Exploiting Spatial-temporal Heterogeneity for Agent-based Pedestrian Crowd Simulation

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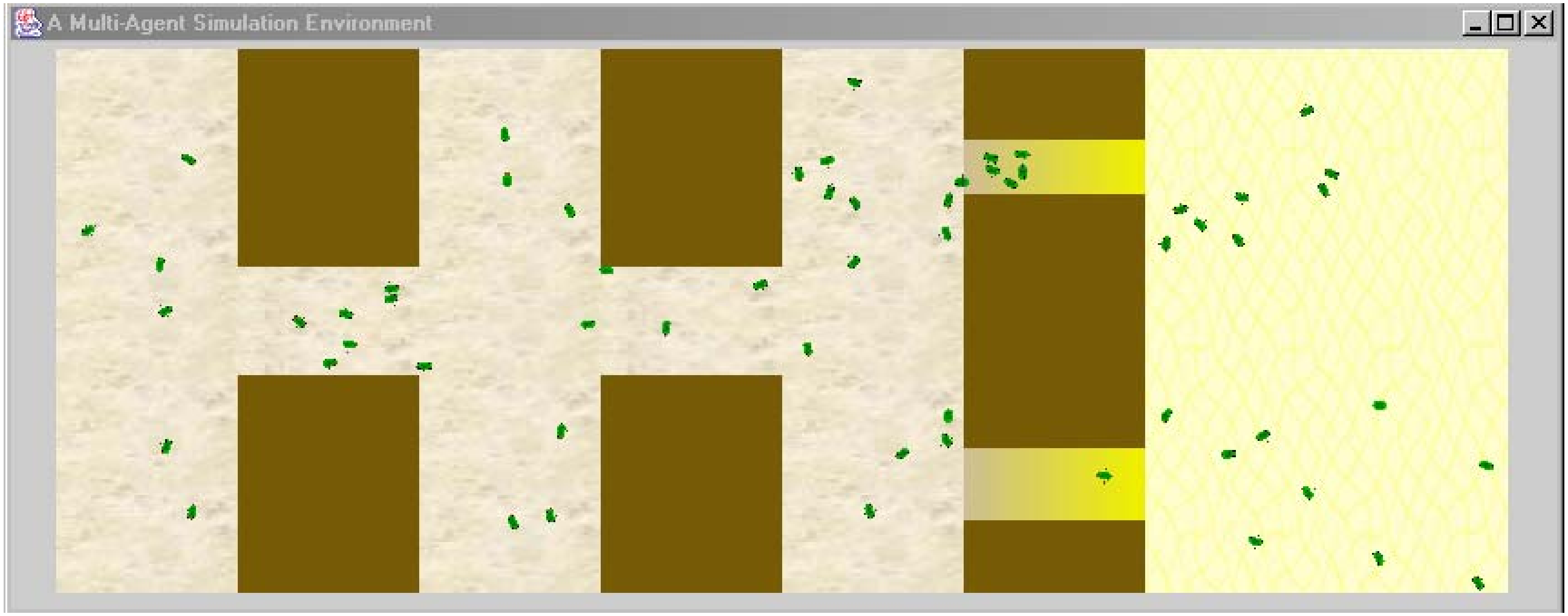
Outline

- Overview of Pedestrian Crowd Simulation
- Spatial temporal heterogeneity in crowd
- The DTS model and the DES model for pedestrian crowd simulation
- Analyze the position errors of DES and DTS models
- Experiments results
- Conclusions and future work

Pedestrian Crowd Simulation

- Study the Complexity and Self-Organization of Human Crowd.
  - Helbing's physical and social force model for simulating lane formation, traffic jams, etc.
- Urban planning and building design for emergency evacuations and safe egress.
  - Competitive, queuing, and herding behaviors during emergency evacuations.
- Computer Animation, Game Design
  - Focus on real time 3D animation and human computer interaction.

Pedestrian Crowd Simulation



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Heterogeneity in Crowd

- Heterogeneity exists in crowd because of individual differences, e.g. moving speed, personality.
  - Spatial heterogeneity, e.g., agents at different locations have different moving speeds.
  - Temporal heterogeneity, e.g., an agent increases or decreases its moving speed.
- In this work, we differentiate non-uniform crowd and uniform crowd based on agents' moving speeds.

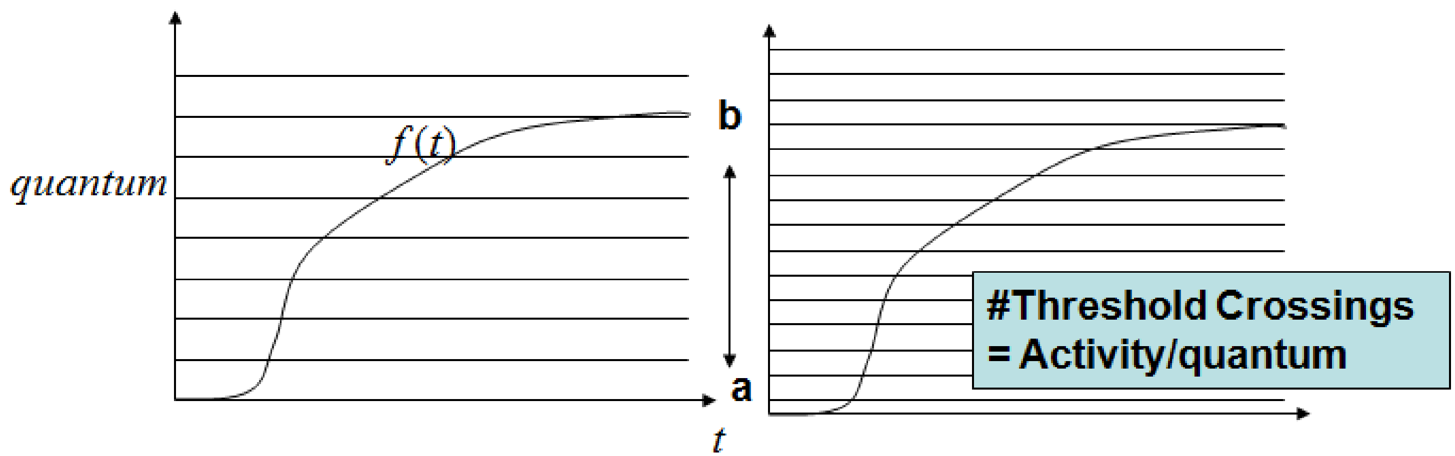
http://nymphoto.blogspot.com/2008/12/conversation-with-laura-napier.html

