

Hunting GPS Jammers



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Overview

- Problem
- Model
- Algorithm

- Improvements
- Conclusion

Problem

INSIDE GNSS NEWS



Newark Liberty International Airport. Port Authority photo

FCC Fines Operator of GPS Jammer That Affected Newark Airport GBAS

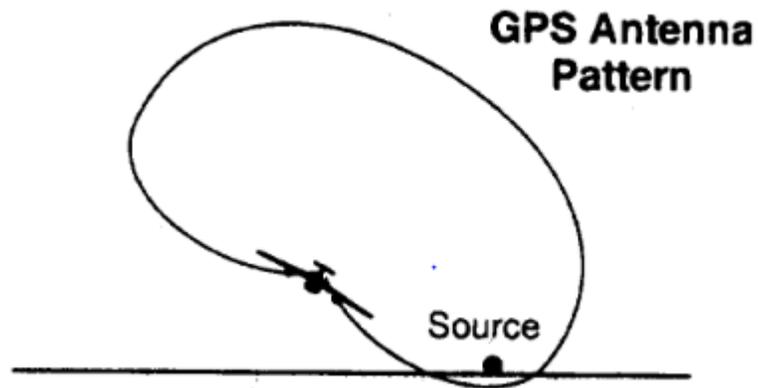
Jamming events continue – an average of five per day at EWR

<http://www.insidegnss.com/node/3676>



foxnews.com

Previous Approaches



Geyer, E. Michael, Bette M. Wirier, and Robert A. Frazier. "Airborne GPS RFI Localization Algorithms." *Proceedings of the 10th International Technical Meeting of the Satellite Division of The Institute of Navigation (ION GPS 1997)*. 1997.

