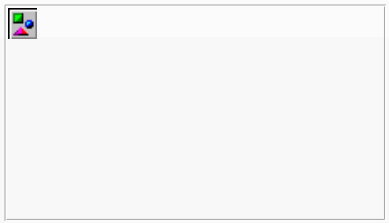
Research Review
Swarming Behaviors Using Probabilistic Roadmap Techniques

O. Burchan Bayazit

Media and Machines

Jyh-Ming Lien



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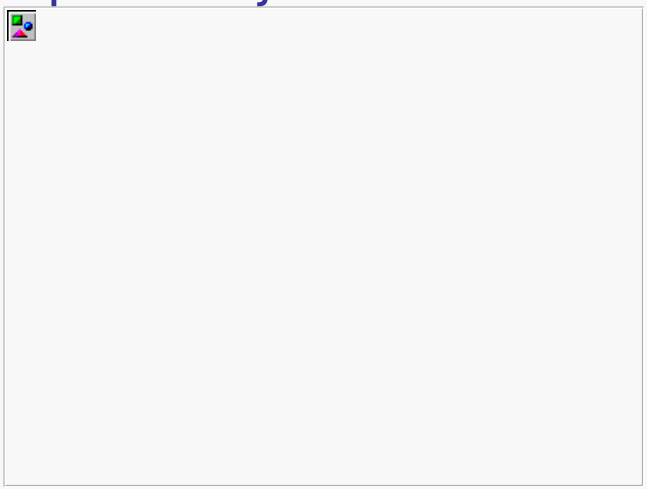
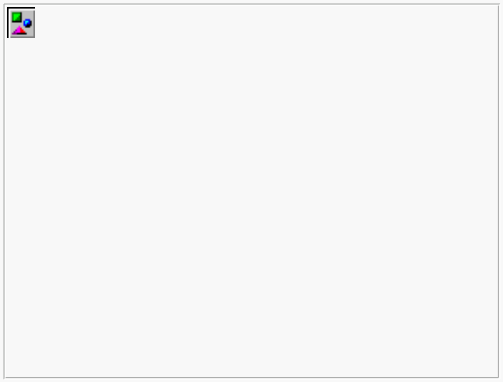
Swarming Behaviors

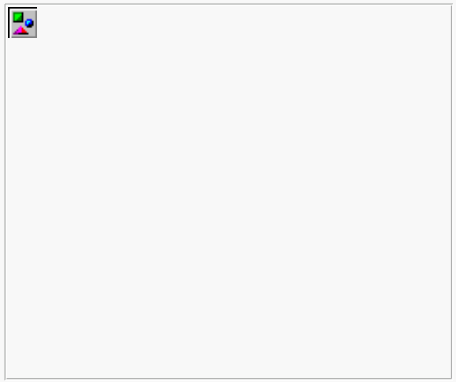
Flocking System [PG'02, ALife'02, WAFR'02, ICRA'04]

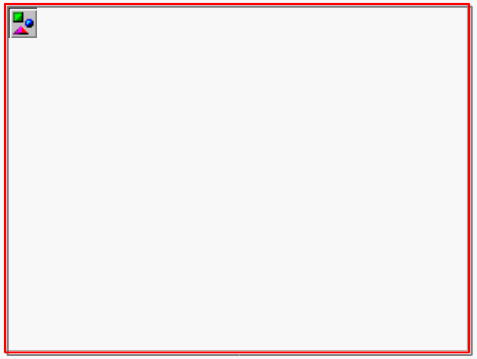
Media & Machines

- **What is a flocking system?**
  - System simulating behaviors of groups of objects (e.g. a school of fish, crowds…)
  - flock formation is selfish
- **Applications**
  - Computer graphics, VR, games
  - Robotics
  - Biological/ecological simulation









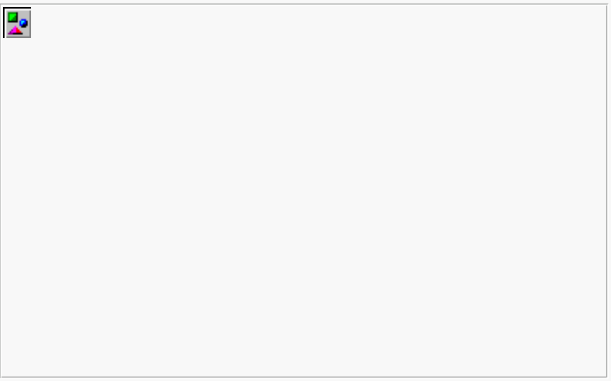
Basic Flocking Behavior

(Reynolds'84)

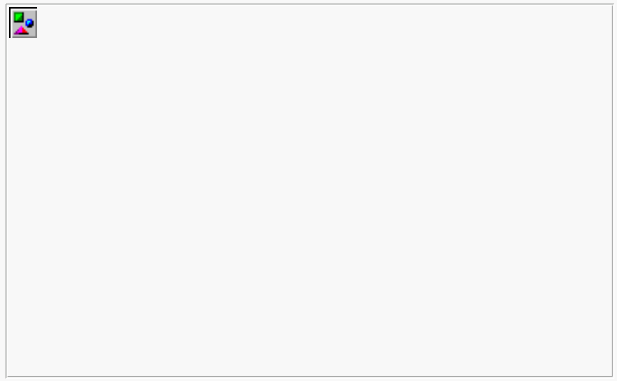
Media & Machines

- Boid: Individual Member of the flock
- Local Information
  - No central control system

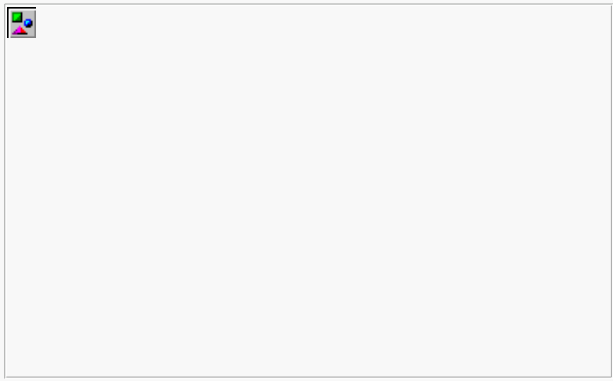
    (individual-based model)
- 3 simple Rules



Separation



Cohesion

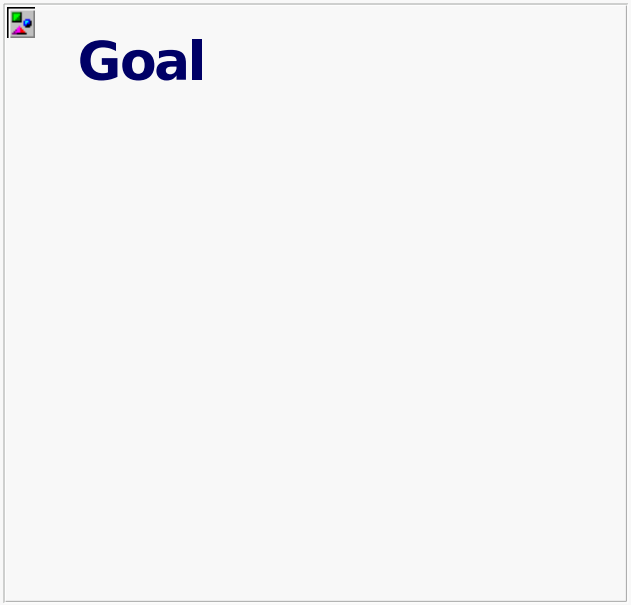


Alignment

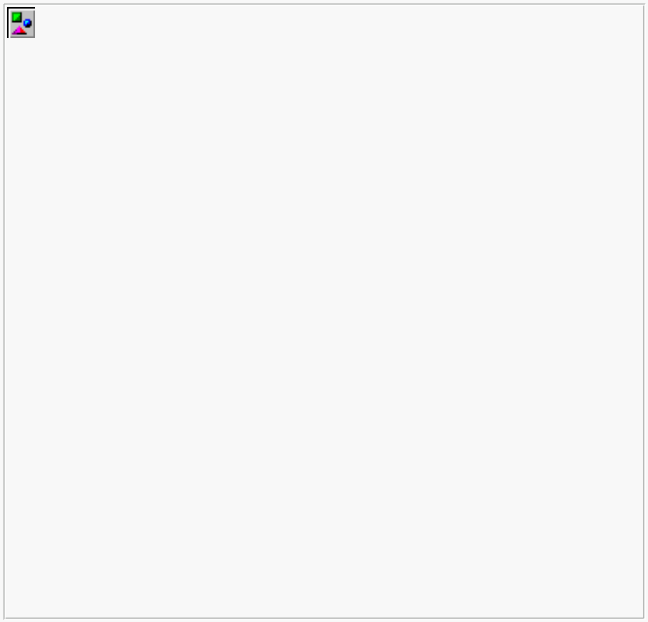
Basic Flocking Behavior

Media & Machines

- How to go towards the goal?
  - **Use a potential field method**



Goal Attraction

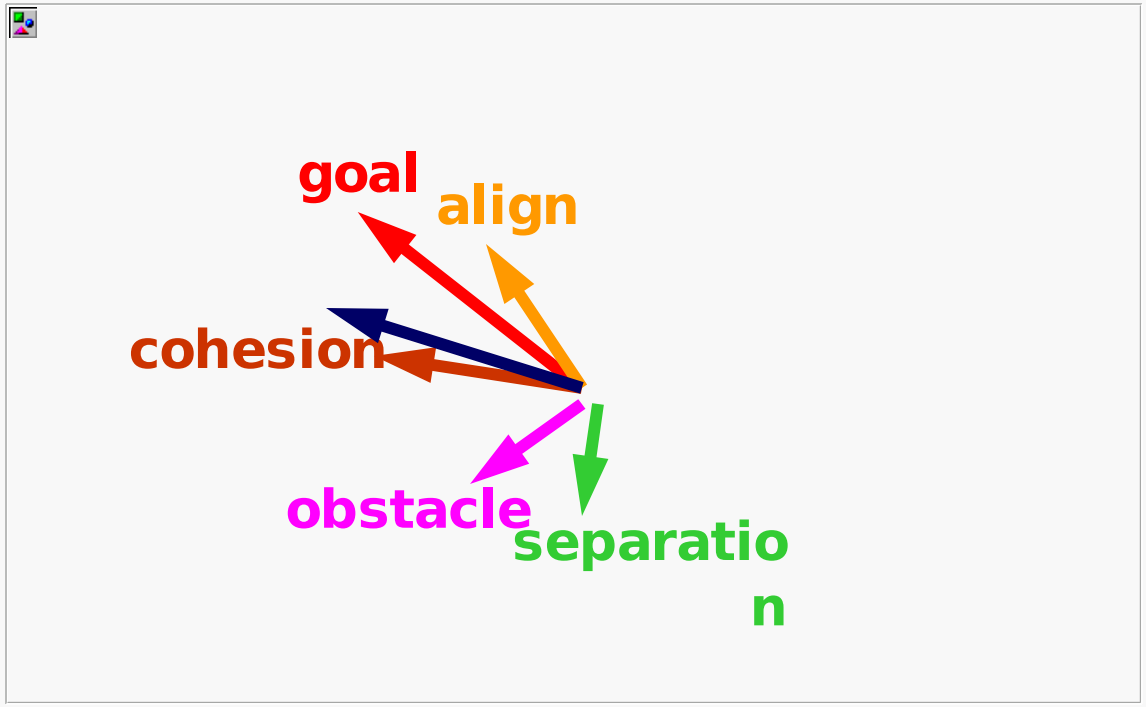


Obstacle Avoidance

Basic Flocking Behavior

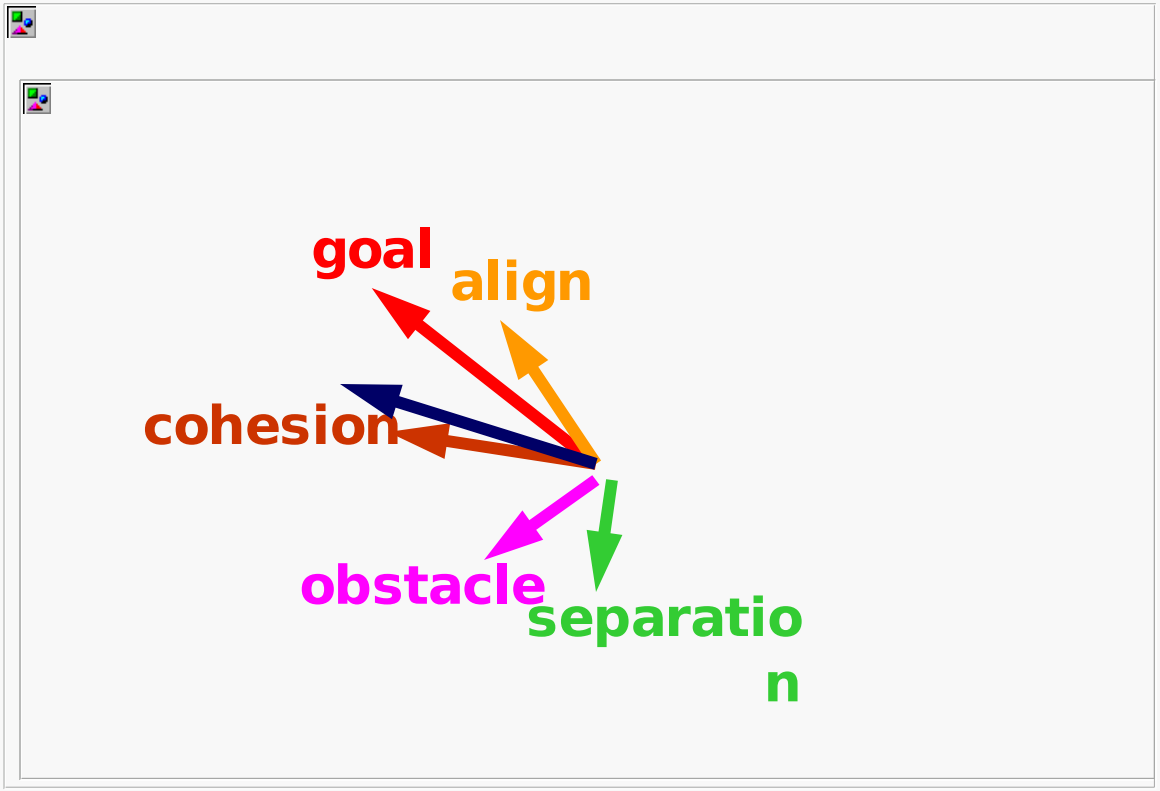
Media & Machines

- Combine all



Basic Flocking Behavior

Media & Machines



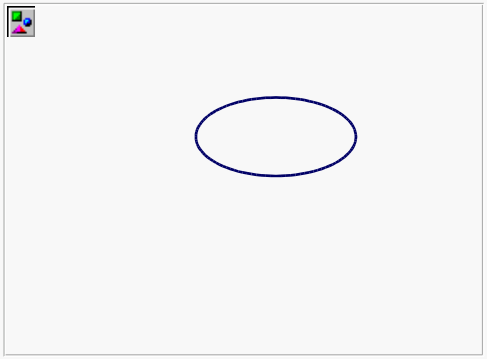
Flocking Systems:
Strengths and Weaknesses

Media & Machines

- Flocking systems are good at group simulations in simple environments
  - schools of fish, crowds, etc in simple env
  - emergent behavior: flock formation is selfish, decentralized, local, and requires no memory
- Flocking systems are not good at complex navigation or customizing behavior in different regions
  - hide-and-seek (need memory)
  - Maze traversal (global map is useful)

example

All rooms are geometrically identical. This alien cannot tell which room has the predator she just encountered.