Discrete Time Crowd Simulation

- Most crowd simulation models are discrete time simulation (DTS) models.
- The simulations proceed in a time-based manner, where each agent performs a decision making to decide its next movement in each **time step (TS)**.
- The discrete time simulation does not exploit the crowd's spatial-temporal heterogeneity resulting from agents' non-uniform movements.
  - All agents use the same time step, independent of agents' speeds.
- Our work focuses on a discrete event modeling approach.

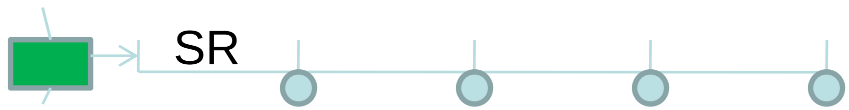
Review of the Activity and Quantization Concepts

- Originally introduced and formulated in the context of ordinary and partial differential equations as the integral of the magnitudes of the state space derivatives.
- Activity is a measure of change in system behavior – when it is divided by a quantum gives the least number of events required to simulate the behavior with that quantum size.



Space Resolution

- **SpaceResolution (SR)** specifies the threshold of an agent's position change.



- Given a moving speed, SR decides the frequency of an agent's position change, and thus the frequency of decision making.
- Under the same SR, the faster the agent moves, the more frequently the agent performs decision making.
- The SR is a fundamental concept in our discrete event model.

The DES Model Overview

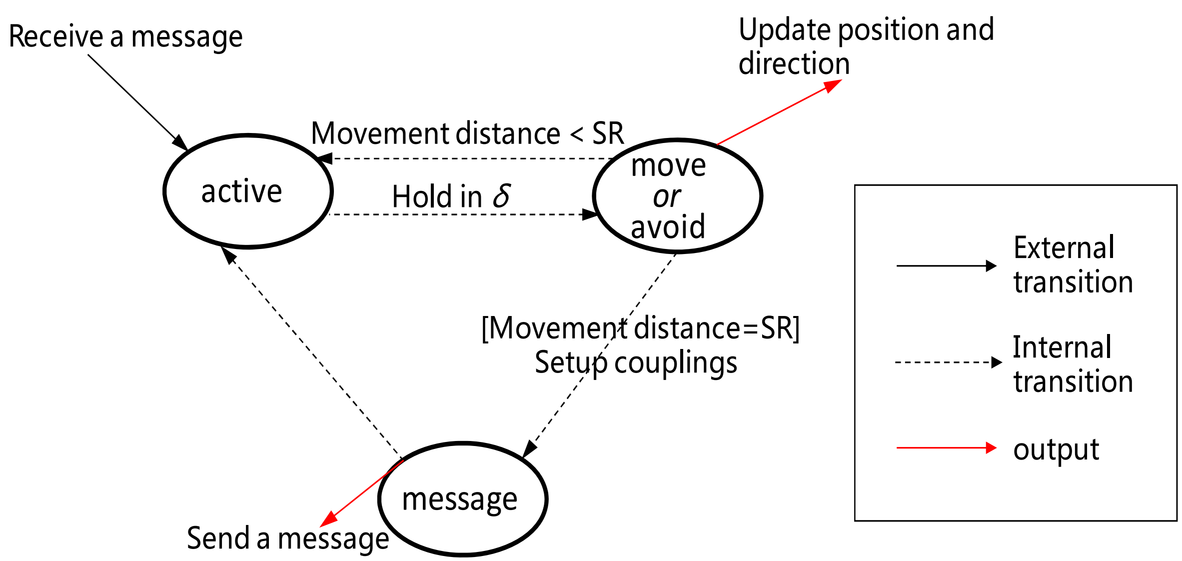
- In the discrete event simulation (DES) model, an agent's decision making is based on the "change" of the agent's own position or "change" of its environment. Specifically, it is triggered by two types of events:
  - internal events due to the agent's own position change, i.e., crossing the threshold of SR
  - external events due to other agents' position changes, i.e., position update messages from other agents
- An agent updates its new position to its neighboring agents whenever it crosses the threshold of SR.
  - The position update is implemented as message passing.
  - An agent is dynamically coupled to its neighboring agents. The distance of the neighborhood range is pre-defined.

The DES Model Overview (Cont.)

- Agent's decision making model is a behavior-based control model, including *moving* and *avoid* behaviors.
- In this work, we use the number of decision making as an indicator of simulation performance.
  - This is based on the observation that an agent's decision making usually involves complex logics, and thus accounts for the most significant part of computation in a simulation.
- We carry out this work based on the Discrete Event System Specification (DEVS) modeling and simulation framework, in particular the DEVSJAVA environment.
  - The DEVS framework was chosen due to its formal formalism and its capability of modeling both the discrete time and discrete event models.

