Pedestrian modelling
from research to commercial applications

Vassilis Zachariadis

PhD Candidate | CASA UCL
Senior Scientist | Legion ltd

zachariadis@gmail.com

Pedestrian movement modelling:

- 1st part – Microscopic movement
- 2nd part – Macroscopic movement

Individual level / Aggregate level

Space representations:

- Continuous state and action spaces
- Discrete information space

Part 1: Microscopic movement
(applies only to agent-based approaches)

- Rule based

- Reactive

- Utility based

Rule based approach:

Agents usually follow discrete & countable sets of context specific rules:

Queuing models (PedRoute)
Cellular Automata models (Blue & Adler 2000)
Other (Castle 2007).

Their simulative flexibility is restricted by the extent of behavioural aspects covered by the pre-identified modelling hypotheses and deriving sets of rules.

The normative approach usually implies deterministic behaviour and lack of simulation of uncertainty related phenomena.

Reactive approach:

At each step, the agent reacts to pull (attraction) and push (repulsion) forces.

Represent: Destinations, Attractions, Obstacles and other Pedestrians

These forces determine the agent's acceleration, velocity and position vectors
- given the pedestrian kinematic constraints.

Force models:

Demonstrate deterministic cause - effect chains and principally focus in the emergent flow patterns (Helbing 1996, Okazaki 1979, Teknomo 2005)

They fail to tackle directly (explicitly) behavioural aspects related to varying uncertainty levels (movement strategies of other pedestrians etc)

Achieved indirectly, by shifting the weighting factors of different types of forces

Utility based approach:

At each step, the agent's goal is to maximise the utility.

Usually, utility is a function of quantifiable parameters that the adopted behavioural model considers causal to aspects of the pedestrian behaviour (Antonini 2006, Legion 2002, Hoogendoorn 2002)

Utility based models follow the long tradition of utility maximising modelling in microeconomics and transport studies

They can be deterministic or stochastic

Can easily be combined with game theory models and particularly non-zero-sum differential games (collision avoidance)

Collision avoidance behaviour: a non-zero-sum game

Sketching the concept:

Assume pedestrians A and B are engaged in trajectories that lead to collision

Cost for Pedestrian A:

	Pedestrian A – Action	Pedestrian A – No action
Pedestrian B – Action	Conservative – Regret	Risky
Pedestrian B – No action	Conservative – No regret	Collision

In general ⟶ Risky < Conservative < Collision

Costs subject to time pressure, velocities of A and B, characteristics of required collision avoidance action etc.

$$u^* = \operatorname*{argmin}_{u \in U} \left\{ E_\theta \left[L(u,\theta) \right] \right\}, \qquad E_\theta[L(u,\theta)] = \sum_{\theta \in \Theta} L(u,\theta) P(\theta).$$

If no estimation model for the action of B:

$$u^* \rightarrow \min \left\{ (\frac{1}{2} risky + \frac{1}{2} collision), (\frac{1}{2} conservative + \frac{1}{2} conservative) \right\}$$

Minimising Regret (=> Nash Equilibria):

$$u^* = \operatorname*{argmin}_{u \in U} \left\{ E_\theta \left[T(u,\theta) \right] \right\} \quad T(u,\theta) = \max_{u' \in U} \left\{ L(u,\theta) - L(u',\theta) \right\}$$

… in this case it gives the same outcome

A more detailed analysis:

- Link to space
- Decide the costs
- Determine the collision avoidance actions
- Provide a probabilistic model to estimate other players actions

1. The running cost:

We assume running cost is linear in parameters.

$$L_p(t, \mathbf{x}, \mathbf{u}) = \sum_k c_{p,k} L_{p,k}(t, \mathbf{x}, \mathbf{u})$$

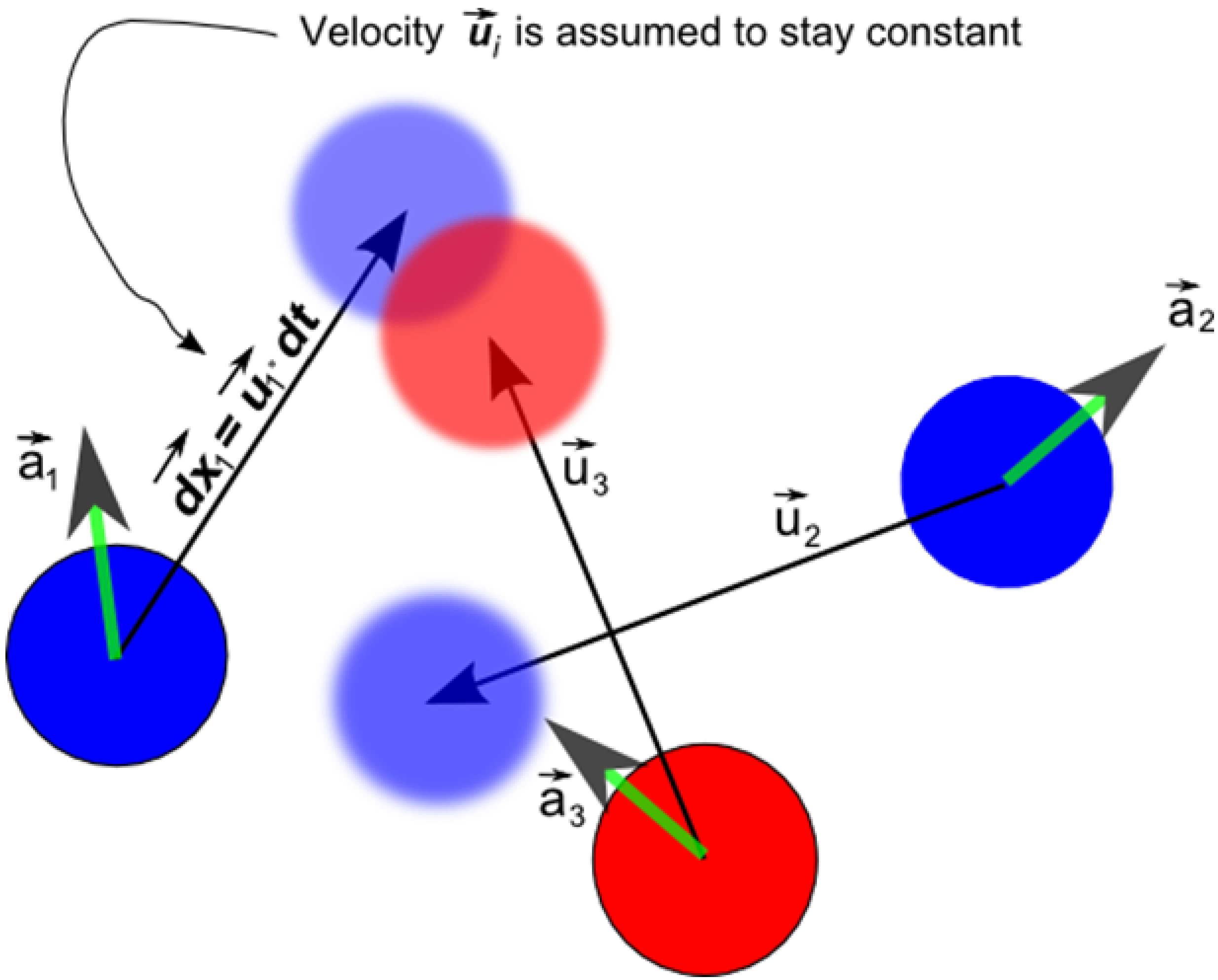
Possible parameters:

- The vector difference between optimum velocity and current velocity
  Represents deviation from target
- Acceleration costs
  Represent interaction with other agents
- Proximity/Collision integrated costs

2. The collision avoidance actions:

Are determined by the cost minimising modelling principle

Collision avoidance:



3. The probabilistic model:

Takes into account the observable state of the opponent (other pedestrian); i.e. current position and velocity

The future state of the opponent is based on its current state and the acceleration and directional change (rotation) control that the opponent is applying.

Assuming lack of knowledge about the opponent's cost function the controls (acceleration and directional change) are normal distributions:

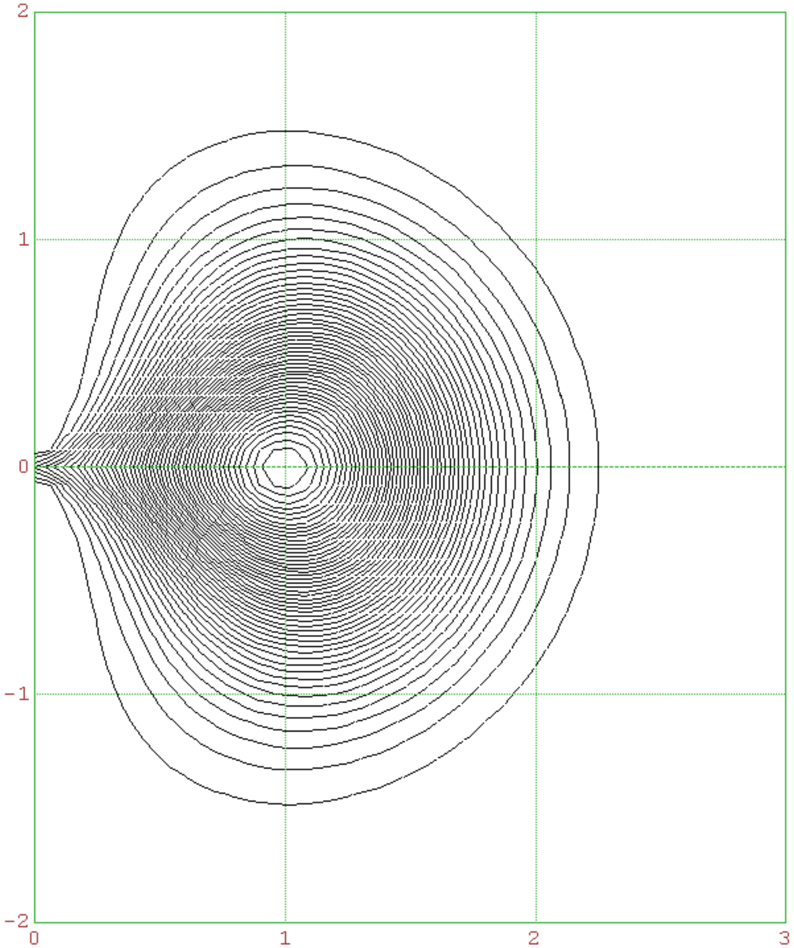
$$X \sim N(\mu, \sigma), \quad \mu = 0$$

Probability Density Function: $\frac{1}{\sigma\sqrt{2\pi}} \exp\left(-\frac{(x-\mu)^2}{2\sigma^2}\right)$

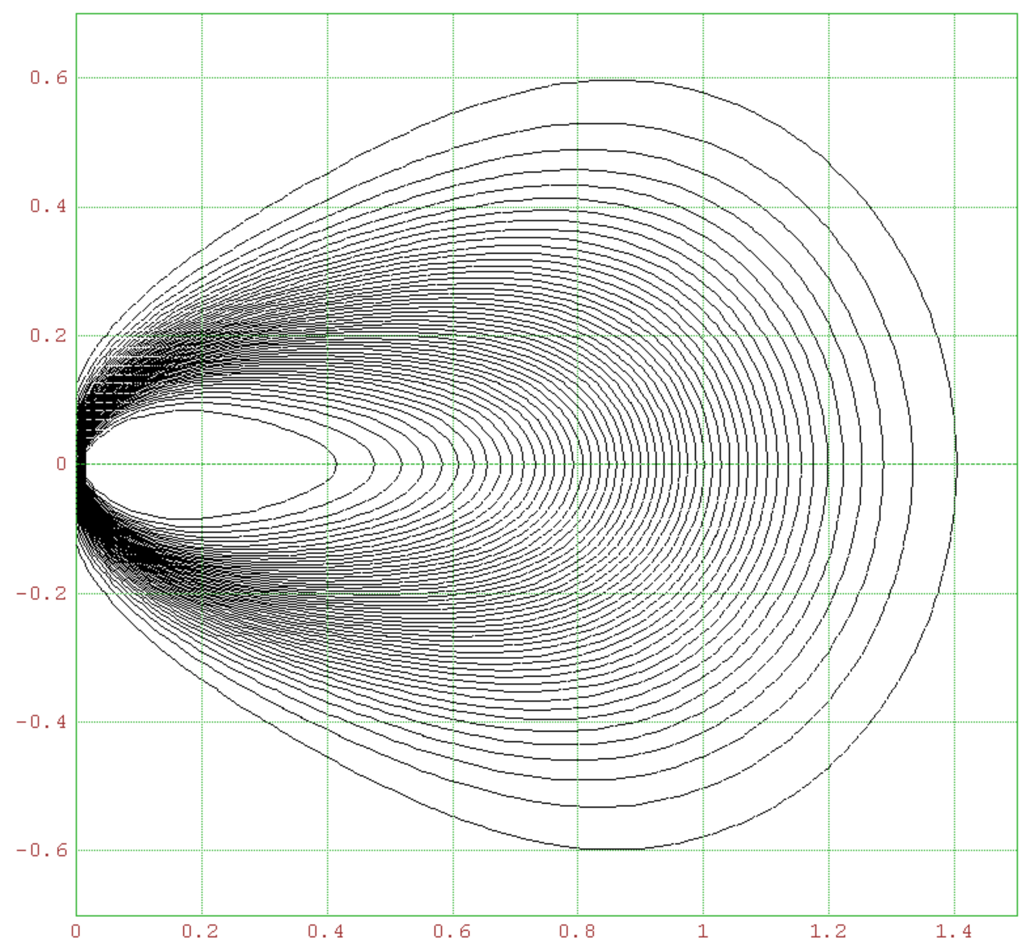
Cumulative Distribution Function: $\frac{1}{2}\left(1 + \operatorname{erf}\left(\frac{x-\mu}{\sigma\sqrt{2}}\right)\right)$

velocity = 1.00 m/s

Probability density:

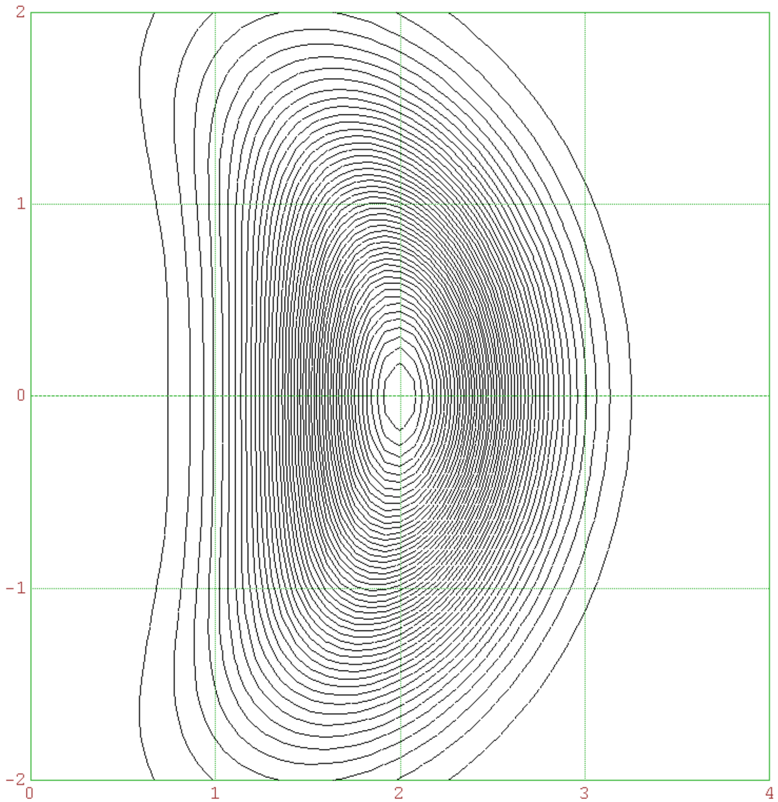


Cumulative distribution:

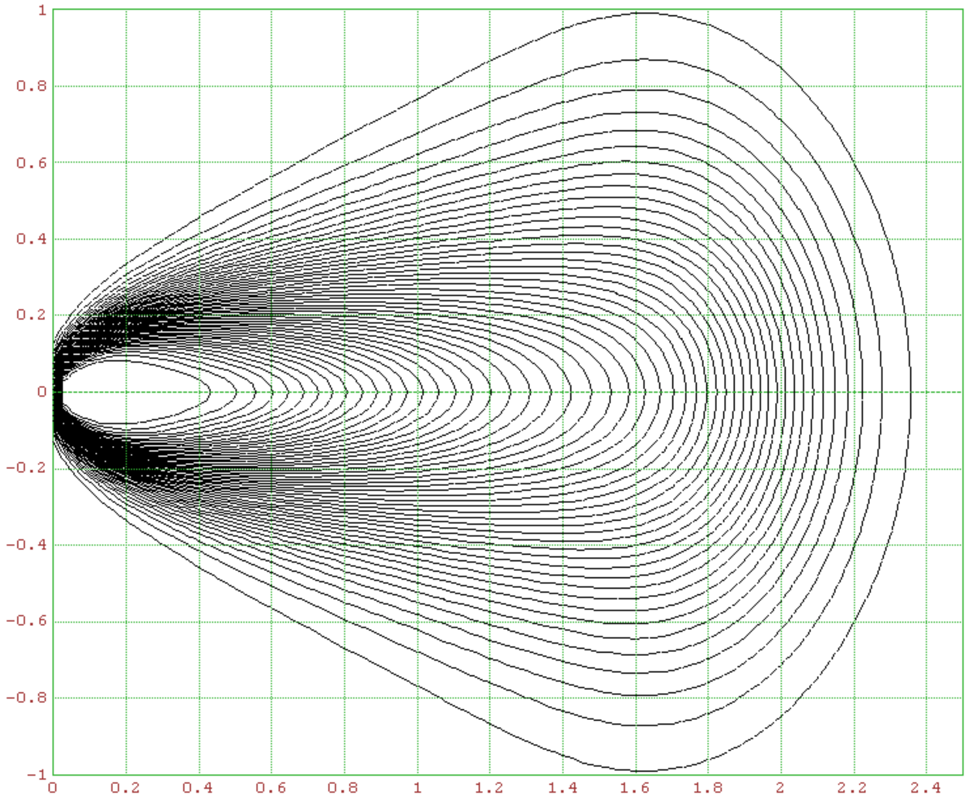


velocity = 2.00 m/s

Probability density:

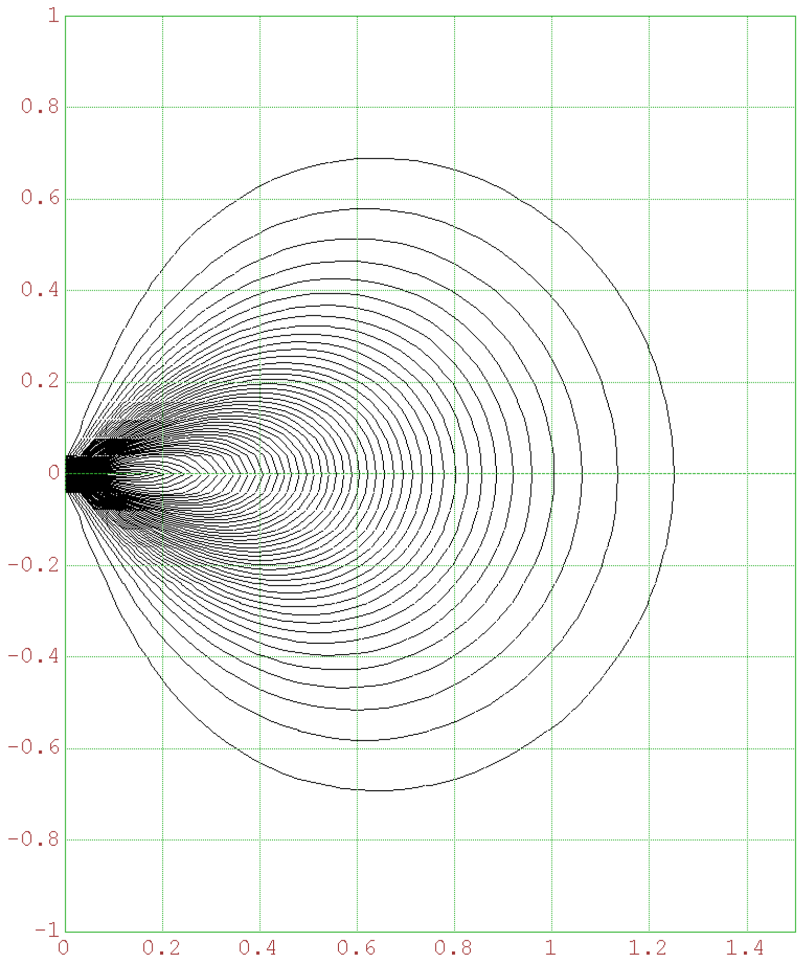


Cumulative distribution:

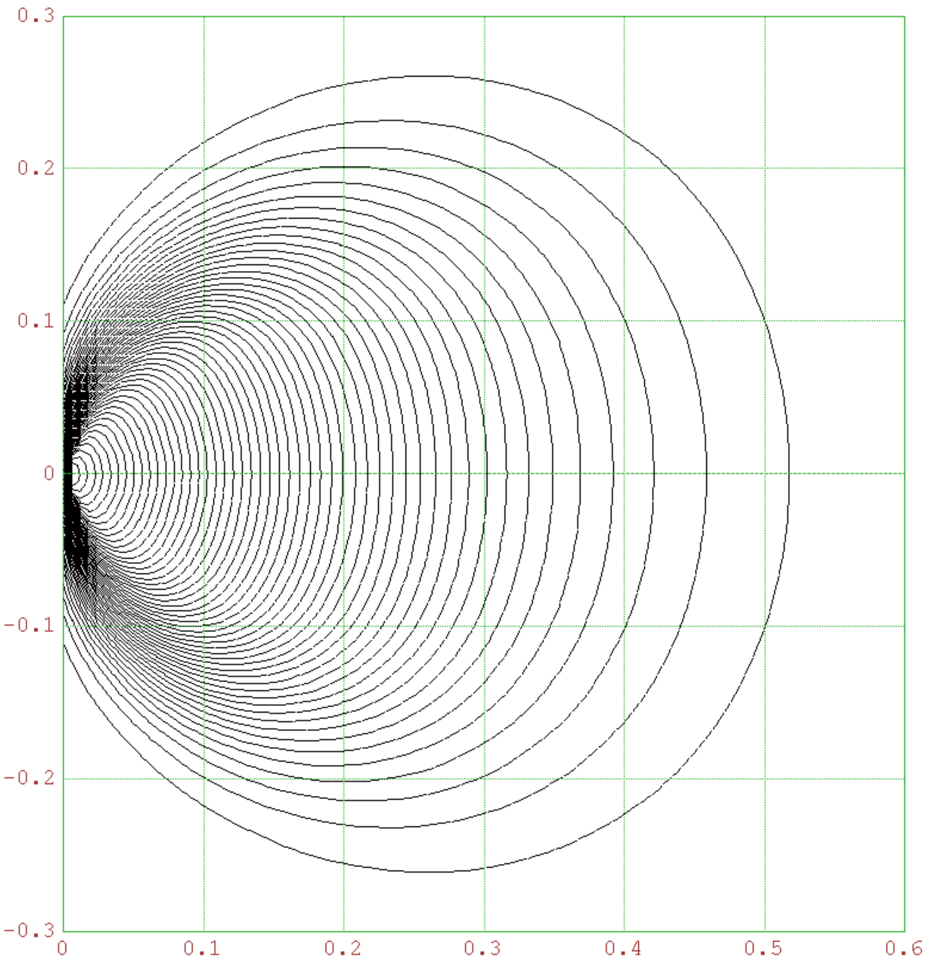


velocity = 0.00 m/s

Probability density:



Cumulative distribution:



Part 2: Macroscopic movement

Cases that present multiple routing options:

Most route choice models adopt utility based approaches; i.e. agents make routing choices, seeking to maximise their expected utility.

(Therefore, are conceptually consistent with microscopic utility based models)

Here the critical modelling decision shifts to the space representation that will be used to define the routing options

The Network v Grid dilemma

Both are discrete!!!

The network based approach:

Used for motor traffic route assignment (User Equilibrium)

INITIALISE

i. Calculate the initial cost of all links of the network (graph arcs)

ii. Assign agents (deterministic or stochastic) to least (initial) cost paths.

LOOP

1. Recalculate the cost of each link based on the emerged traffic conditions.

2. Compute the preferred paths (deterministic or stochastic) of the agents based on the updated link costs.

3. Switch paths for *some* (Frank-Wolfe algorithm) agents based on the updated path preferences

4. Check if the algorithm has converged (no further switches were necessary)

Problems:

- Defining the movement network
- Determining aggregate cost functions based on flows
- Handling asymmetric costs (link costs due to conditions in other links)
- Consideration of local configurational issues

Possible Solution:

(Assuming the network definition is possible)

Run an agent-based simulation of the study area with the appropriate agent route assignments every time the link costs need to be updated.

