Confidence-aware motion prediction for real-time collision avoidance

Andrea Bajcsy

Long-term Human Motion Prediction Workshop

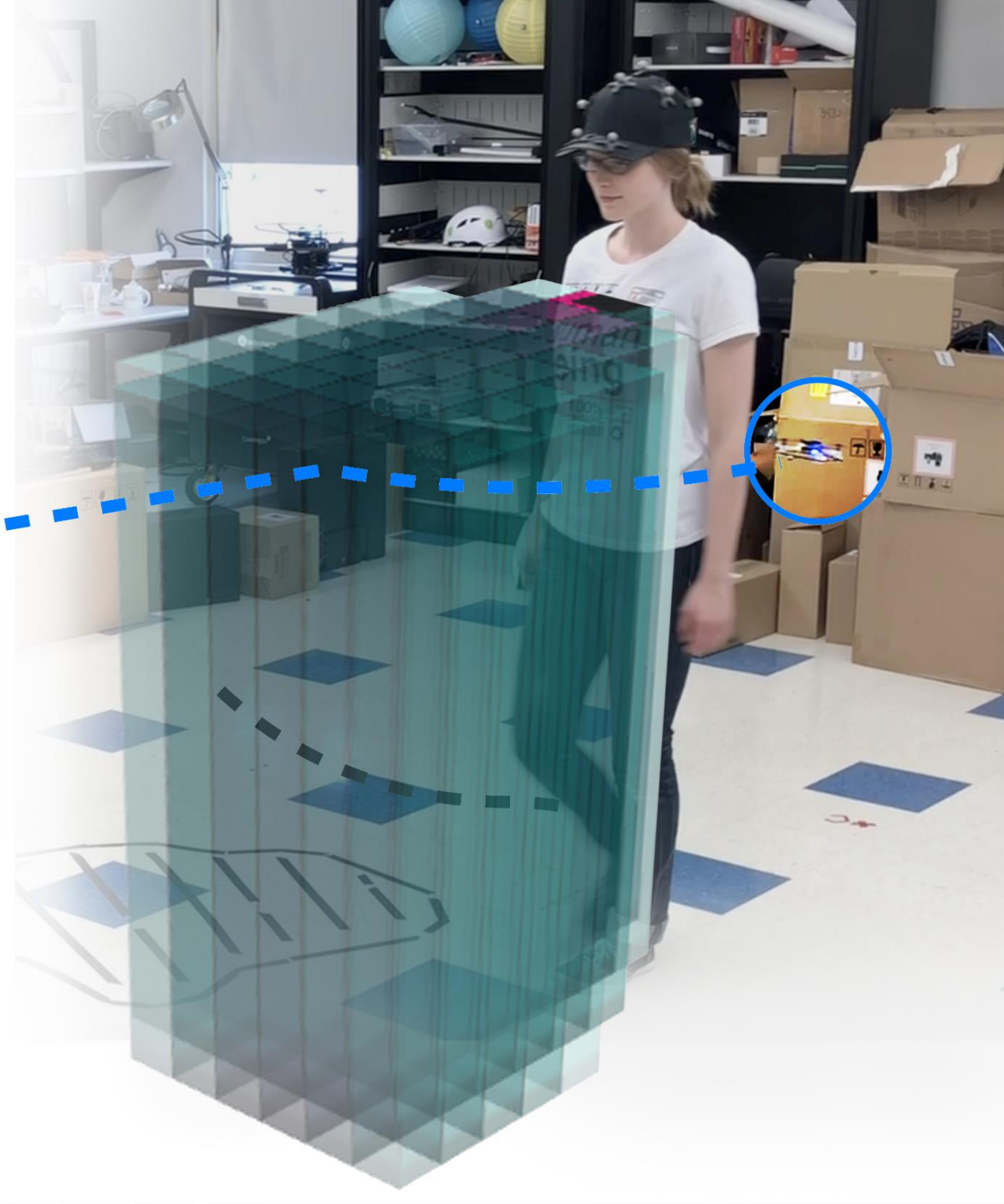
ICRA 2019

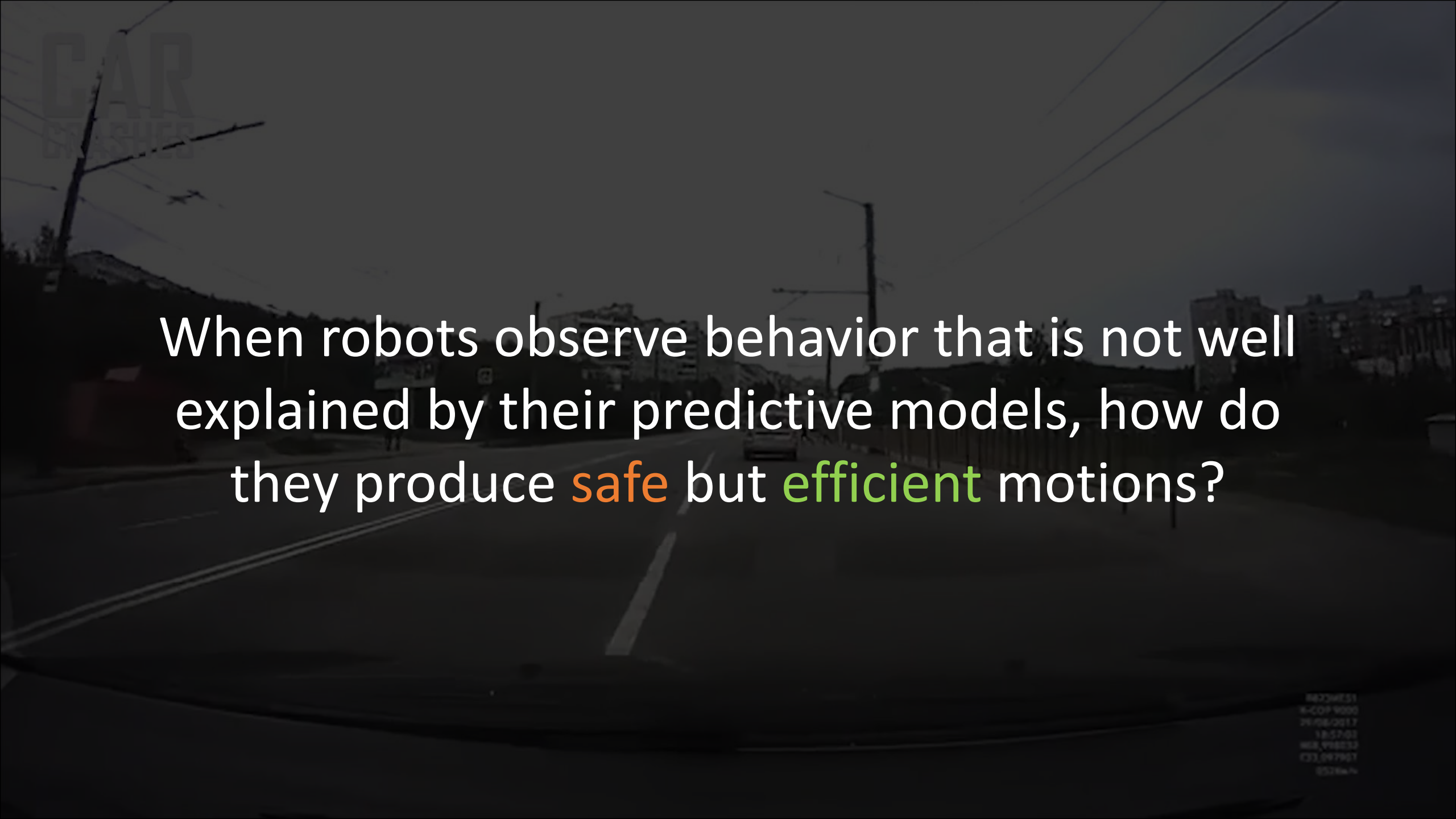
Work with Sylvia Herbert, Jaime Fisac, David Fridovich-Keil, Steven Wang, Sampada Deglurkar, Claire Tomlin and Anca Dragan

InterACT Laboratory

BAIR BERKELEY ARTIFICIAL INTELLIGENCE RESEARCH

Hybrid Systems Lab



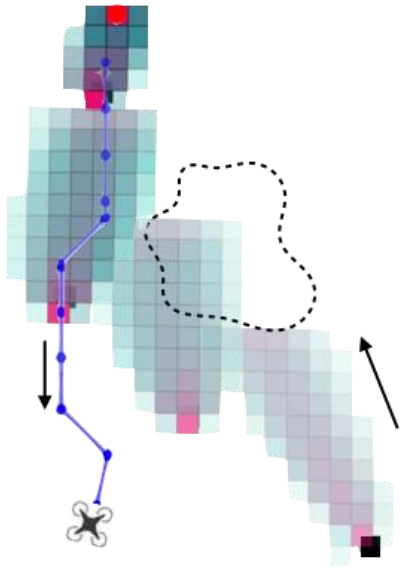

When robots observe behavior that is not well explained by their predictive models, how do they produce safe but efficient motions?

Confidence-aware prediction & planning

Connections to reachability analysis

Scaling up to multi-robot, multi-human scenarios

Confidence-aware prediction & planning

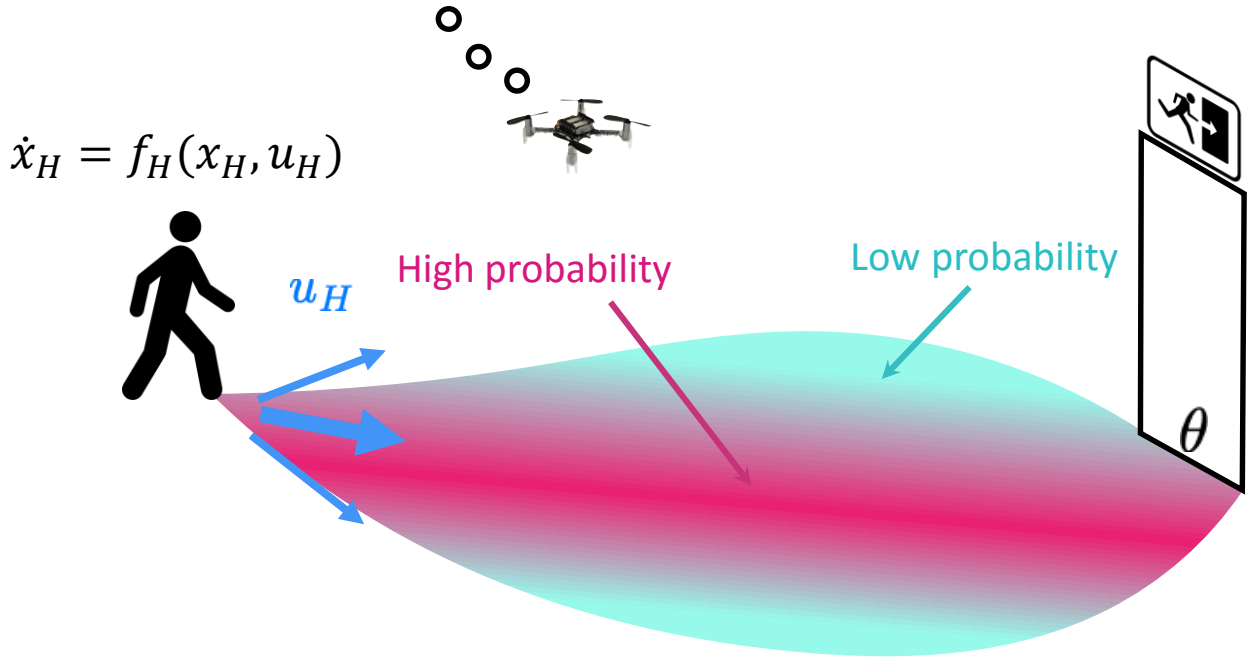


Connections to reachability analysis

Scaling up to multi-robot, multi-human scenarios

Noisily-Rational Human Motion Prediction

$$P(u_H \mid x_H; \theta, \beta) \propto e^{\beta Q(x_H, u_H; \theta)}$$



[Luce, 1959]

[Baker et al., 2007]

[Schultz et al., ICRA 2017]

[Pfeiffer et al., IROS 2016]

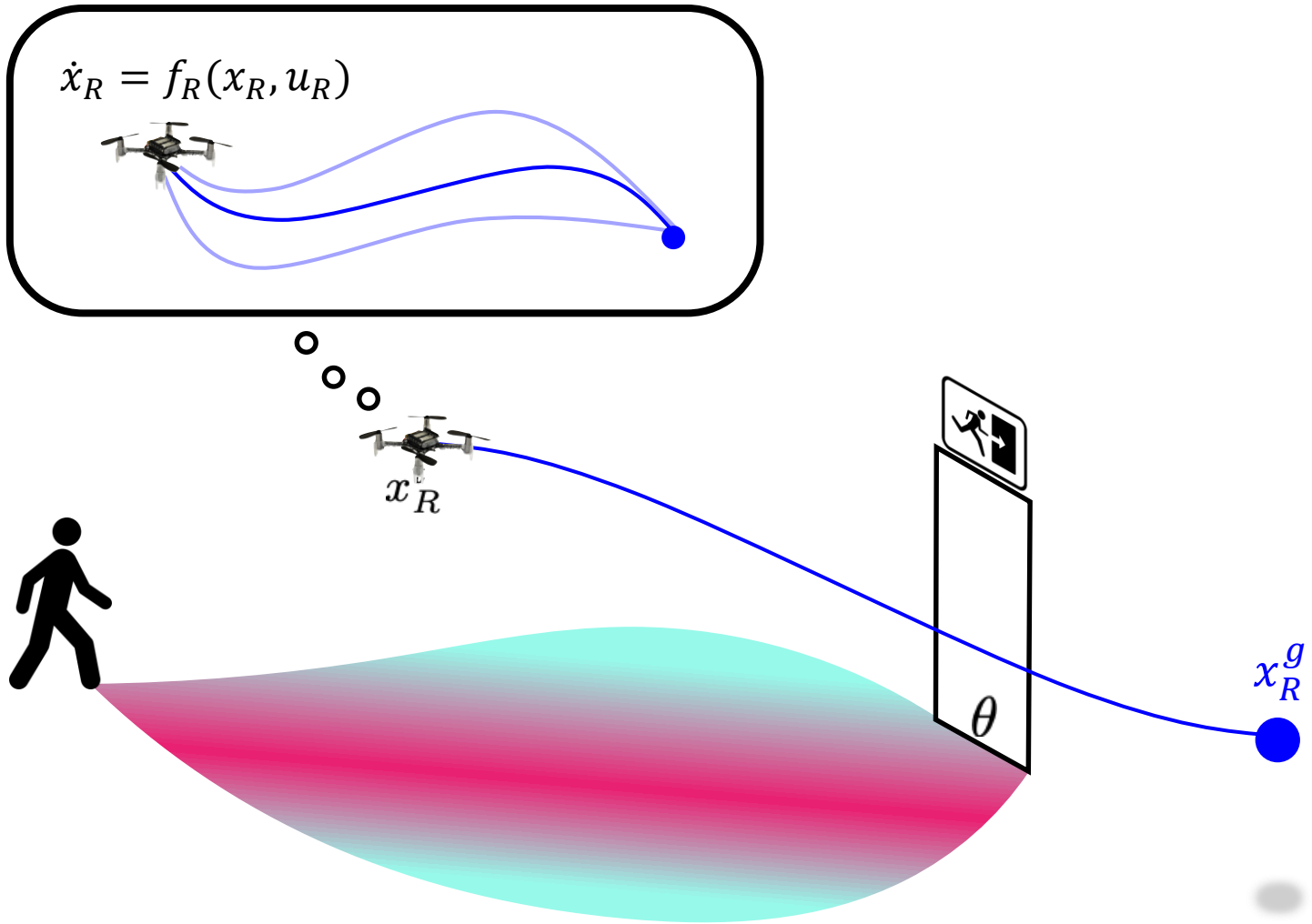
[Finn et al., ICML 2016]

