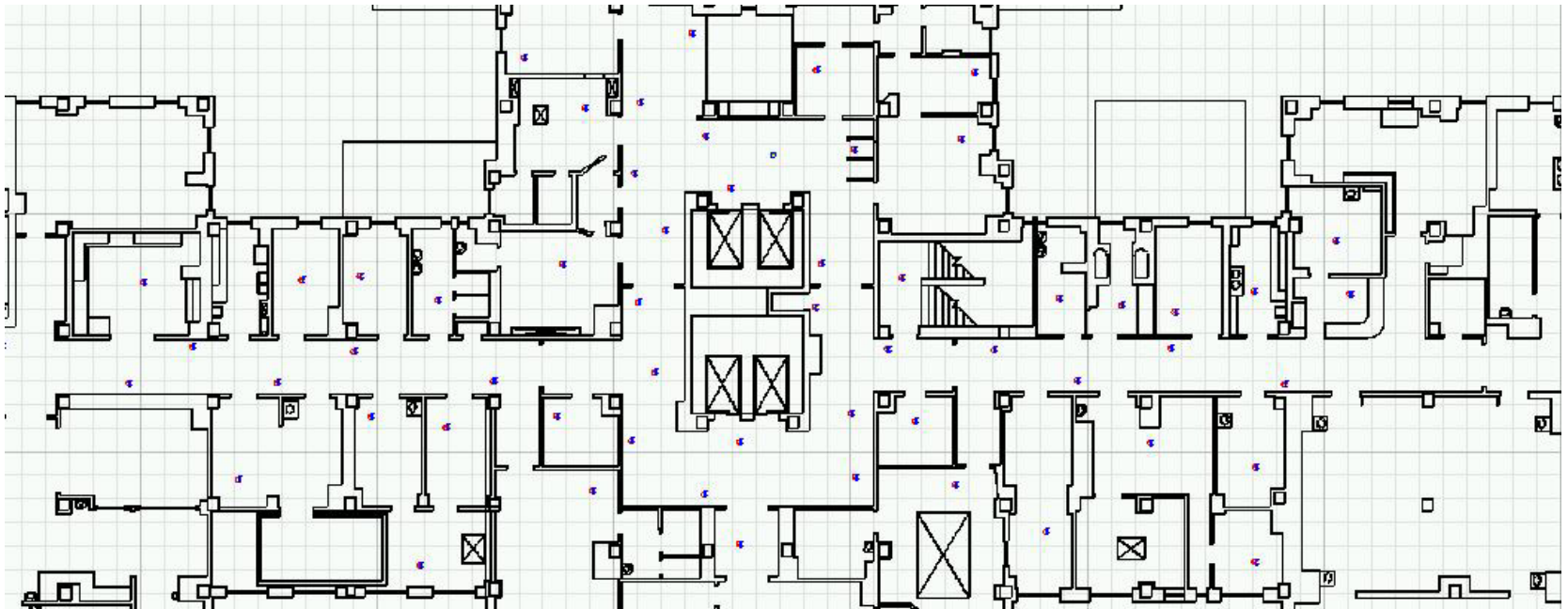


Search/Coverage, Part II

February 4, 2003

Class Meeting 7



Objectives

- Bonus! Application of swarm technology to music
- Search/Coverage, Part II
- Paper #8 presentation: Yifan Tang

