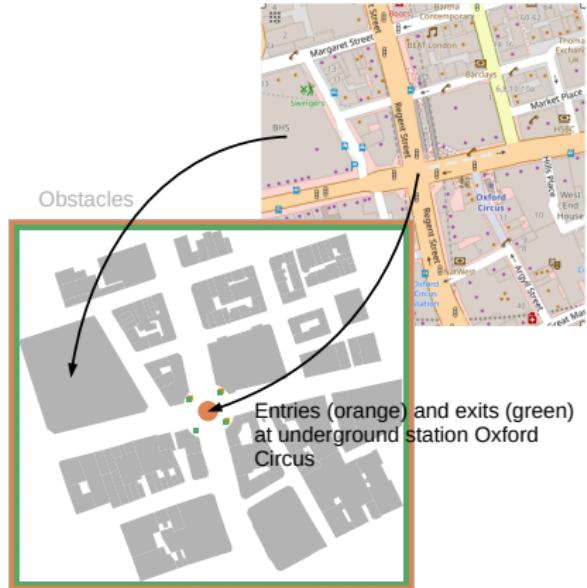


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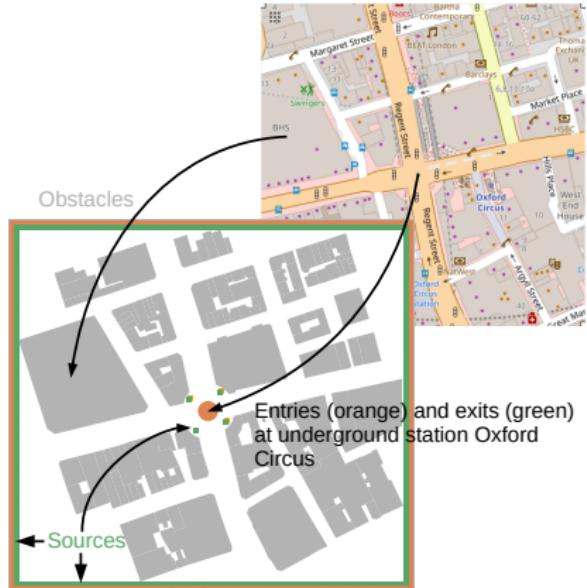
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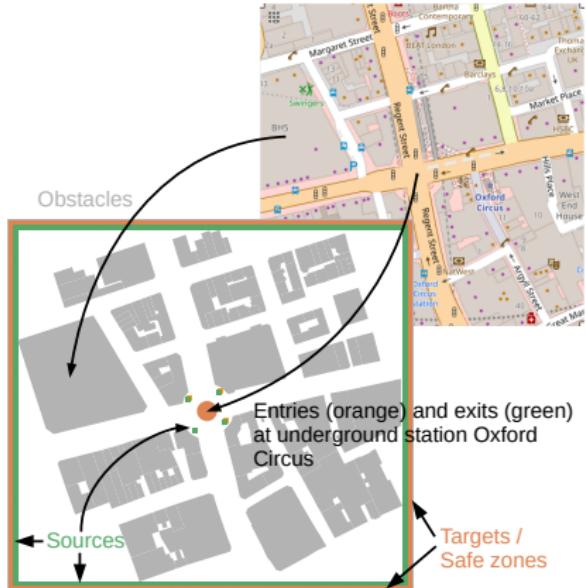
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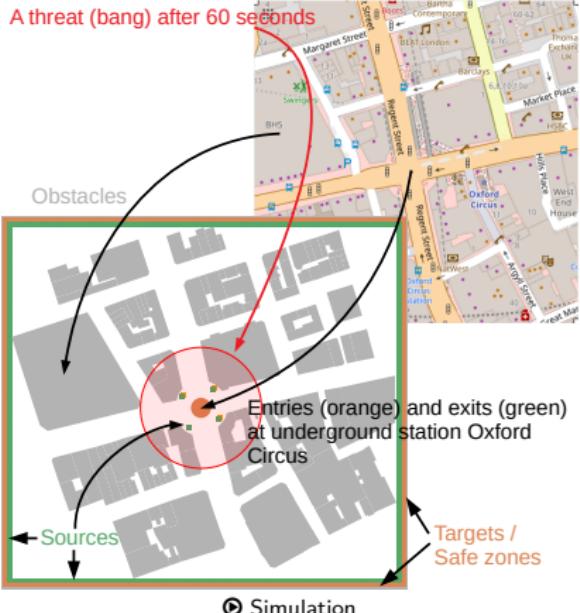
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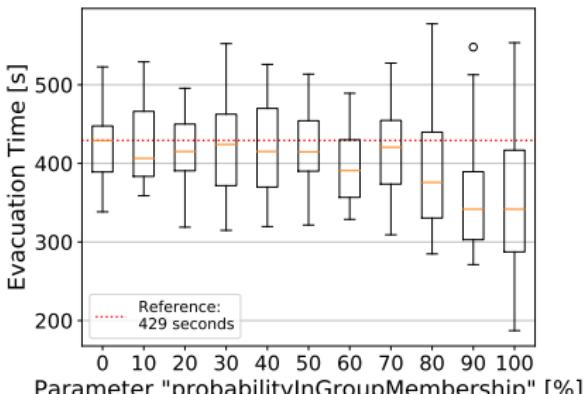
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Note: 30 runs per parameter set