The DES model

- Once a “change” happens, an agent
  - check environment
  - make a decision
  - perform action
  - notify nearby agents



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The DES Model

```
procedure deltint()
if the agent's current state is "active"
         update the position;
         check the environment;
         Action a = perform a decision making;
         holdIn(a.name, a.duration);
else
         if the agent's current state is not "message"
                perform the action;
                if movement distance greater than SR
                        setup couplings with the neighborhood agents;
                        holdin("mesage", 0.0);
                        return;
         else
                holdin("active", 0.0);
end if.
end procedure delint.
```

The DTS Model Implementation

- At every time step (TS), each agent
  - checks its environment (e.g., destination, other agents' positions)
  - makes a decision to decide its next movement (e.g., move forward, or move sideways to avoid collision)
  - carries out the movement for this time step.

```
procedure deltint()
if the agent's current state is "decision_making"
      check the environment;
      Action a = perform a decision making;
      holdIn("update_position", 0.0);
else if the agent's current state is "update_position"
      execute the action and update position;
      holdIn("decision_making", Timestep);
end if.
end procedure deltint.
```

The TS and SR Compared

- The time step (TS) is used in the DTS model. The space resolution (SR) is used in the DES model.
- Both TS and SR affect the frequency of agent's decision making in the DTS and DES models respectively.
  - The larger the TS, the less frequent the decision making.
  - The larger the SR, the less frequent the decision making.
- Both TS and SR affect the accuracy of the simulations.
  - In DTS, position is considered unchanged within a TS.
  - In DES, position is considered unchanged before crossing the threshold of SR.
- In the DES model, the SR makes an agent's position update (and decision making) depend on the agent's moving speed.
  - For a non-uniform crowd where agents have different moving speeds, this can lead to more efficient computation.

The Position Error in DES and DTS

- We compare both the DES and DTS models with an analytic model for position update.

$$\vec{p}_{t,j} = \vec{p}_{t1,j} + \int_{t1}^{t} \vec{v}_{t,j}\, dt \qquad (1)$$

- *In the analytic model, position is continuously changed*.

The Position Error of DES and DTS

- DTS model

$$\vec{p}_{t,j} = \begin{cases} \vec{p}_{t-1,j} & \text{if } t < t-1+TS \\ \vec{p}_{t-1,j} + \int_{t-1}^{t} \vec{v}_{t,j}\,dt & \text{if } t = t-1+TS \end{cases} \qquad (2)$$

The maximum position error

- DES model

$$\vec{p}_{t,j} = \begin{cases} \vec{p}_{t-1,j} & \text{if } \left|\int_{t-1}^{t} \vec{v}_{t,j}\,dt\right| < SR_j \\ \vec{p}_{t-1,j} + \int_{t-1}^{t} \vec{v}_{t,j}\,dt & \text{if } \left|\int_{t-1}^{t} \vec{v}_{t,j}\,dt\right| = SR_j \end{cases} \qquad (3)$$

The maximum position error

The Position Error of DES and DTS

- To make a fair comparison, ***the maximum position error in both DES and DTS should be the same.***

$$SR = \left| \int_{t-1}^{t-1+\Delta t} \vec{v}_{\max} dt \right| \qquad (4)$$

- When agents' speeds are constant in a time step in DTS:

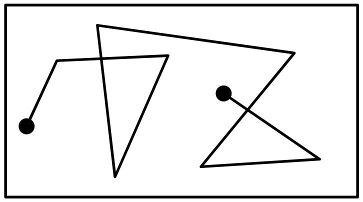
$$SR = V_{\max} * TS \qquad (5)$$

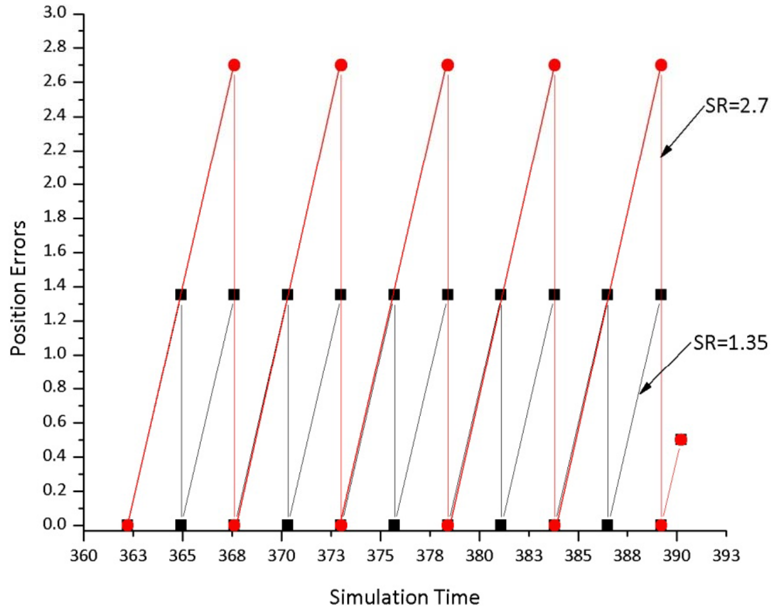
Experiments

- We compare the DTS and DES model and get some preliminary results. Note that to ensure fair comparison, SR = V_{max}*TS.
- The results focus on two aspects: **position errors** and **number of decision makings (# of DM)** for both *DES* and *DTS* models.
  - The number of decision making is used as an indicator for simulation performance.
- We also measured the execution time of DES and DTS in one of the experiments.
  - The goal is to show that DES is more computation efficient than DTS for simulating non-uniform crowds.

