Finding Convex Hulls of Agents with Sensor Networks

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Introduction

- Relational approach to algorithm design
- Determine if agent is surrounded by enemies
- Minimize number of sensor queries required
Overview

- Introduction
- Problem Definition
- Generative Model
- Inference in the Network
- Integrated Sensor Selection Techniques
- Experimental Results
- Conclusion
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Problem Definition

- LF in convex hull with high probability?
- PIR and Amplitude sensors

Known
- LF  (location of friendly agent)
- \(S_1 \ldots S_M\)  (type of each sensor)
- \(LS_1 \ldots LS_M\)  (locations of sensors)
- \(C_1 \ldots C_T\)  (sensor observations)

Unknown
- \(LE_1 \ldots LE_N\)  (locations of enemy agents)
PIR Sensors

- Passive Infrared Intrusion Sensor
- Detects agents in triangle adjoining sensor
- Algorithm choose direction of sensing
- \[ P(d \mid d') = 1 - 0.2 \times p \]
- \[ P(d \mid \neg d') = 0.1 \]
Amplitude Sensors

- Detects enemy in circle surrounding sensor
- Returns presence and distance to nearest agent
- \( P(d \mid d') = 1 - 0.2 \times p \)
- \( P(d \mid \neg d') = 0.1 \)
- \( s \sim N(s', u) \)
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Generative Model

- SENSOR: Results of sensing
- LE: Locations on enemies
- CCW: CCW over LE variables
- CONTAIN: LF in subset convex hull
- SURROUNDED: LF in entire convex hull
Generative Model

SENSOR_1
SENSOR_2
SENSOR_3
LE_1
LE_2
LE_3
LE_4
CCW_1_2
CCW_1_3
CCW_1_4
CCW_2_3
CCW_2_4
CCW_3_4
Generative Model
Generative Model

CCW_1_2  CCW_1_3  CCW_1_4  CCW_2_3  CCW_2_4  CCW_3_4

CONTAIN_1_2_3  CONTAIN_1_2_4  CONTAIN_1_3_4  CONTAIN_2_3_4

SURROUNDED_1_2_3_4
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Inference in the Network

- Difficulties with traditional inference
- Posterior estimation via particle filters
  - Compute LE posteriors given SENSOR variables
  - Compute CONTAIN posteriors given LE
  - Bound SURROUNDED given CONTAIN
LE Posterior from SENSOR

Particles in green gain weight; other particles unaffected

Particles in blue lose weight
Data Association Problem

- Impossible to differentiate enemy agents
- Find joint posterior over LE given SENSOR
- Run K-means to use in later inference
- Hard assignment of points to clusters
- Model selection for number of enemies
CONTAIN Posteriors Given LE

- Using CCW would yield inaccurate posteriors
- Sample from point clouds of each LE variable
- Count number of times assertion holds
- N-sided polygons often helpful
SURROUNDED Given CONTAIN

- CONTAIN variables generally not independent
  - Greedily choose pairwise disjoint variables
  - Calculate posterior over chosen sets

- Independent if LE variables used disjoint
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Intrinsic Difficulty

- Inherently difficult scenarios:
  - When agent is not surrounded
  - When required agents outside sensor range
  - Friendly agent collinear with enemy agents
- Certain configurations confound particle filter
- Simple metric:
  - Inverse of distance to convex hull
  - Infinite if not surrounded
Sensor Utility Computation

- Want to maximize sensor utility
- Exact computation
  - Build search tree of sensor choices
  - Choose first sensor of best branch
  - Exponential in number of sensors
- Greedy computation
  - Depth limited search
  - Linear in inference time
Algorithm RANDOM

- Chooses sensors randomly
- Repetition of sensors never allowed
- Better than sensing at all sensors
Algorithm TRIANGLE

- Uses RANDOM until three affirmative readings
- Build triangles:
  - Two pre-determined enemy agent locations
  - One sensor location as potential agent location
  - Triangle contains friendly agent
- Choose unused sensor with most triangles
Algorithm ENTROPY

- Uses RANDOM until three affirmative readings
- Calculate entropy for each expected reading
  - Do calculation for each unused sensor
  - Only affirmative response calculated
- Choose unused sensor with lowest entropy
- Running time linear with number of sensors
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Algorithm RANDOM
Algorithm TRIANGLE
Algorithm ENTROPY
Varying Number of Enemies

![Graph showing different number of enemies with Triangle, Entropy, and Random lines.](image)
Varying Number of Sensors
Varying Sensor Composition
Varying Field of View
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Conclusion

- Probabilistic model for Surrounded problem
- Inference technique for calculating posteriors
- Algorithms to choose subsequent sensors