



Cooperative robots in people guidance mission: DTM model validation and local optimization motion.



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Overview

- Motivation.
- Modelling people's motion.
- Modelling the motion space.
- Local Optimal Robot Task Assignment for the Cooperative Mission.
- Model Validation
- Implementation results.
- Conclusion.

Motivation

- Guiding people in urban settings using several mobile robots.

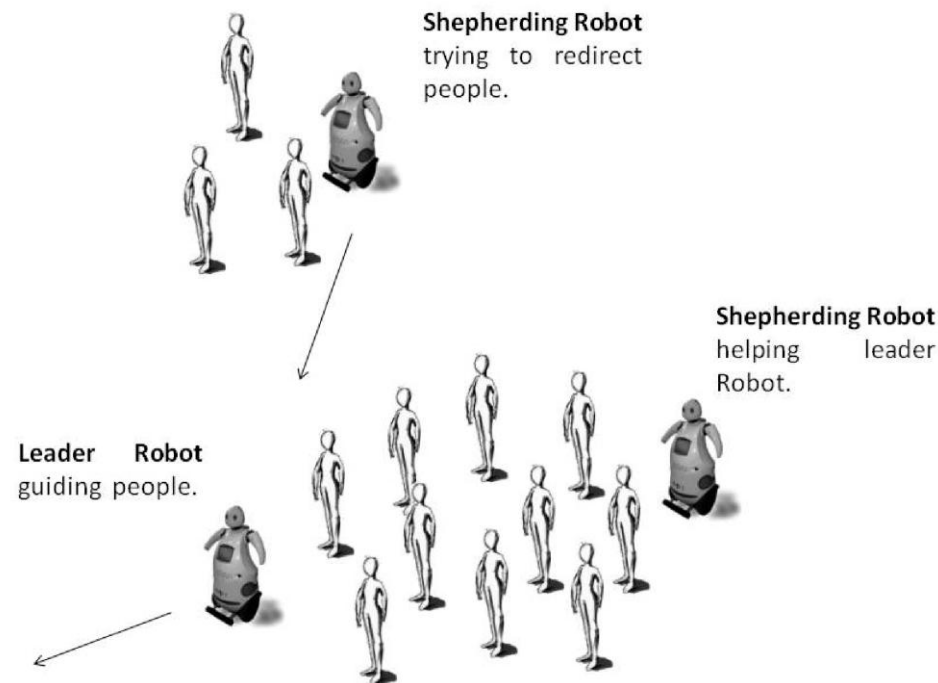
(Work performed under the European Project URUS)



Motivation (ii)

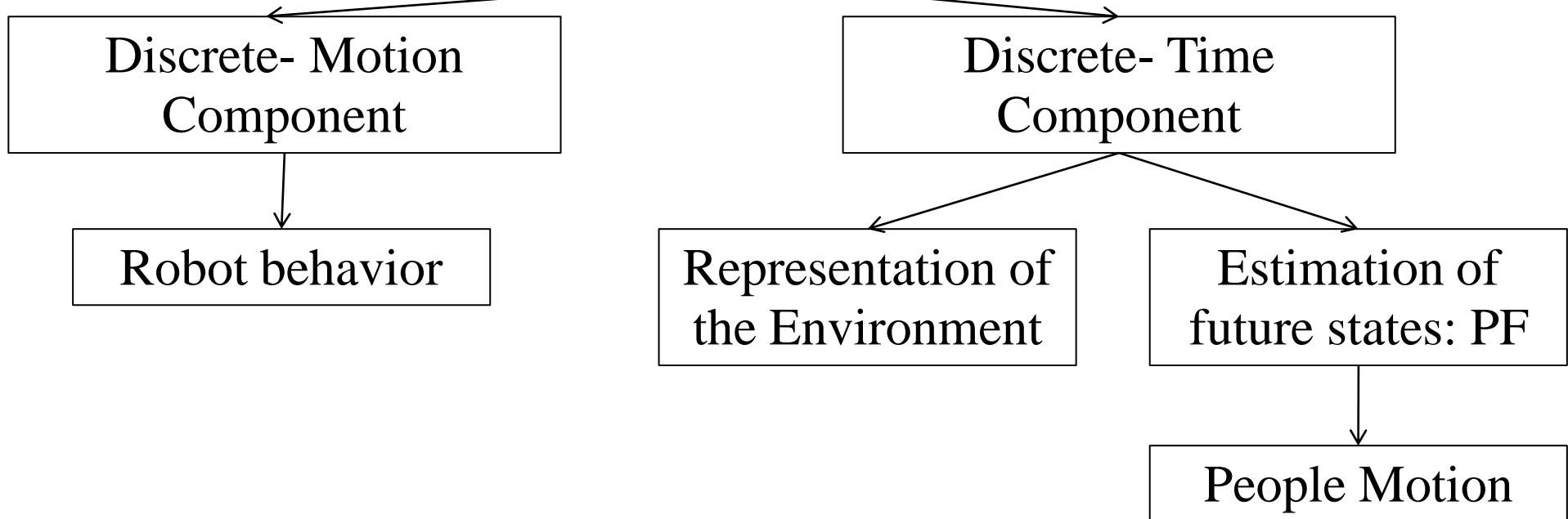
- **Robot tasks:**

1. Robot leader, it guides the group of people.
2. Shepherd robot:
 1. It has to look for people that can potentially escape from the crowd formation and regroup.
 2. It has to go behind the people in order to push them.

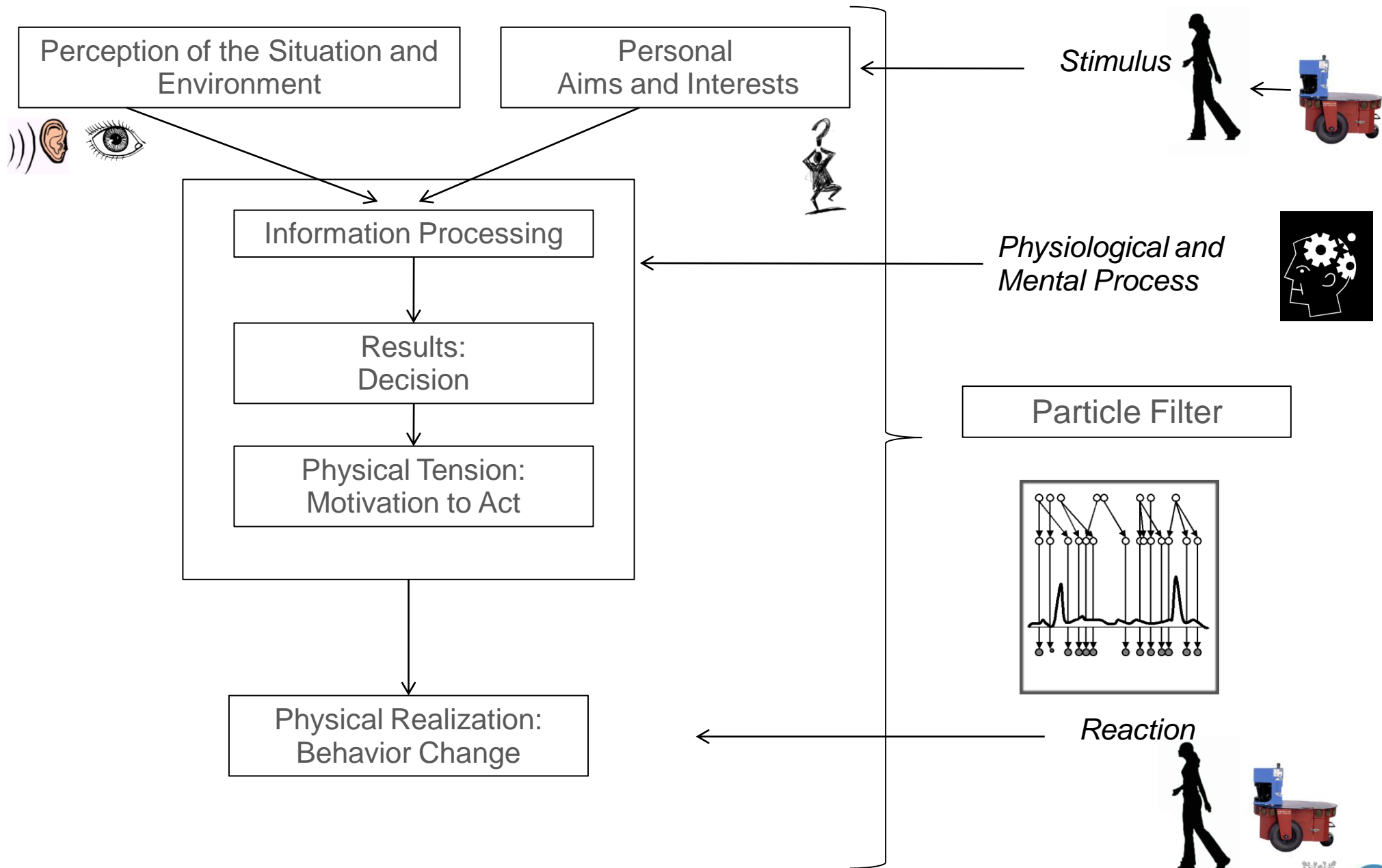


Model Description

Discrete-Time-Motion Model



Modeling People's Motion (i)



Modeling the Motion Space

- Modeling the whole environment.
- Estimating the position and velocity of each individual.
- Key element: Discrete-Time-Motion Model (DTM)
 - Evaluates the estimation data in discrete time instance, every k units of time.
- DTM's components:
 - Discrete Time Component
 - Discrete Motion Component



Modeling the motion space: Discrete Time Component (ii)

