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

Institut de Robòtica i Informàtica Industrial

Anaís Garrell
Alberto Sanfeliu

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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.

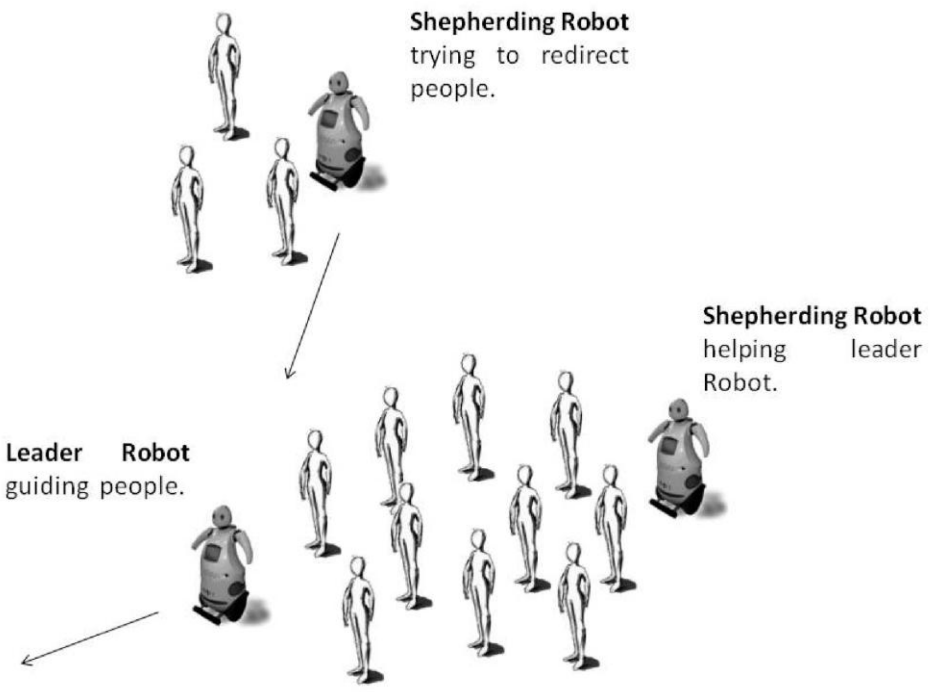
# Motivation

- Guiding people in urban settings using several mobile robots.

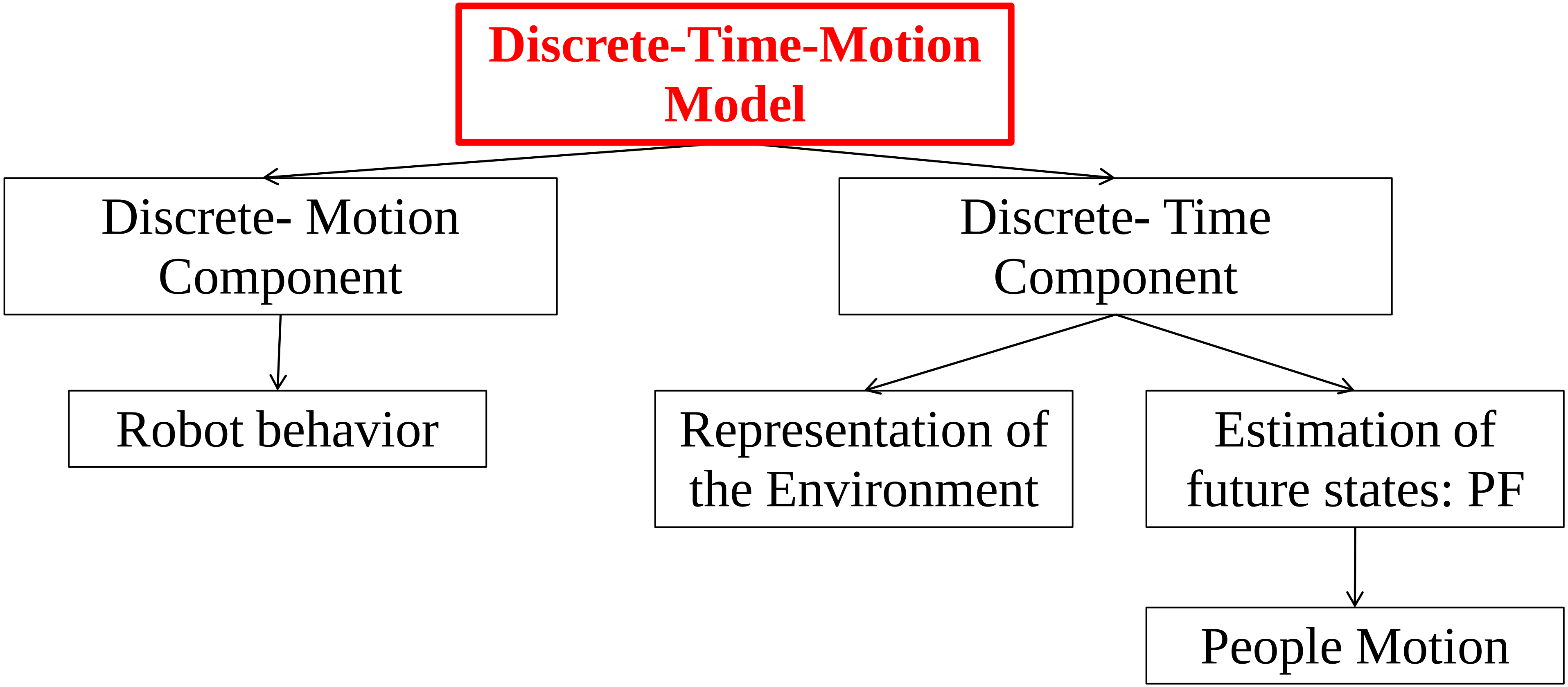
(Work performed under the European Project URUS)

# Motivation (ii)

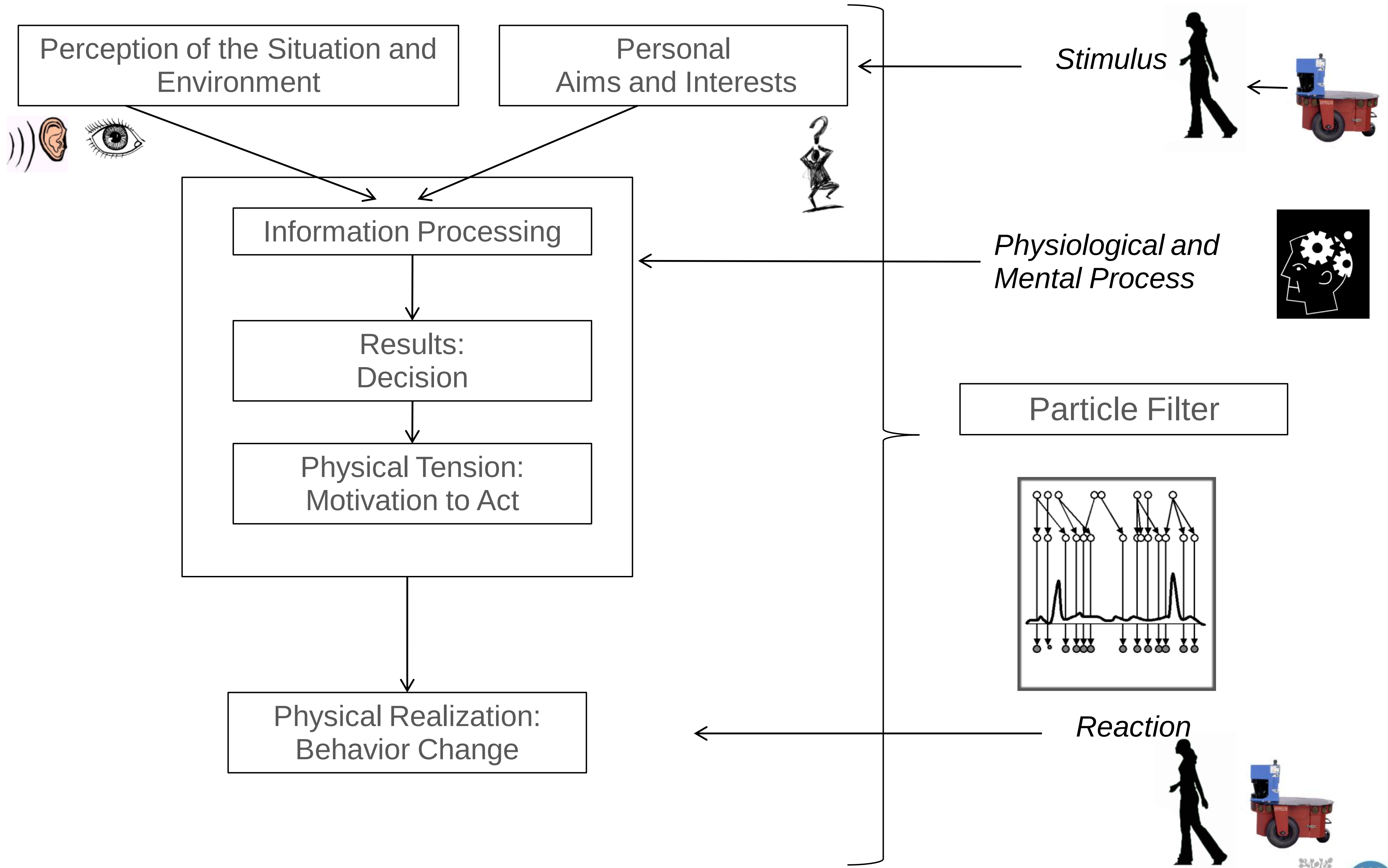
- **Robot tasks:**
  1. Robot leader, it guides the group of people.
  2. Shepherd robot:
     1. It has to look for people that can potentially escape from the crowd formation and regroup.
     2. It has to go behind the people in order to push them.