[Herman et al., ICRA 2015]

[Ziebart et al., AAAI 2008]

[Ramachandran et al., IJCAI 2007]

Robust Robot Planning with Human Predictions



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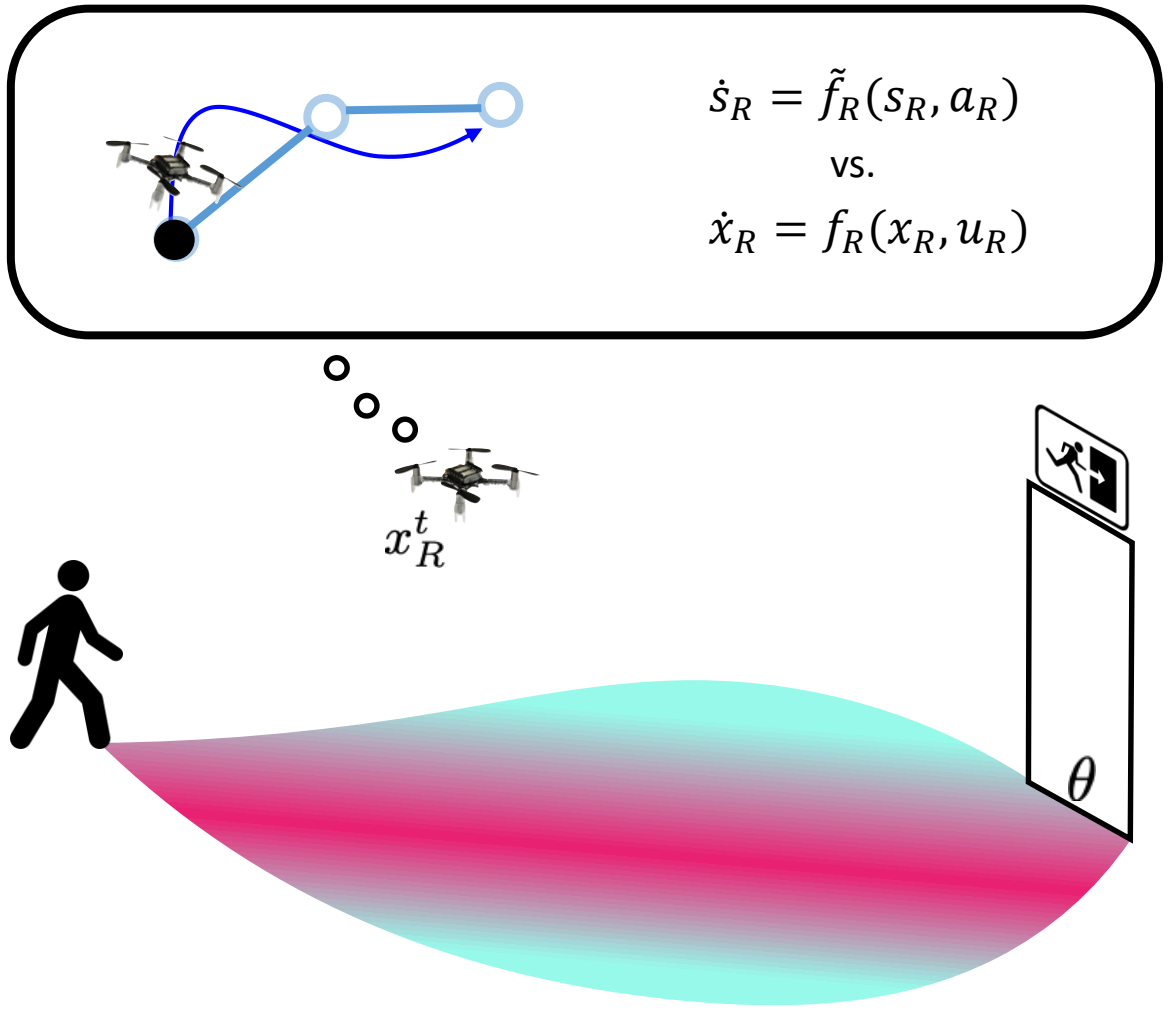

[Lygeros, 2005]

[Mitchell, 2005]

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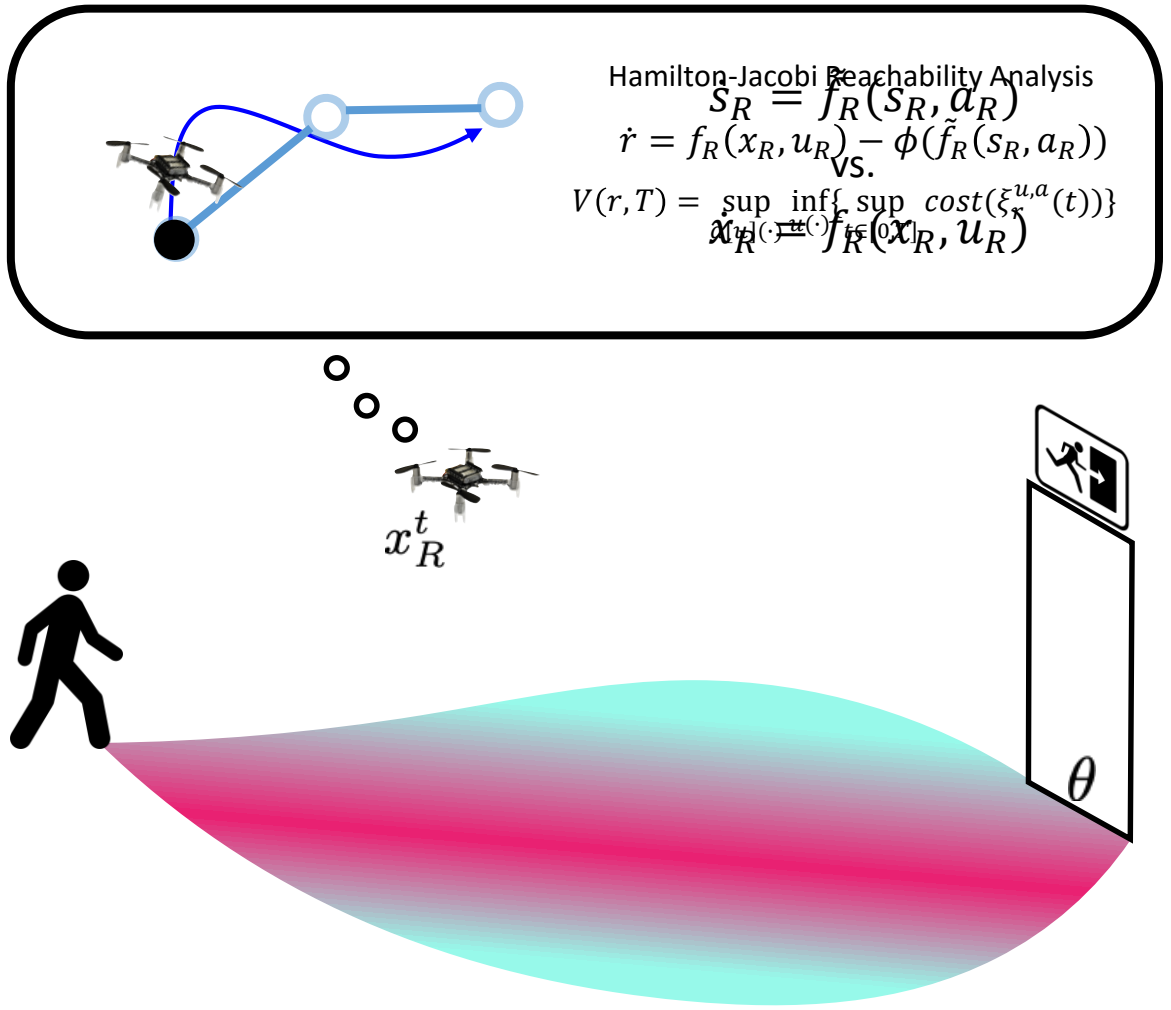

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[Herbert, Chen*, Han, Bansal, Fisac, Tomlin. "FaSTrack: a Modular Framework for Fast and Guaranteed Safe Motion Planning." CDC, 2017.]

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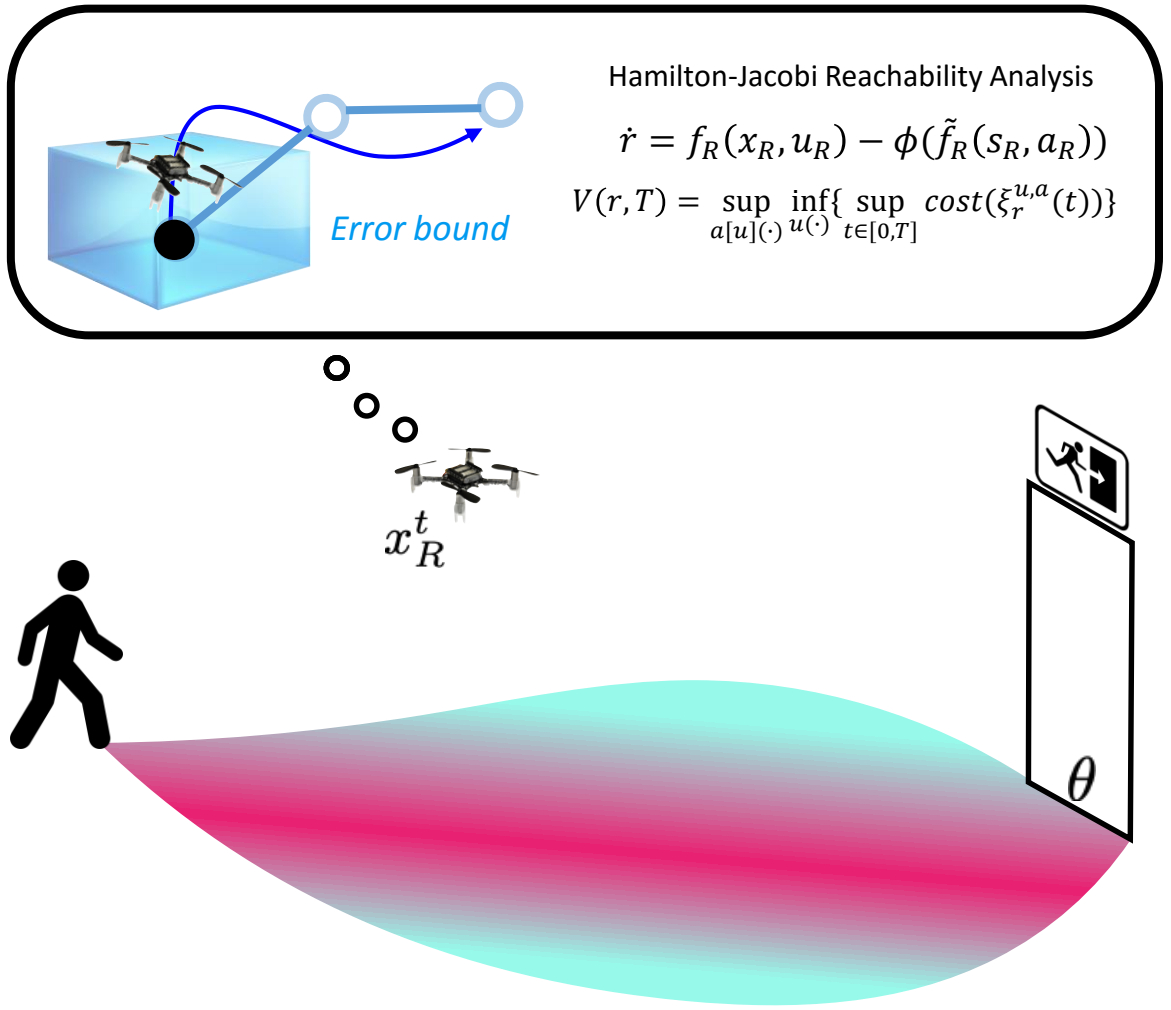

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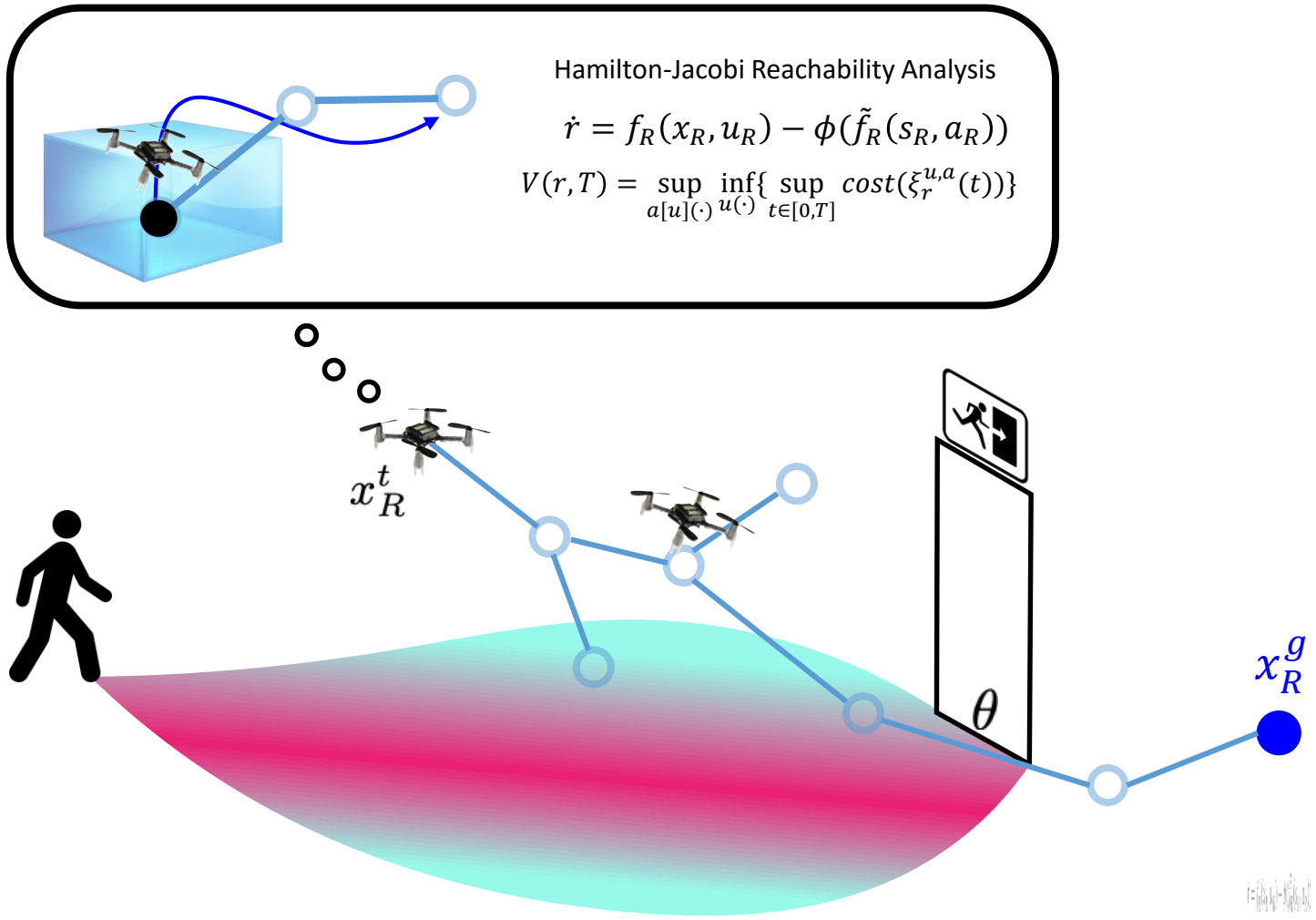

