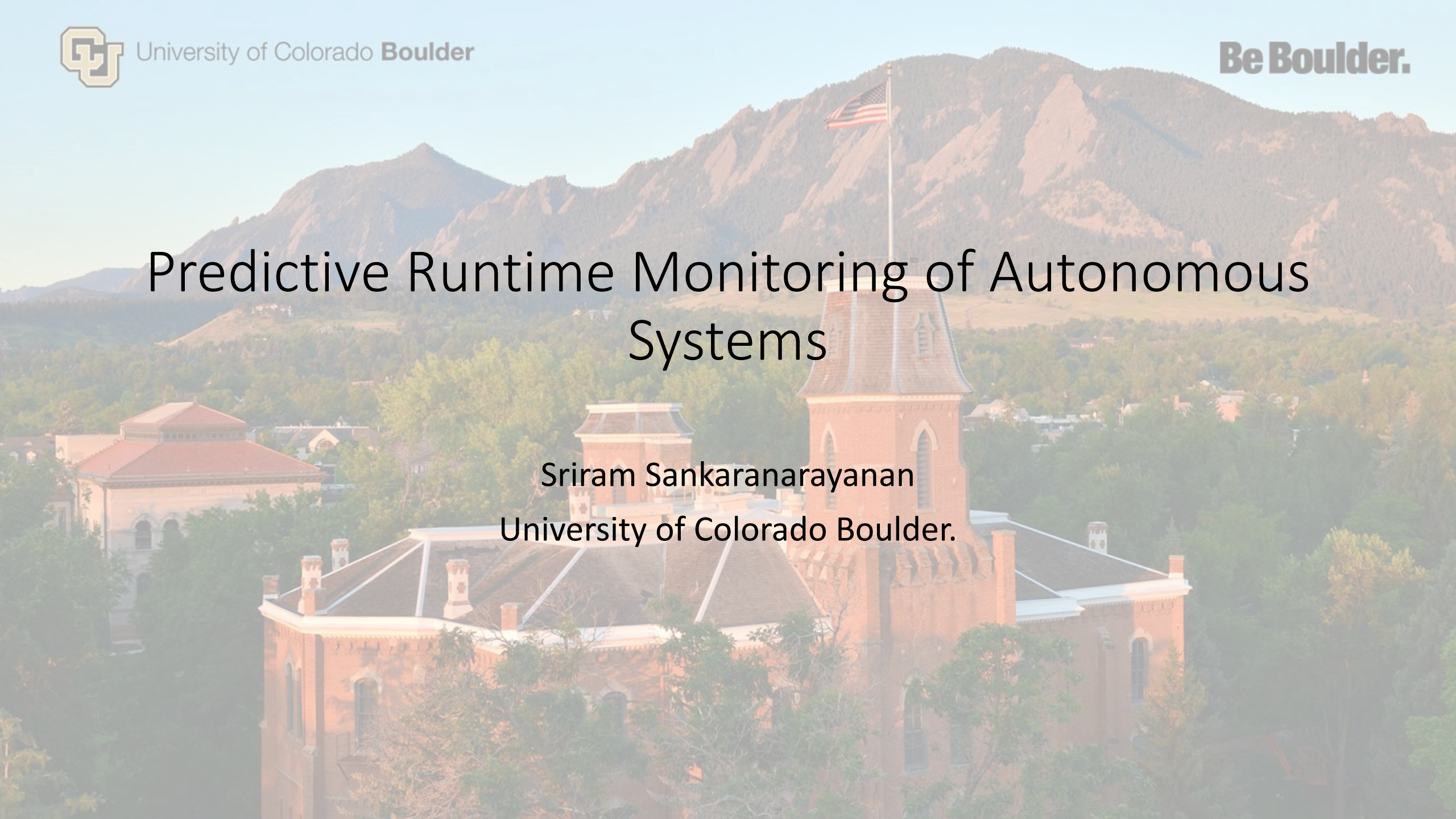


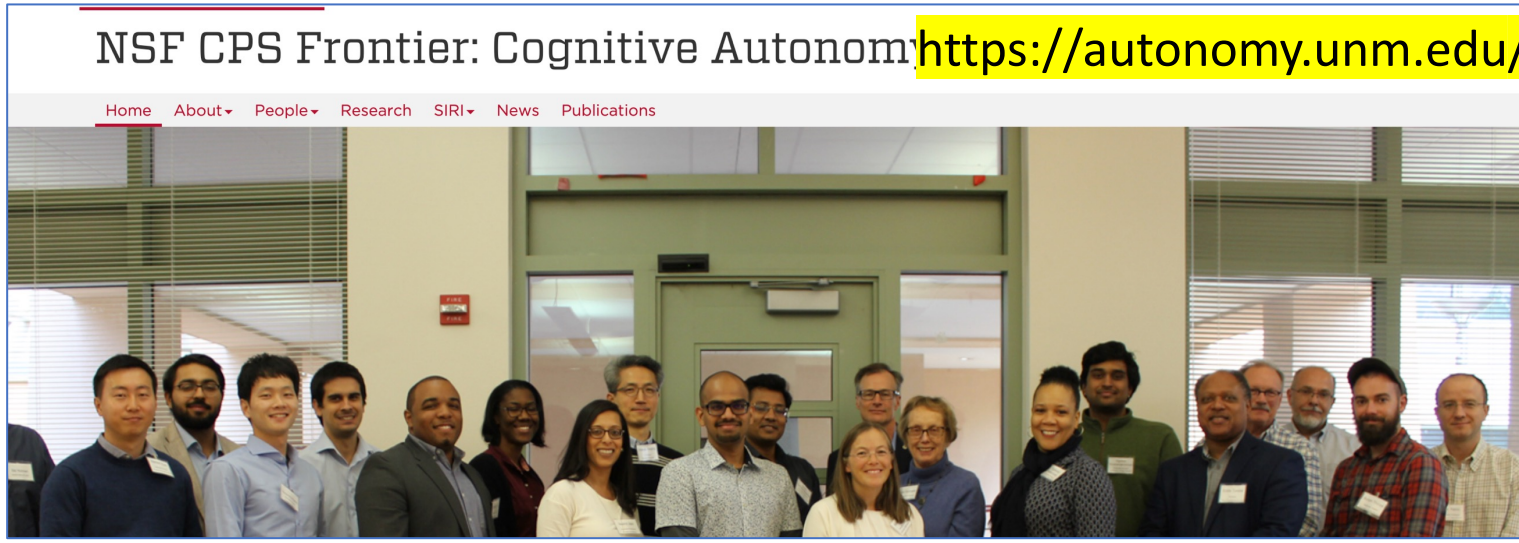
Predictive Runtime Monitoring of Autonomous Systems

Sriram Sankaranarayanan

University of Colorado Boulder.