# Model Description



# Modeling People's Motion (i)

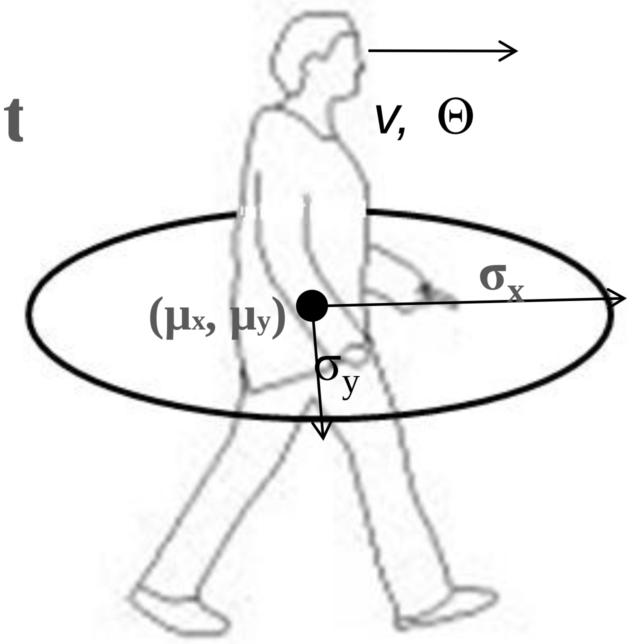


# Modeling the Motion Space

- 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:

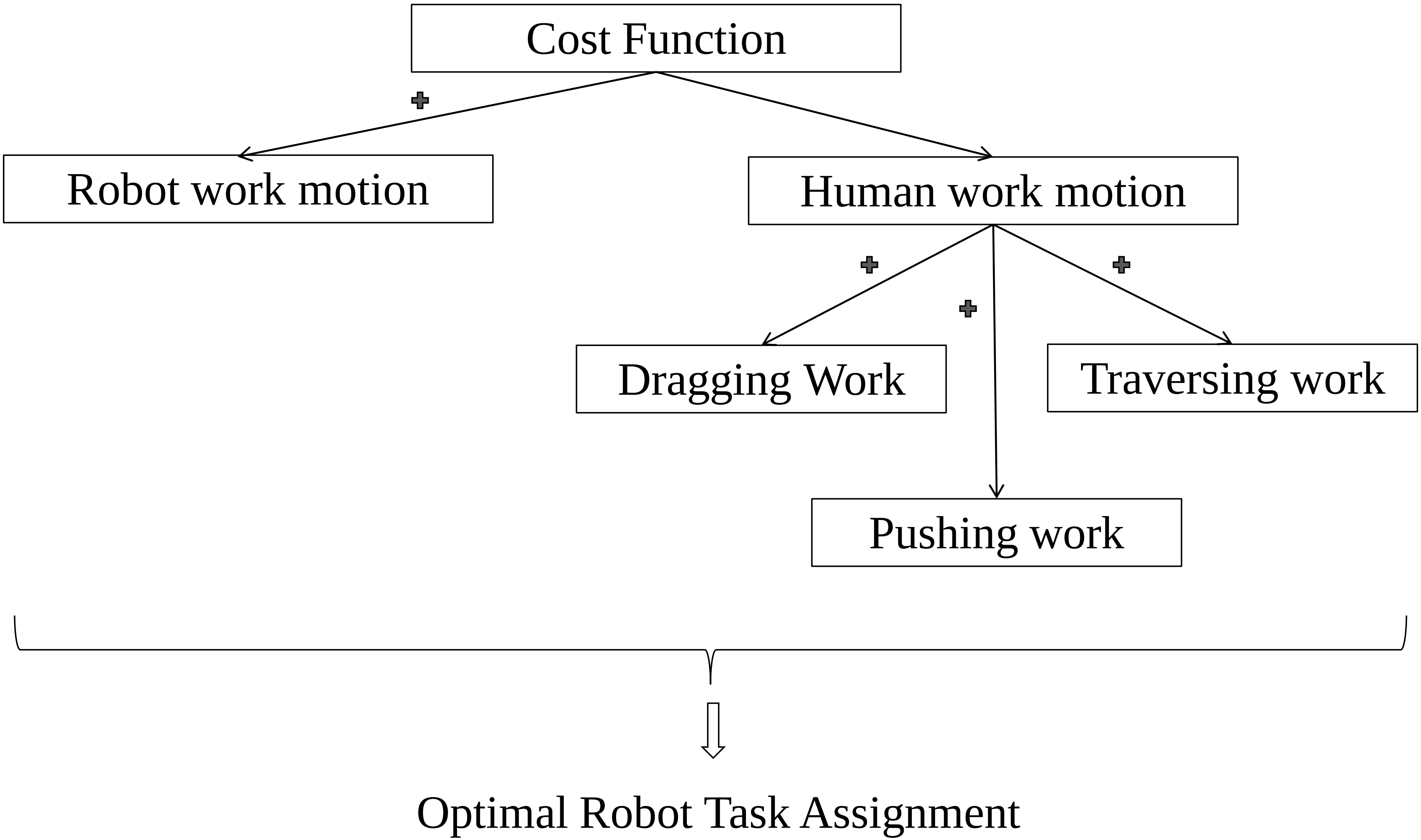
$$T_p(\mu_p,\Sigma_p)(x) = \frac{1}{|\Sigma_p|^{1/2}(2\pi)^{n/2}} e^{-1/2(x-\mu_p)^T\Sigma_p^{-1}(x-\mu_p)}$$

# Modeling the motion space: Discrete Time Component (iii)

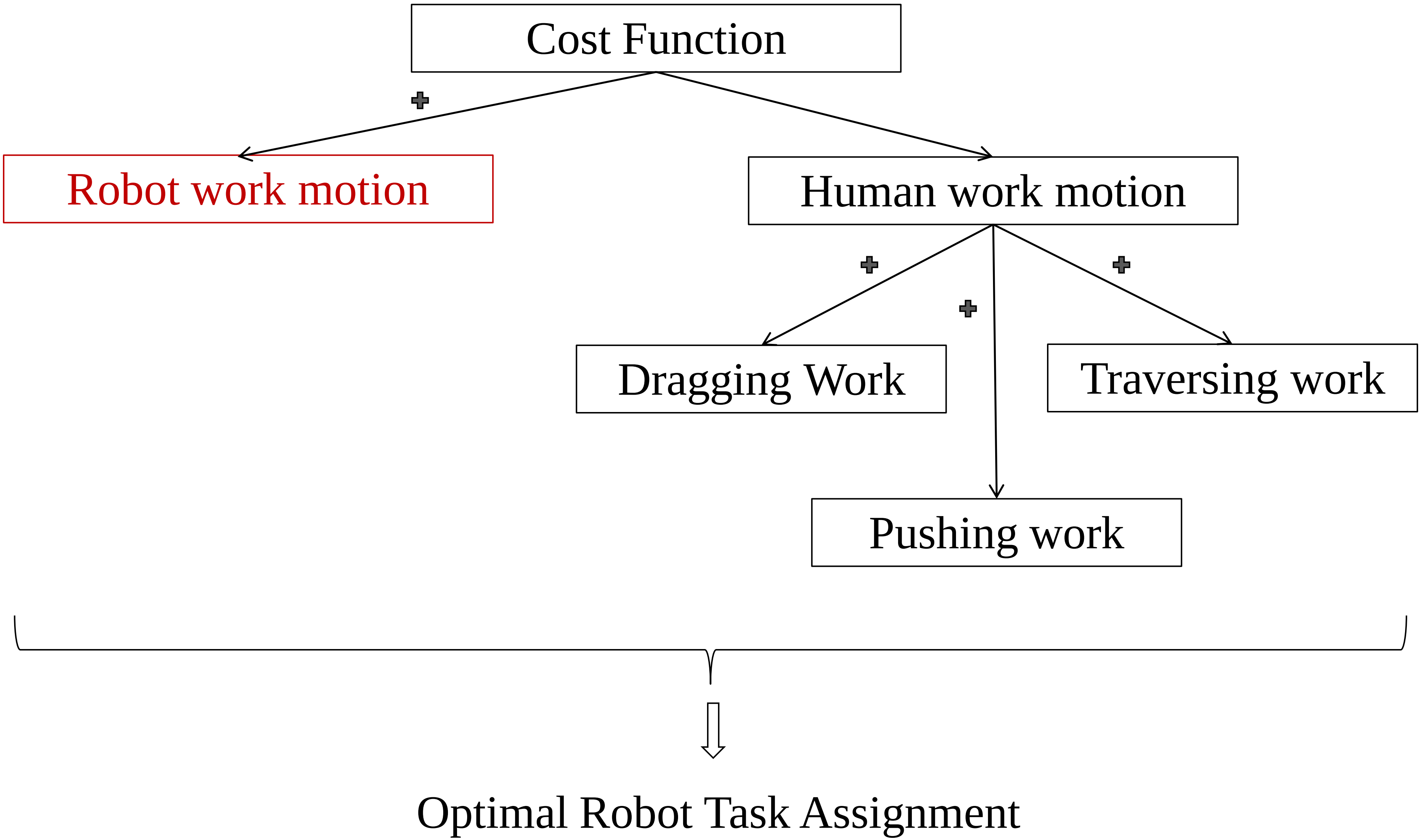
## Characterization of the obstacle tensions:

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

# Local Optimal Robot Task Assignment for the Cooperative Mission



# Robot Work Motion



# Robot Work Motion (iii)

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

Mas of i-th robot

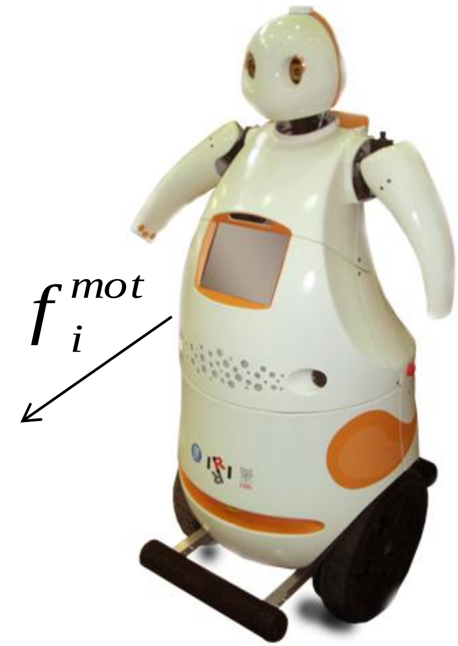
acceleration of i-th robot

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

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

Space traversed by the robot to achieve its goal

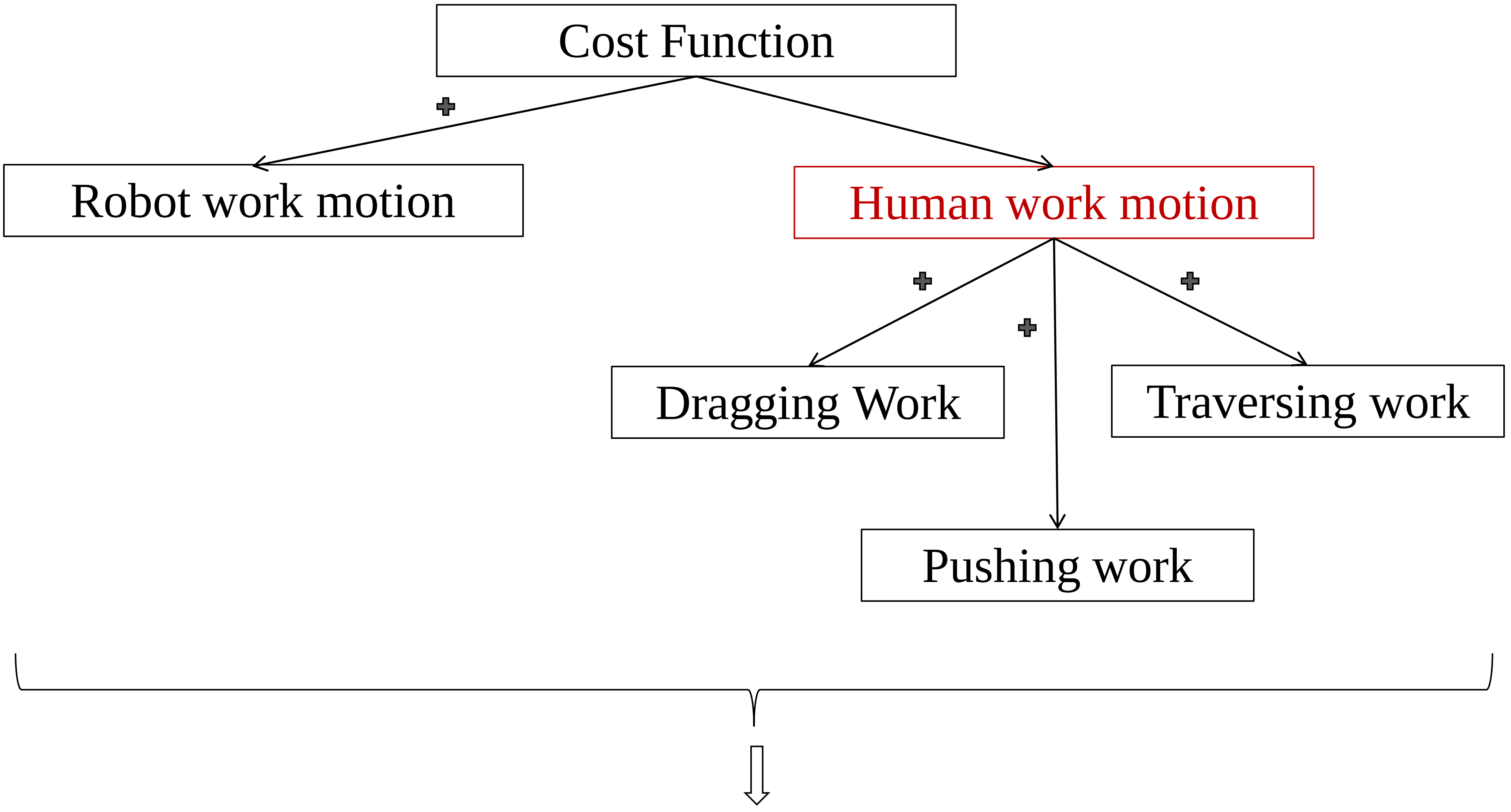
$f_i^{mot}$



Goal dynamic

$\Delta s_i$

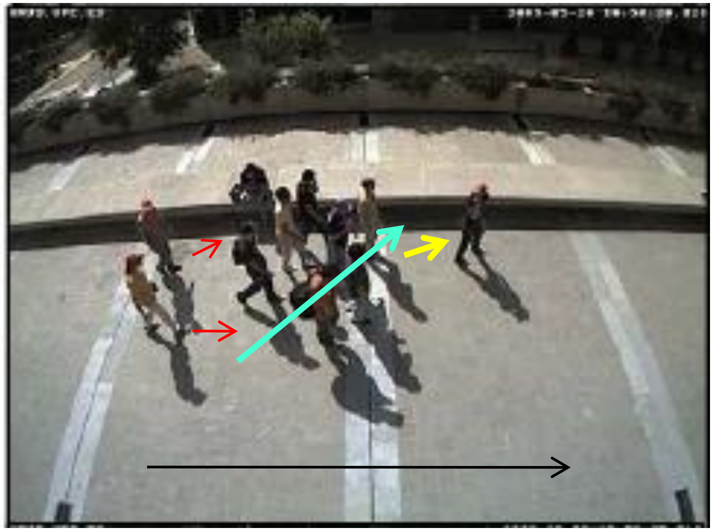
# Human Work motion




Optimal Robot Task Assignment

