Guaranteeing Safe Navigation in Dynamic Environments

A Workshop of the IEEE Int. Conf. on Robotics and Automation

Friday May 7, 2010 – 9h00 to 12h30 in Egan Center Room 1

Thierry Fraichard, INRIA (FR) & **James Kuffner**, The Robotics Institute (US)

- Program

Motion Safety

Epilogue

Program

9h00-9h30: Guaranteeing Motion Safety in Dynamic Environments, an Introduction
Thierry Fraichard & James Kuffner

9h30-10h00: Optimal Reciprocal Collision Avoidance
Dr. Jur van den Berg, University of California, Berkeley (US)

10h00-10h30: Distributed Reactive Collision Avoidance
Dr. Emmett Lalish, University of Washington & Moiré Incorporated (US)

10h30-10h45: *Coffee Break*

10h45-11h15: The Nonlinear Velocity Obstacle Revisited: the Optimal Time Horizon
Prof. Zvi Shiller, Ariel University Center (IL)

11h15-11h45: Detecting if a Robot Trajectory is Guaranteed Continuously Collision-Free in Unknown and Unpredictable Environments
Prof. Jing Xiao, University of North Carolina, Charlotte (US)

11h45-12h15: Safety and Computational Efficiency Tradeoffs in Replanning with Sampling-based Planners
Prof. Kostas Bekris, University of Nevada, Reno (US)

12h15-12h30: Final discussion and conclusion

Guaranteeing Motion Safety in Dynamic Environments, an Introduction

- Program

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- Motivations
- Motion Safety Criteria
- Compactor Scenario
- Motion Safety
- Literature Review
- ICS-Check + Avoid
- Deterministic World Model
- Probabilistic World Model

Epilogue

Motivations

Now. . .

- Factory Robotics

Caged robots!

Motivations

In the future. . .

- Service/Personal Robotics
- Intelligent Transport Systems (ITS)

Robots and humans living together!

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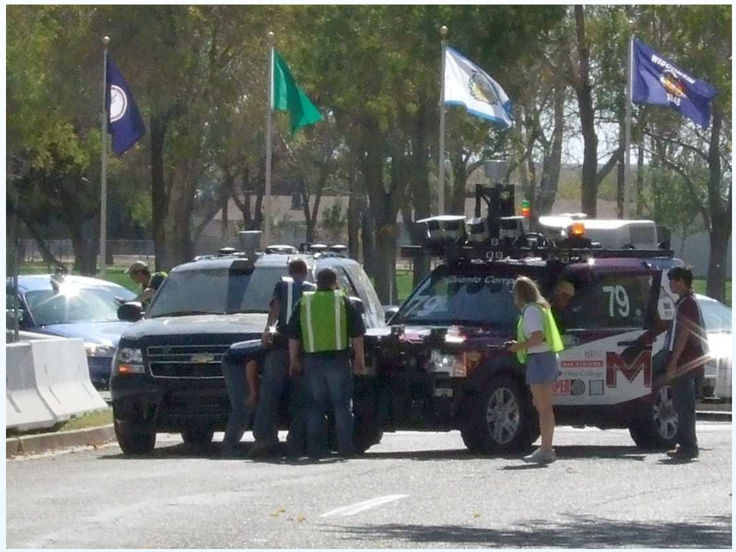
Safe Navigation? Hum. . . Not Yet

DARPA Urban Challenge *[Nov. 2007]*



Robots are potentially dangerous $\rightsquigarrow$ Motion Safety issue. . .

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Moving Safely in Dynamic Environments

Why do collisions occur?

