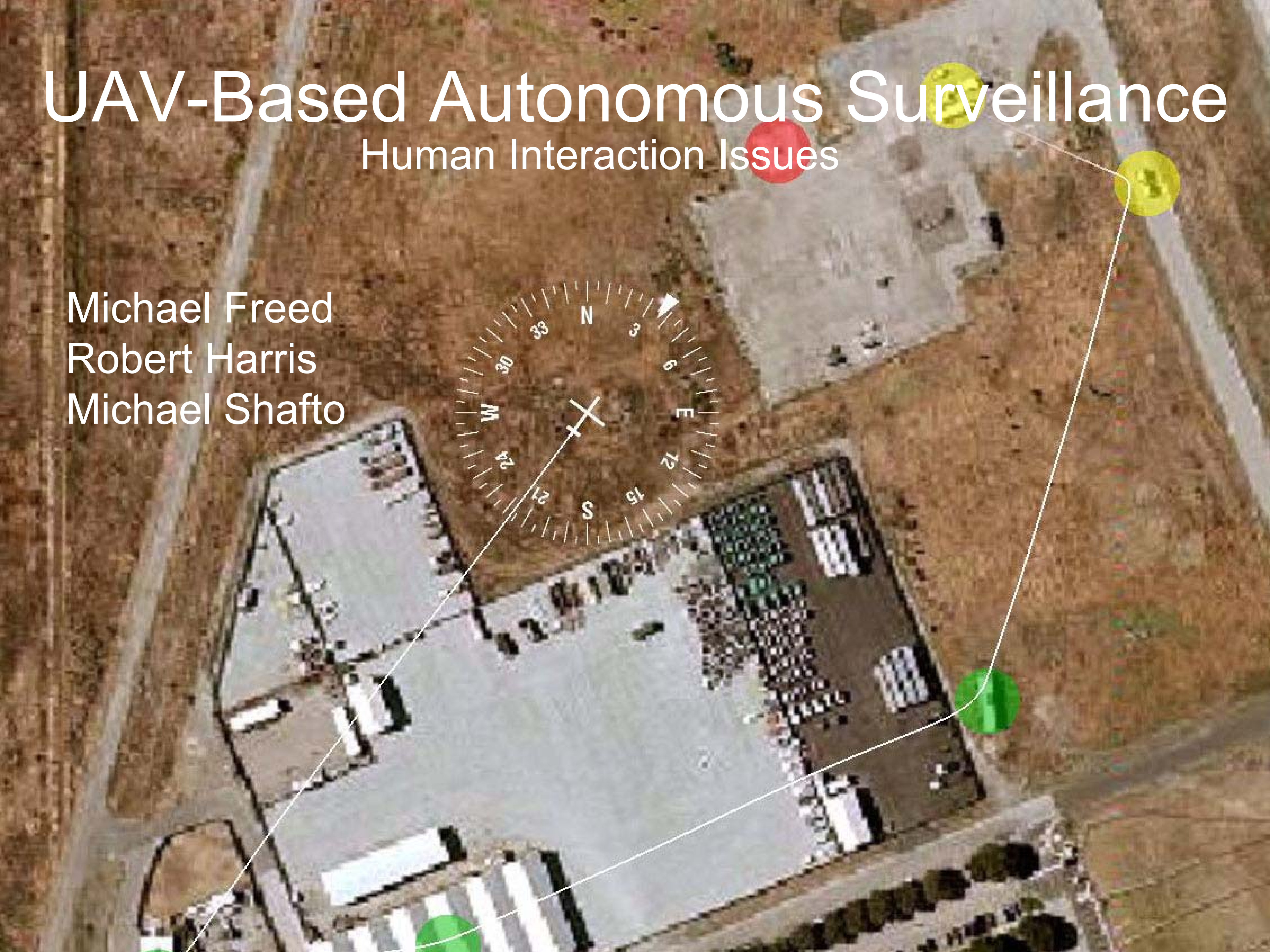
UAV-Based Autonomous Surveillance

Human Interaction Issues

Michael Freed
Robert Harris
Michael Shafto



Army/NASA Autonomous Rotorcraft Project

Army/NASA Autonomous Rotorcraft Project

Project objective: versatile, practical airborne observation platform effective for range of missions

- Capabilities of modified Yamaha RMAX
  - Enough payload cap. for lots of sensors, computing, …
  - Enough range and speed for operationally significant
- Surveillance mission decision-making
  - Human users (information consumers) define targets and values initially, revising as desired during missions
  - **Robot role**: depends on how effective autonomy mechanisms (Apex) likely to be at serving user goals

Army/NASA Autonomous Rotorcraft Project

Many useful observation functions

Why focus on surveillance?

- Acknowledged as a critical function in diverse operational environments
- Current practice unsatisfactory (too boring)
- Achievable with current perception/action technology

Talk outline

Human-Interaction Emphasis: allocation of decision-making responsibilities between human and autonomy based on empirical characterization of relative strengths

1. What is surveillance? What does it mean to do it well?
2. Mission scenario testbed/tools for measuring surveillance performance
3. Pilot study: comparing human to algorithm performance