JAGER

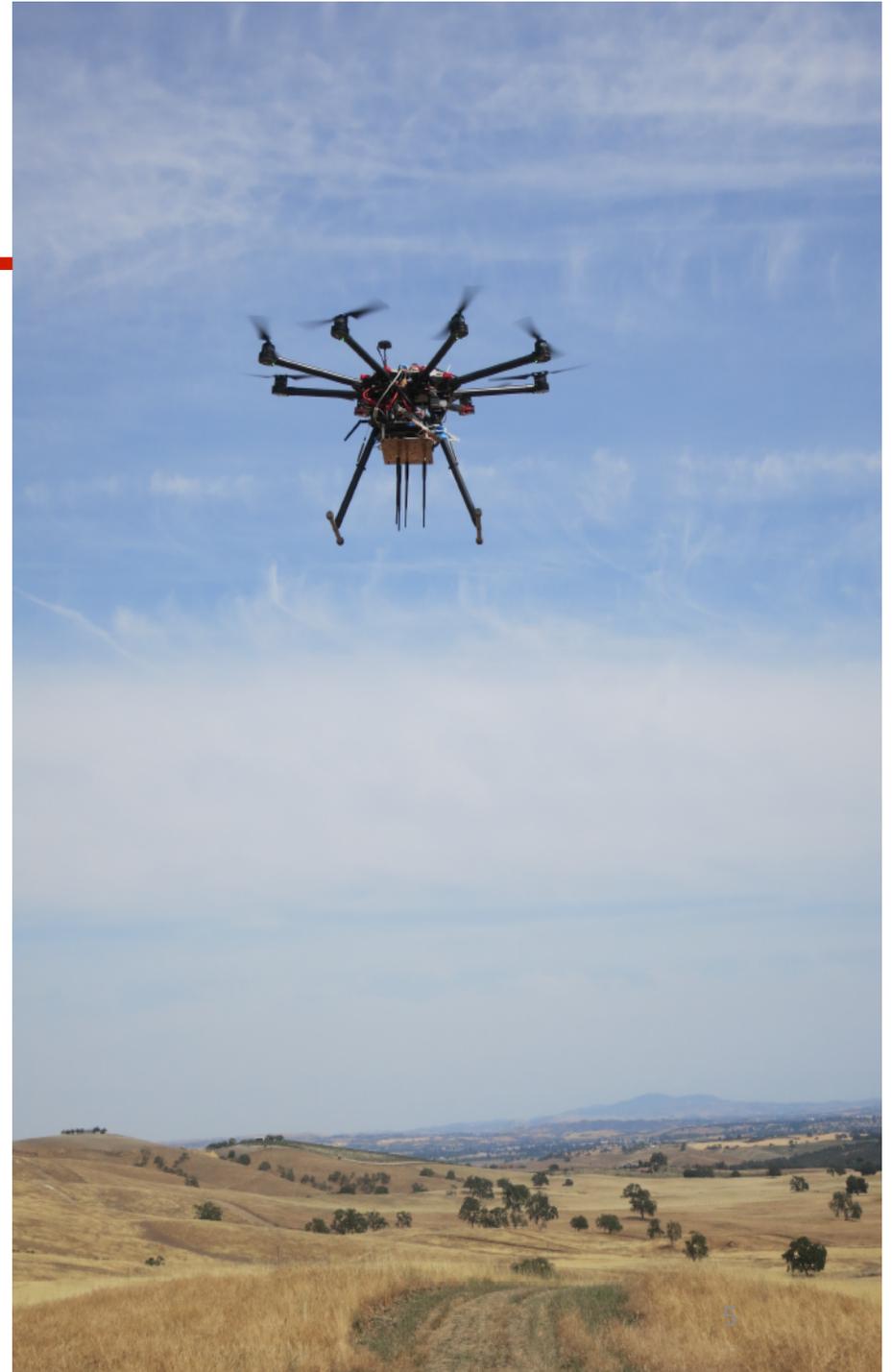
Jammer

Acquisition with

GPS

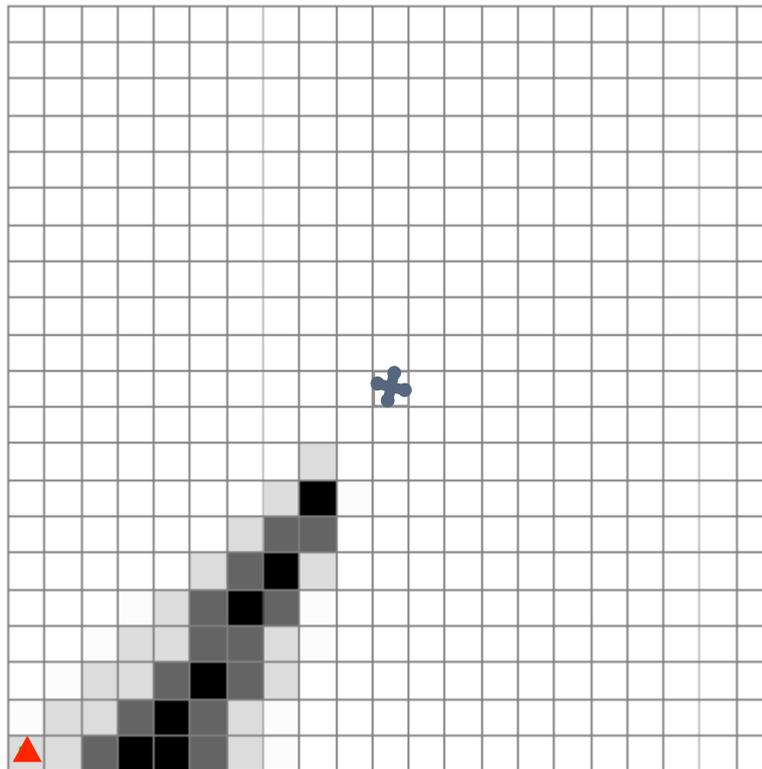
Exploration and

Reconnaissance



Model

State Space



$$s = [x \downarrow v, y \downarrow v, x \downarrow j, y \downarrow j]$$

$$b \in \mathbb{R}^{21 \times 21}$$

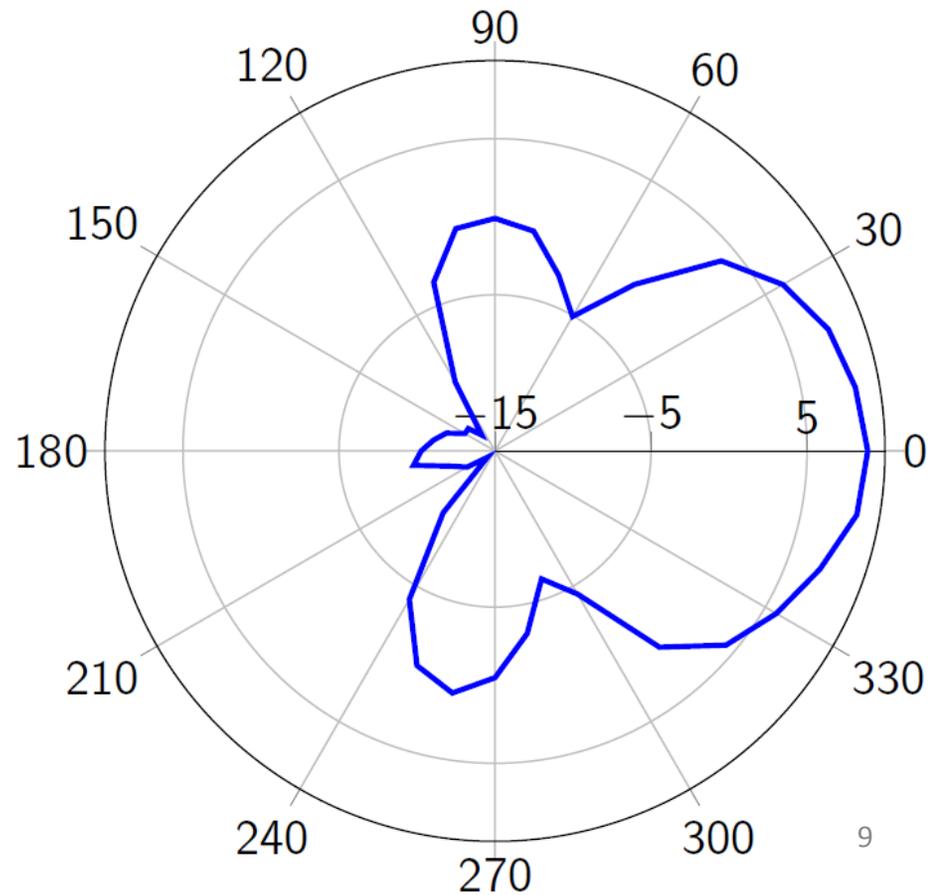
Control Inputs

- Vehicle can rotate, translate, and climb at once
- **Difficult** because:
 - Large control space to reason over
 - Hard to estimate bearing from measurements
 - Hardware
- Let's **decouple** rotation
 - Rotate to get rough bearing is a control input
 - Translating to another cell is a control input

Observation Model



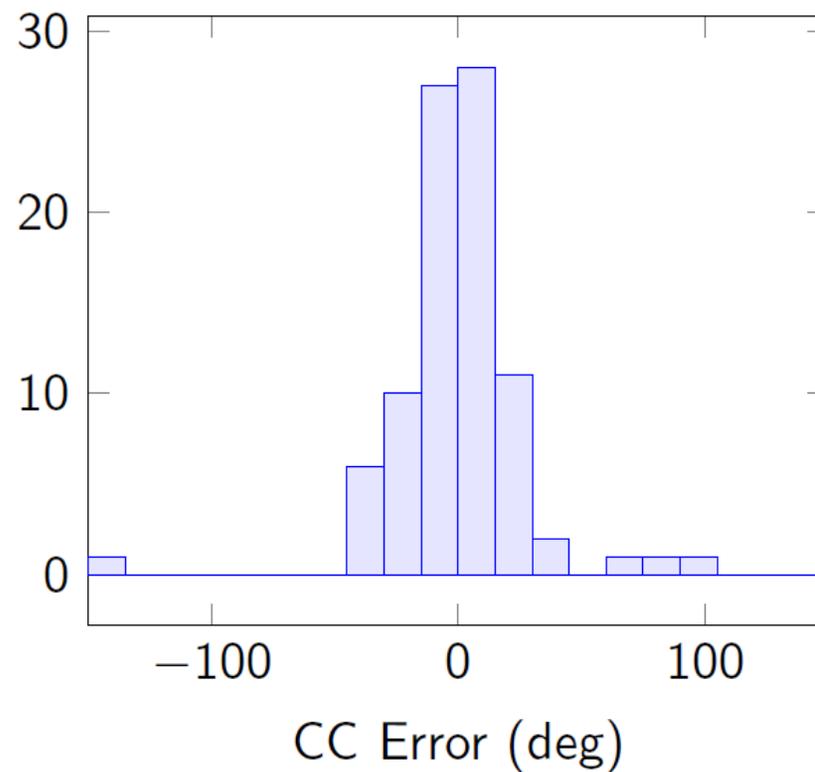
Rotate at $15^\circ/\text{sec}$
Sample at 2 Hz



