Decentralized & Prioritized Navigation and Collision Avoidance for Multiple Mobile Robots

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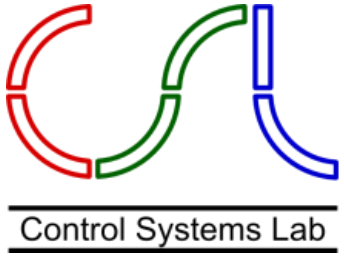

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Motivation

- Navigation of multiple mobile robots
  - Perform **tasks** of different priorities
- Guaranteed collision avoidance
- Decentralisation
- Efficient manoeuvring

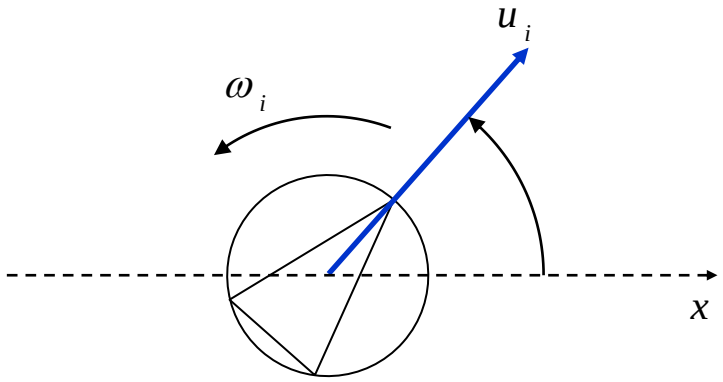
Presentation Outline

- Problem Description
- Navigation Functions
  - Explicit prioritisation
  - Limited Sensing
  - Implicit Prioritisation
- Control Algorithm
- Results
- Conclusions – Future Research

Problem Description

- Spherical, planar unicycle robots

$$\dot{x}_i = \cos(\phi_i)\cdot u_i$$
$$\dot{y}_i = \sin(\phi_i)\cdot u_i$$
$$\dot{\phi}_i = \omega_i$$



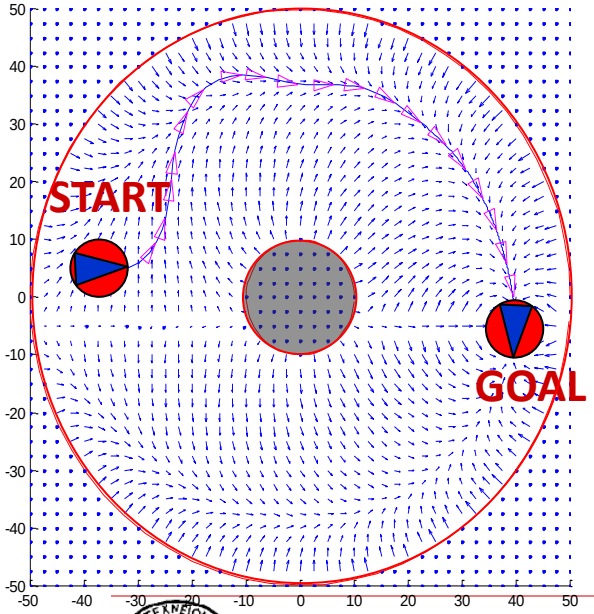
- **Decentralised** algorithm
  - Each robot moves without knowing others' destinations
  - Implicit coordination only
- **Limited sensing** range
  - Onboard sensors
  - Less information to process
  - Unknown, dynamic environment
- Explicit robot **prioritisation** according to **task importance**

Navigation Functions

- **Motivation**
  - **Guaranteed** Collision avoidance
  - **Decentralised** Algorithm - Only Sensory data required
  - **Real-time** Feedback scheme
    - computationally efficient
    - Handle measurement and modeling errors
- **Main Contribution**
  - **Limited Sensing Area**
  - **Prioritisation** (Explicit, Implicit)
  - **Static and Moving Obstacles**

Navigation Functions

- Artificial Potential Field
  - Repulsive (MAX) wrt obstacles and other robots
  - Attractive (MIN) wrt the destination q_{id}
  - ⇨ Move downhill to avoid collisions and reach the destination
- NF advantage: Exactly one global minimum at the destination
  - Guaranteed convergence and collision avoidance



- Each robot uses a Decentralised Navigation Function Φ_i
  - Negated gradient $-\nabla_i \Phi_i$ creates a reference vector field
  - **Control Scheme** designed to follow the reference vector field to the destination