The Surveillance Problem

Example Scenario

Area of operations

Valuable assets

- docks
- warehouses
- lighthouse
- orchard tract

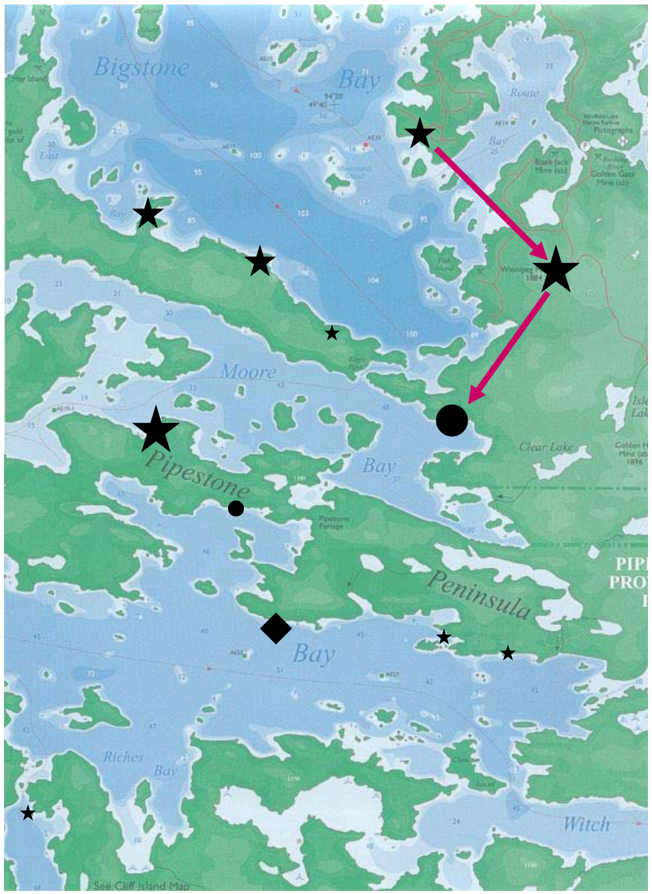
Risk: structure can start on fire at any time

UAV Goal: do a good job detecting fires

What does it mean to do a good job at surveillance in this kind of scenario?

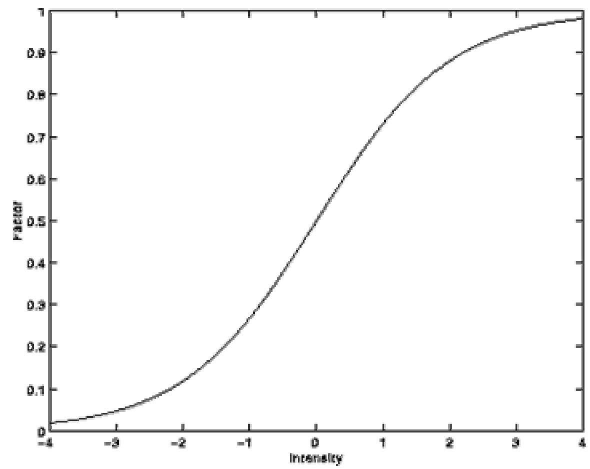
The Surveillance Problem

Surveillance Performance Factors



The more often a target is visited the better.

$

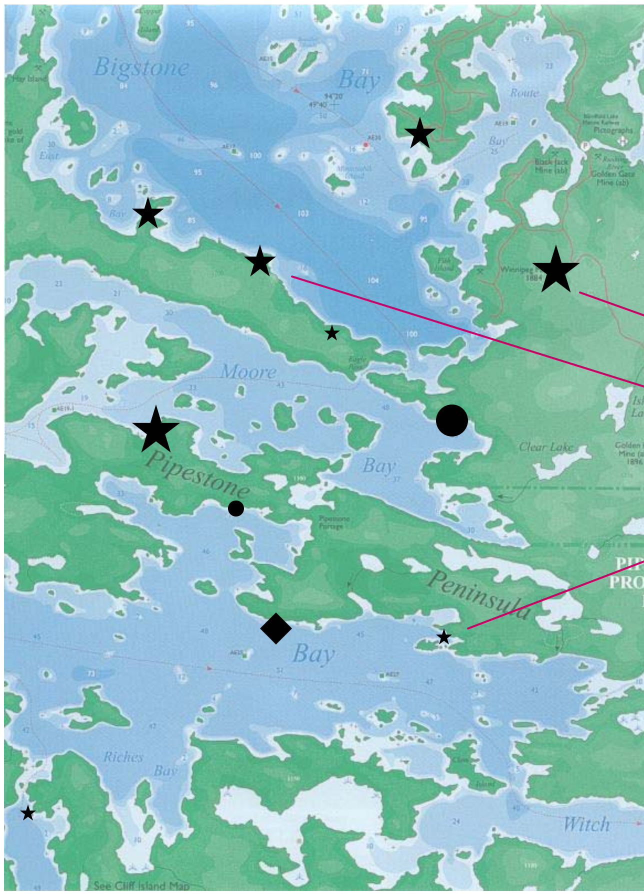


Time

⇨ fly efficient routes to observe targets as frequently as possible

The Surveillance Problem

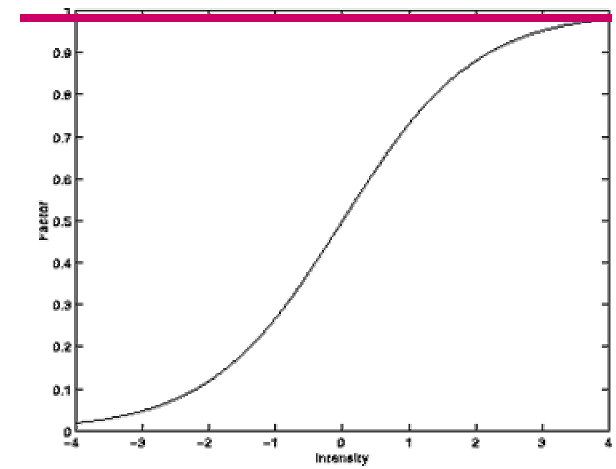
Surveillance Performance Factors



Some targets are more valuable than others

max cost

$5M
$2M
$1M



⇨ Visit some targets more often than others
⇨ Possibly skip some entirely

The Surveillance Problem

Surveillance Performance Factors

remote, unimportant, needy

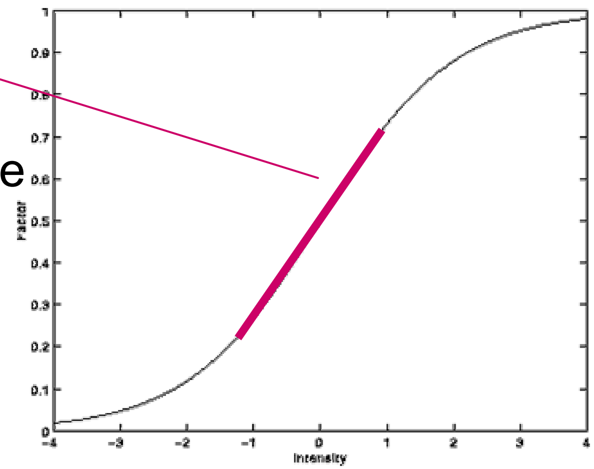
Some targets accumulate cost (burn) faster than others

rate

brick/stone

wood

mixed



⇨ Visit some targets more often than others

⇨ Possibly skip some entirely

The Surveillance Problem

Surveillance Performance

Other potentially important factors

- probability of occurrence
- detection latency
- communication latency
- intervention latency
- repeatability / concurrency