1. Hardware failure
2. Software bugs
3. “Mis-understanding”
4. “Mis-reasoning”

Motion safety criteria for dynamic environments *[Fraichard 07]*:

Key aspect: time {
1. Reasoning about the future
2. Appropriate lookahead
3. Decision time constraint

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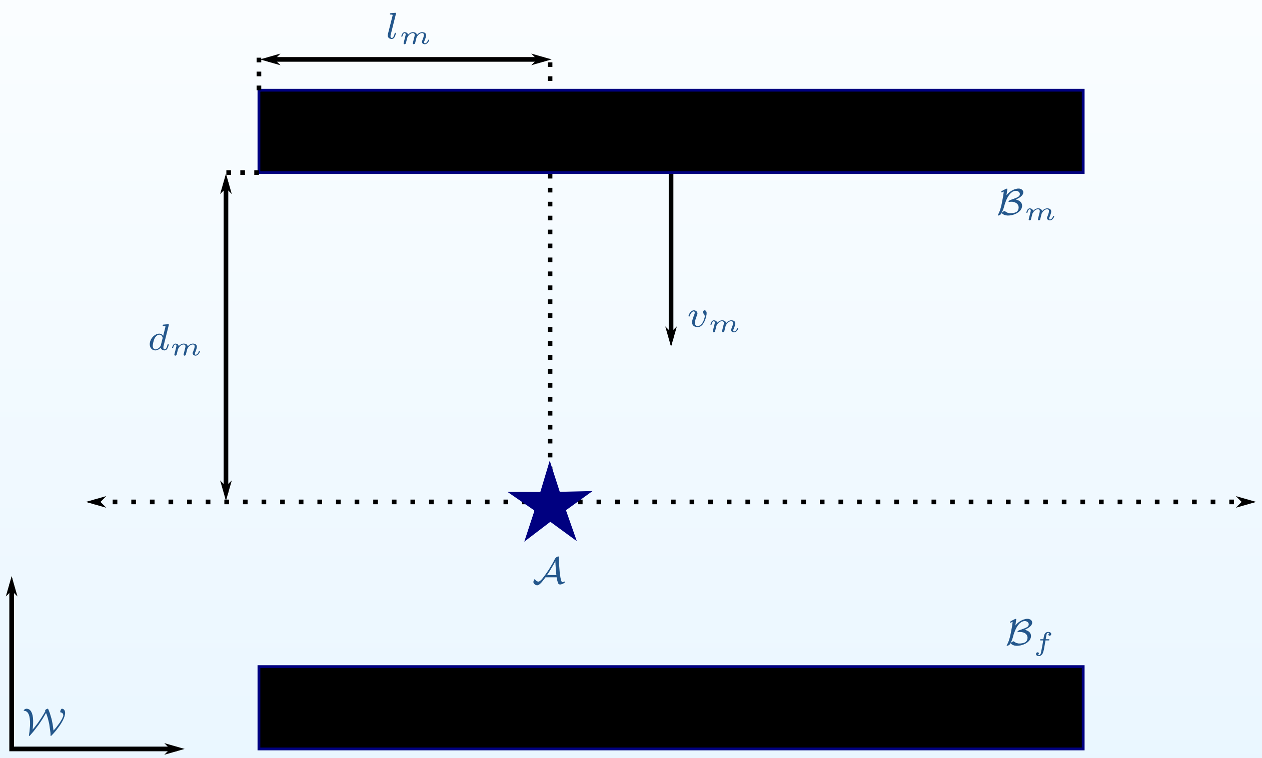
“Compactor” Scenario



$$\mathcal{A} : s = p \in [0,1], u = v \in [-v_{\max}, v_{\max}], \dot{s} = u$$

Time to collision: $t_c = d_m / v_m$

$\leadsto$ Collision condition: minimum time to escape $t_e = l_m / v_{\max} > t_c$