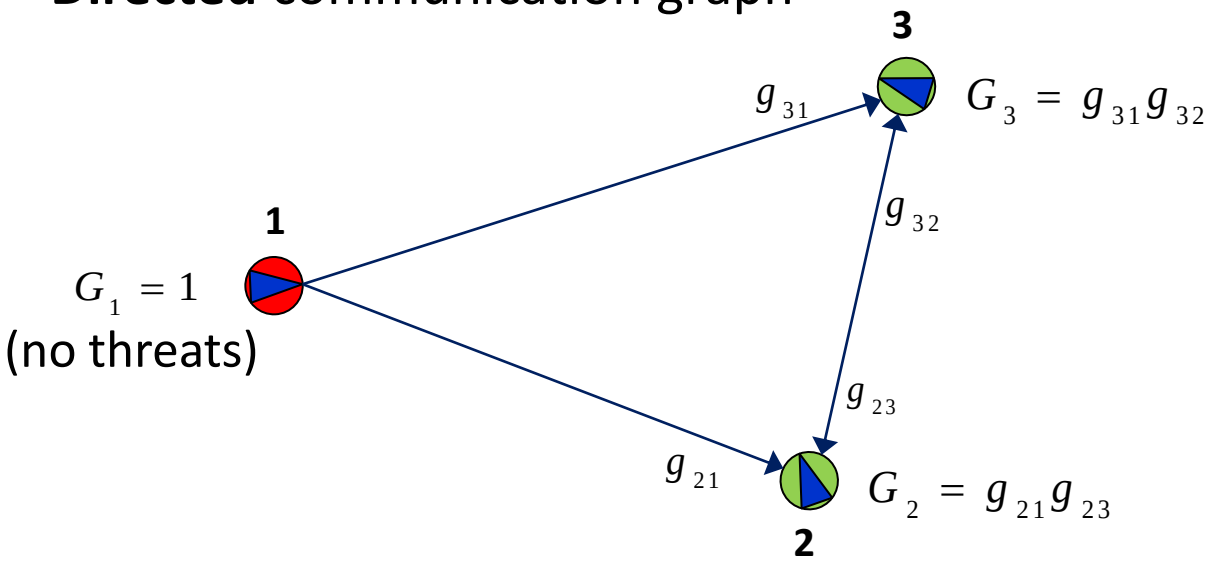
NF Construction

$$\Phi_i = \Phi_i(q_i) = \frac{\gamma_{di}}{\left(\gamma_{di}^{\,k} + G_i \cdot \beta_i\right)^{1/k}}$$

- $\gamma_{di} = \left\| q_i - q_{id} \right\|^2$: distance from target q_{id}, **attractive** potential
  - $\gamma_{di} = 0$ at the destination
- $G_i = \prod g_{ij}$: sensing of other robots and obstacles in workspace
  - Each robot/obstacle j contributes its own g_{ij} to Φ_i.
    - $G_i = 0$ on the boundary of obstacles/robots, **repulsive**
- β_i : sensing of workspace boundary
  - $\beta_i = 0$ on collisions with workspace boundary
- $\Phi_i = 0$ **at the destination** q_{id}, $\Phi_i = 1$ **on collisions**

Explicit Priorities

- Robots classified in **priority classes**
  - Classification according to task significance, robot capabilities etc
- Only **equal or higher** priority robots contribute to G_i
  - **Directed** communication graph



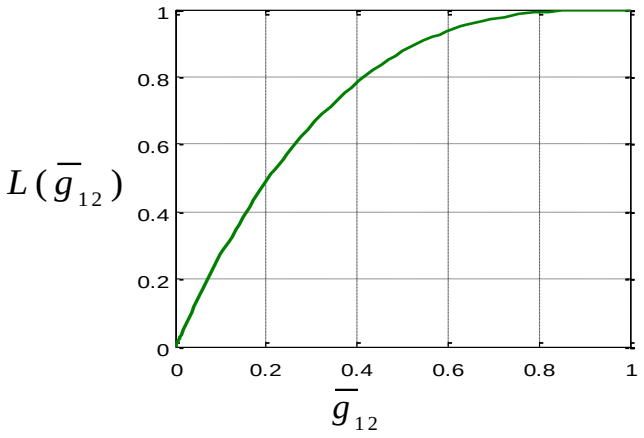
- High priority robots maintain **Right of Way**
- **Obstacles** have **HIGHEST** priority!