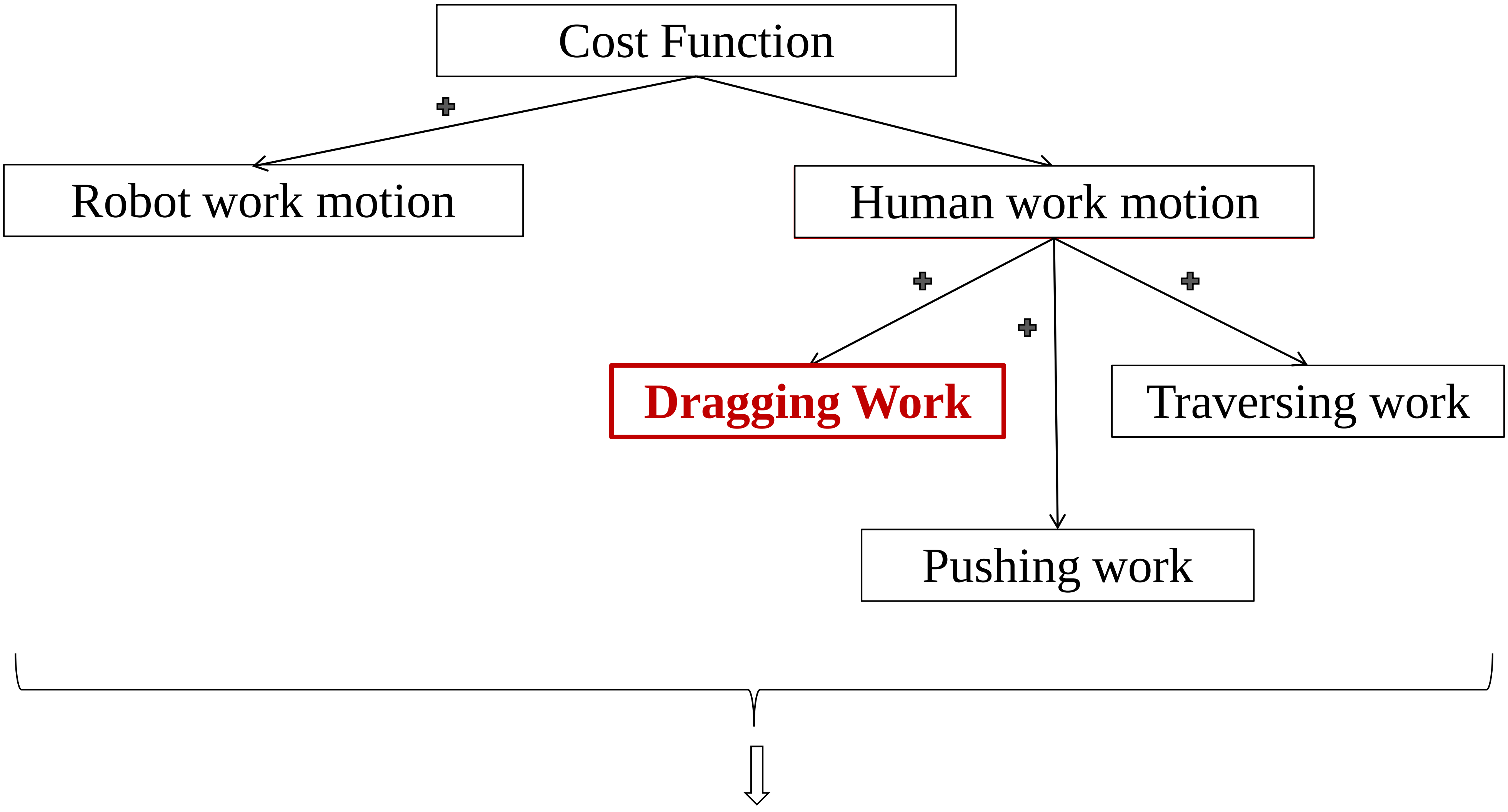
# Human Work Motion (ii)

- **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*:

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

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

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

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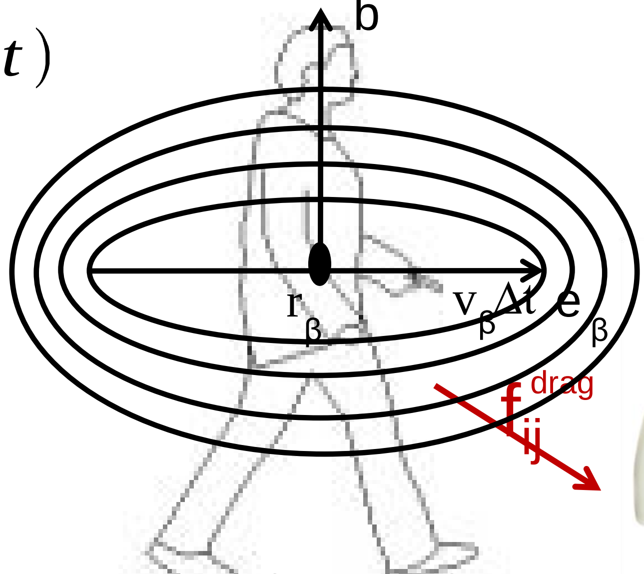
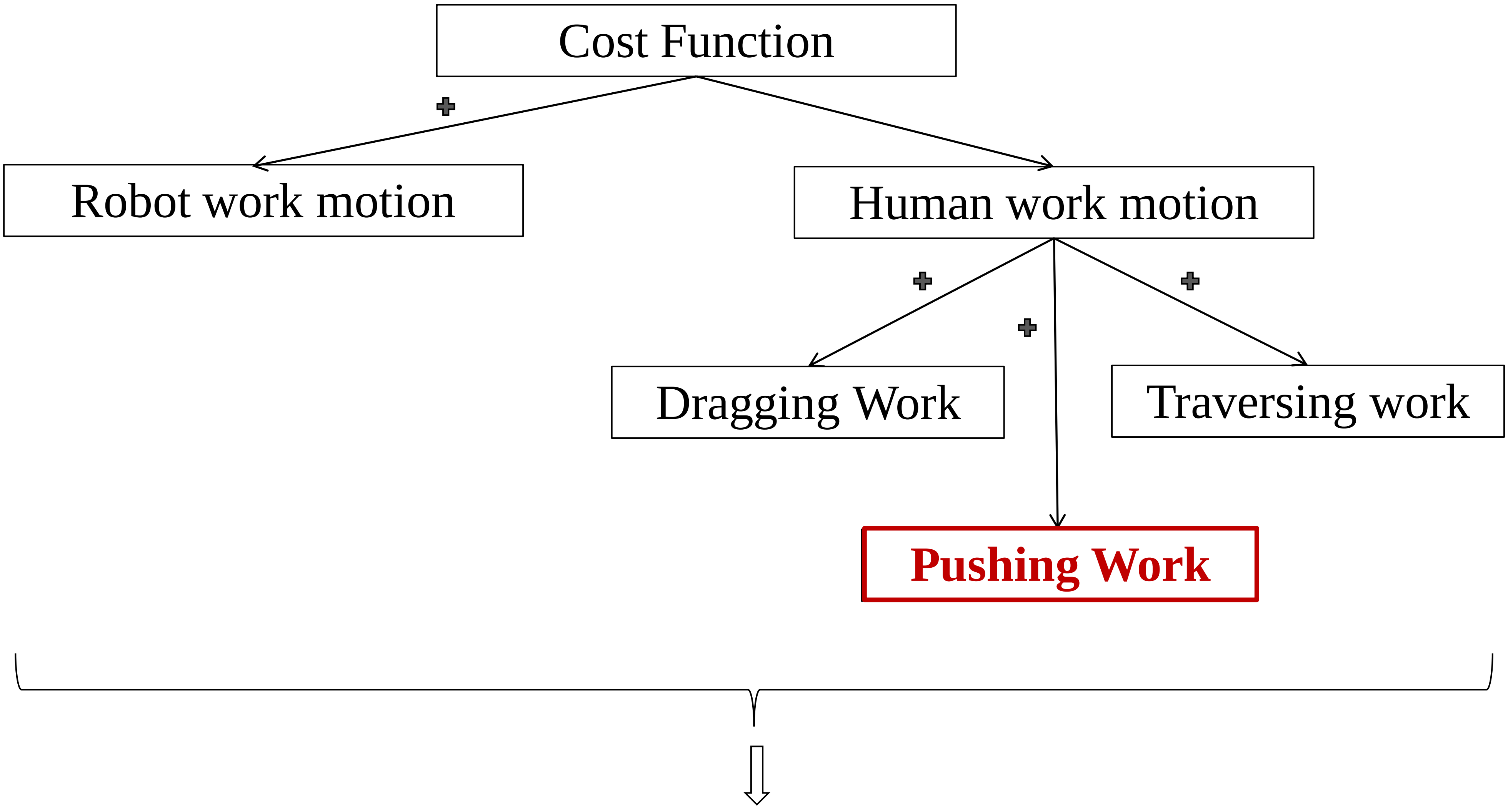



Definition of people's vital territory

# Pushing work




Optimal Robot Task Assignment

# Pushing Work (ii)

- Pushing force:
  - Done be 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*:

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

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

Ai: interaction strength

rij = ri – rj , usually 1.5m

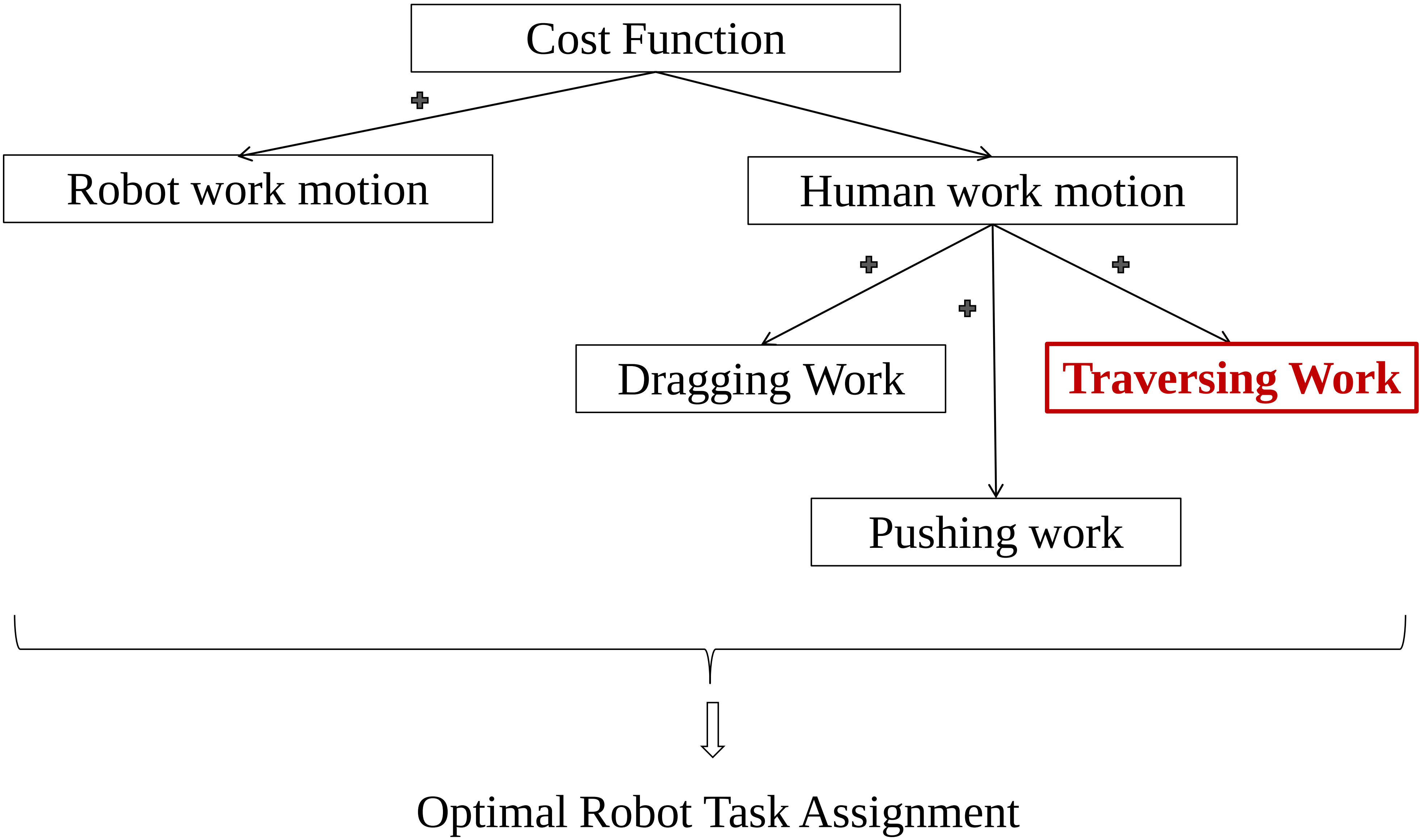
Bi: parameter of repulsive interaction

λ <1,

φij : angle of the directions

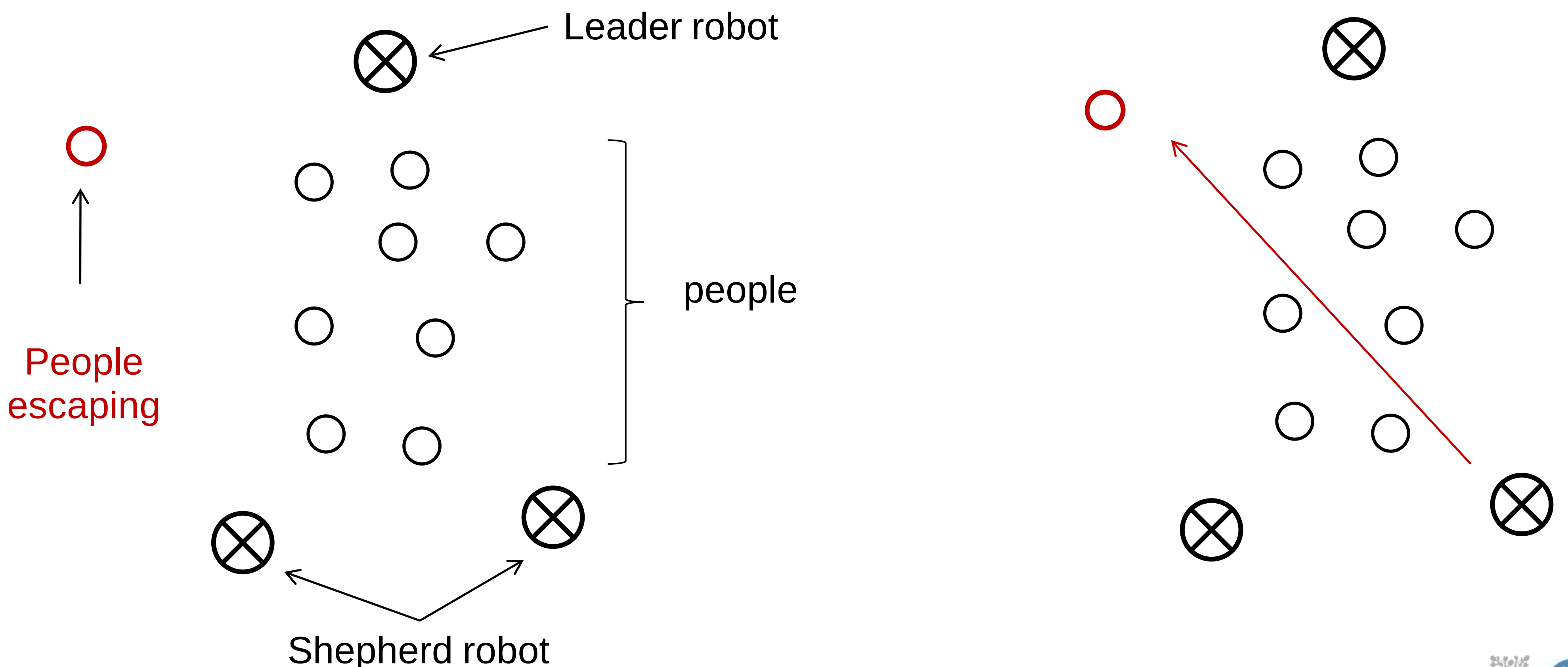
Ω: perople affected by pushing forcec

# Traversing work

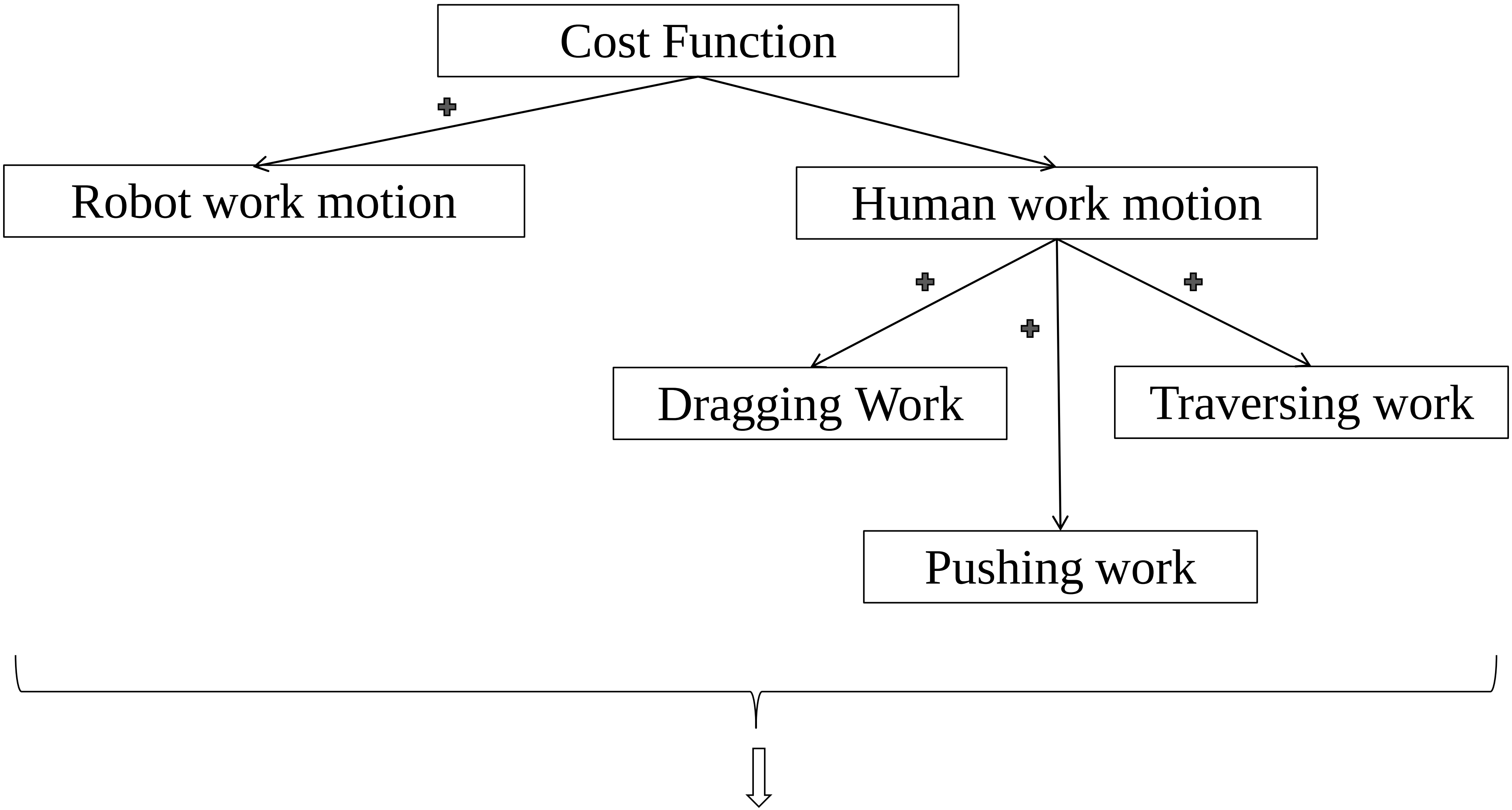


# Traversing Work (ii)

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



# Optimal Robot Taks Assignment




**Optimal Robot Task Assignment**

# Optimal Robot Taks Assignment (ii)

- Total cost function for robot *i*:

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