[Fisac, 2018]

[Lygeros, 2005]

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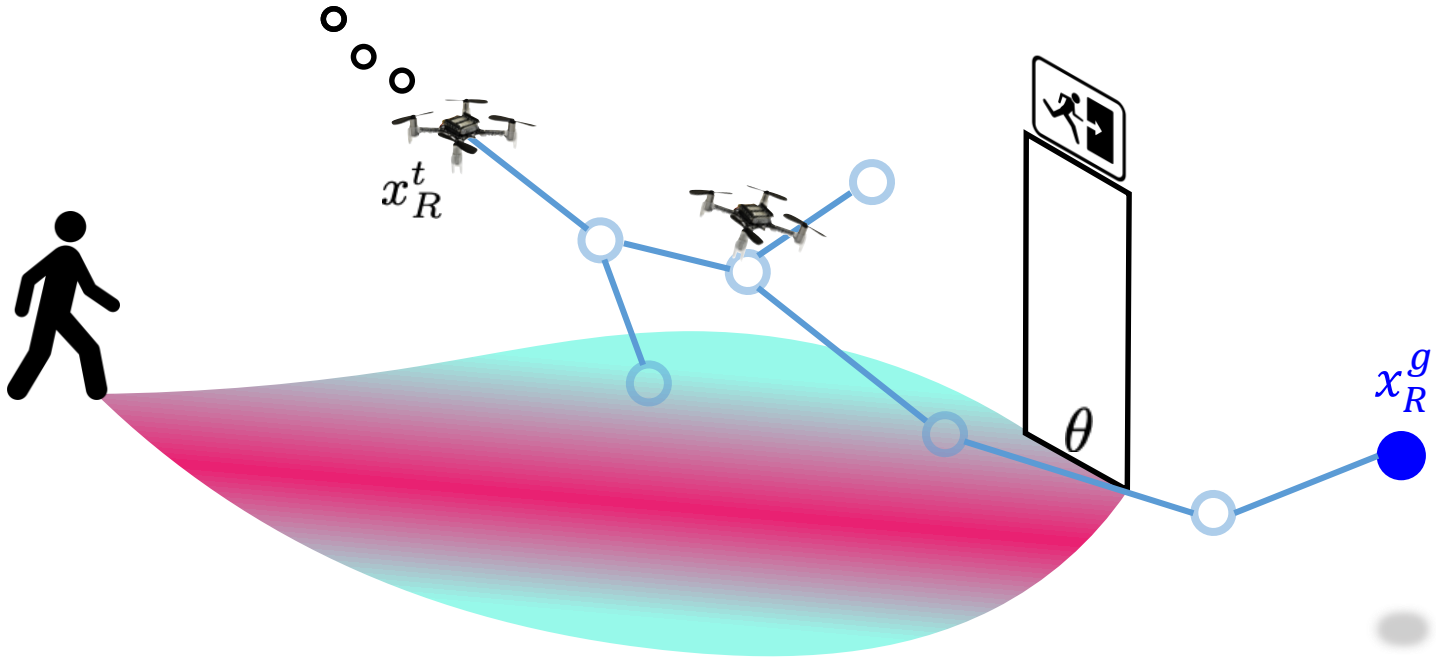
Robust Robot Planning with Human Predictions

$$P(\text{Crash}(\text{  })) > collision_{thresh}$$



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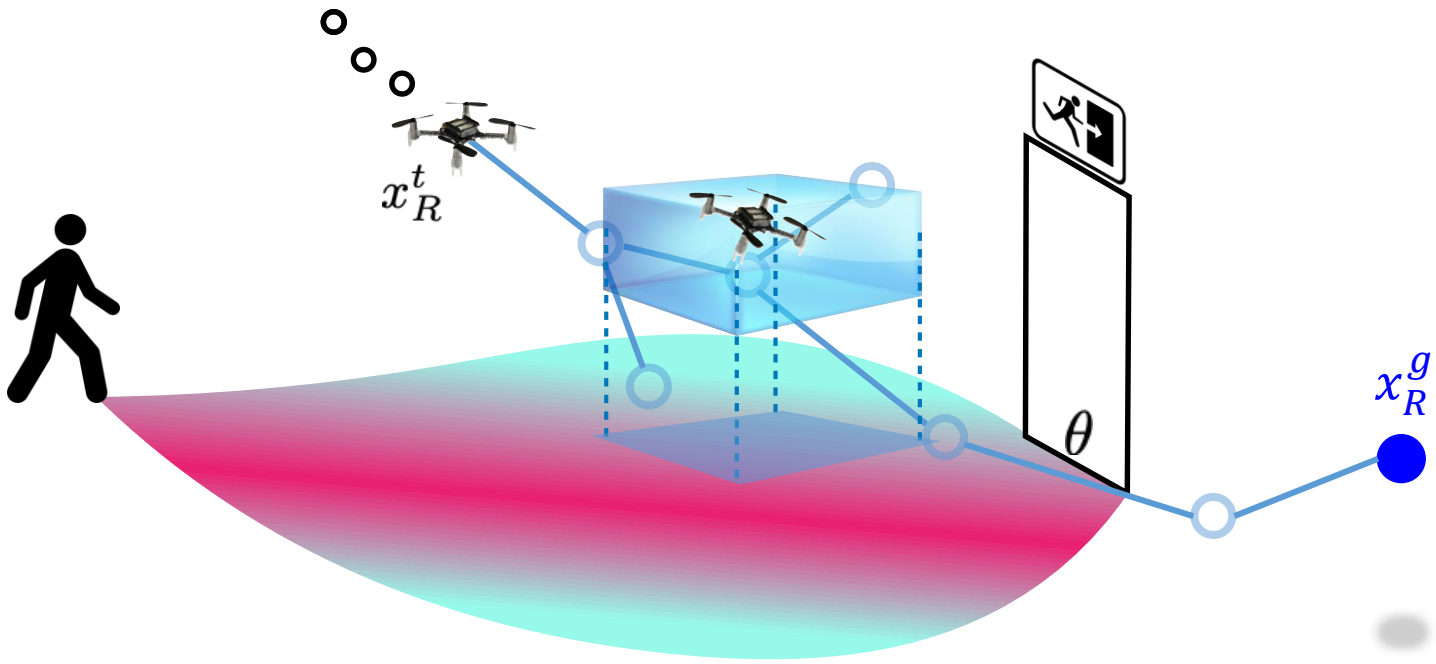

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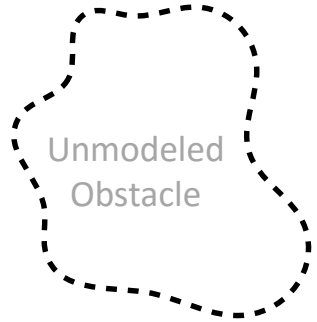
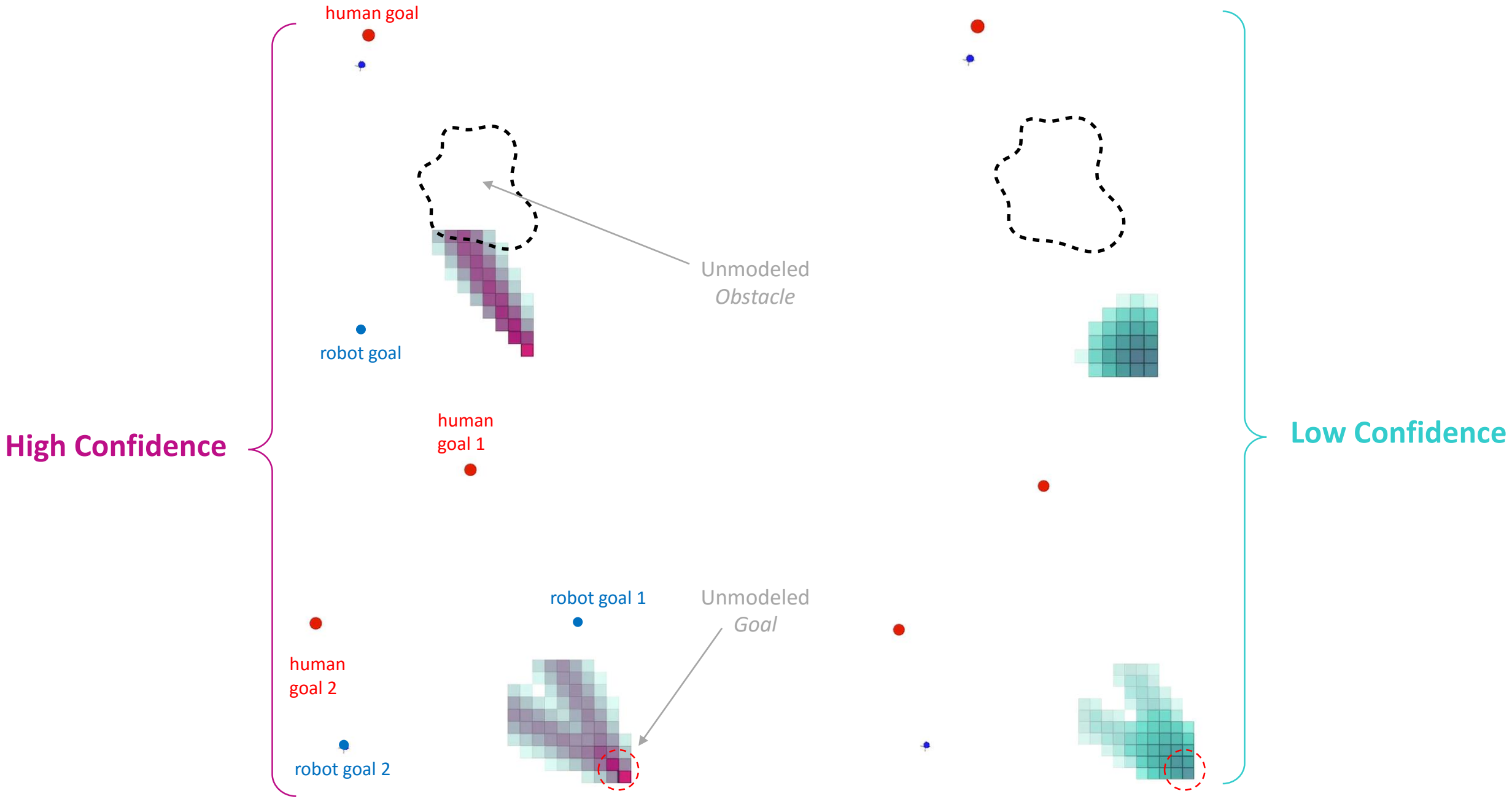
What if the predictive model is *wrong*?

Modeled
human goal

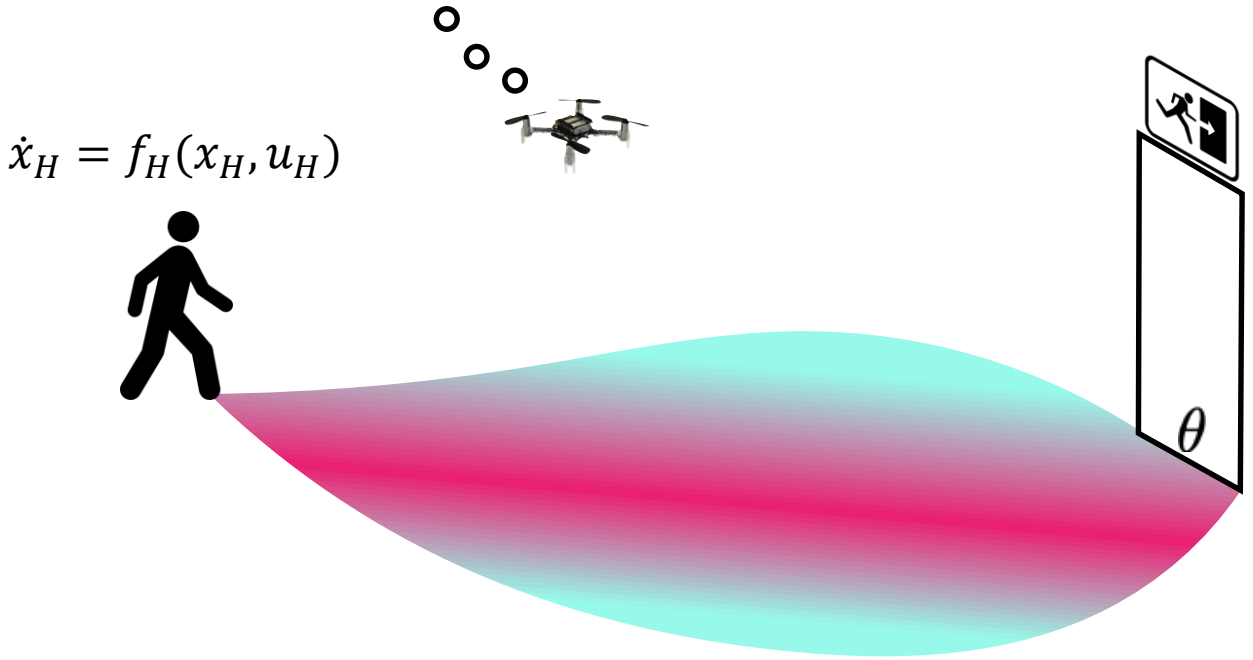


Robot goal


human goal
robot goal
Unmodeled
Obstacle
human
goal 1
High Confidence
robot goal 1
Unmodeled
Goal
human
goal 2
robot goal 2
Low Confidence