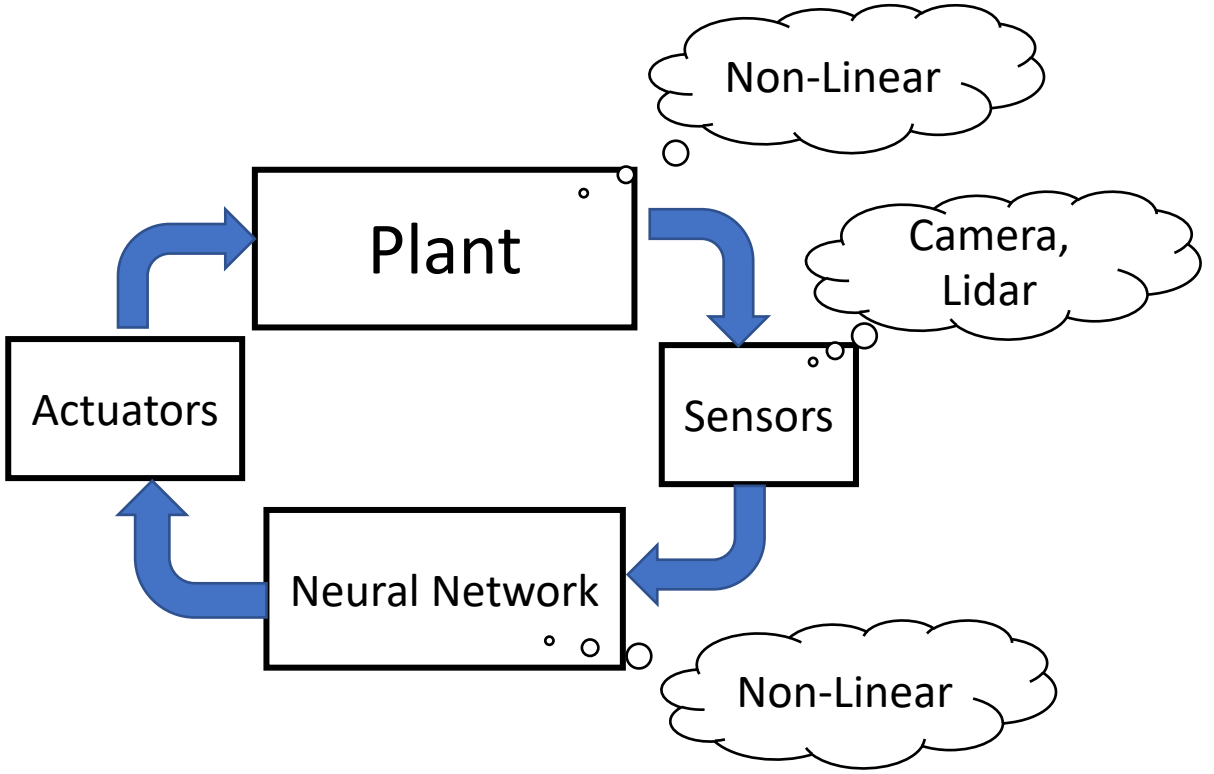
Context: Cognitive Autonomy Project

- Highly “dynamic" environments: human and robot interactions.
- Runtime monitoring.
  - Reason about behavior of agents.
  - Predict how various agents will behave over time.
- *In this talk:* Predict future states of an agent from observations.

