Lecture with Computer Exercises: Modelling and Simulating Social Systems with MATLAB

How do participants act during an apéro at ETH?

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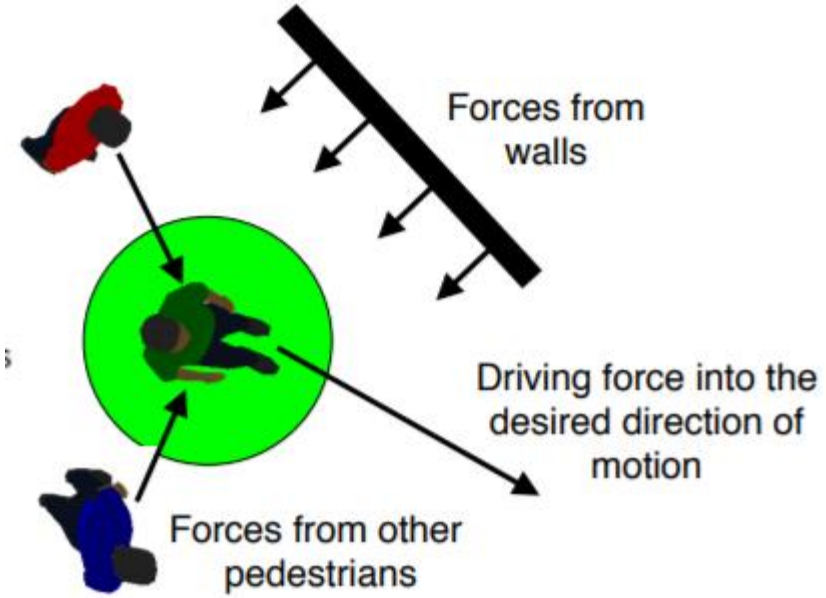
Pedestrian Traffic Simulation