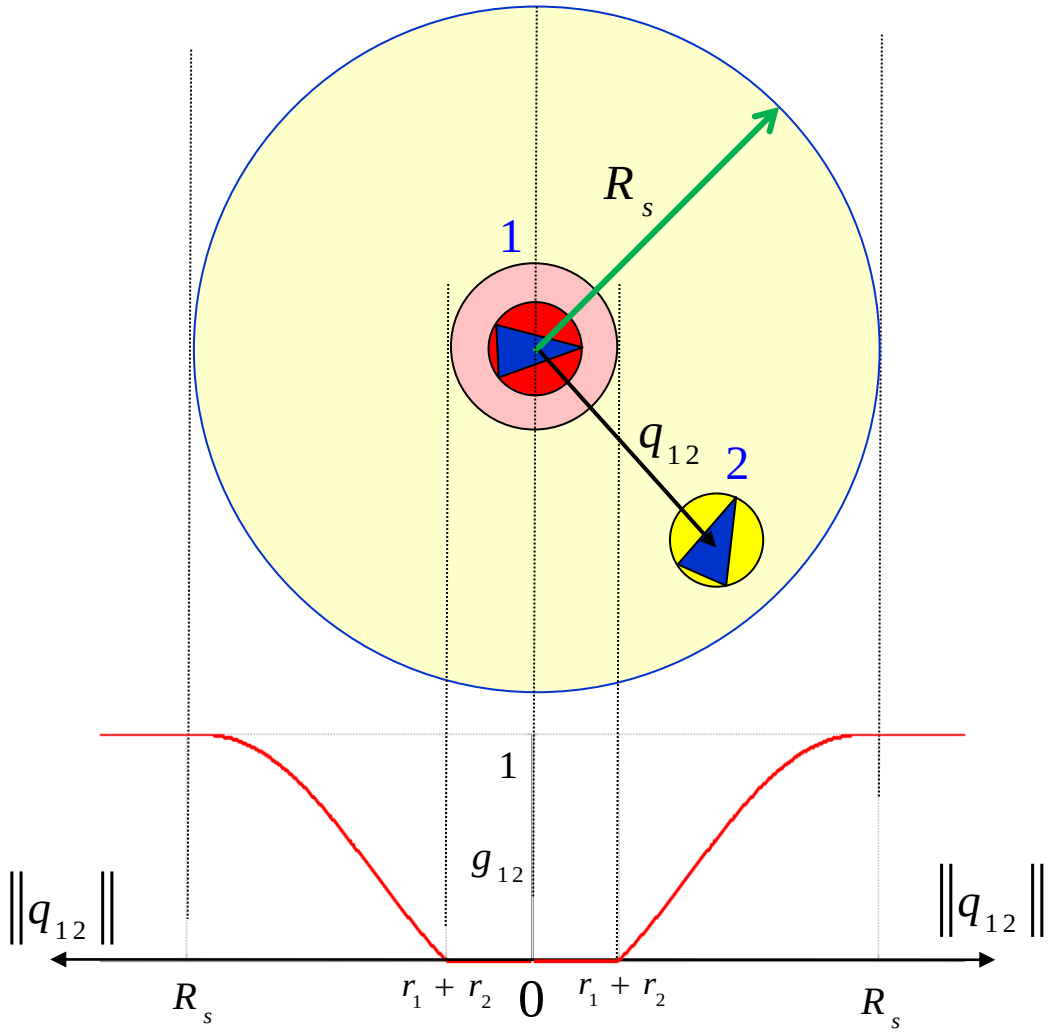
Local Sensing

- Restrict sensing in a finite area around each robot
  - **Circular** Sensing area

$$\bar{g}_{12} = \frac{\|q_{12}\|^2 - (r_1 + r_2)^2}{R_s^2 - (r_1 + r_2)^2}$$

$$g_{12} = \begin{cases} L(\bar{g}_{12}), & \|q_{12}\| \le R_s \\ 1, & \|q_{12}\| > R_s \end{cases}$$





