Collaborative Foraging using Beacons

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Motivation



Highly constrained large scale multi-robot systems
Noisy sensors

Limited computational resources

Very limited communication capacity

Example Environments
Disaster recovery
Space exploration
Battlefield scenarios

Why Collaborative Foraging?
Originally motivated by social insects, which share similar constraints

费洛蒙，一种化学信息素
Pheromones
Indirect communication through chemical trails in the environment

Prior work

Focused mainly on single pheromone trails
Ad-hoc methods for determining path back to nest

R. J. Collins and D. R. Jefferson. Antfarm : Towards simulated evolution. Artificial Life II, 1992

R. T. Vaughan, K. Støy, G. S. Sukhatme, and M. J. Mataric. Whistling in the dark: Cooperative trail following in uncertain localization space. Proceedings of the Fourth International Conference on Autonomous Agents, 2000

A more intuitive approach
Multi-pheromone trails

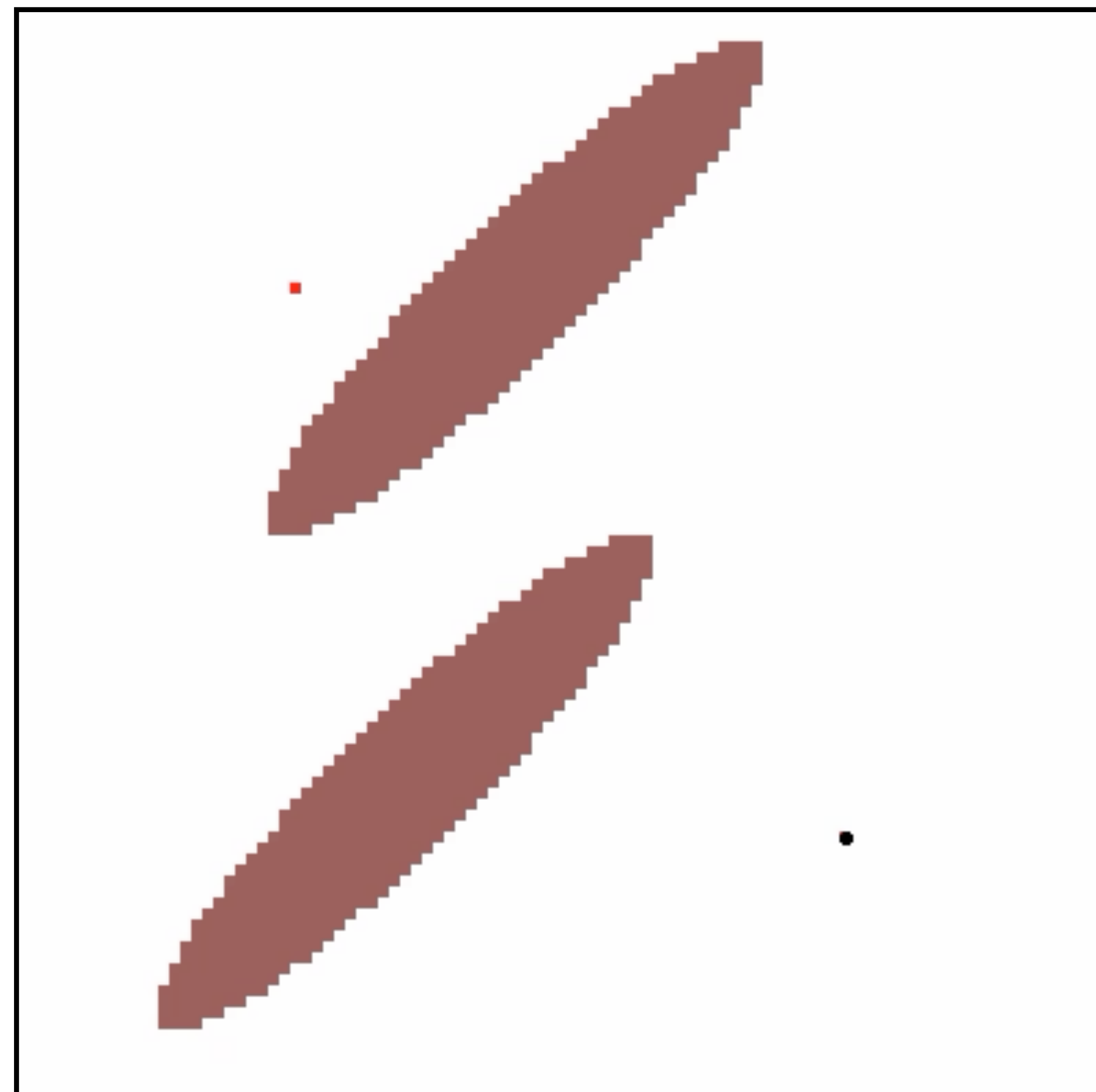
Our previous work

A Pheromone-based Utility Model for Collaborative Foraging
AAMAS 2004

Environment is a 2D grid
Each cell can contain several pheromone values

Agents can read/write multiple pheromones
When fetching food, build up the "nest" pheromone
When returning with food, build up the "food" pheromone

An agent follows a single pheromone according to its current task



Agent behavior

At each timestep:
Pick a new state, s'