Measuring Surveillance Performance

Goal of surveillance is to:

minimize the total expected cost of ignorance for all targets in the operational area over a specified mission time interval

Expected Cost of Ignorance for target τ over interval [t1, t2] in which τ is not observed:

$$\mathrm{ECI}_{\tau}(t_1, t_2) = \int_{t=t_1}^{t_2} p(t) \cdot \mathrm{cost}(t_2 - t)\,dt$$

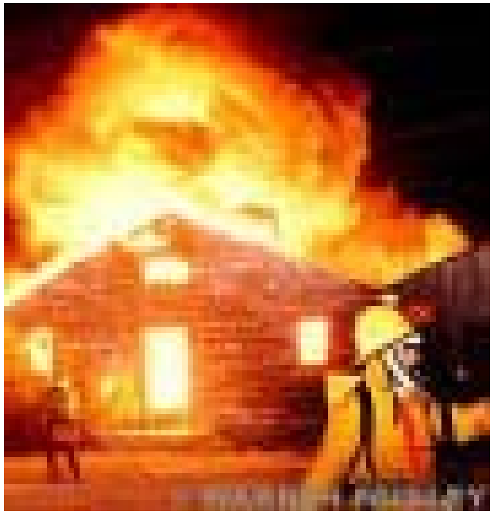
probability density function for event (e.g. fire)

occurrence cost function (e.g. sigmoid)

ECI is the sum for all points in the interval of the probability an event occurs at that point times the cost if it occurs at that point.

Measuring Surveillance Performance

Example



Probability of occurrence (pdf)

$p(t) = ae^{-at}$ ← exponential

Cost if it occurs

sigmoid

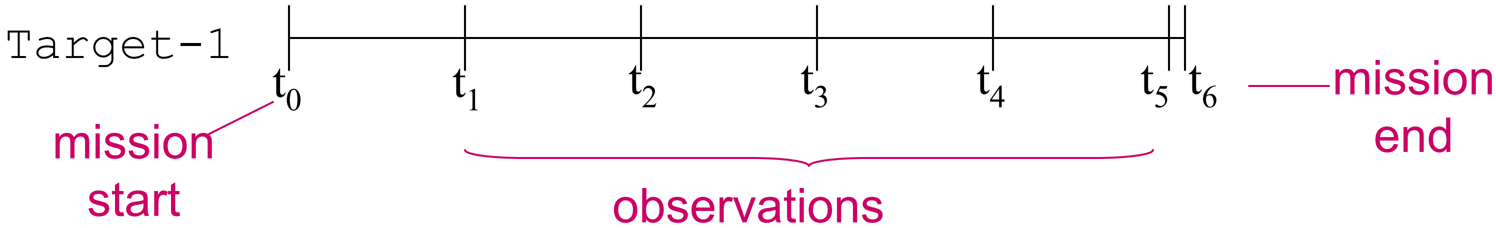
$$\text{cost}(d) = c_0 + \left(\frac{2}{1 + e^{-k(d + l_1 + l_2)}} - 1 \right)(m - c_0)$$

Expected cost of ignorance [t_1 t_2]

$$\text{ECI}_{\tau}\text{ (t1, t2, a, k, m)} = \int_{t=t1}^{t2} ae^{-at} m\left(\frac{2}{1 + e^{-k(t2 - t)}} - 1\right) dt$$

Measuring Surveillance Performance

The observation timeline for a target specifies at what times (if any) the target was (or will be) observed.



Total mission ECI for one target is the of ECI values for inter-observation intervals (including mission start/end points):

$$\text{target-ECI}\ (\tau) = \sum ECI(t_{i-1}, t_i)$$

Measuring Surveillance Performance

Mission-ECI, the total cost of ignorance for all targets accumulated over the mission

$$\text{mission-ECI} = \sum^{\text{targets}} \text{target-ECI}(\tau)$$

The overall surveillance goal is to minimize this value

The value of a surveillance method (algorithm or human operator) in a particular mission is

$$\text{Value}_{<\text{method}>} = \text{mission-ECI}_{\text{max}} - \text{mission-ECI}_{<\text{method}>}$$

worst case performance (no observations made during mission)

Surveillance Algorithms

Scheduling + a bit of planning

- Traveling Salesman Problem (TSP)
- Orienteering Problem
  - Time maximum (visit only subset of targets)
  - Reward varies for individual targets
- Surveillance Problem
  - Repeat visits yield multiple rewards
  - Reward value time-varying
  - Traverse time-cost state-dependent
  - **Reactive version of problem (weather, users)