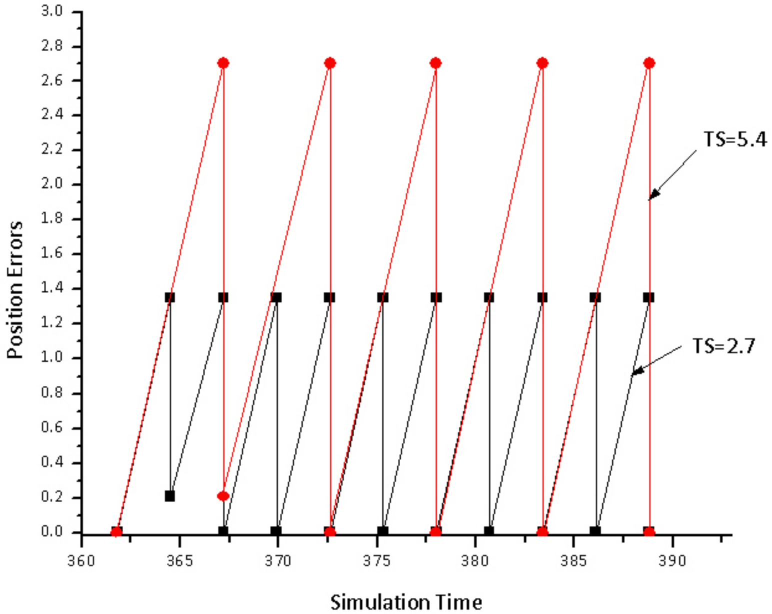
Experiment 1 – Position Error

Simulate one agent with moving speed 0.5. The agent moves through a series of predefined destinations.





DES model



DTS model

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Experiment 1 -- # of Decision Making

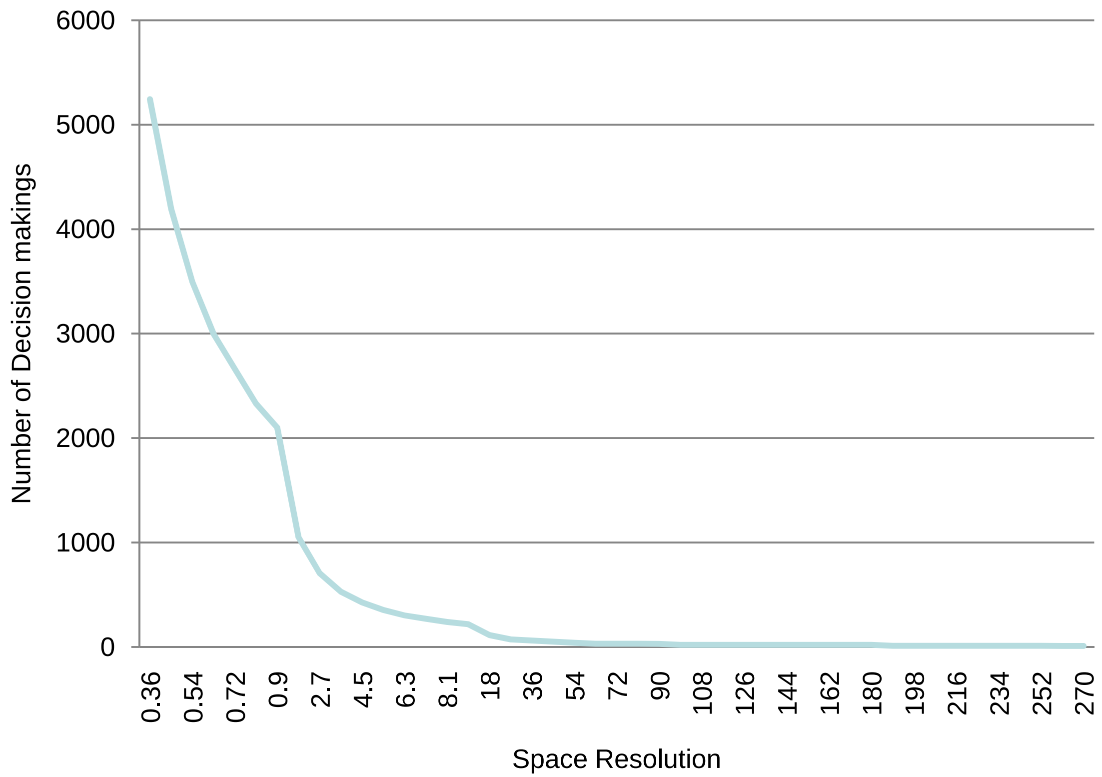

Fig. 8 Relationship between space resolution and number of decision makings

The DES model

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Experiment 2 – Average # of DM

Two different crowds are considered:

- One is a *uniform* crowd containing 3 agents with moving speed 0.5.
- The other is a *non-uniform* crowd containing 3 agents with different moving speeds (0.005, 0.05 and 0.5 respectively).