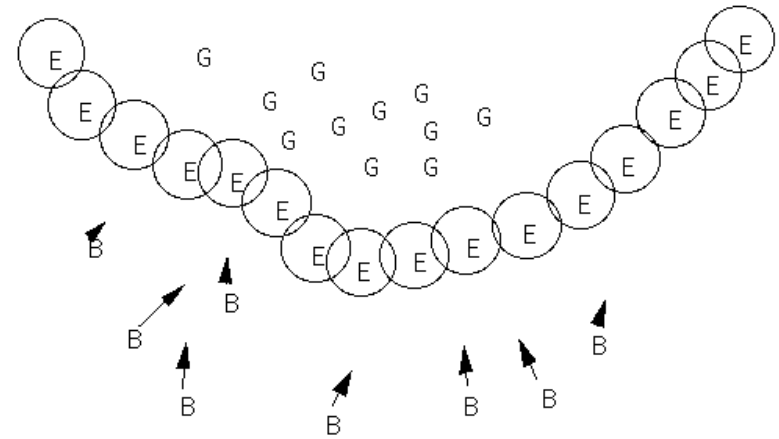
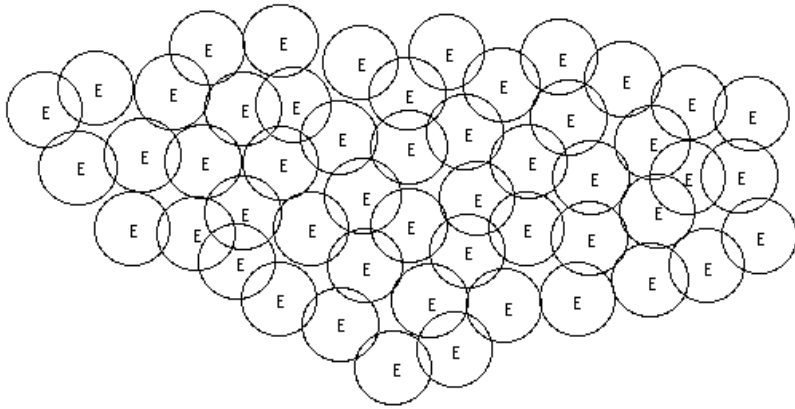
Bonus! Application of Swarm Technology to Music

- *Discover*, March 2003: “Music of the Swarms”
- See <http://www.timblackwell.com>

Search/Coverage, Part II:

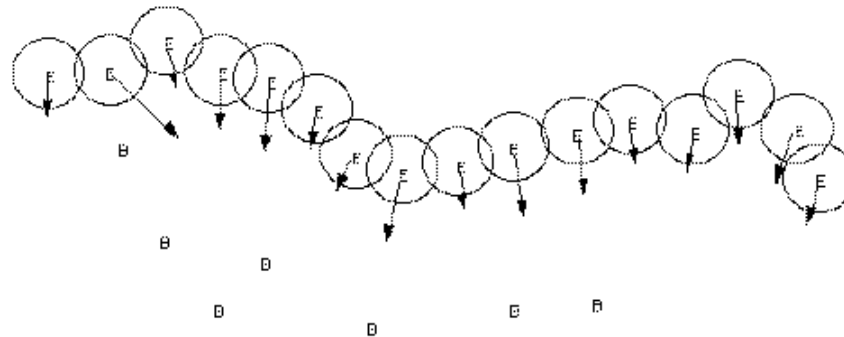
Recall: Three Types of Search/Coverage (from Gage)