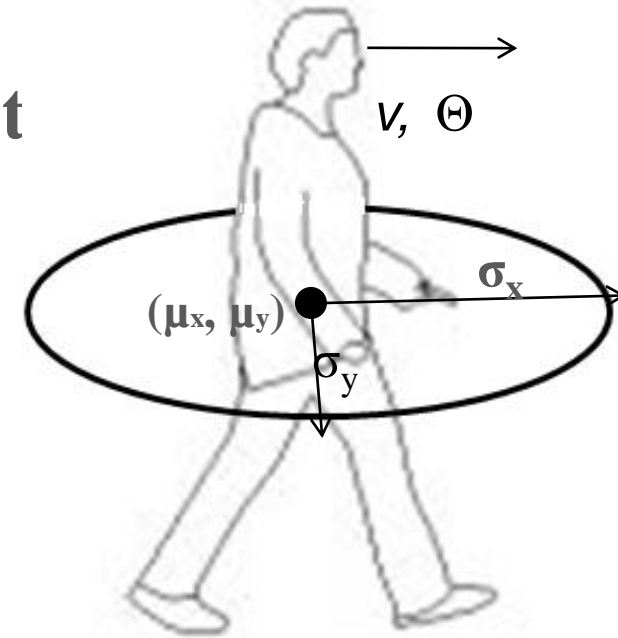
Characterization of people and robot tensions:

- People and robots are characterized by:

$$\{(\mu_x, \mu_y), (\sigma_x, \sigma_y), v, \Theta, T\}$$

- The tension for people and robots is:

$$T_p(\mu_p, \Sigma_p)(x) = \frac{1}{|\Sigma_p|^{1/2} (2\pi)^{n/2}} e^{-1/2(x-\mu_p)^T \Sigma_p^{-1} (x-\mu_p)}$$



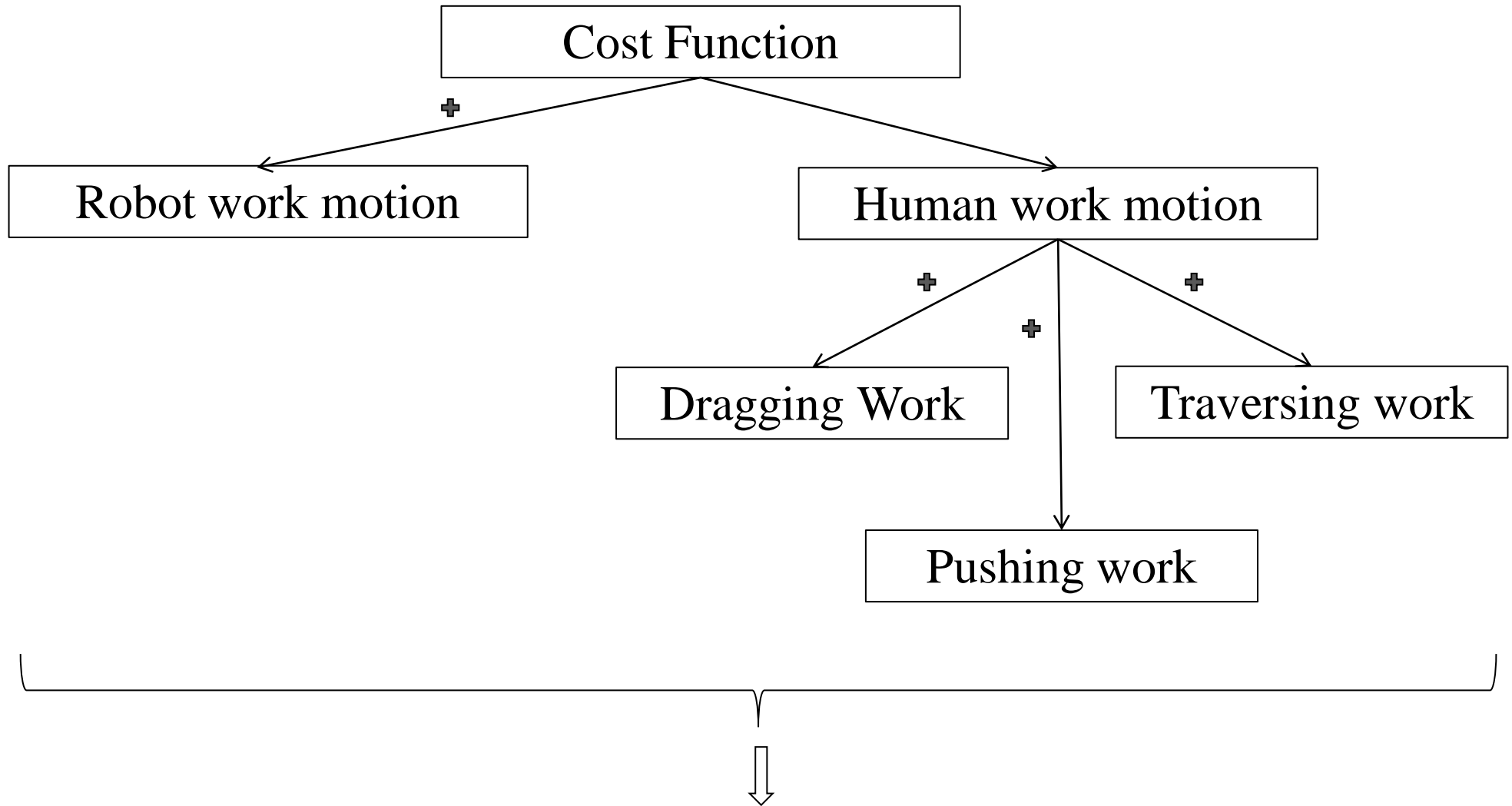
Modeling the motion space: Discrete Time Component (iii)

Characterization of the obstacle tensions:

- A set of a Gaussian functions collocated at regular intervals around their boundaries. $X = \{(x_1, y_1), \dots, (x_n, y_n)\}$
- By the set: $\{(\mu_x, \mu_y), (\sigma_x, \sigma_y), T\}$ for $i=1, \dots, n$.

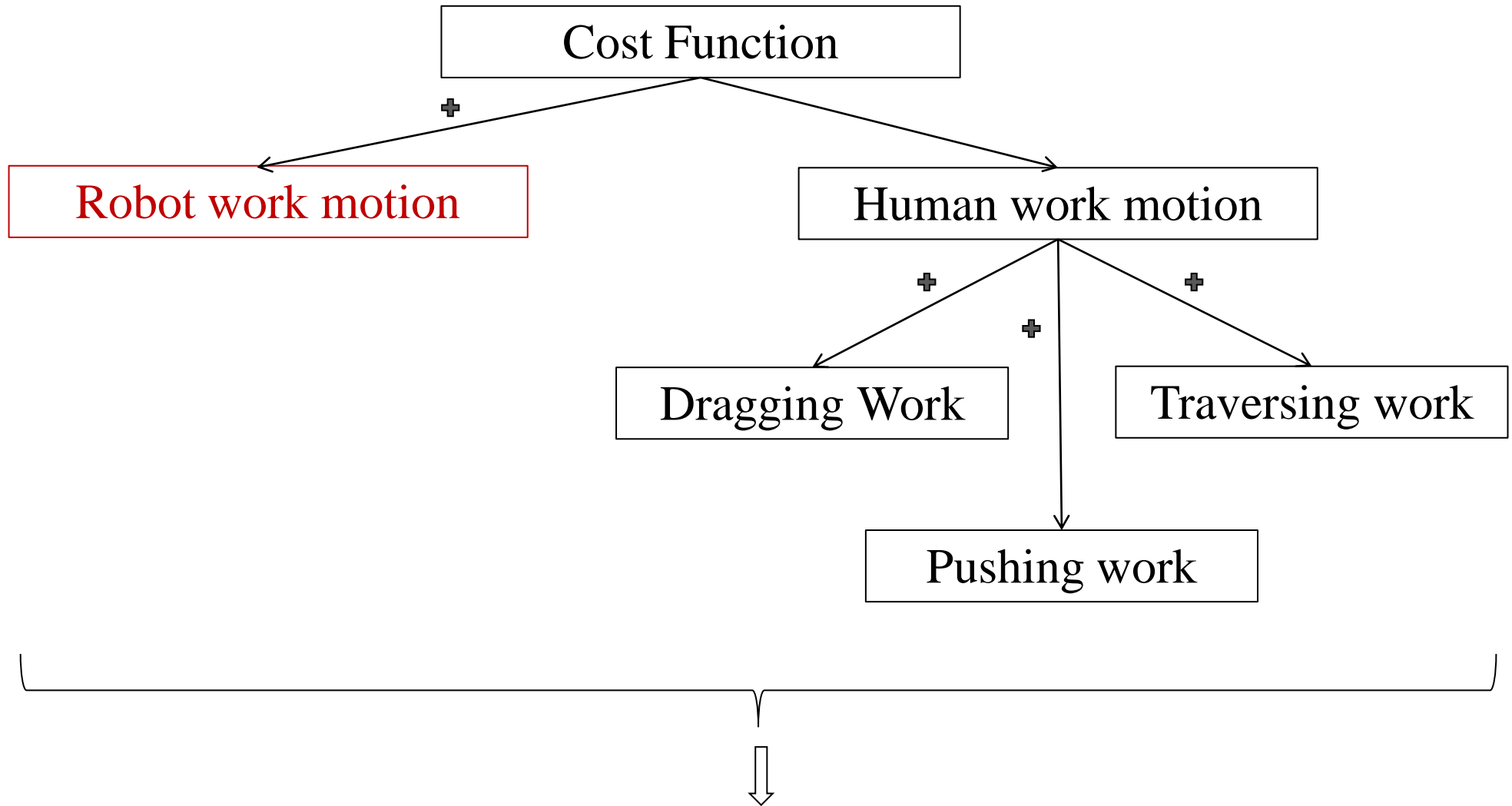


Local Optimal Robot Task Assignment for the Cooperative Mission



Optimal Robot Task Assignment

Robot Work Motion



Optimal Robot Task Assignment

Robot Work Motion (iii)