https://www.youtube.com/watch?v=UUHFMtR9q9M

Introduction and Motivation

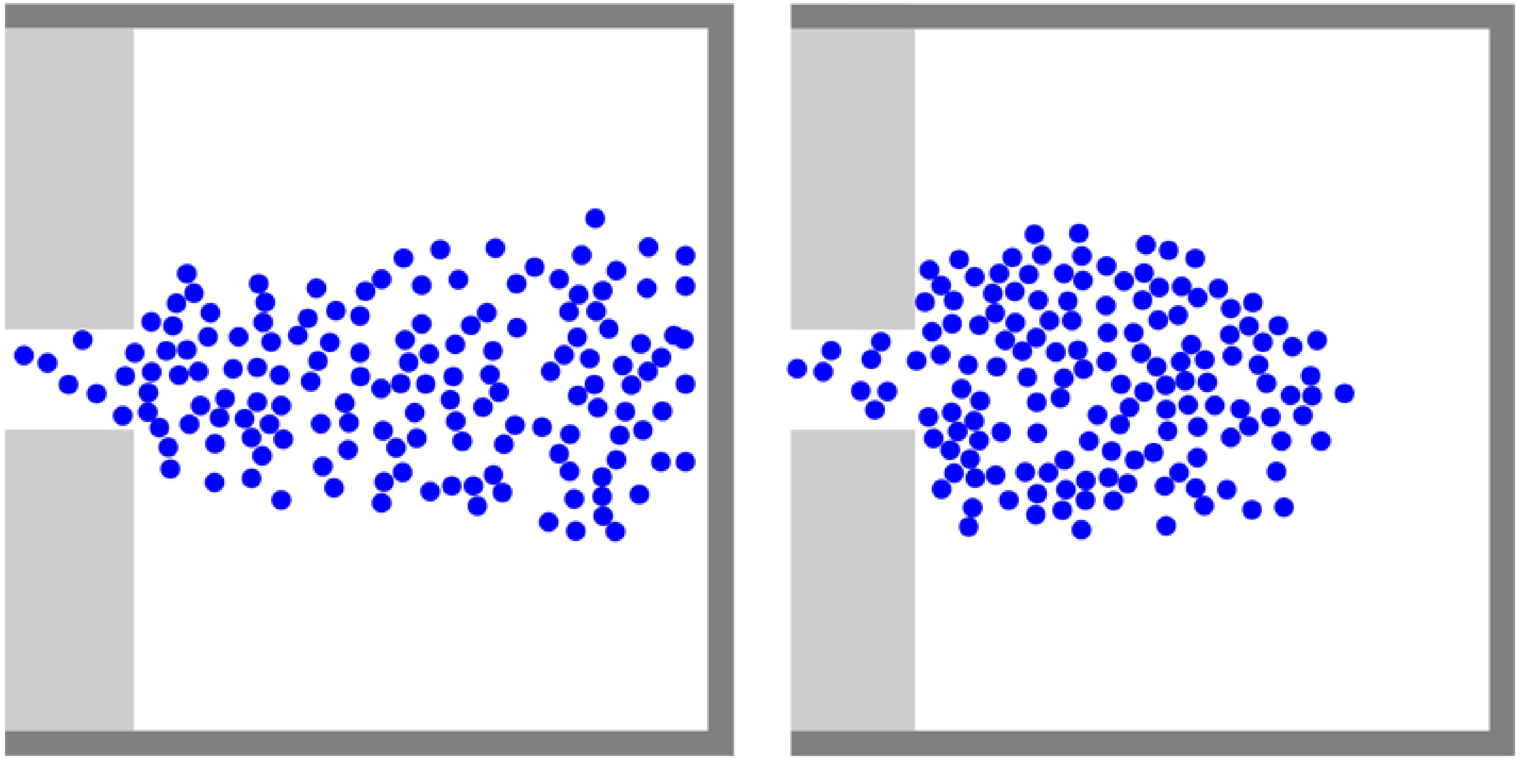
Social Force Model

$$\underbrace{\frac{dv_\alpha}{dt}}_{\text{acceleration}} = \underbrace{\frac{1}{\tau_\alpha}\left(v_\alpha^0 e_\alpha^0 - v_\alpha\right)}_{\text{driving force}} + \underbrace{\sum_{\beta(\neq\alpha)} F_{\alpha\beta}^{\text{int}}}_{\text{interactions}} + \underbrace{F_\alpha^{\text{walls}}}_{\text{boundaries}}$$



Dirk Helbing and Peter Molnar. Social force model for pedestrian dynamics. Phys. Rev. E, 51:4286, May 1995.

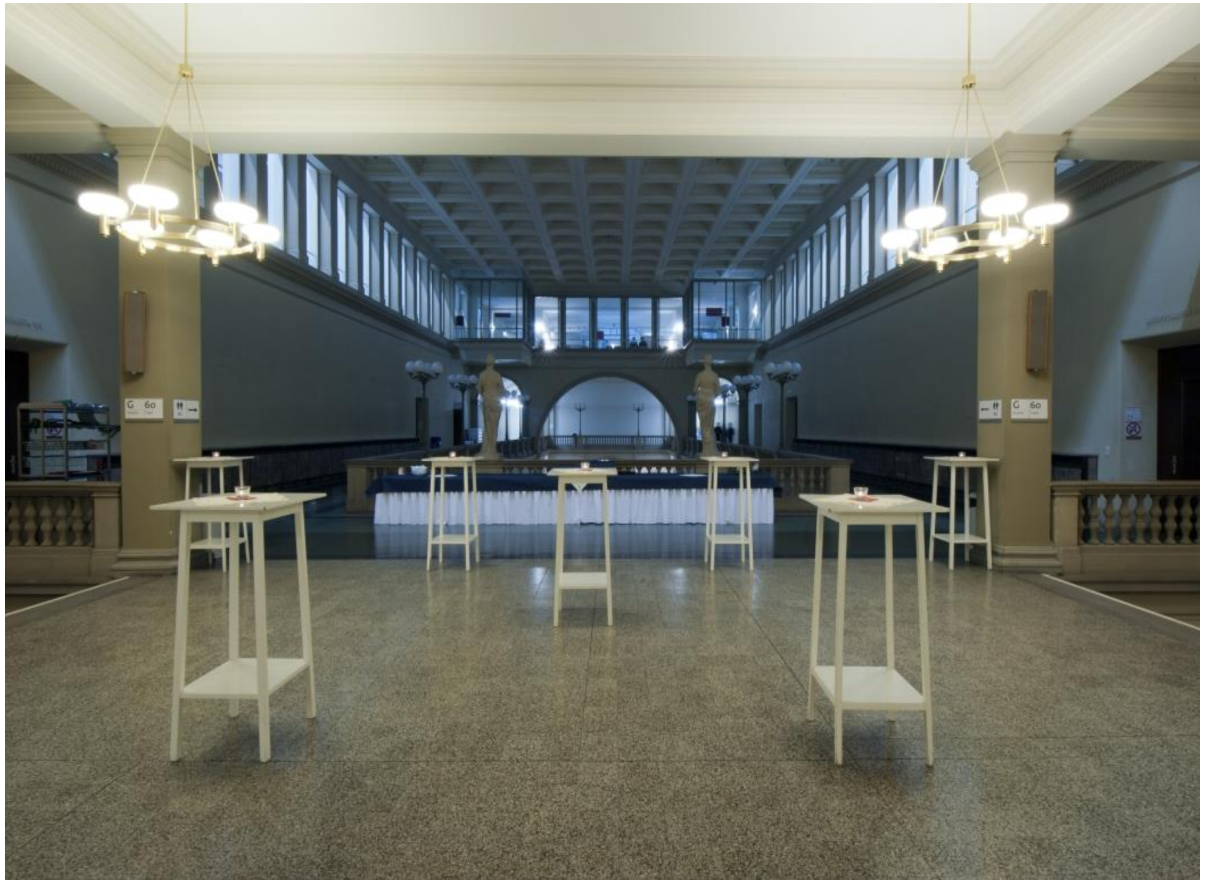
Introduction and Motivation



SEITZ, Michael J. et al. The Superposition Principle: A Conceptual Perspective on Pedestrian Stream Simulations.**Collective Dynamics**, [S.l.], v. 1, p. 1-19, mar. 2016. ISSN 2366-8539. Available at: <https://collective-dynamics.eu/index.php/cod/article/view/A2>.