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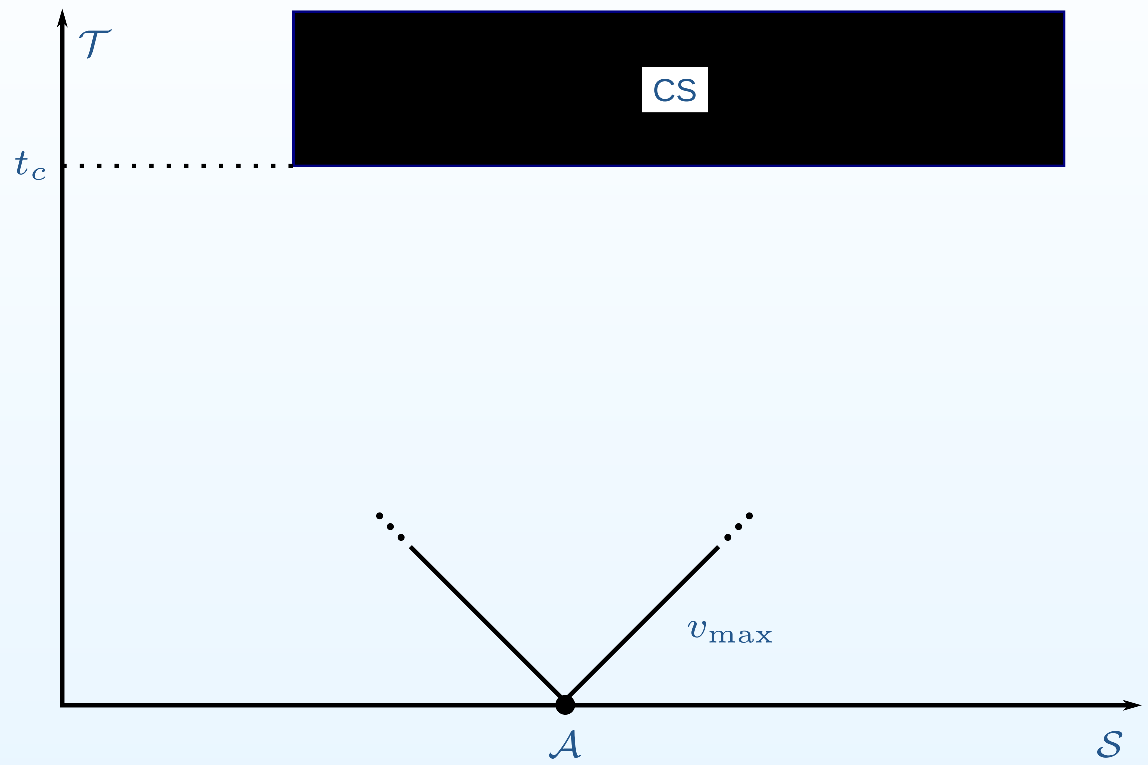
“Compactor” Scenario: Reasoning about the Future