- Quantified: Decreasing evacuation time
- The reusable psychology layer is a benefit for practitioners.
- They can scrutinize “collective flight” incidents.

- ▶ When and how do people flee?
- ▶ When do they follow (or ignore) others?
- ▶ ...

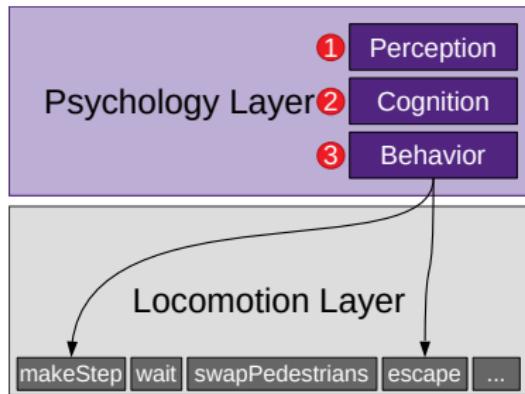
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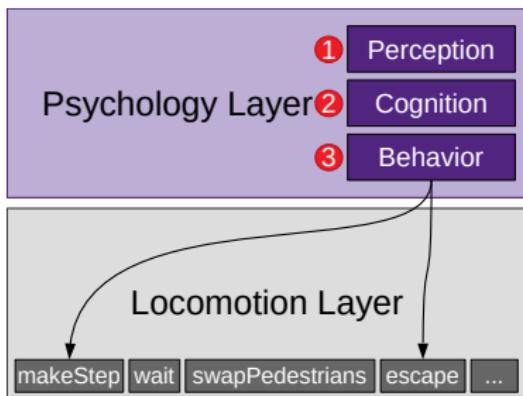
## My proposal:



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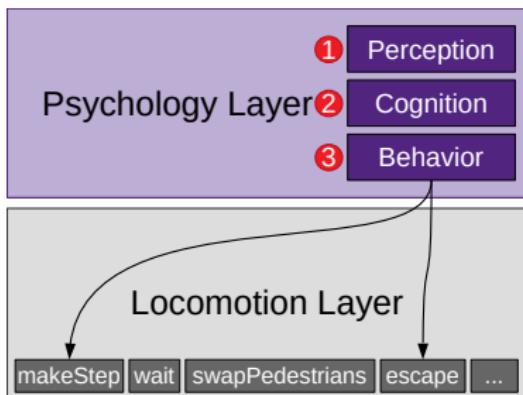
## Contributions to modeling:

1. My psychology layer
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  - ▶ tested by practitioners (police Rhineland-Palatinate)
2. I operationalized the process of behavioral changes into three sequential phases with social psychologists

## Research question:

How can changes in human behavior be operationalized for simulations?