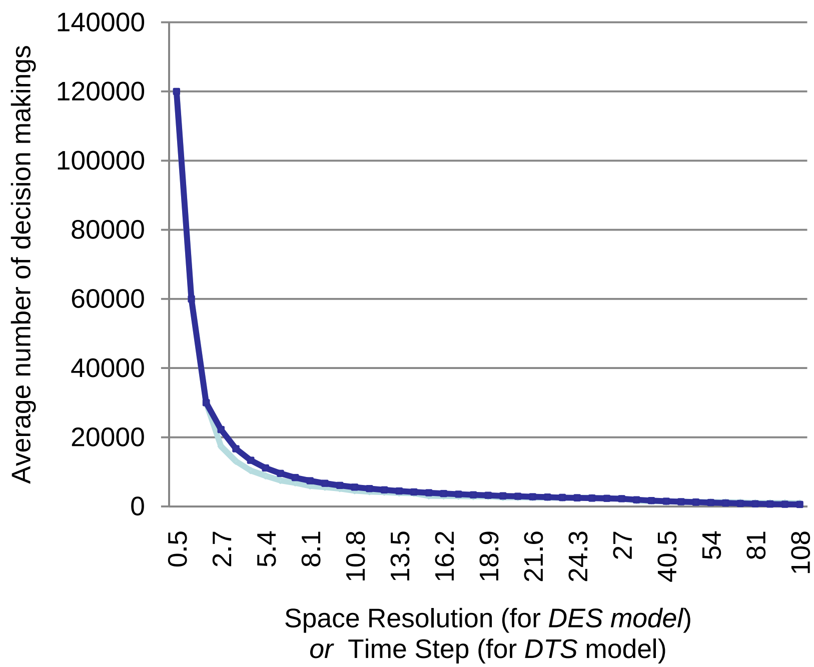

Fig. 9 SR/TS and decision makings (same speed)

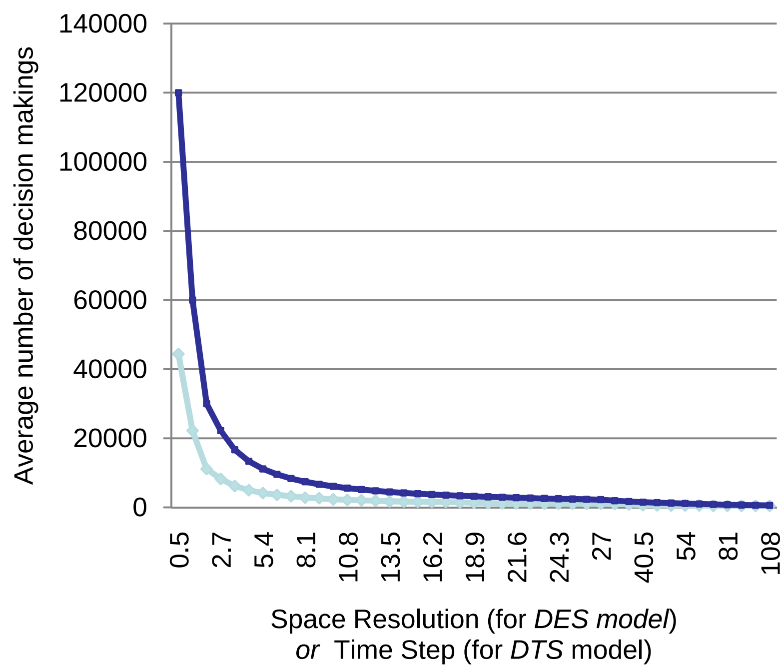

Fig. 10 SR/TS and decision makings (different speed)

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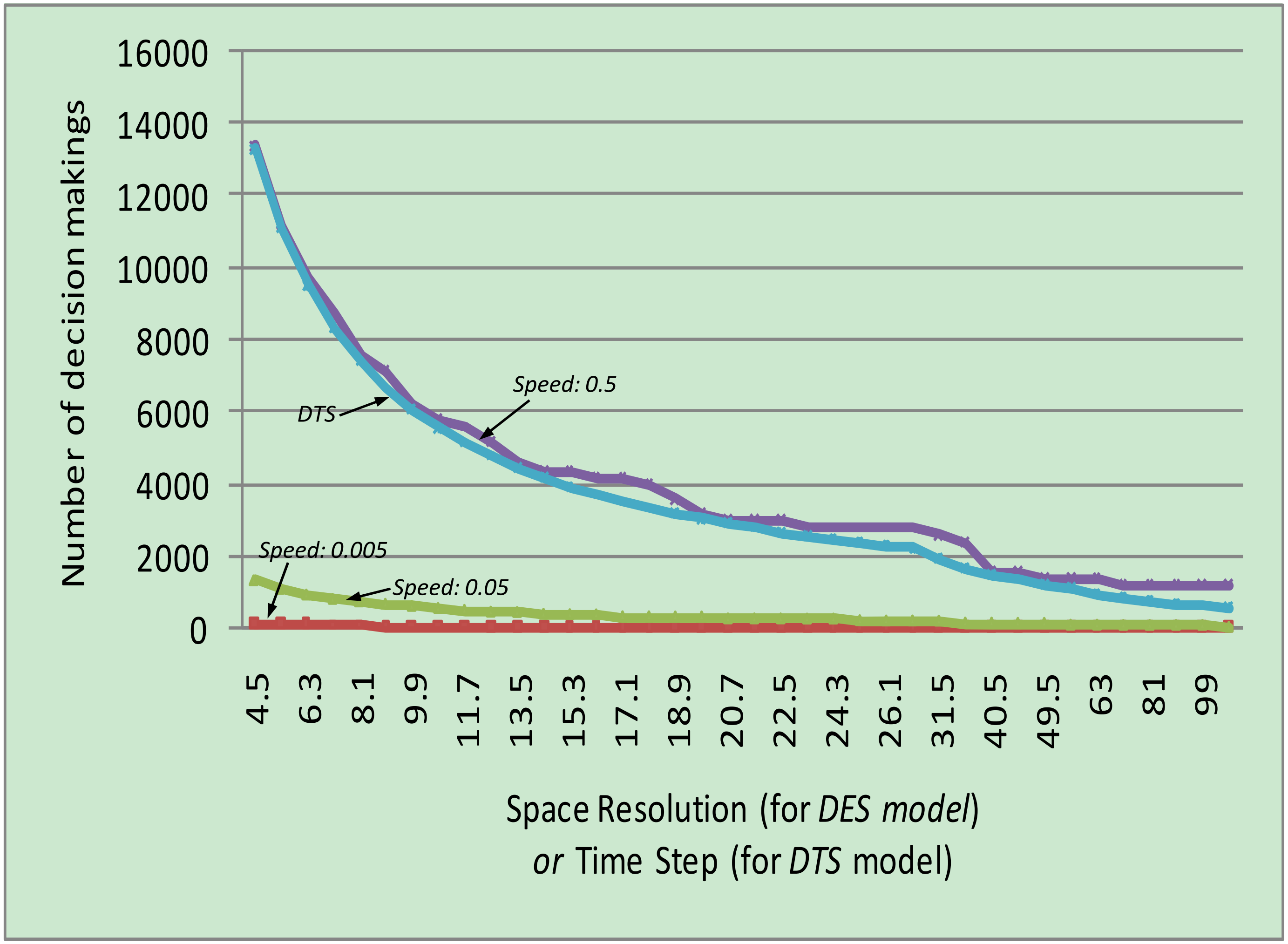
Experiment 2 – Individual agents' # of DM