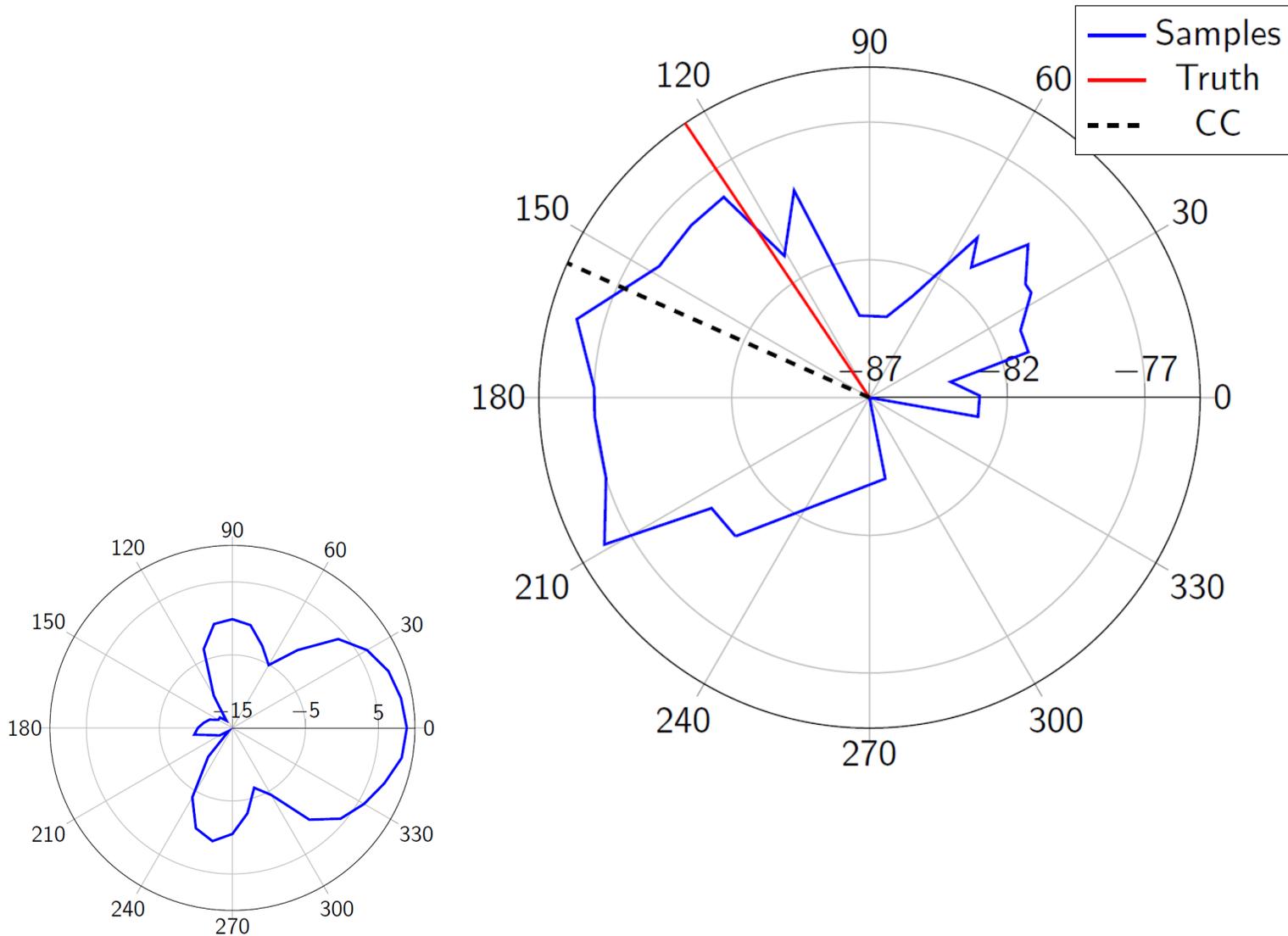


Observation Model

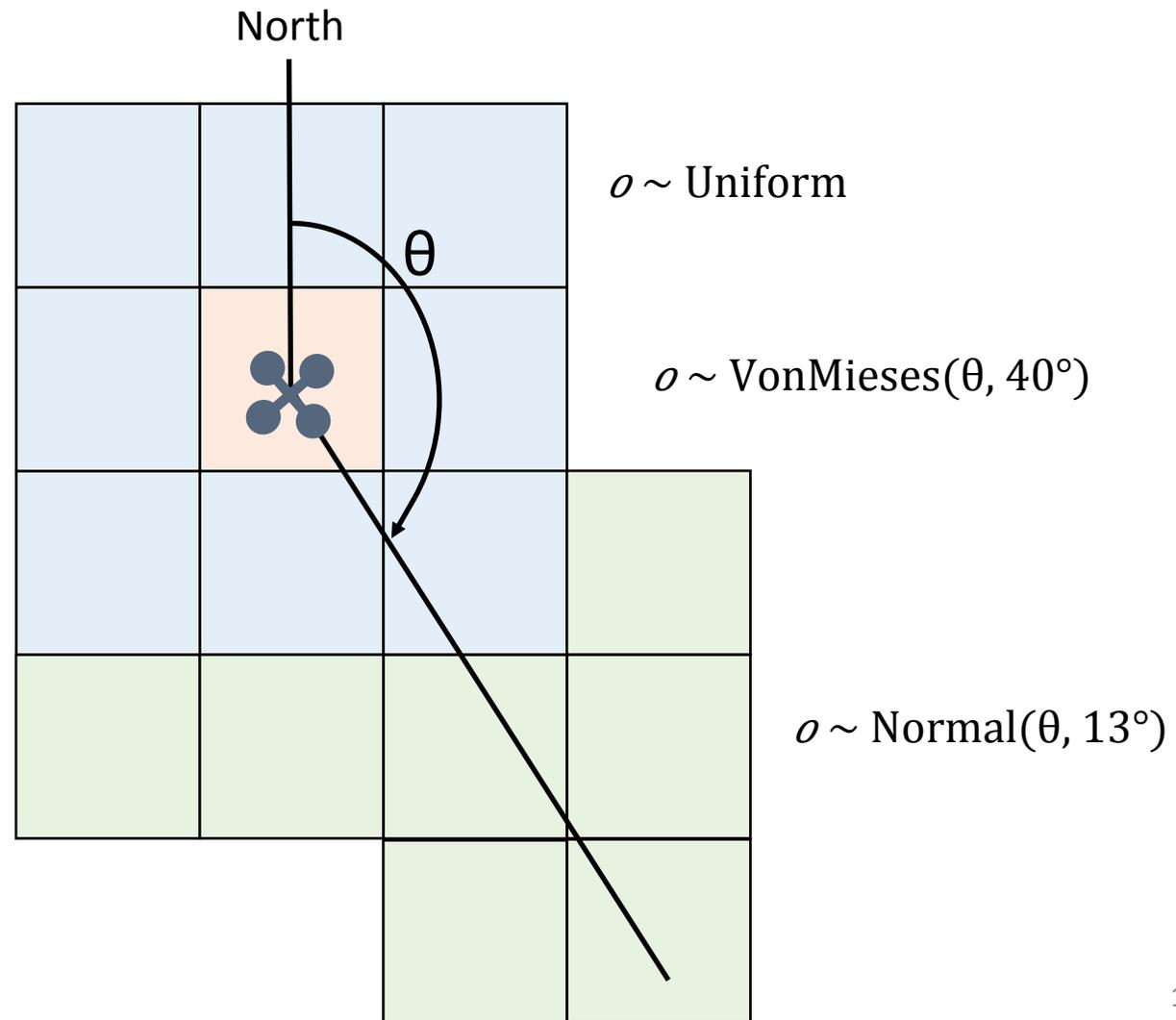
Std Dev. Angular Error	Range
44.2°	Close
13.7°	Else



