Inevitable Collision States: a Probabilistic Perspective

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Context

Safe autonomous navigation of a robotic system in open dynamic environments

DARPA Urban challenge 2007: the technology is here but accidents took place

$\Rightarrow$ **Motion safety remains an issue**

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Motion Safety

Motion safety requires to [Fraichard, 2007]

1. reason about the future
2. with an appropriate look ahead

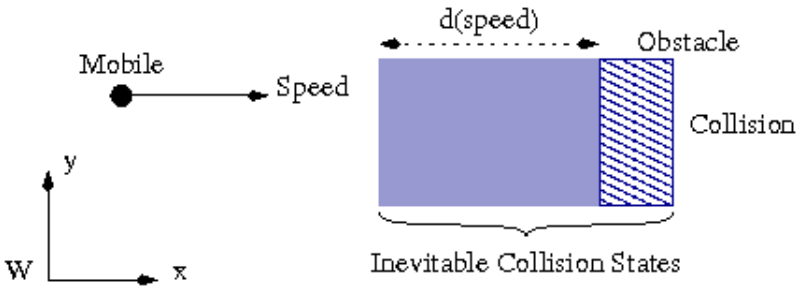
A concept that addresses these issues:
Inevitable Collision States [Fraichard & Asama, 2004]

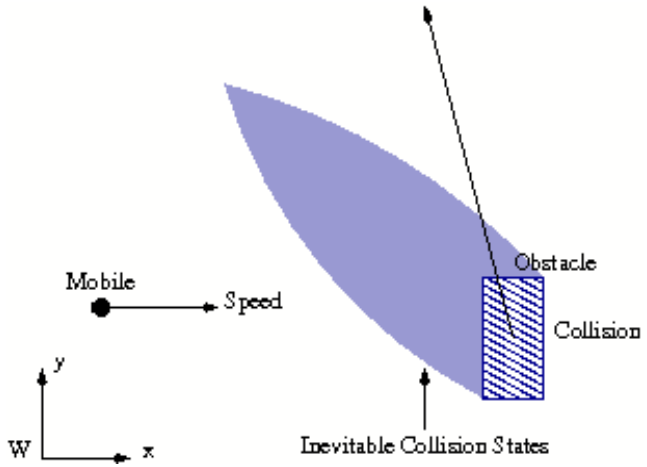
Related concepts:

- Obstacle Shadow [Reif & sharir, 1985]
- Region of Inevitable Collision [LaValle & Kuffner, 2001]
- Viability Kernel: Viability Theory [Aubin, 1991]
- Backward Reachable Set [Mitchell & Tomlin, 2003]

Inevitable Collision States

State in which whatever the control trajectory sequence applied by the robotic system, a collision will eventually occur



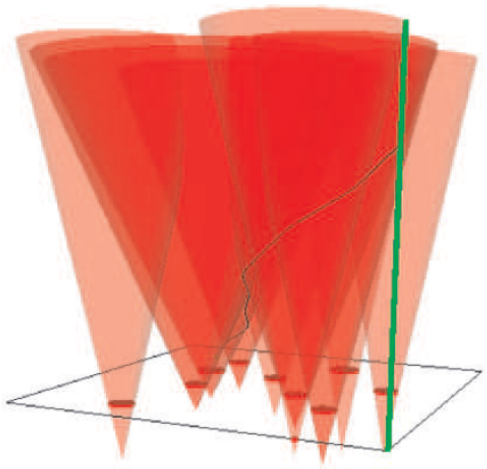


Deterministic the model of the future

Open environments are uncertain (prediction of the future motion of obstacles)

$\longrightarrow$ Safety requires to be conservative

Using a worst-case scenario e.g. : Growing discs
[van den Berg & Overmars, 2007]