Symmetrical Sensing: $g_{12} = g_{21}$

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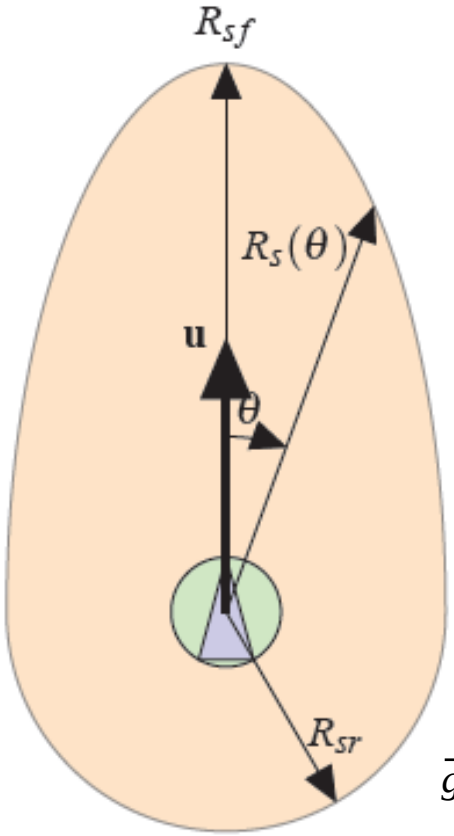
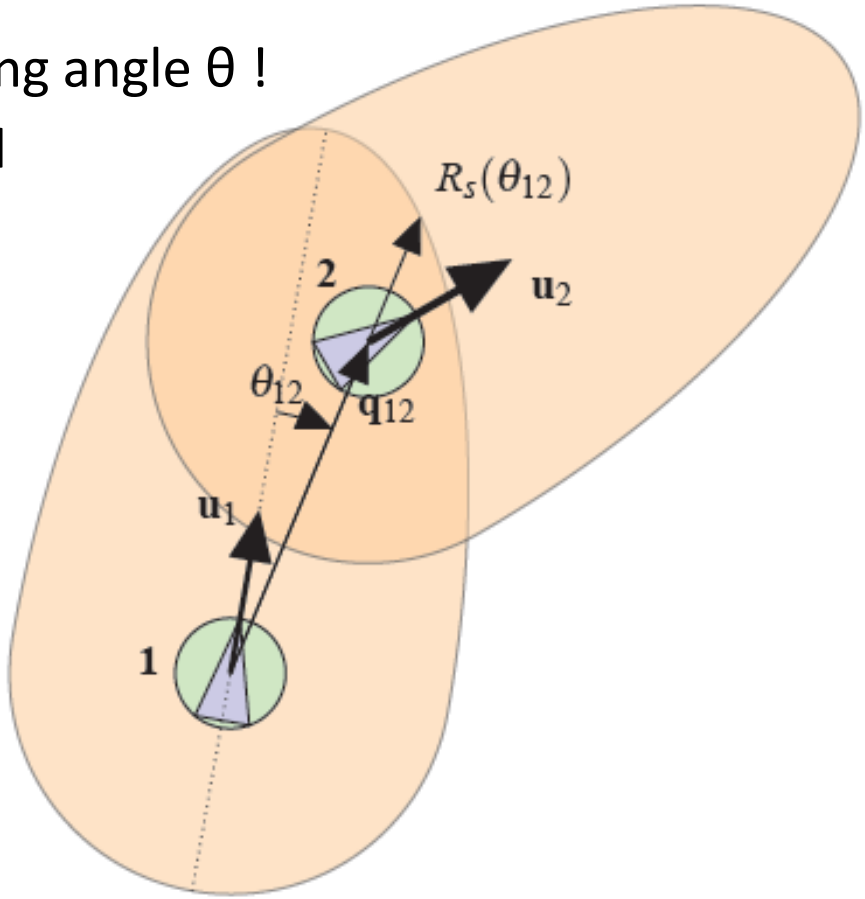
Implicit Priorities

- **Non-circular** sensing area
  - Contribution depends on bearing angle θ !
  - More influence shifted forward