Introduction and Motivation

Apero in ETH

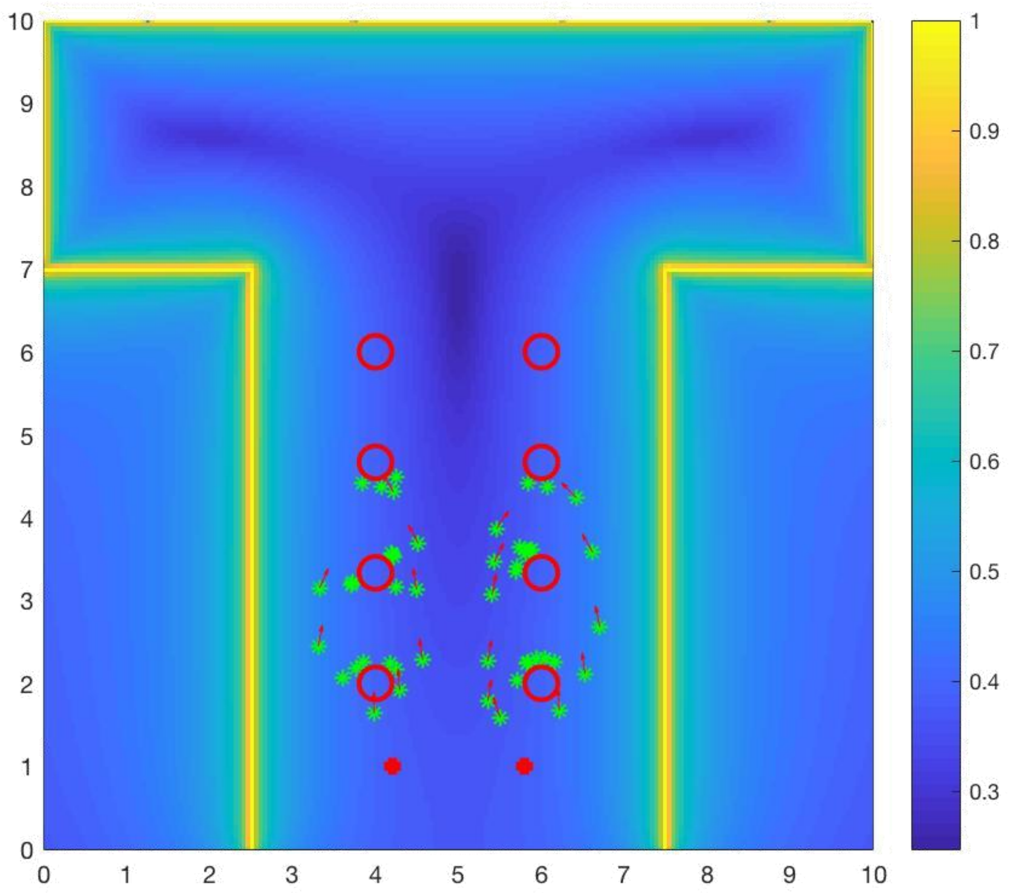


Introduction and Motivation

- Number of People
- Distance between Food Locations
- Tables' Disposition

Affect the behavior of the participants ?

Social Force Model

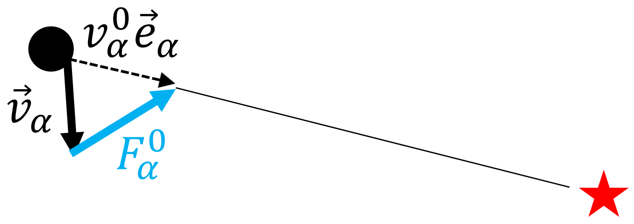


Description of the Model

- Force due to Destination

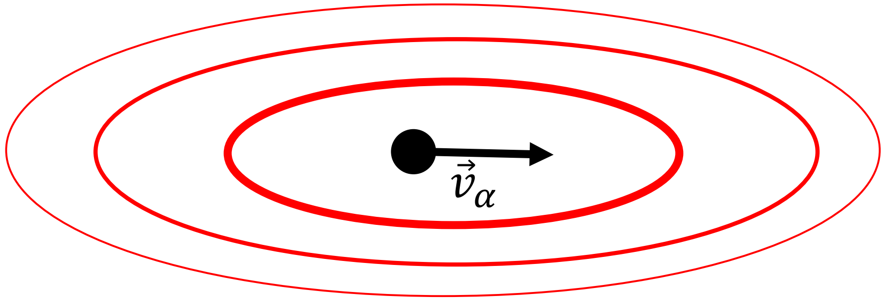
  - Considering a pedestrian alfa:

$$F_\alpha^0\left(\vec{v}_\alpha, v_\alpha^0 \vec{e}_\alpha\right) := \frac{1}{\tau}\left(v_\alpha^0 \vec{e}_\alpha - \vec{v}_\alpha\right)$$



- Force due to other pedestrians

  - Monotonic decreasing force field with elliptical shape



$$\vec{f}_{\alpha\beta} := -w \nabla_{\vec{r}_{\alpha\beta}} V_{\alpha\beta}[b(\vec{r}_{\alpha\beta})] \quad \text{with} \quad 2b := \sqrt{\left(\|\vec{r}_{\alpha\beta}\| + \|\vec{r}_{\alpha\beta} - v_\beta \Delta t \vec{e}_\beta\|\right)^2 - \left(v_\beta \Delta t\right)^2}$$