Blanket/Field



Barrier

Sweep



Recall Paper from last Time: Gage's Analysis

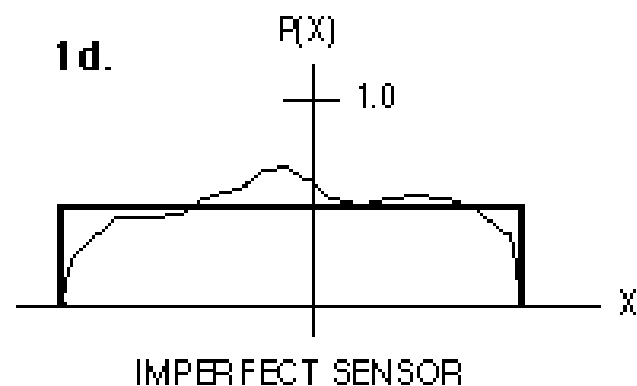
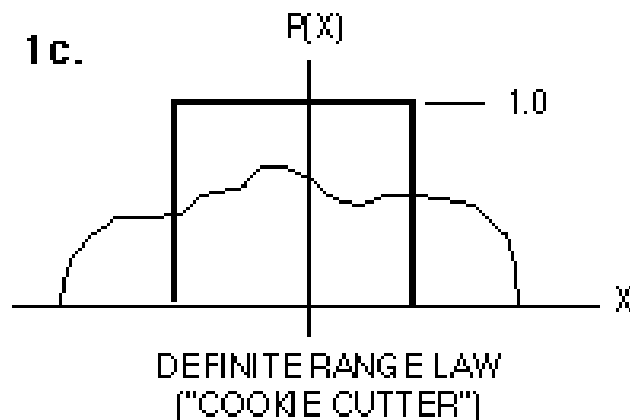
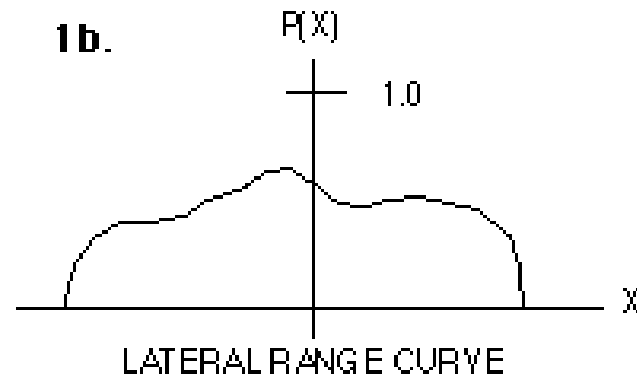
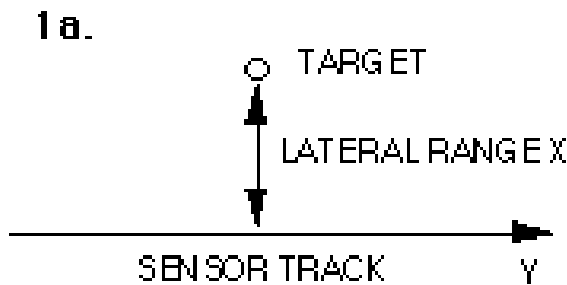
- What type of search/coverage addressed?
 - Sweep
- Issues in algorithm development for sweep coverage?
 - Group pattern followed (i.e., how does group as a whole move?)
 - Formation-keeping
 - We'll study this more a bit later in the semester

From Gage: Target Detection Sensor Abstractions

- Basic search problem:
 - One or more searchers
 - Each searcher carries a detection sensor
 - Each searcher moves through a predefined search area to detect one or more stationary target objects
 - Targets are *a priori* equally likely to be at any point within the search area
 - Searcher detection of any given target at any instant depends on:
 - Relative geometry of searcher and target at that instant
 - Physical characteristics of the detection sensor(s), the environment, and the target itself.

Probability of Detection with Abstract Sensors

- Calculate cumulative probability of detection:
 - Integrate over instantaneous probability of detection as searcher moves toward target, passes by, and retreats
- Result: Lateral Range Curve



The Search Process

- N robots
- Imperfect sensor: range r , detection probability p
- Max travel distance: d
- Search space has area A

- Calculate “sweep fraction”:

$$S = 2 r d N / A$$

Coordinated vs. Random Searching

- Expected fraction of targets detected: D

- Coordinated Search:

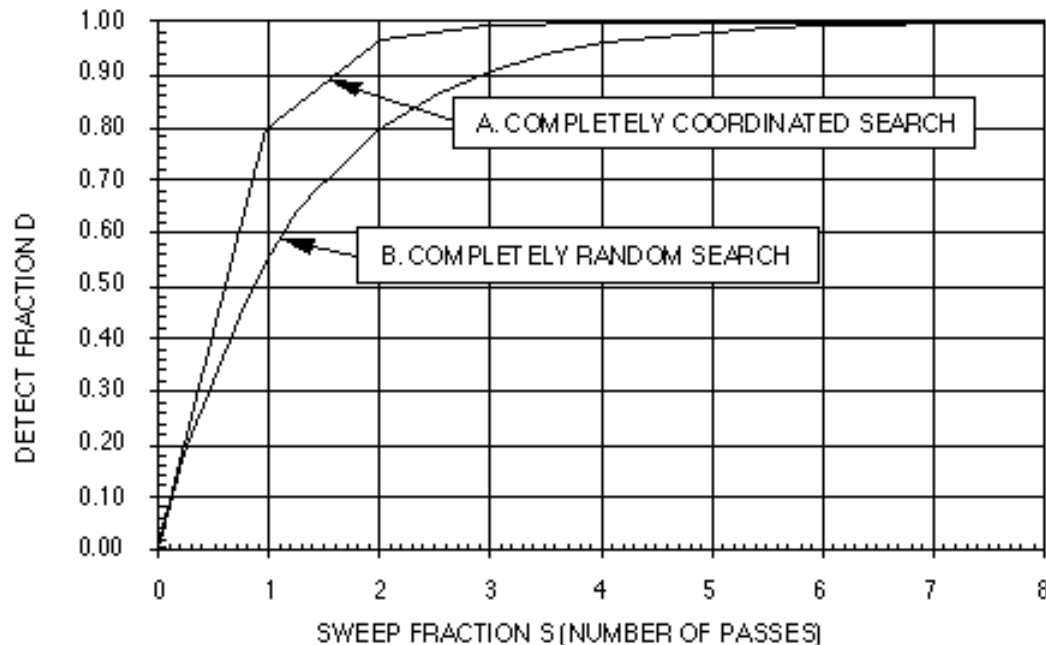
- “Lawnmower-type” motions
- Do not revisit locations that have already been visited
- S_c represents “Sweep fraction” of locations visited

$$D_c = 1 - (1 - p)^{S_c}$$

- Random Search:

- Completely random motions within search area
- (Not unlike Roomba)
- S_r represents “Sweep fraction” of locations visited

$$D_r = 1 - e^{-pS_r}$$



$p=0.8$

Calculating “Search Gain” of Coordinated vs. Random Search

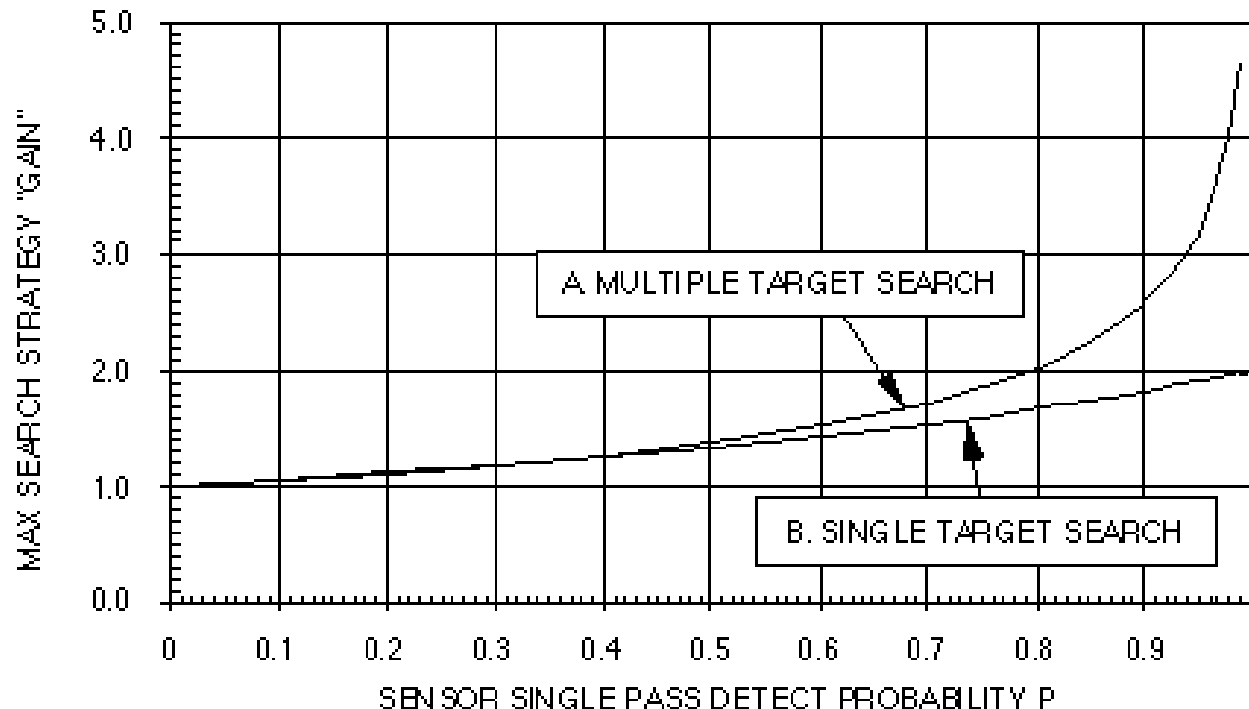
- Equate D_c and D_r , yielding Search Gain G :