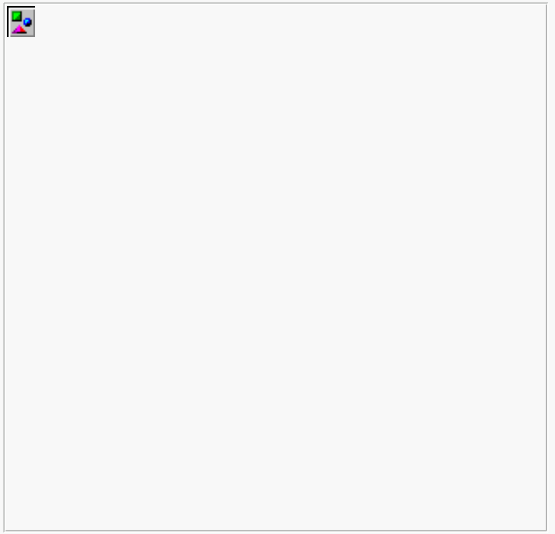


Roadmaps = Global Information

Media & Machines

- Roadmaps are Global information
  - encode global information (e.g. topology)
  - data structure for storing and accessing information

Roadmap example.



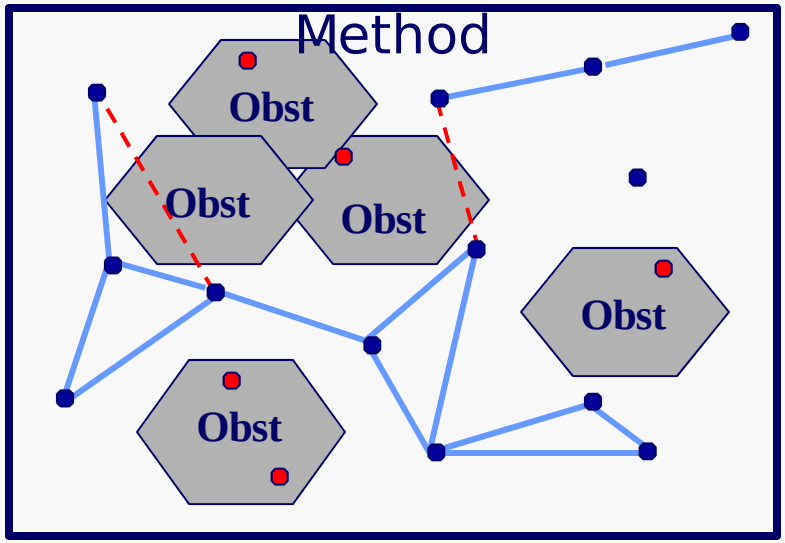
Roadmap Generation

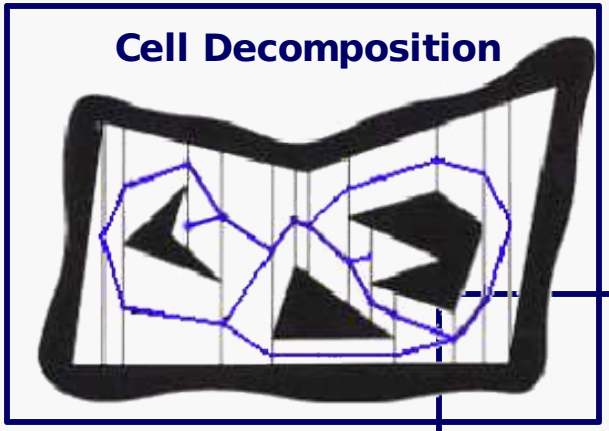
Media & Machines

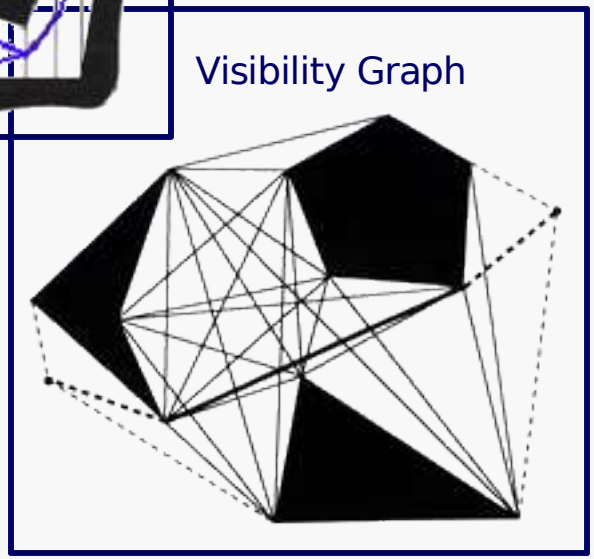
For a given environment, many techniques exist for automatically constructing roadmaps

(We use MAPRM and OBPRM)

Probabilistic Roadmap Method



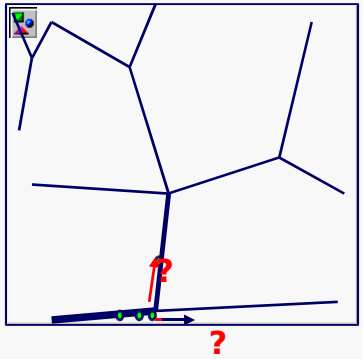


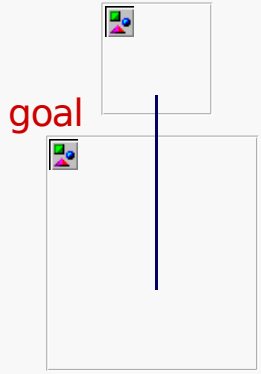


Overview: Roadmap-based Flocking

Media & Machines

- Agents have traditional flocking behavior
- Agents dynamically (locally) select routes in roadmap
  - edges selected based on edge weights
  - Edge weights updated as agents traverse them (ant pheromone)
- Roadmap supports implicit communication among group
  - Customize agent behavior in different regions



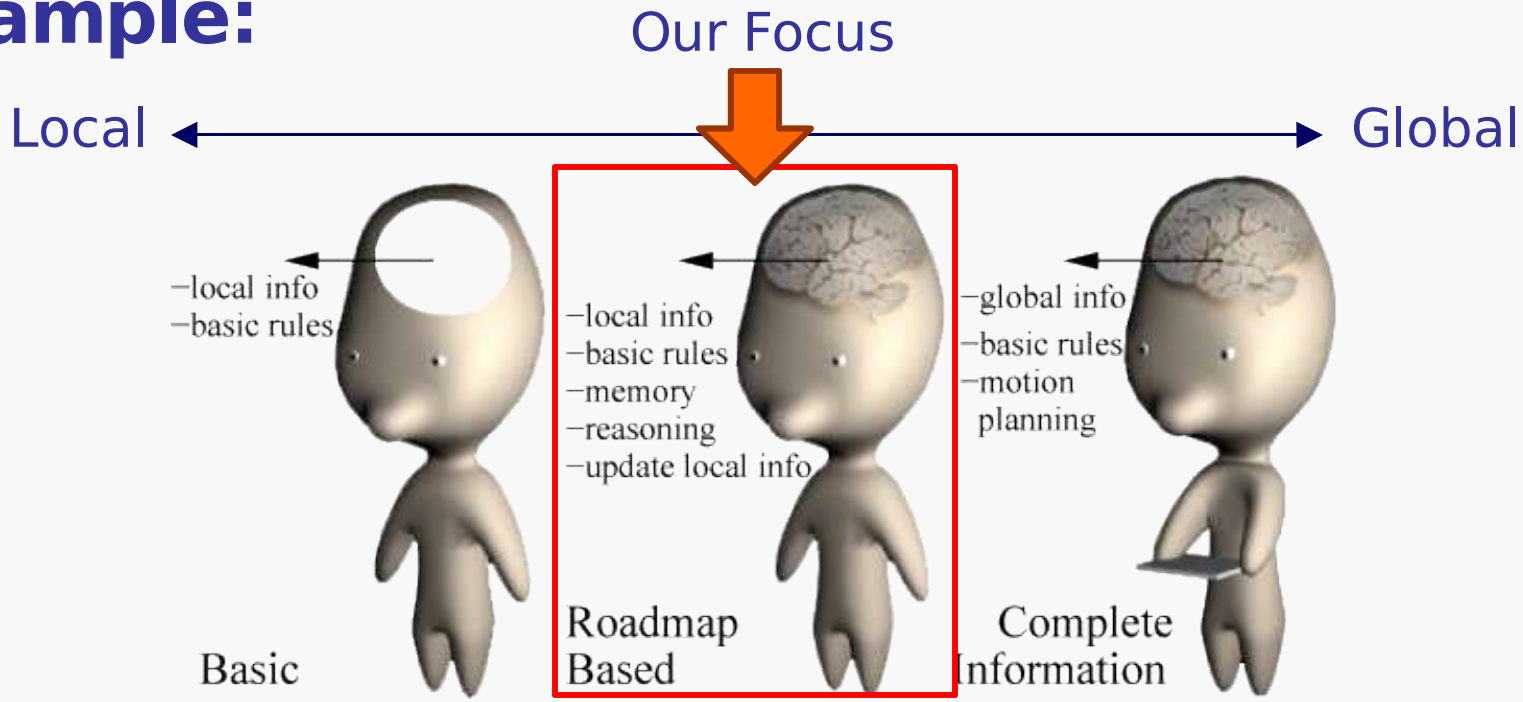


Local vs. Perfect Knowledge

Media & Machines

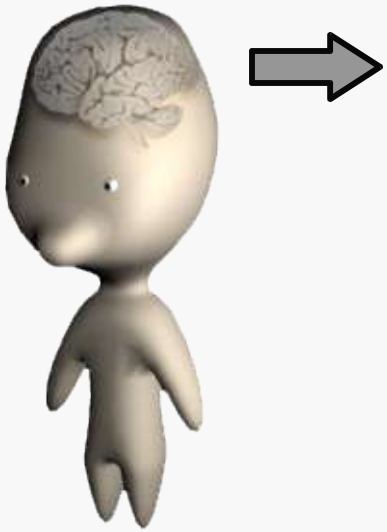
- Global info is useful, but should use it carefully
  - we don't want our creatures to be too smart
  - no creature will have complete/perfect knowledge of global state

Example:



Roadmap-based Agent

Media & Machines



- Local information
  - Environment locally available
  - Roadmap locally/globally available
- Update local information (dynamic roadmap)
  - Update information stored in the roadmap
- Memory
  - Remember the visited places
- Reasoning
  - next step based on current info and memory

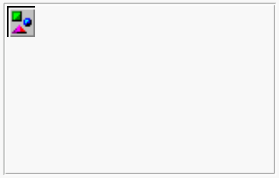
Dynamic Roadmaps

Media & Machines

Information stored in roadmap is updated during simulation

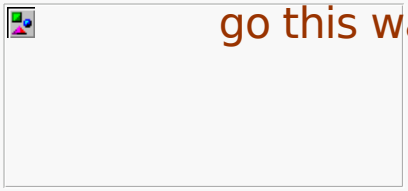
- update weights on good (or bad) paths found

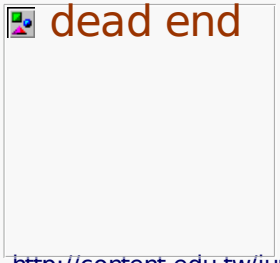
Ant

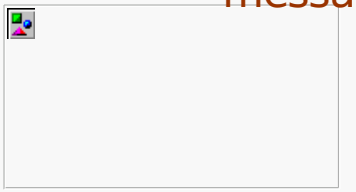


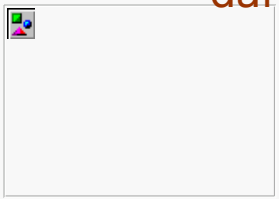
Ants deposit pheromone on the road.

Human







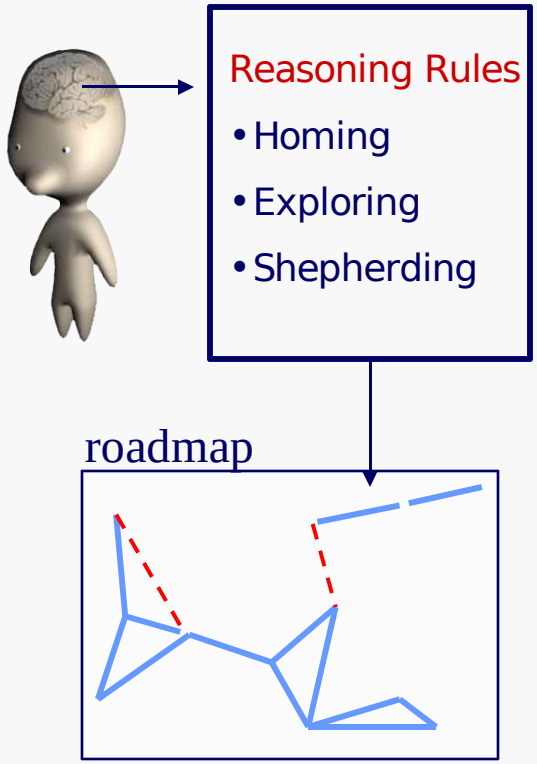


http://content.edu.tw/junior/scouting/tc_jr/108/brief03.htm

Rule-based Roadmaps

Media & Machines

- Storing rules in the roadmap enables tuning the flock's behavior to surrounding environment
  - Different rules in different regions

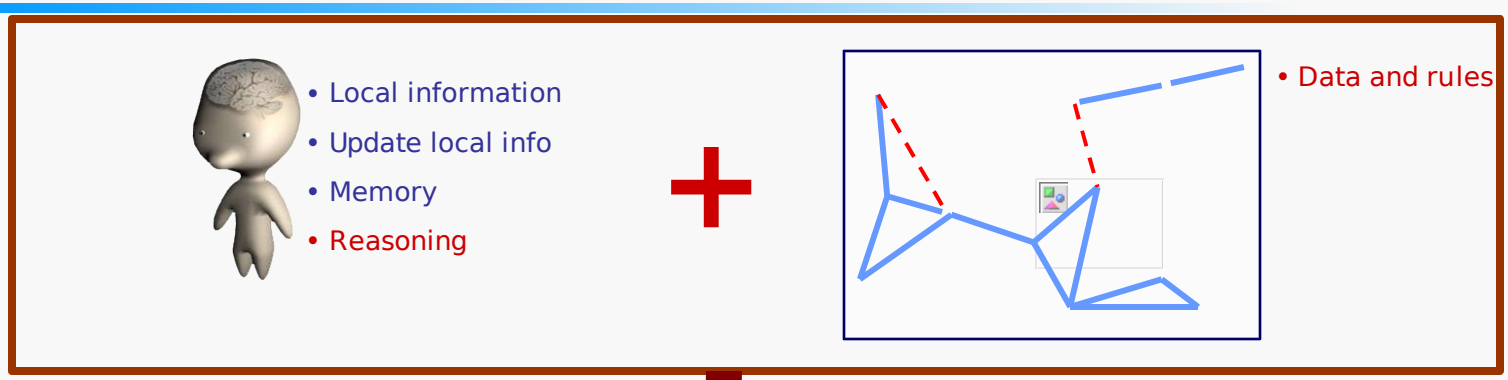


Example

- Traffic signs are rules of the road

Roadmap-based Behaviors

Media & Machines



We study several behaviors:

- Homing
- Exploring
  - Covering
  - Goal Searching
- Traversing Narrow Passages
- Shepherding

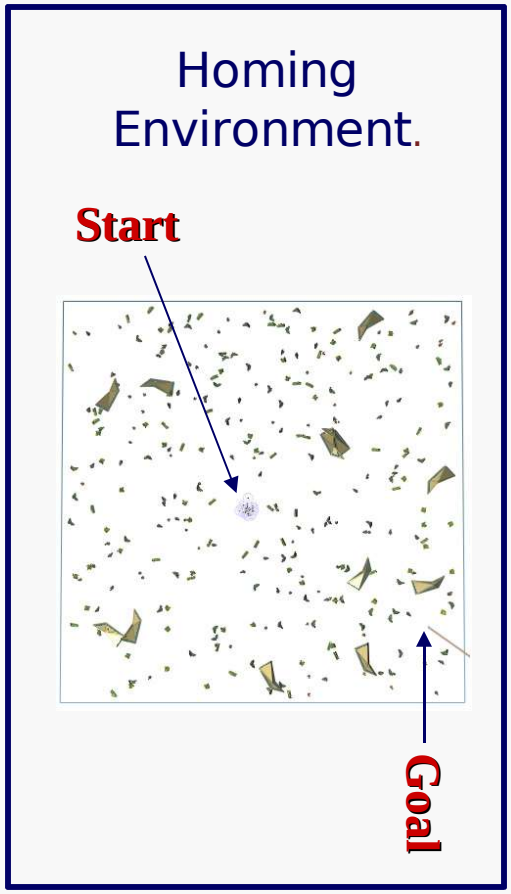
Swarming Behaviors:
Homing [PG'02, ALife'02, WAFR'02]

- Local information
- Update local info
- Memory
- Reasoning

Media & Machines

The Homing Problem: Find a path from the current position to known goal

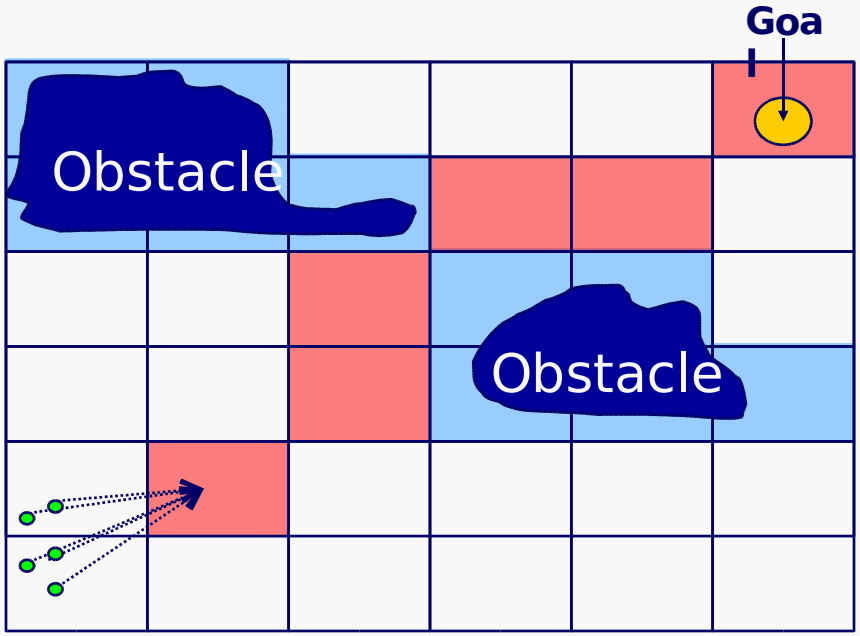
- Homing is a very simple behavior:
  - Study how to integrate and maintain basic flocking with new behaviors
  - Compare with most popular approaches
    - Potential Field method
    - Grid Based Navigation (A* search)



Homing using a Grid

Media & Machines

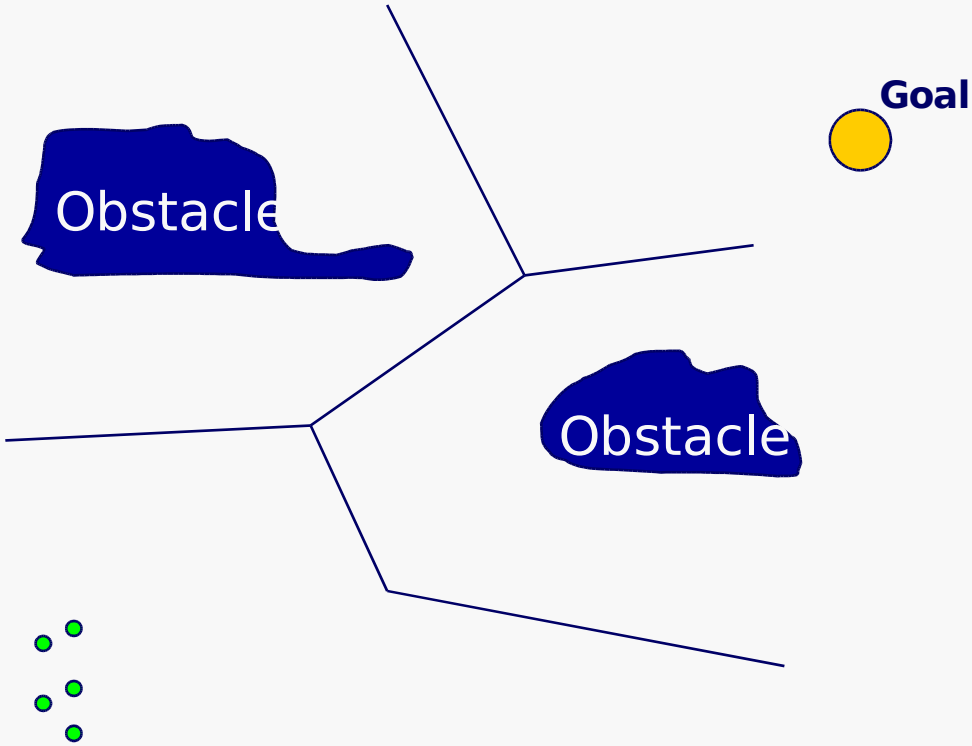
- Most commonly used approach
- Use A* search to find a path through free grid cells



Homing using Roadmaps

Media & Machines

- Find a path on the map
- Flock is attracted to sub-goals on the path



Homing using Roadmaps

Media & Machines

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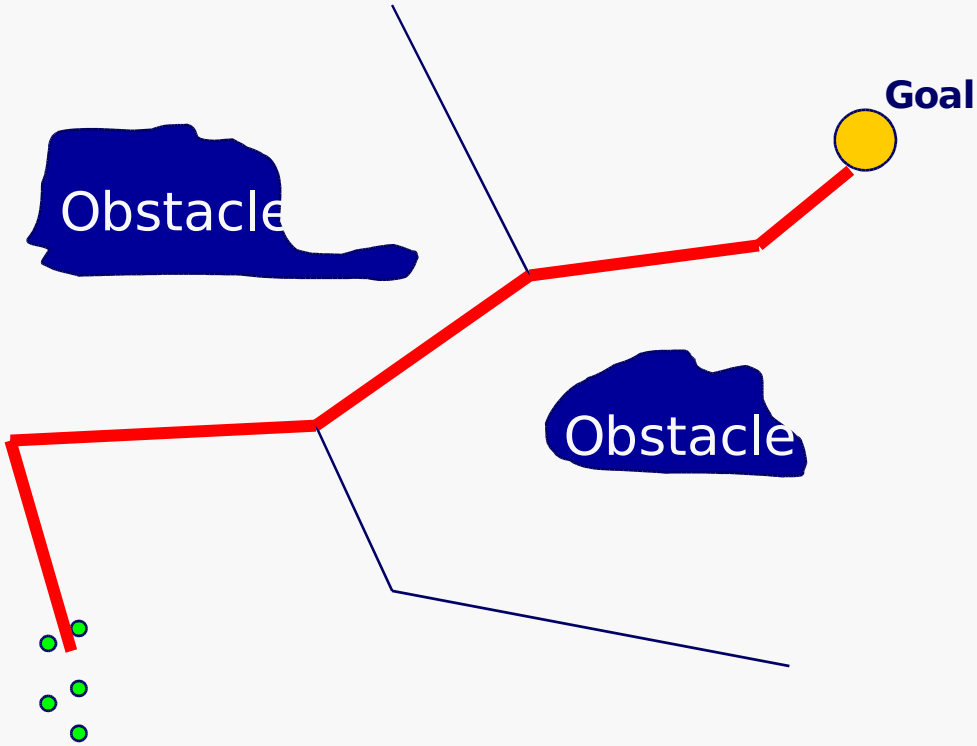
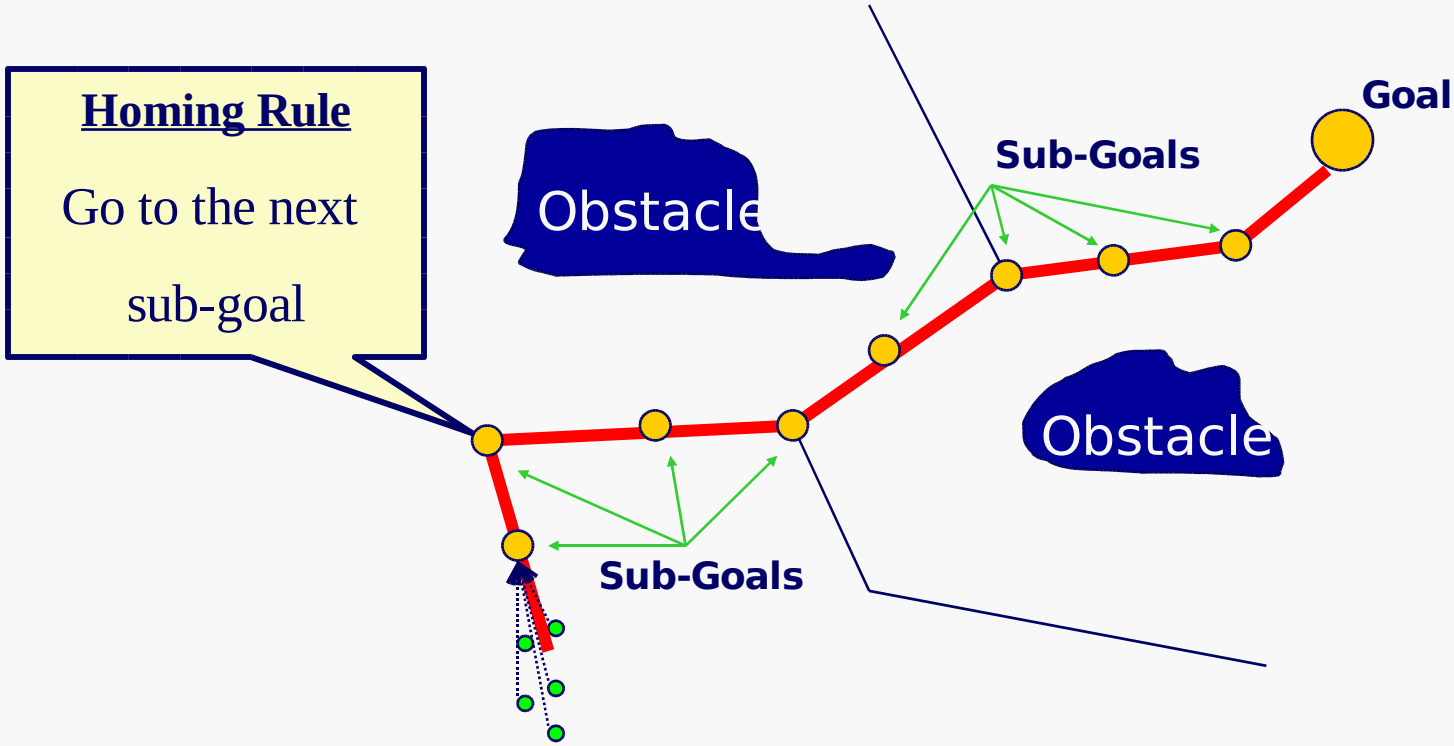


Homing using Roadmaps

Media & Machines

- Find a path on the map
- Flock is attracted to sub-goals on the path



Homing using Roadmaps

- 40 flock members
-Environment size: 420 m * 420 m
-301 obstacles (6 types)
-Simulation updated every 100ms

Media & Machines

Homing Movie.

• Goal (pole) randomly selected, new goal selected when all agents reach current

• Agents select roadmap path (and subgoals) to goal and are attracted to it

Homing: Experiments

Media & Machines

- **Compare Roadmap Based method to Basic Flocking and Grid-Based A* Search**
  - **How many flock members can reach the goal?**
  - **How long does it take?**

boids reaching goal

Method	# Reached goa
Basic	10
A*	40
Roadmap	40

Solution Time A* vs. Roadmap

Method	Init Time	Path Time	Local Minima #	Local Minima Escape (s)
A*	6.02	5.757	2005	1035.43
Roadmap	0.88	0.652	255	22.99

Roadmap is better

Swarming Behaviors

Exploring: Covering [PG'02, ALife'02, WAFR'02]

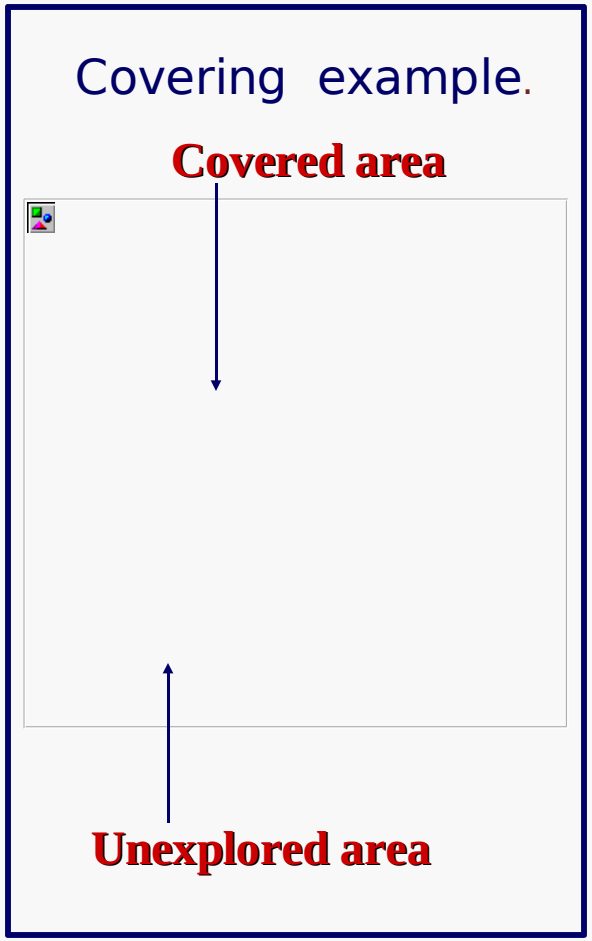
- Local information
- Update local info
- Memory
- Reasoning

Media & Machines

The Covering Problem: have some agent visit (cover) all regions of the environment

minesweeping, vacuuming, mowing

- A point p is "covered" if p is in the visibility range of one or more flock member