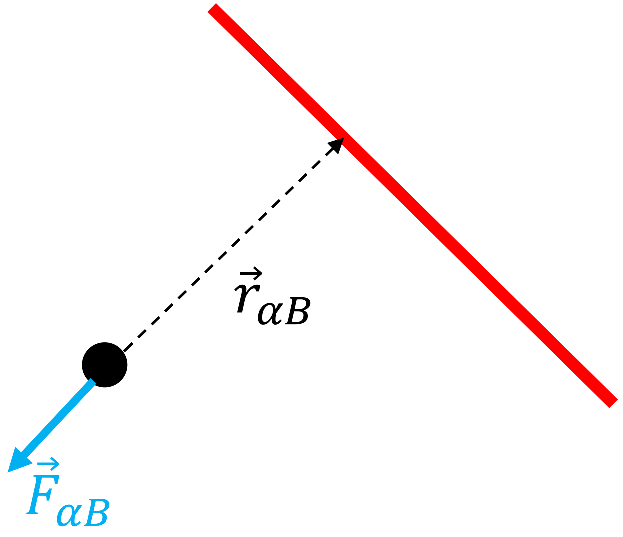
Dirk Helbing and Peter Molnar. Social force model for pedestrian dynamics. Phys. Rev. E, 51:4286, May 1995.

Description of the Model

- Force due to obstacles and walls

  - ➢ Monotonically decreasing force field

$$\vec{F}_{\alpha B} := -\nabla_{\vec{r}_{\alpha B}} U_{\alpha B}(\|\vec{r}_{\alpha B}\|)$$



- Total Force

  - ➢ Summation of all forces

$$\vec{F}_{\alpha}(t) := F_{\alpha}^{0}\left(\vec{v}_{\alpha}, \vec{v}_{\alpha}^{0}\vec{e}_{\alpha}\right) + \sum_{\beta} \vec{f}_{\alpha\beta} + \sum_{B} \vec{F}_{\alpha B}$$

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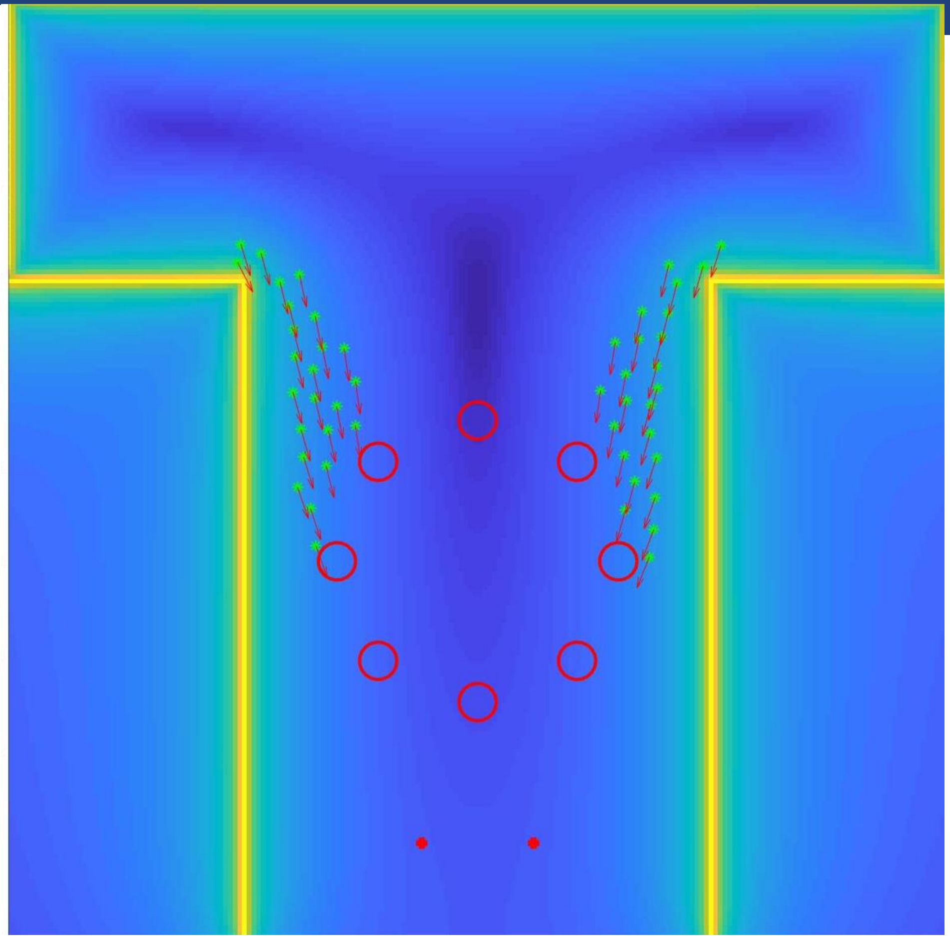
Implementation

Initial position of tables, people and food points

- Two table configurations: rectangular and circular dispositions.
- The people are initially located on the top-left and top-right of the map.
- The position of the tables where the food is distributed are two and they are located on the bottom of the room.