Bayesian Model Confidence

$$P(u_H \mid x_H; \theta, \beta) \propto e^{\beta Q(x_H, u_H; \theta)}$$



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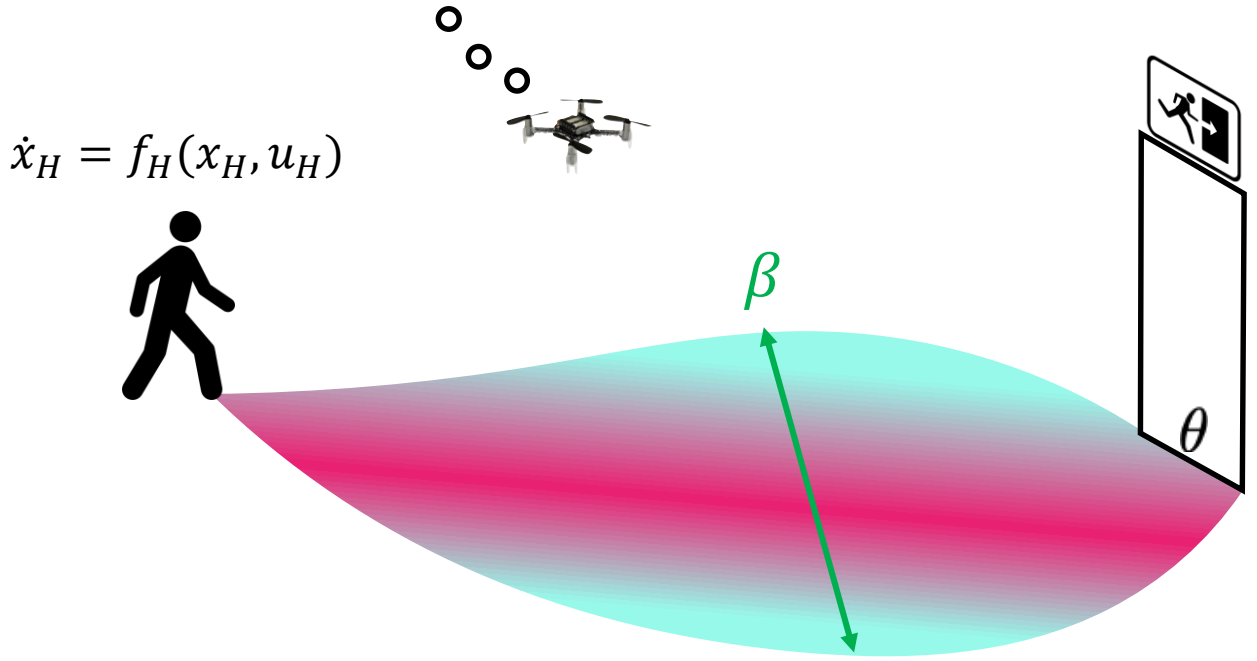

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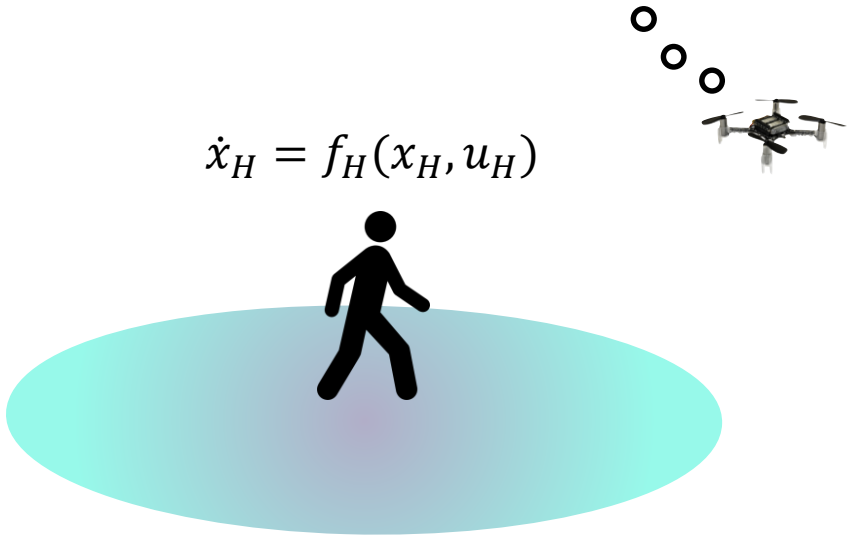

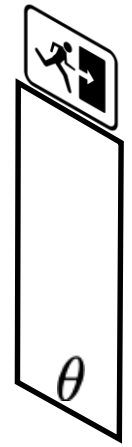

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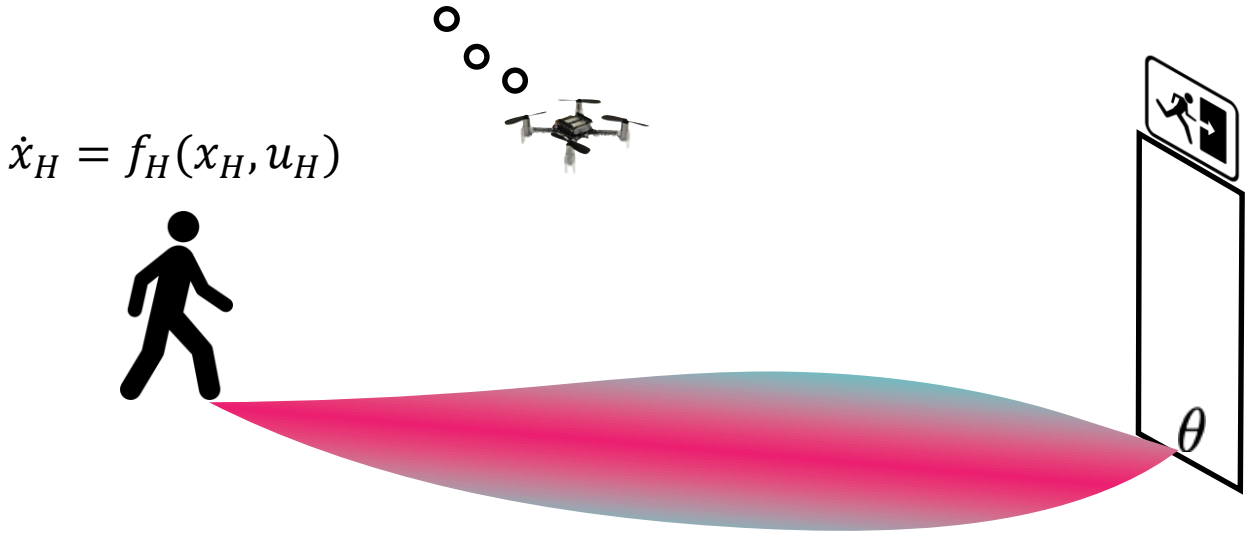
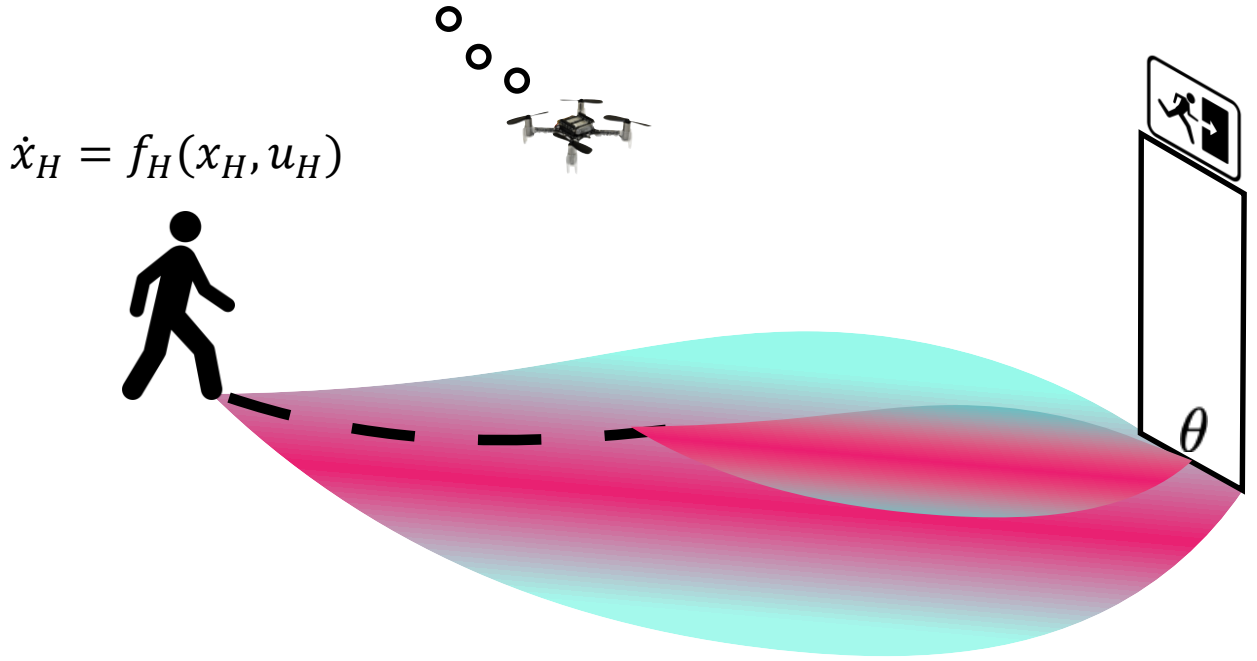


Bayesian Model Confidence

$$b^t(\beta) \propto P\left(u_H^t \,\middle|\, x_H^t; \theta, \beta\right) b^{t-1}(\beta)$$



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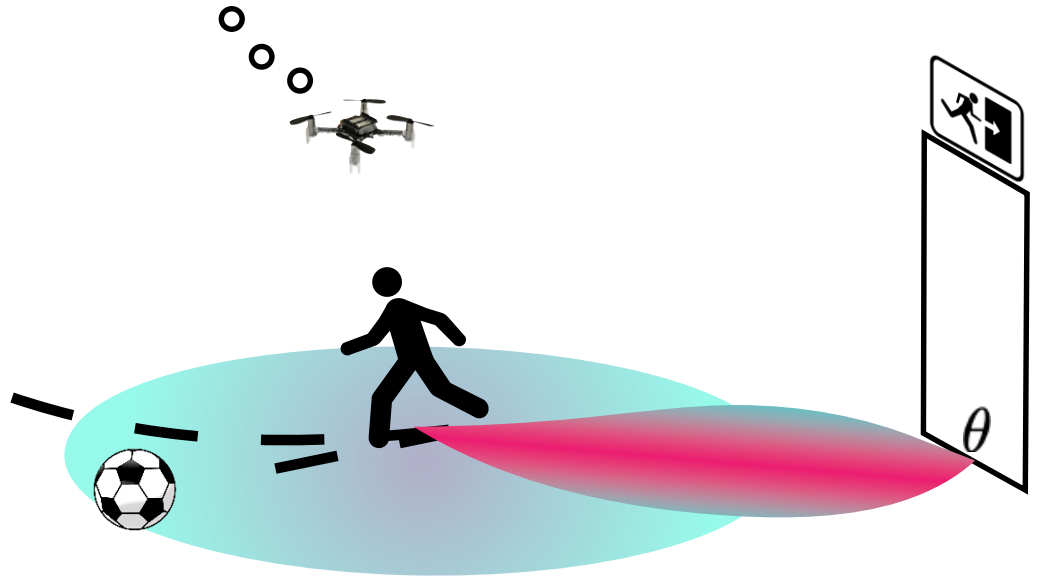
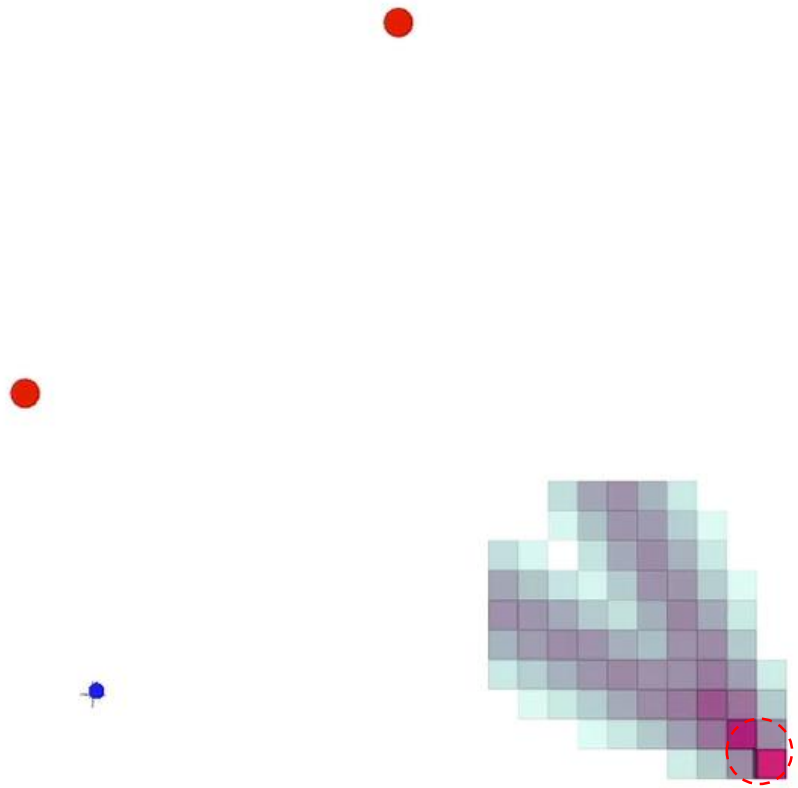
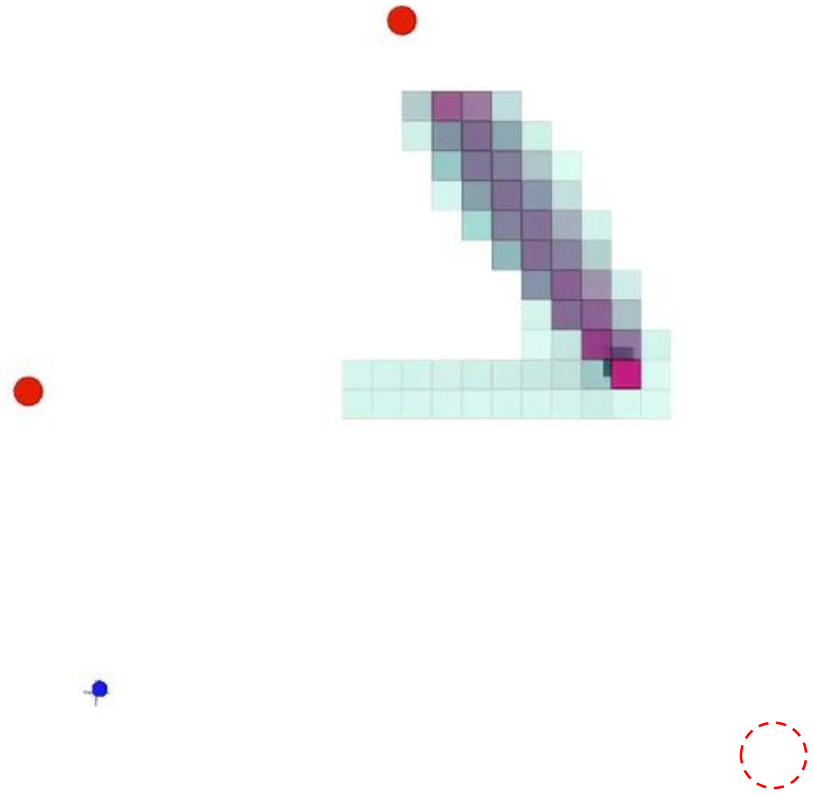


Fixed confidence $\overline{\beta}$



Bayesian confidence $b^t(\beta)$

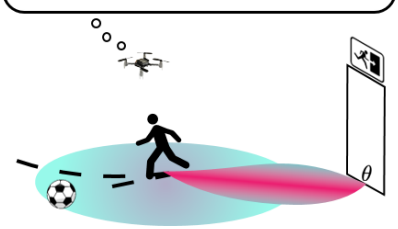


More confident!