Characterizing General Strengths and Weaknesses

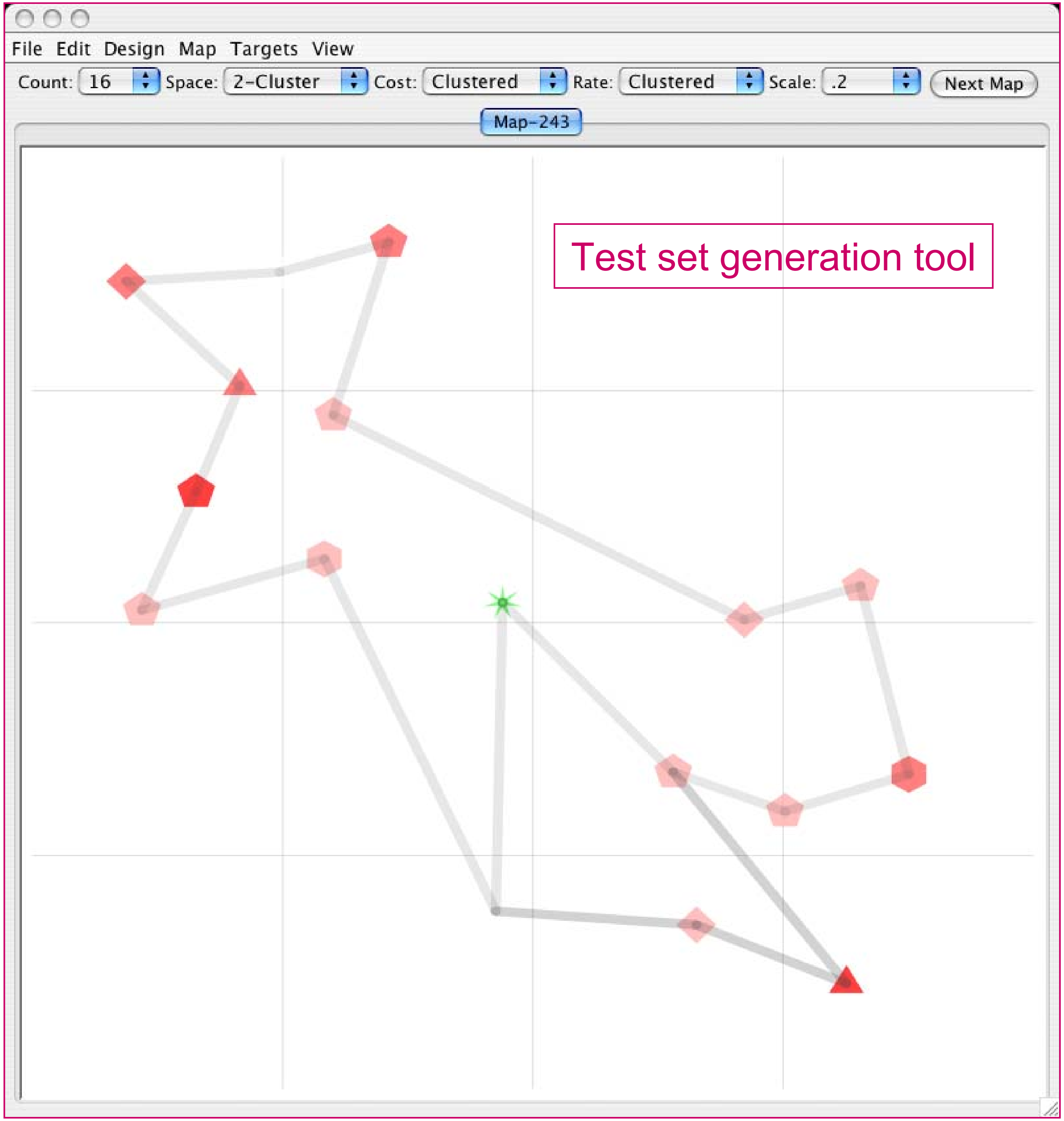
Why

- Picking the best algorithm for the current situation
- Incremental improvement of individual algorithms
- Knowing when human decisions likely to be better

How

- Create set of qualitatively distinct scenarios that cover an interesting part of the space of possible missions
- Create tool to run algorithms and human subjects in all scenarios, quantify/tabulate performance
- Apply tool; abstract out hi/lo performance conditions