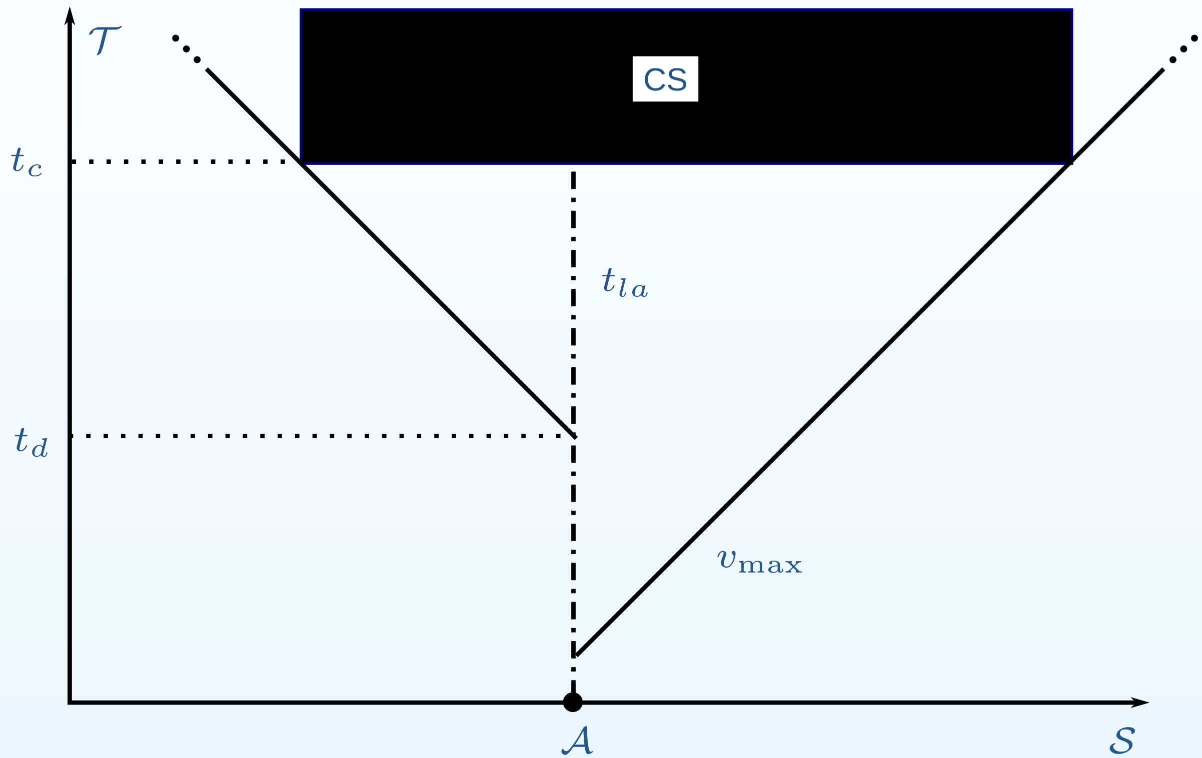


1. Reasoning about the future: Space $\times$ Time reasoning

- Configuration $\times$ Time space *[Erdmann & Lozano-Perez 87]*
- State $\times$ Time Space *[Fraichard 92]*

– Future behaviour of the moving objects
– Robot’s dynamics (reachable states)

"Compactor" Scenario: Lookahead & Decision Time



2. Appropriate lookahead $t_{la} > t_e$
3. Decision time constraint $t_d < t_c - t_e$

} f(environment)

Key issue: t_{la} (resp. t_d) arbitrarily large (resp. small)

e.g. $v_m \to 0$ and $l_m \to \infty \Rightarrow t_{la} \to \infty$

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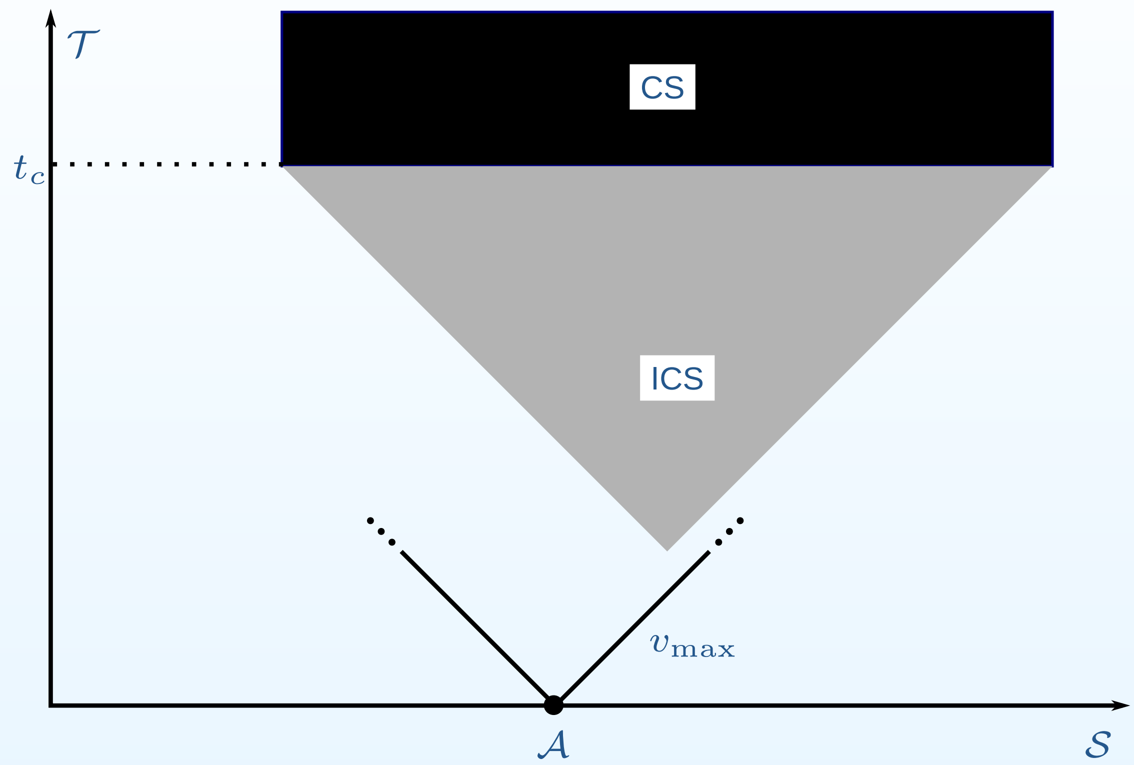
"Compactor" Scenario: Inevitable Collision States