Less confident!

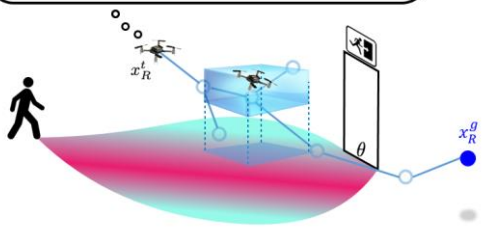
Confidence-aware prediction

$$b^t(\beta) \propto P\left(u_H^t \,|x_H^t; \theta, \beta\right) b^{t-1}(\beta)$$



Robust motion planning

$$P\left(\text{Crash}(\quad)\right) > collision_{thresh}$$



Connections to reachability analysis

Scaling up to multi-robot, multi-human scenarios

Confidence-aware prediction

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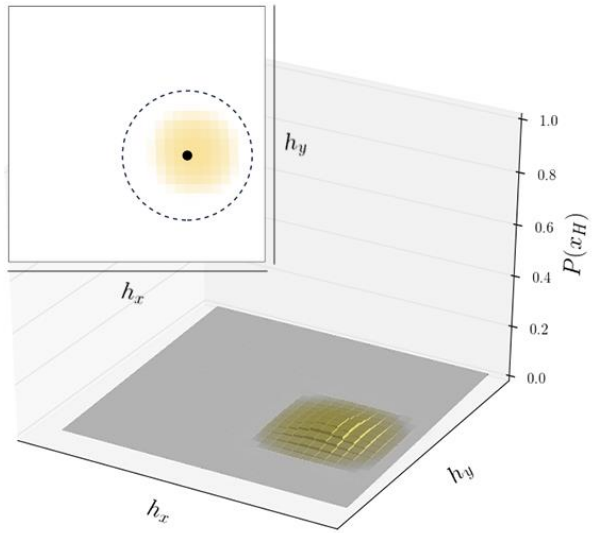
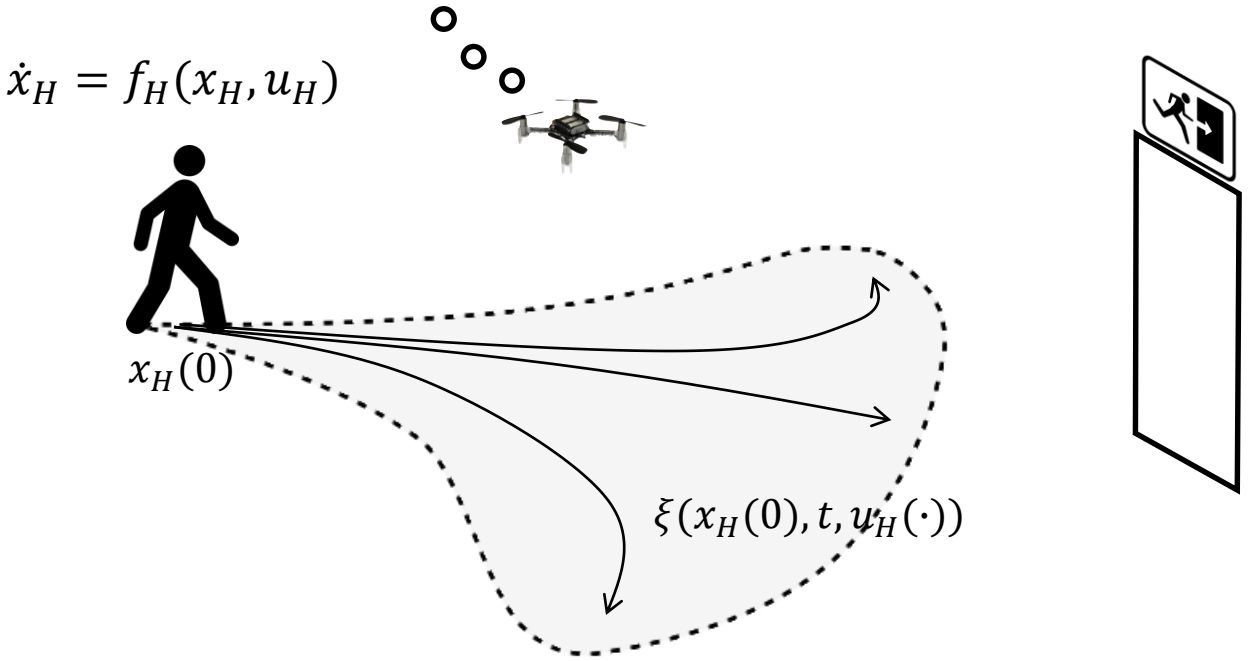


Scaling up to multi-robot, multi-human scenarios

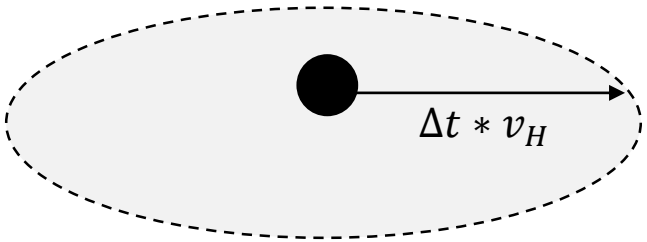
Forward Reachable Set

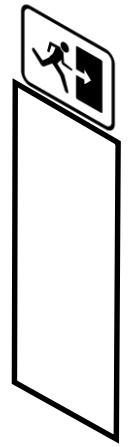
$$FRS(x_H, t) \coloneqq \{x' \colon \exists u_H(\cdot), x' = \xi(x_H, t, u_H(\cdot))\}$$



Forward Reachable Set

$$\dot{h}_x = v_H \cos(u_H)$$
$$\dot{h}_y = v_H \sin(u_H)$$





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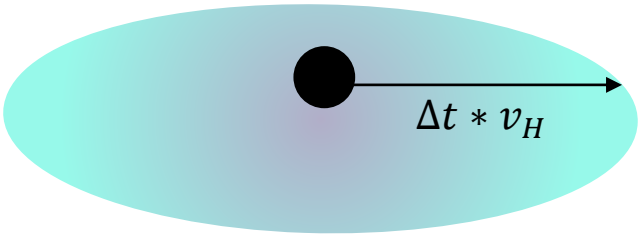

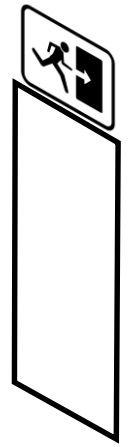

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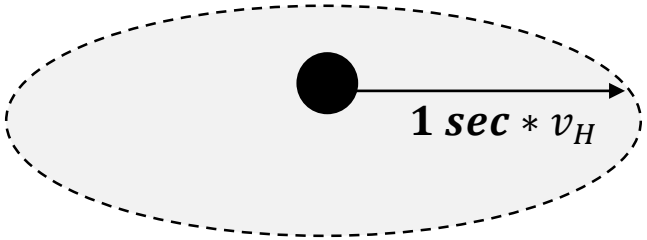

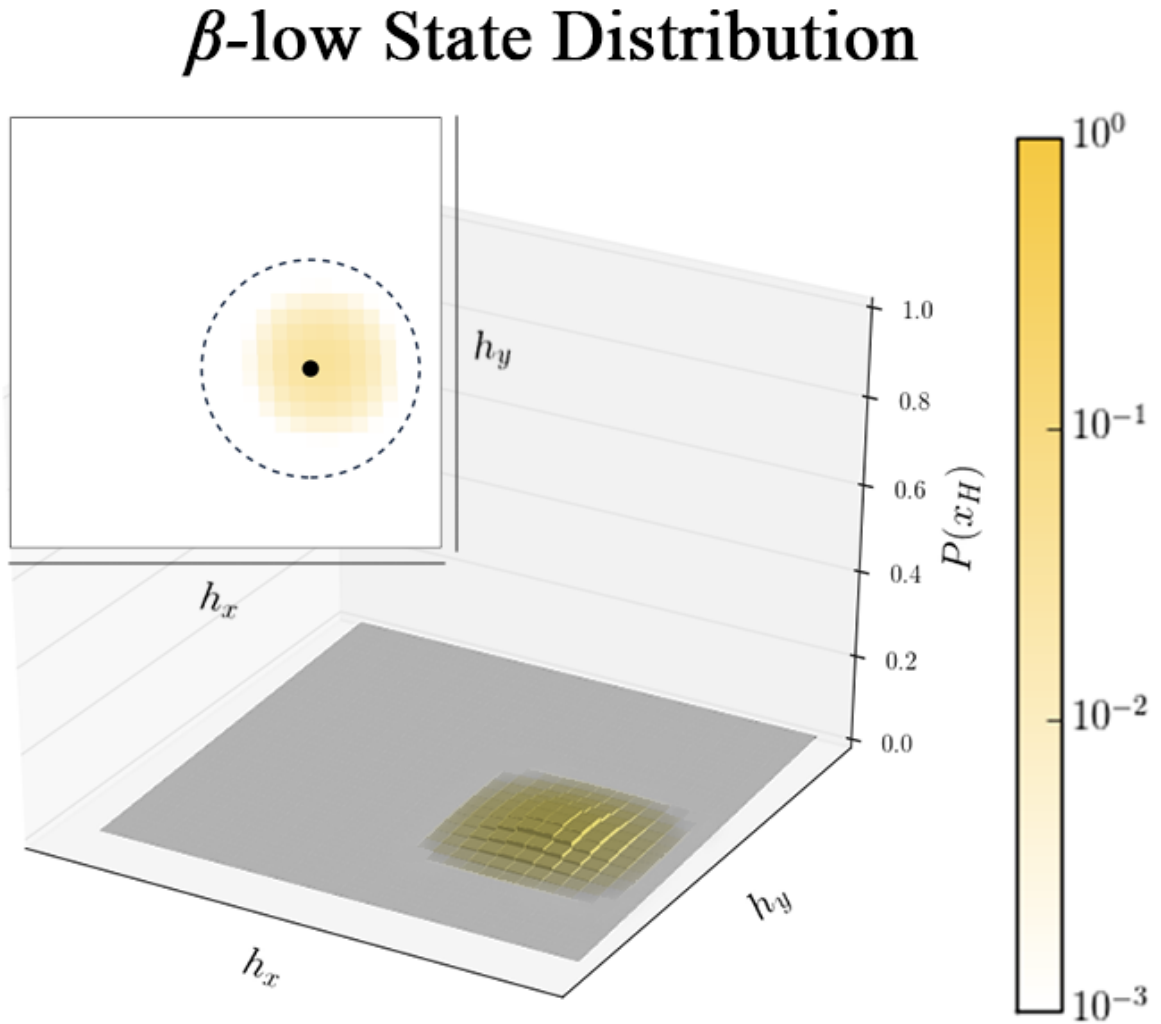

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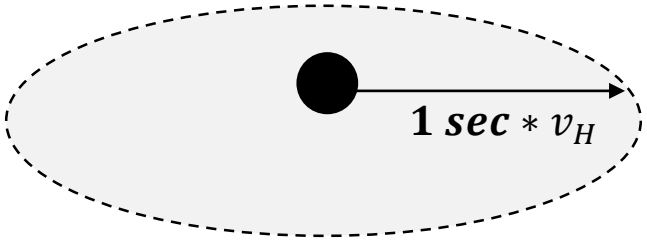

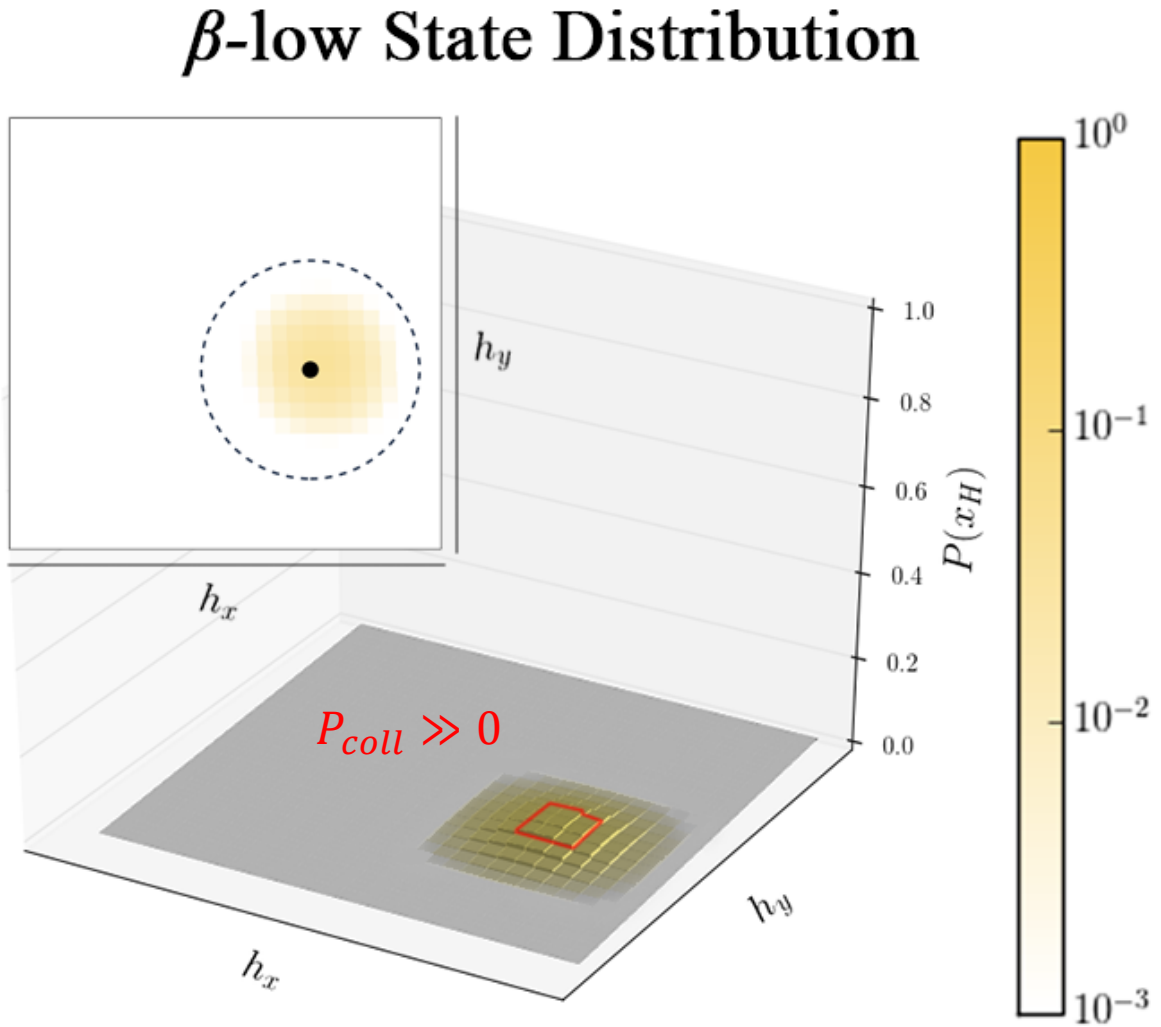

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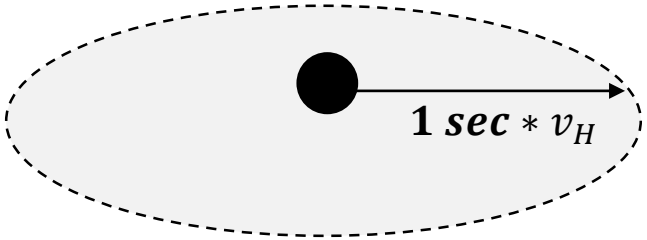