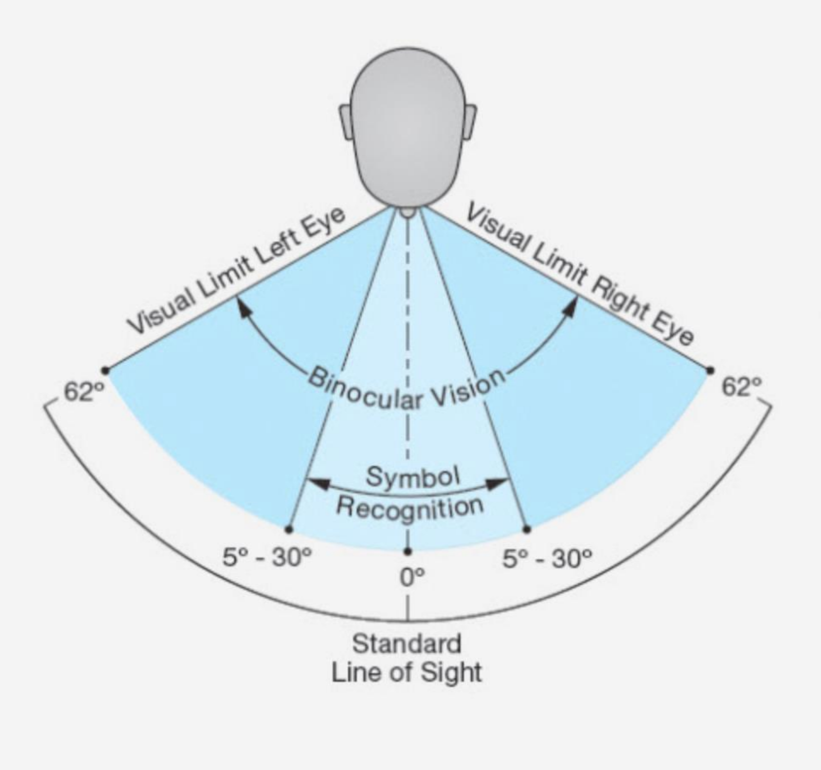
Implementation

Person-people repulsive force

- Exponential force that decreases with the distance among pedestrians.

$$\vec{F}_{\alpha B} = \omega A e^{b/B}$$

- $A = 2\ N$
- $B = 0.1\ {}^{1}/_{m}$
- $\omega\left(\vec{e}\cdot\vec{f}\right) = \begin{cases} 1 & if \quad \vec{e}\cdot\vec{f} \geq \left\|\vec{f}\right\| \cos(\phi) \\ 0.3 & otherwise \end{cases}$
- $\phi = 60°$ visual field



Implementation

Table-person repulsive force

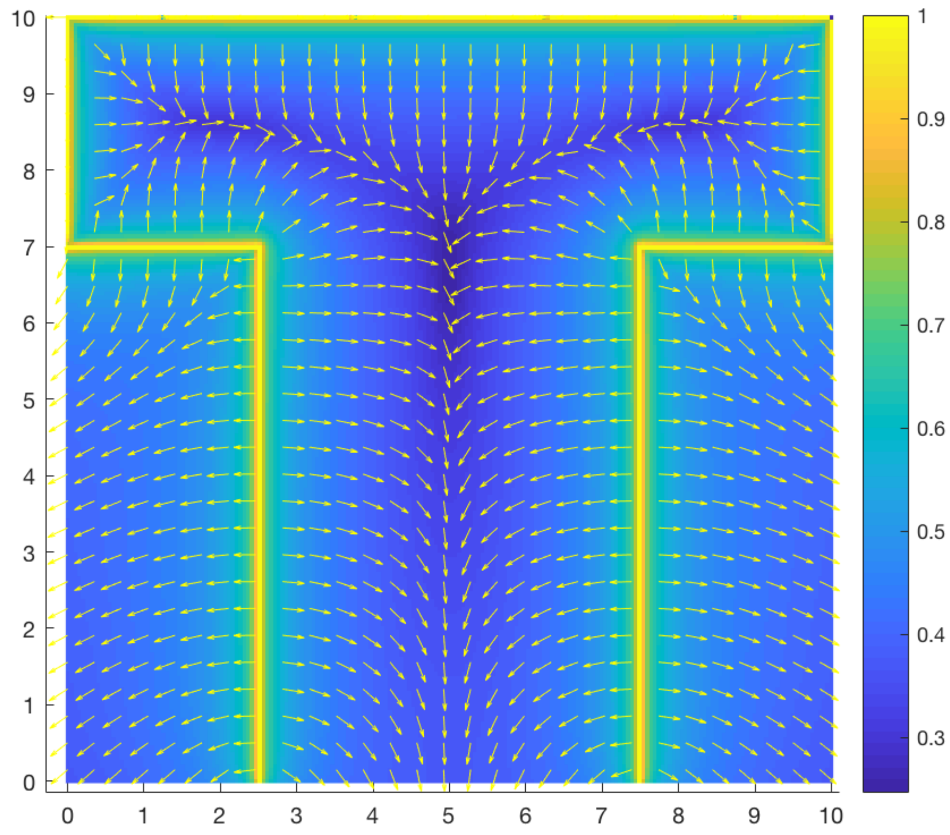
- The tables hinder the motion of the people while pedestrians move towards their objective.
- Tables are modeled as point-like particles.
- Table-person constant C_t is set equal to $0.05\ {}^{N}/_{m}$ for all the tables.