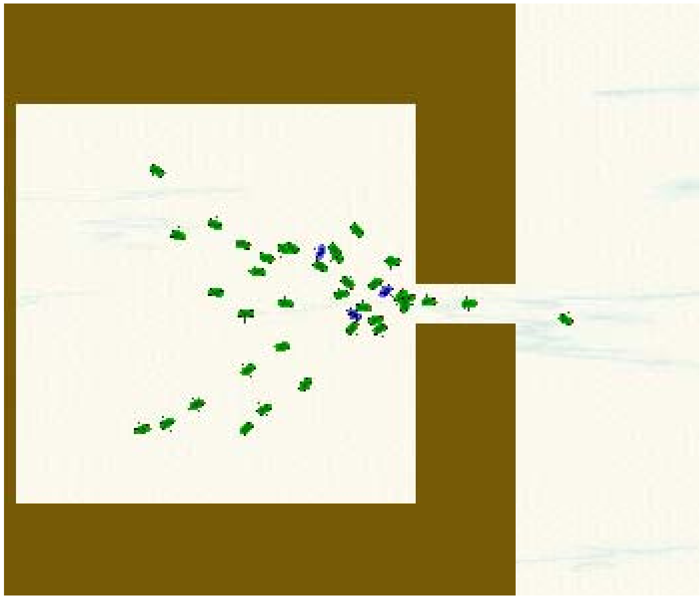
Non-uniform crowd

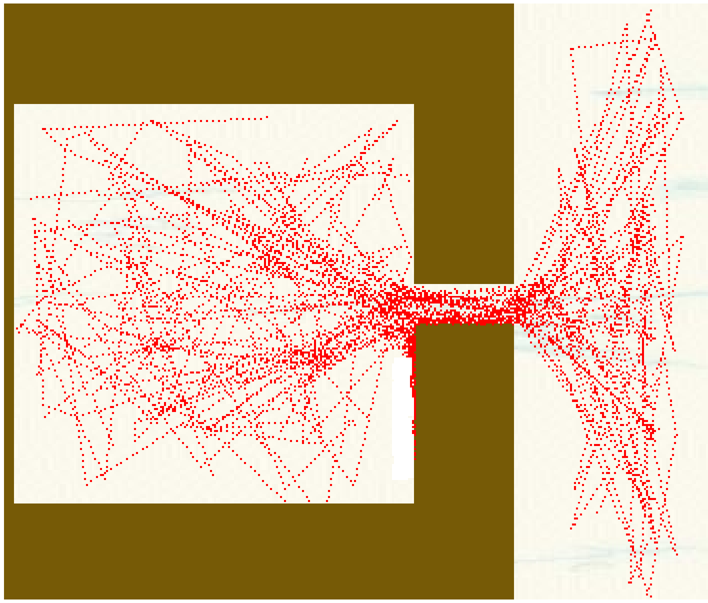
Experiment 3

- Two types of crowds (20 agents) are considered:
  - A uniform crowd with all agent's speed being 0.05.
  - A non-uniform crowd with agents' speed randomly generated within the range [0.05, 0.5].
- To show temporal heterogeneity, we also make agents' speeds change temporally: when an emergency situation occurs, all agents double their speeds.