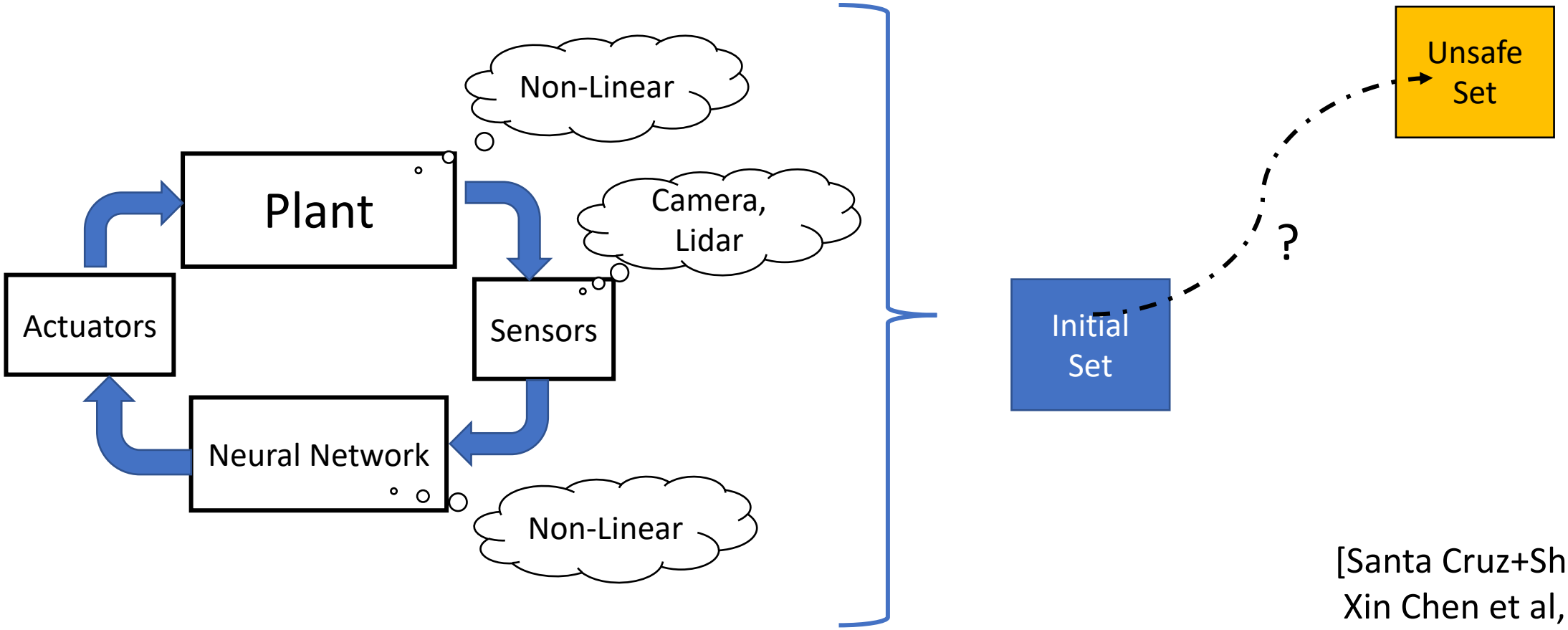


Safe Autonomy: Challenge

Will this UAV land safely?

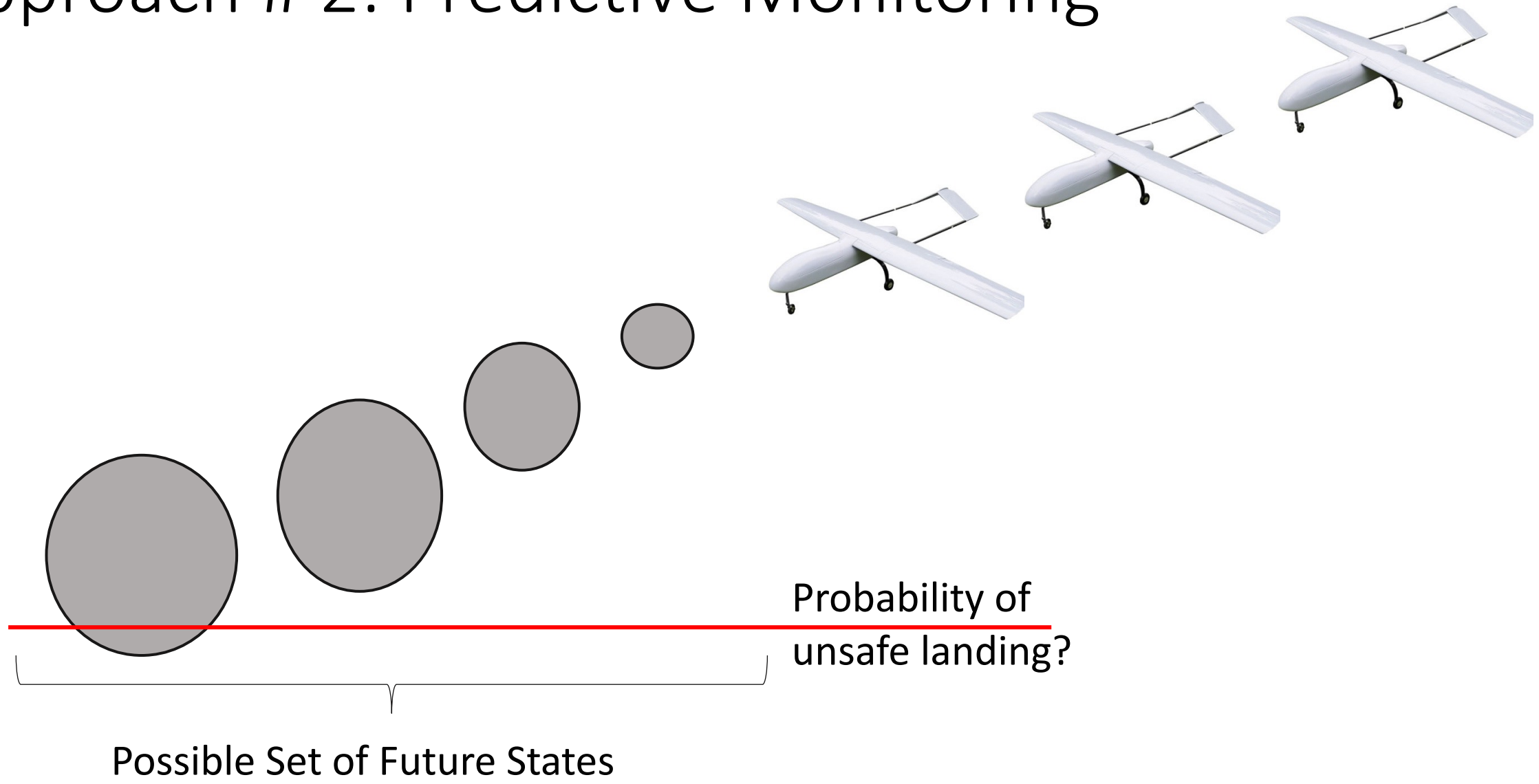


Approach # 1: Reachability Analysis



[Santa Cruz+Shoukry NFM '22
Xin Chen et al,
Ivanov et al,
Johnson et al,
Kochendorfer et al, …]