$$F_{p-t_i} = \frac{C_t}{d_{p-t_i}^2}$$

$$\vec{F}_{p-t} = \sum_{t_i=1}^{Nt} \vec{F}_{p-t_i}$$

Implementation

Wall-person repulsive force



- The walls generate a force field inversely proportional to the distance.
- In order to express the effect of the walls, we discretize them into several point-sources at constant distance.
- Since the effect of the walls is constant in time, we discretized the Apéro room into a rectangular mesh of points and save and save the force field into a file.
- Person-wall constant $C_w = 0.0003\ {}^{N}/{}_{m}$

$$F_{p-w_i} = \frac{C_w}{d_{p-w_i}^2}$$

$$\vec{F}_{p-w} = \sum_{w_i=1}^{Nw} \vec{F}_{p-w_i}$$

Implementation

Path towards the objective

- Pedestrian follows the shortest polygonal route.
- 1st objective: Apéro table.
- 2nd objective: nearest table in the Apéro room.

$$\vec{e}_\alpha(t) = \frac{\vec{d}_\alpha - \vec{r}_\alpha(t)}{\left\|\vec{d}_\alpha - \vec{r}_\alpha(t)\right\|}$$

$\vec{e}_\alpha$: vector pointing towards the objective
$\vec{d}_\alpha$: destination position
$\vec{r}_\alpha$: pedestrian's position

Attraction towards the objective

- Stronger attraction if the person is not walking at the desired velocity or if is not moving towards the objective.
- Relaxation time $\tau = 0.5 \div 0.8\ s$.
- Desired velocity $v_\alpha^0 = 0.3\ {}^{m}/_{s}$.

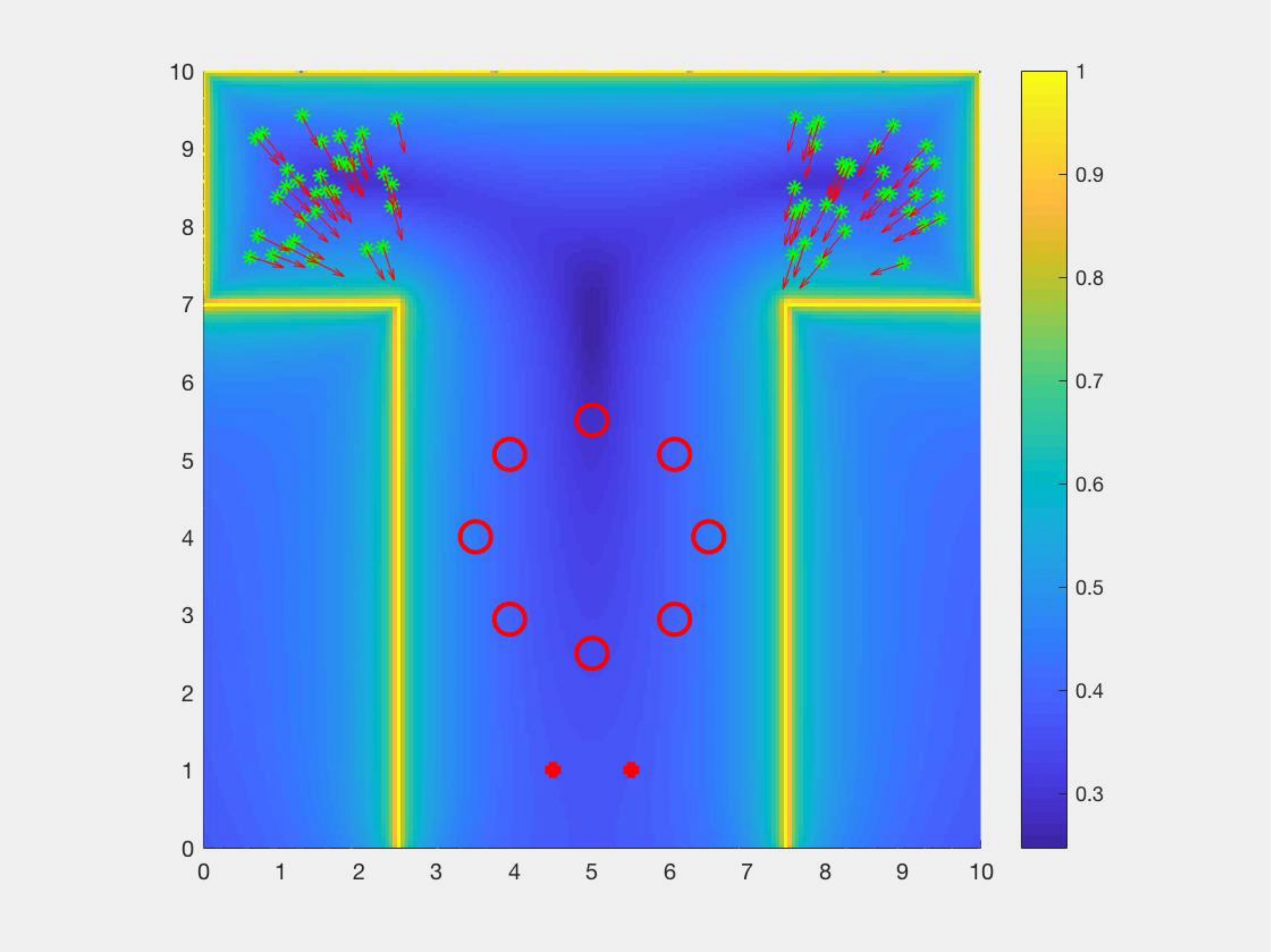
$$F_{p-o} = \frac{1}{\tau}(v_\alpha^0 \vec{e}_\alpha - \vec{v}_\alpha)$$