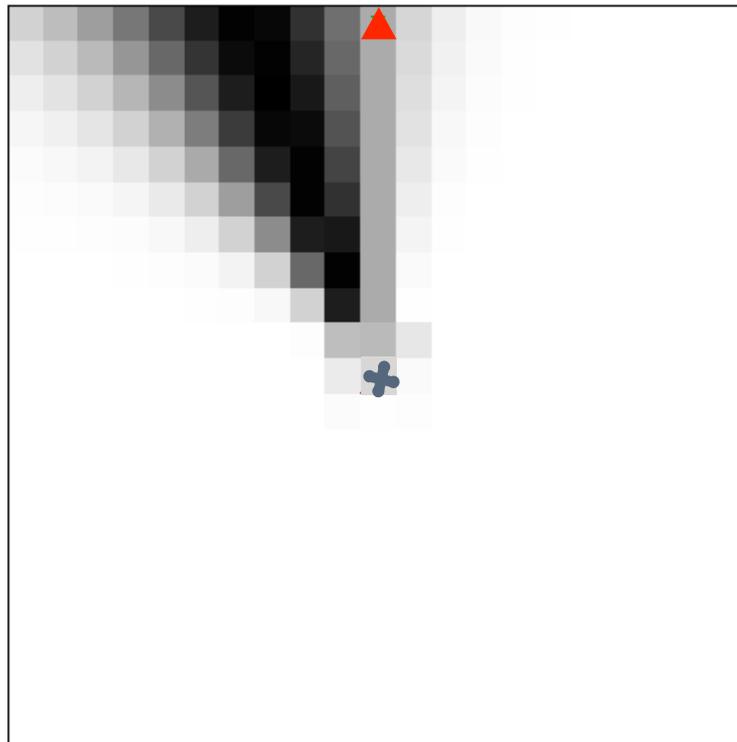
Close (7m)