$$G_{\text{many targets}} = \frac{S_r}{S_c} = -\ln \frac{1-p}{p}$$

$$G_{\text{single target}} = \frac{S_r}{S_c} = \frac{1/p}{1/p - 1/2} = \frac{2}{2-p}$$

Goal: minimize cost of detecting specified fraction D of targets

Goal: minimize search effort for detecting single target



Important “Take-Home” Message

- Since gain, G , is different for multi-target vs. single-target search:
 - Optimal choice of sensor, search strategy, etc., may be different
- Possible to have 2 algorithms, A and B , such that:
 - A finds any specified percentage of a field of targets with less cost than B
 - B , on average, finds a single mine with less cost than A

Randomized Search Strategies

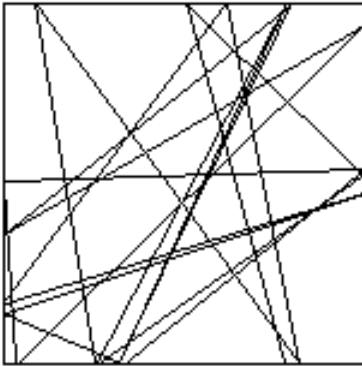
- In circular area:
 - Use paths consisting of chords within search area
 - Reflection approaches:
 - Specular
 - Uniform
 - Diffuse: Only approach shown to provide uniform search coverage
- Extension to convex search areas:
 - Use chord-lengths to opposite boundary to select direction of reflection
- General approach cannot be extended to nonconvex areas, since some points in search space aren't reachable by a chord trajectory