v_α^0: desired velocity
τ: relaxation time
$\vec{v}_\alpha$: actual velocity

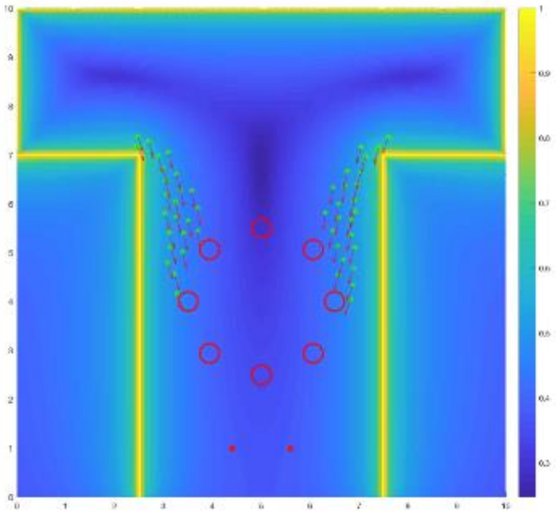
Implementation

Additional constraints

- Maximum velocity $v_{max} = 2 * v_{\alpha}^{0} = 0.6\,{}^{m}/_{s}$.
- Table capacity $c_t = 6 \div 9$ people.
- Time step $dt = 0.4s$



Simulation

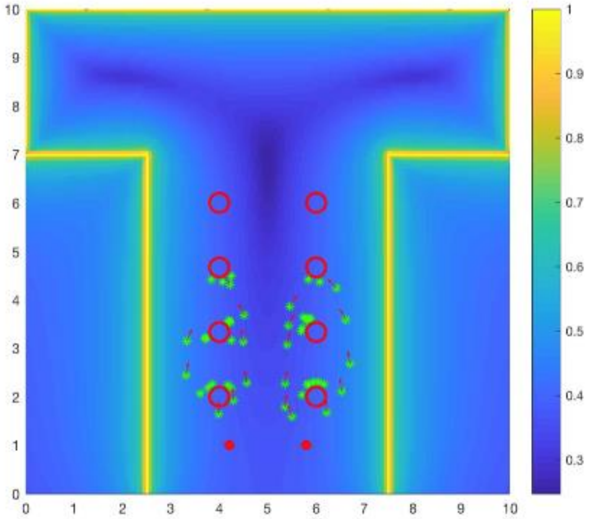


- 3 functions are used to consider the cost of every simulations:

    - Time cost function
    - Velocity cost function
    - Force cost function

- Simulation conducted by averaging different simulations over 20 attemps each.
  The parameters that changed are:

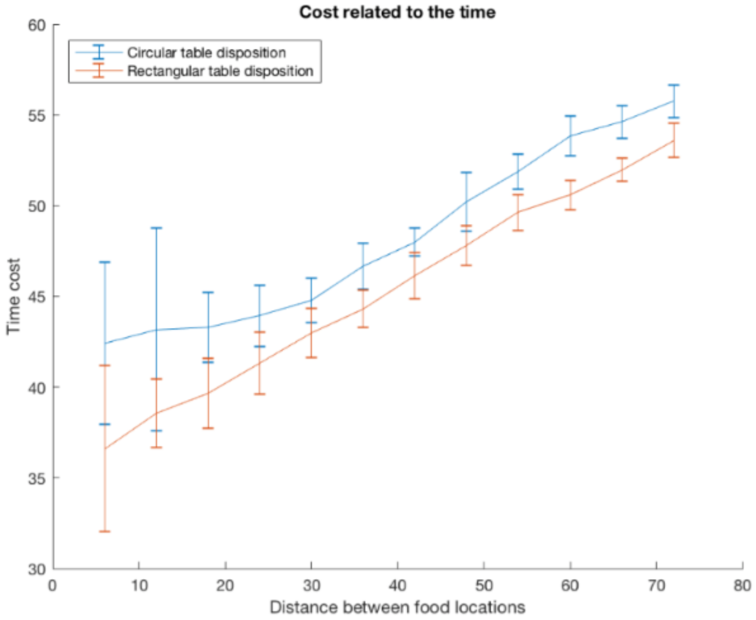
    - Number of participants
    - Number of tables
    - Disposition of tables (circular or rectangular)
    - Distance between food positions on the buffet table