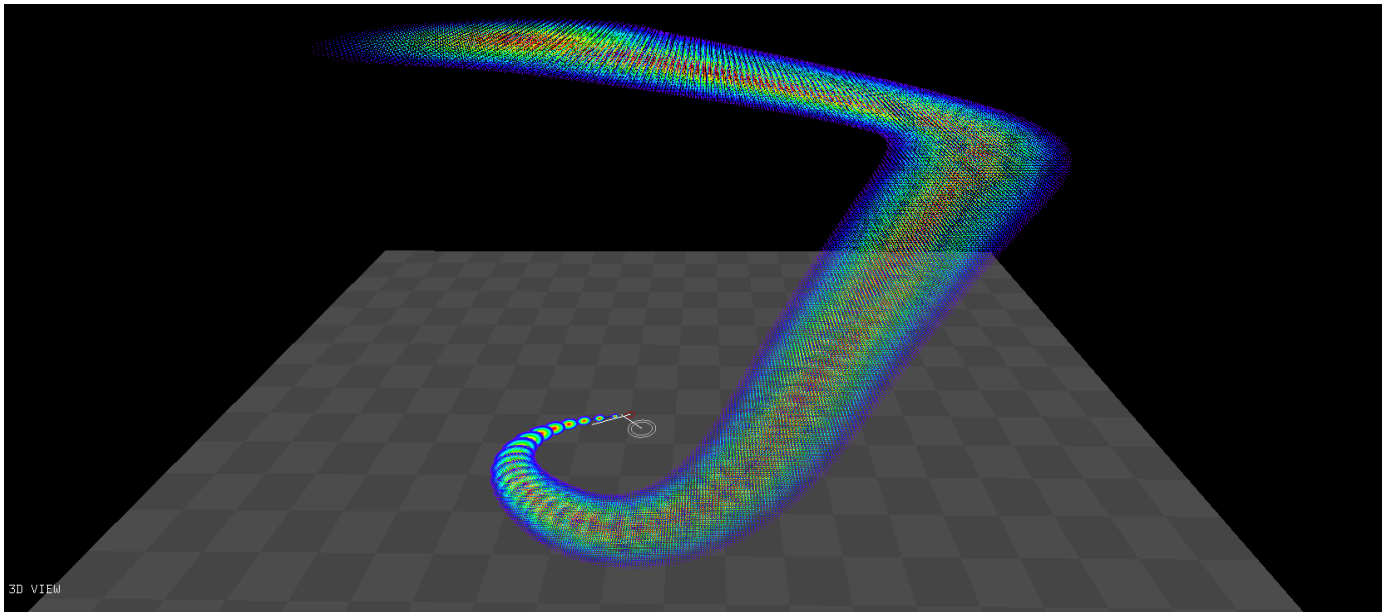
$\Rightarrow$every state is an ICS

Probabilistic model of the future

Model for the future motion of Obstacles:

$P_{occ\ [\mathcal{B}_i,t]}(x_w, y_w)$ is available $\forall\ x_w, y_w, t, i$

$\longrightarrow$ Assumed available (can be built from various methods)



Lookahead is set to the time when the distributions of the obstacles are uniform

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Probabilistic ICS

Contribution of this work :

Characterize ICS using a probabilistic model of the future
Probabilistic ICS-checking algorithms

Probabilistic ICS Definition (New notion)

$$P_{ICS}(s) = P(s \in \text{ICS}(\mathcal{B})) = \min_{\forall \tilde{u} \in \tilde{\mathcal{U}}} (P_{ICS[\tilde{u},\mathcal{B}]}(s))$$

Probabilistic ICS Checking Algorithm (New algorithm) can be plugged into planning algorithm like Partial Motion Planning or RRT (future works)

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Backward Probabilistic ICS-Check Algorithm

Direct adaptation of the Deterministic ICS Checker
[Martinez Gomez & Fraichard, 2008]

Key step 2 explained on next slide

1. Select $\mathcal{E}$ with $\mathcal{E} \subset \tilde{\mathcal{U}}$, a subset of the whole set of possible future trajectories (conservative approximation)
2. Compute $P_{ICS[\mathcal{B}_i,\tilde{u}_j,t]}(s)$ for all t,every $\mathcal{B}_i$ and every $\tilde{u}_j \in \mathcal{E}$, $s \in \hat{\mathbf{z}}_\mathbf{c}$
3. Compute $P_{ICS[\mathcal{B}_i,\tilde{u}_j]}(s) = \bigcup_{t_0..t_{la}} P_{ICS[\mathcal{B}_i,\tilde{u}_j,t]}(s)$ for every $\mathcal{B}_i$ and every $\tilde{u}_j \in \mathcal{E}$
4. Compute $P_{ICS[\tilde{u}_j]}(s) = \bigcup_{i=1\cdots n_b} P_{ICS[\mathcal{B}_i,\tilde{u}_j]}(s)$ for every $\tilde{u}_j \in \mathcal{E}$
5. Compute $P_{ICS}(s_c) = \min(P_{ICS[\tilde{u}_j]}(s_c))$