Results: Diffuse vs. Chord Searches

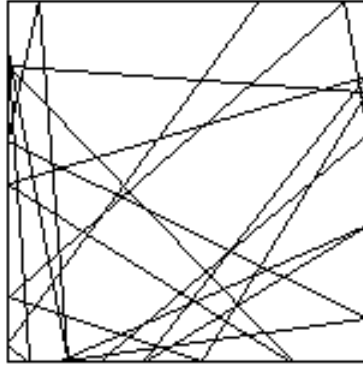
- Square search area – 1:1 aspect ratio

Chord Length Algorithm

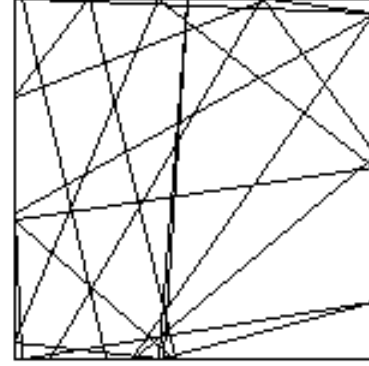
mode 2, chords 19, length 52.9



mode 2, chords 20, length 50.3

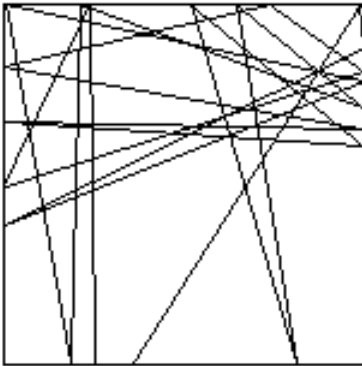


mode 2, chords 21, length 50.5

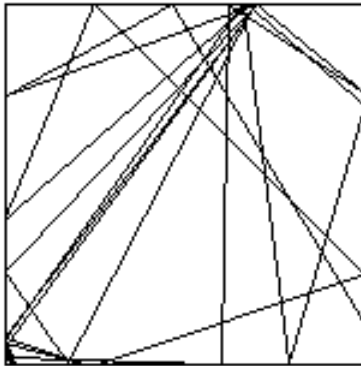


Diffuse Reflection Algorithm

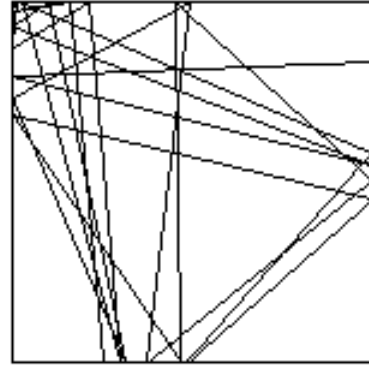
mode 1, chords 24, length 52.2



mode 1, chords 26, length 50.6



mode 1, chords 23, length 51.4

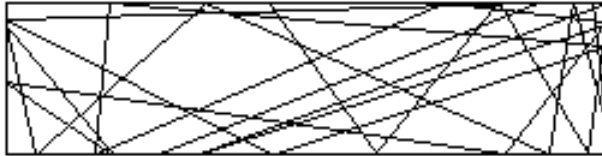


Results: Diffuse vs. Chord Searches

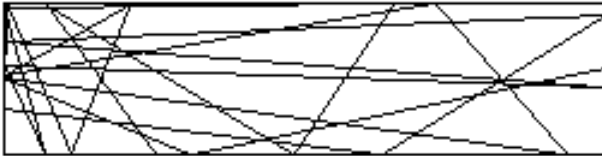
- Rectangular search area – 4:1 aspect ratio