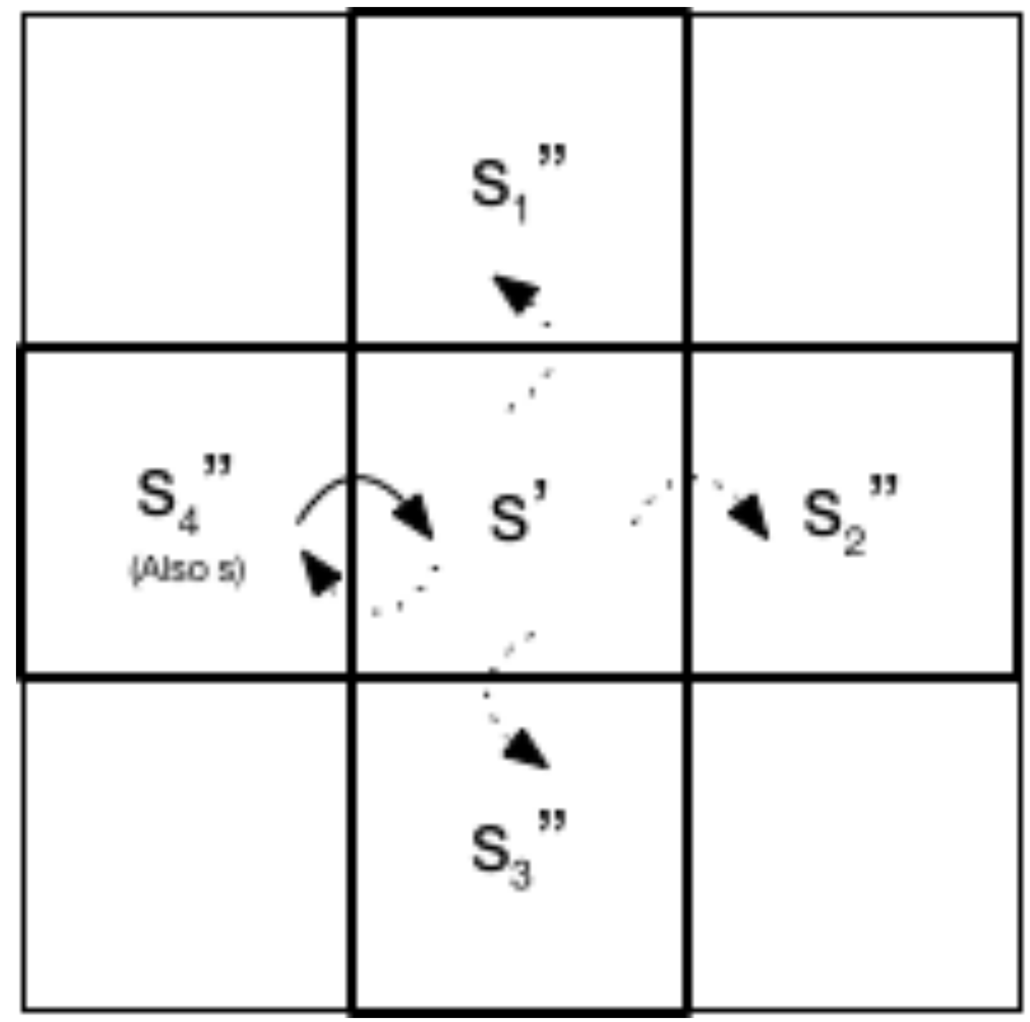
Transition to new state

Update pheromone value

$$U_p(s') = R(s') + \gamma \max_{s'' \in S''} U_p(s'')$$

Agent follows the gradient by picking s' according it's pheromone level

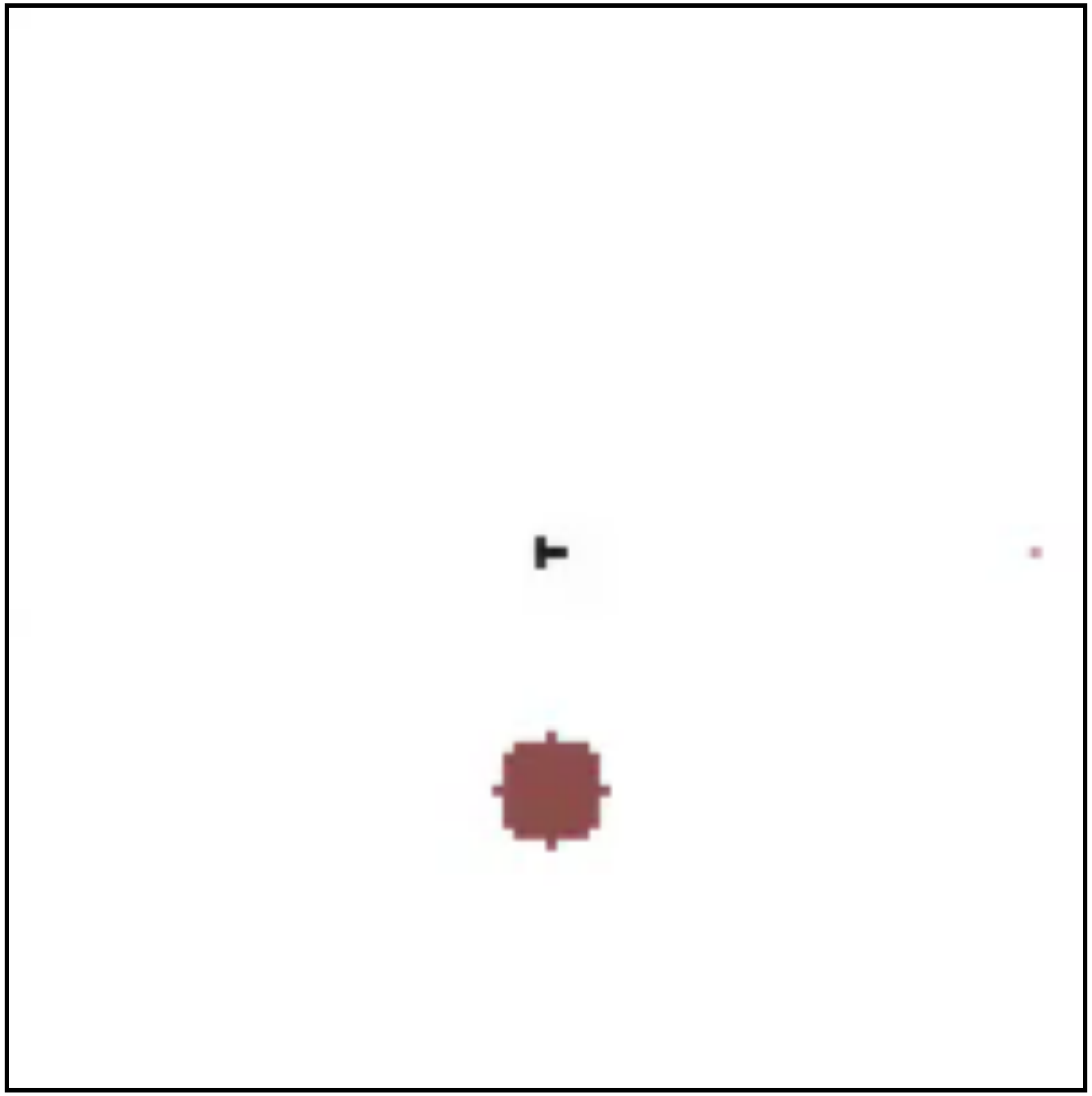
Exploration: random move with probability (wander pheromone)



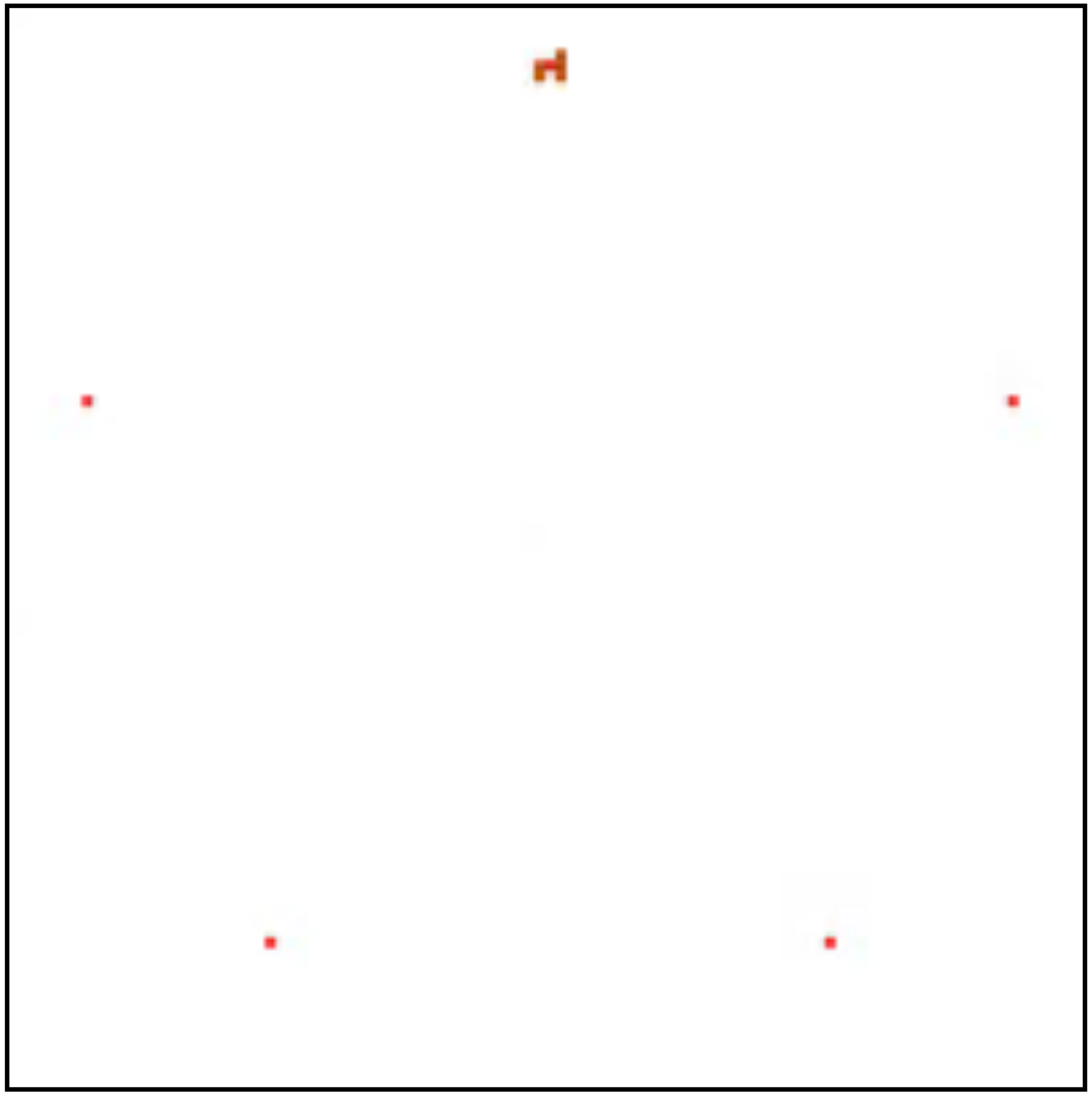
s: previous state
s': current state
s": potential state

R(s'): reward at state s'
U(s"): utility at state s"

More examples



Ant Clock



Multi-waypoint Tours

How do we move to a more realistic environment?

What's more realistic?
Continuous environment
Non-invasive/non-permanent markers

Beacons 运动
An object with no locomotion, some memory, and a limited communications range

Partitions the environment
We can use a utility based formulation

Related work

Marker-to-marker communication
K. O'Hara, D. Walker, and T. Balch. "The GNATs — Low-cost Embedded Networks for Supporting Mobile Robots" Third International Multi-Robot Systems Workshop. March 2005.

Virtual markers
R. T. Vaughan, K. Støy, G. S. Sukhatme, and M. J. Matarić. "LOST: Localization-space trails for robot teams" IEEE Transactions on Robotics and Automation, 2002

Immobile markers
V. A. Ziparo, A. K. B. Nebel, and D. Nardi. RFID-based exploration for large robot teams. In Proceedings of International Conference on Robotics and Automation, 2007