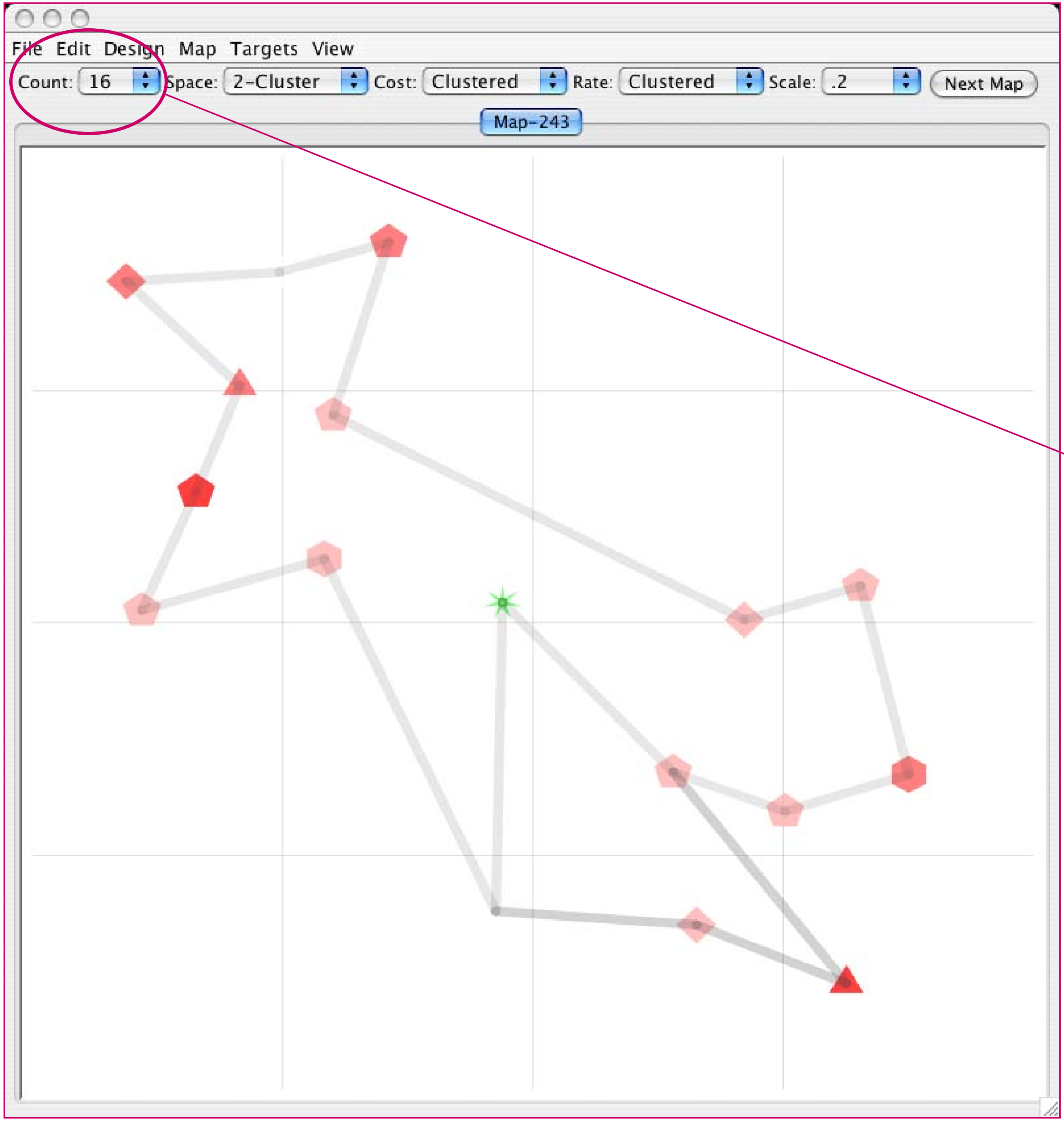
Scenario test set



<u>243 Scenarios</u>

5 dimensions (iv's)

3 values for each



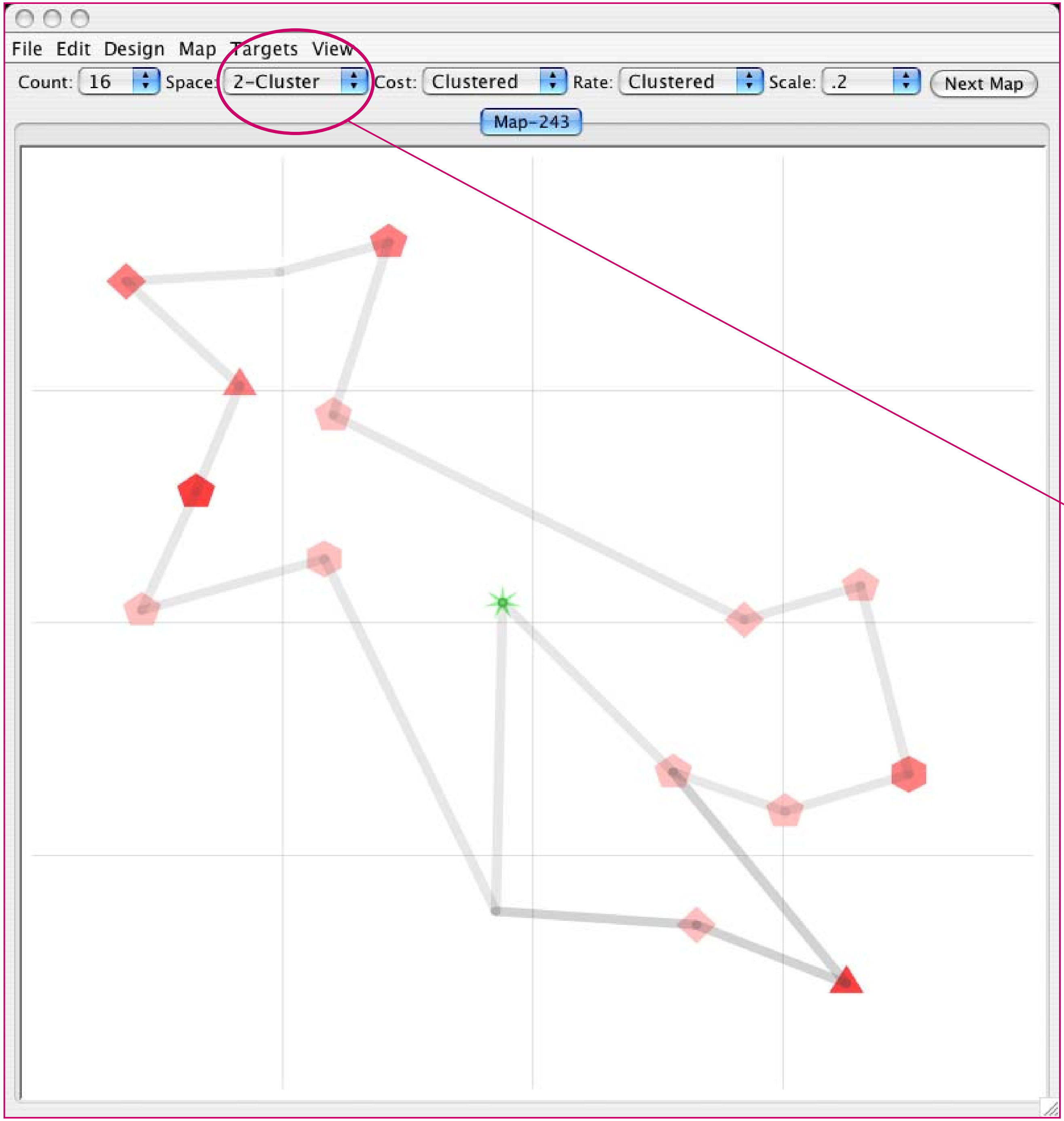
Scenario test set

<u>243 Scenarios</u>

5 dimensions (iv's)