From Collision States to Inevitable Collision States: whatever the future trajectory followed by the robot, a collision eventually occurs *[Fraichard 03]*

Similar concepts: Obstacle Shadow *[Reif & Sharir 85]*, Region of Inevitable Collision, *[Lavalle & Kuffner 99]*, Viable Kernels *[Aubin 91]*, Backward Reachable Sets *[Mitchell & Tomlin 02]*

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Moving Safely in Dynamic Environments

Key aspect: time {
1. Reasoning about the future
2. Appropriate lookahead
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The Three Laws of motion safety. . .

Q: how to guarantee motion safety, *i.e.* never ending up in a situation where a collision eventually occurs?

A: avoid Inevitable Collision States

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A Little Bit of History

World models used:

1. “Quasi-static” / “Frozen world” assumption: Potential Field *[]Khatib 86*, , Dynamic Window *[Fox etal 97]*, Nearness Diagram *[Minguez & Montano 00]*, Vector Field Histogram *[Ulrich & Borenstein 00]*
2. Reasoning about the future: Velocity Obstacle *[Fiorini & Shiller 98]*, Dynamic Window++ *[Seder & Petrovic 07]*, Urban Challenge 07
3. Lookahead issue remains largely untouched

Ways to “ensure” safety should a problem arise:

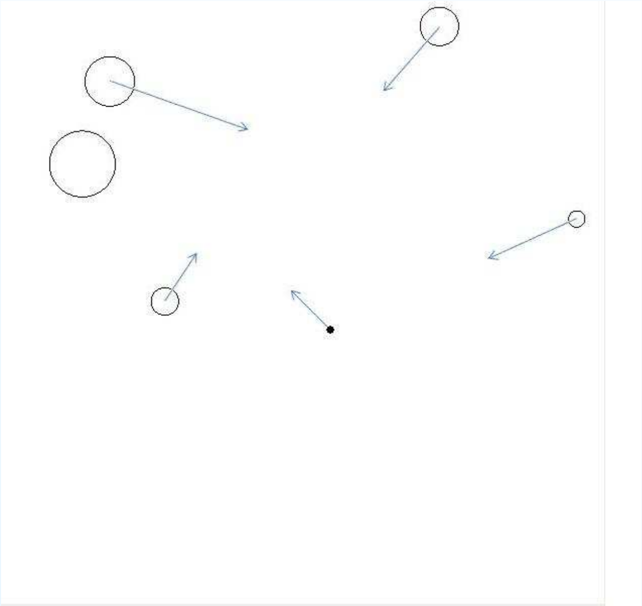
1. Reactivity:
   ... No problem, I can react fast
2. τ-safety:
   ... I take you there safely, then you have time τ to find a solution
3. Evasive trajectories:
   ... No problem, I have a backup plan

$\rightsquigarrow$ Guaranteed motion safety not there yet...