## My proposal:



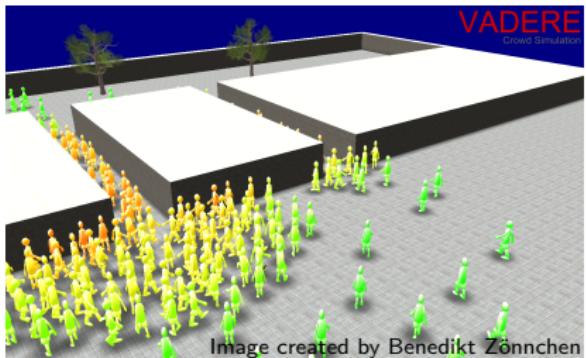
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## Contributions to software reusability:

1. I carried out simulations and validated the model successfully
2. I encapsulated my approach as reusable psychology layer (for other simulators)

Thanks for your attention!



Thank you very, very much to my supervisors (**Prof. Dr. Bungartz** and **Prof. Dr. Köster**) and an **amazing research group** for an inspiring and wonderful time.

- For details, see publications:
  - ▶ The dissertation
  - ▶ Kleinmeier, Köster, and Drury 2020, ...
- All source code contributions are open source: <https://gitlab.lrz.de/vadere/vadere>
- Reviewer feedback on the psychology layer: *"The solution proposed by the authors is simple and yet universal and may become a reference approach for future researchers."*

-  Kleinmeier, Benedikt and Gerta Köster (2020). "Experimental Setups to Observe Evasion Maneuvers in Low and High Densities". In: *Traffic and Granular Flow 2019*. Ed. by Iker Zuriguel, Ángel Garcimartín, and Raúl Cruz. Springer Proceedings in Physics. Springer. DOI: 10.1007/978-3-030-55973-1\_15.
-  Kleinmeier, Benedikt, Gerta Köster, and John Drury (2020). "Agent-Based Simulation of Collective Cooperation: From Experiment to Model". In: *Journal of the Royal Society Interface* 17 (171), p. 20200396. ISSN: 1742-5662. DOI: 10.1098/rsif.2020.0396. URL: <https://arxiv.org/abs/2005.12712>.
-  Kleinmeier, Benedikt, Benedikt Zönnchen, et al. (2019). "Vadere: An Open-Source Simulation Framework to Promote Interdisciplinary Understanding". In: *Collective Dynamics* 4. DOI: 10.17815/CD.2019.21.
-  Sivers, Isabella von, Gerta Köster, and Benedikt Kleinmeier (2016). "Modelling stride length and stepping frequency". In: *Traffic and Granular Flow '15*. Ed. by Victor L. Knoop and Winnie Daamen. 27–30 October 2015. Springer International Publishing, pp. 113–120. DOI: 10.1007/978-3-319-33482-0.
-  Wiffers, Erik (2010). *Here, revellers flee out of the tunnel and the deadly stampede*. Agence France-Presse (AFP), Accessed: 10. December 2020. URL: <https://www.spiegel.de/fotostrecke/photo-gallery-a-catastrophe-at-the-love-parade-fotostrecke-57501.html>.
-  Wijermans, Nanda (2011). "Understanding Crowd Behaviour: Simulating Situated Individuals". PhD thesis. Rijksuniversiteit Groningen. URL: <https://www.rug.nl/research/portal/files/14565243/13complete.pdf>.
-  Zönnchen, Benedikt, Benedikt Kleinmeier, and Gerta Köster (2020). "Vadere—A simulation framework to compare locomotion models". In: *Traffic and Granular Flow 2019*. Ed. by Iker Zuriguel, Ángel Garcimartín, and Raúl Cruz. Springer Proceedings in Physics. Springer. DOI: 10.1007/978-3-030-55973-1\_41.