3 values for each

1. Number of targets
   4
   8
   16



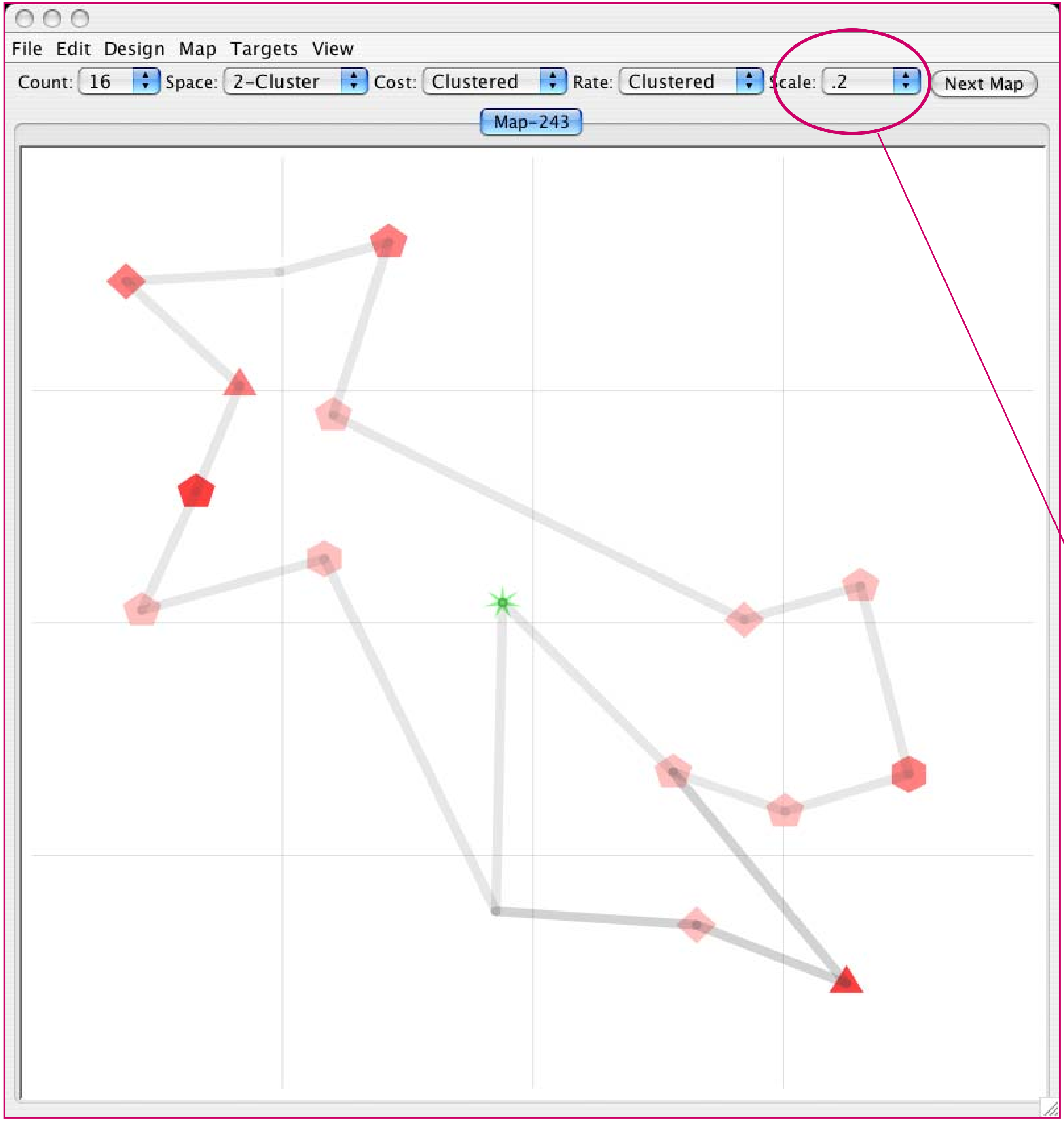
Scenario test set

<u>243 Scenarios</u>

5 dimensions (iv's)