From ICS-Check to ICS-Avoid *[Martinez & Fraichard 08-09]*

ICS-Check: generic and efficient ICS-checker for planar robots

- Deterministic model of the future
- Appropriate lookahead



Car-like robot: $s = (x, y, \theta, v, \xi); u = (\dot{v}, \dot{\xi})$

ICS-Avoid: first provably safe collision avoidance scheme but *wrt* the model of the future used

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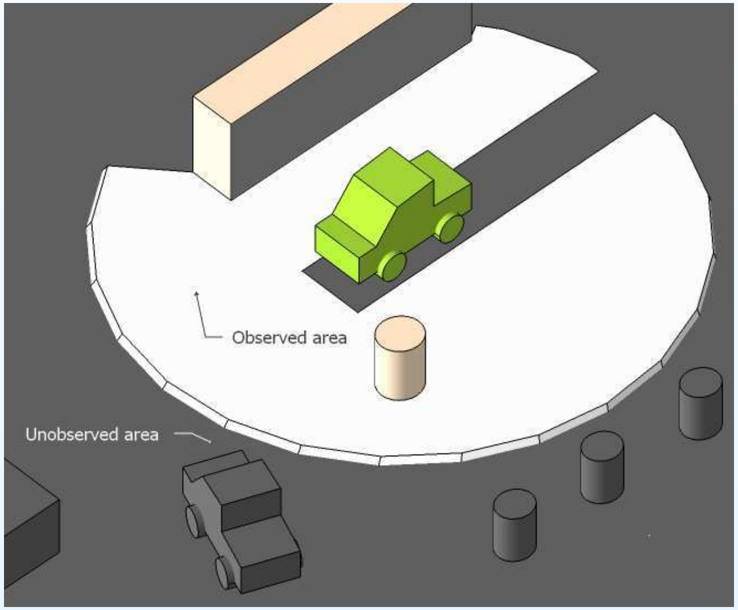
First Assessment of the Situation

Is ICS-based collision avoidance the answer to motion safety?

In theory, yes. One caveat though: omniscience required!



How to deal with incomplete information / uncertainty?

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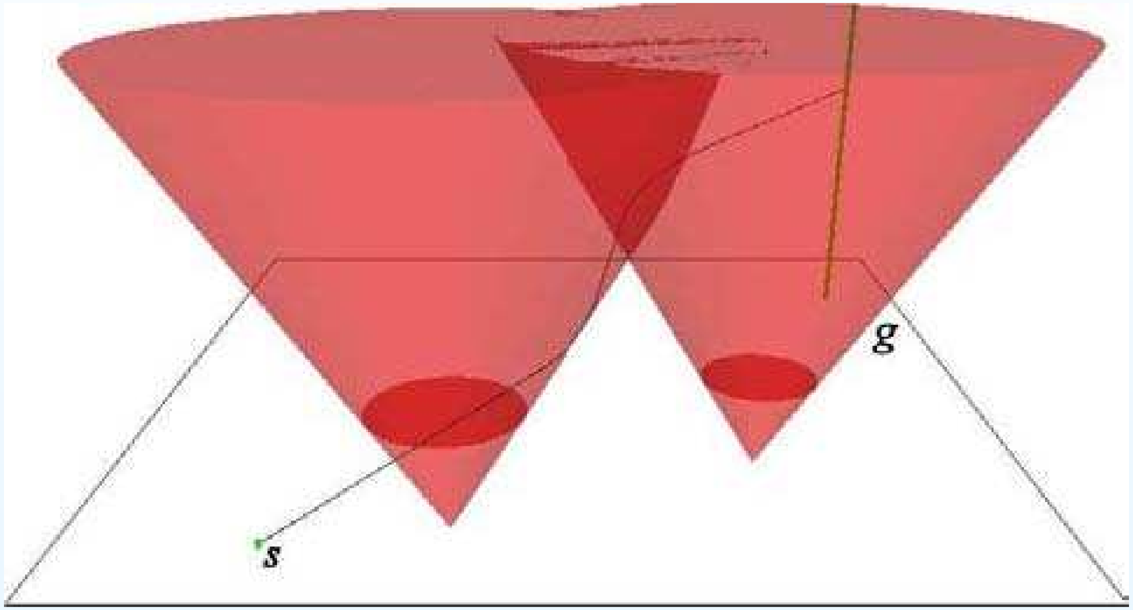
Deterministic Model