Agent behavior 1 — following pheromone trails

An individual agent's behavior
Pick a state from those in **range**

Move to new state

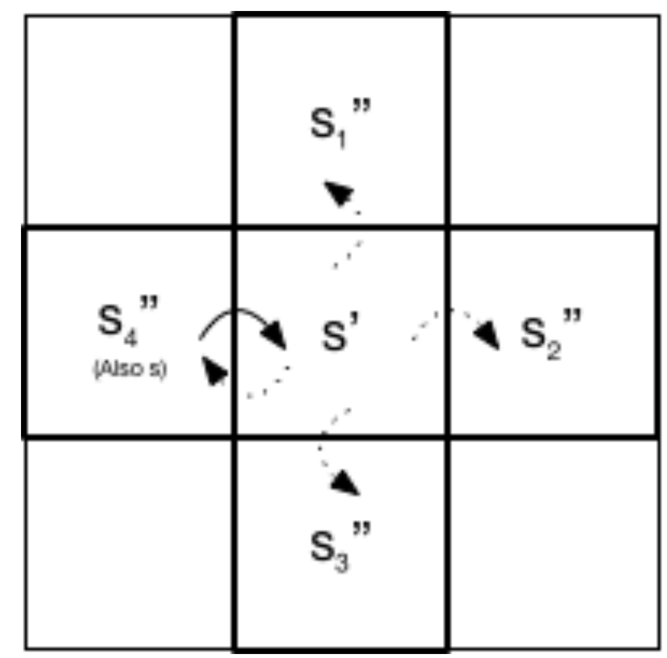
Update pheromones

$$U_p(s') = R(s') + \gamma \max_{s'' \in S''} U_p(s'')$$

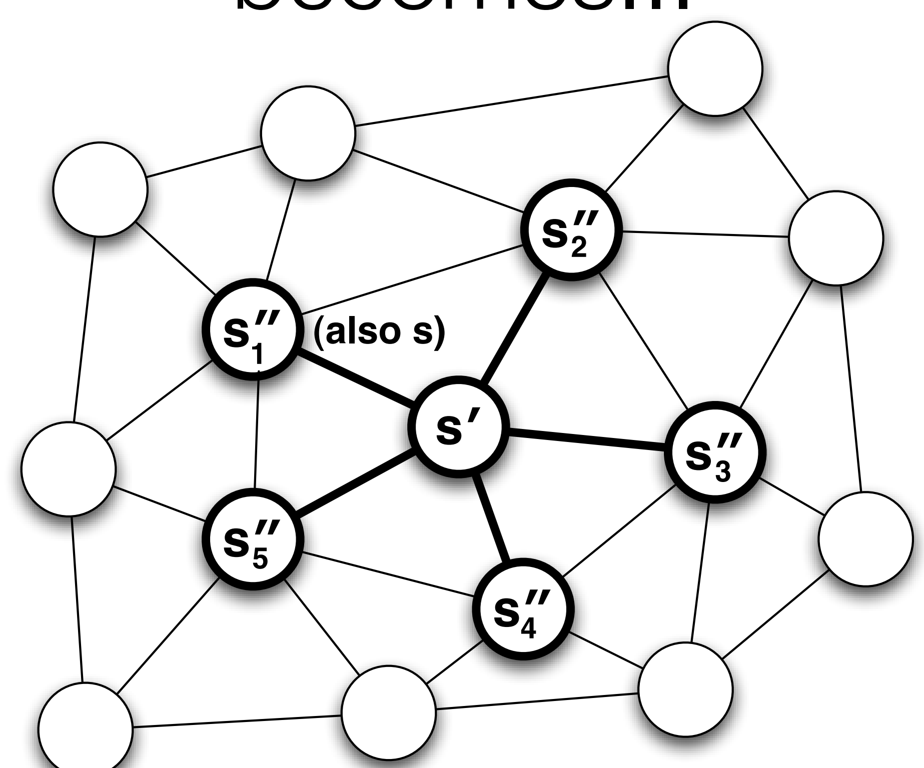
Agent follows the gradient by picking s' according it's pheromone level

s: previous state
s': current state
s": potential state

R(s'): reward at state s'
U(s"): utility at state s"



becomes...



Agent behavior 2 — moving beacons

An agent can also...
Add a beacon if the beacon neighborhood is small, **remove** a beacon if the area is overcrowded, and **move** a beacon to "straighten" the pheromone trail

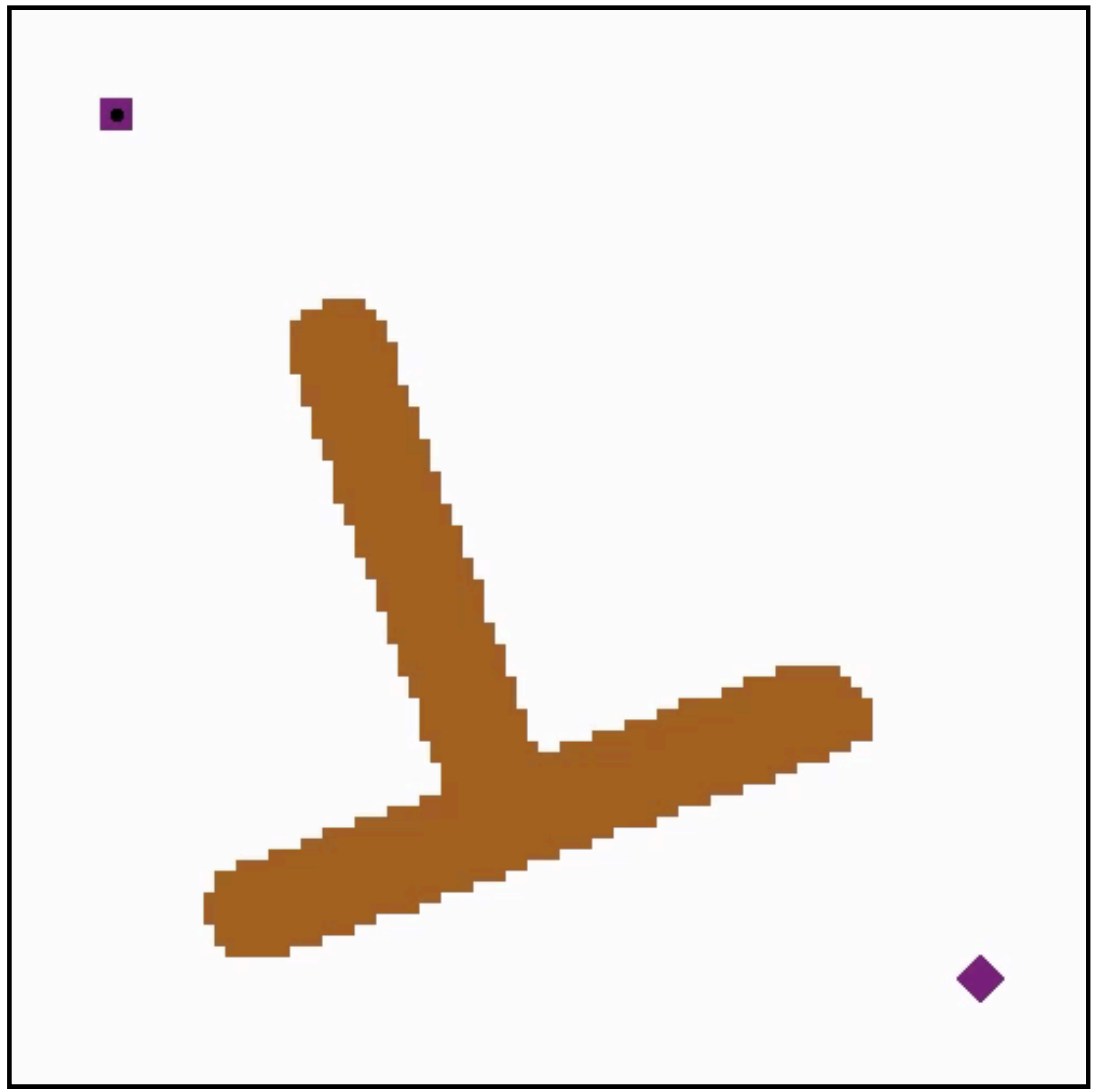
When is it safe to move a beacon?
Don't move beacons if it would disconnect the neighborhood

Don't remove beacons that are heavily used

Being conservative means we can use beacons later if the environment changes to make that area interesting

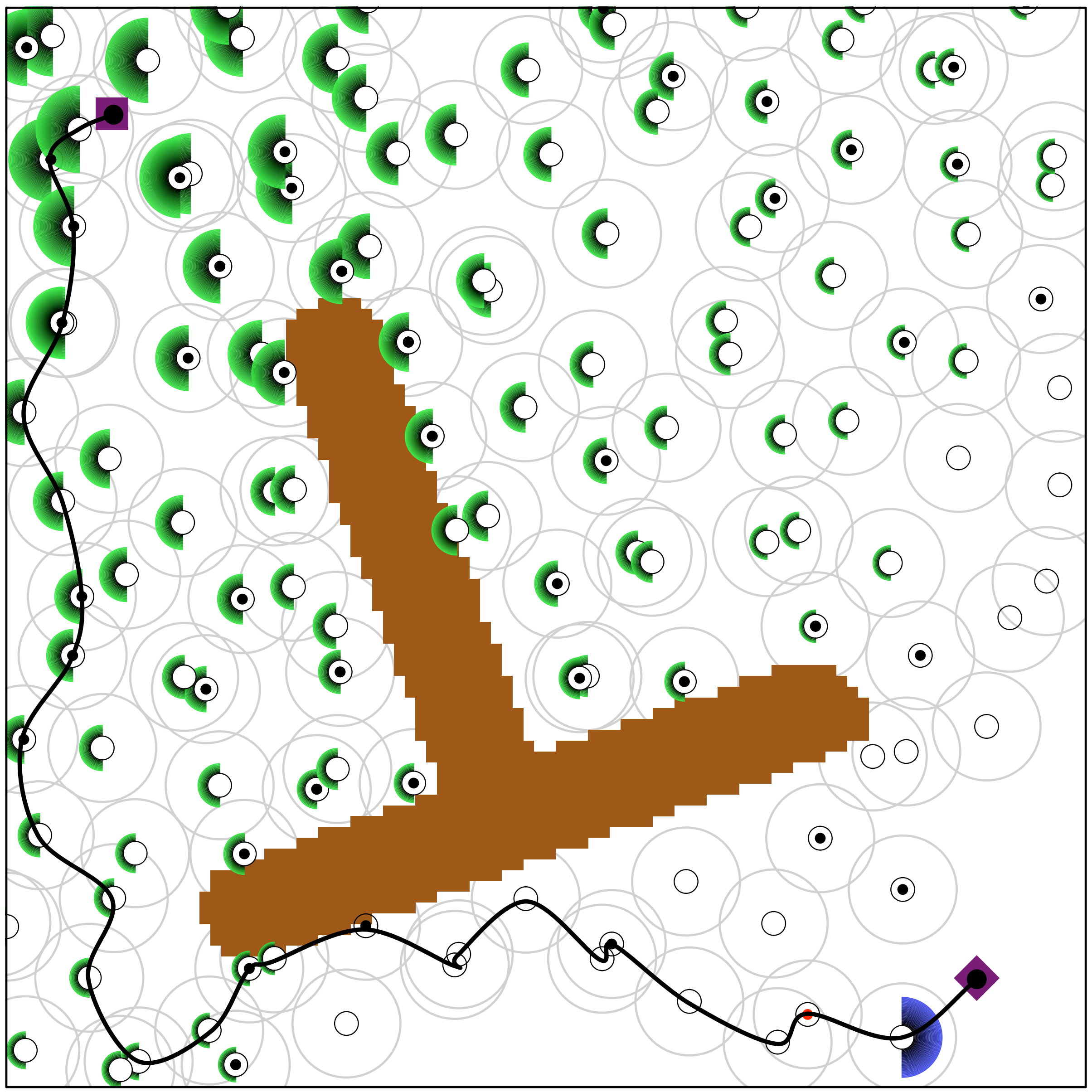
Initial environment with nest (top left), food (diamond) and a T-shaped obstacle.