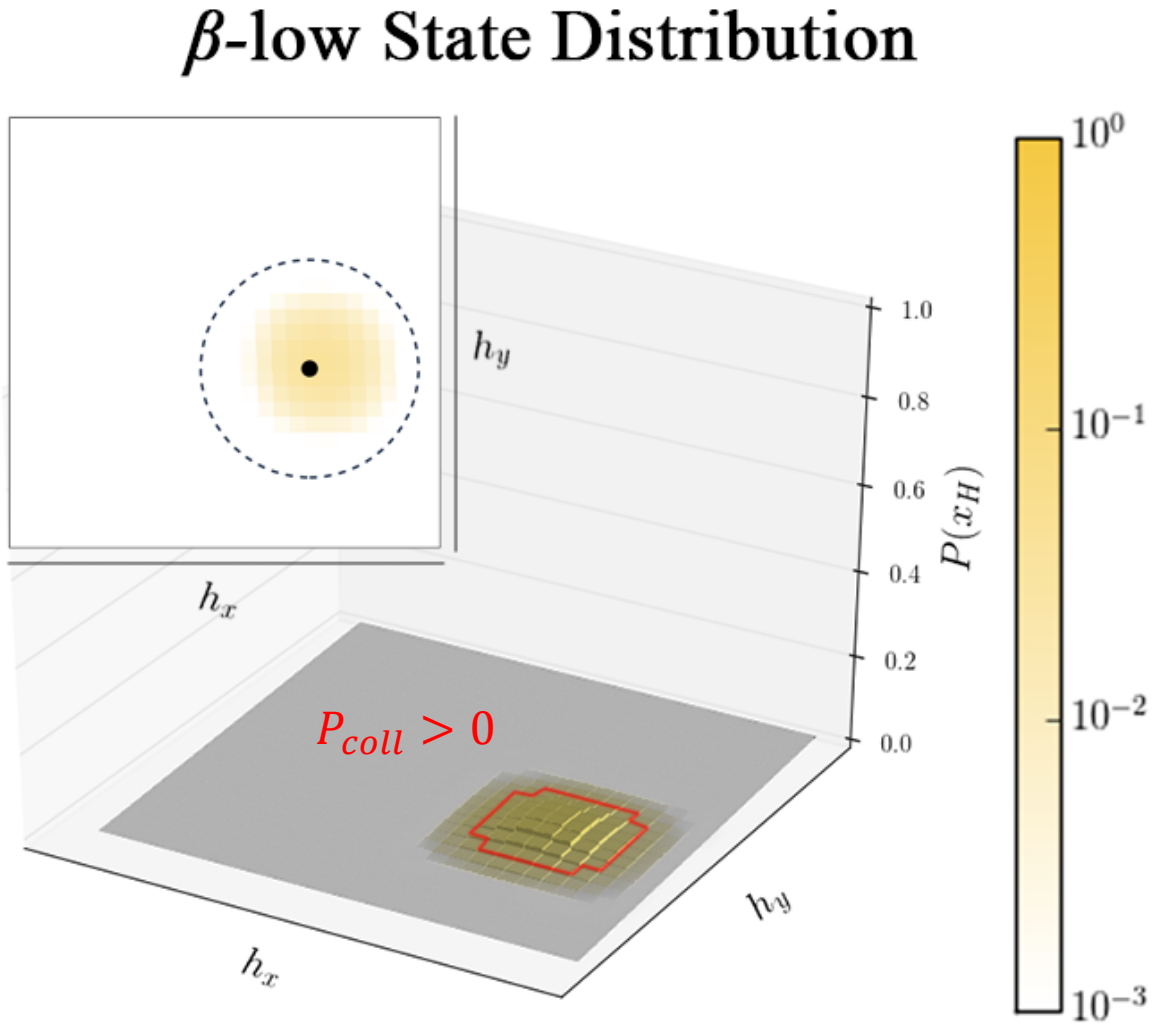

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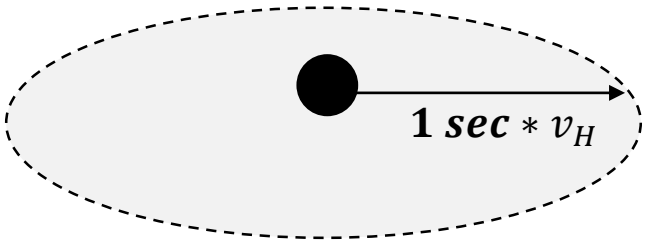

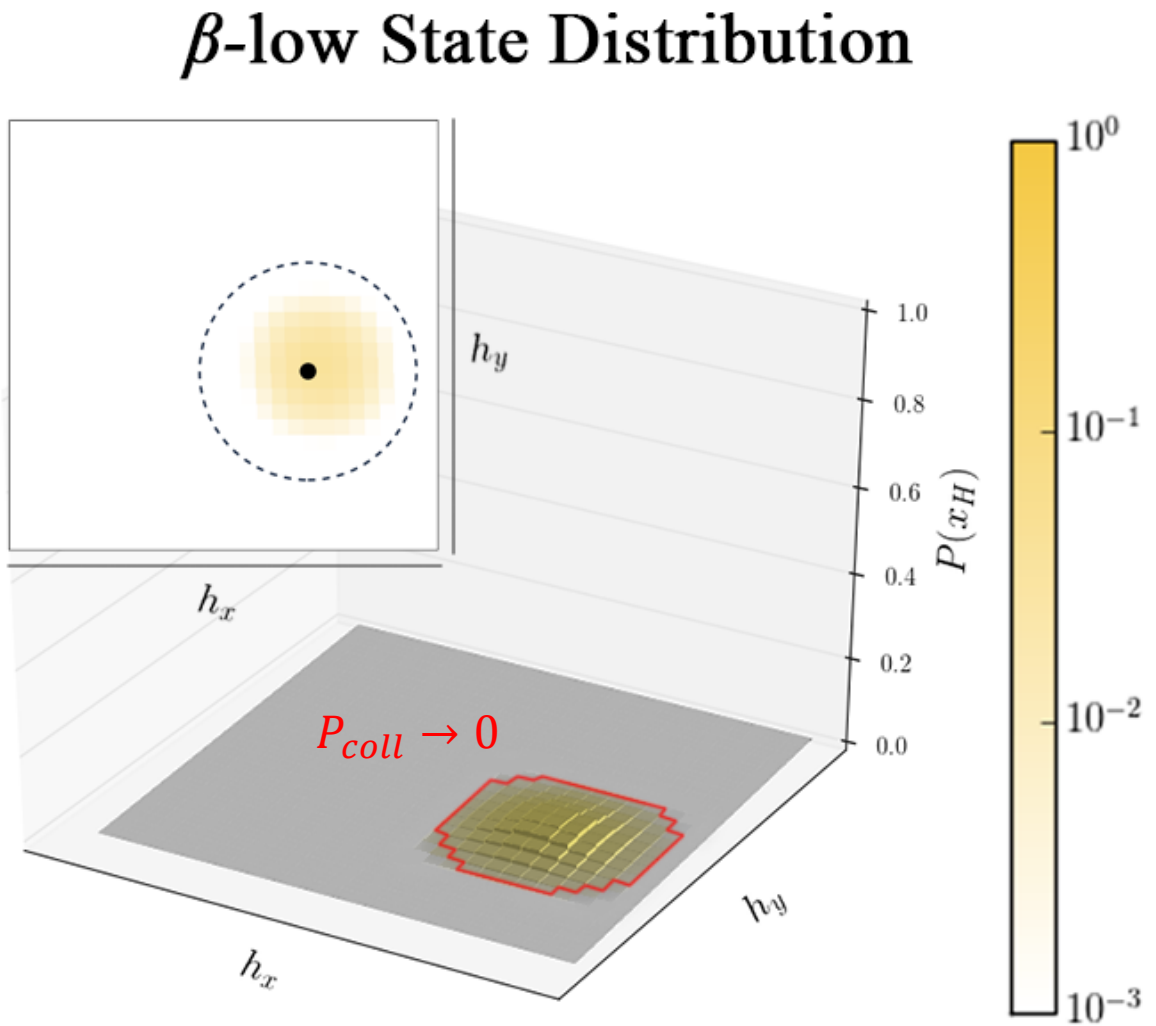

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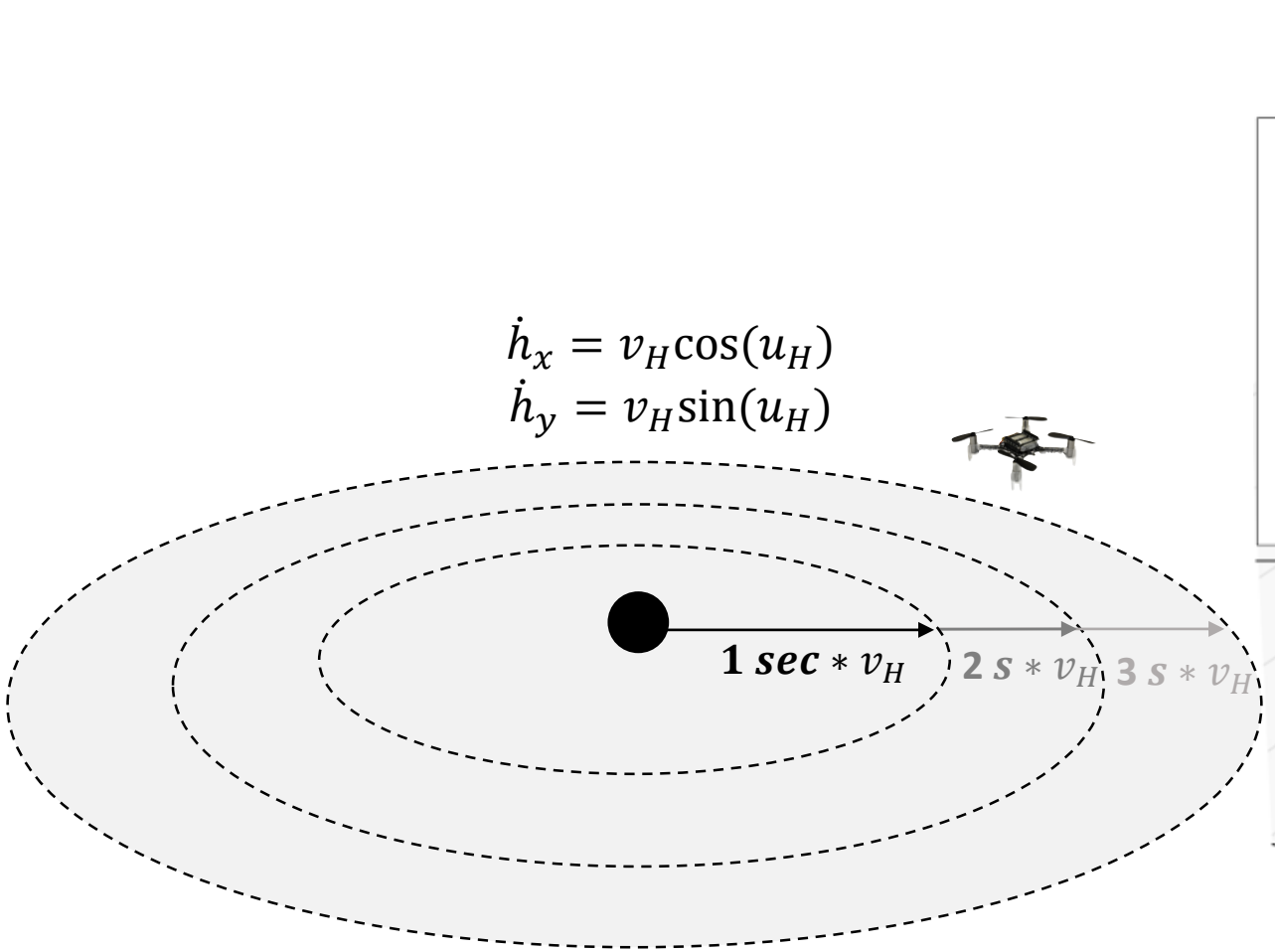

