Multi-Feature Collective Decision Making in Robot Swarms

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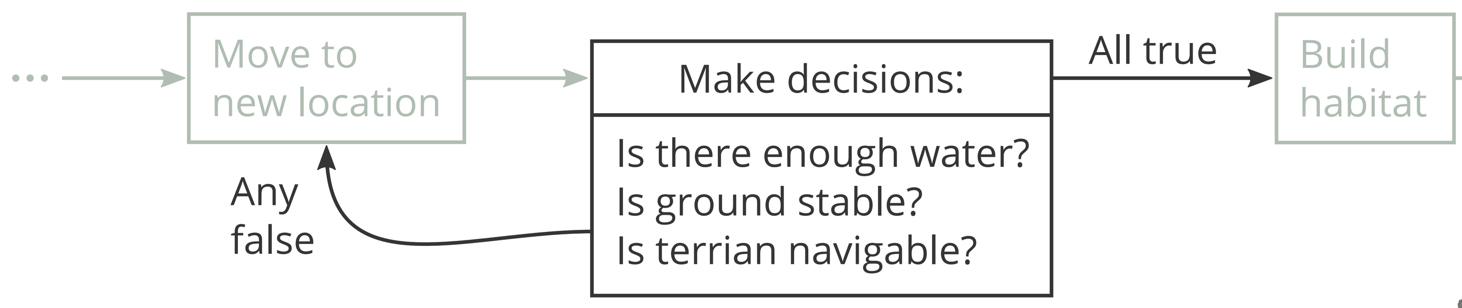
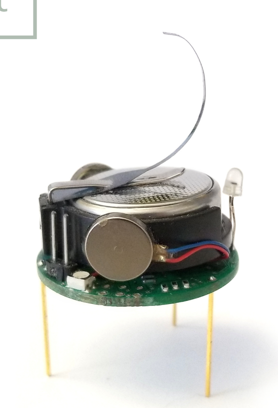
Background

Problem

Distributed collective decision making is an important component of complex, autonomous robot swarm behavior.



How can a group of robots best decide on **multiple features** of their environment, with **limited communication** and **noisy observation**?



Model System

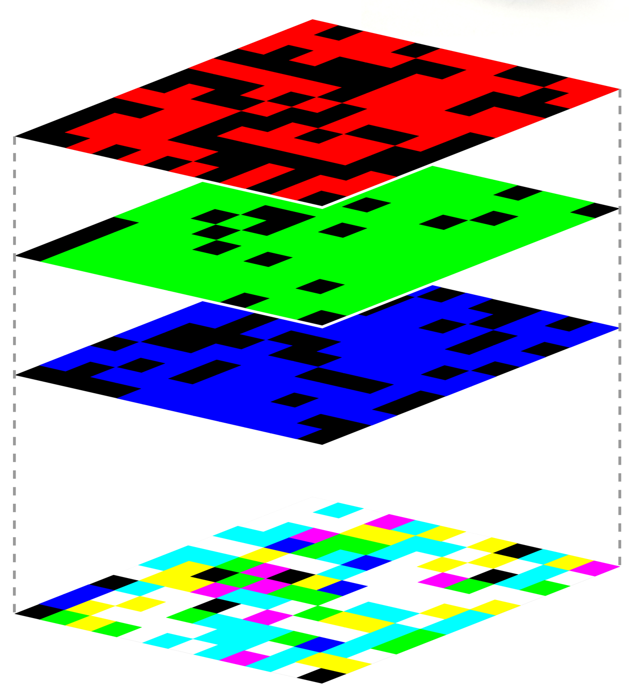
Goal: Binary discrimination of majority color
Is the environment mostly light or dark?