3 values for each

1. Number of targets
2. Spatial Distribution
   uniform
   globular
   2-cluster



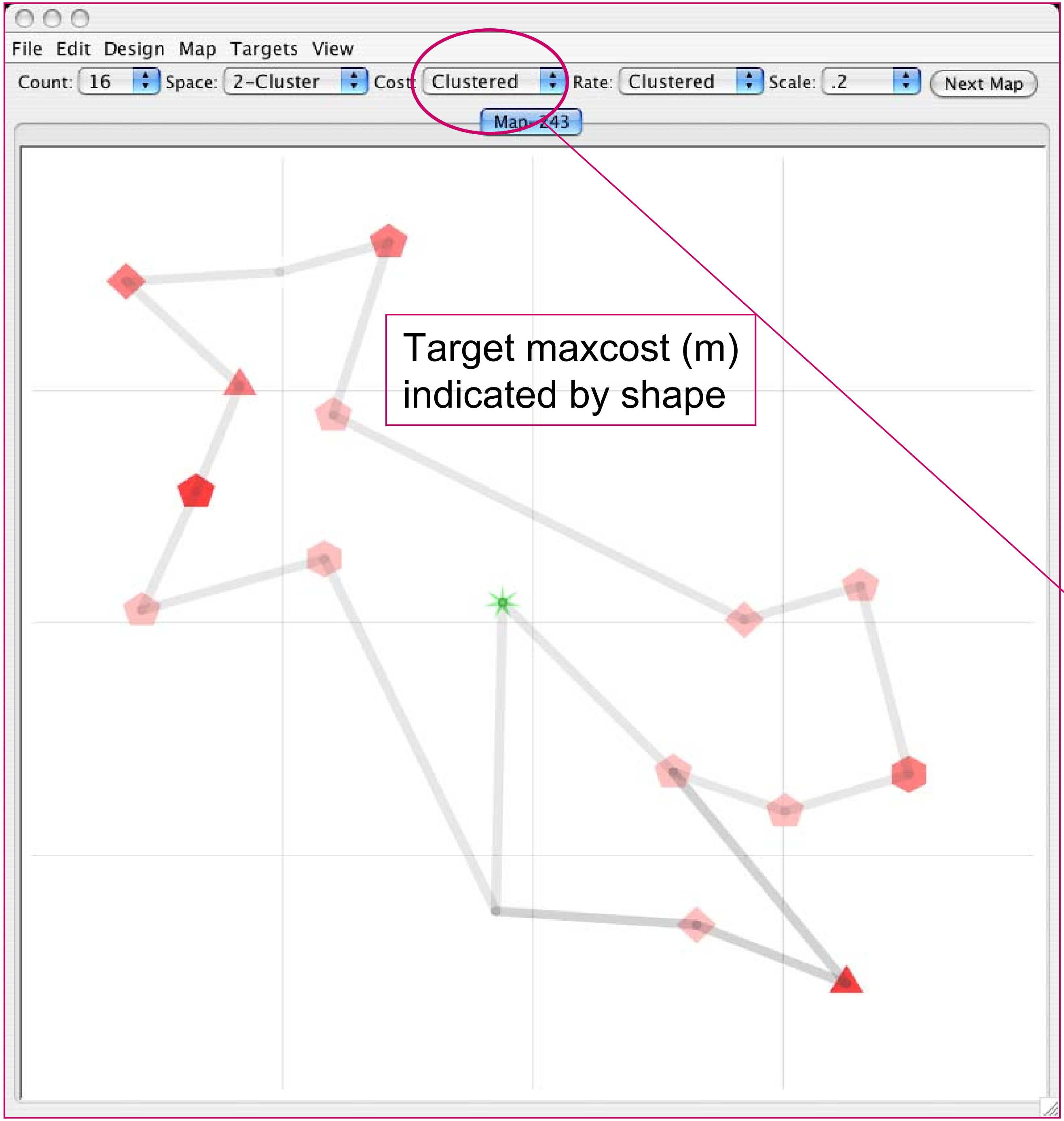
Scenario test set

<u>243 Scenarios</u>

5 dimensions (iv's)

3 values for each

1. Number of targets
2. Spatial Distribution
3. Spatial Scale
   small (.002)
   medium (.02)
   large (.2)



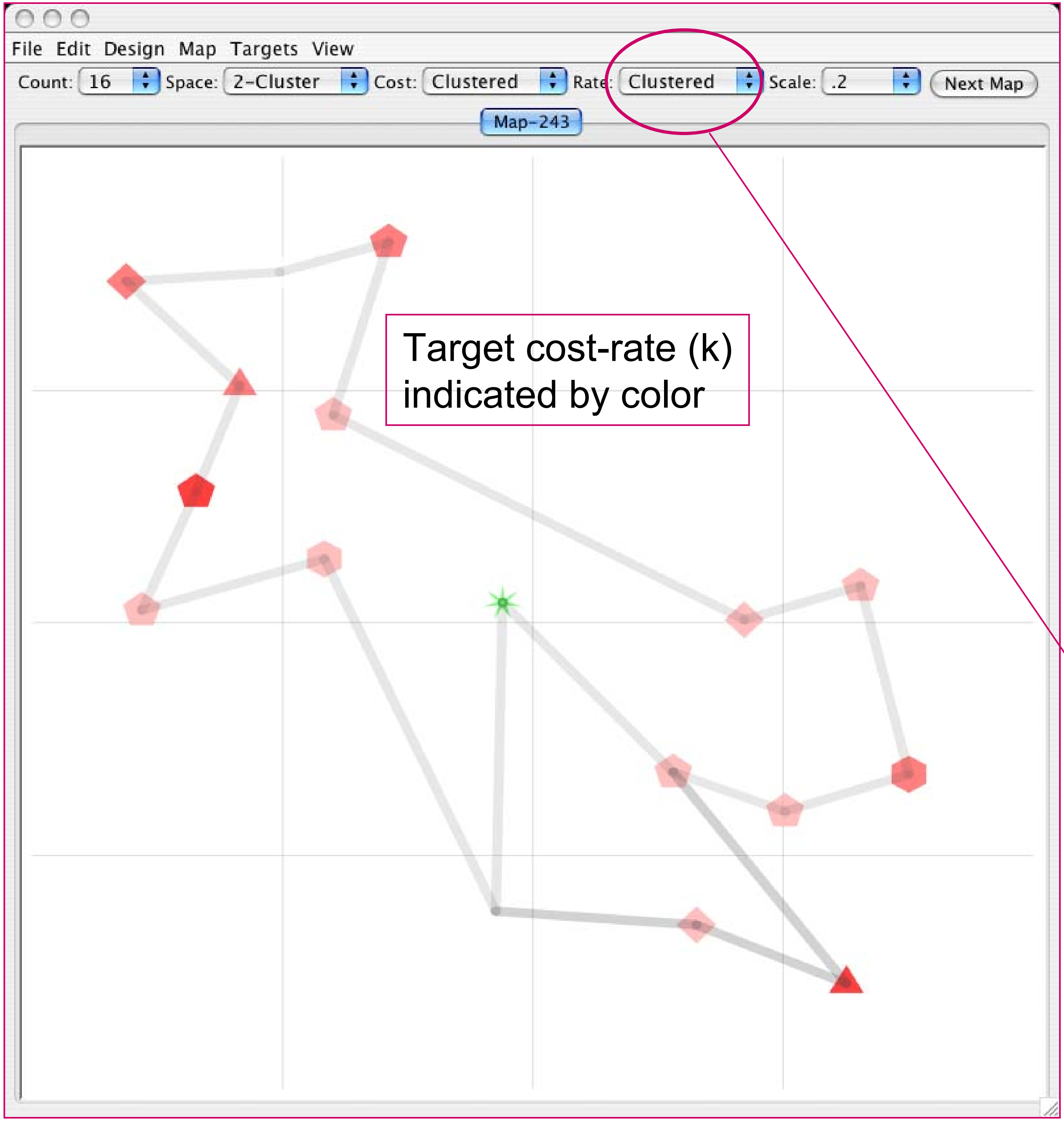
Scenario test set

<u>243 Scenarios</u>

5 dimensions (iv's)

3 values for each

1. Number of targets
2. Spatial Distribution
3. Spatial Scale
4. Maxcost Distribution
   fixed (30)
   uniform (10 20 30 40)
   peaked (30)



Scenario test set

<u>243 Scenarios</u>

5 dimensions (iv's)