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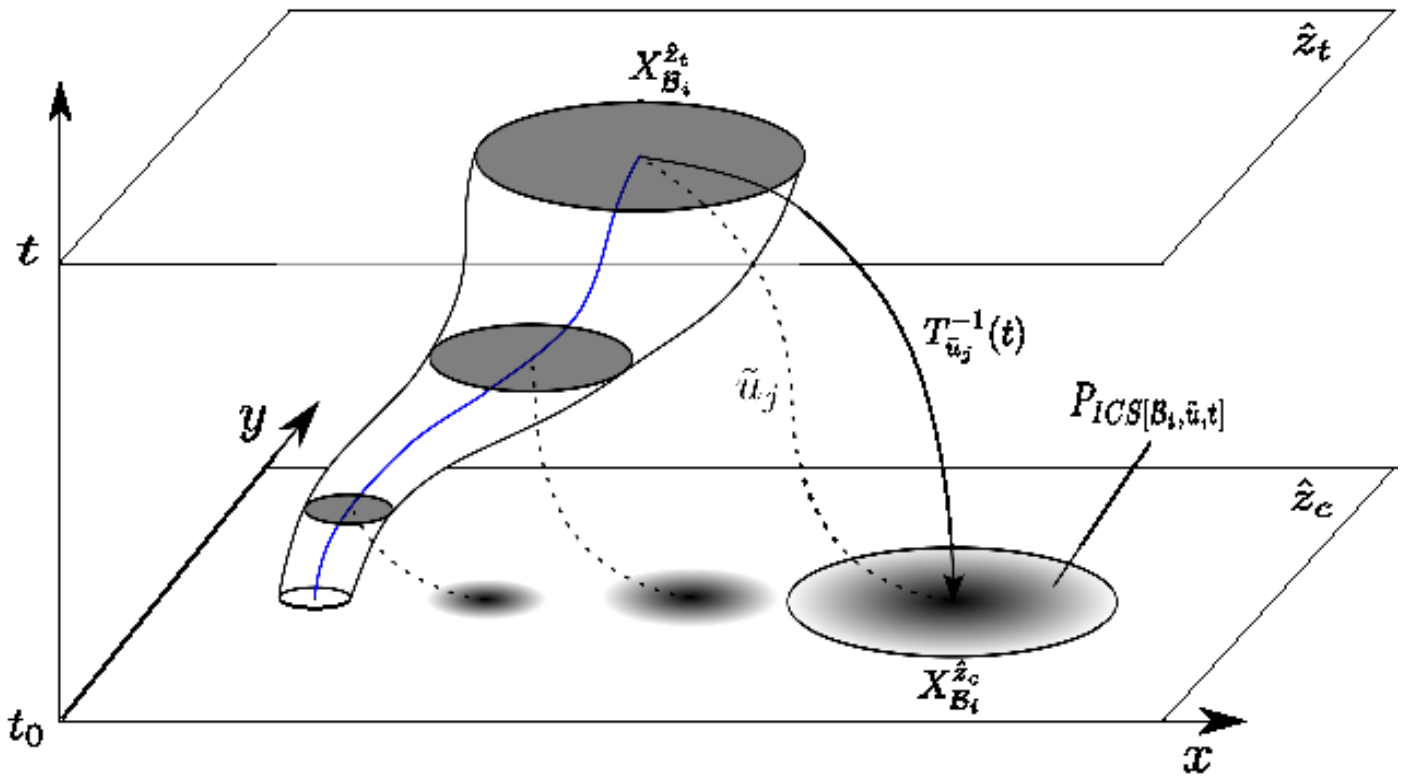
Backward Probabilistic ICS-Check Algorithm