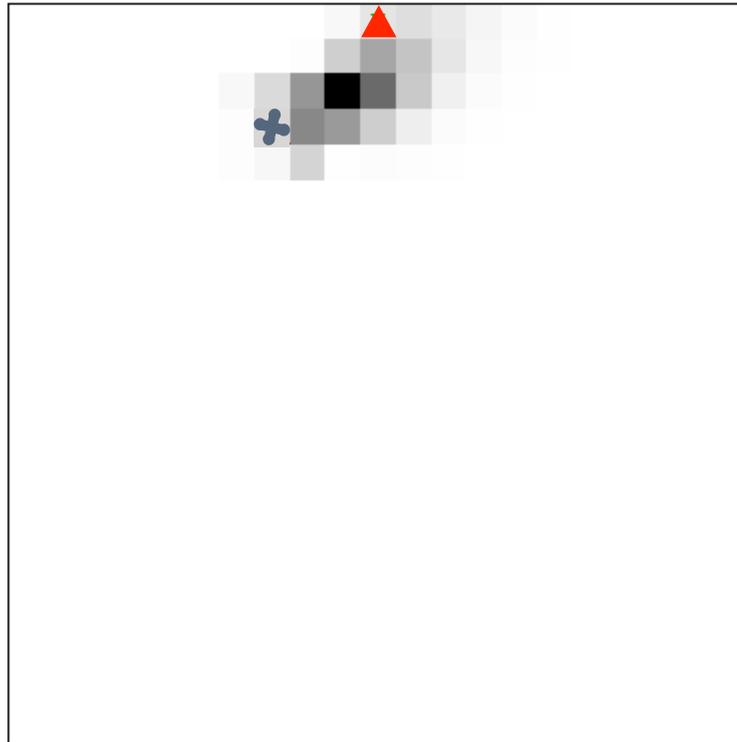
Observation Model

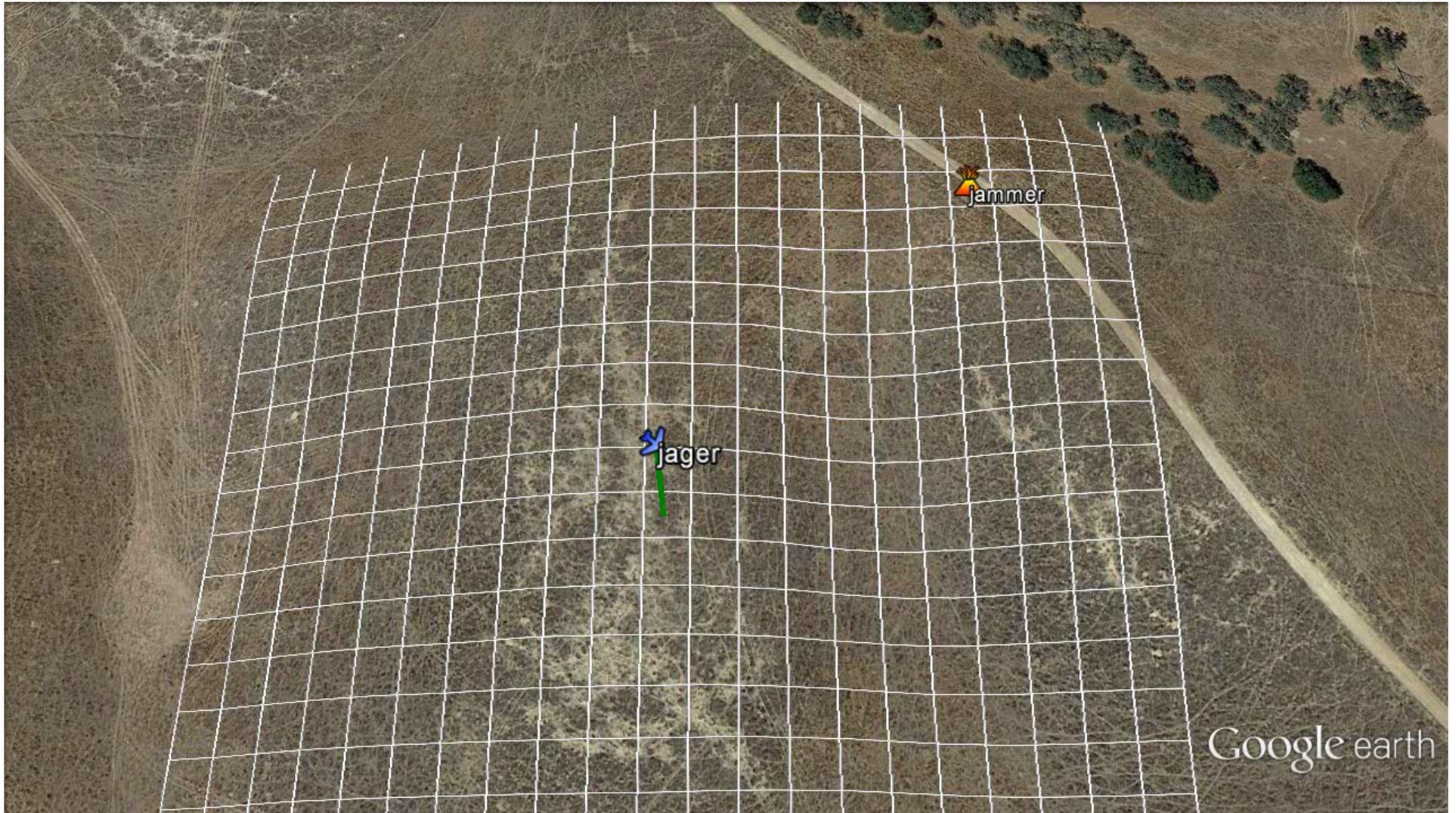


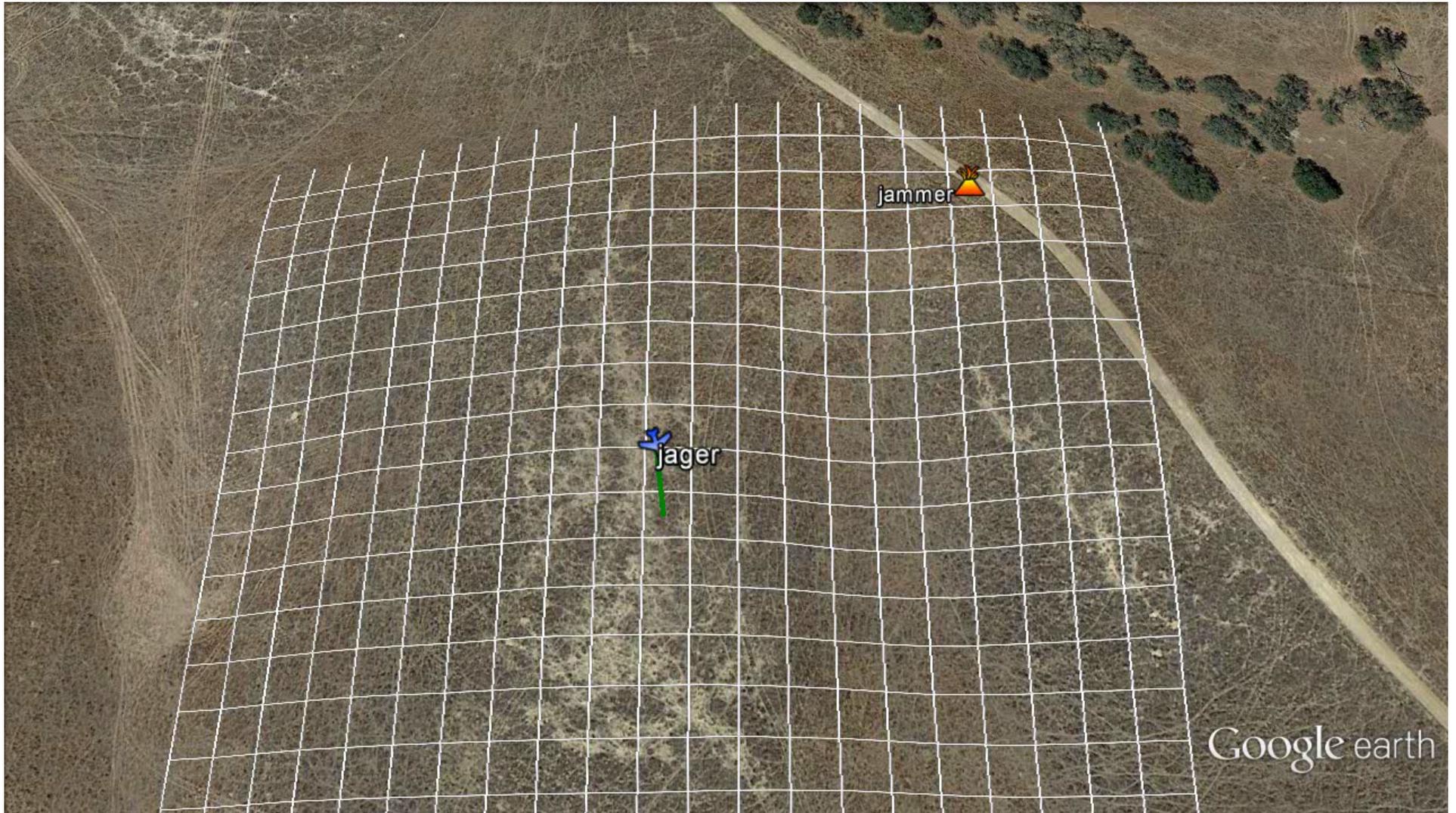
Greedy Minimization of Entropy



Greedy Minimization of Entropy







Improvements

POMDP

- What if we don't want to be greedy?
- Partially observable Markov decision Process (POMDP)
 - Theoretically optimal, non-greedy

- A POMDP consists of:

- State space

$$s = [x \downarrow v, y \downarrow v, x \downarrow j, y \downarrow j]$$

- Action space

- Transition function

$$T(s' | s, a)$$

- Observation function

$$O(o | s)$$

- Reward function

$$R(s, a) \text{ vs } J(b, a)$$

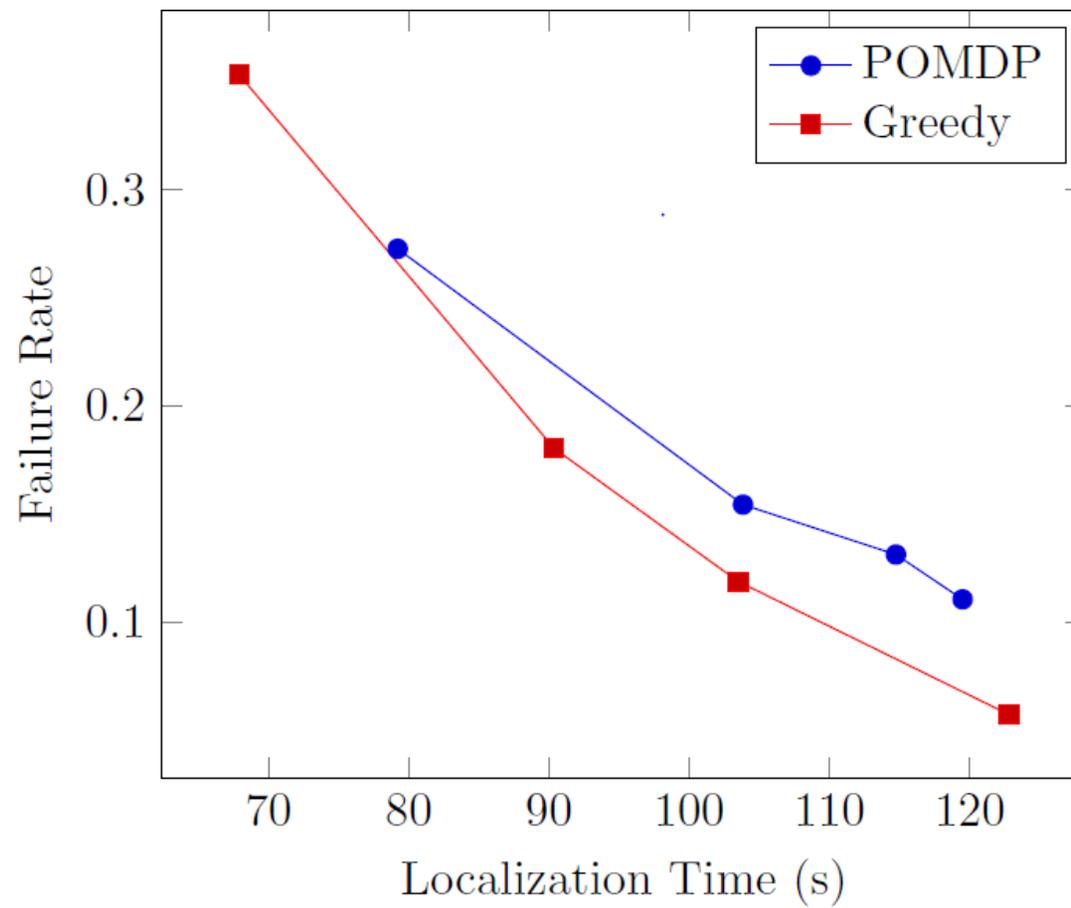
- Discount factor

γ

Goal: maximize

$$\sum_{t=0}^{\infty} \gamma^t R(s, a)$$

POMDP Performance

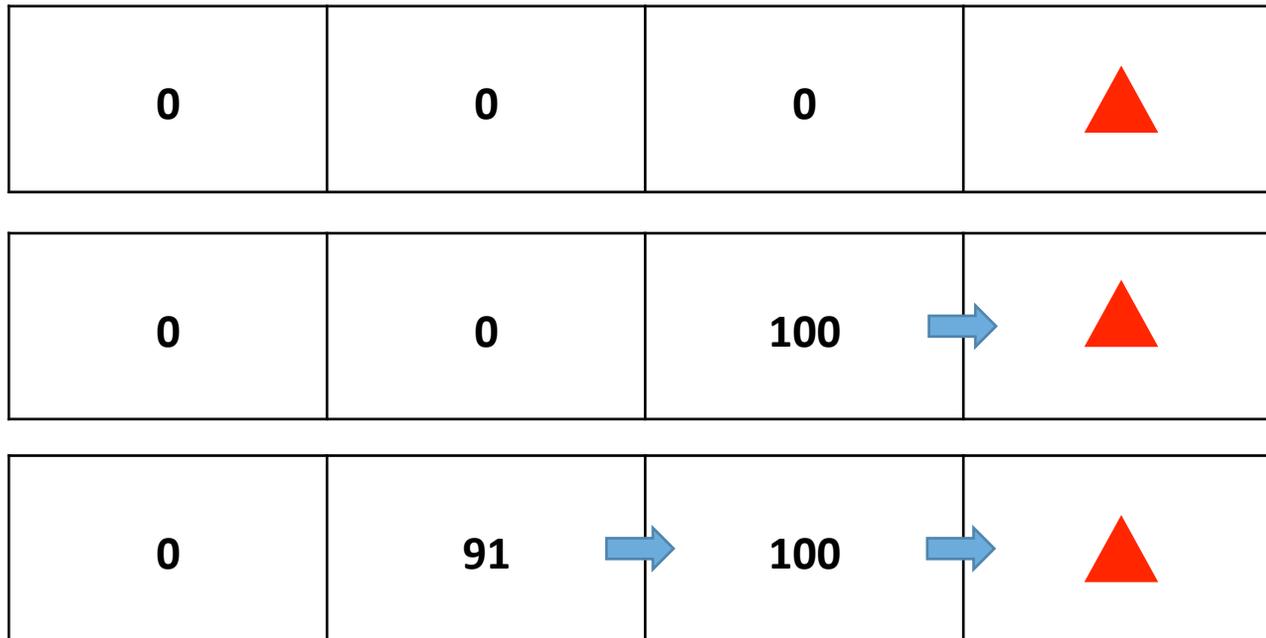


Road Map

- Value function requires $R(s,a)$ for PWLC
- Rewrite $\rho(b,a)$ as PWLC (Araya 2010)
- Toy problem and implementation