Chord Length Algorithm

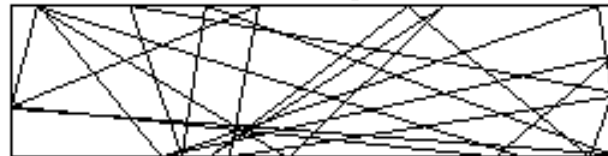
mode 2, chords 25, length 51.1



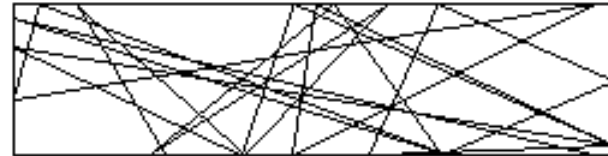
mode 2, chords 20, length 50.1



mode 2, chords 22, length 51.1



mode 2, chords 22, length 53.3

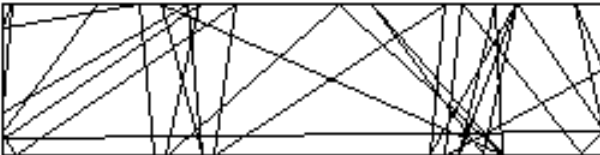


Diffuse Reflection Algorithm

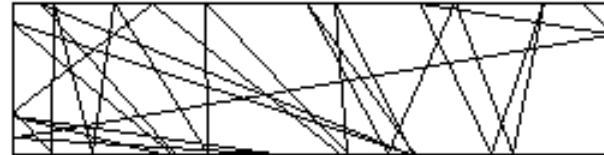
mode 1, chords 35, length 51.7



mode 1, chords 33, length 50.6



mode 1, chords 29, length 50.9



mode 1, chords 34, length 52.7

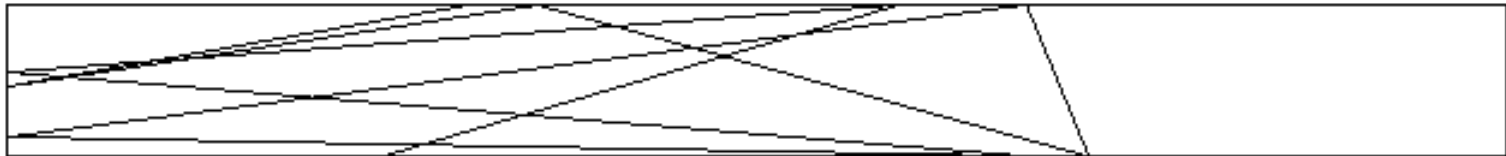


Results: Diffuse vs. Chord Searches

- Rectangular search area – 10:1 aspect ratio

Chord Length Algorithm

mode 2, chords 9, length 52.7

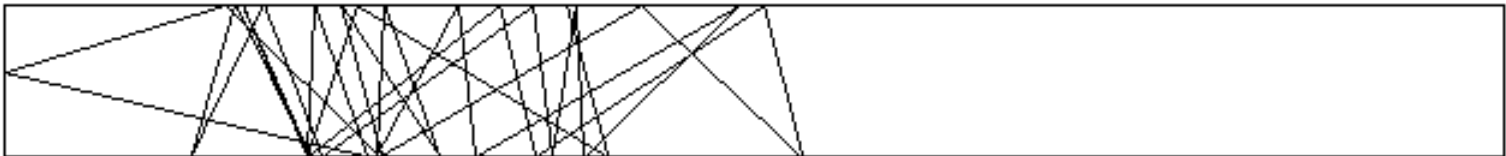


mode 2, chords 7, length 51.4



Diffuse Reflection Algorithm

mode 1, chords 32, length 51.1



mode 1, chords 21, length 50.9



Results: Diffuse vs. Chord Searches

- Rectangular search area – 25:1 aspect ratio

Chord Length Algorithm

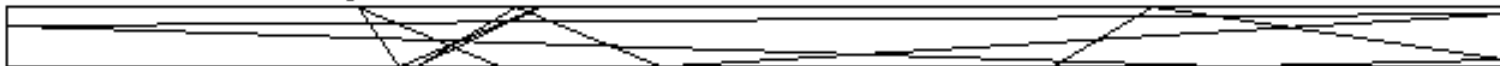
mode 2, chords 13, length 54.0



mode 2, chords 12, length 56.8

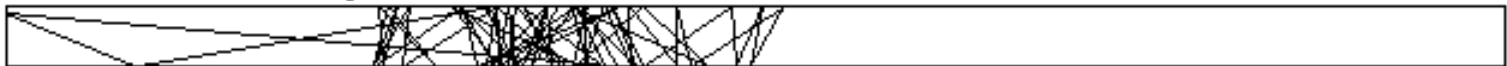


mode 2, chords 12, length 50.6



Diffuse Reflection Algorithm

mode 1, chords 63, length 50.3



mode 1, chords 61, length 50.5



mode 1, chords 49, length 50.5



Conclusions from Gage's Studies

- Many inexpensive robots → randomized instead of coordinated search:
 - Increase in effectiveness provided by coordinated search decreases as capability of search sensor decreases
 - Cost of implementing navigation capabilities necessary to support coordinated search may be prohibitive, relative to cost of less capable searchers
- Need careful analysis to select and implement appropriate strategy