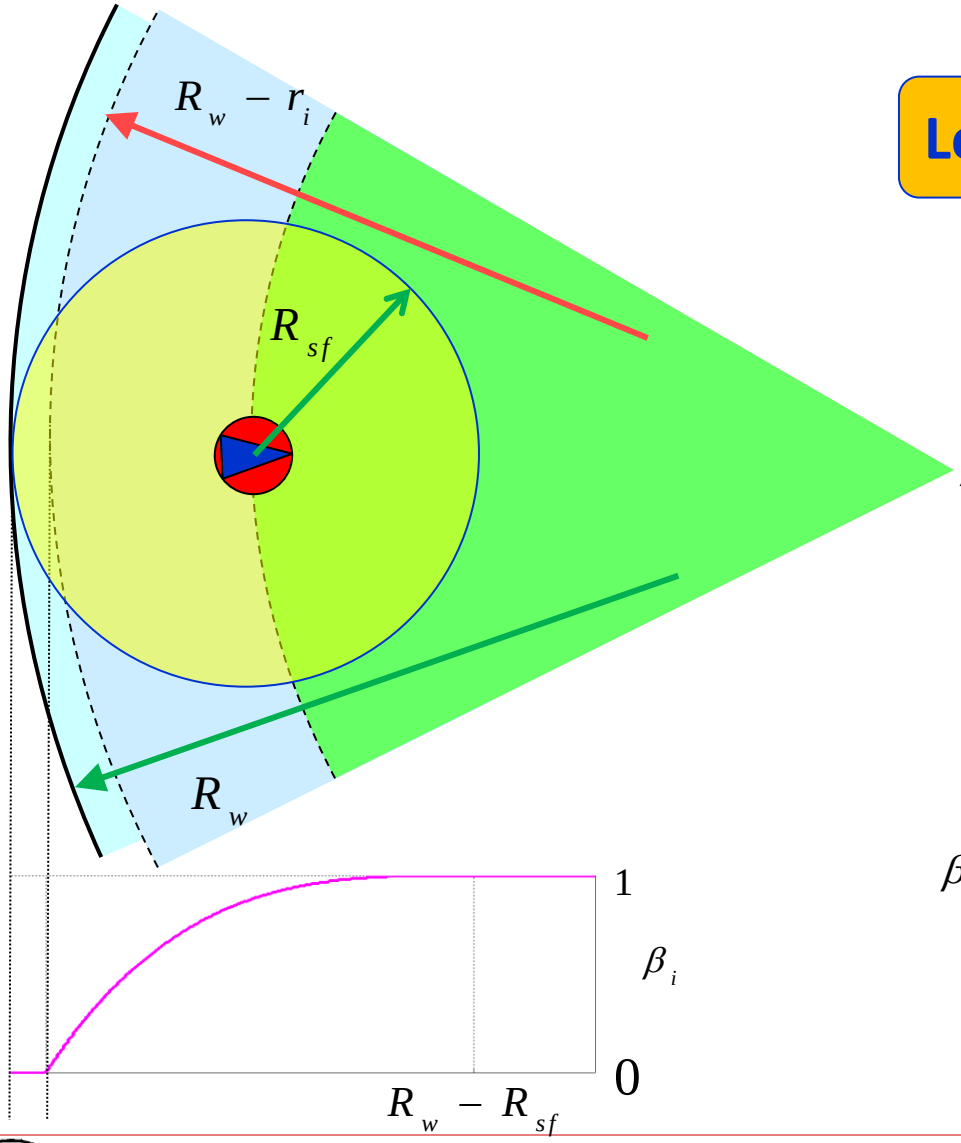
$$R_s = R_s(\theta_{12})$$



$$\bar{g}_{12} = \frac{\|q_{12}\|^2 - (r_1 + r_2)^2}{R_s(\theta_{12})^2 - (r_1 + r_2)^2}$$

Assymetrical Sensing: $g_{12} \neq g_{21}$

Workspace Boundary



Local Influence Only

$$\bar{\beta}_i = \frac{(R_w - r_i)^2 - \|q_1\|^2}{(R_w - r_i)^2 - (R_w - R_{sf})^2}$$

$$\beta_i = \begin{cases} L(\bar{\beta}_i), & \|q_i\| \geq R_w - R_{sf} \\ 1, & \|q_i\| < R_w - R_{sf} \end{cases}$$