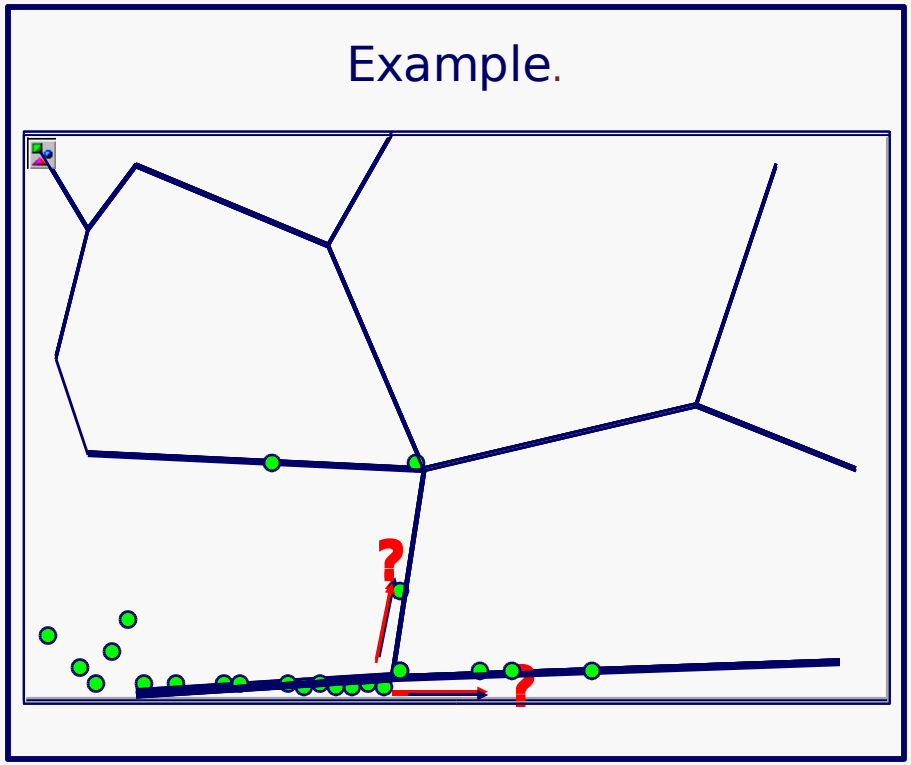
Swarming Behaviors

Exploring: Covering[PG'02, ALife'02, WAFR'02]

- Local information
- Update local info
- Memory
- Reasoning

Media & Machines

- Agents move `on' roadmap
- If an agent reaches a node with more than two edges, the next direction is selected probabilistically based on edge weights (favor low weights)
- Initially, all weights the same
- Weights increase as edges traversed (dynamic roadmap)



Covering using Roadmaps

Media & Machines

-50 flock members

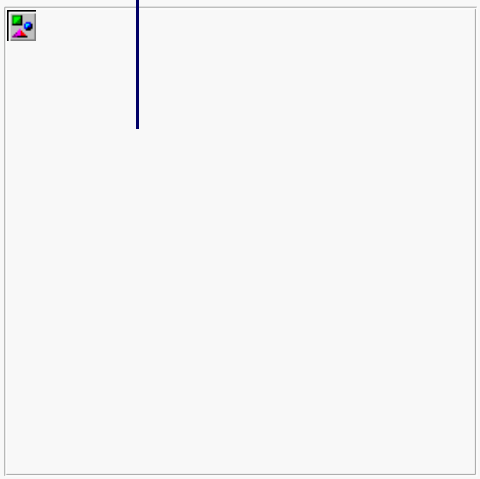
-Environment size: 80 m *100 m

-16 obstacles

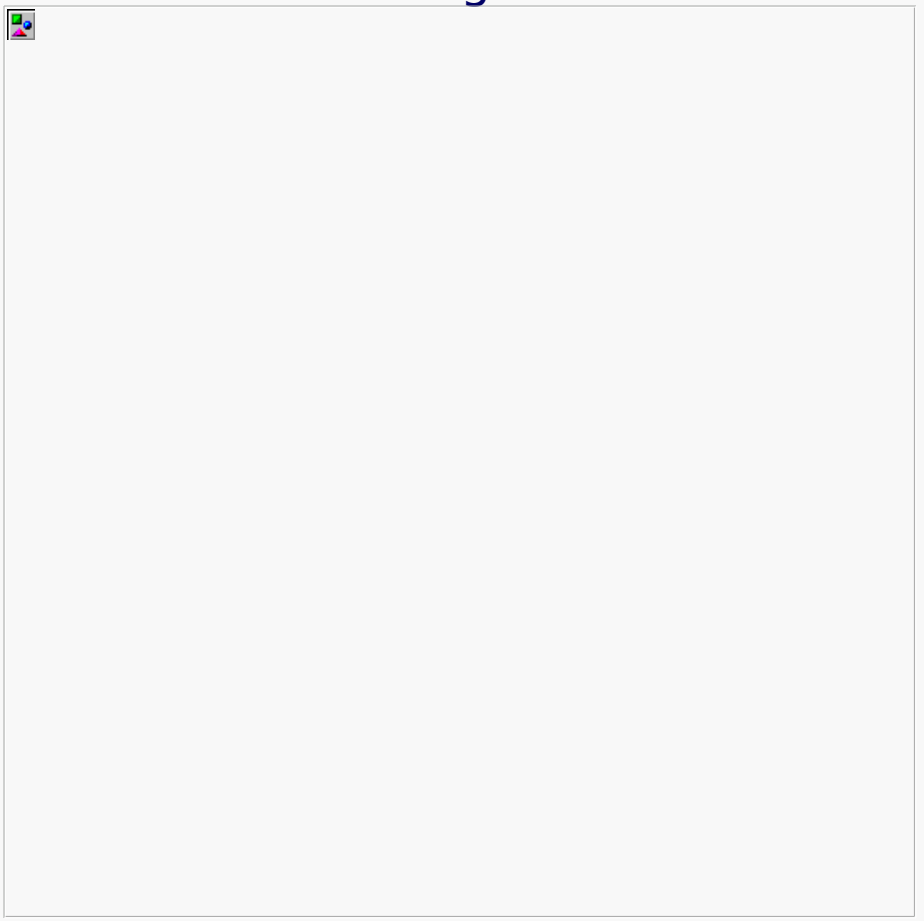
-Sensory range: 5 m

Covering Rule

Go to the less visited edge



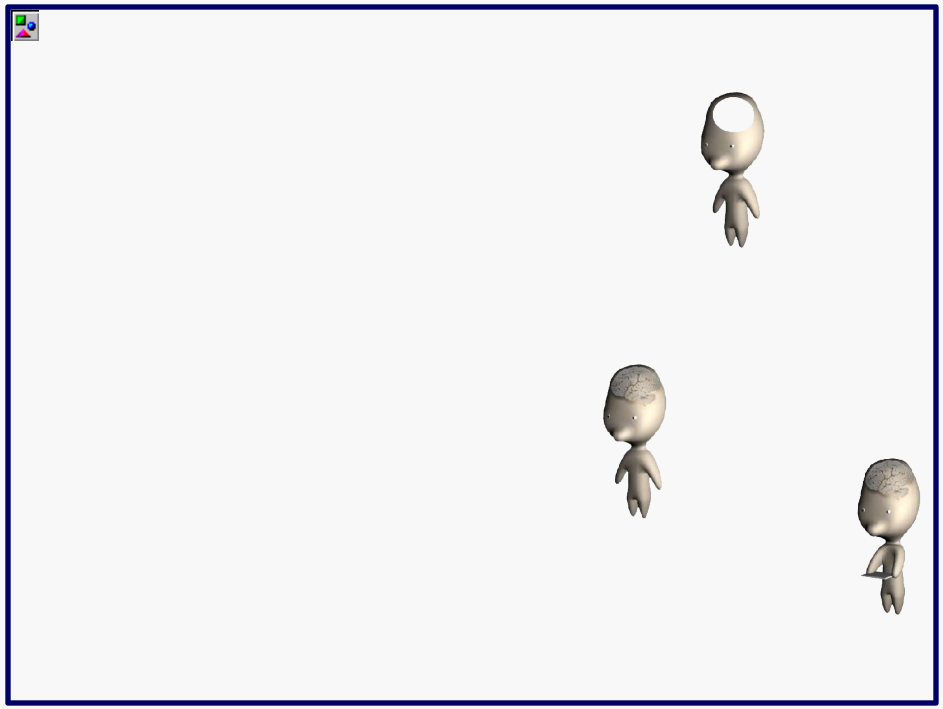
Covering Movie.



Covering: Experiments

Media & Machines

- **Compare adaptive roadmap method to random walk.**
- **Uncovered regions are known v.s. unknown.**
- Roadmap based method can cover the space within reasonable time



Swarming Behaviors:

Exploring: Goal Searching [PG'02, ALife'02, WAFR'02]

- Local information
- Update local info
- Memory
- Reasoning

Media & Machines

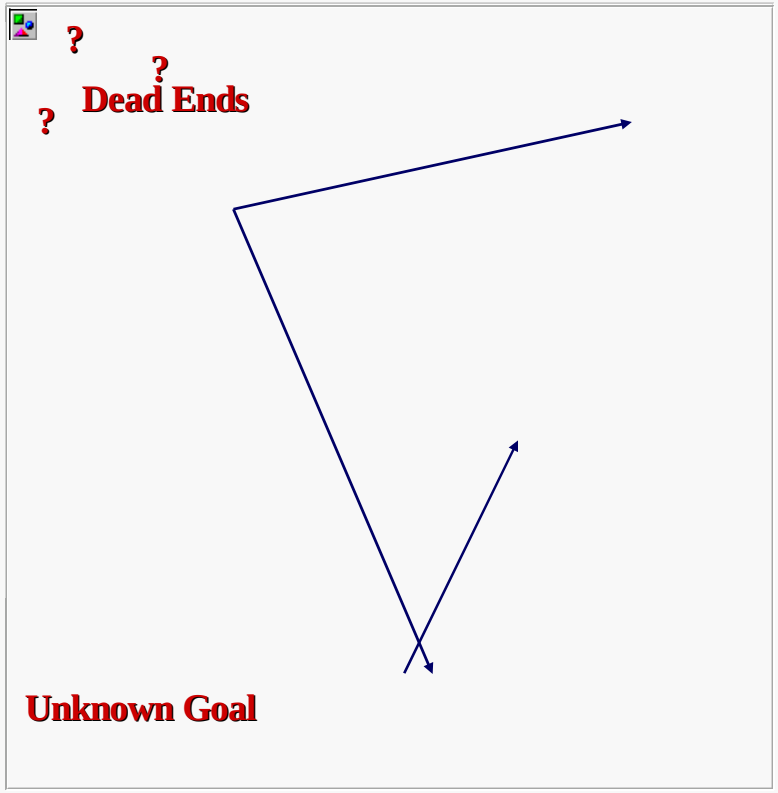
Look for unknown goal (covering)

Update edge weights on good (and bad) paths

Then, all agents go to goal (homing)

5.

The rest of members reach the goal.



Applications: Exploring Goal Searching

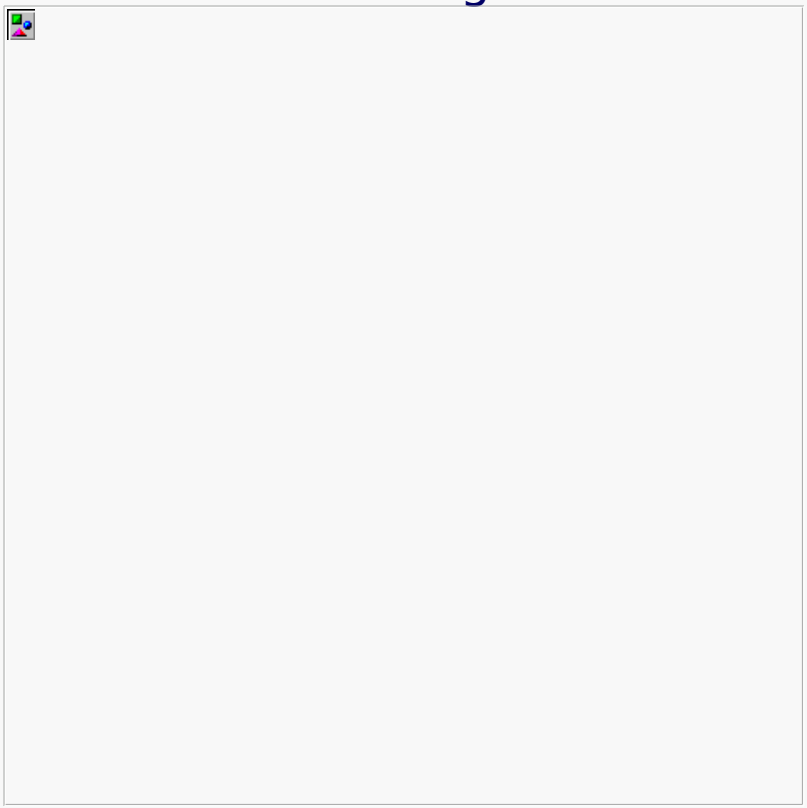
Media & Machines

-50 flock members

-Environment size: 80 m *100 m

-Sensory range: 5 m

Goal Searching Movie 1.



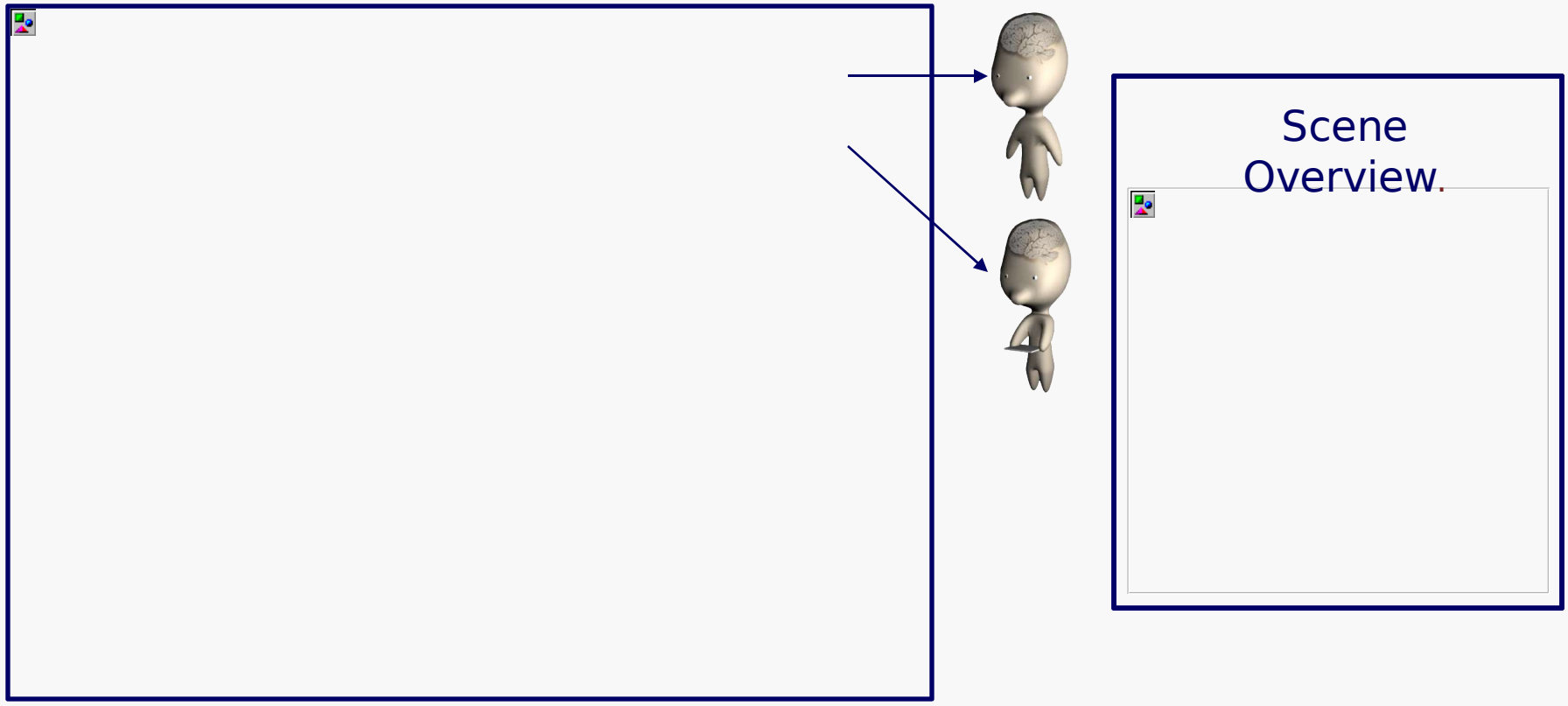
Goal Searching Movie 2.