- **Robot work motion:**
- For each robot i we consider:

$$f_i^{mot} = m_i a_i$$

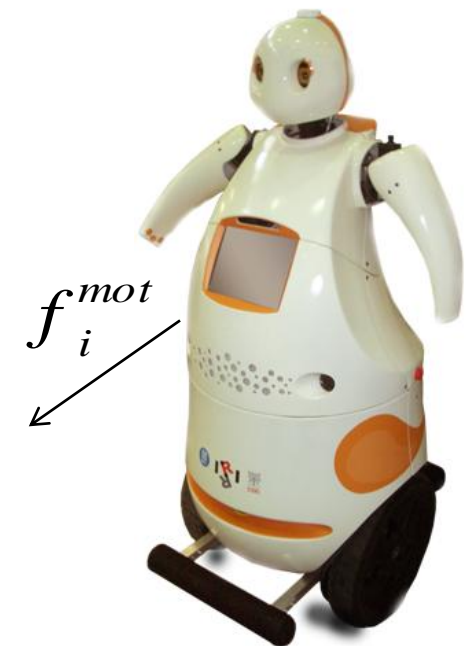
Mas of i-th robot

acceleration of i-th robot

$$W_i^{mot} = f_i^{mot} \Delta s_i$$

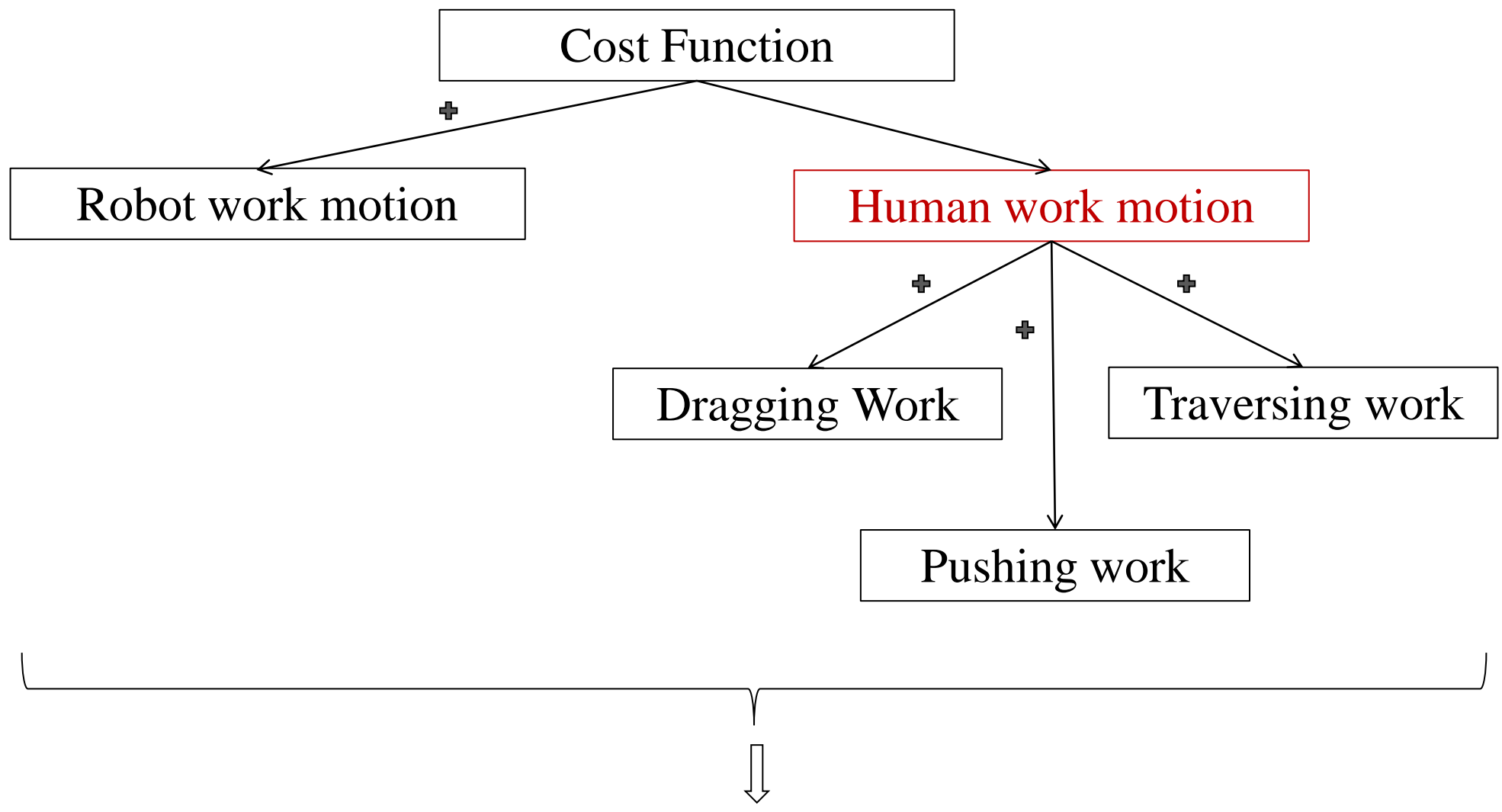
Space traversed by the robot to achieve its goal

Goal dynamic



Δs_i

Human Work motion

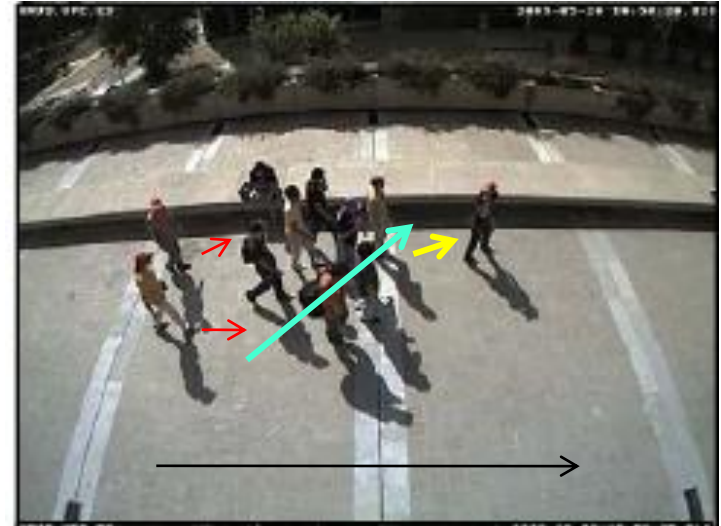


Optimal Robot Task Assignment

Human Work Motion (ii)

- **Three types of forces on this kind of interaction:**

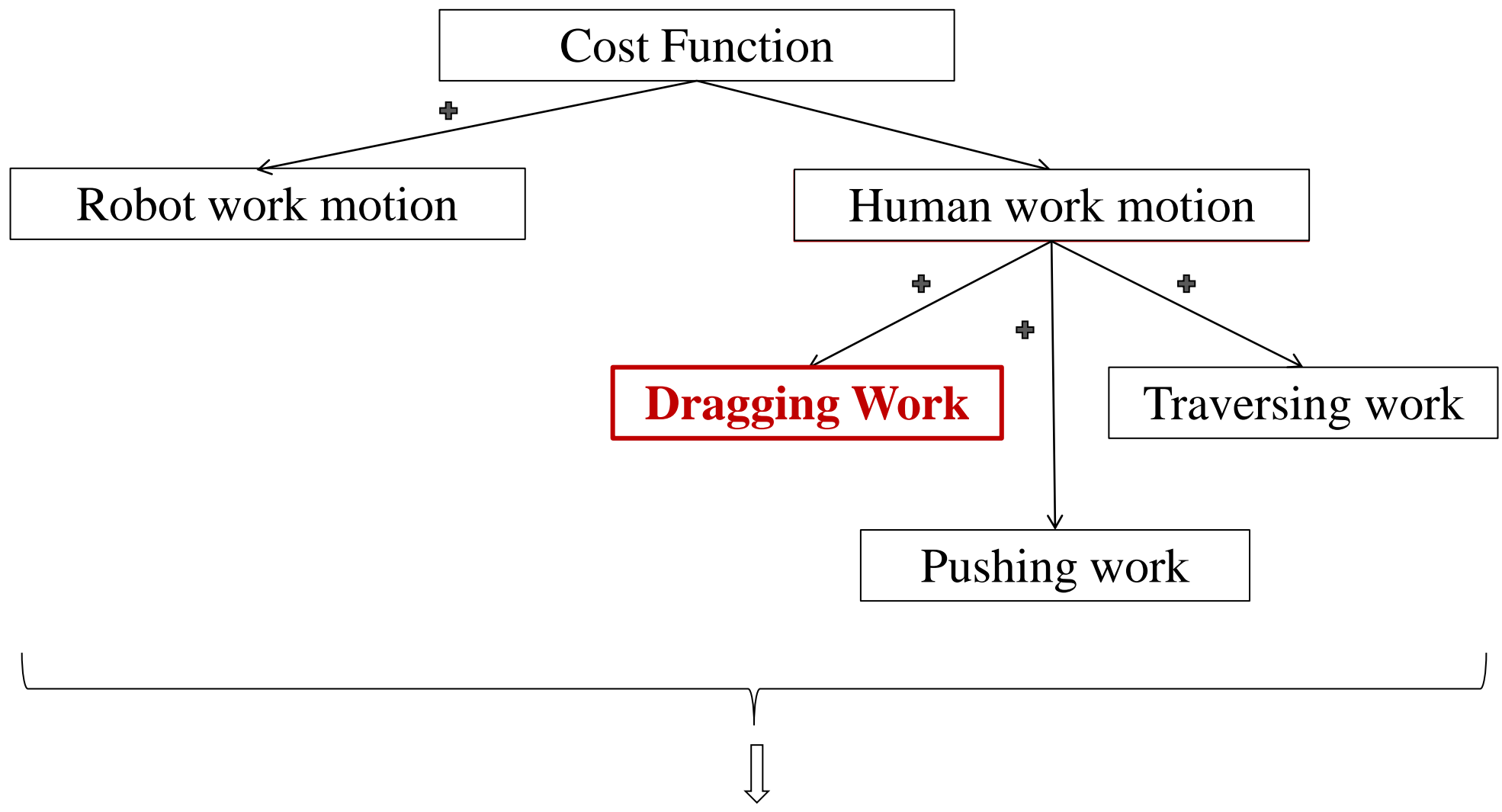
- Dragging force
- Pushing force
- Crowd intrusion force