Value Function

$$V_{i+1}(s) = \max_a \{R(s,a) + \gamma \sum_{s'} T_{s'|s,a} V_i(s')\}$$



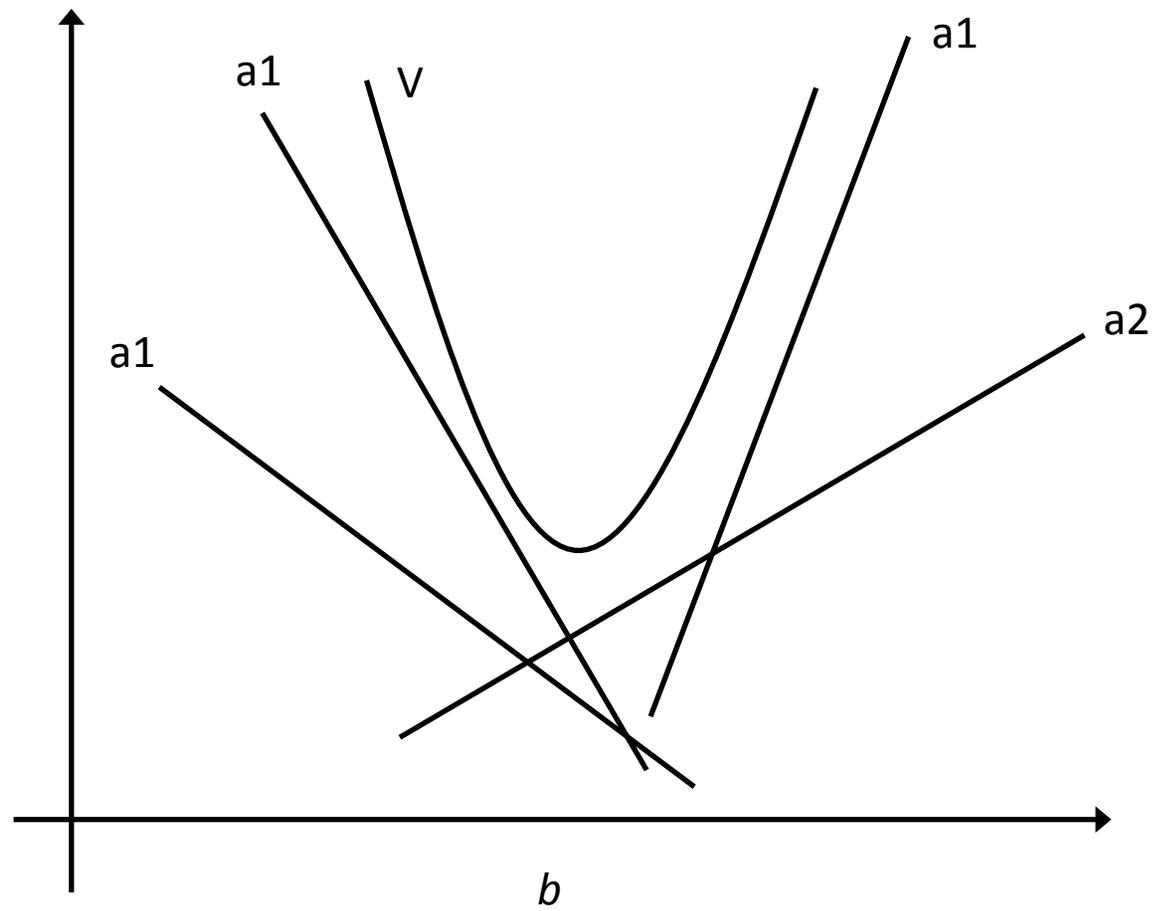
POMDP Value Function

$$V_{i+1}(b) = \max_a \{ \rho(b, a) + \gamma \sum_{o \uparrow} P_{oa, b} V_i(b') \}$$

$$V_{i+1}(b) = \max_a \{ \sum_{s \uparrow} R(s, a) b(s) + \gamma \sum_{o \uparrow} P_{oa, b} V_i(b') \}$$

$V_{i+1}(b)$ will be **PWLC!**

POMDP Value Function



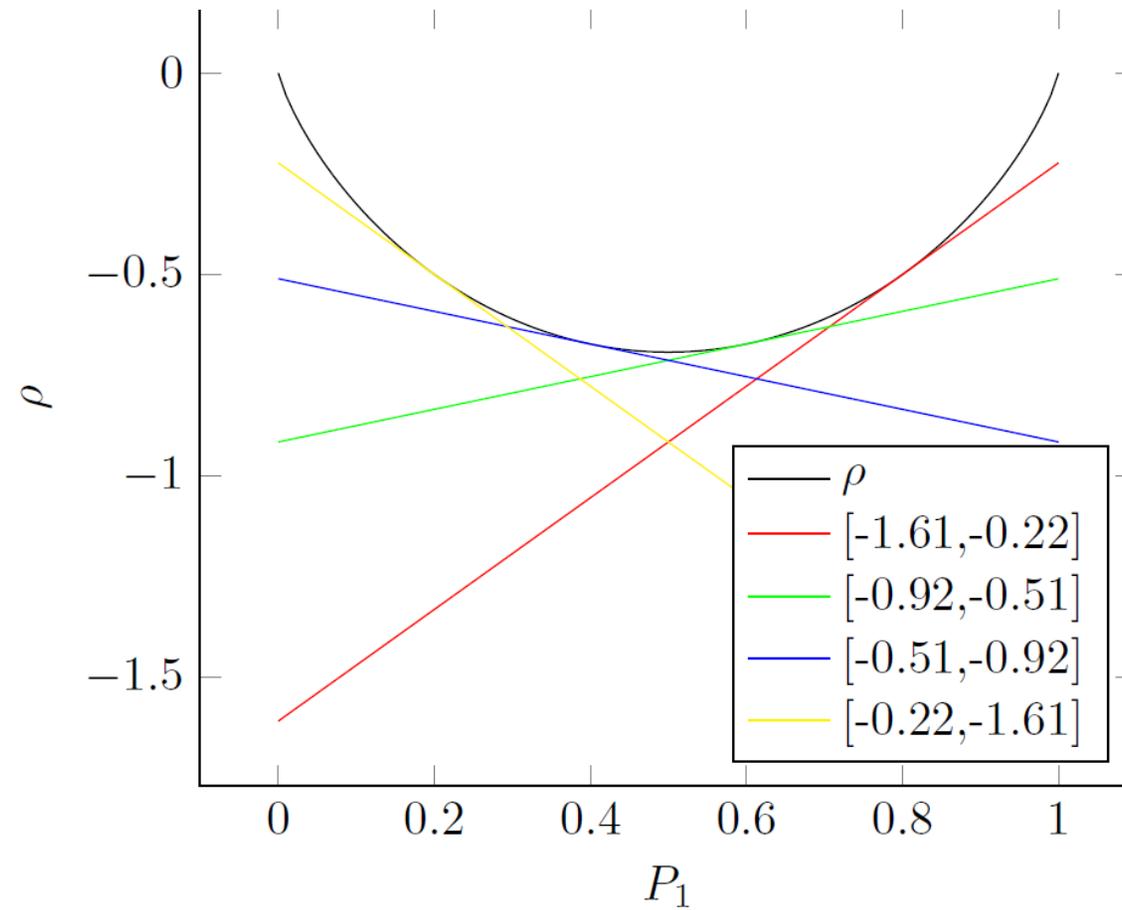
Represent ρ as PWLC!

$$V_{i+1}(b) = \max_{\tau, a} \{ \rho(b, a) + \gamma \sum_{o \uparrow} P_{oa, b} V_i(b') \}$$

$$V_{i+1}(b) = \max_{\tau, a} \{ \sum_{s \uparrow} R(s, a) b(s) + \gamma \sum_{o \uparrow} P_{oa, b} V_i(b') \}$$