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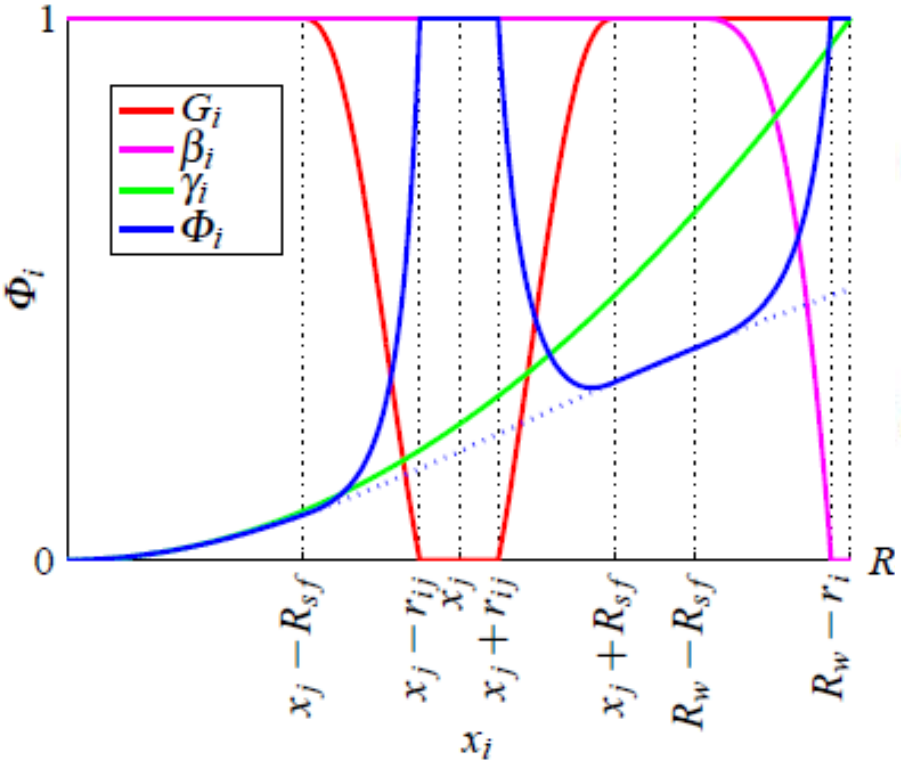
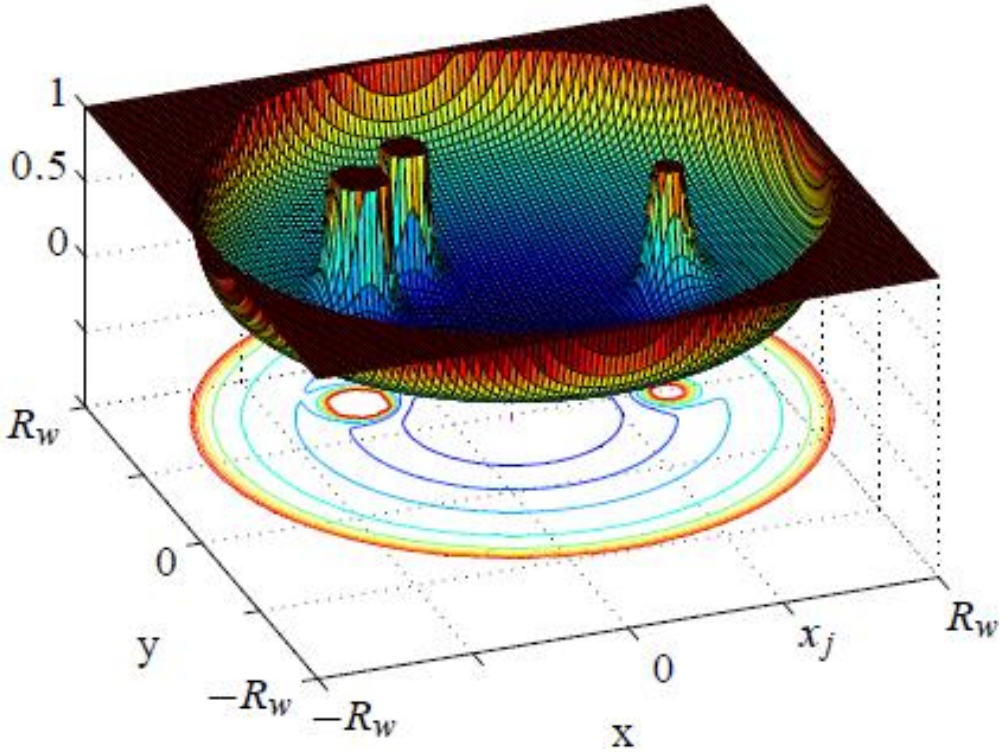
Potential Construction

- Normalised goal function: $\gamma_{di} = \dfrac{\left\| q_i - q_{di} \right\|^2}{R_w^2}$

$$\Phi_i = \frac{\gamma_{di}}{\left(\gamma_{di}^{\,k} + G_i \cdot \beta_i \right)^{1/k}}$$