- **Effect of robots on people as forces:**

- Leader Robot: attractive force (dragging)
- Shepherding robot: Repulsive force (pushing / traversing)

Human Work motion



Optimal Robot Task Assignment

Dragging Work

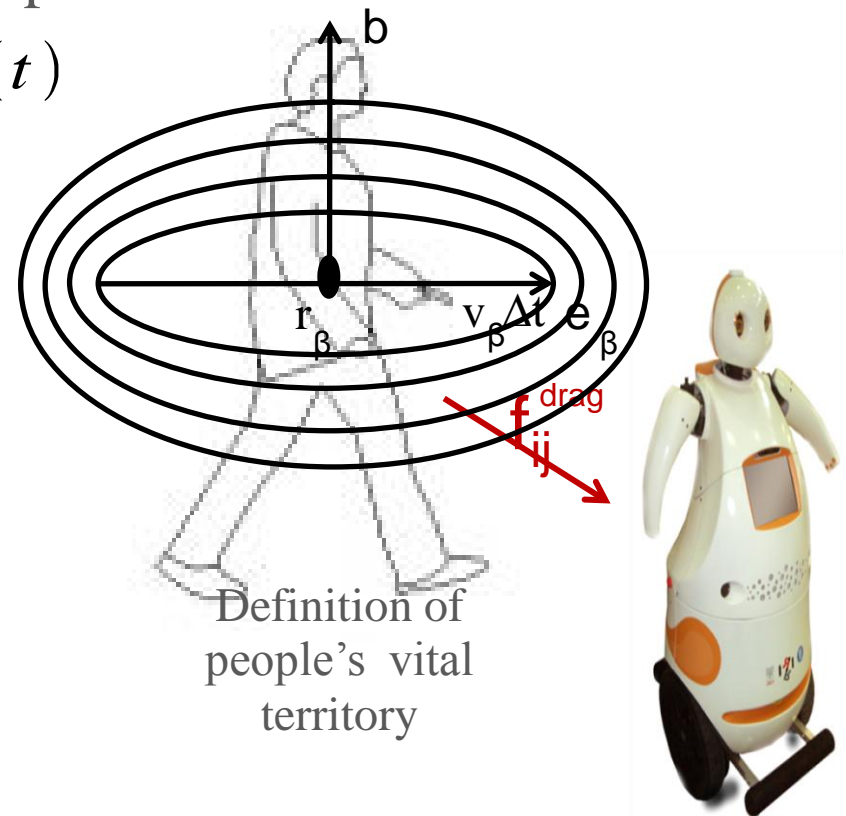
- Dragging force:
 - Necessary when the leader robot guides the group.
 - Attractive force
- Force applied by robot leader i to each person k :

$$f_{ij}^{drag}(t) = -C_{ij} \vec{n}_{ij}(t) = -C_{ij} \frac{x_i(t) - x_j(t)}{d_{ij}(t)}$$

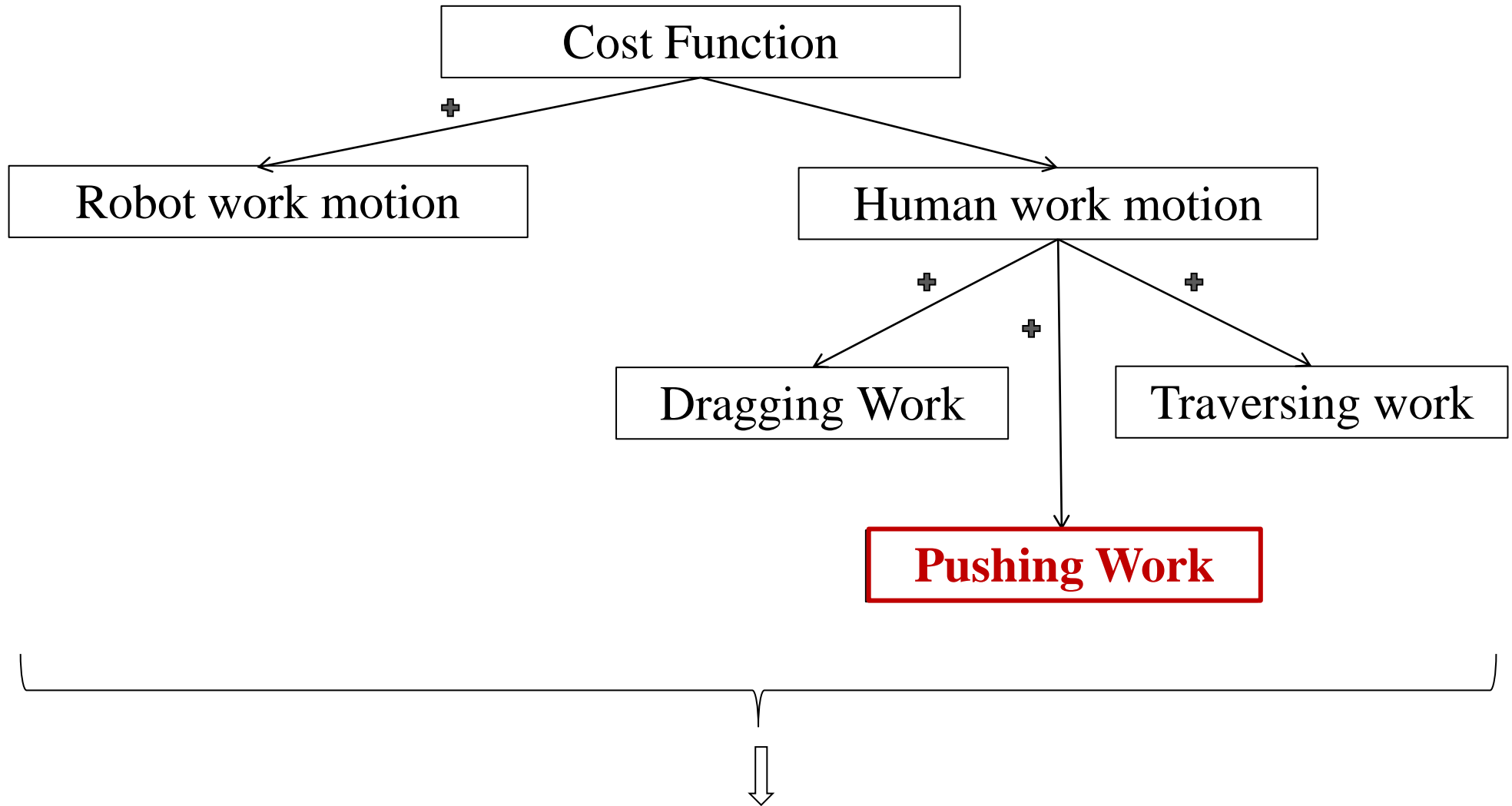
$$d_{ij} = \|x_i(t) - x_j(t)\|$$

$$W_{drag} = \sum_{\forall \text{ person } j} f_{ij}^{drag} \Delta s_j$$

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Pushing work



Optimal Robot Task Assignment

Pushing Work (ii)

- Pushing force:
 - Done by Shepherding robot for regrouping people (or the broken crowd) in the main crowd formation
 - Repulsive force
 - It is due by intrusion of robot in people's living space
- Force applied by robot leader i to each person k :

$$f_{ij}^{push} = A_i \exp((r_{ij} - r_{ij}) / B_i) \vec{n}_{ij} (\lambda_i + (1 + \lambda_i) \frac{1 + \cos(\varphi_{ij})}{2})$$