Approach # 2: Predictive Monitoring



Attack on Saudi oil facility

(from CNN)

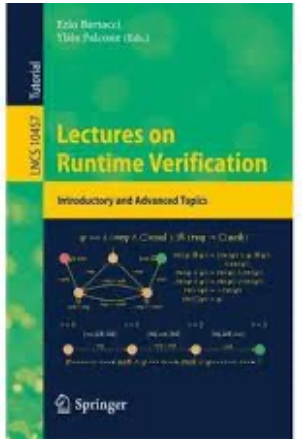
Gatwick airport shutdown

(from CBS17)

Fort Worth airfield intrusion

(from 911security)

Runtime Verification



[Rozier et al. R2U2
Finkbeiner et al. RT-LOLA …]

Wind, GPS error

UAV Dynamics

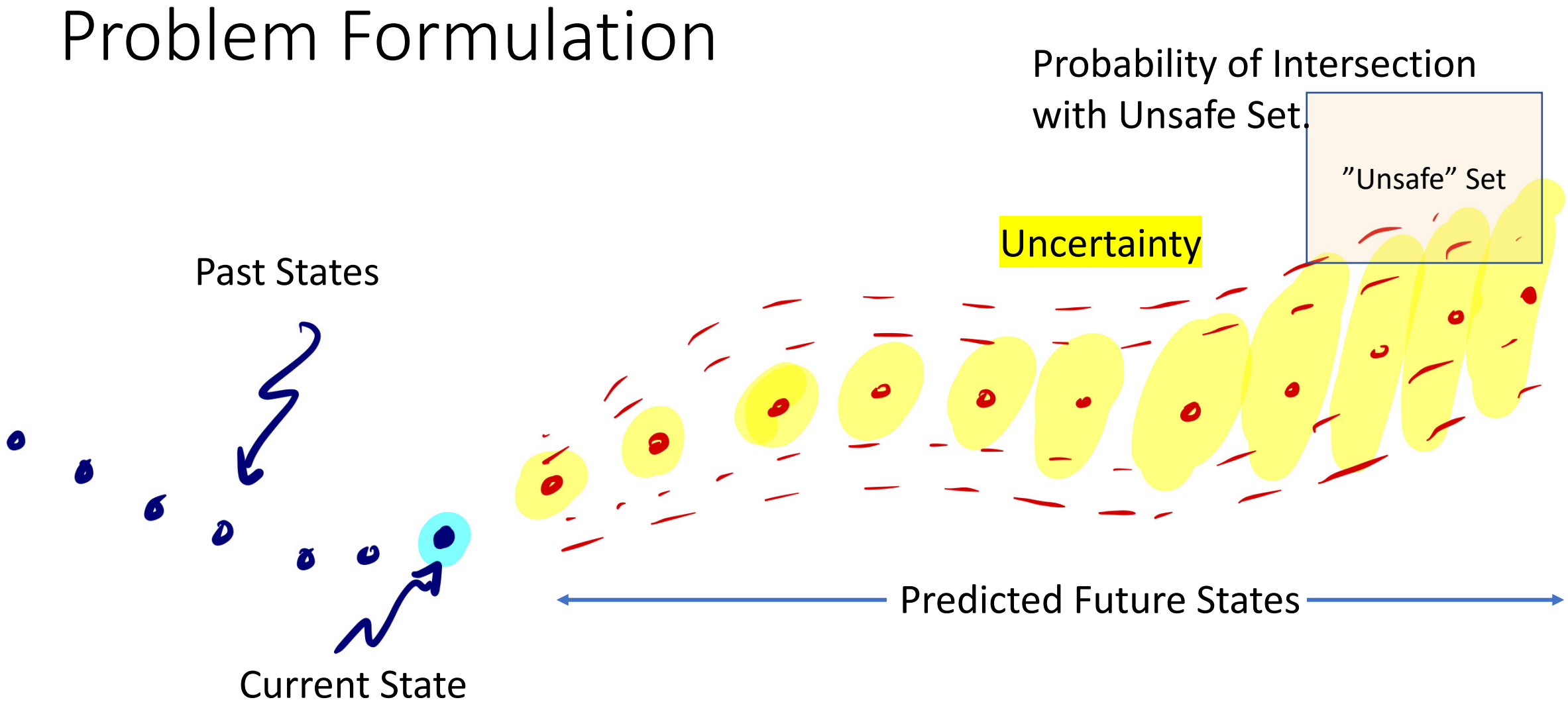
Guidance,
Navigation,
control

Trace

Temporal Specifications