An example

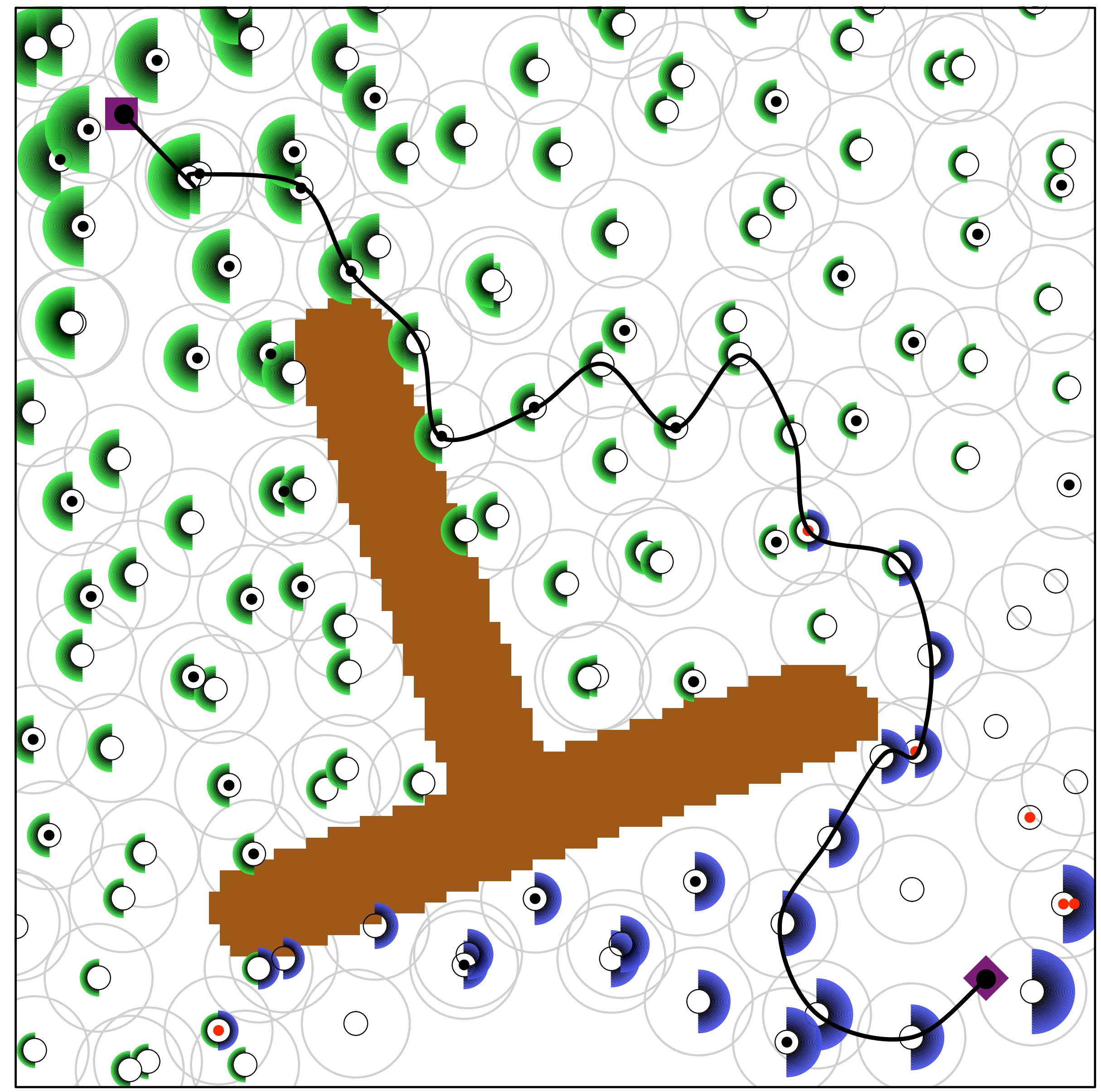


Beacon-Based Pheromone Navigation

First path to food established. Foraging pheromone strength shown on right half of beacons. Food-laden ants are red dots centered at current beacons.

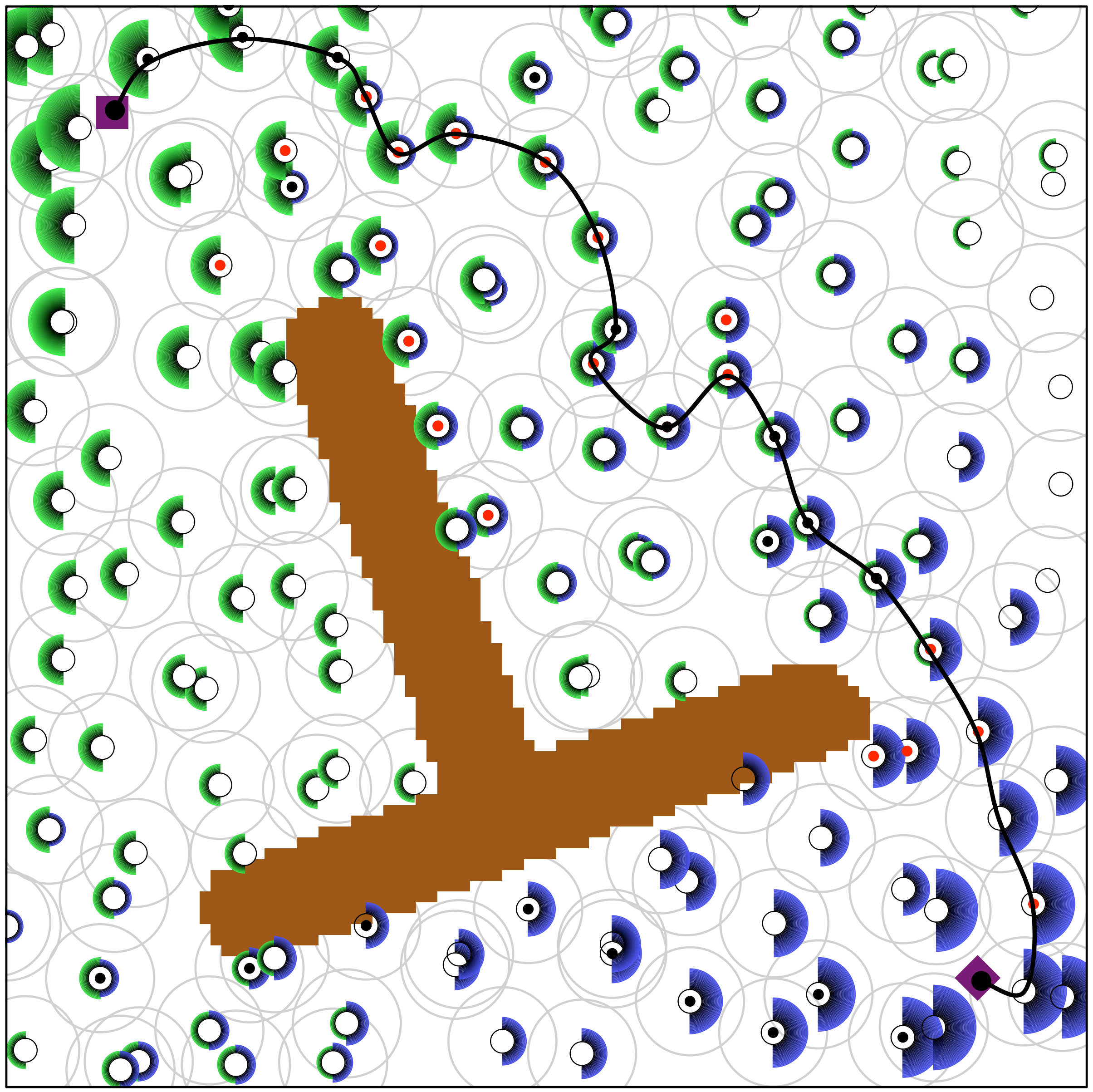


Ants leave the nest and establish beacons. Ferrying-pheromone strength shown on left half of beacons. Ants are black dots centered at beacons.