A_i : interaction strength

$r_{ij} = r_i - r_j$, usually 1.5m

B_i : parameter of repulsive interaction

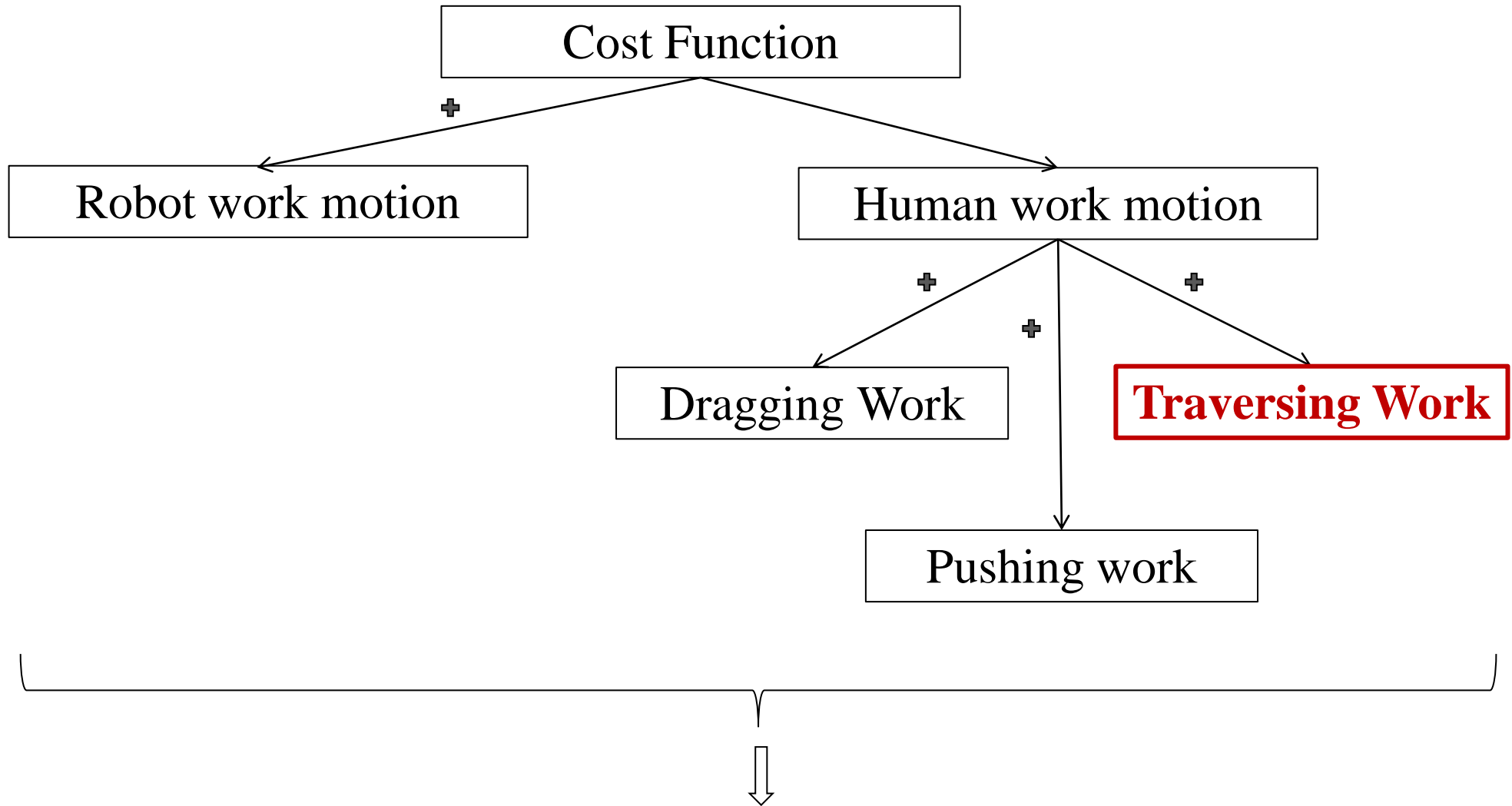
$\lambda < 1$,

φ_{ij} : angle of the directions

Ω : people affected by pushing force

$$W_{push} = \sum_{\forall person \in \Omega_i} f_{ij}^{push}(t) \Delta S_j$$

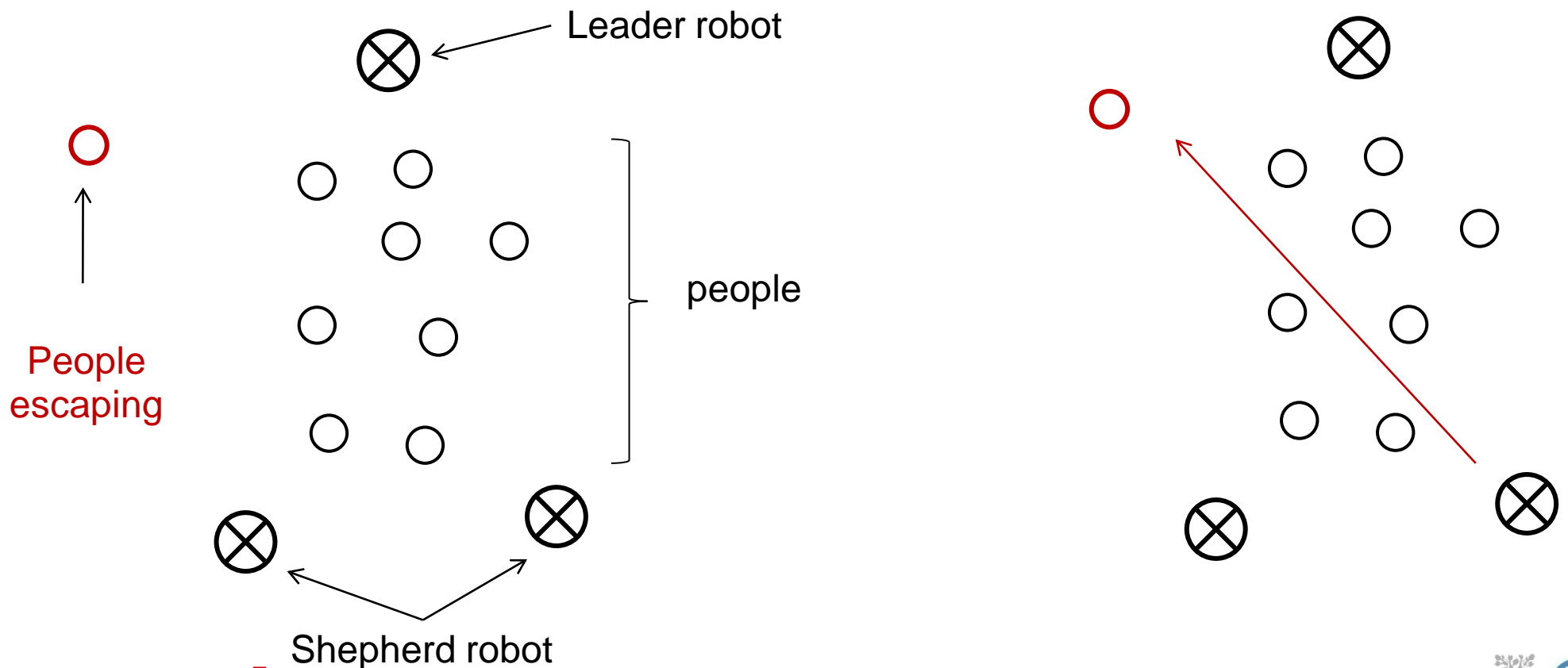
Traversing work



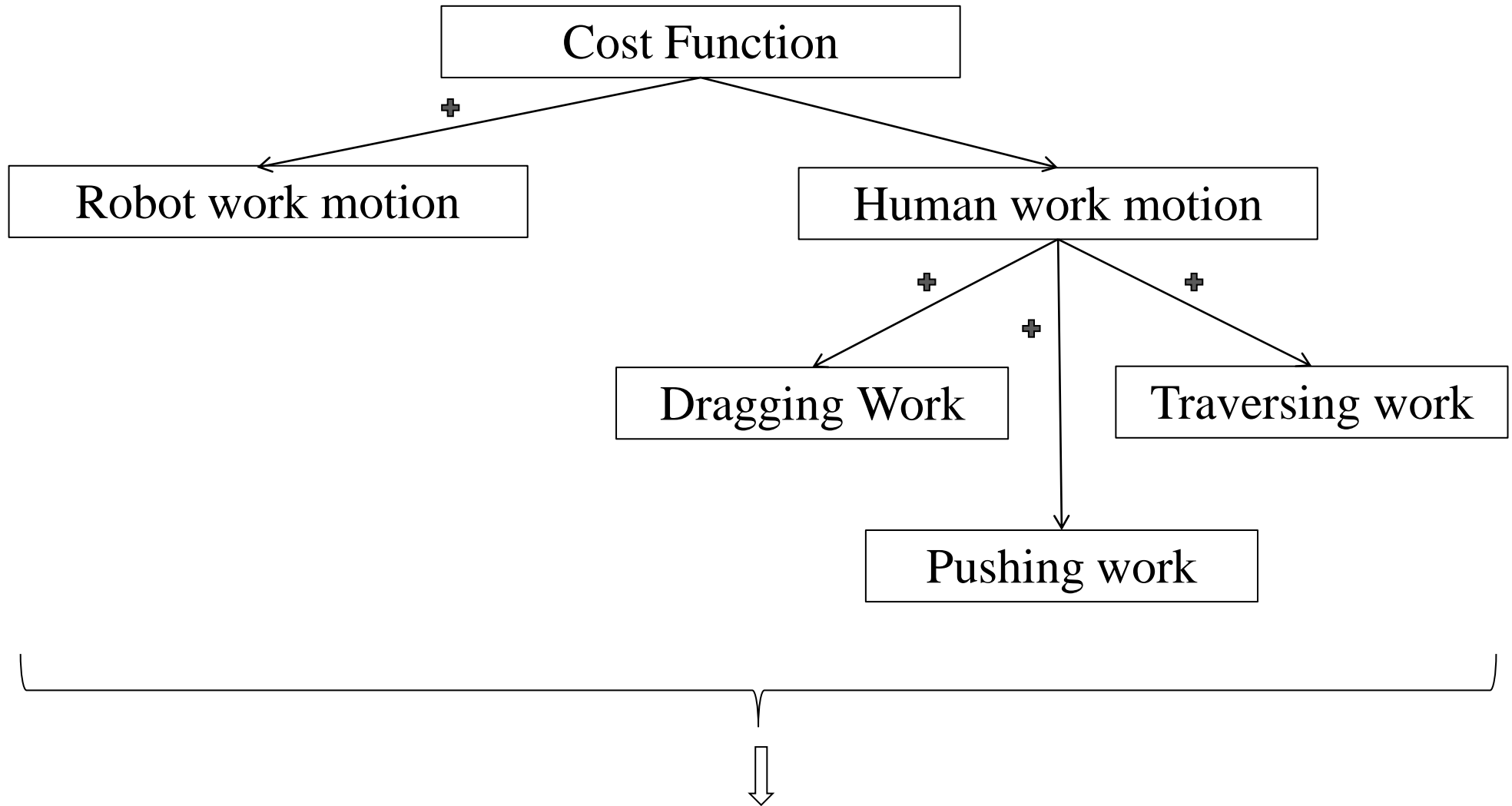
Optimal Robot Task Assignment

Traversing Work (ii)