Runtime Monitor

Problem Formulation



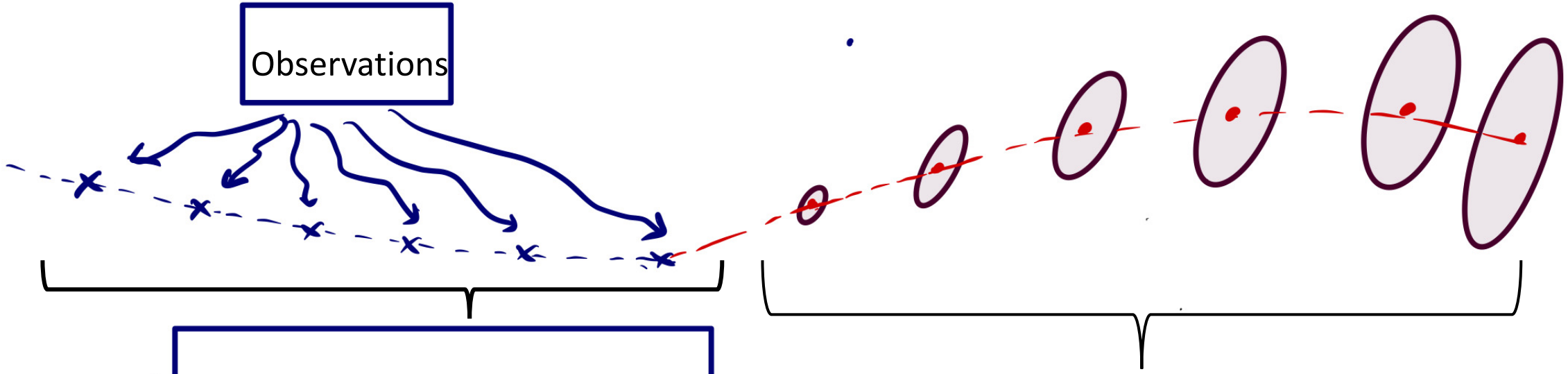
Approach #1 : Extrapolating dynamics.

Predictive Runtime Monitoring of Vehicle Models Using Bayesian Estimation and Reachability Analysis

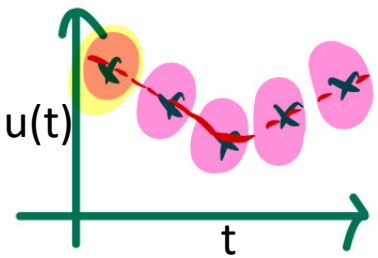
Yi Chou, Hansol Yoon, and Sriram Sankaranarayanan

Intl. Conference on Intelligent Robots and Systems (IROS), pp. 2111-2118, 2020.

Approach # 1: Dynamical Extrapolation.