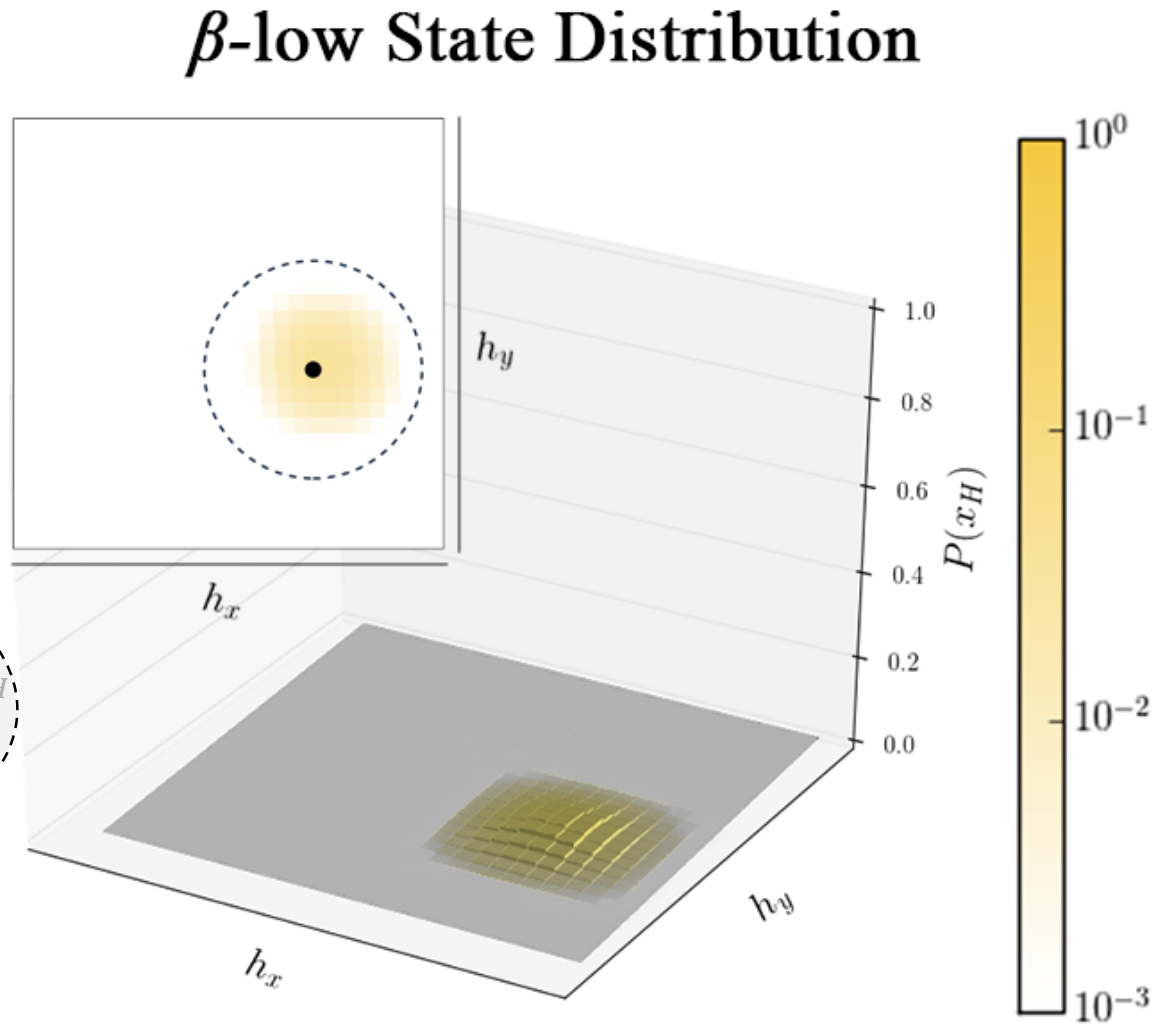

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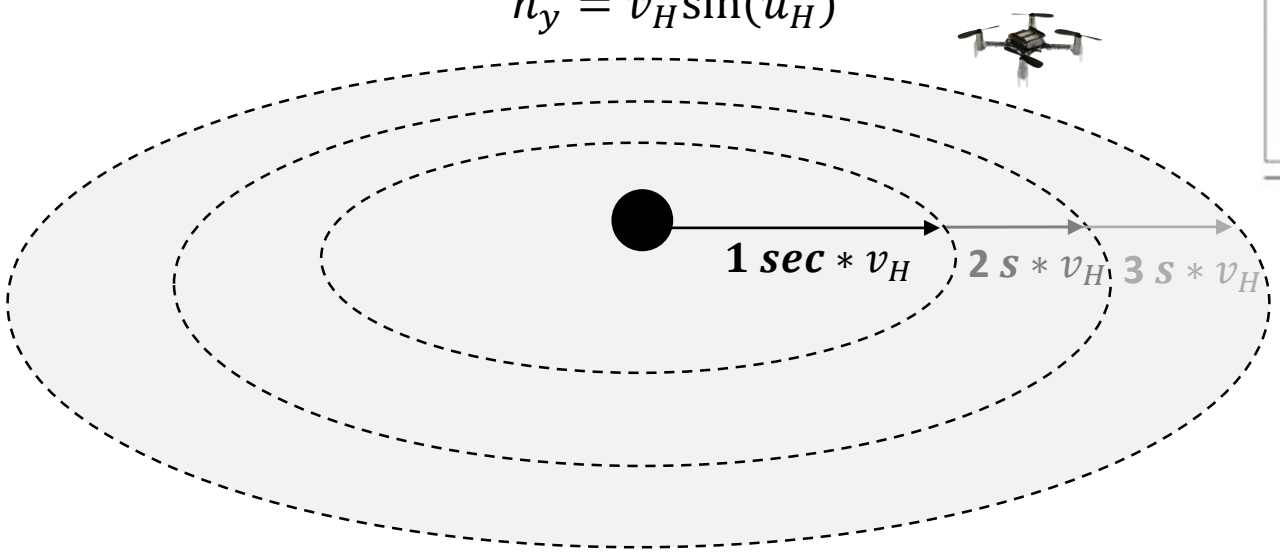

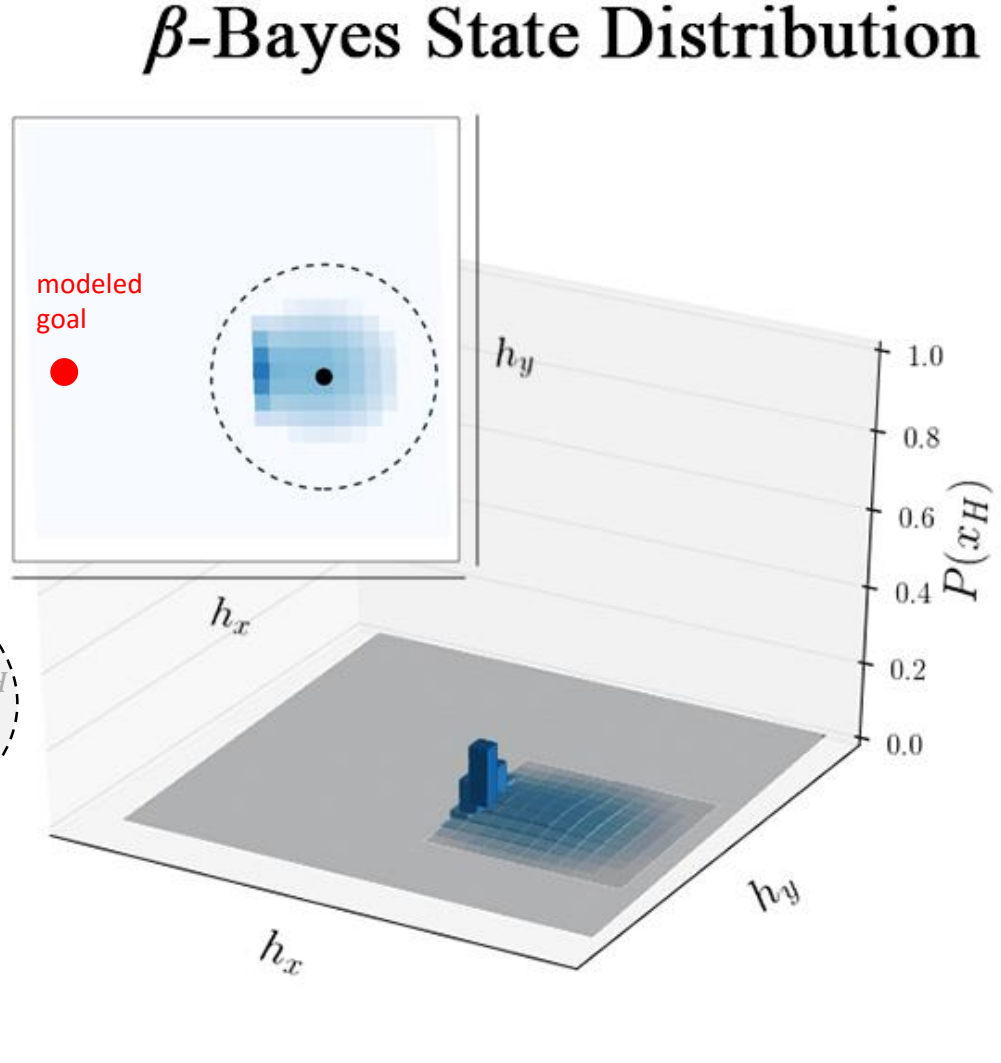

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Robust motion planning

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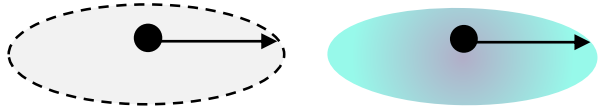
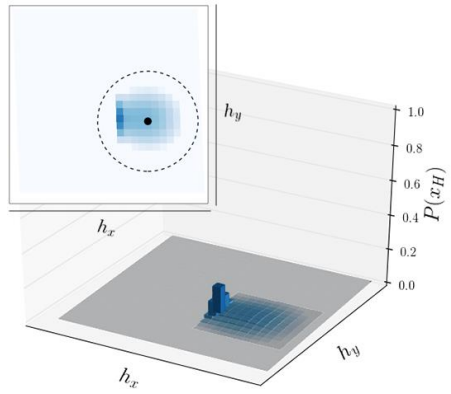
Connections between predictions and FRS



Confidently determining subsets of the FRS to avoid



Scaling up to multi-robot, multi-human scenarios

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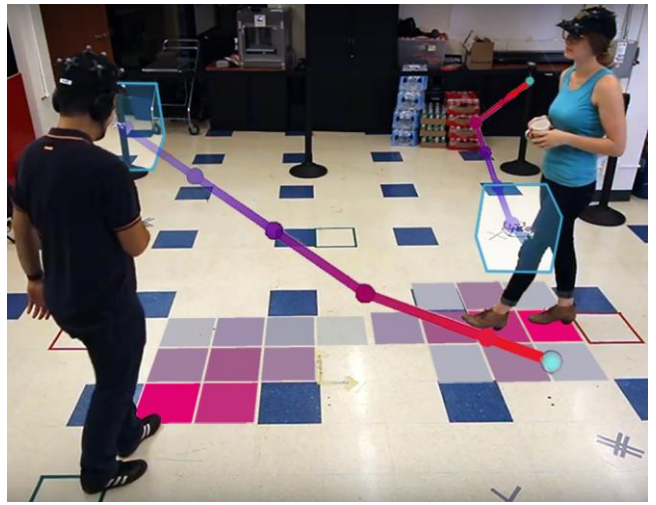
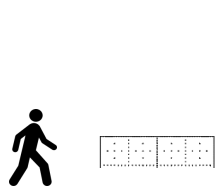
Connections between predictions and FRS