Simulation

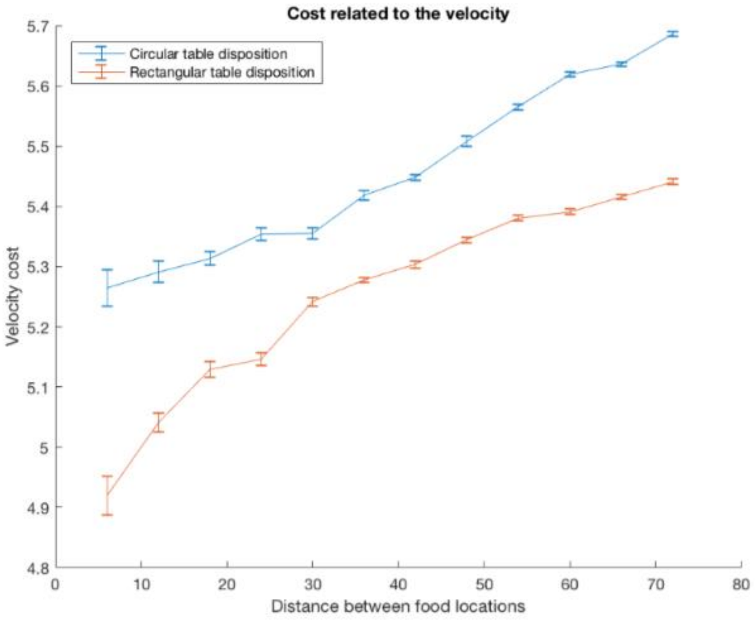
- Changing the number of participants

  - ➢ Number of people: from 6 to 72
  - ➢ Number of tables: 8
  - ➢ Capacity of tables:9
  - ➢ Distance between food points: 1



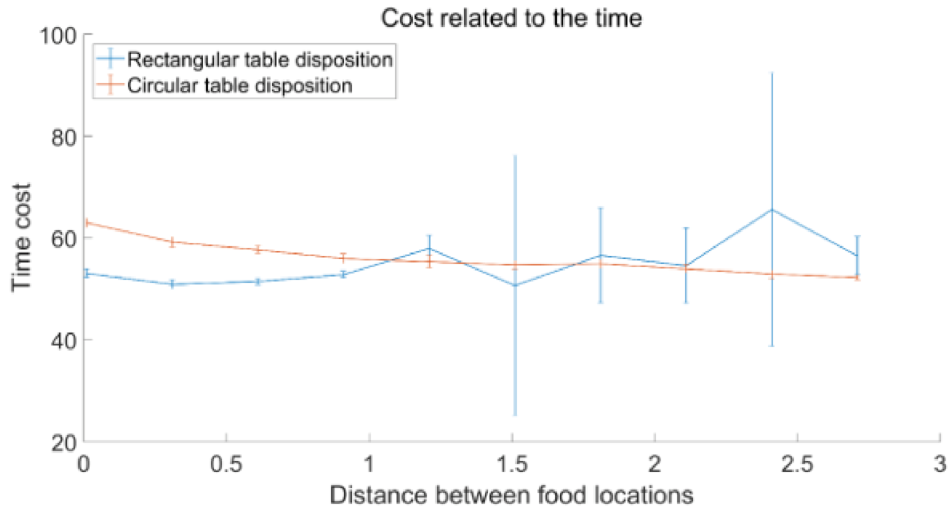
Results

- ➢ Linear increase of time cost with increasing number of participants
- ➢ Rectangular table disposition is preferred with respect to the circular table disposition
- ➢ Rectangular table disposition:
  - ✓ the velocity cost is insignificant in case of few participants.
  - ✓ Clusters begin around 15 people
  - ✓ Stable situation in case of crowded apéros



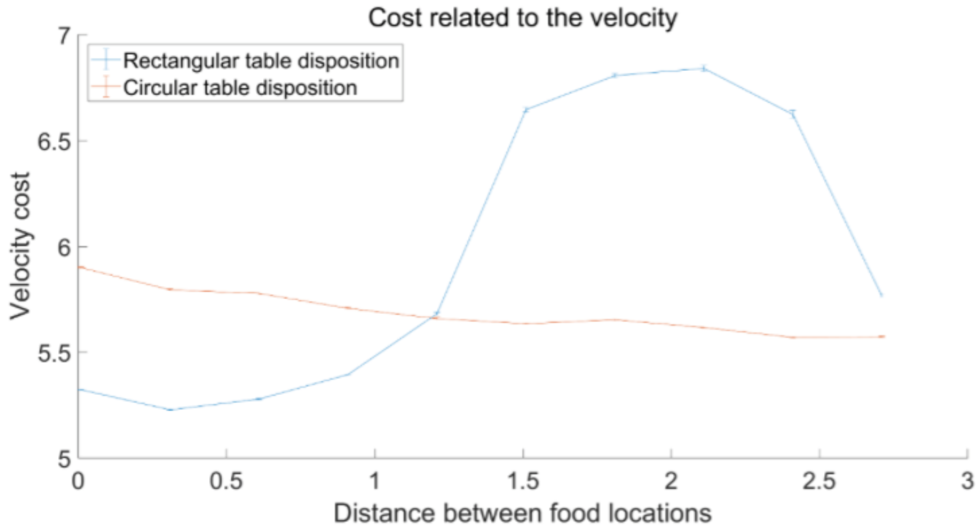
Simulation

- Changing the food positions
  - ➢ Distance between food points: from 0 to 2.7
  - ➢ Number of tables: 8
  - ➢ Capacity of tables: 9
  - ➢ Number of people: 72



Results

- ➢ Cost of time has no significant correlation with the distance of food points
- ➢ Cost of velocity
  - ✓ Circle: decreases monotonously
  - ✓ Rectangle: down-”U”shape



Summary

- Description of Social Force Model
- Implementation: person-person, table-person, wall-person, objective destination change.
- Time cost function increase as number of people increase.
- Rectangular table disposition is better than circular one.
- Food points separates as far as possible for circle arrangement of table, a bit for rectangular arrangement.

Thank you