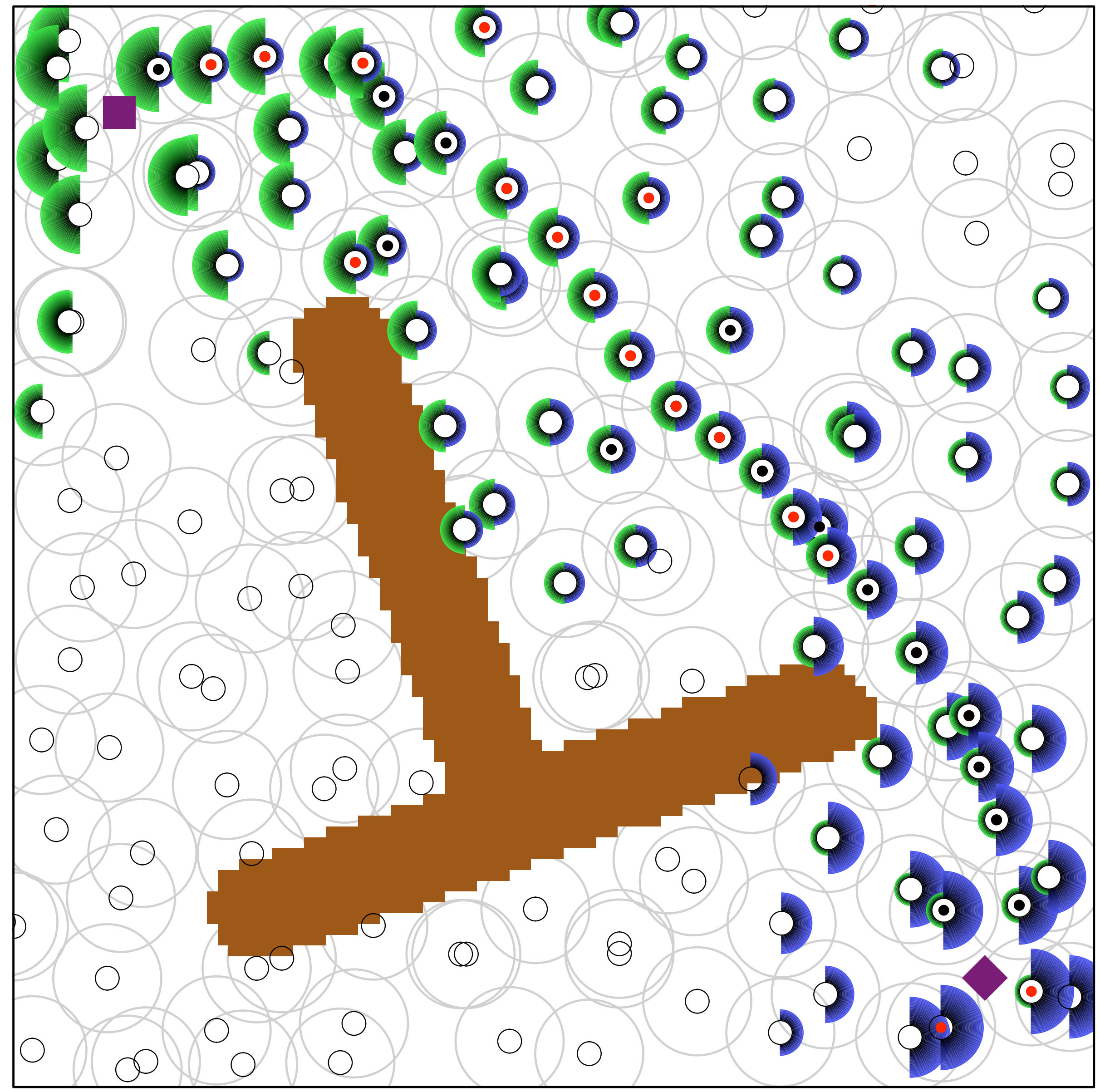


Second shorter path to food established.

Beacon-Based Pheromone Navigation



Second path is improved, the first path has been abandoned.



Ants move beacons to begin to optimize the path.
Disused pheromones are gradually depleted.

Experiments

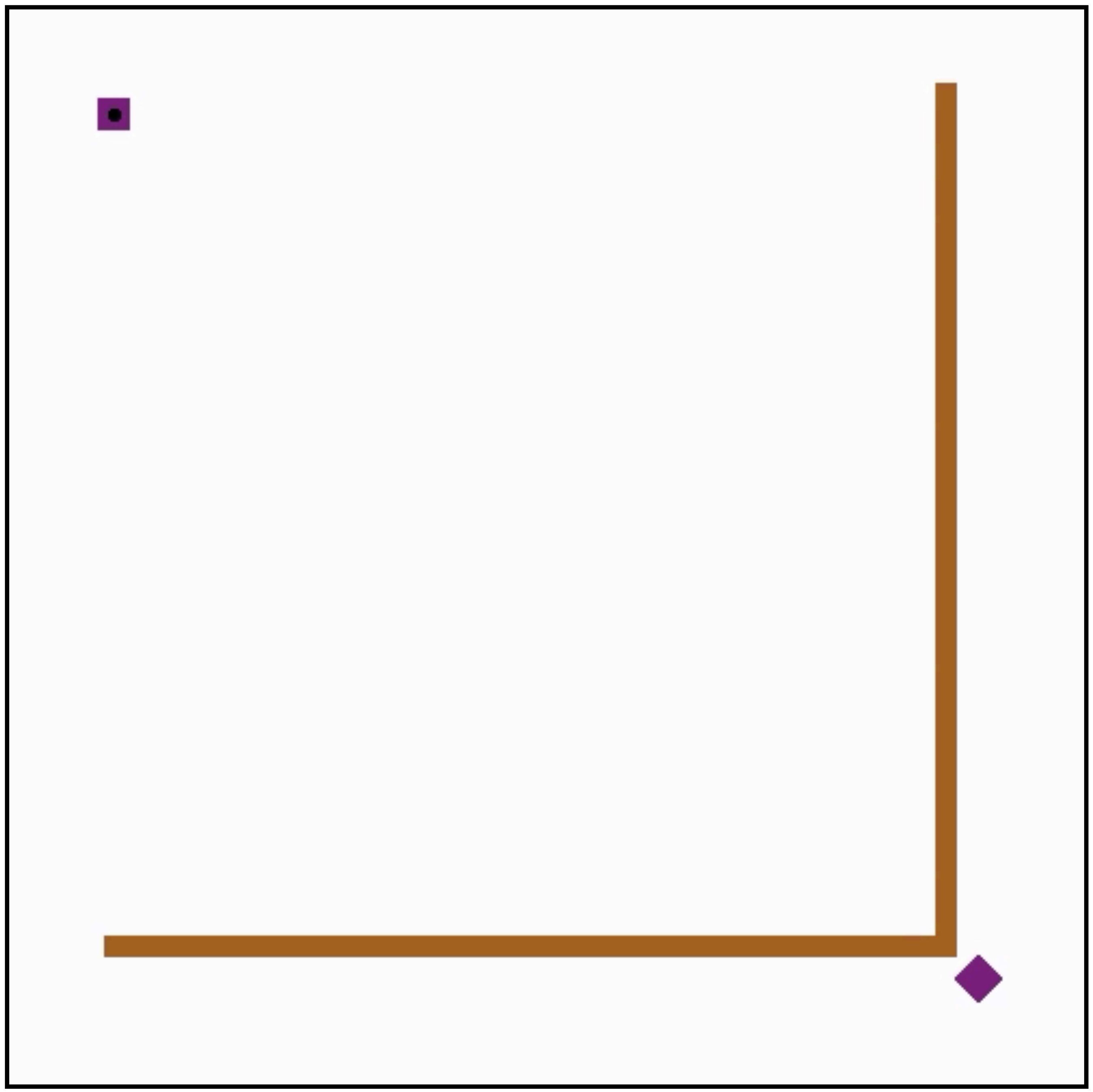
Removing obstacles
Do agents adopt better trails when they become available?

Adding obstacles
Can the agents recover from trail disruption?

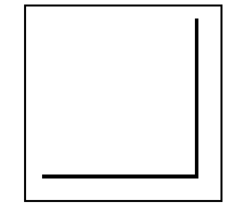
Dynamic food location
Can the agents adapt to other kinds of changes to the environment?

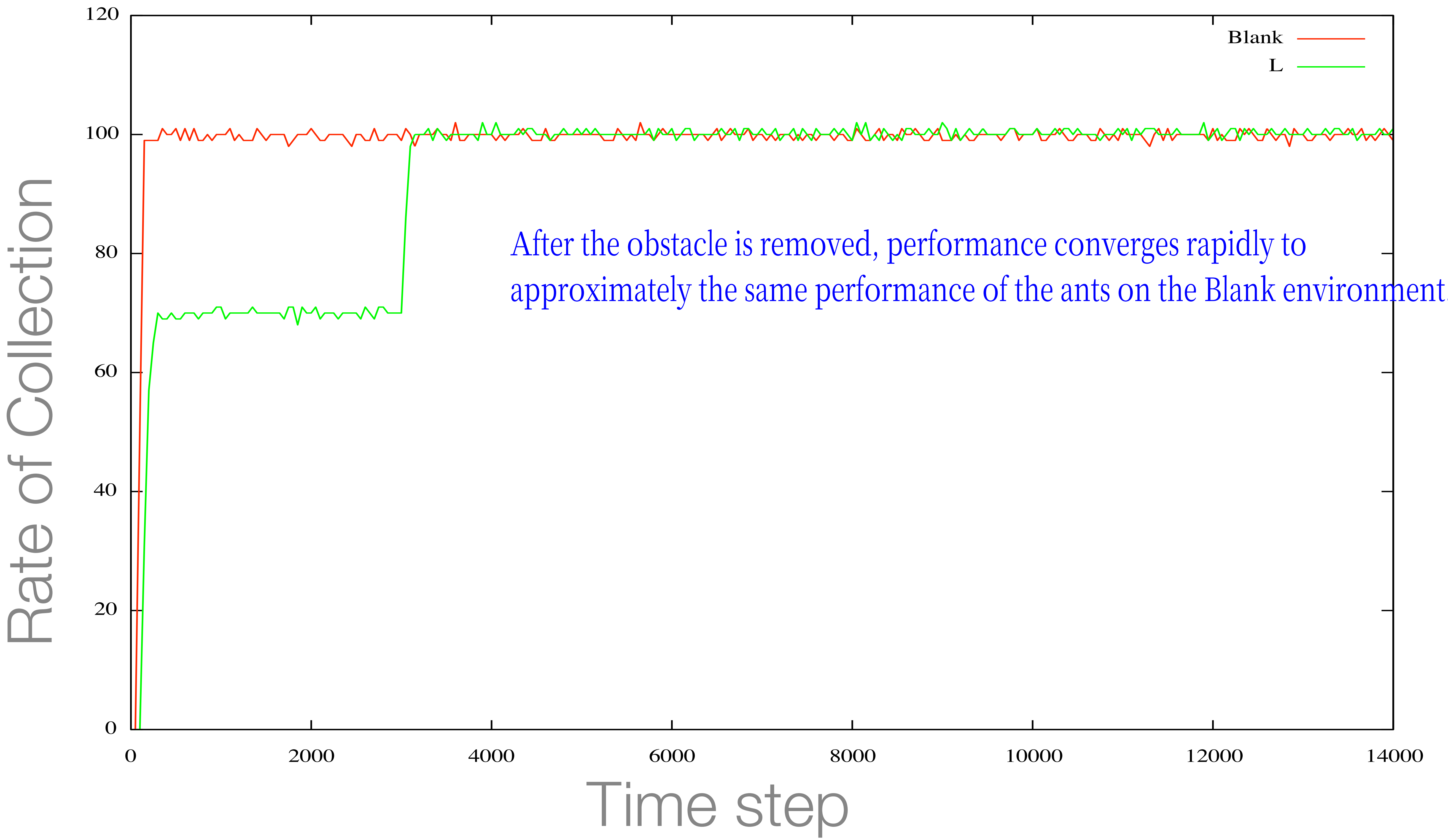
Performance metric: units of food collected per time-step