Experiment 3

- Spatial heterogeneity and temporal heterogeneity





Temporal Heterogeneity Illustration

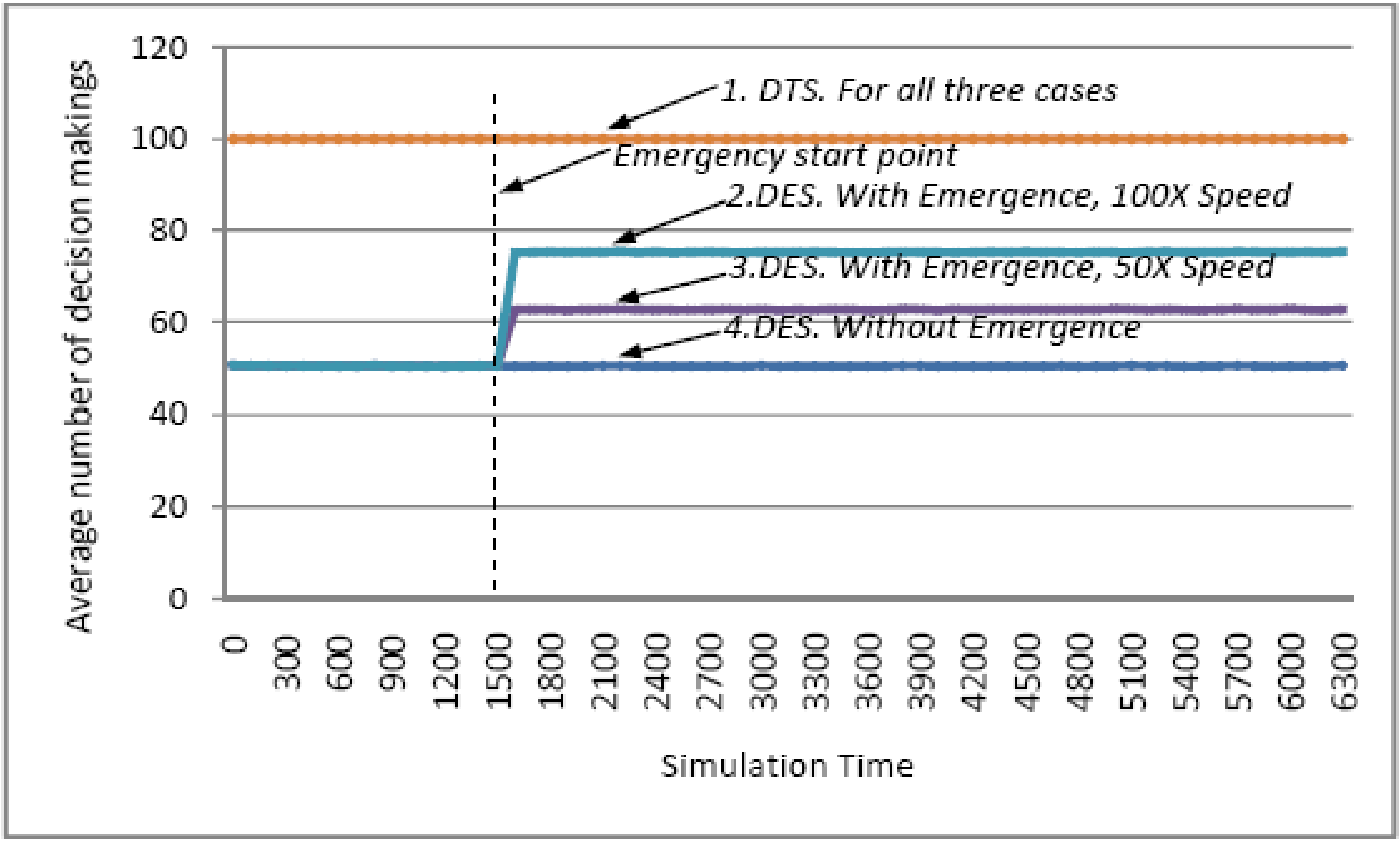


Fig.13 The distribution of the average number of decision makings

20 agents, speed: 0.00005,0.005, and 0.5; SR = 0.5; TS = 1.0.

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Experiment 3 – execution time and # of DM for different SR/TS (uniform crowd)