Experiments on Exploring Goal Searching

Media & Machines

Compare goal searching to known goal location.

Flock with basic behavior can not find the unknown goal



Swarming Behaviors:

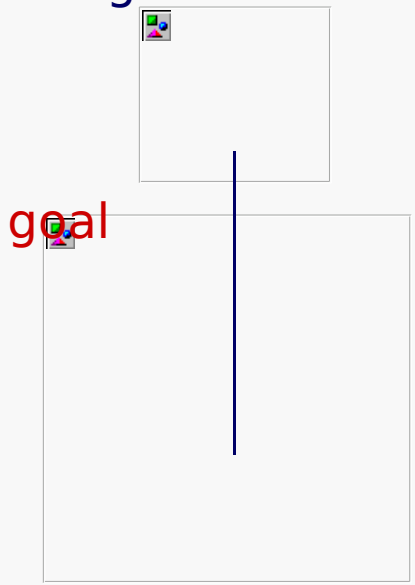
Traversing Narrow Passages [PG'02, ALife'02, WAFR'02]

Media & Machines

- Tune flocking behavior based on surrounding environment
- The main purpose of the rule is to increase the distance between agents so that they will spread out in narrow passage

Narrow Passage Rule

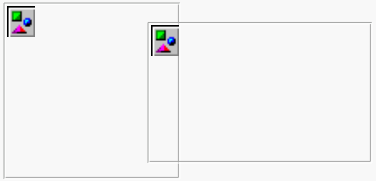
2. Gather at entrance
3. Follow the leader through



Swarming Behaviors:

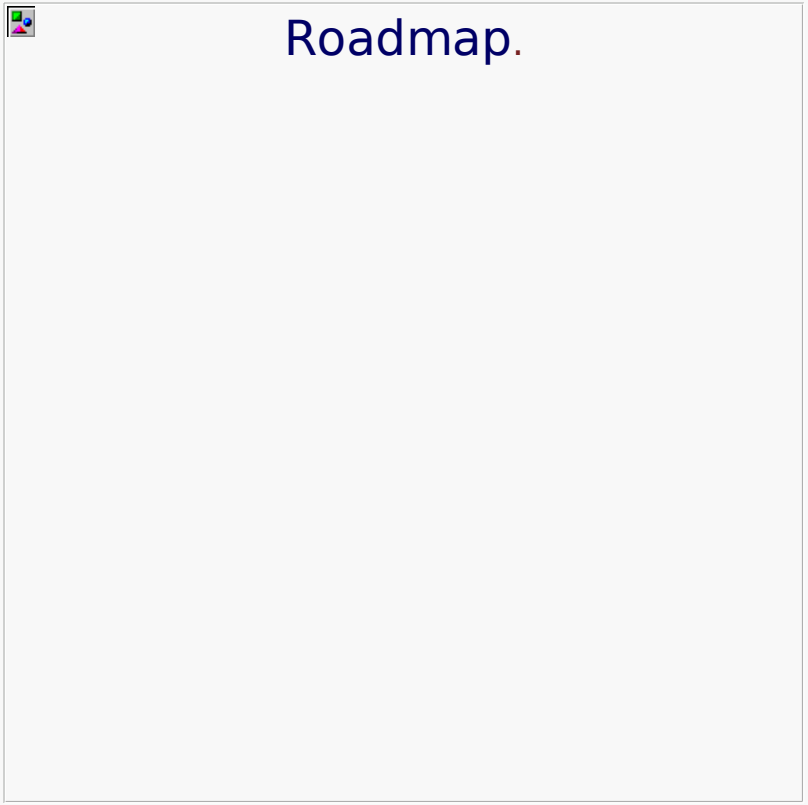
Traversing Narrow Passages

Media & Machines



Flock with Roadmap.

Flock with Rule Based Roadmap.

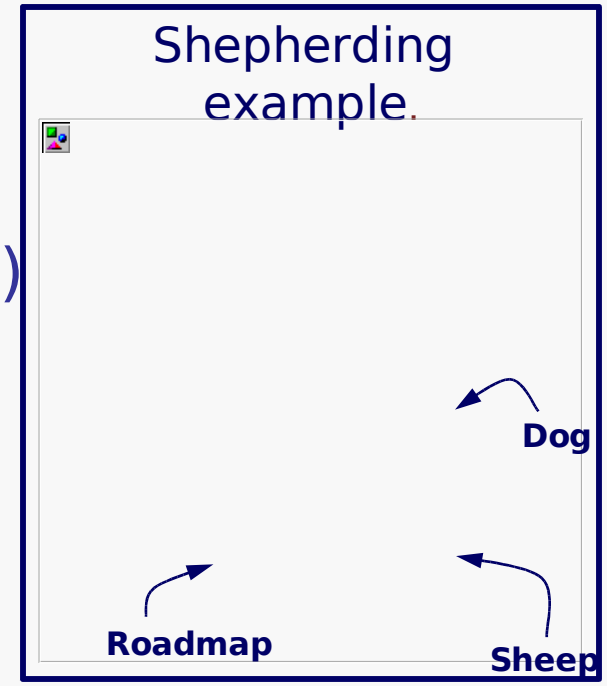


Group Behaviors:
Shepherding [PG'02, ALife'02, WAFR'02, ICRA'04]

- Local information
- Update local info
- Memory
- Reasoning

Media & Machines

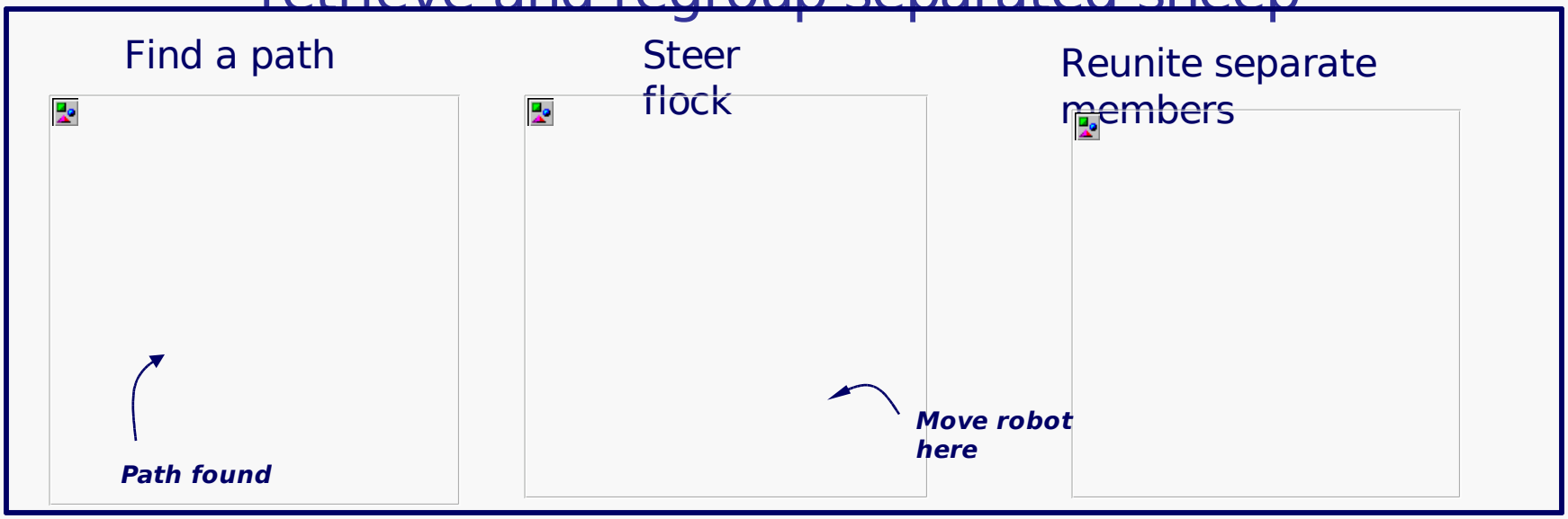
- Sheep (boids)
  - have basic flocking behavior
  - avoid dog (repulsive force)
  - no global knowledge (no roadmap)
- Dog (external agent)
  - controls flock motion
  - uses roadmap



Group Behaviors:
Shepherding

Media & Machines

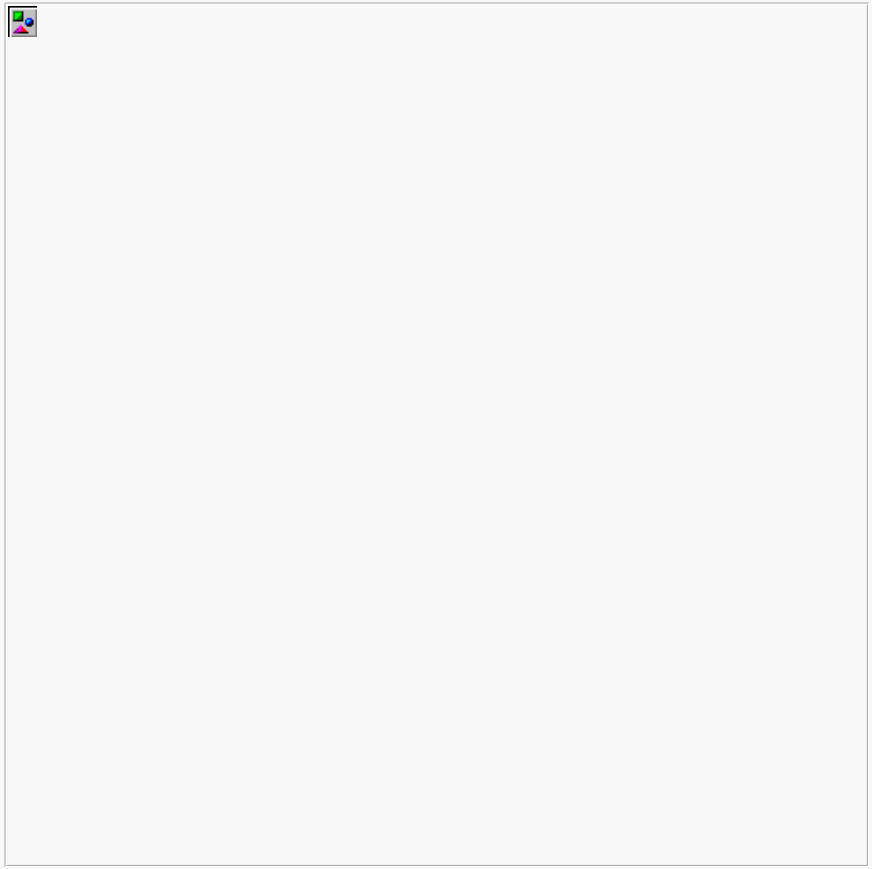
- The dog's tasks include
  - Find path in roadmap taking sheep towards goal
  - Steer (some) sheep in useful direction
  - retrieve and regroup separated sheep



Group Behaviors:
Shepherding

Media & Machines

Shepherding Movie.

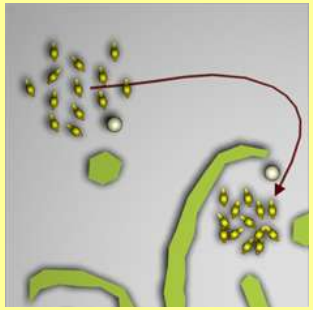


Shepherding Behaviors

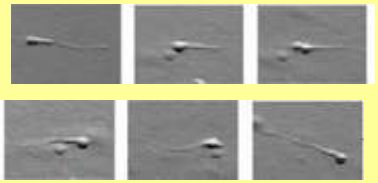
Potential Applications

Media & Machines

herding



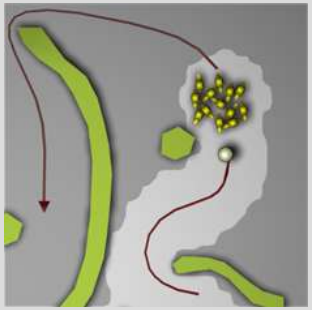
[Vaughan et al ‘00]



Neuron Migration

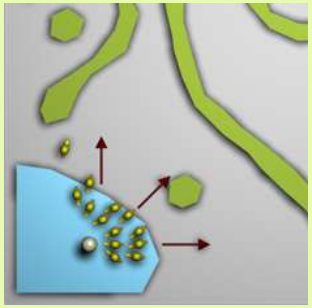
[Ward et al ‘03]

covering



- Mine sweeping
- Surveillance
- Tour guide
- Vacuuming
- Mowing

patrolling

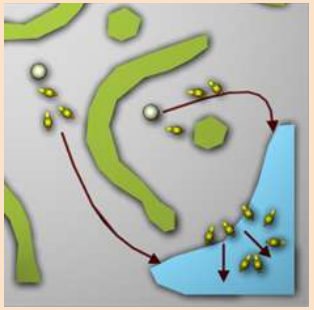


- Bird Strike: Every year, over 1 billion dollars is wasted and lives are endangered worldwide when birds and other wildlife collide with aircraft.

http://www.birdstrike.org/

- Keep swimmers or children away from dangerous areas.

collecting



skimmer

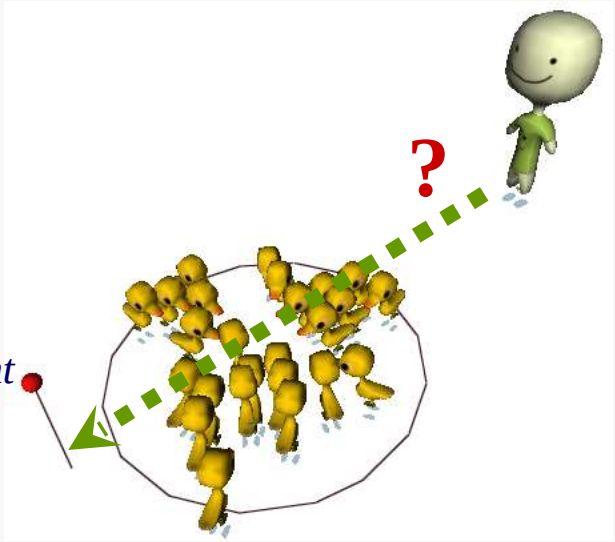
- Oil spill: Nearly 14,000 spills are reported each year in U.S., accounting for about 100 million gallons of oil. www.cleanupoil.com
- Lions hunt, dogs gather a herd of cattle.

