Guarding, Searching and Pursuing Evaders using Multiagent Systems

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Computer Vision and Active Perception (CVAP)

Todays topics

- Cooperative guarding
  - Static guards
- Cooperative search
  - Static targets
- Cooperative pursuit evasion
  - Moving targets and guards

Example Scenario

- Airport
- Power plant
- Military base
- Port
- Factory
- ...

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This field is very broad
- Overview of problems, results and tools

Common theme: Discretizing the search space

- Partitioning search space into convex sets is often useful
- Create a graph
  - Set <-> vertex
  - Neighbor <-> edge

Some naive solutions:
- Guarding
  - Each set has guard on border
- Search
  - Travelling salesman

Can we improve on these conservative solutions?
Problem (Minimum set cover) Let \( E = \{e_1, \ldots, e_n\} \) be a finite set.

Problem: 
- Min number of cameras,
- Max coverage with \( N \) cameras,
- Weighted coverage
- Environment: 2D/3D

Greedy algorithm performs well , Chvatal (1975) proved bound: \( \text{Floor}(n/3) \)

Further reading on Guarding

- Efrat (2002) randomized search instead of the greedy

Bounds on number of Guards

- The General Art Gallery Problem: What is the smallest number of guards needed to cover any polygon with \( n \) vertices and \( h \) holes.
- For \( h=0 \), Chvatal (1975) proved bound: \( \text{Floor}(n/3) \)
- Hoffman (1991) proved bound: \( \text{Floor}((n+h)/3) \)

Minimize number of guards (3D etc)

- Problem: (Min number of guards)
- Problem (Minimum set cover) Let \( E = \{e_1, \ldots, e_n\} \) be a finite set of elements, and let \( S = \{s_1, \ldots, s_m\} \) be a collection of subsets of \( E \), i.e. \( s_j \subseteq E \). The problem minimum set cover is the problem of finding a minimum subset \( S' \subseteq S \) such that every element of \( E \) belongs to at least one subset in \( S' \). We say that \( E \) is covered by \( S' \).
- \( \text{NP-hard} \)
- Greedy algorithm performs well , Eidenbenz (2002)

Minimizing number of guards (3D etc)

- Marangoni (2000)
- Triangulation of 3D environment
- Vertex coloring to find subset
- Visibility computation to get candidates
- Efrat (2002) randomized search instead of the greedy

Guarding with resolution constraints

Movie: Guarding with resolution constraints
Bullo Coverage

- Distribute agents \( p_i \) to
- Minimize Expected squared distance
- From random event
- To nearest agent

\[
H(p_W) = \sum_{i=1}^{n} \int_{W_i} |y_i - p_i(x,y)| dy
\]

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Cooperative Search (Background: TSP)

- Travelling Salesperson Problem (TSP)
- Variations
  - Multi-TSP
  - Metric TSP
  - Vehicle routing problem
  - Max capacity
  - Time windows
  - ...

1300 cities, 2468 edges, 10076 vertices, 16086040 distance units.

It involves ideas from polyhedral combinatorics and computational geometry, integer and linear programming, combinatorial optimization, operation research, algorithms and data structures, parallel computing, software engineering, numerical analysis, graph theory, and more.

Cooperative Search

- Sensor range gives two cases
- Range similar to environment size
  - (next slide)
- Range << environment size
  - Shuzhi (2005) proposes solution

Cooperative Search (long sensor range)

- Possible approaches:
  - Use Guard positions and solve m-TSP
  - Discretize to a graph and solve m-TSP
  - Use convex cover and solve m-TSP...

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Example of Cooperative search (Anisi 2010)

Cooperative Search

- How can we make search less conservative?
- Replace partition with overlapping convex cover

Create Convex Cover Sets

Perform Tabu Search on Order of Set Visitation

Solve Shortest Path Problem to find Paths Visiting Sets

Further reading on cooperative search


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Cooperative Pursuit Evasion

- First introduced by Parsons (1976)
  - Problem on a graph
  - Multiple searchers
  - simple polygon
  - single searcher (k-searcher)
- Limited field of view: Gerkey et al. (2006)
  - capability of a robot with a camera
  - (phi-searcher)
Randomized Pursuit Evasion

- Randomized strategy: Isler et al. (2005).
- By repeating a randomized strategy, capture probability can be made arbitrarily high (if simply connected).

Cooperative Pursuit Evasion

- Efrat et al. (2000) consider chains of searchers in simple polygons
- Hollinger et al. (2007) a probabilistic similar to Markov Decision processess (MDP) and partially observable MDP (POMDP)

MILP/MPC approach to Pursuit Evasion

- Constraints addressing

MILP approach to Pursuit Evasion

- Too short planning horizon ...
- More searchers or decompose problem

MILP: Recontamination

- Sometimes recontamination is required
- Then success depends on planning horizon
MILP: Additional constraint

- Additional constraint can be added:
  - Line of sight every 4th timestep

MILP/MPC Pros and Cons

- Handles recontamination (planning horizon)
- Handles connectivity constraints
- Scales poorly with planning horizon length
- Scales poorly with environment size
- Add static "guard" to partition environment
- Scales well with number of agents

Further reading on pursuit evasion


MILP approach to Pursuit Evasion

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Thank you ...