Step 2: Compute $P_{ICS[\mathcal{B}_i,\tilde{u}_j,t]}(s)$

$\hat{z}$ slice reasoning [Martinez Gomez & Fraichard, 2008]:
Planary System State: $s = (x, y, \hat{z})$



Results for a $\hat{z}_c$ slice

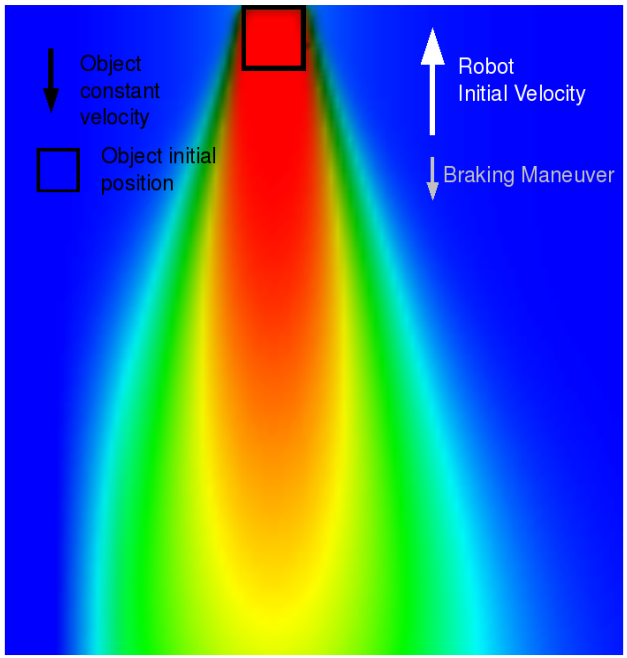
Computing probabilistic ICS for :

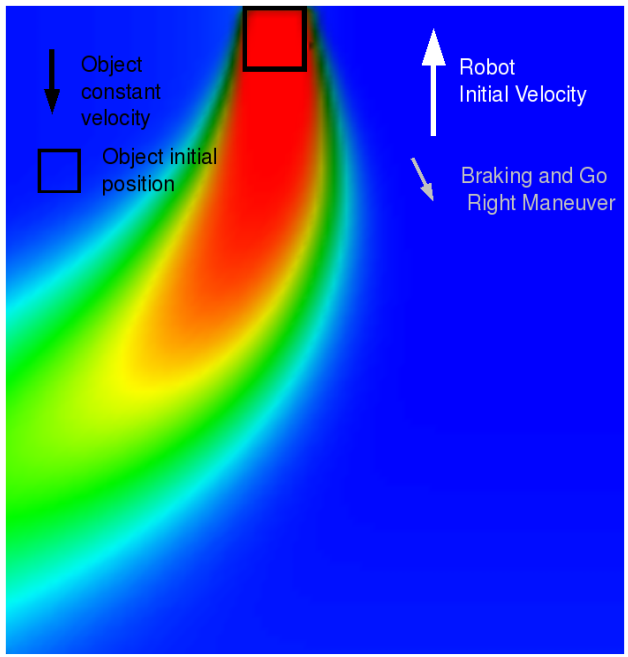
Point mass system with an initial state : $\dot{x} = 0 \quad \dot{y} = 10$

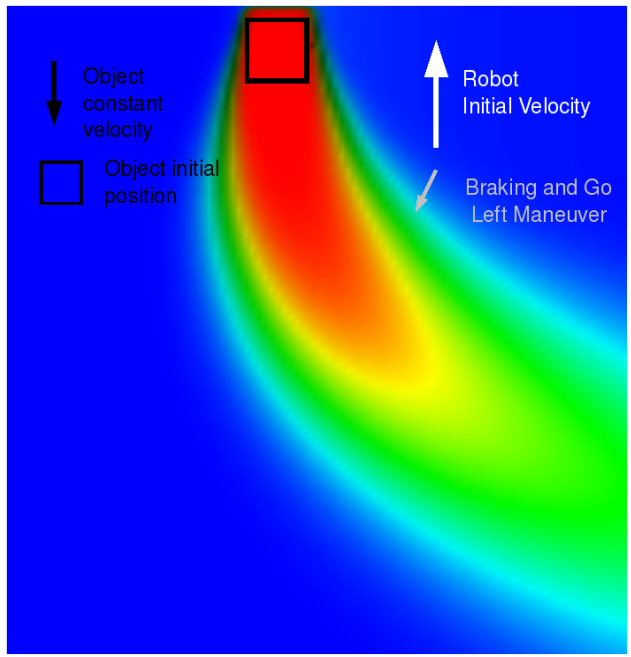
3 different control trajectories

1 obstacle moving down (probabilistically)