Shepherd's Locomotion

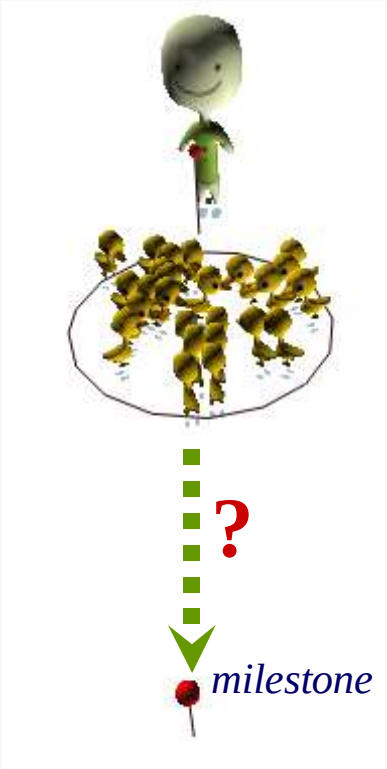
Media & Machines

- **Shepherd's locomotion: how the shepherd will move in order to control the flock**
- **Two sub-problems**

1. Approaching the flock

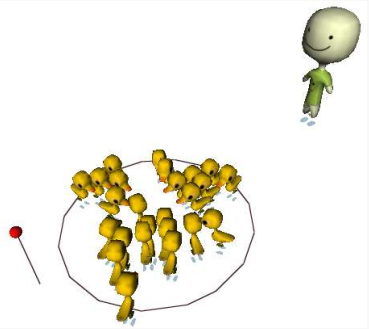


2. Steering the flock



Locomotion

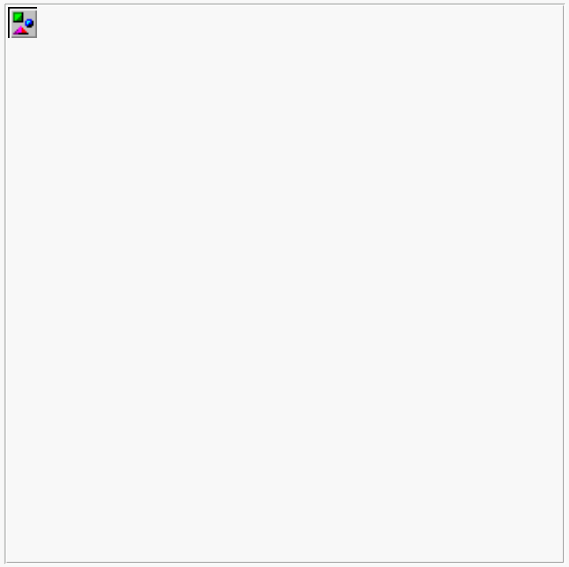
Approaching the Flock



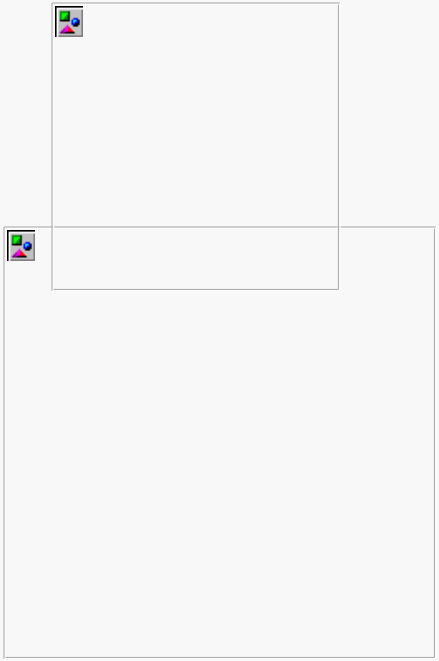
Media & Machines

- **Three approaching methods**
  1. Approaching using a straight line [*Vaughan et al.'00, Bayazit, Lien, Amato'02*]
  2. Approaching using a safe zone
  3. Approaching using a local (dynamic) roadmap

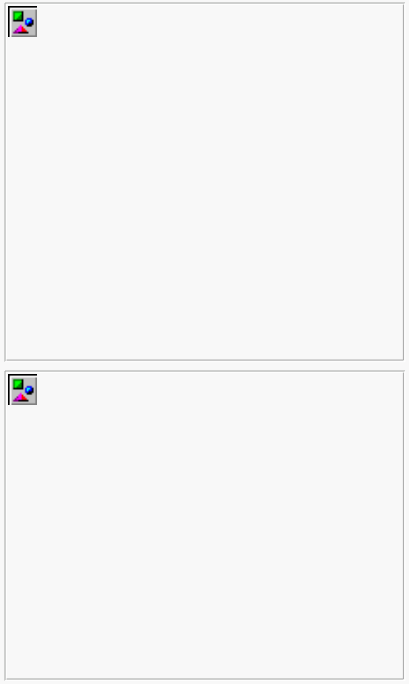
1. Using a straight line



2. Using a safe zone



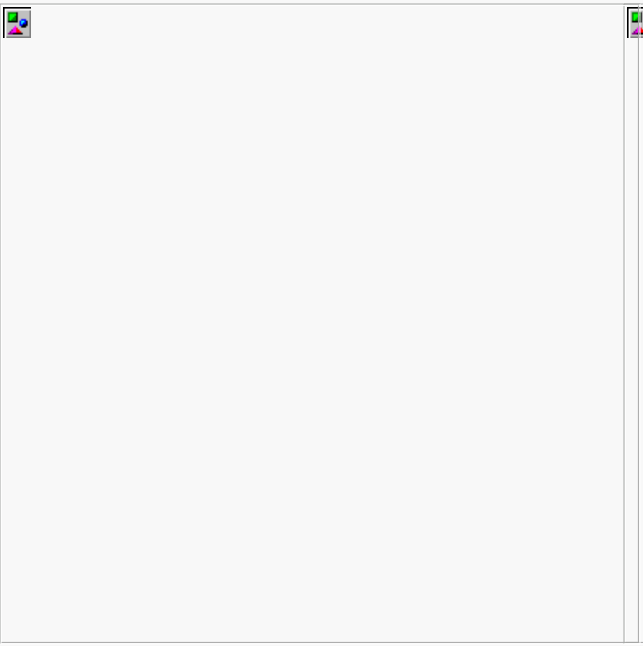
3. Using a local roadmap



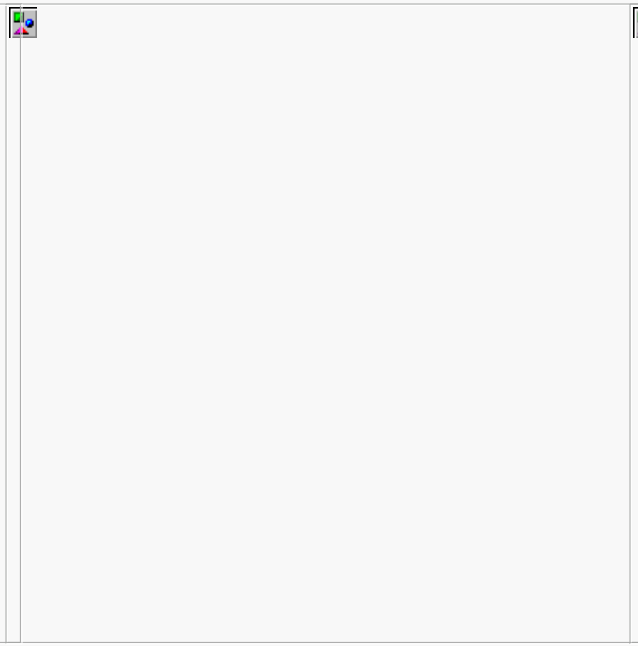
Approaching using a Safe Zone

Media & Machines

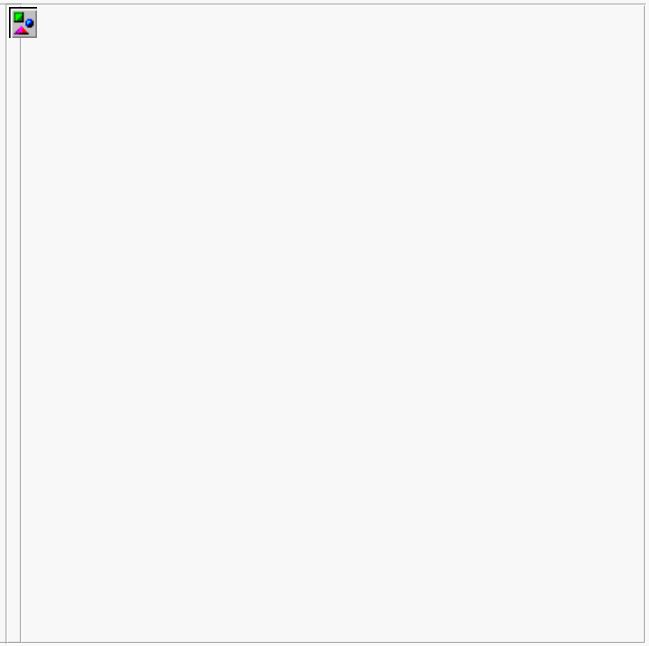
- A *safe zone* is a region around the flock outside of which the shepherd can move freely without disturbing the contour of the flock



Exact safe zone



Convex hull safe zone

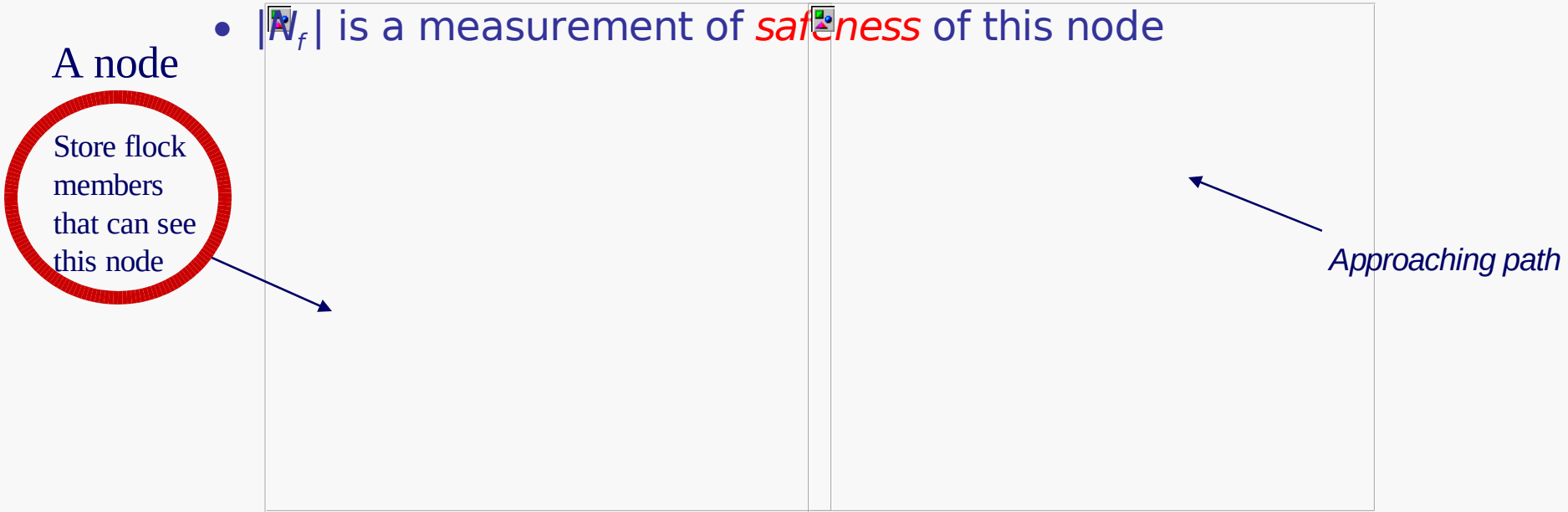


Circular safe zone

Approaching using a Dynamic Roadmap

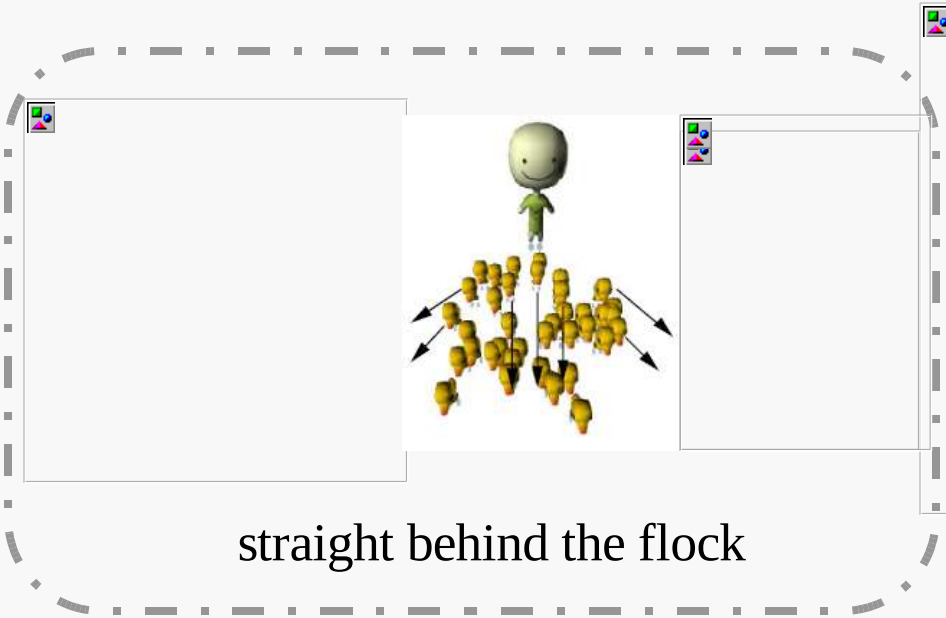
Media & Machines

- ***Constructed during the simulation***
  - To reflect the dynamic states of the flock
  - Nodes are created near the flock when the shepherd is approaching
    - Nodes are distributed as $P = 1 - |P_{gauss}|$
  - Each node store its *visible flock members*, N_f
    - A node will be *removed* if $|N_f| = 0$
    - $|N_f|$ is a measurement of *safeness* of this node

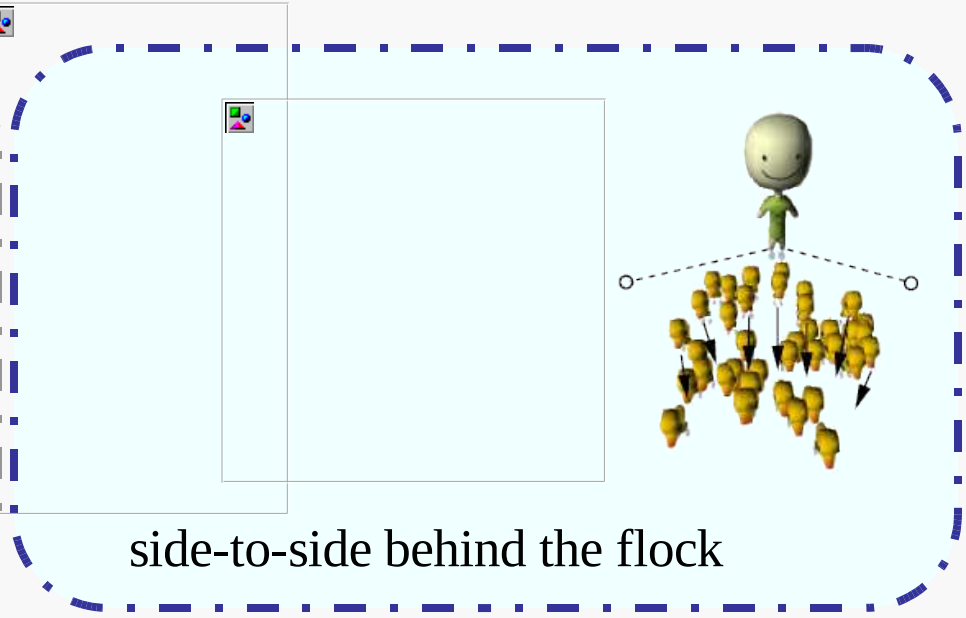


Steering the Flock

- **Forward steering**
  - Steering straight behind the flock [*Schultz et al.'94, Vaughan et al.'00, Bayazit, Lien, Amato'02*]
  - Steering side-to-side behind the flock



straight behind the flock



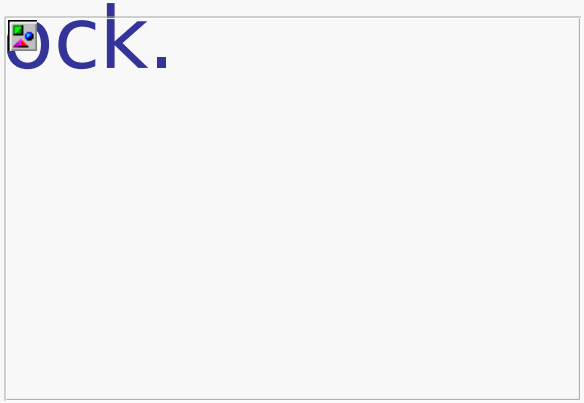
side-to-side behind the flock

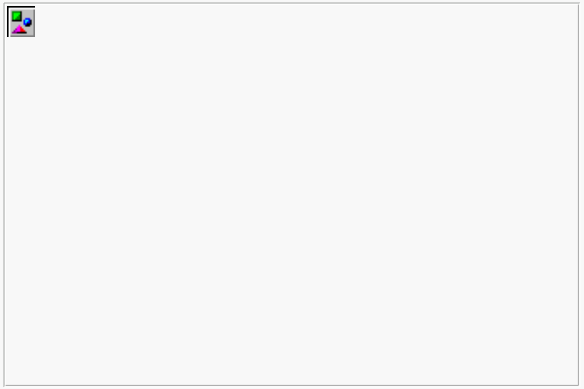
Side-to-Side Steering

Media & Machines

- Some sheep dogs walk side-to-side behind the flock to steer the flock.