Removing obstacles — L environment example



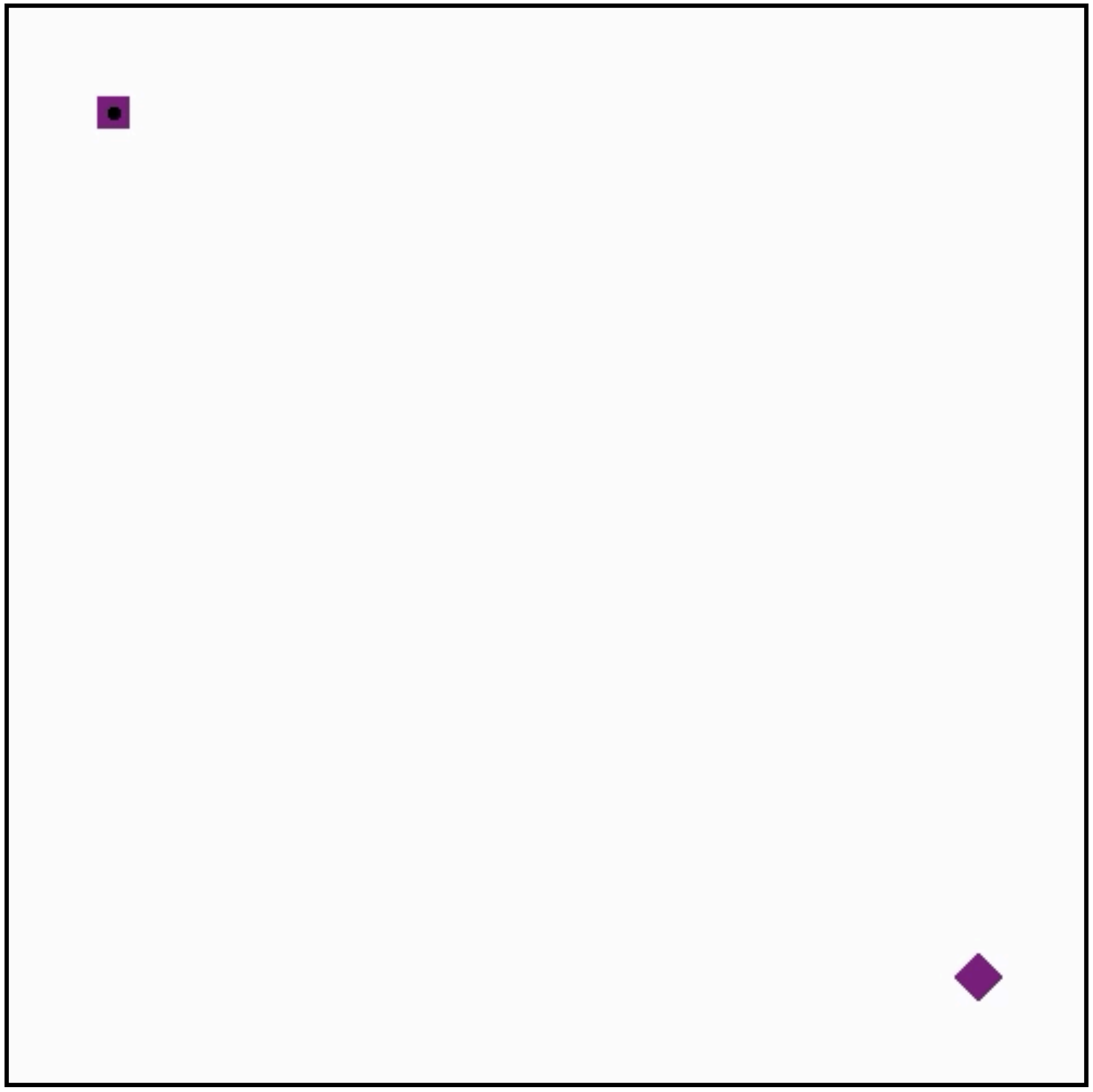
Removing obstacles — L environment



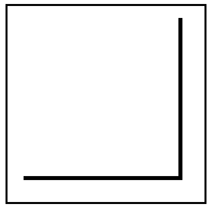


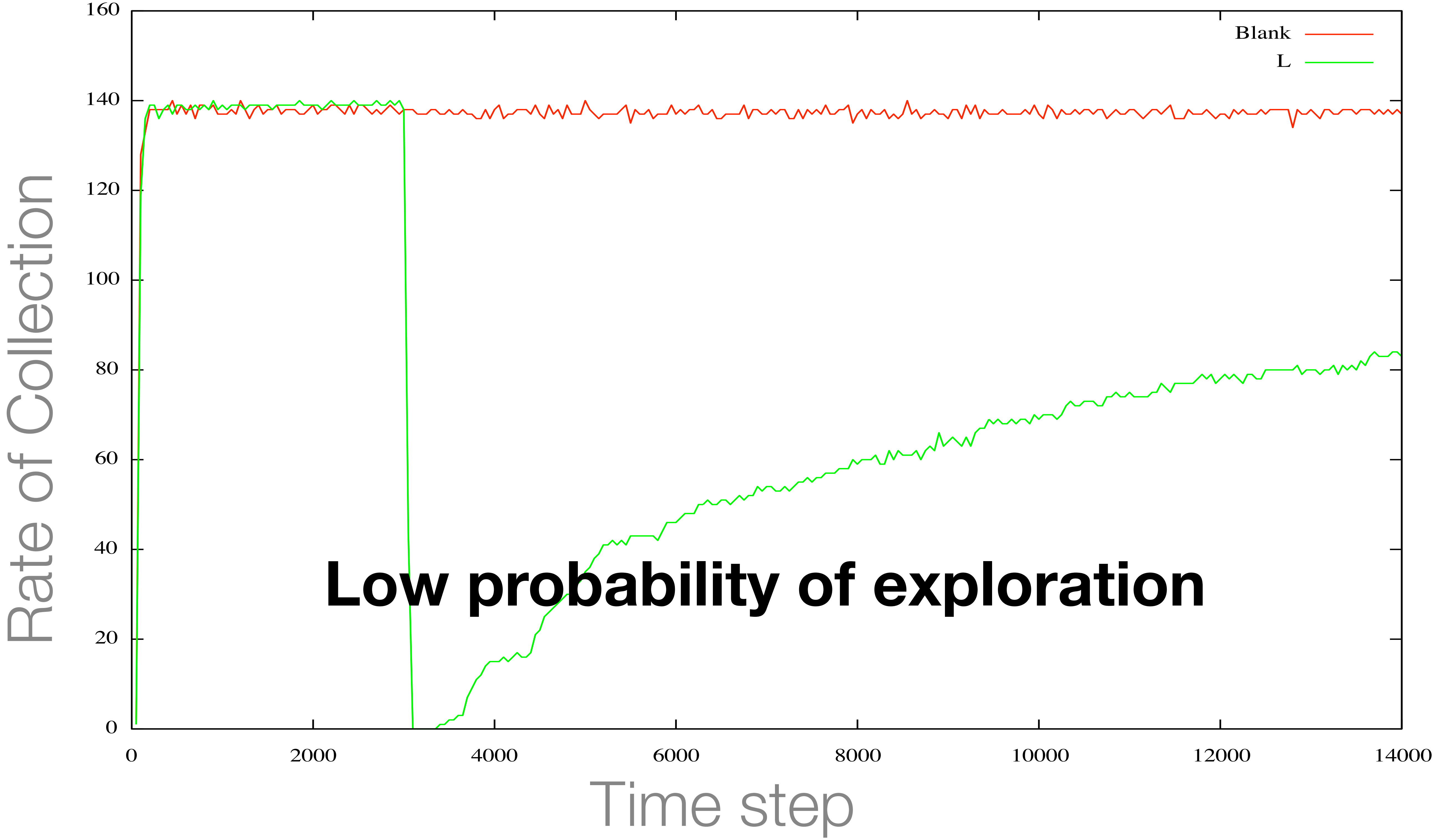
After the obstacle is removed, performance converges rapidly to approximately the same performance of the ants on the Blank environment.