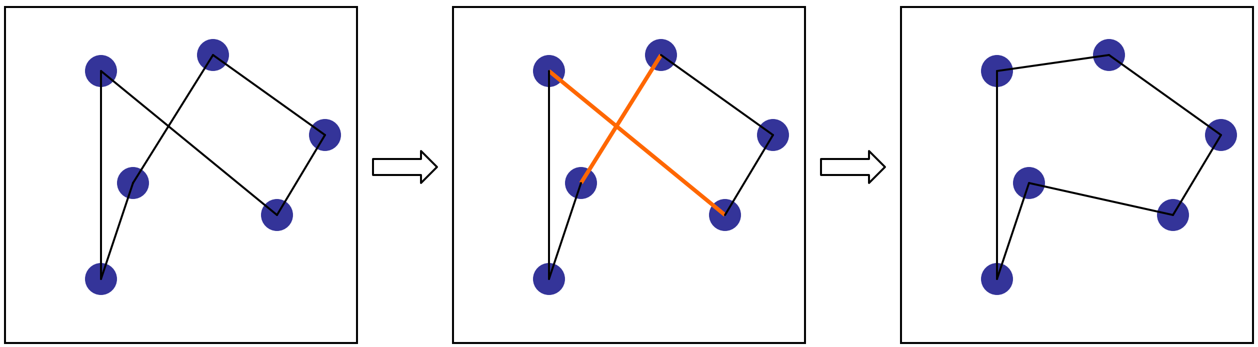
3 values for each

1. Number of targets
2. Spatial Distribution
3. Spatial Scale
4. Maxcost Distribution
5. Cost-Rate Distribution
   fixed (60)
   uniform (20 40 60 80)
   peaked (60)

Comparative Evaluation

Human vs. 2-OPT Algorithm

- Modified 2-OPT algorithm
  - Basic 2-OPT computes approximate solutions for Traveling Salesman Problem
  - Approach: start with a random tour; iteratively find and apply a tour-improving exchange of 2 tour segments until none found

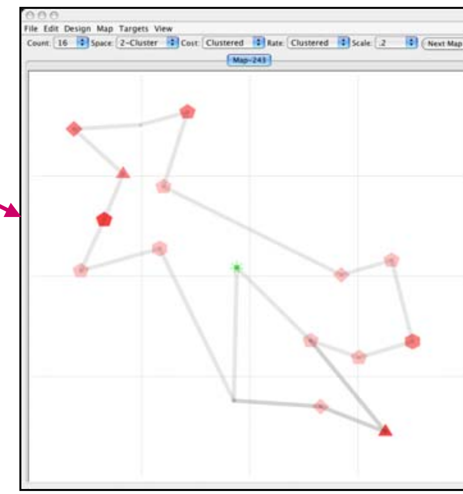


  - Modifications
    - Use UAV kinematics model ("smoother") to compute traverse time
    - Evaluate return-to-home point given maximum flight duration = 60 minutes
  - Surveillance performance metric

Comparative Evaluation

Human vs. 2-OPT Algorithm

- Human subject test (pilot study)
  - Software /procedure
    - Subject uses GUI to create/mod tours
    - Shows scenario/target attributes…
  - Test conditions: all 243 scenarios (~4 hrs)
  - Surveillance performance metric
  - Pilot study
    - 2 subjects so far
    - Training materials & GUI evolving
    - Decision aids evolving
    - Scenario presentation schedule ad lib



Performance Comparison

Pct. Adv.			N	Spatial							
			4			8			16		
Scale	Rate	Cost	2-Cluster	Globular	Uniform	2-Cluster	Globular	Uniform	2-Cluster	Globular	Uniform
0.002	Fixed	Fixed	0	0	0	0	**14**	0	6	**31**	-3
		Clustered	0	0	0	0	**16**	5	7	**29**	7
		Uniform	0	0	-1	**42**	**24**	5	2	10	**10**
	Clustered	Fixed	0	0	0	0	0	**11**	0	0	**11**
		Clustered	0	0	0	0	0	0	0	0	1
		Uniform	0	0	0	0	0	0	0	0	1
	Uniform	Fixed	**143**	**47**	0	**130**	19	**47**	**10**	**93**	**47**
		Clustered	**22**	**28**	**23**	0	**12**	6	3	8	0
		Uniform	**61**	**20**	-2	0	**18**	7	2	5	9
0.02	Fixed	Fixed	0	0	0	1	1	0	0	1	0
		Clustered	0	0	0	1	1	0	0	1	0
		Uniform	0	0	0	1	1	0	1	2	0
	Clustered	Fixed	0	0	0	1	0	0	1	6	0
		Clustered	0	0	0	1	0	0	0	9	1
		Uniform	0	0	0	1	**16**	0	0	6	0
	Uniform	Fixed	0	0	0	1	0	0	2	2	0
		Clustered	0	0	0	1	0	0	2	2	1
		Uniform	0	0	0	1	0	0	0	2	1
0.2	Fixed	Fixed	1	0	0	0	-1	0	-2	**-22**	4
		Clustered	1	0	0	-1	5	-10	-6	**-15**	3
		Uniform	0	0	-1	-2	4	-8	-5	**-19**	4
	Clustered	Fixed	0	0	0	8	0	**14**	9	-1	10
		Clustered	0	0	0	9	-1	**-11**	**11**	**-14**	5
		Uniform	0	0	-1	**16**	8	3	5	**-10**	4
	Uniform	Fixed	3	0	**23**	**14**	-7	**22**	2	-7	**10**
		Clustered	**16**	0	**23**	9	-3	**-12**	9	**-16**	8
		Uniform	**23**	0	**31**	**15**	4	2	-3	**-26**	5

% difference; 1 pilot subject; positive values favor 2-OPT

Pilot Study Summary

- 2-Opt significantly out-performed humans overall ($p < 0.01$)
- Human subjects differed significantly ($p < 0.05$)
- Humans' & 2-Opt's performance were strongly correlated ($r > 0.9$)
- Most discriminating i.v. seemed to be Scale
- Least discriminating seemed to be Target-Count
- Humans seemed to do relatively poorly with small-scale maps, small N, low spatial structure (uniform distribution)
- Humans seemed to do relatively well with large-scale maps, large N and high spatial structure (cluster, globular)
- Humans seemed vulnerable to errors in target-exclusion decisions
- Humans, but not 2-Opt, could benefit from multiple visits to the same target. This is an artifact due to the definition of the TSP problem.

Ongoing and Future Work

Ongoing

- Better human subject data (possibly on-line data-collection)
- Better surveillance algorithms and heuristics

Future

- Multiple surveillance vehicles
- Varied functions: mapping, recon,…
- Eliciting and maintaining cost/probability knowledge from users
- Handling run-time user requests, utility changes
- Operational integration with human organizations and systems

For More Information

{mfreed, rharris, mshafto}
@mail.arc.nasa.gov