Formal Properties Maintained





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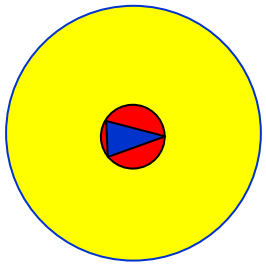
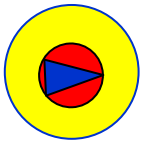
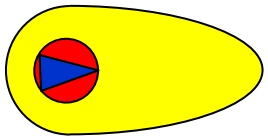
Control Scheme

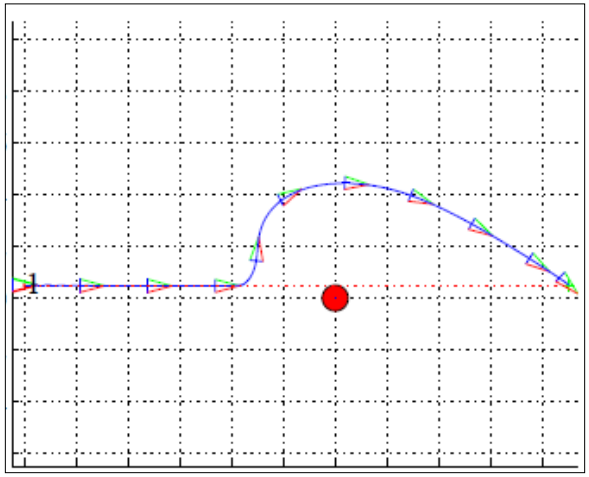
- Each robot i steers toward the direction of $-\nabla_i \Phi_i$
- Speed u_i regulated to ensure $\dot{\Phi}_i < 0$
- **Collision Avoidance** Guaranteed
- Formal **Convergence** proof