$$x(t+h) = F(x(t), u(t))$$



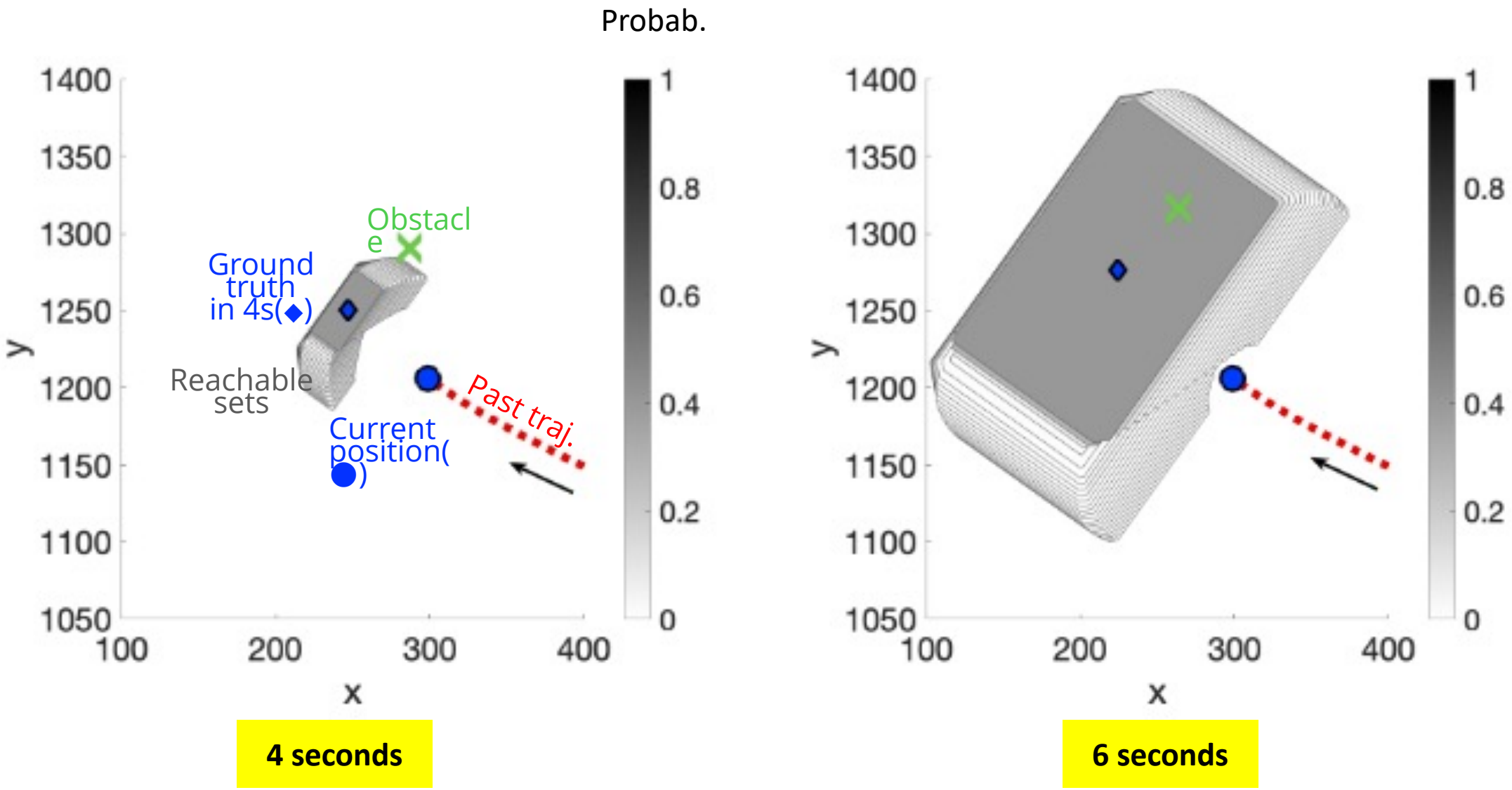
"Extrapolate" forward in time.

Infer how the system is being controlled.

[Chou Yi + Hansol Yoon + Sank. IROS 2020]

Bayesian Predictive Monitoring

Dataset: 45 minutes of UAV flight over eastern Colorado.



Approach # 2 : Intent Inference

Predictive Runtime Monitoring for Mobile Robots using Logic-Based Bayesian Intent Inference

Hansol Yoon, and Sriram Sankaranarayanan

In International Conference on Robotics and Automation (ICRA), pp. 8565-8571, 2021.

Can we do better?

Intent Inference

Essential Meaning of *intent*

: the thing that you plan to do or achieve **:** an aim or purpose

// She thinks I'm trying to make things difficult for her, but that's not my *intent*.

// What was the writer's *intent*?