Adding obstacles — L environment example

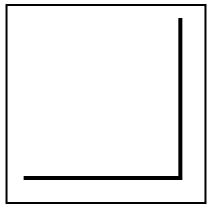


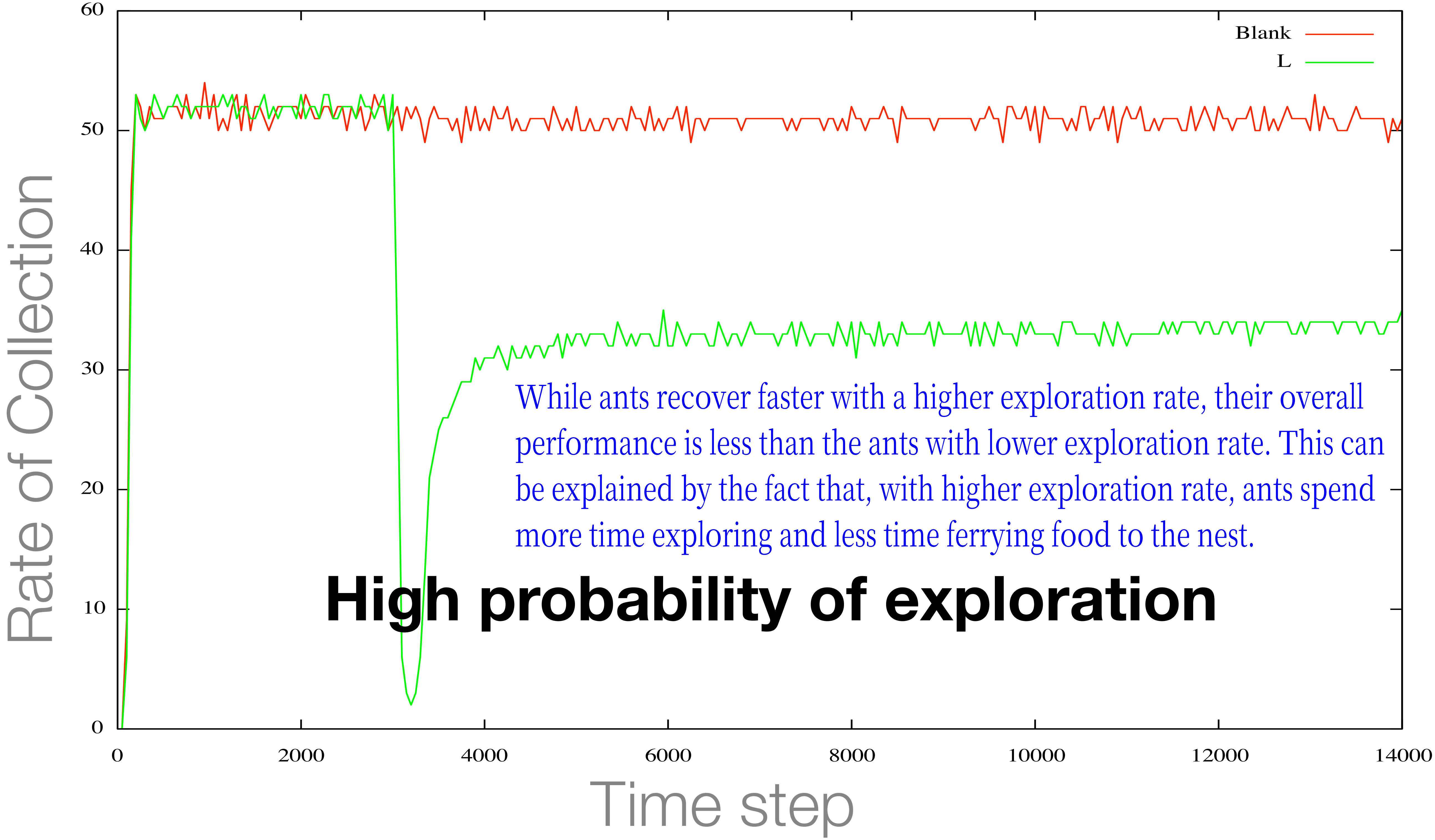
Adding obstacles — L environment





Adding obstacles — L environment

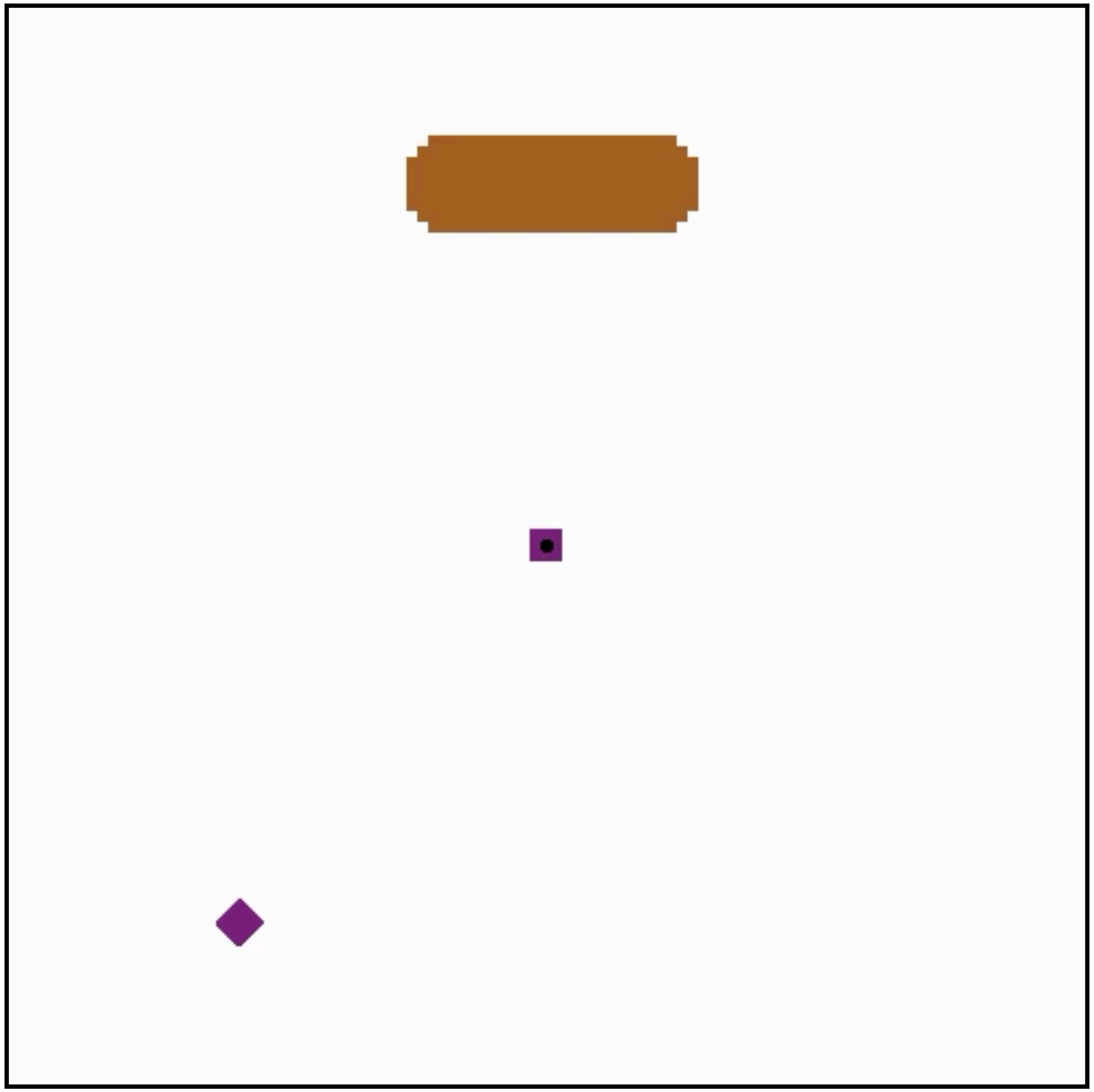




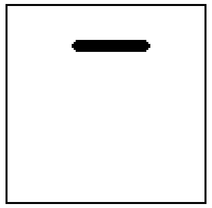
While ants recover faster with a higher exploration rate, their overall performance is less than the ants with lower exploration rate. This can be explained by the fact that, with higher exploration rate, ants spend more time exploring and less time ferrying food to the nest.