Obstacle constant velocity : $\dot{x} = 0 \quad \dot{y} = -10$





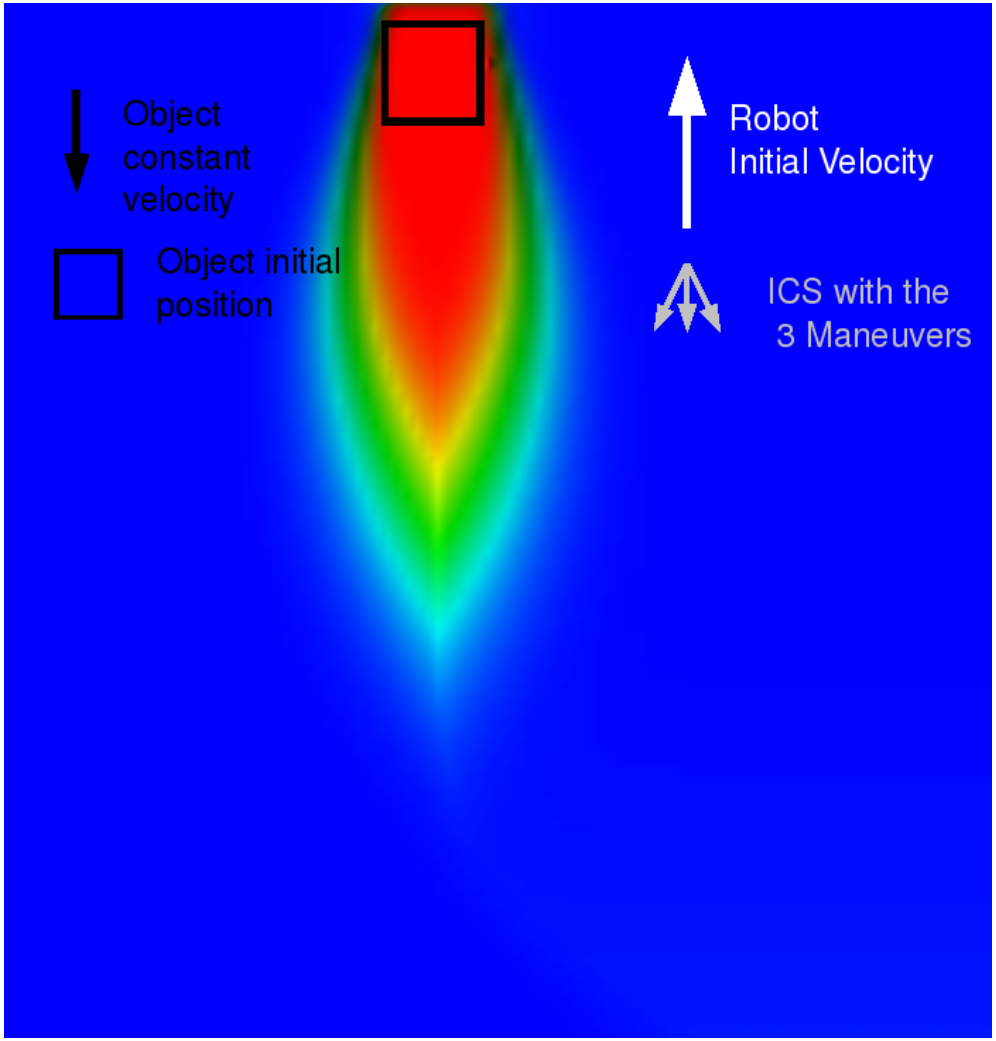


Control trajectory :