- Pushing force:
 - Forces applied by robots when they traverse the formation.
 - Repulsive force
 - For security reasons, its value is considered as infinity



Optimal Robot Tasks Assignment



Optimal Robot Task Assignment

Optimal Robot Tasks Assignment (ii)

- Total cost function for robot i :

$$W_i = \delta_{mot} W_i^{mot} + \delta_{drag} W_i^{drag} + \delta_{push} W_i^{push} + \delta_{trav} W_i^{trav}$$

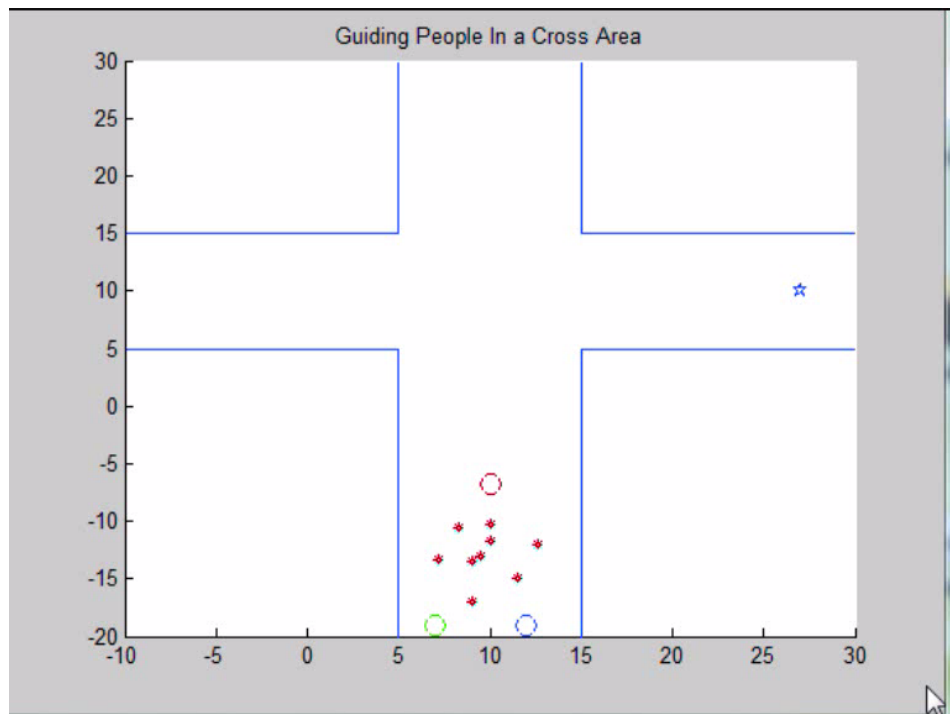
Where,

$$\delta_k = \begin{cases} 1 & \text{if this task is assigned} \\ 0 & \text{if this task is not assigned} \end{cases}$$

Finally, the task assignment for robots will be the one that minimizes the cost required

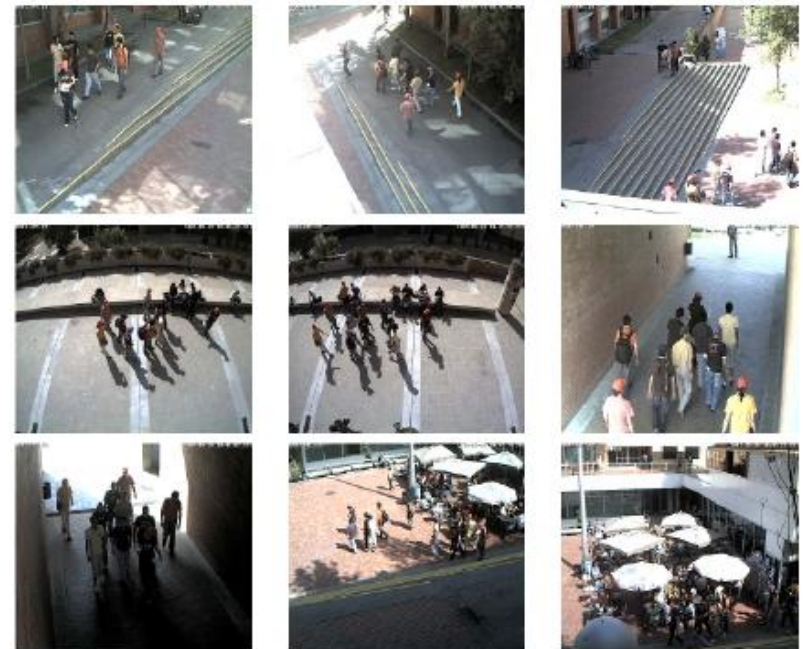
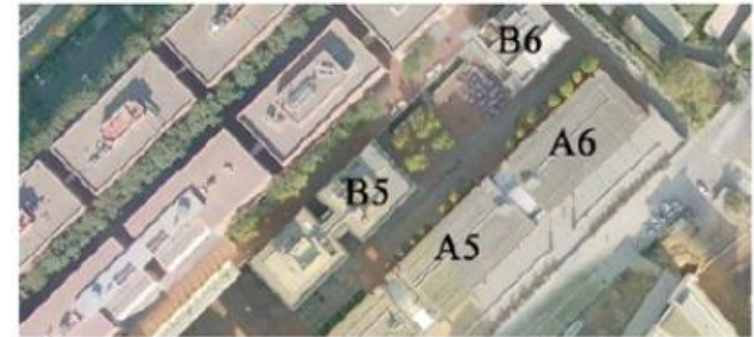
$$C = \operatorname{argmin}(W_{total}(C)), \forall \text{ configuration } c$$

Simulations



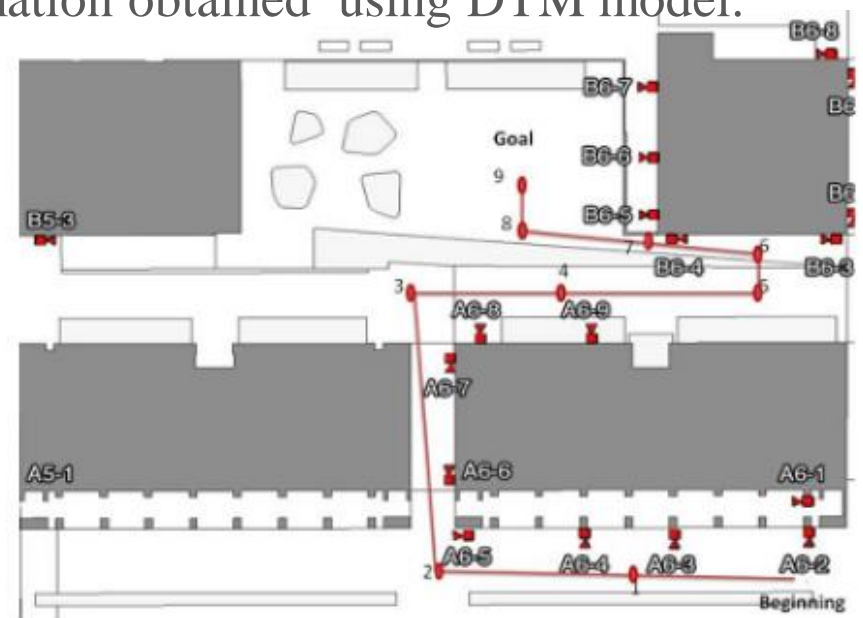
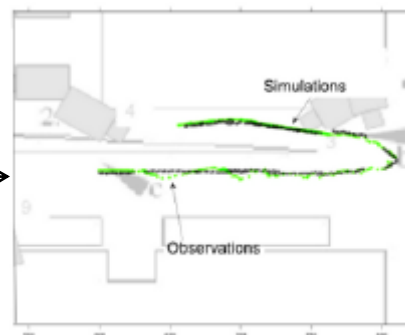
Data Collection

- Data collection:
 - Camera Network mounted on Barcelona robot Lab
 - 21 interconnected cameras
- People behavior
 - The group follows the instructions of the guides.
 - A person who is being led, if he goes away from the group one of the guides has to regroup him.
 - Several people escape at the same time in opposite directions.
 - The group stops and moves again,



Data Collection

- Data collection process:
 - Video sequences were registered.
 - Each frame was rearranged in order to synchronize the complete sequence.
 - Complete path was registered by 15 cameras.
 - Position of people was annotated manually
 - 10.000 images where labeled.
- The trajectory of every person has to be taken into account in the complete path.
- This trajectories are compared against the estimation obtained using DTM model.