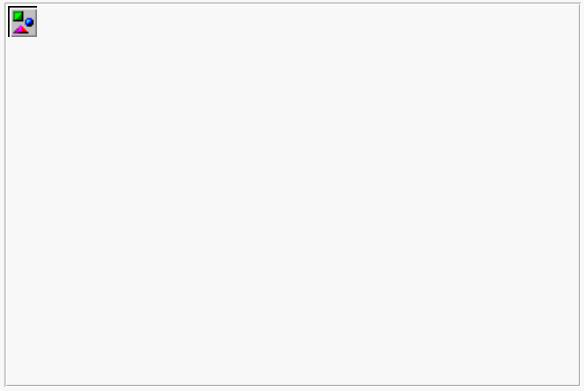
cattle

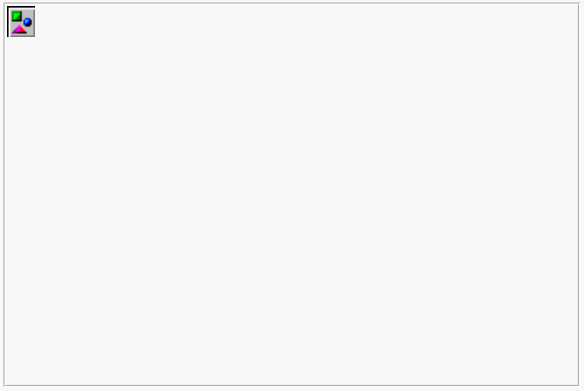




sheep

horses





ducks

Turn steering

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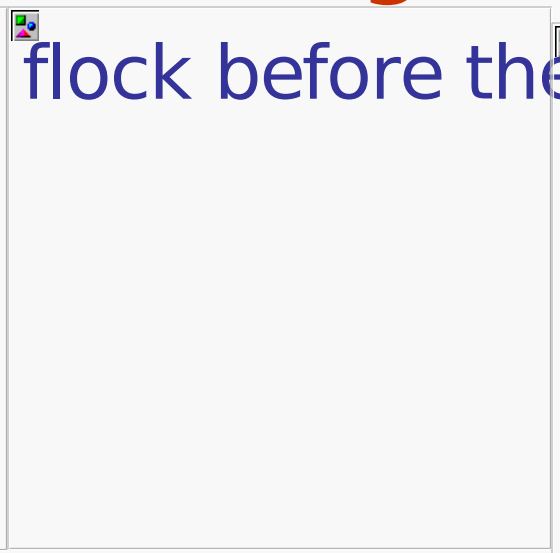
- **Stop-turn steering**
  - Stop the flock and then change the flock's heading dir
- **Pre-turn steering**
  - Turn the flock before the turn takes place

No turn steering



Stop-turn steering

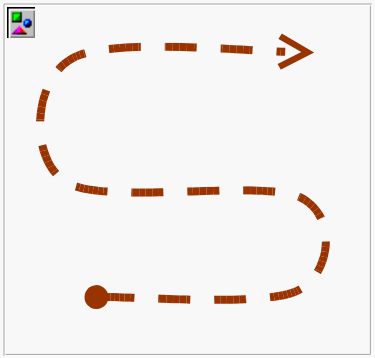
Stop + pre-turn steering

Simulating Shepherding Behaviors

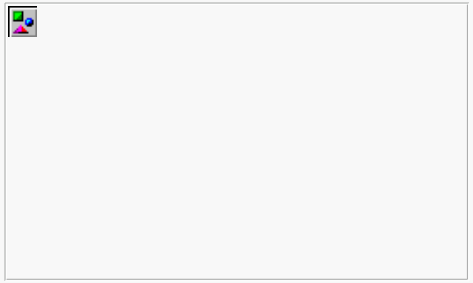
Media & Machines

These shepherd locomotions are used as a *common* base to simulate following behaviors

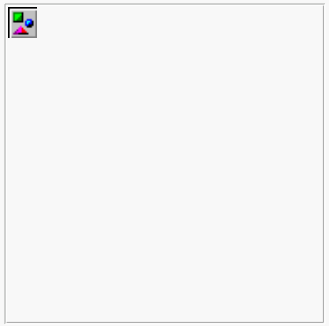
Herding



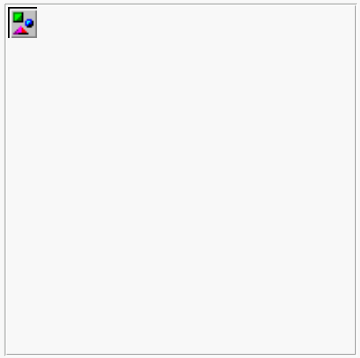
Patrolling



Collecting



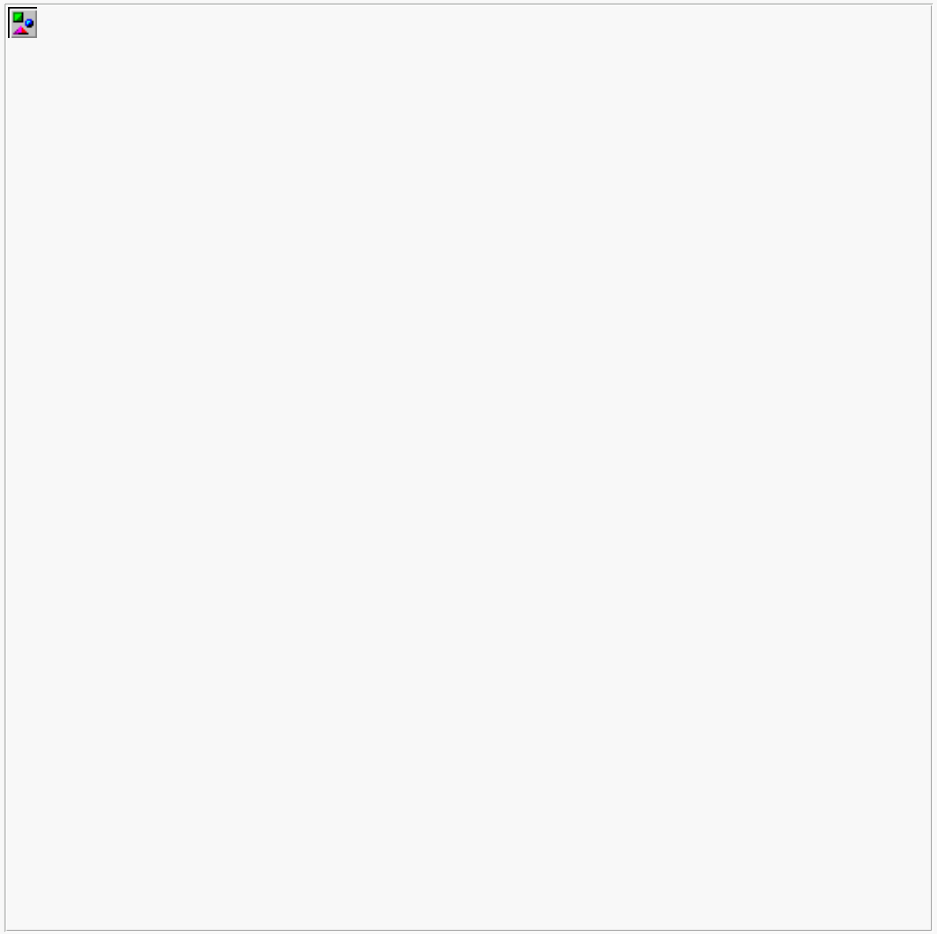
Covering



Shepherd Herding

Media & Machines

The speed of these videos is 10× faster than the speed of simulation



Shepherd Herding

Media & Machines

	Approaching	Steering: Forward Steering	Steering: Turn-steering
LL	Straight-line	Straight-line	
SL	Safe-zone	Straight-line	
SS	Safe-zone	Side-to-side	
SSS	Safe-zone	Side-to-side	Stop-turn
SSSP	Safe-zone	Side-to-side	Stop-turn & Pre-turn
DSS	Dynamic-roadmap	Side-to-side	Stop-turn
DSSP	Dynamic-roadmap	Side-to-side	Stop-turn & Pre-turn

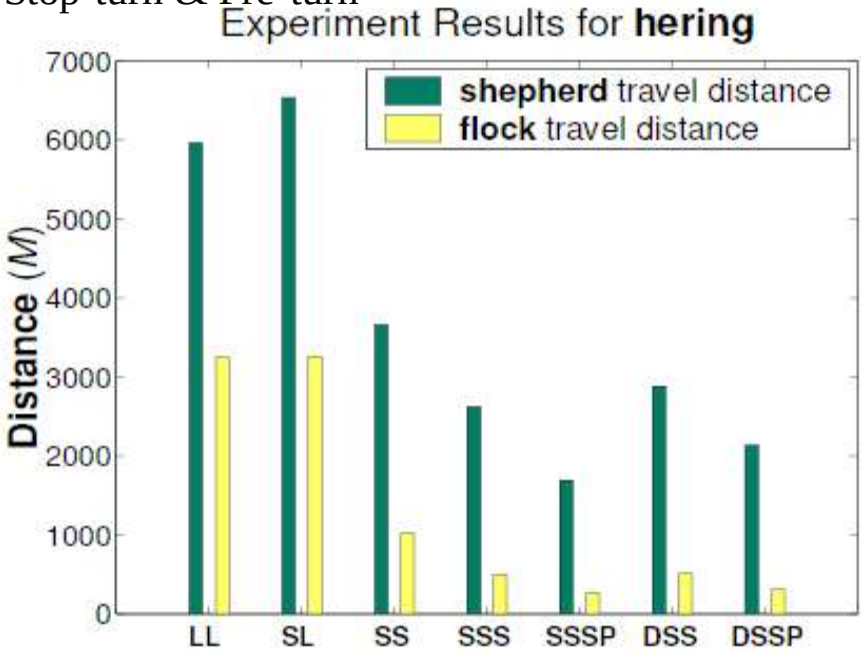
- Safe-zone and Dynamic-Roadmap approaching is better than Straight-line approaching
- Side-to-Side steering with stop-turn and pre-turn steering is the best way to steer
- Shepherd with better locomotion travels less (less time spent on corrections and reuniting)

Shepherd Herding

Media & Machines

	Approaching	Steering	Turn-steering
LL	Straight-line	Straight-line	
SL	Safe-zone	Straight-line	
SS	Safe-zone	Side-to-side	
SSS	Safe-zone	Side-to-side	Stop-turn
SSSP	Safe-zone	Side-to-side	Stop-turn & Pre-turn
DSS	Dynamic-roadmap	Side-to-side	Stop-turn
DSSP	Dynamic-roadmap	Side-to-side	Stop-turn & Pre-turn

The shepherd with "better" locomotion actually travels less.

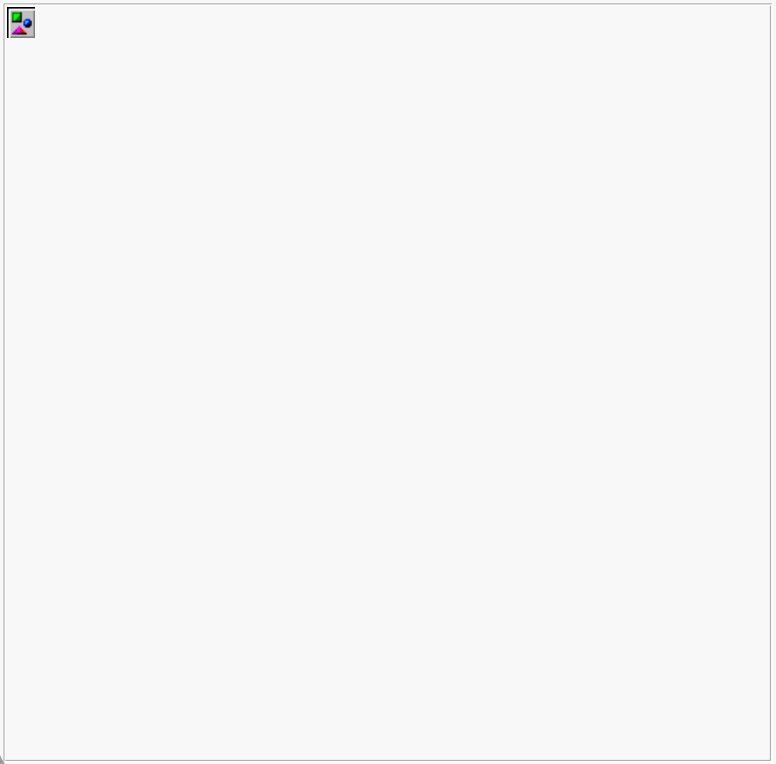


Shepherd Covering

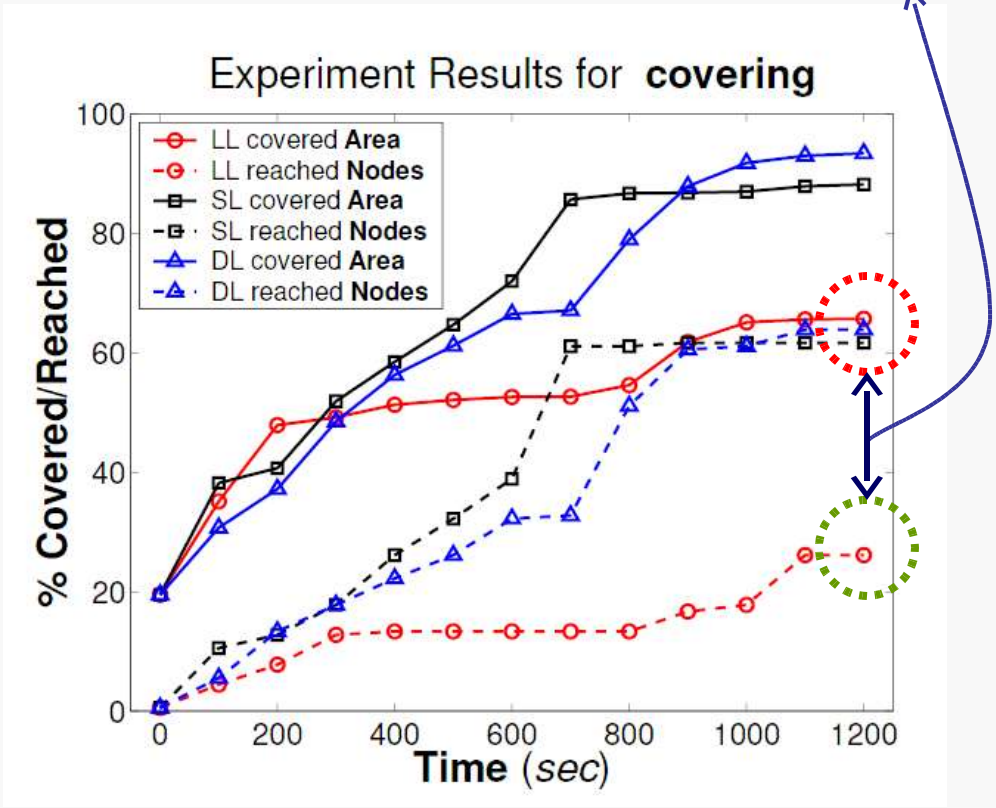
Media & Machines

20 flock members

Video is in simulation speed



Benefit of using our new locomotion



LL: Straight-line locomotion.