$\ddot{x} = 0 \quad \ddot{y} = -1$ $\qquad$ $\ddot{x} = +1 \quad \ddot{y} = -1$ $\qquad$ $\ddot{x} = -1 \quad \ddot{y} = -1$

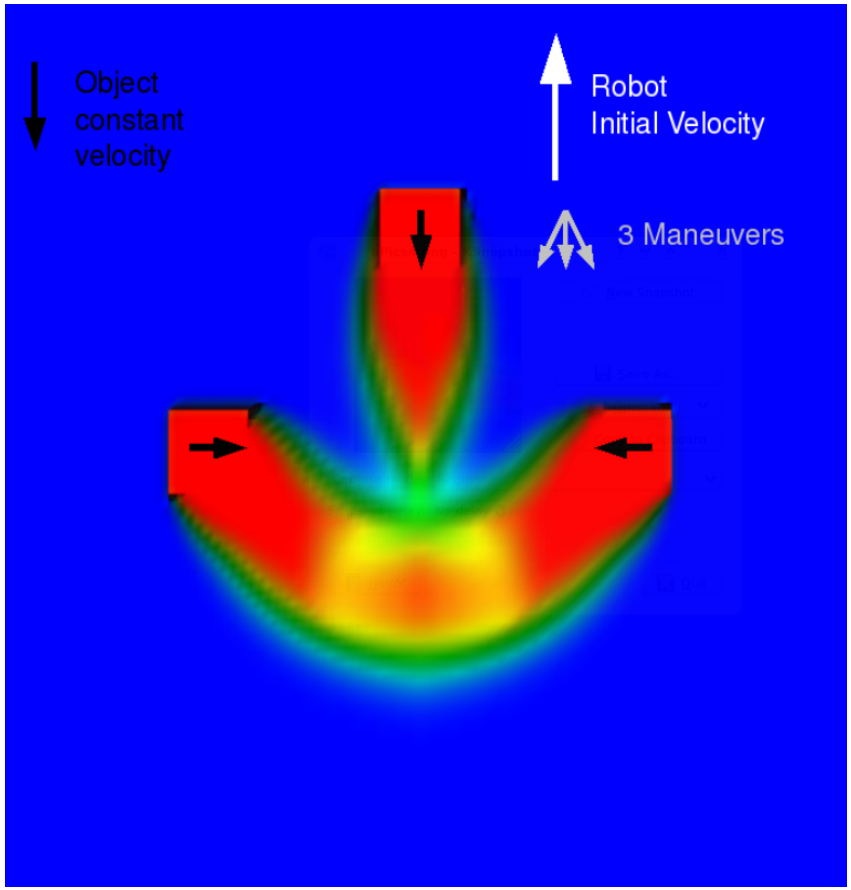
Results

The resulting probabilistic ICS set



Results

ICS set using 3 control trajectories and 3 obstacles



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Complexity issue

Starting from the obstacle trajectory, it is not know beforehand which obstacle will influence the P_{ICS} of the state we want to check.
$\longrightarrow$ compute P_{ICS} for all the states that lead to a possible collision.

$\longrightarrow$ Find a more efficient algorithm

Start from the state to be checked : Evaluate a subset of forward reachable state