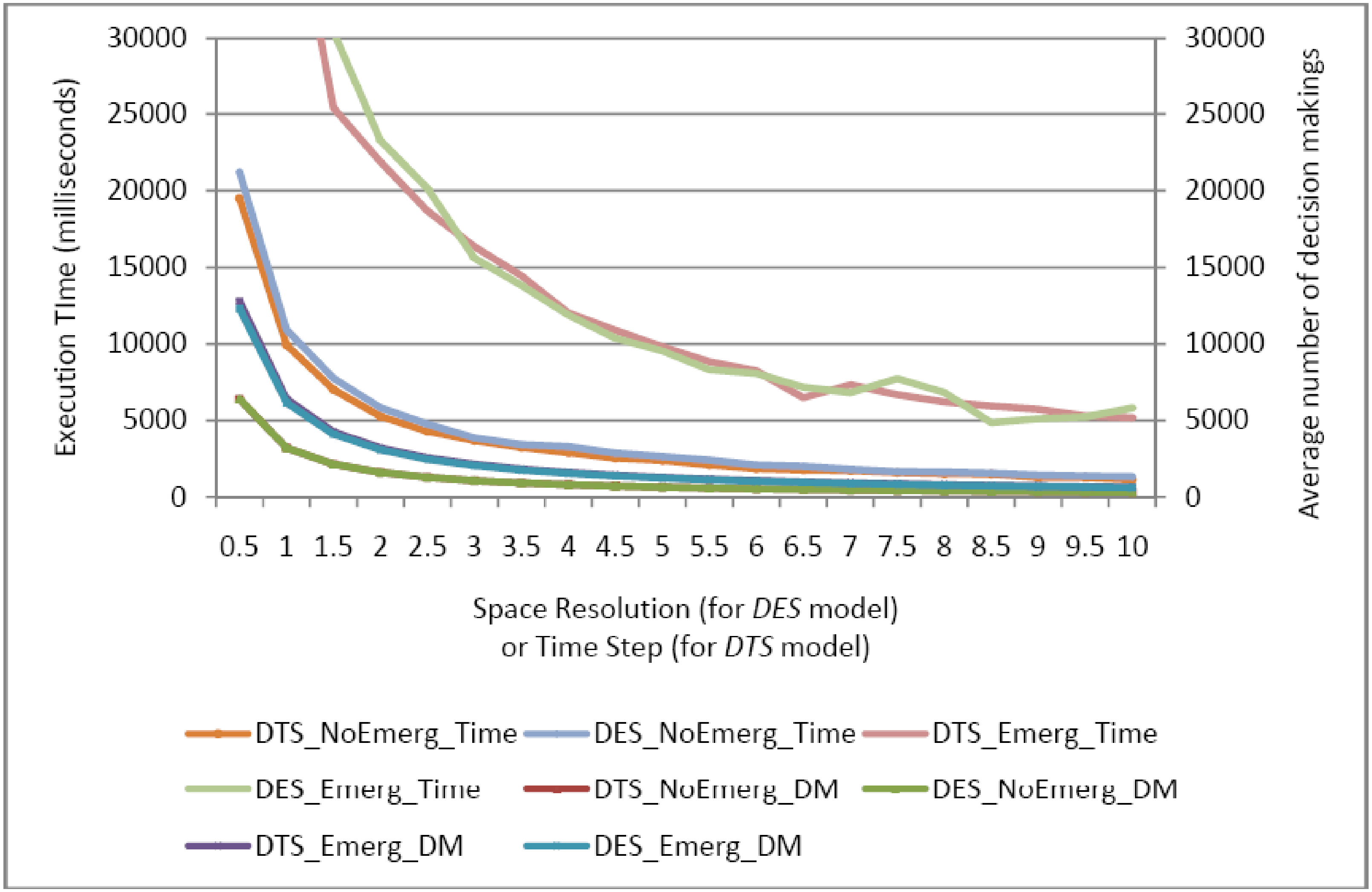

Fig. 14 Execution time of *uniform crowd* in emergent evacuation

Experiment 3 – execution time and # of DM for different SR/TS (nonuniform crowd)

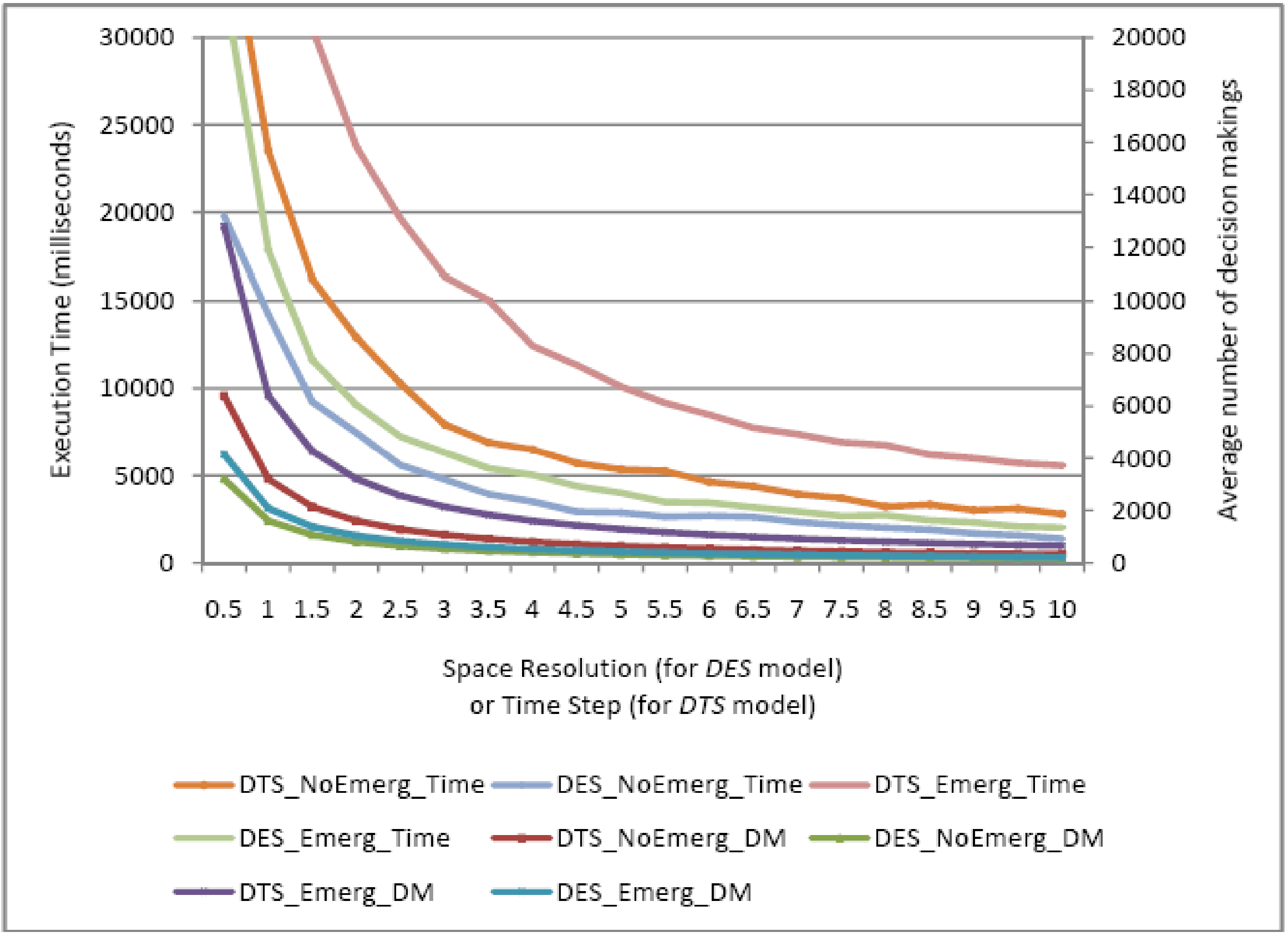

Fig. 15 Execution time of *non-uniform crowd* in emergent evacuation

Conclusions and Future work

- This paper presents a discrete event model for simulating pedestrian crowd. Our goal is to exploit the crowd system's spatial-temporal heterogeneity resulting from agents' non-uniform movements for better simulation performance.
  - For better simulation accuracy?
- Preliminary results show that the DES model is computation more efficient (fewer decision makings and less execution time) than the DTS model for non-uniform crowds.
- Further work include:
  - how spatial heterogeneity affects agent interaction, e.g., message passing;
  - how to choose an appropriate SR for a given simulation;
  - parallel/distributed simulation exploiting spatial temporal heterogeneity.

Thank You

- Questions & Comments

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