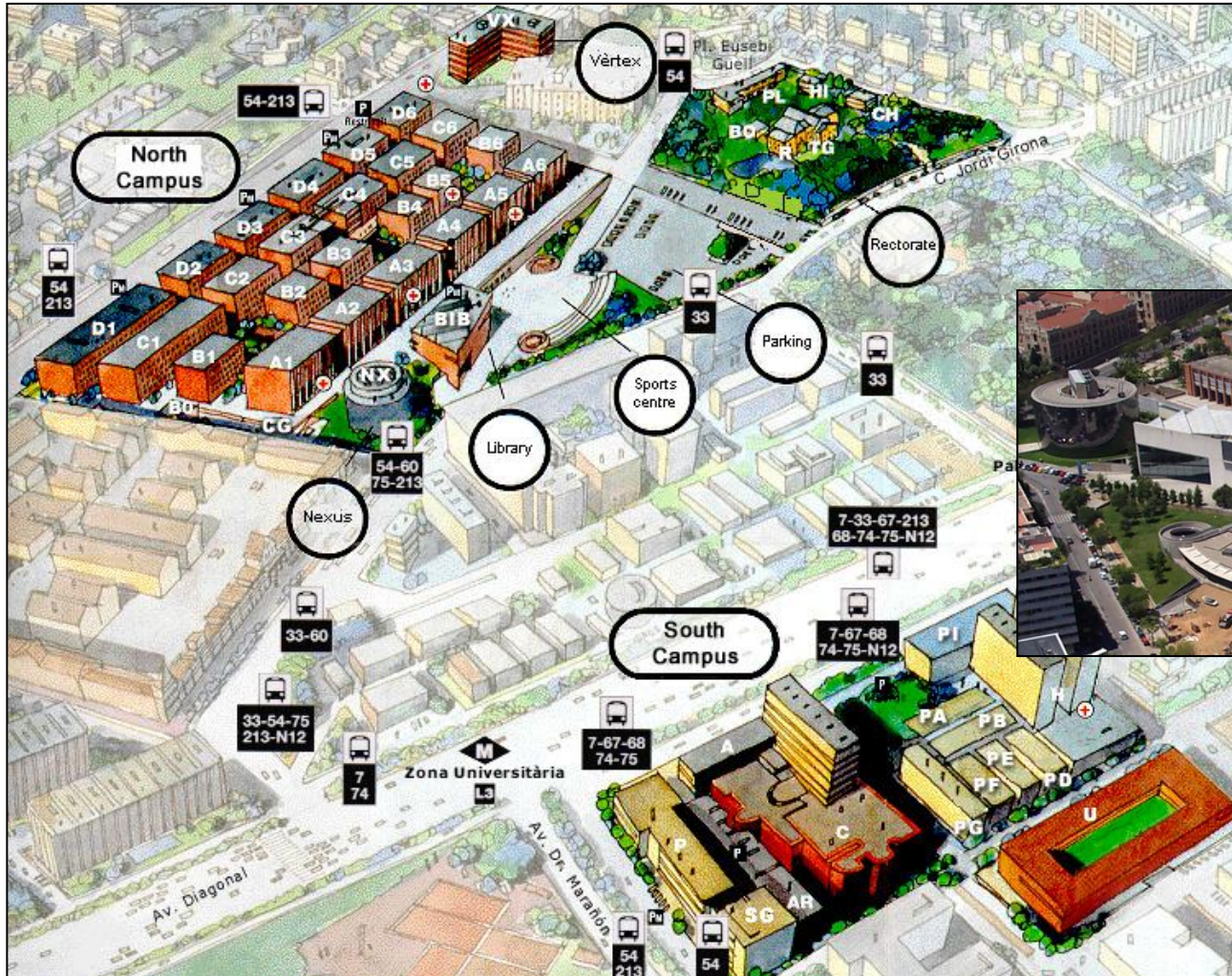


Validation Process

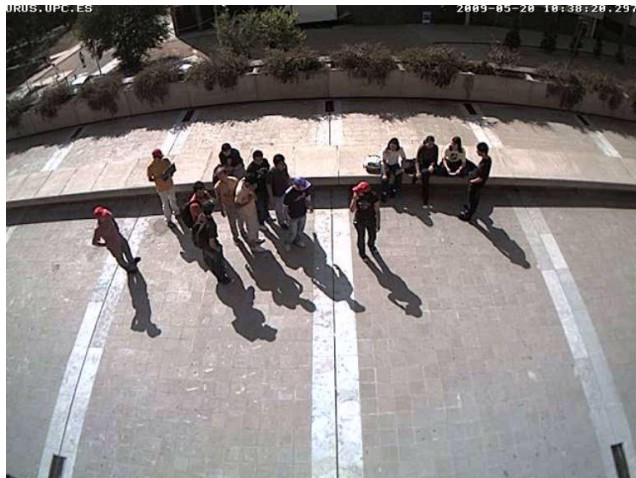
- **Two cases were studied:**
 - The motion behavior of robots:
 - Shepherd robots
 - Leader robot
 - Motion behavior of the guided people.
- **Robots' analysis:**
 - A comparison of the real motion and simulated motion is performed in different scenarios
- **People analysis**
 - A comparison of estimation motion and real motion is performed.
- Via quadratic error:

$$error_k = \sqrt{(y_k - \hat{y}_k)^2}$$

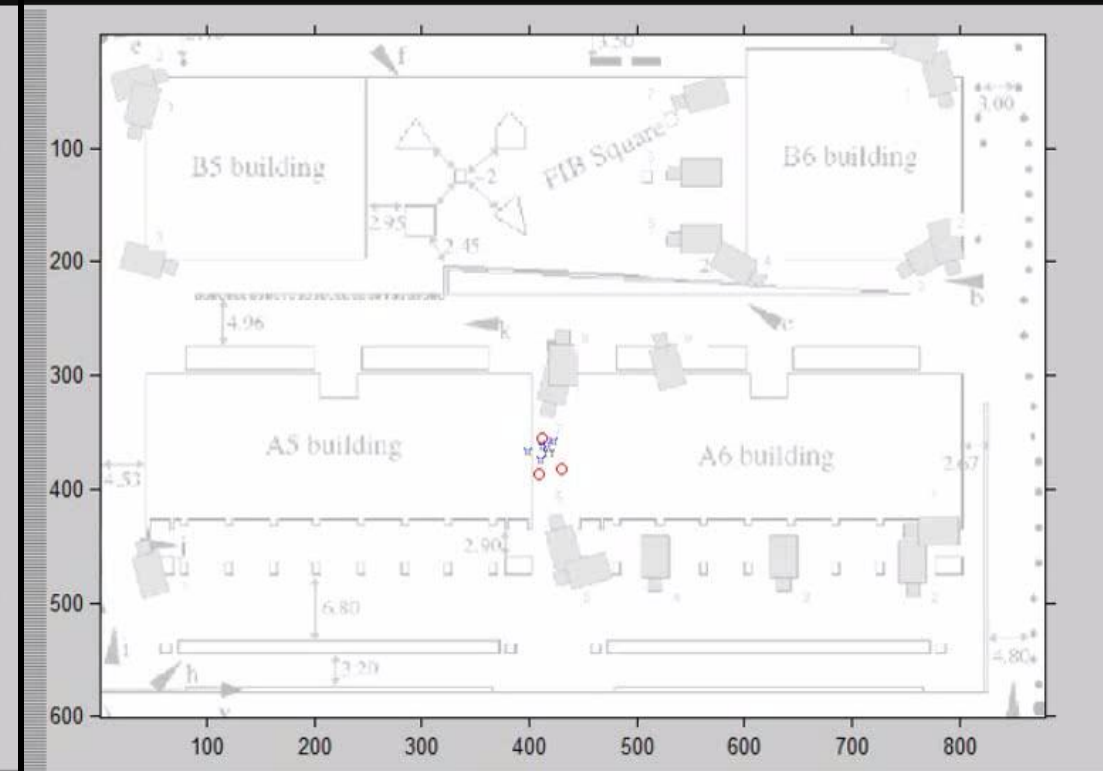
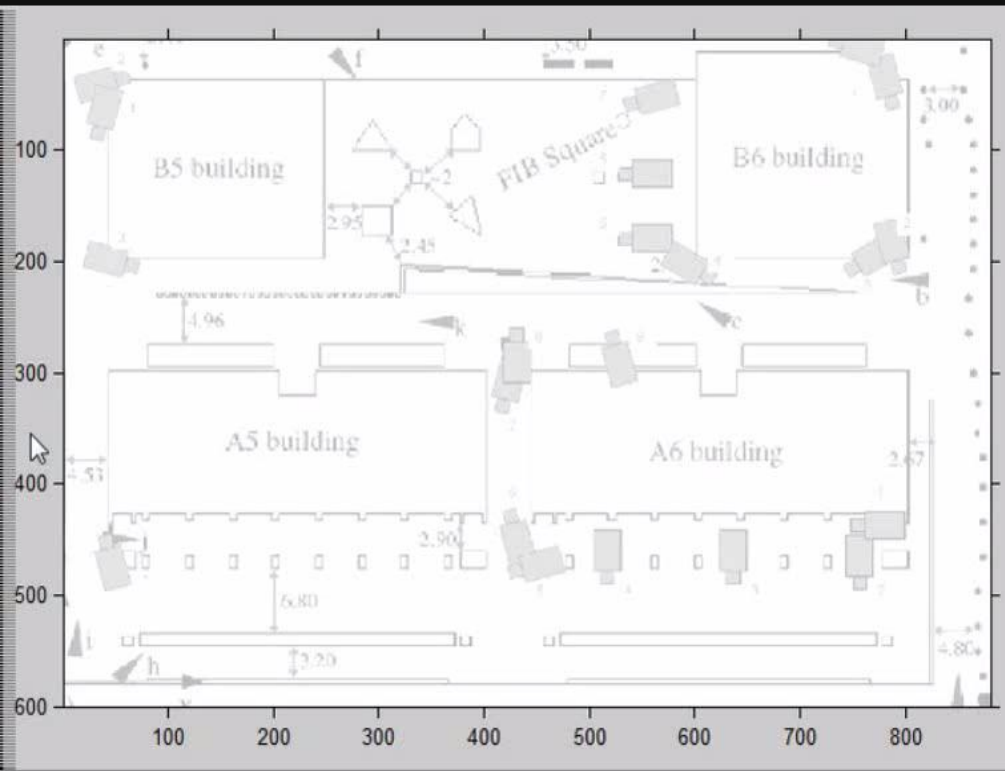
Experiment Location