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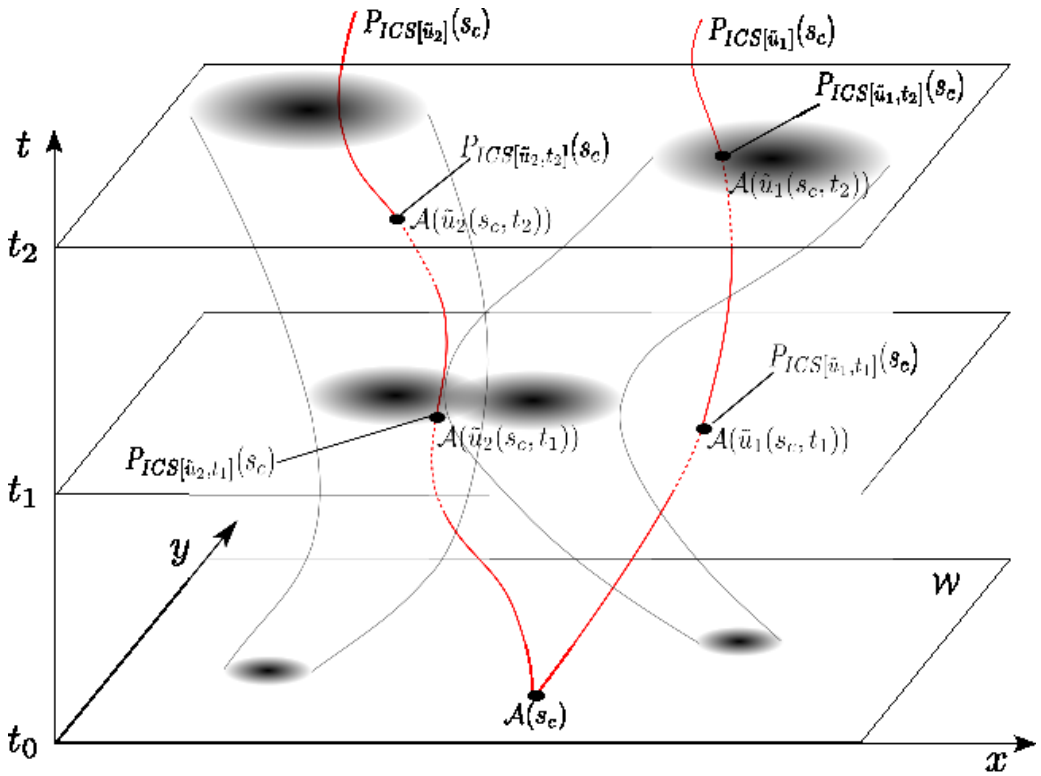
Forward Probabilistic ICS-Check Algorithm

1. Select $\mathcal{E}$
2. Compute $P_{ICS[\tilde{u}_j,t]}(s)$ for all t and every $\tilde{u}_j \in \mathcal{E}$
3. Compute $P_{ICS[\tilde{u}_j]}(s) = \bigcup_{t_0..t_{la}} P_{ICS[\tilde{u}_j,t]}(s)$ for every $\tilde{u}_j \in \mathcal{E}$
4. Compute $P_{ICS}(s_c) = \min(P_{ICS[\tilde{u}_j]}(s_c))$