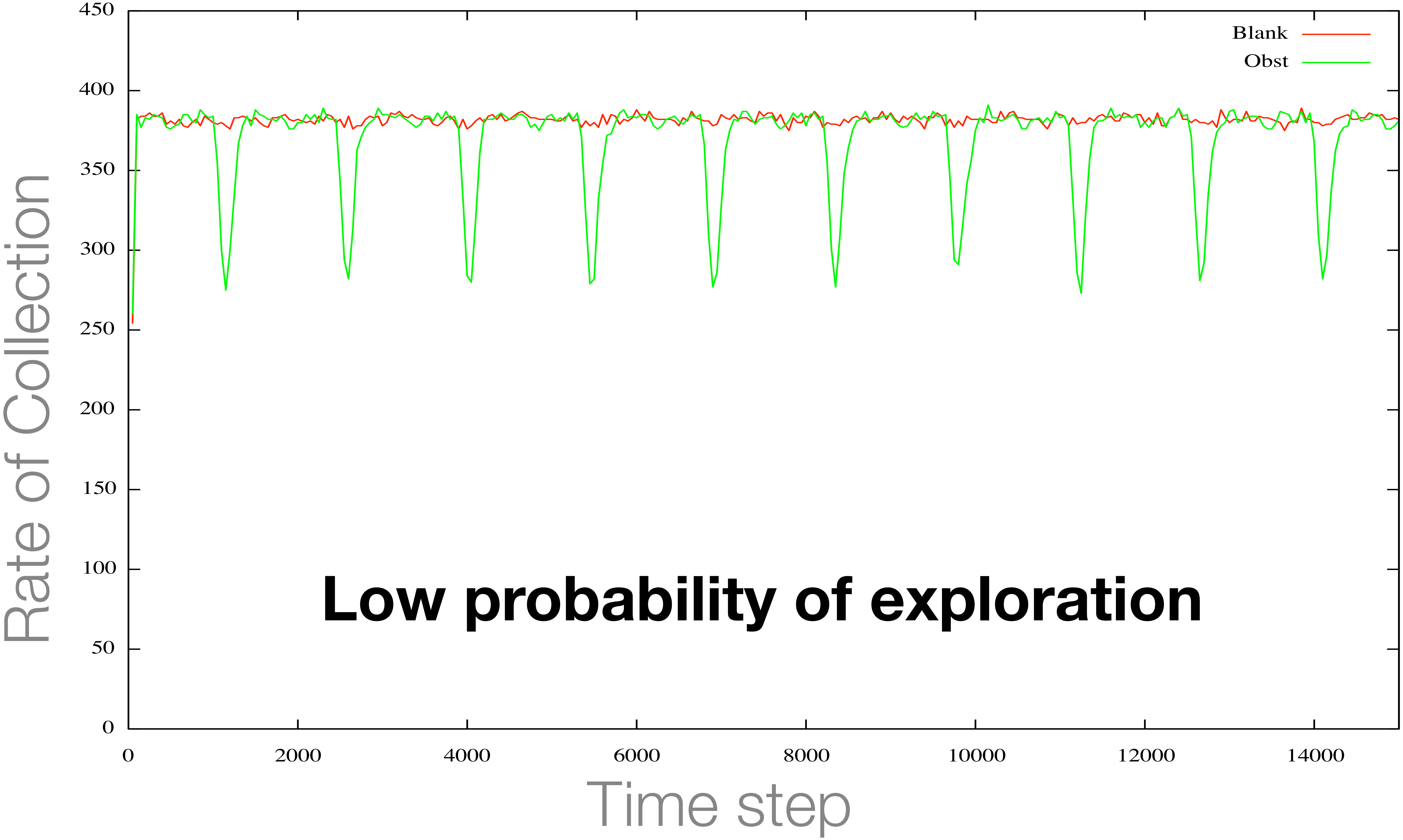
High probability of exploration

Dynamic food location — Ant Clock example

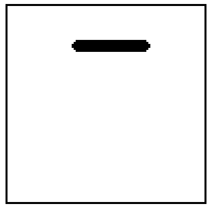


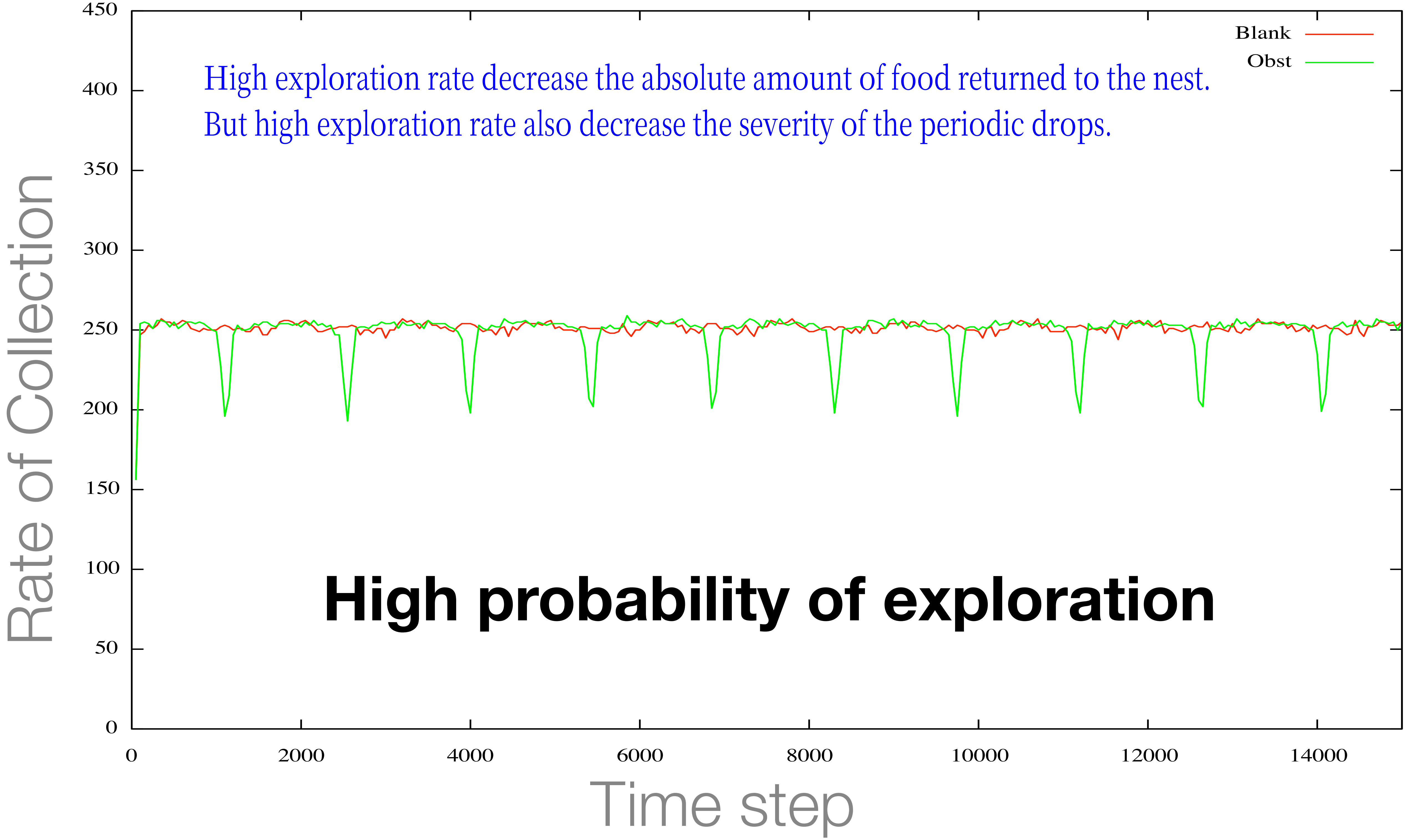
Dynamic food location — Ant Clock





Dynamic food location — Ant Clock





Conclusions

Our approach
Optimizes trails between nest and food

Efficiently uses resources (beacons)

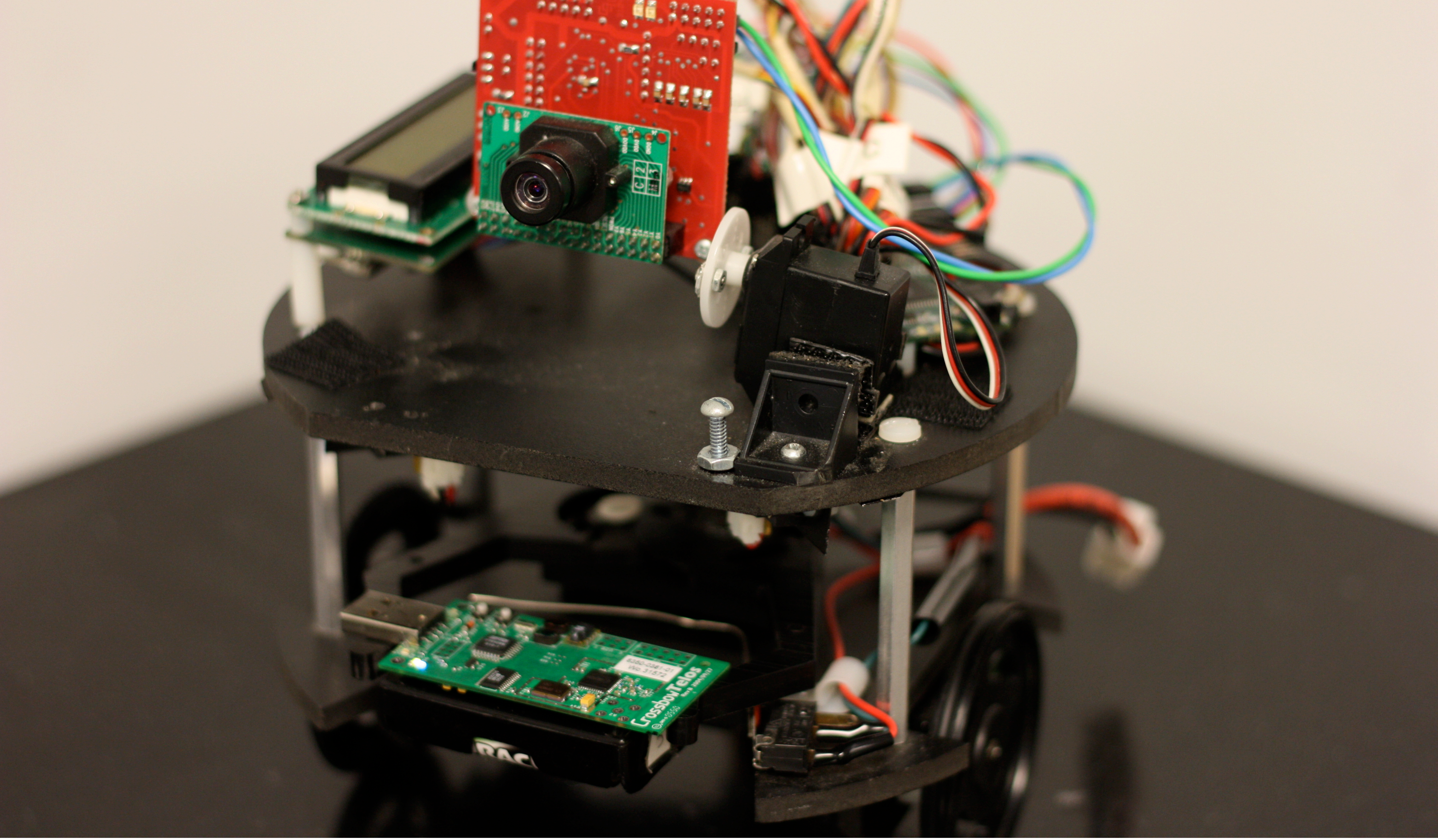
Reacts to dynamic changes in the environment

Shows recovery to disrupted trails

Beacons can be implemented in real hardware!
RFID tags

Sensor motes

Minimal storage and communication requirements



Next Step

Physical platform — Flockbots

cs.gmu.edu/~eclab/projects/robots/flockbots/

Questions?