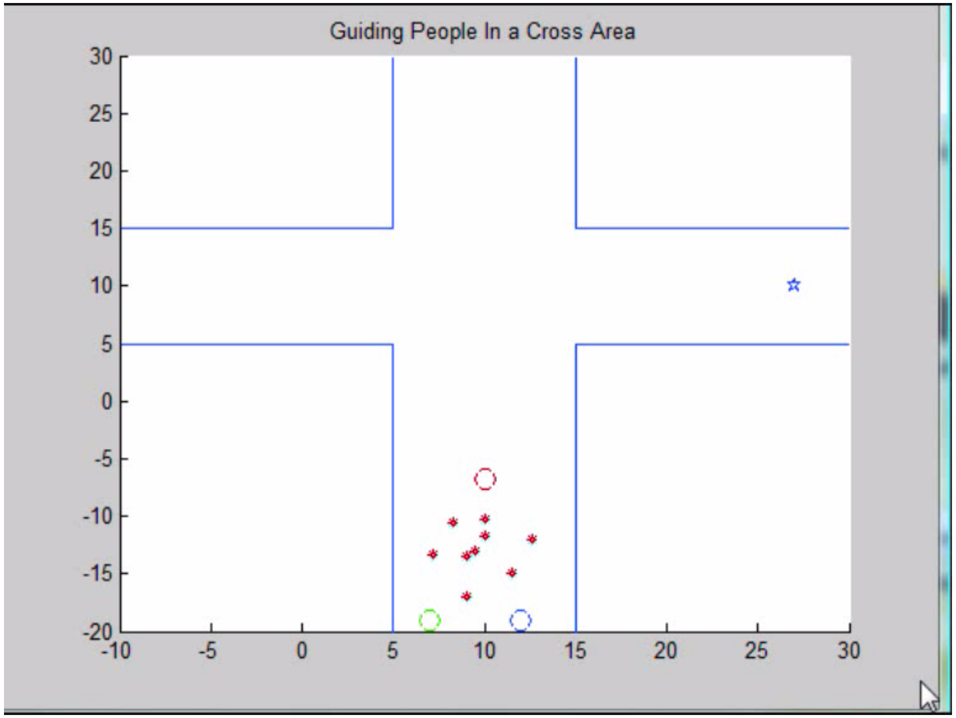
Where,

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

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

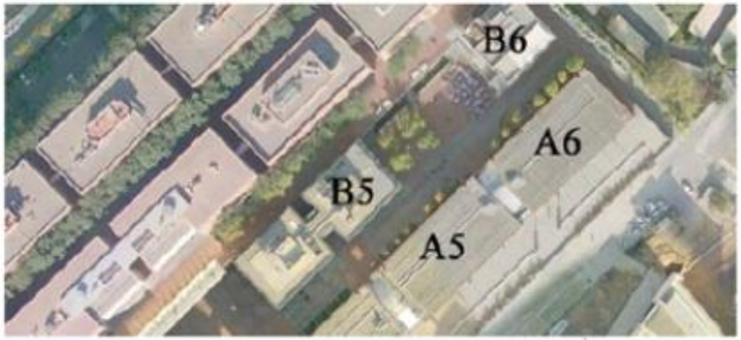
$$C = argmin(W_{total}(C)), \forall \; configuration \; c$$

# Simulations



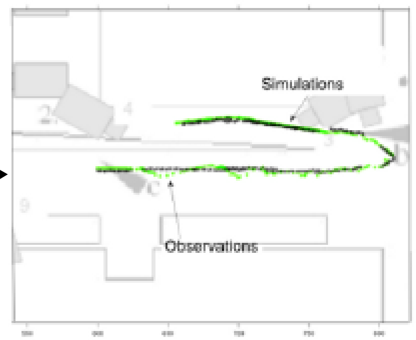
# Data Collection

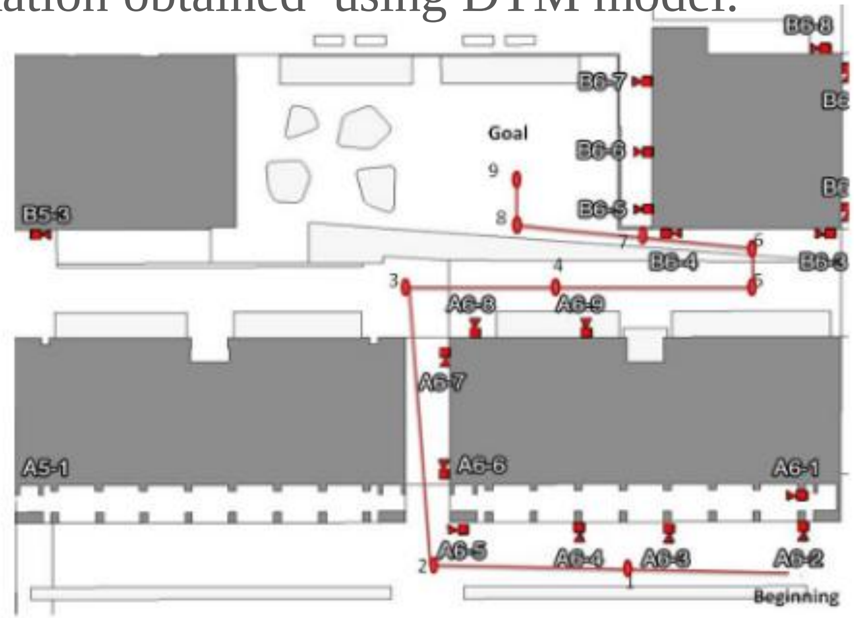
- Data collection:
  - Camera Network mounted on Barcelona robot Lab
  - 21 interconnected cameras
- People behavior
  - The group follows the instructions of the guides.
  - A person who is being led, if he goes away from the group one of the guides has to regroup him.
  - Several people escape at the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