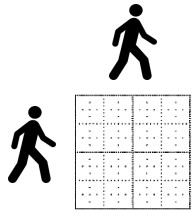
Determining subsets of the FRS to avoid

Scaling up to multi-robot, multi-human scenarios

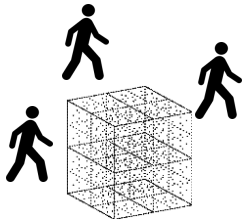




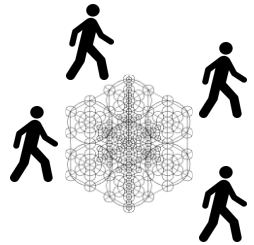
1000



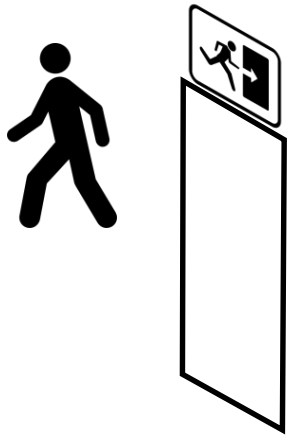
1000 x 1000 = 1M

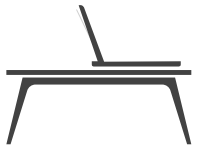


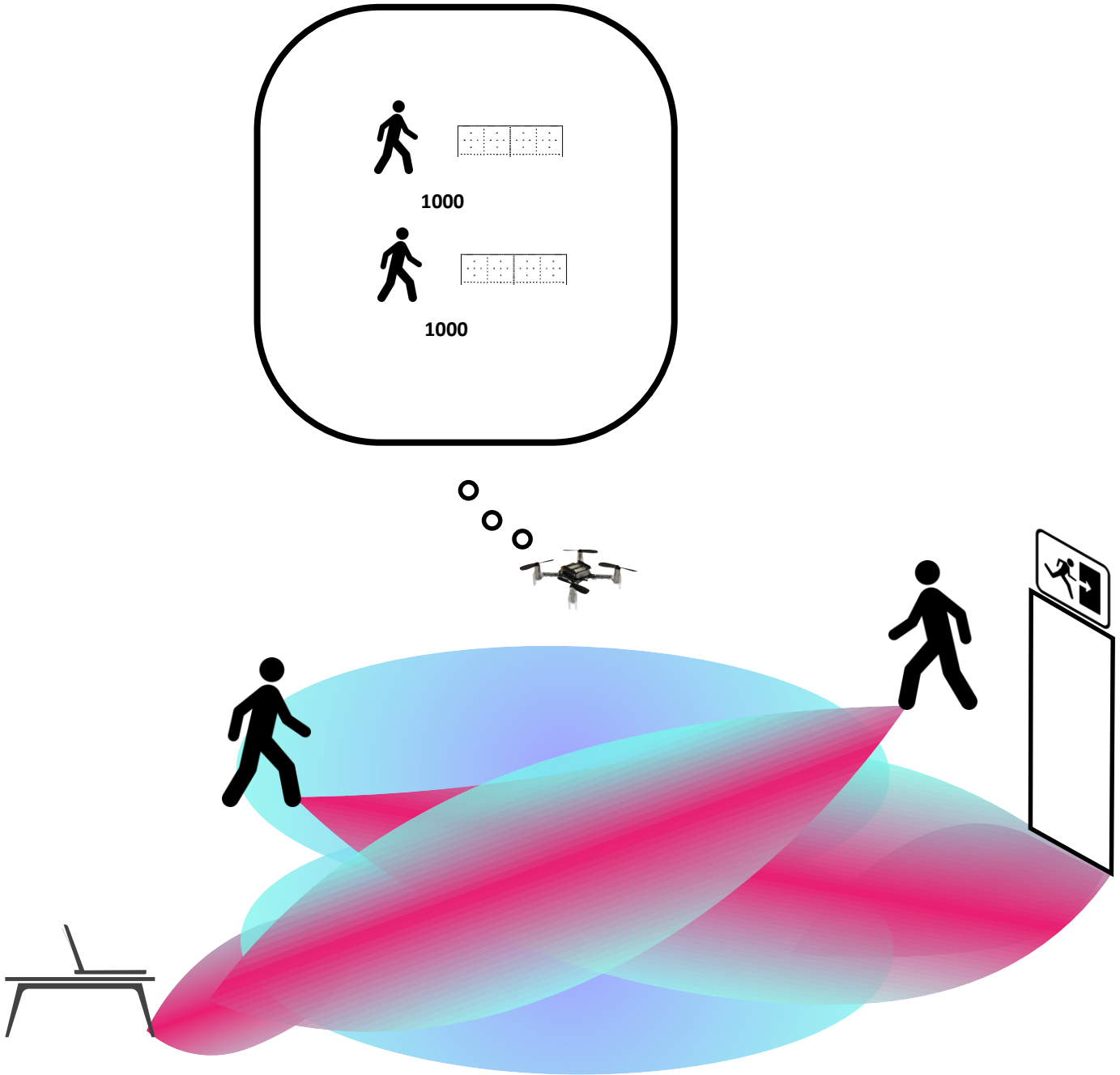
1000 x 1000 x 1000 = 1B



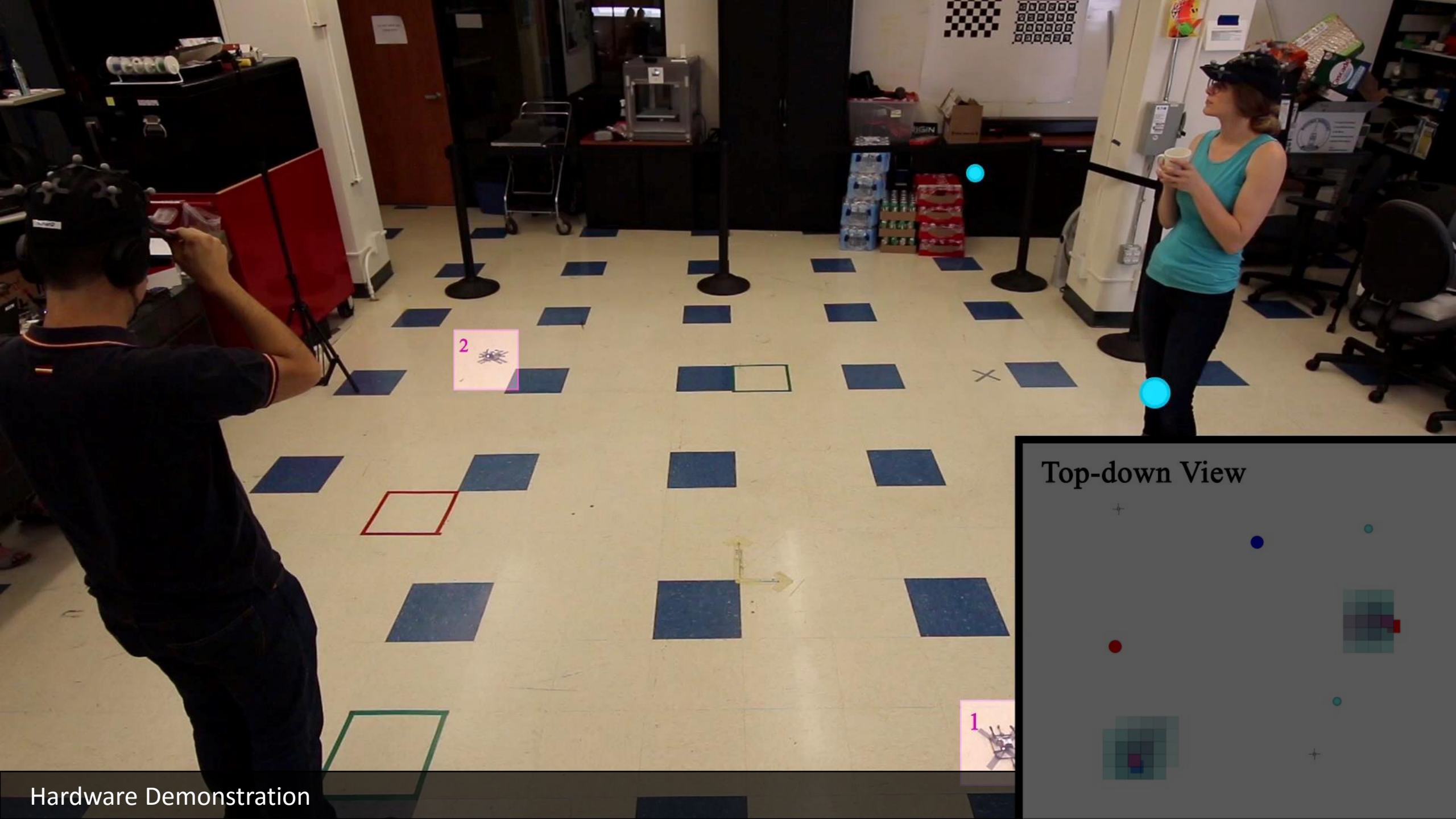
1000 x 1000 x 1000 x 1000 = 1T



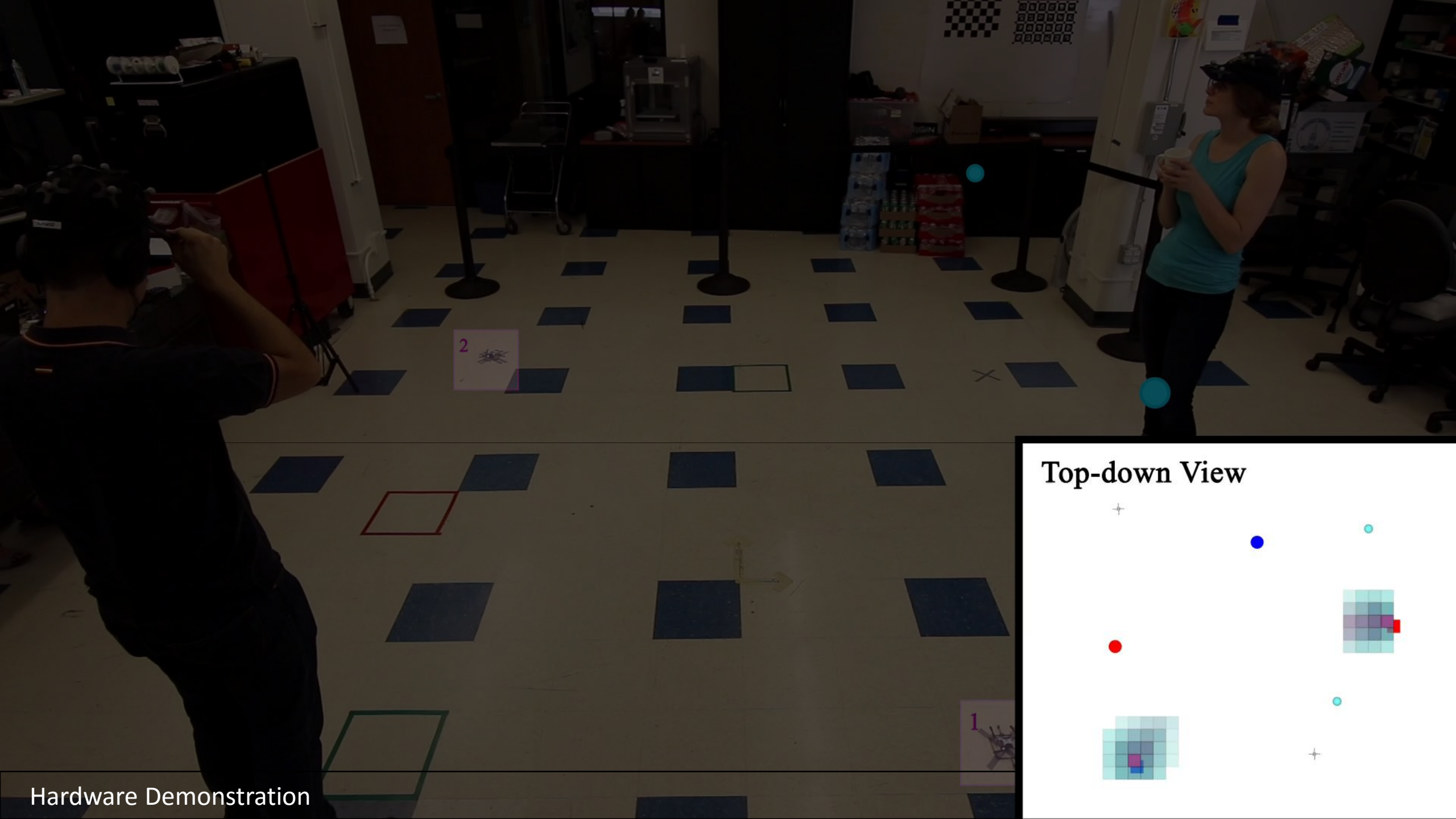




[Bajcsy, 2019]



Hardware Demonstration



Hardware Demonstration

Confidence-aware prediction

$$b^t(\beta) \propto P\left(u_H^t \,|x_H^t; \theta, \beta\right) b^{t-1}(\beta)$$

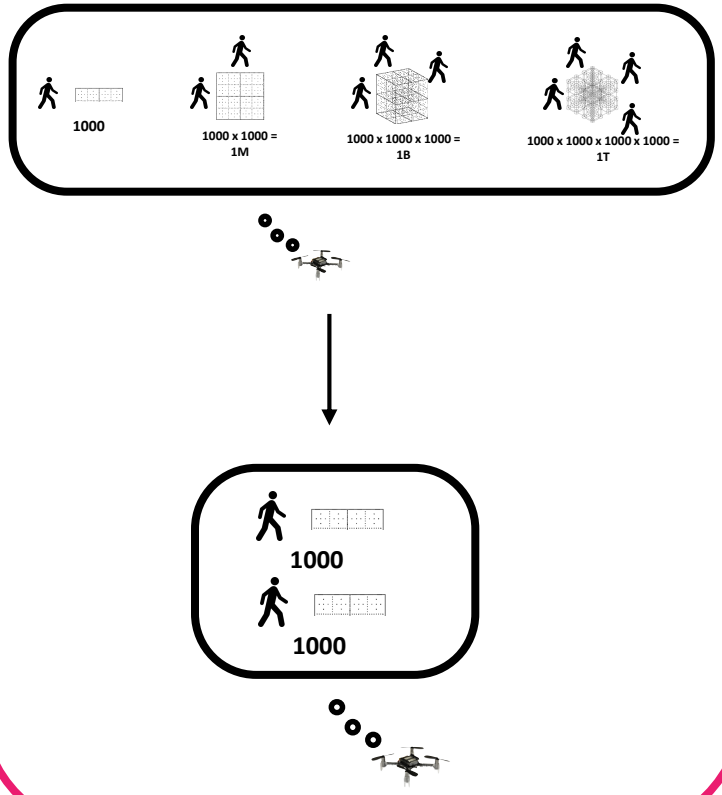
Robust motion planning

$$P\left(\text{Crash}(\quad)\right) > collision_{thresh}$$

Connections between predictions and FRS

Determining subsets of the FRS to avoid

Confidence-aware predictions offer promising directions for scaling



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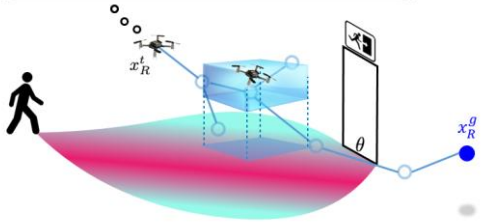
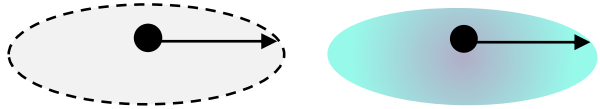
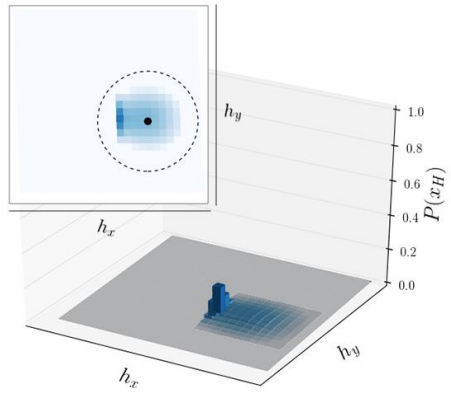


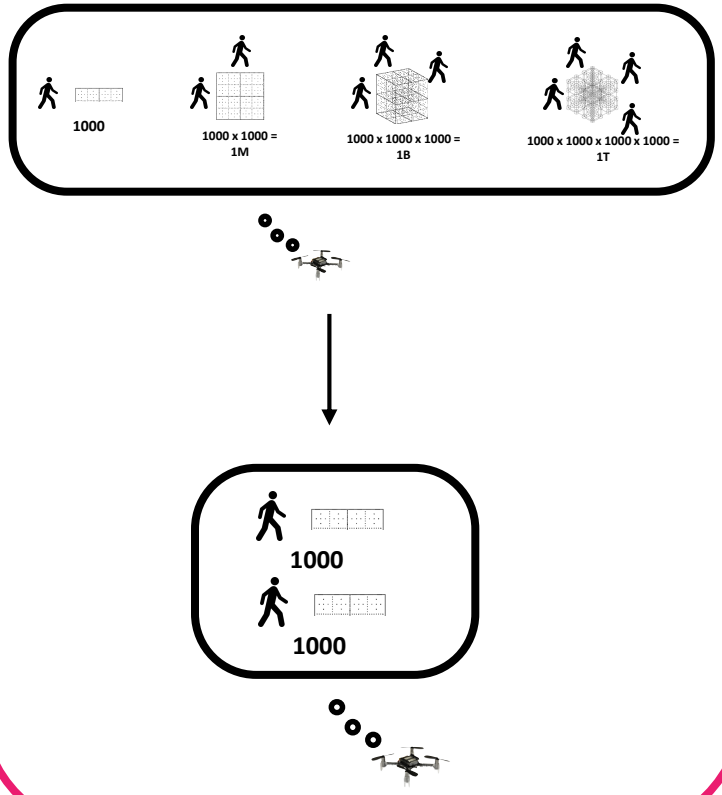
Connections between predictions and FRS



Determining subsets of the FRS to avoid

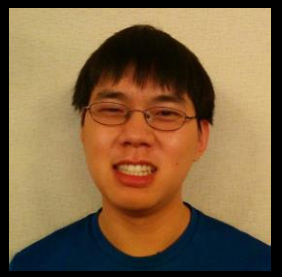


Confidence-aware predictions offer promising directions for scaling










Papers

Fisac*, Bajcsy*, Herbert, Fridovich-Keil, Wang, Tomlin, and Dragan. "Probabilistically Safe Robot Planning with Confidence-Based Human Predictions." RSS, 2018.

Fridovich-Keil*, Bajcsy*, Fisac, Herbert, Wang, Dragan, and Tomlin. “Confidence-Aware Motion Prediction for Real-Time Collision Avoidance.” IJRR, 2019

Bajcsy*, Herbert*, Fridovich-Keil, Fisac, Deglurkar, Dragan, and Tomlin, “A Scalable Framework for Real-Time Multi-Robot, Multi-Human Collision Avoidance.” ICRA, 2019.

Herbert*, Chen*, Han, Bansal, Fisac, Tomlin. "FaSTrack: a Modular Framework for Fast and Guaranteed Safe Motion Planning." CDC, 2017.

Code

Multi-robot, multi-human planning: https://github.com/HJReachability/faSTPeople

Fast and safe robot tracking: https://github.com/HJReachability/fastrack

Pedestrian prediction: https://github.com/shwang/pedestrian_prediction

ROS wrapper for pedestrian prediction: https://github.com/abajcsy/crazyflie_human