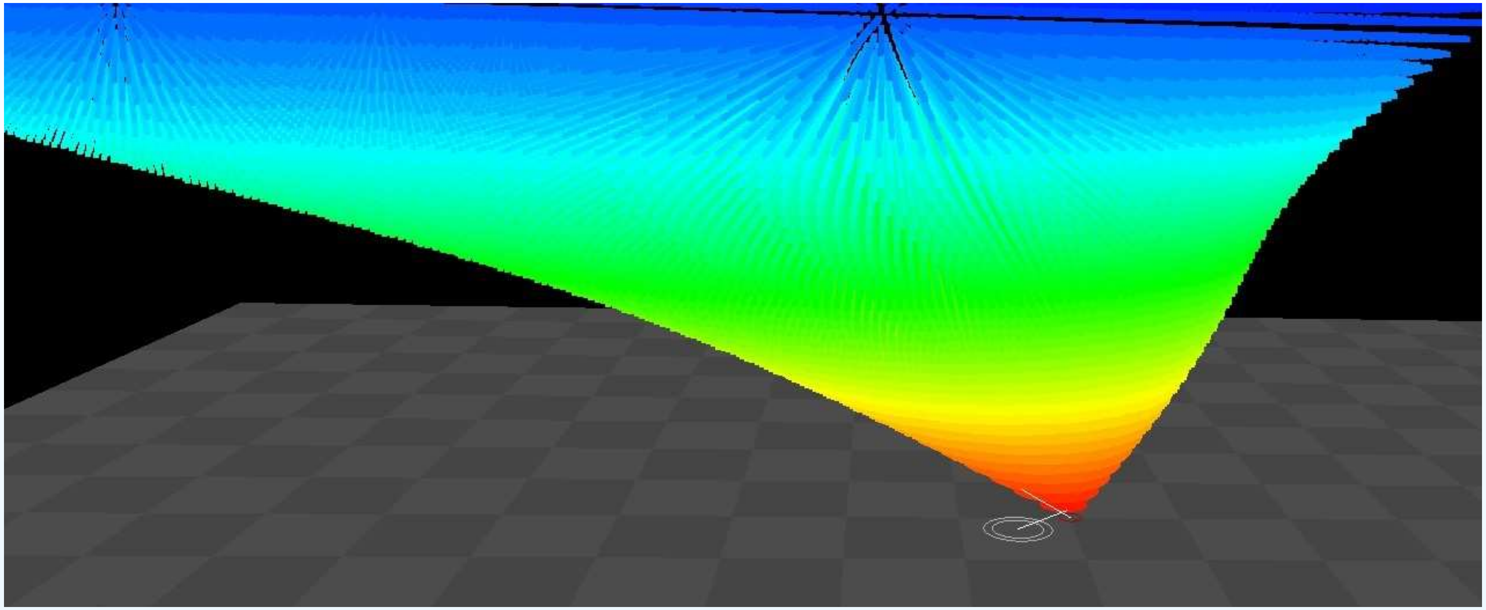
Nominal motion $\leadsto$ No safety



To be safe, be conservative *[Van den Berg 07, Vatcha & Xiao 08]*

Obstacles everywhere eventually $\leadsto$ ICS everywhere. . .

Probabilistic Model



Obstacles vanish eventually $\rightsquigarrow$ Lookahead *[Kushleyev & Likhachev 09]*

Uncertainty taken into account but ICS lost $\rightsquigarrow$ Probabilistic ICS *[Althoff etal 10; Bautin & Fraichard 10]*

● Program

Motion Safety

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● Program

Final Assessment of the Situation

Is absolute motion safety achievable in open & dynamic environments?

Maybe not. . .

Is probabilistic motion safety sufficient?

Maybe not. . .

What can be done then?

Weaker levels of motion safety, *e.g.* “Passive Safety”, “Friendly Passive Safety” *[Macek & Fraichard 08]*

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