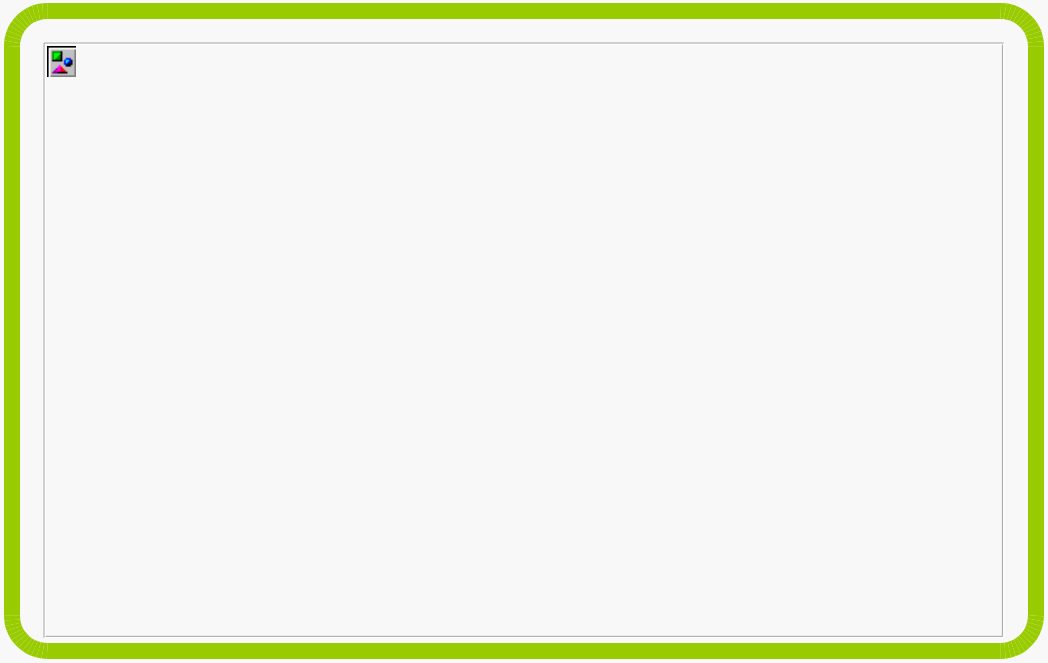
SL: Safe-zone and “better” steering.

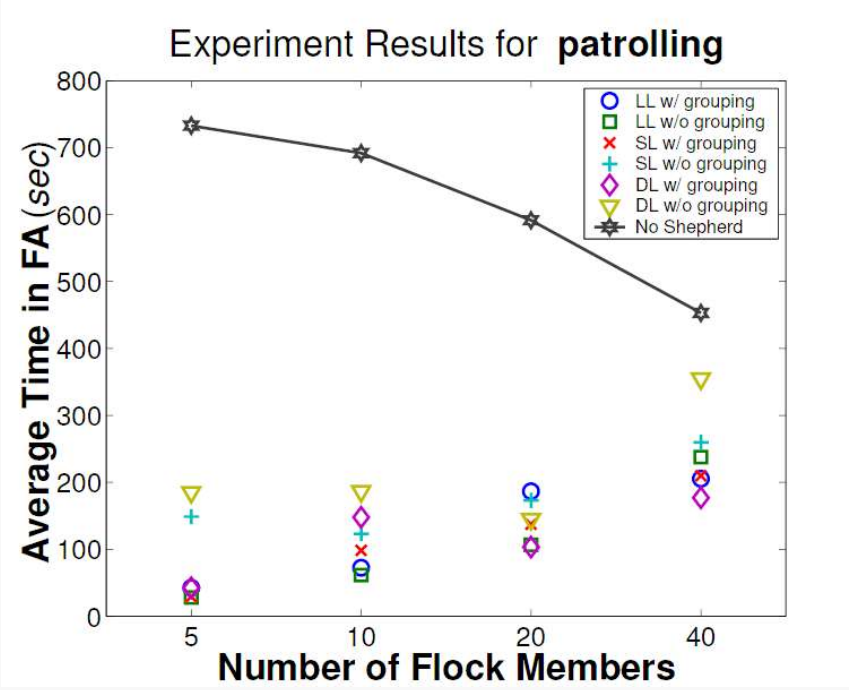
DL: Dynamic-roadmap and “better” steering.

Shepherd Patrolling

LL: Straight-line locomotion.
SL: Safe-zone and "better" steering.
DL: Dynamic-roadmap and "better" steering.

Media & Machines



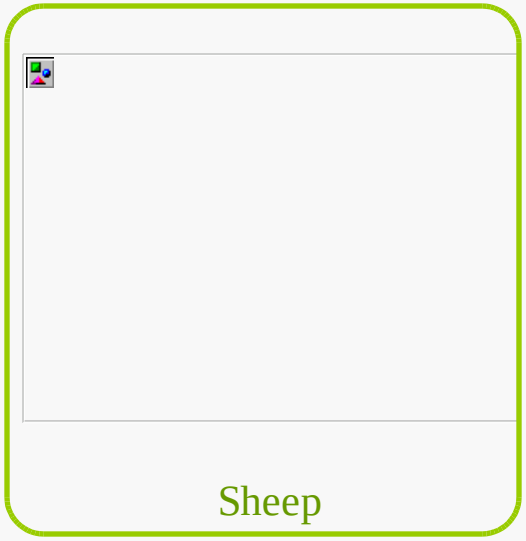


- For small flocks, straight-line approaching/steering performs best
- For larger flocks, more intelligent techniques are needed
- The performance degrades as the flock size increases

Shepherd Collecting

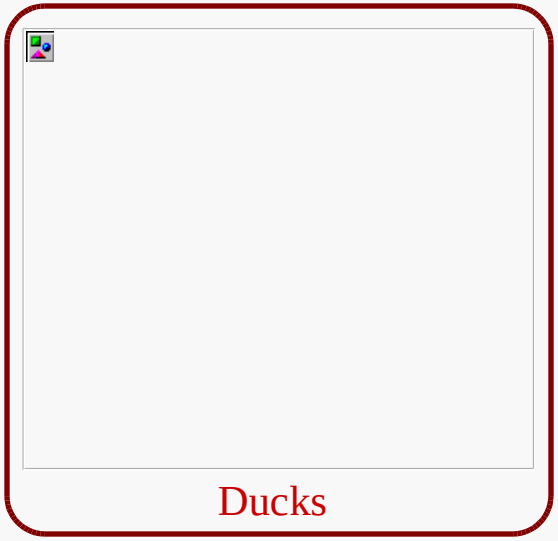
Media & Machines

with *50* flock members



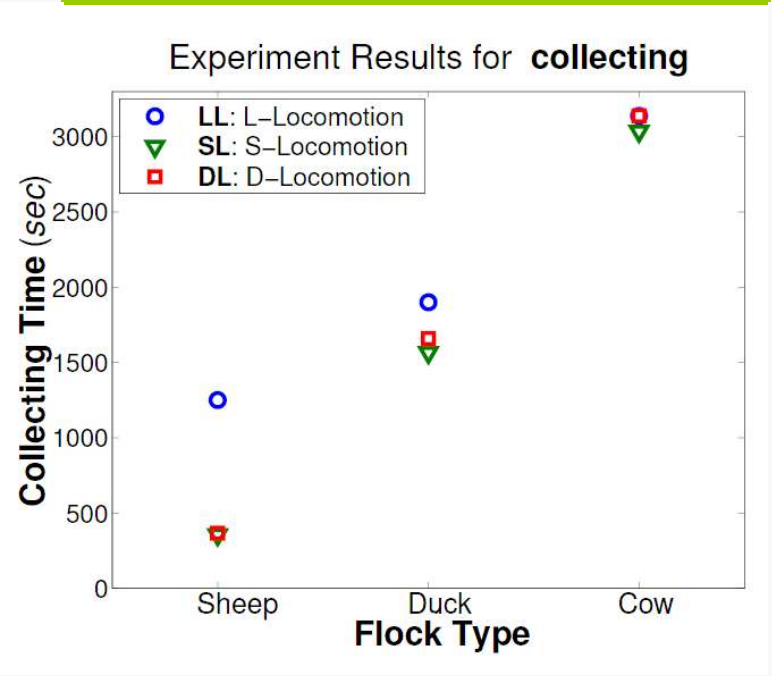
Sheep

Videos are 10× faster



Ducks

Sheep	Duck	Cow
stay together	Easy to separate	Easy to separate
intimidated	intimidated	Less intimidated



- Intelligent locomotion is better than straight-line approaching/straight-line steering
- Cows are hardest to steer (they have their own mind!!!)

LL: Straight-line locomotion

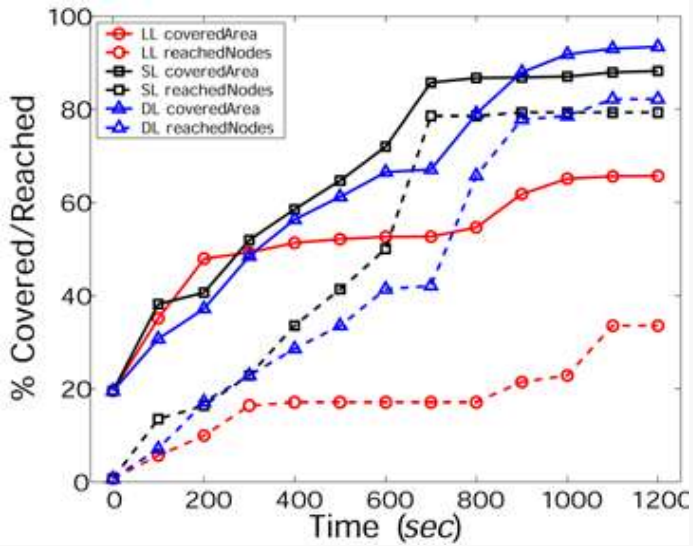
SL: Safe-zone and "better" steering

DL: Dynamic-roadmap and "better" steering

Shepherd Covering

Media & Machines

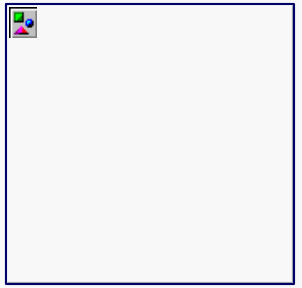
20 Flock members

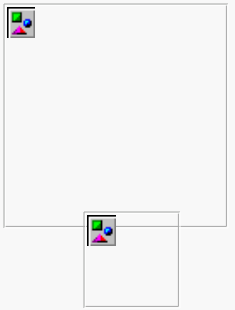


Conclusion

Media & Machines

- Basic flocking systems are good at simulating simple Swarming Behaviors
- More sophisticated behaviors can be generated using global information provided in a roadmap
- Dynamic roadmaps support implicit communication among agents
- Rule-based roadmaps enable region specific customization

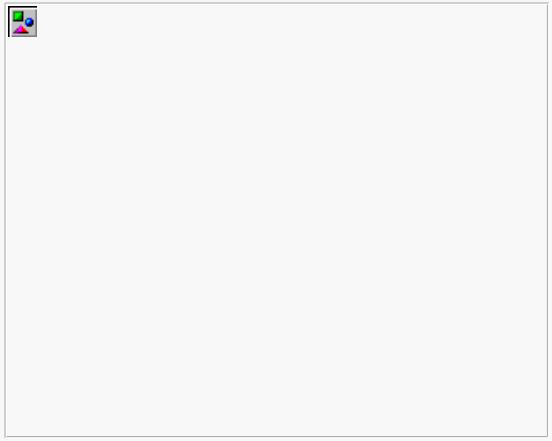




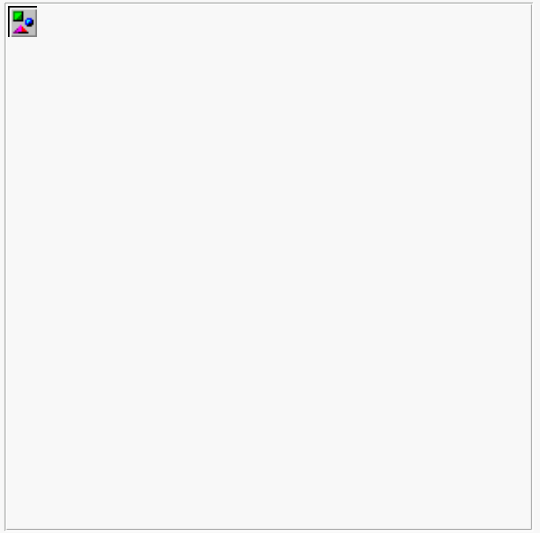
Future Work

Media & Machines

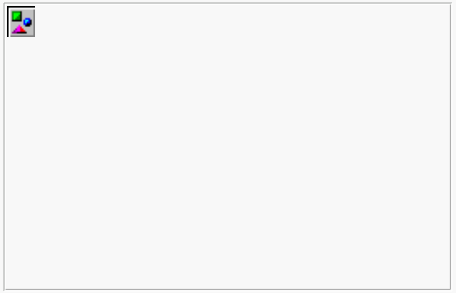
Crowd Animation



Unknown Environments



Multiple Shepherds

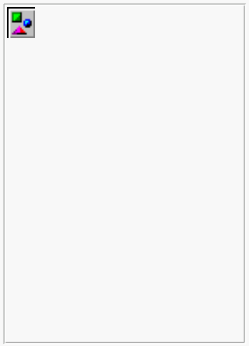


More information & Movies at

Media & Machines http://www.cse.wustl.edu/~bayazit/, bayazit@cse.wustl.edu

Burchan

bayazit@cse.wustl.edu



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Special thanks

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