- Extremely computationally intensive

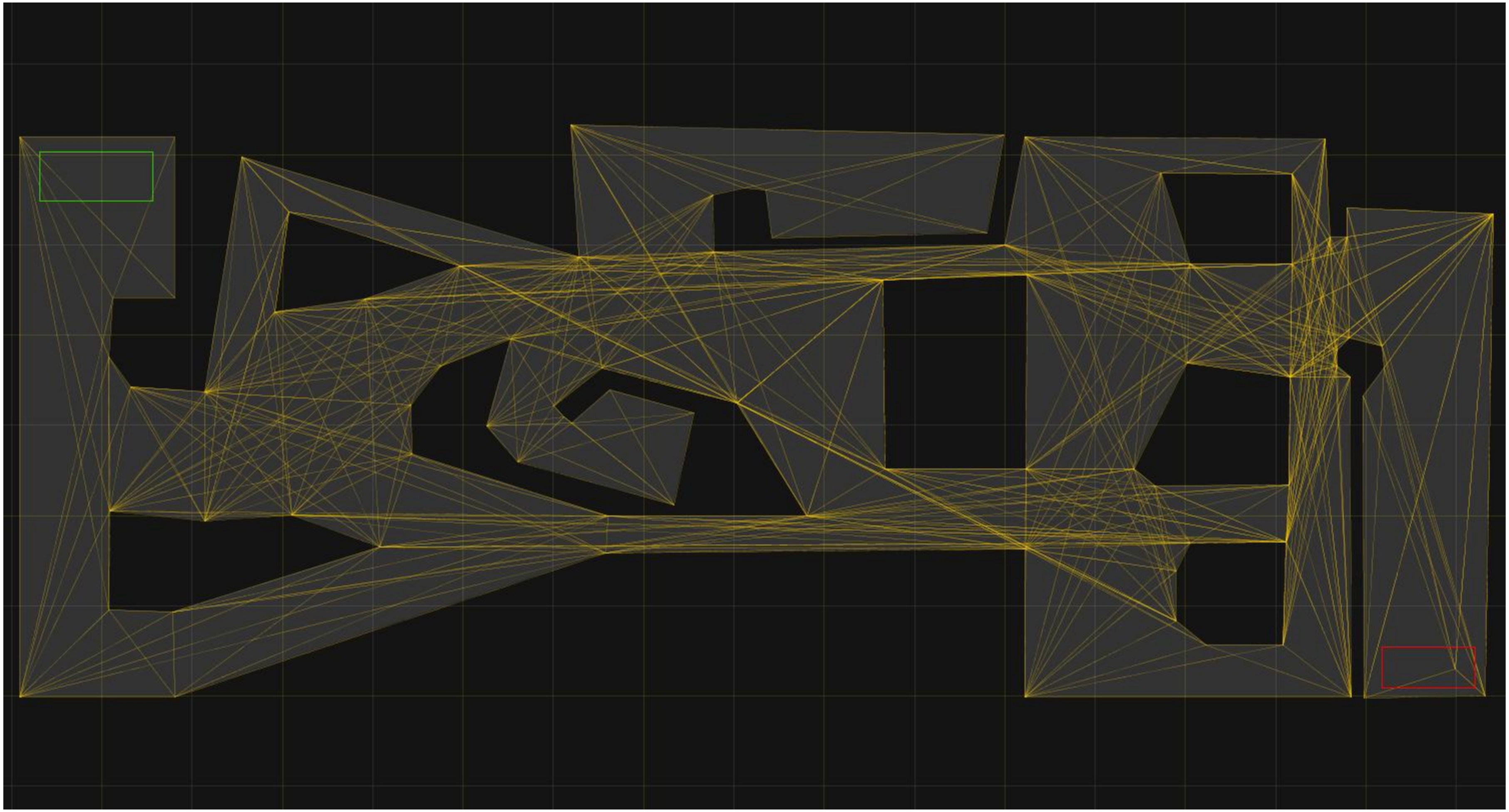
- May not be possible to complete an agent-based circle due to configurational restrictions (blockage => asymmetric costs)

configurational restrictions leading to asymmetric costs

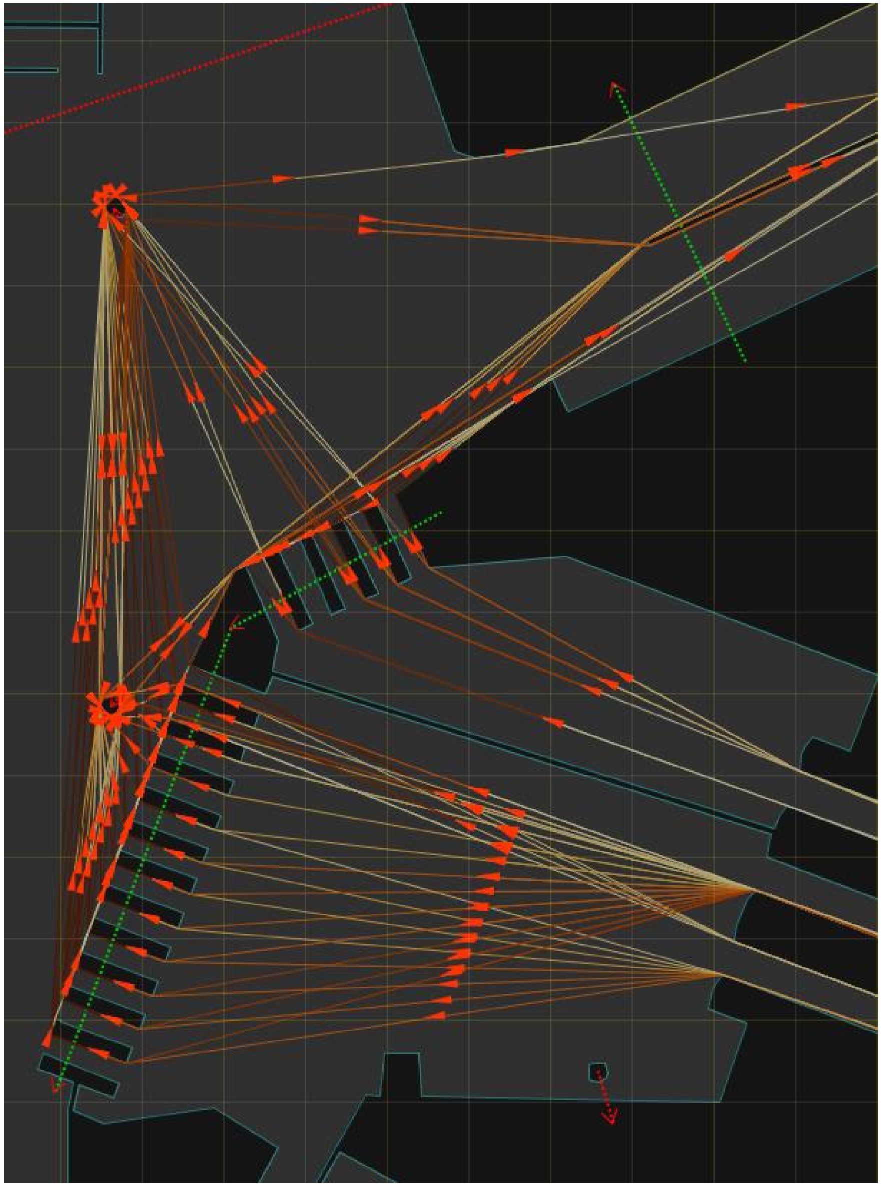
Movement network definition – an isovist based approach:

From visual graphs to movement networks

The visual graph:



Movement options:



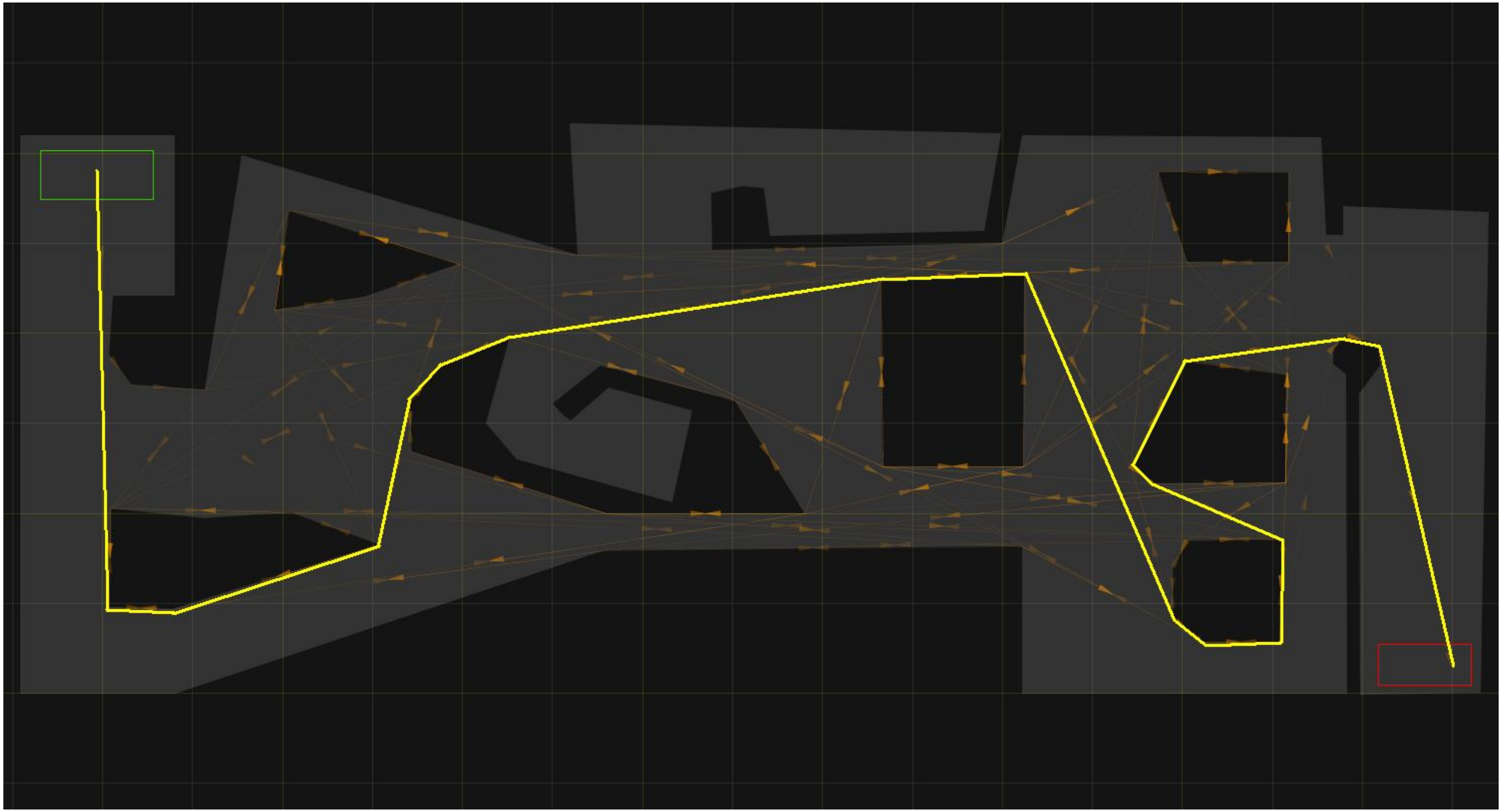
Selecting a complete route:

1. Define alterative options
2. Evaluate alternative options
3. Select a complete route

- Number of alternative options can be enormous
- The evaluation criteria may change while the selected trajectory is traversed

Alternative: selecting intermediate targets on-the-fly…

Random valid(?) complete path:



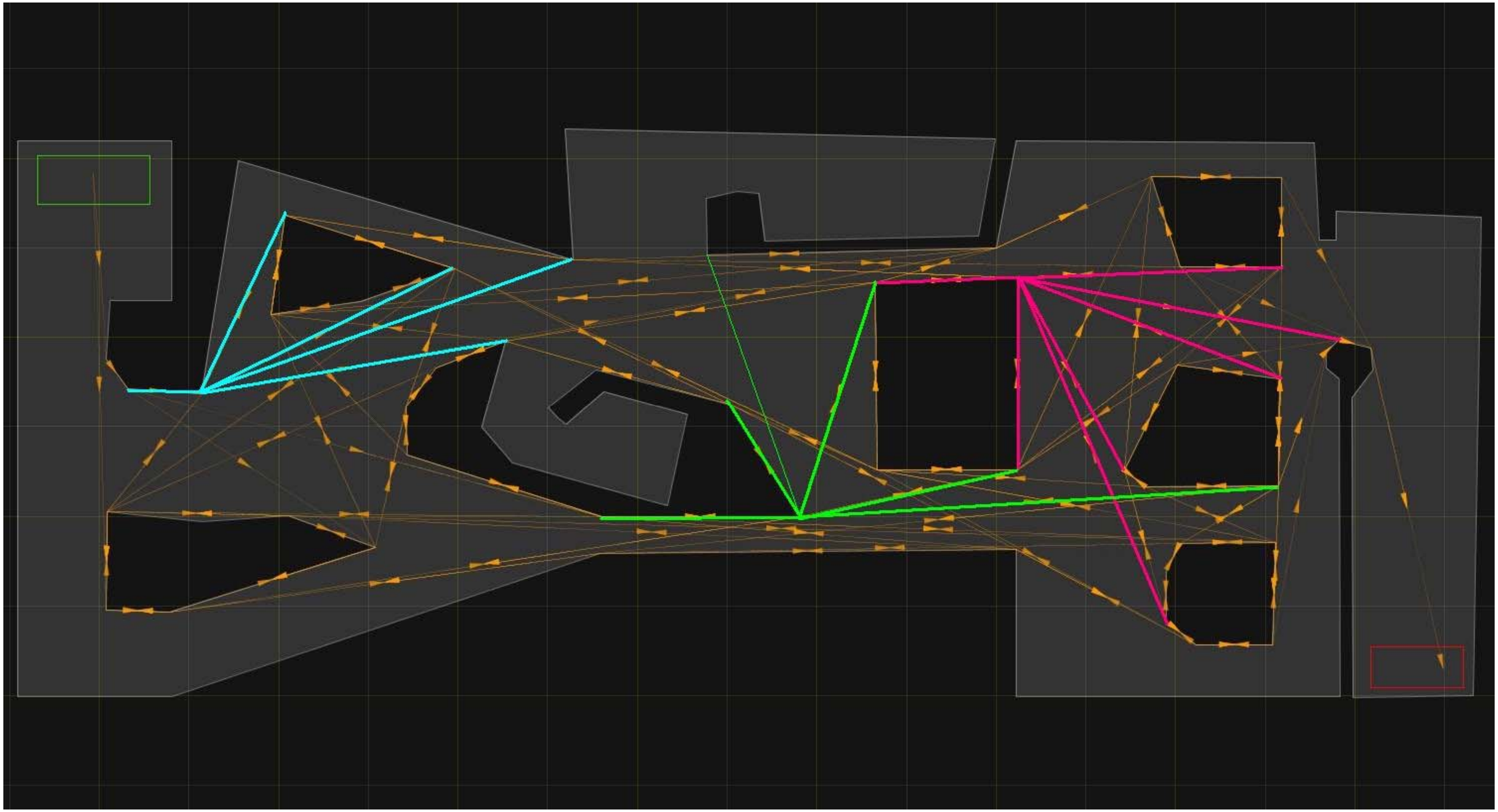
The proposed routing system:

- Agents based
- Continuous space

1. Compute initial costs to destination (no traffic related costs) for all nodes
2. Initial costs => initial probabilities:

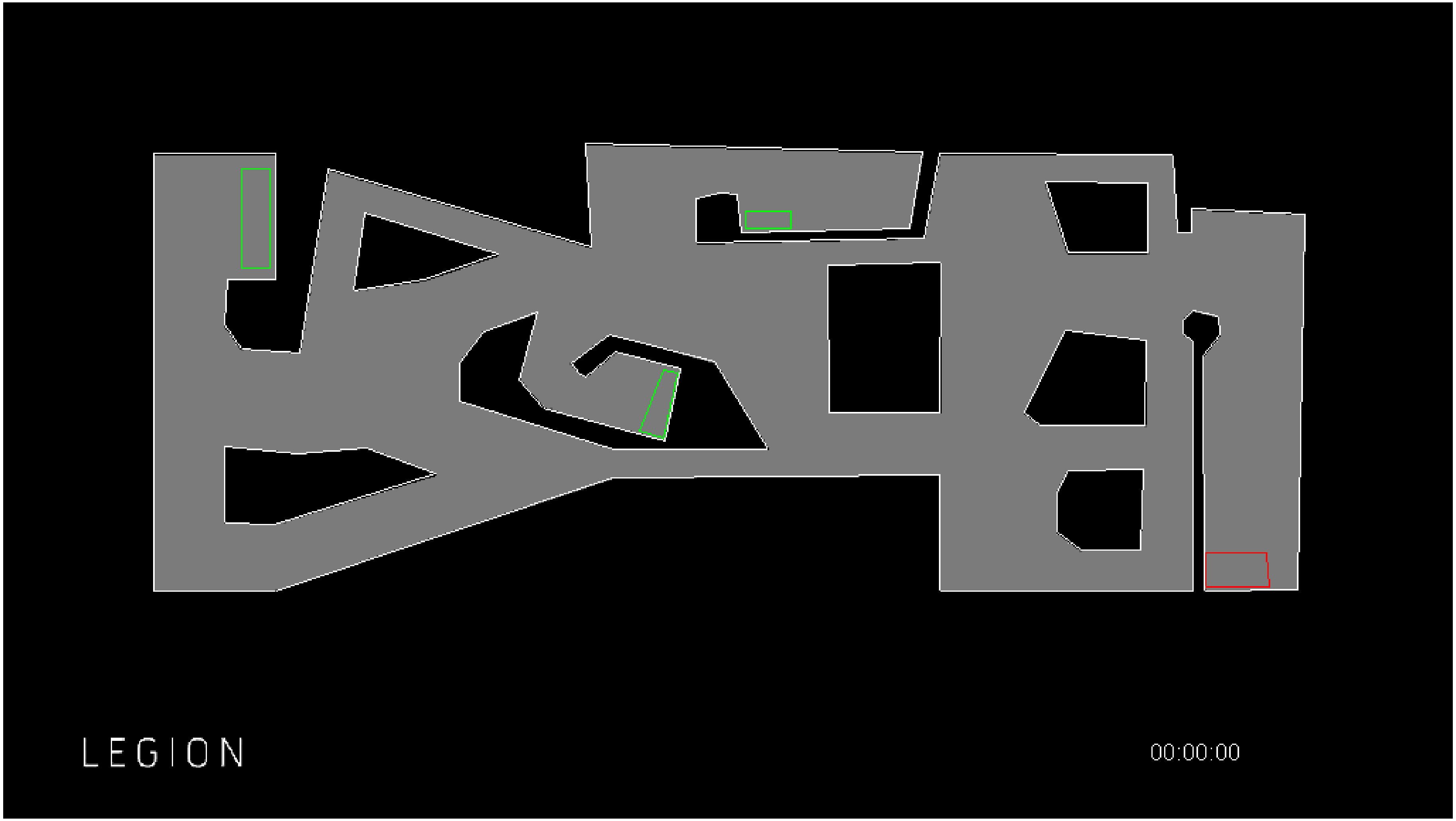
   Prob_c_n = f (Cost_n, Cost_i) i in *forward star* of *c*
3. Distribute agents stochastically using the initial probabilities
4. Agents reaching to their destination feed-back their ***experienced*** cost for the network links that form their trajectory
5. Probabilities adjusted to take into account the feed-back results

The forward stars:

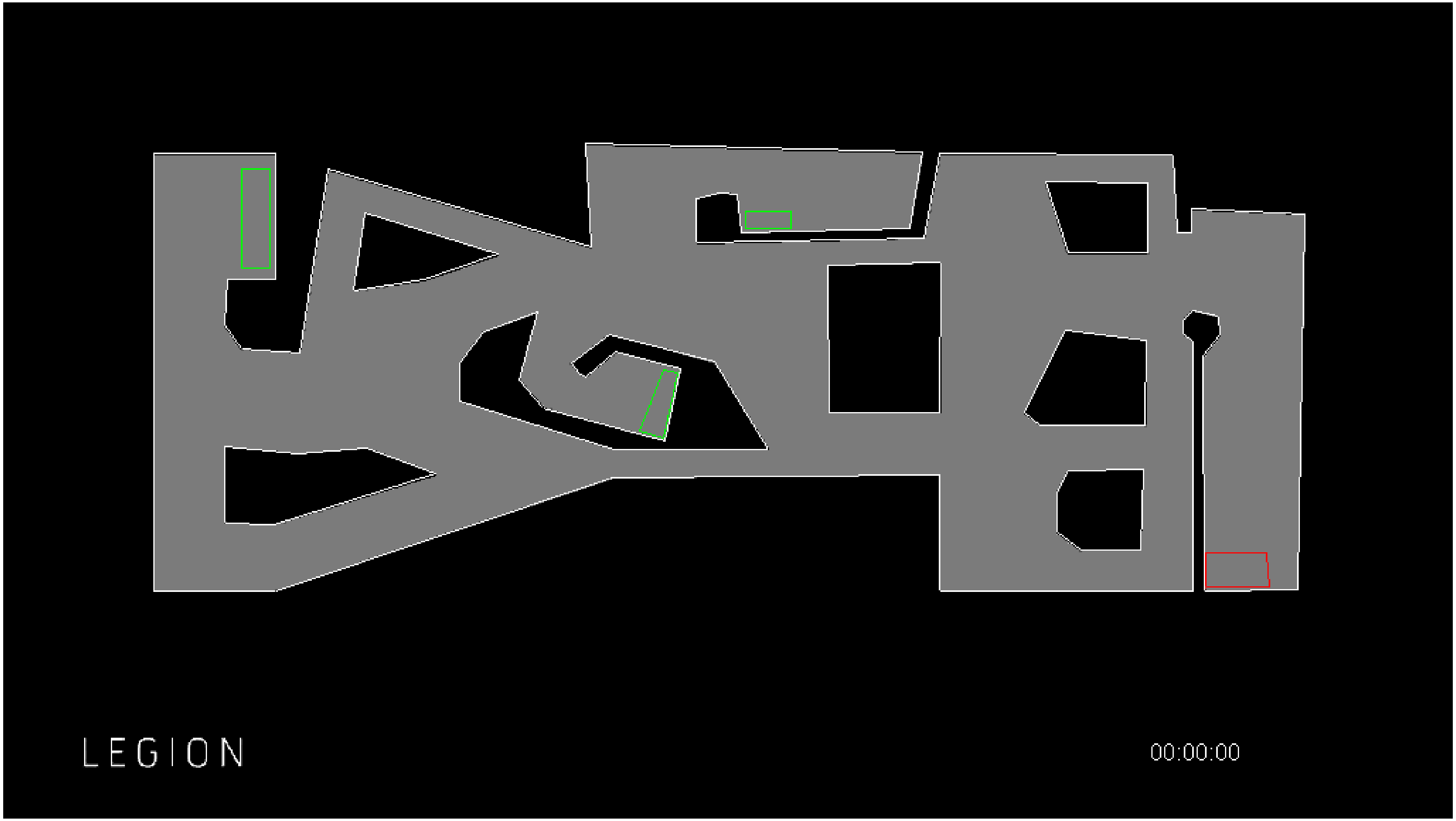


Running the model:

Running the model – learning phase:

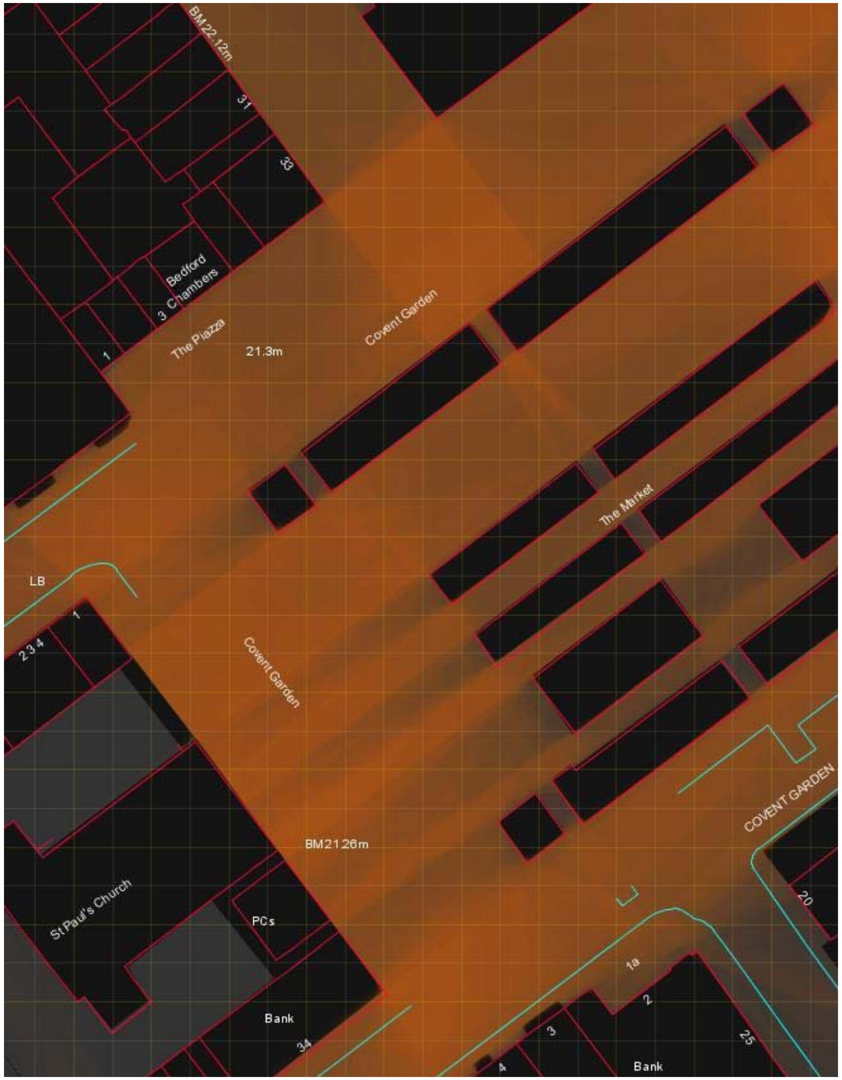


Running the model – 1st degree of experience:



Running the model – interaction with other streams:

Thank you!



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