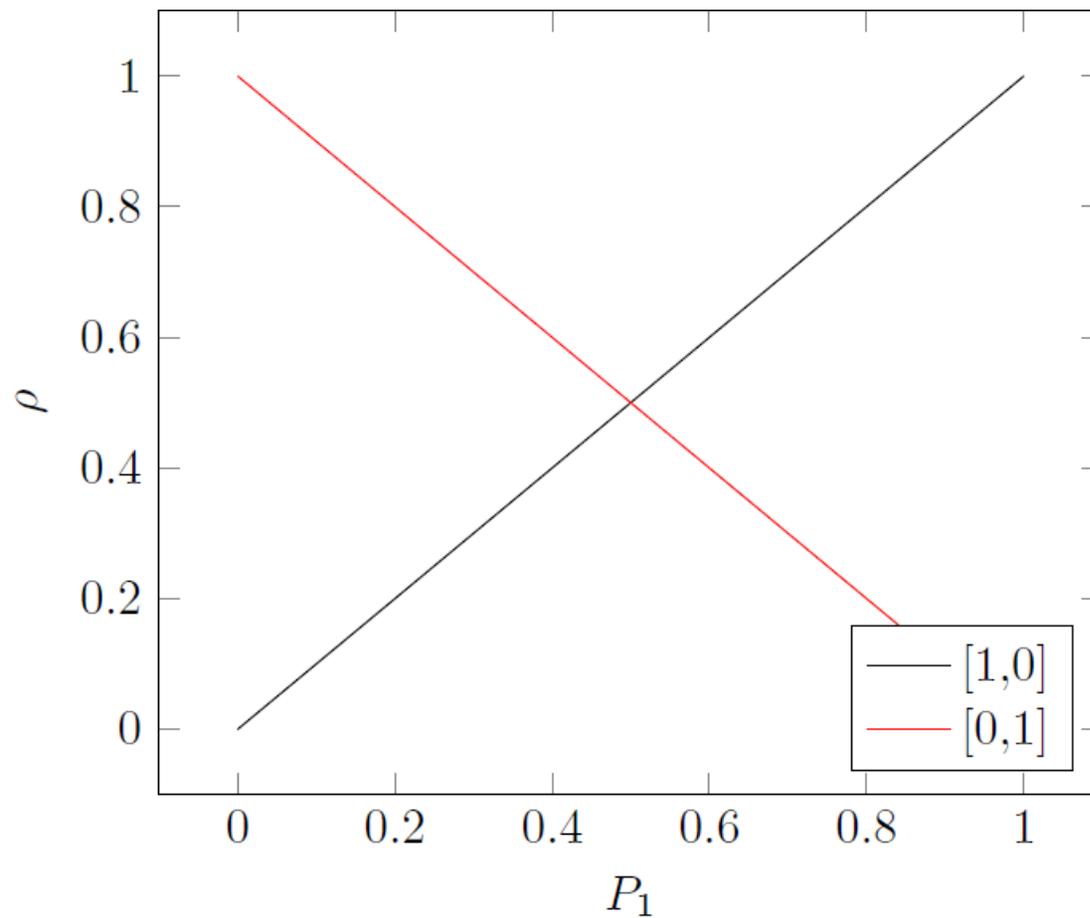
$$V_{i+1}(b) = \max_{\tau, a} \{ \max_{\alpha \in \Gamma} \rho \uparrow \sum_{s \uparrow} \alpha(s) b(s) + \gamma \sum_{o \uparrow} P_{oa, b} V_i(b') \}$$

PWLC Approximation of Entropy



Maximum Probability of Belief

Standard
Basis Vectors



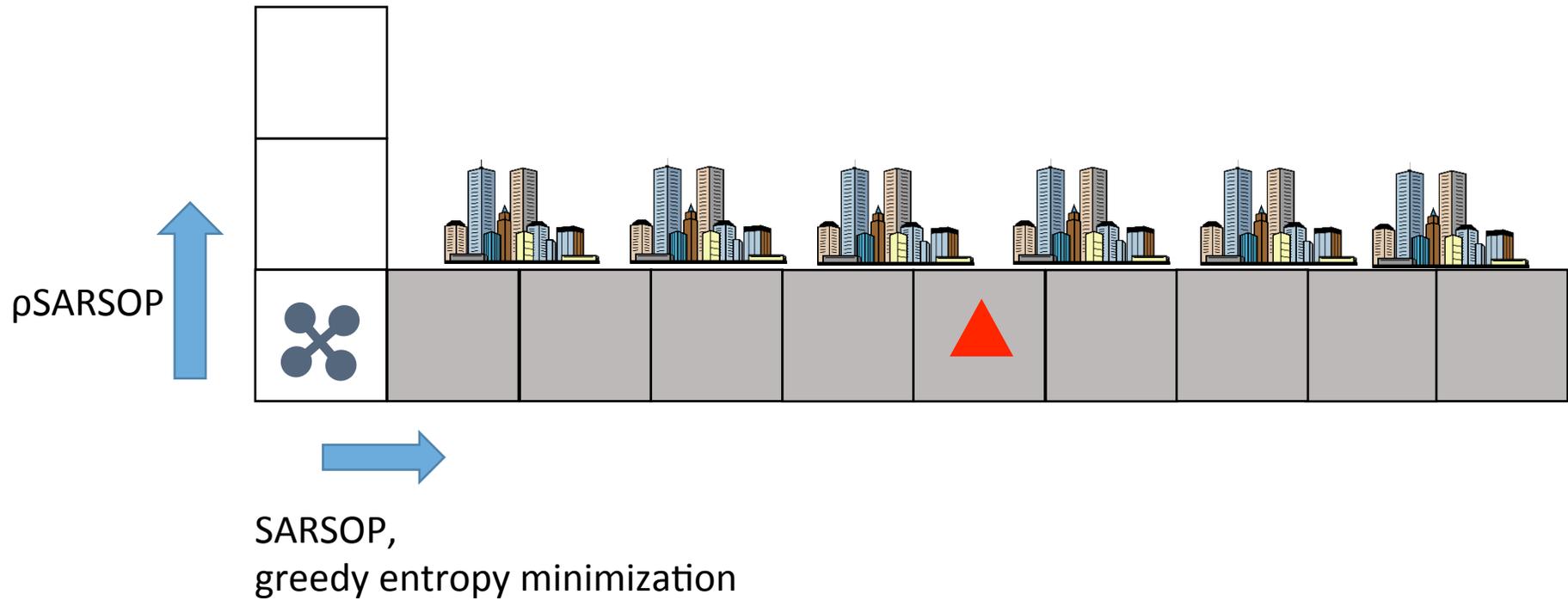
Implementation

- APPL's SARSOP is state of the art solver

Problem	APPL (s)	Me (s)
Tiger	0.015	0.015
Shuttle	0.02	0.02
Lazy Scout	0.45	5.3

- Implement and modify SARSOP => ρ SARSOP

Lazy Scout



ρ SARSOP gets the optimal, non-greedy action

Why do we care?

Principled, optimal approach to localization.

Why do we care?

Principled, optimal approach to **navigation**.

Conclusion

So far:

- Modeling
- Greedy, entropy minimizing control policy
- Hardware implementation

Future

- Scale up ρ SARSOP
- Recouple bearing and motion
- Characterize noise in urban environment

APNT



Active Sensing for Bearing

- Which direction to rotate?
- How fast, how long?