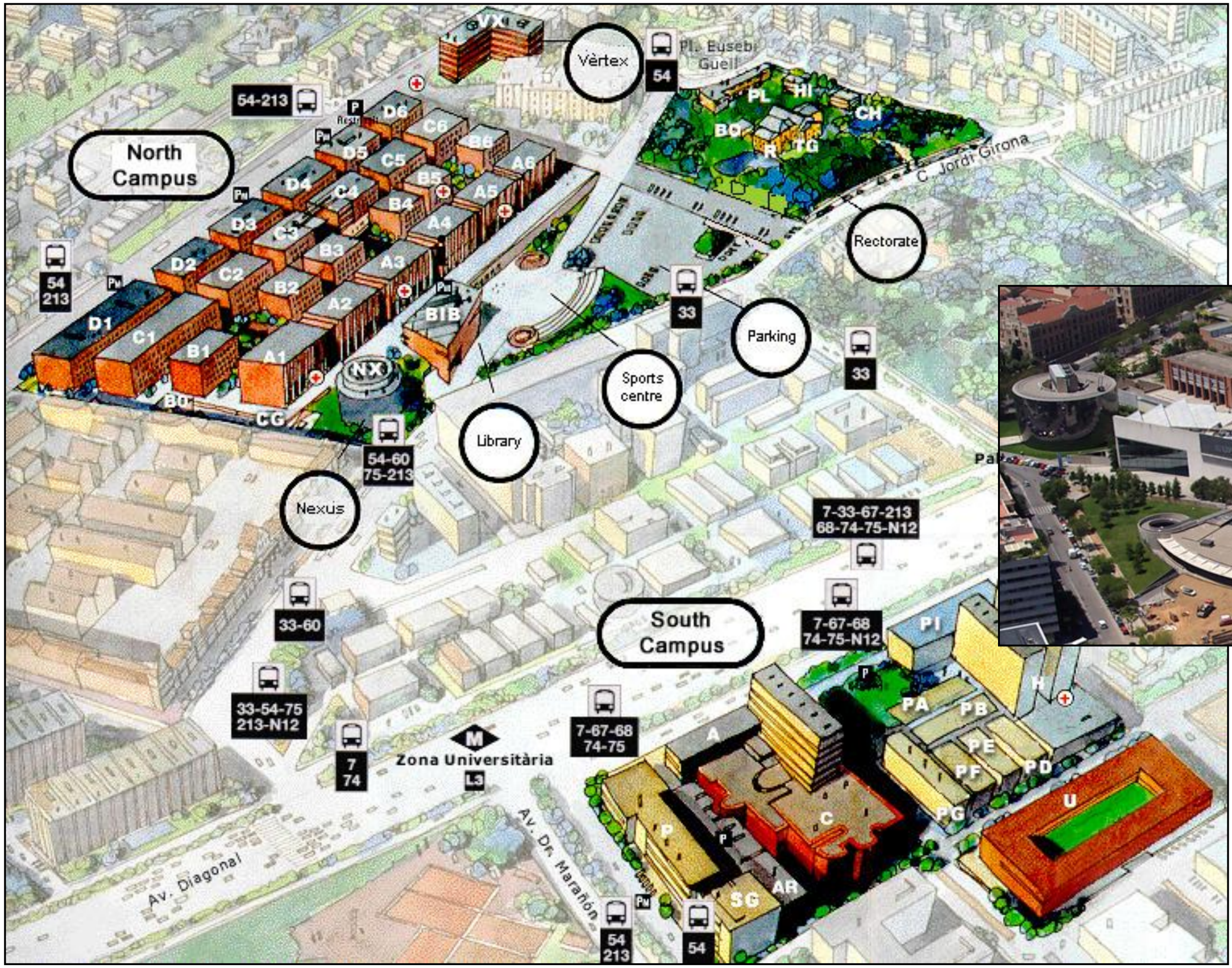



# Validation Process

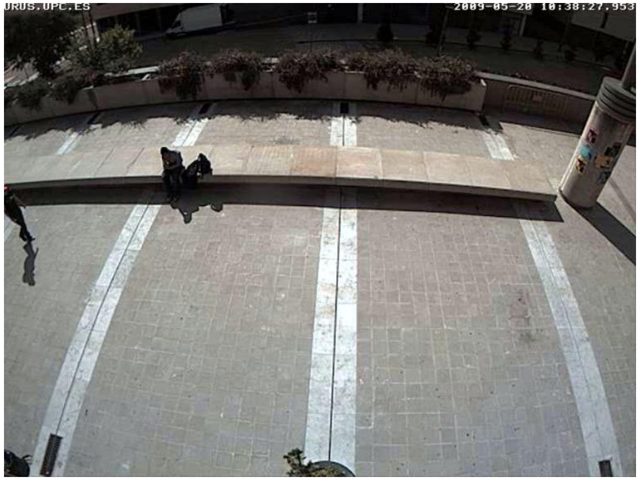
- **Two cases were studied:**
  - The motion behavior of robots:
    - Shepherd robots
    - Leader robot
  - Motion behavior of the guided people.
- **Robots' analysis:**
  - A comparison of the real motion and simulated motion is performed in different scenarios
- **People analysis**
  - A comparison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

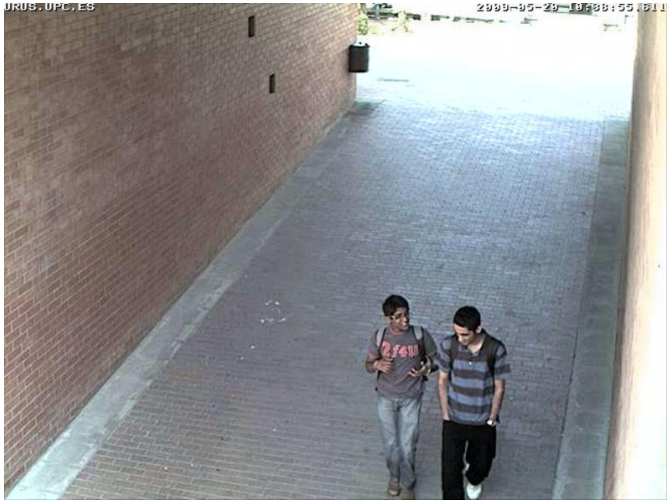
$$error_k = \sqrt{(y_k - \hat{y}_k)^2}$$