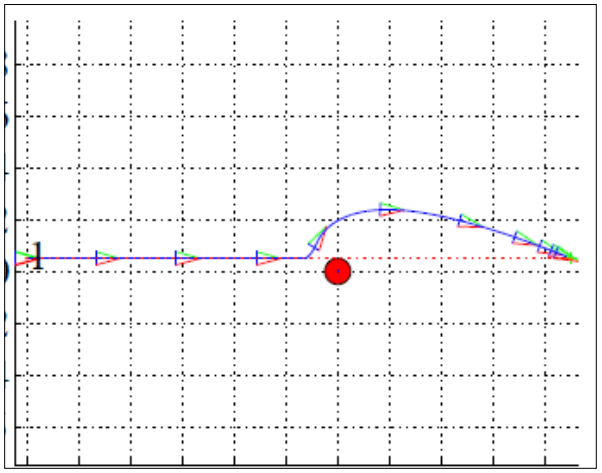
Examples

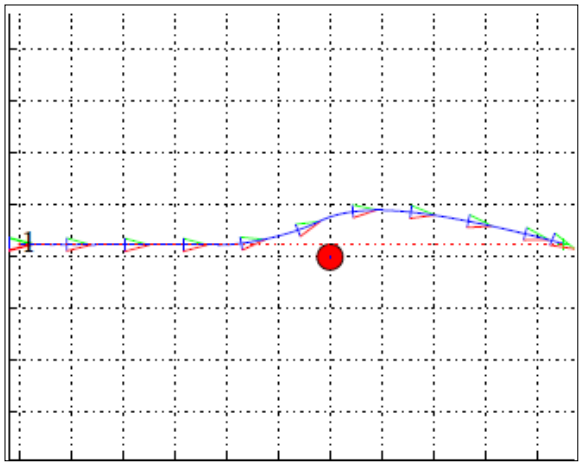






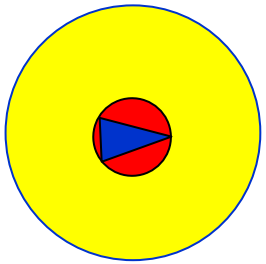


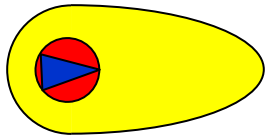


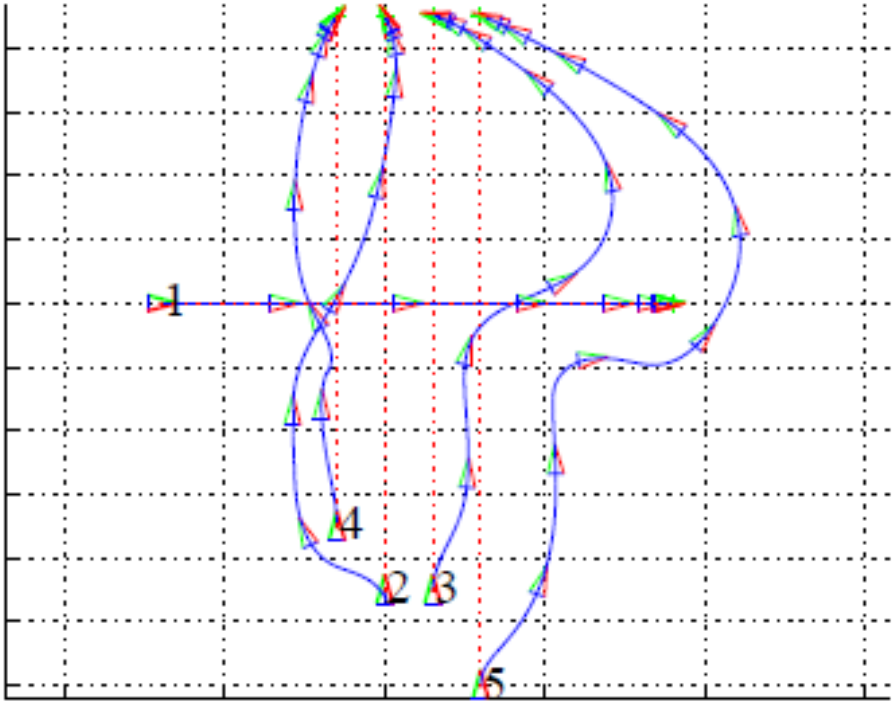


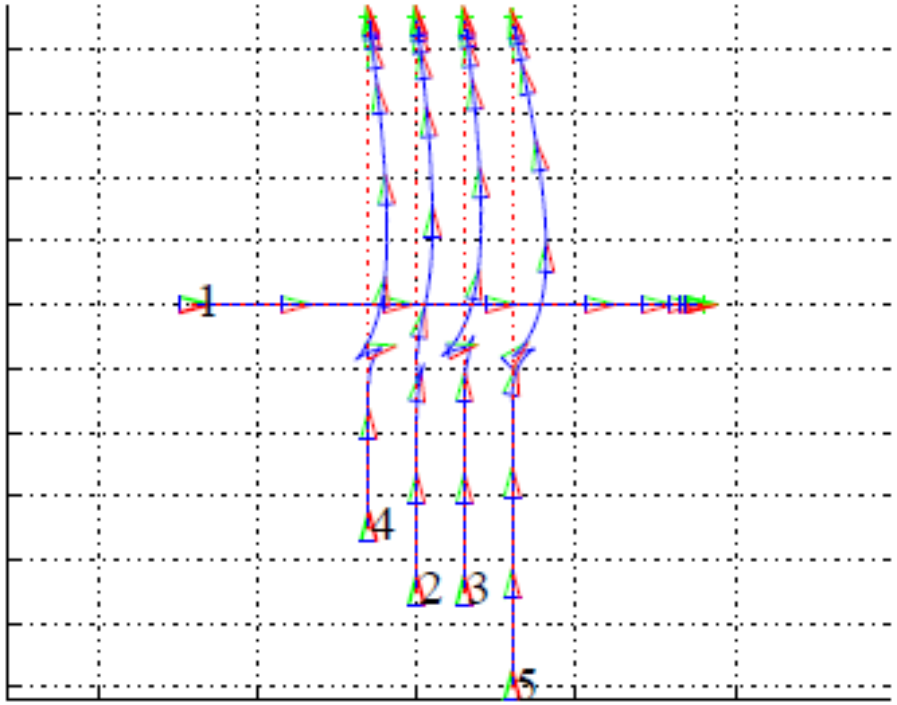
Computation Time	**25s**	**26s**	**20s**
Path length	**7.56**	**6.59**	**5.13**
Total steering angle	**6.11**	**5.00**	**3.66**

Examples









Total Paths length	7.56	5.13

Conclusions

- **Decentralised** navigation and conflict avoidance for mobile robots
- **Limited sensing**
- **Prioritisation** (Explicit & Implicit)
- **Collision avoidance** and **Convergence** formally guaranteed
- Algorithm and path **efficiency** improved

- **Future work**
  - Optimise the **shape** of sensing area
  - **3D navigation**

Thank you!
Questions?