See More Examples

Source: Merriam-Webster Online

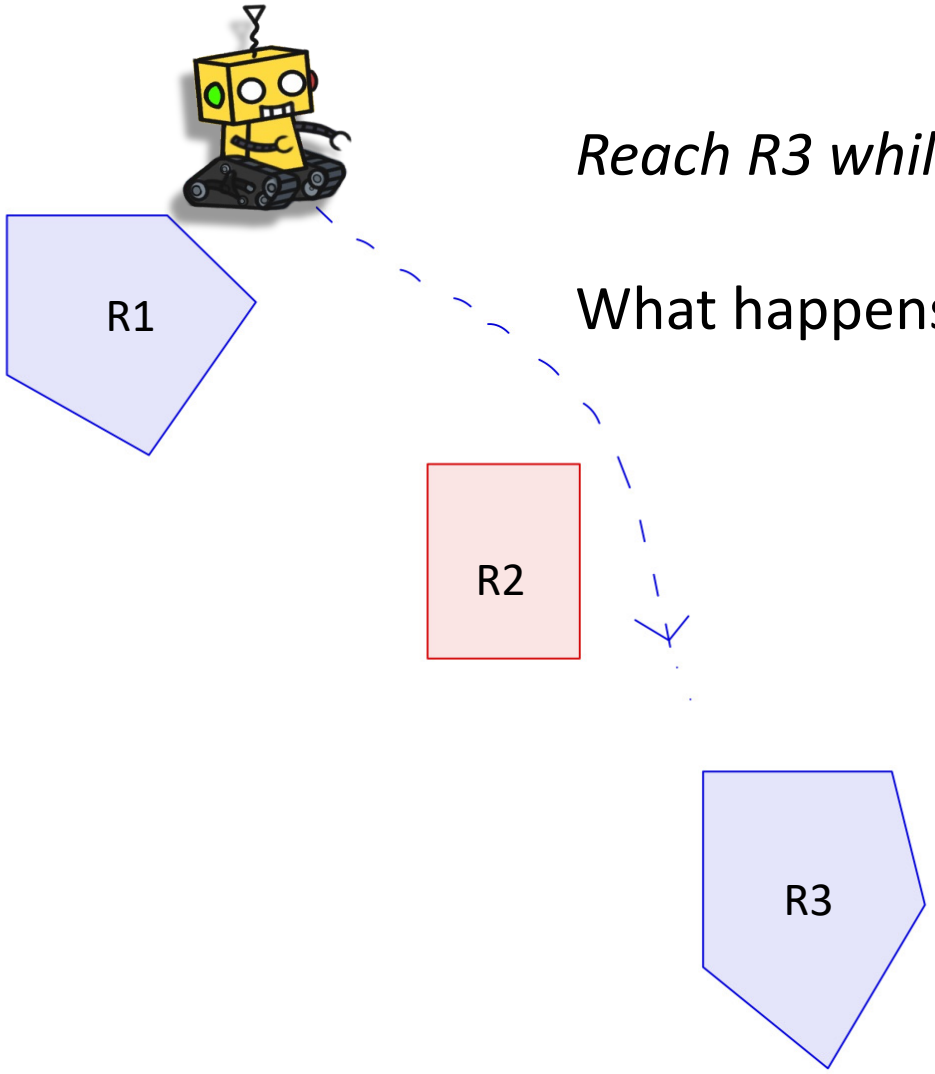
- Robot's intents are drawn from a finite set.
- Intents can change over time.
- Restricted class of temporal logic: Reach-while avoid

Intent Inference: Conclusions

- Intents vastly improve upon extrapolation of past trajectories.
- Longer time horizons with better accuracy.
- Drawback # 1: *Simplified robot dynamics*.
- Drawback # 2: *Restrictive language for intents*.

Approach # 3 : Hierarchical Intent Inference

Hierarchical Intent Inference



Reach R3 while avoiding R2.

What happens after robot reaches R2?

Immediate Intent/Goal vs. Long Term Goals

Hierarchical Intent Inference

- Idea: Hypothesize long term intents using temporal logic.
- “Most” automation tasks can be expressed in temporal logic.
  - *Claudio Menghi et al. Specification Patterns for Robotic Missions, IEEE Trans. Software Engg.*

- *Challenge: Extend notions of “cost” and “rationality” to temporal logic properties.*

Thank You

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  - Chou Yi (PhD alumna)
  - Hansol Yoon (PhD alumnus)
  - Prof. Morteza Lahijanian, CU Boulder.