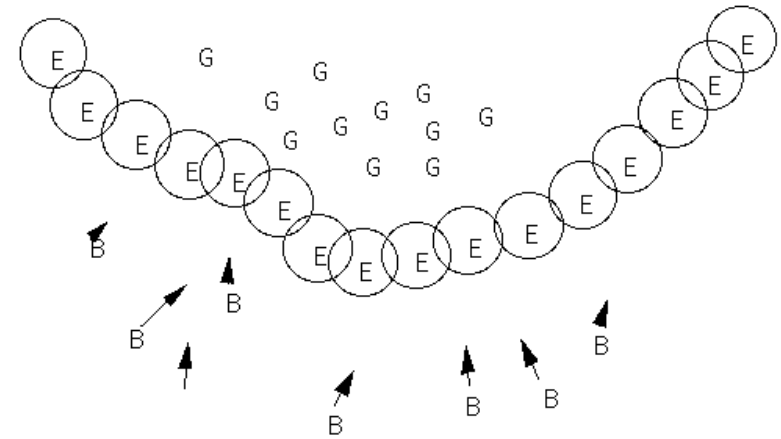
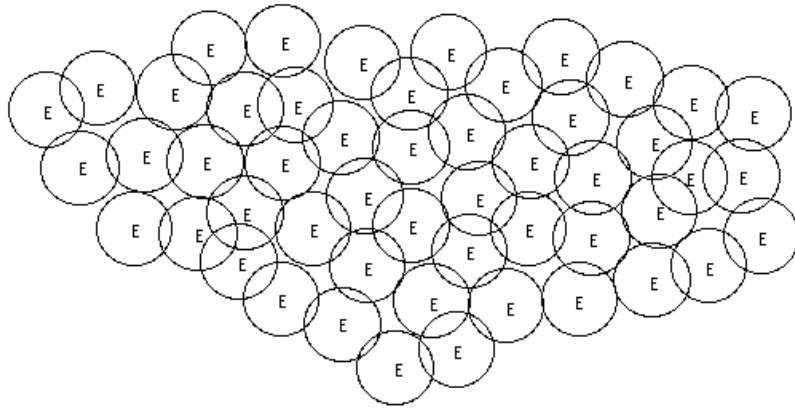
Student Paper Presentation

- “An Incremental Self-Deployment Algorithm for Mobile Sensor Networks”, by Howard, Mataric, and Sukhatme, *Autonomous Robots* 13(2): 113-126, 2002.
- Presented by Yifan Tang

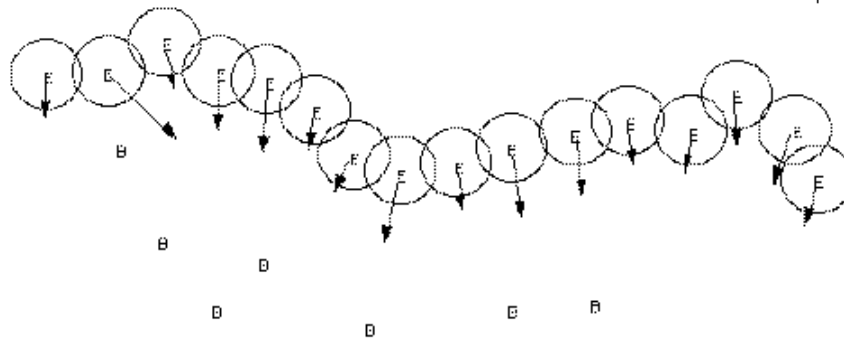


Recall: Three Types of Search/Coverage

Blanket/Field



Sweep



Barrier

What type of search/coverage does Howard et al. address?

- Blanket/Field

Issues in Blanket/Field Coverage

- Key Issue in algorithm development for blanket/field coverage?
 - Deployment strategy
- What are possible deployment strategies?
 - For wide-open area:
 - Aggregation/dispersion (closely related to potential fields)
 - For area with structure, obstacles, etc:
 - Potential fields (adding in obstacle repulsion vectors)
 - Incremental deployment (as described in Howard et al., 2002)

Important “Take-Home” Messages from Howard et al., 2002

- Understanding of general technique for incremental deployment:
 - Deployment positioning determined based on **coverage** and **reachable/unreachable boundaries**
- Note how the experiments and analysis use the **empirical evaluation** technique we discussed previously
- **Environment** plays a key role in the performance of the algorithm
- **Optimal solutions** may be difficult to compute; therefore, **heuristics** that perform well in practice are appropriate

Preview of Next Class

- Sensor Networks