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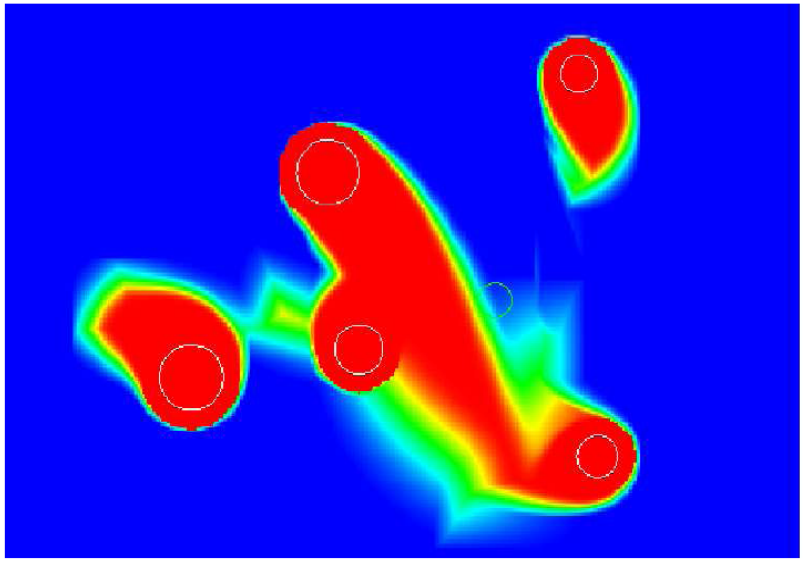
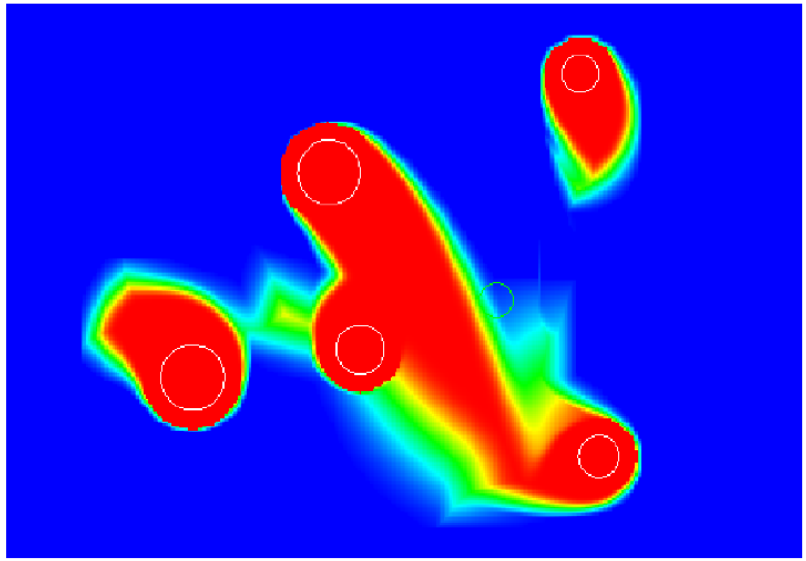
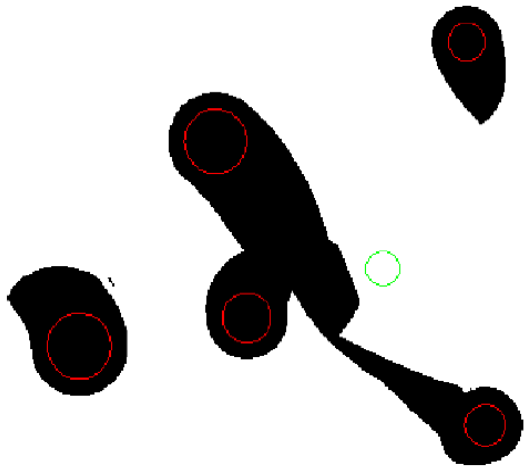
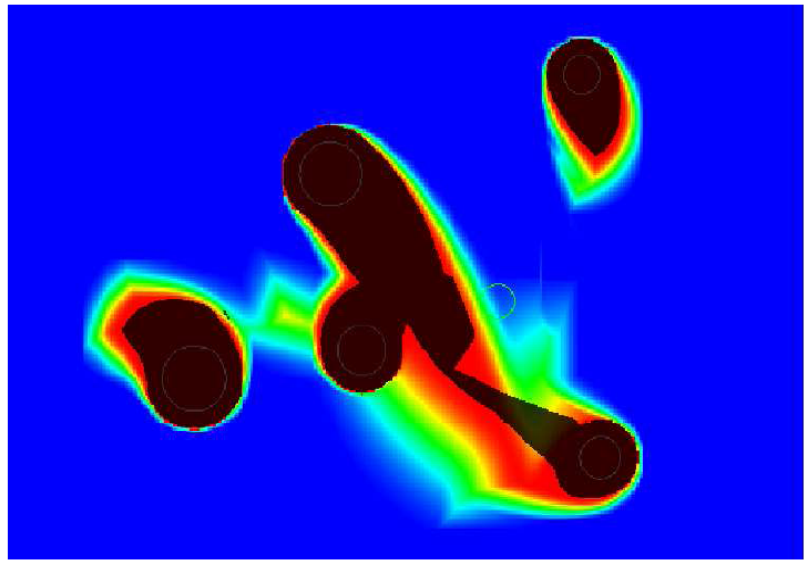
Results





Backward and Forward PICS-CHECK algorithms





ICS-CHECK and ICS-CHECK overlay on PICS-CHECK

Conclusion

Contribution:

- Probabilistic ICS formulation of the ICS concept
- Presentation of 2 Probabilistic ICS-Checkers algorithms

Backward Probabilistic ICS-Check Algorithm :

- Costly

Forward Probabilistic ICS-Check Algorithm :

- Effective

Future Works: Embedding of PICS-CHECK Algorithms in navigation schemes

1. Reactive collision avoidance like ICS-Avoid [Martinez Gomez & Fraichard, 2009]
2. Global navigation scheme

Questions?

Thank you for your attention

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