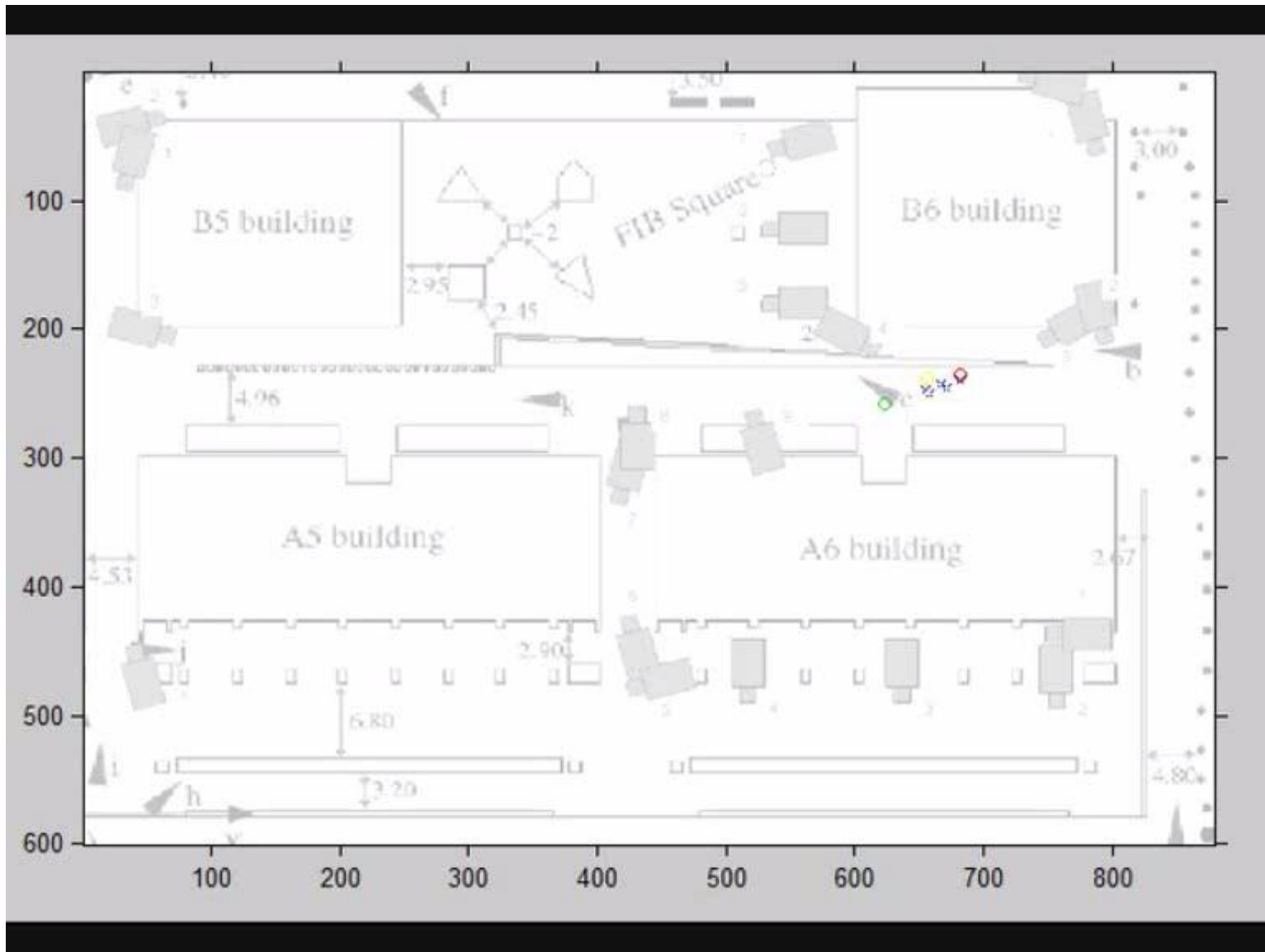
Simulations



Simulations



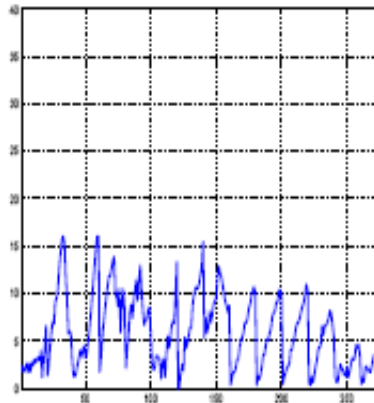
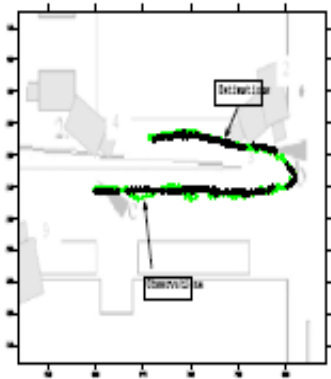
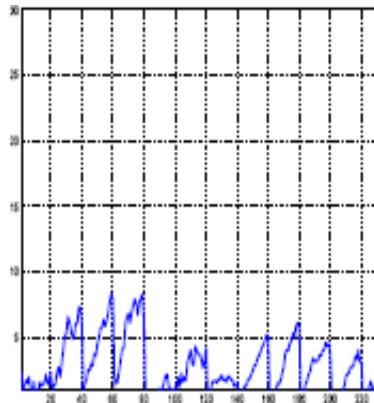
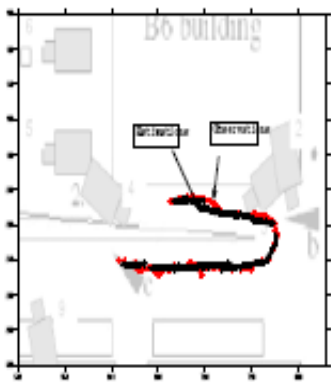
Simulations



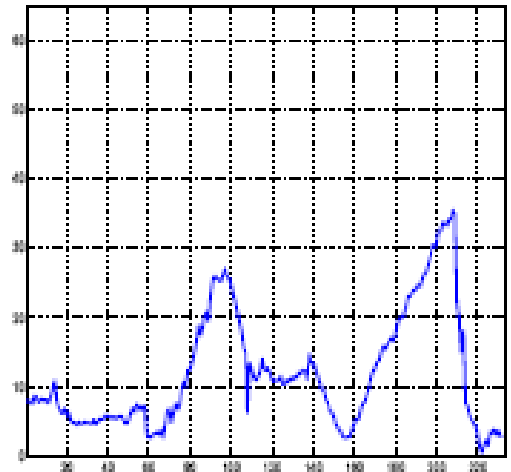
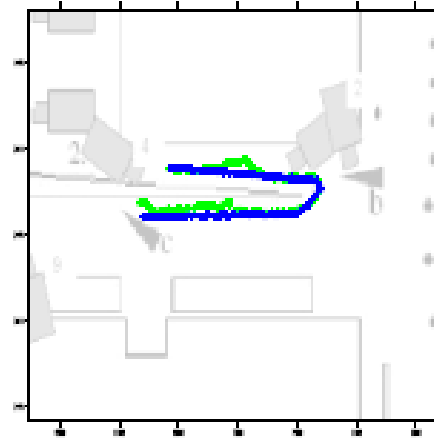
Results

- Corridor:

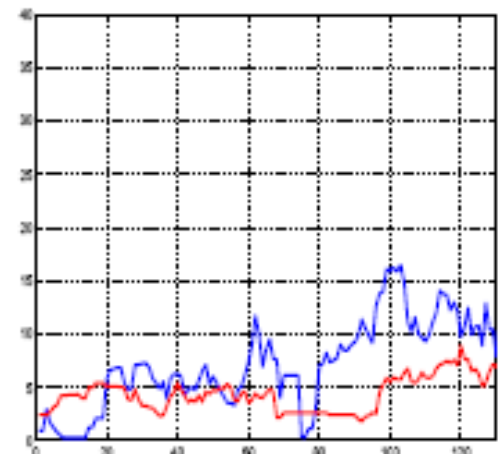
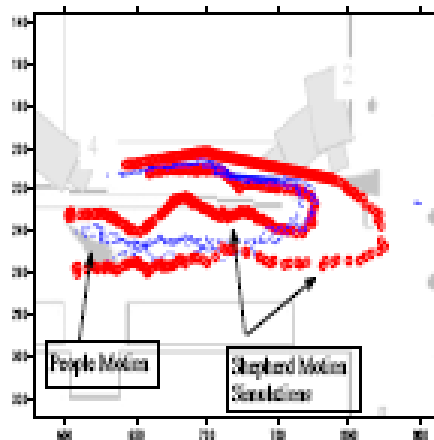
- People



- Leader Robot



- Shepherd Robots



Conclusions

- We have presented a new model to guide people in urban areas with a set of mobile robots working cooperatively.
- In contrast to existing approaches, DTM model can tackle with more realistic situations.
- Various results in different situations have been presented.
- In all simulations robots can act early enough to guide the group of people through a path computed previously.

- **What's next?**
- Increase the number of robots.
- Develop real experiments

Thank you!



Discrete Time Motion Model for Guiding People in Urban Areas Using Multiple Robots



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