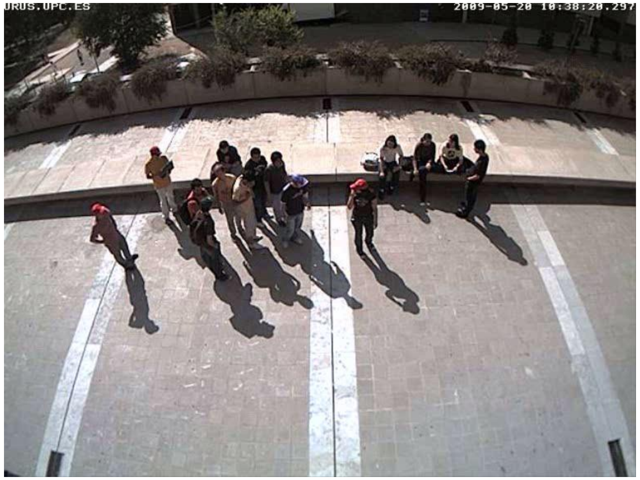
# Experiment Location

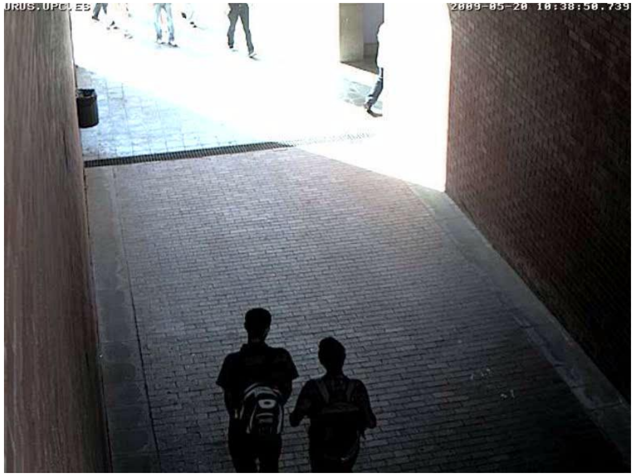




# Simulations





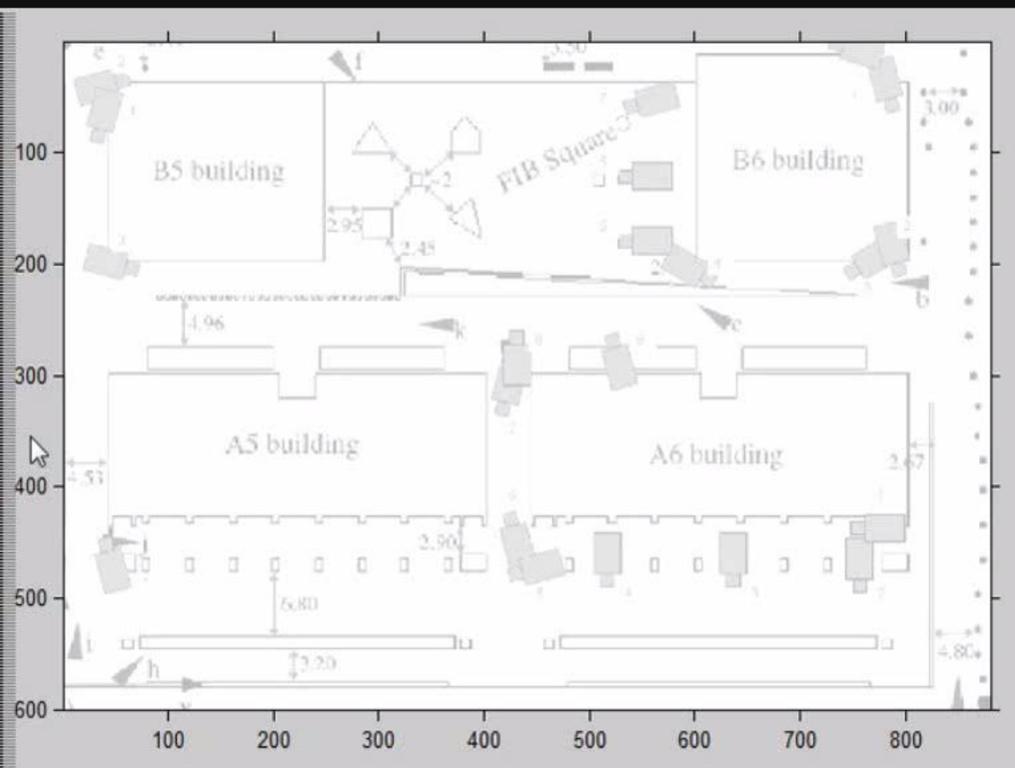


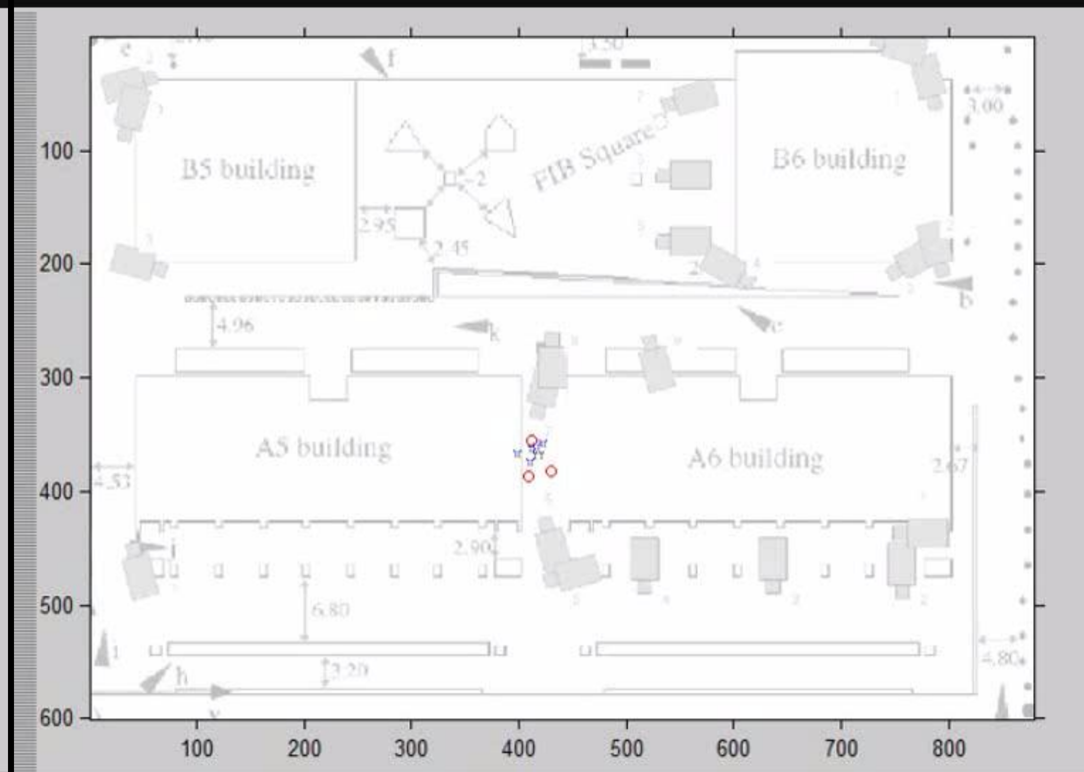


# Simulations

Ubiquitous Networking Robotics in Urban Settings

CogSys

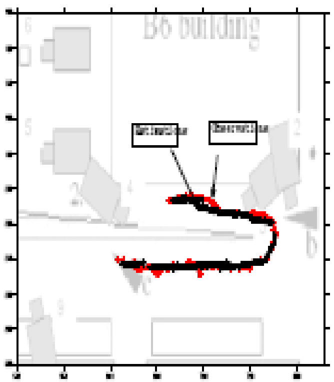


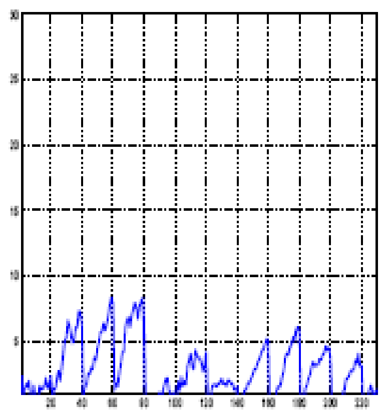



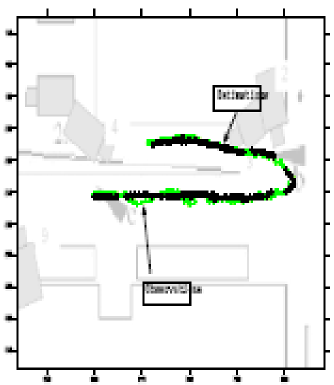
# Simulations

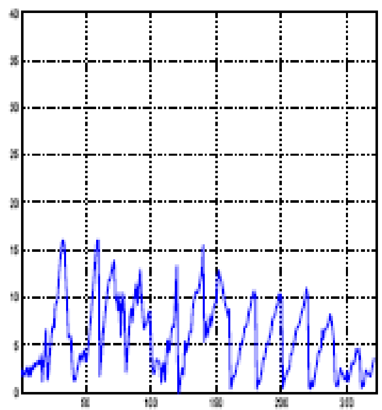
# Results

- **Corridor**:
  - People

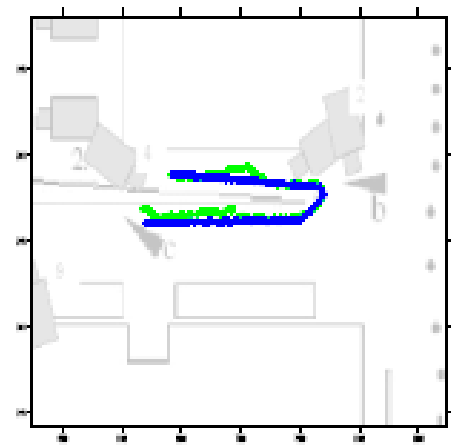


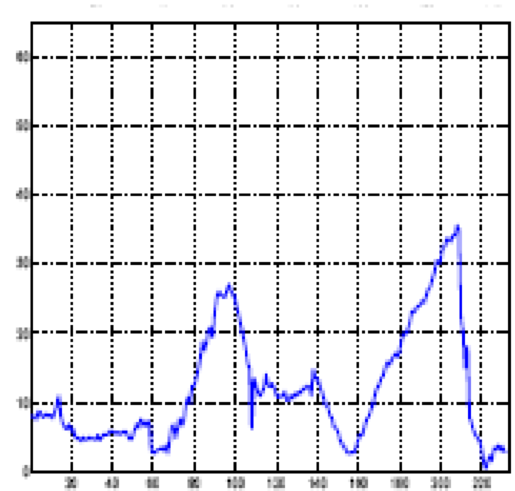





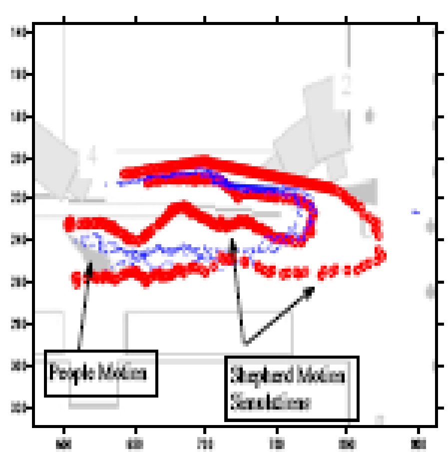


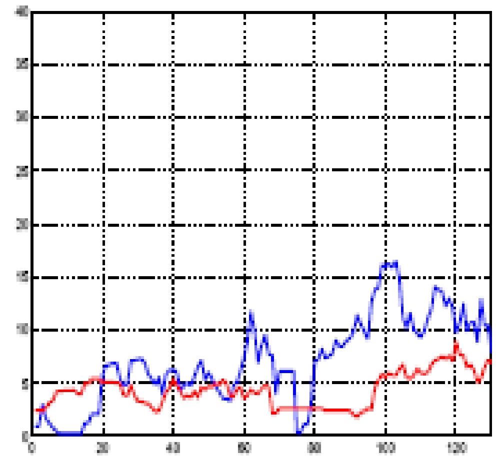
  - Leader Robot





  - 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

Institut de Robòtica i Informàtica Industrial

Anaís Garrell
Alberto Sanfeliu

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