Features: Red, Green, Blue

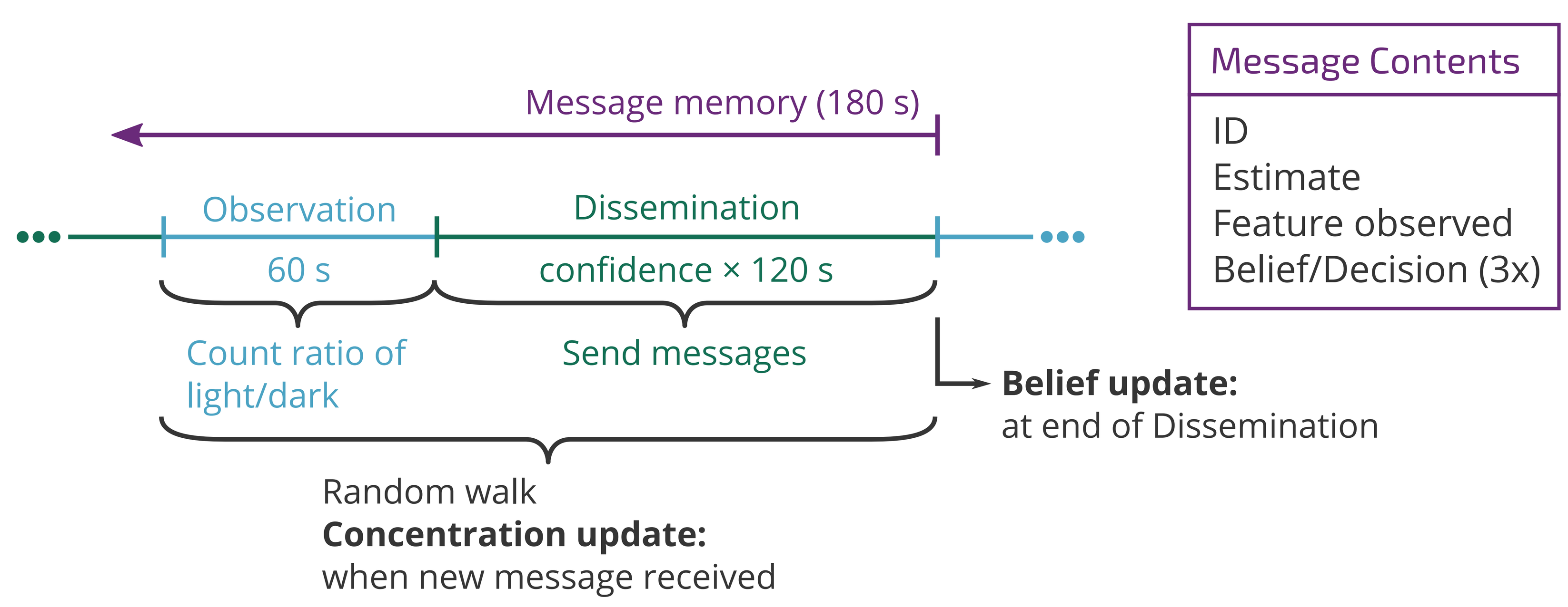
Agents: 100 simulated Kilobots with light sensor

Environment: 2D arena (75x75 bodylengths)

Assumptions and Limitations:
- Detect one feature at a time
- Communication is local and low bandwidth
- Features are independent



Behavior & Algorithm

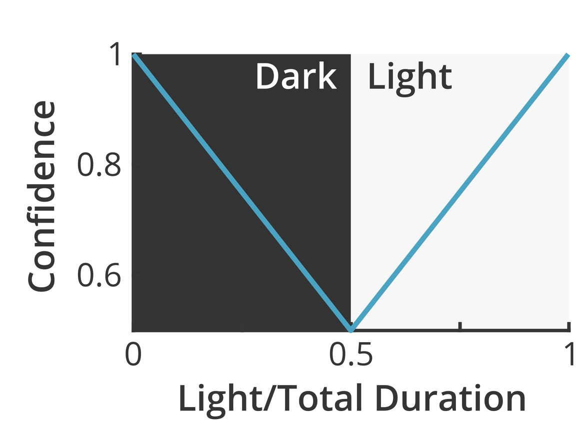


Decision Making

Estimate → Belief → Concentration → Decision

Estimate: What *I saw* in the world

Majority color seen during observation period (0 = dark, 1 = light)
Confidence is proportional to color ratio



Belief: What *others tell me* they saw in the world

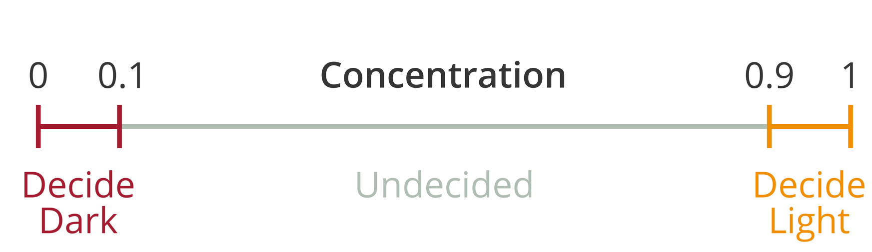
Majority from neighbors' estimates in memory
Integrates information over space

Concentration: What I think *everyone believes* about world

Updated concentration whenever a new belief is received
Integrates information over time

$$C^* = 0.9C + 0.1B$$

Previous concentration (C), New belief (B), Updated concentration (C^*), Diffusion constant (0.1)



Decision: What *I concluded* the world is

Make a decision when past the threshold for 30 s
After making a decision, agents send decision instead of belief

Feature Switching Options

Switch **when:**
- After **decision** on observed feature
- Before each **observation**
- Never (static allocation)

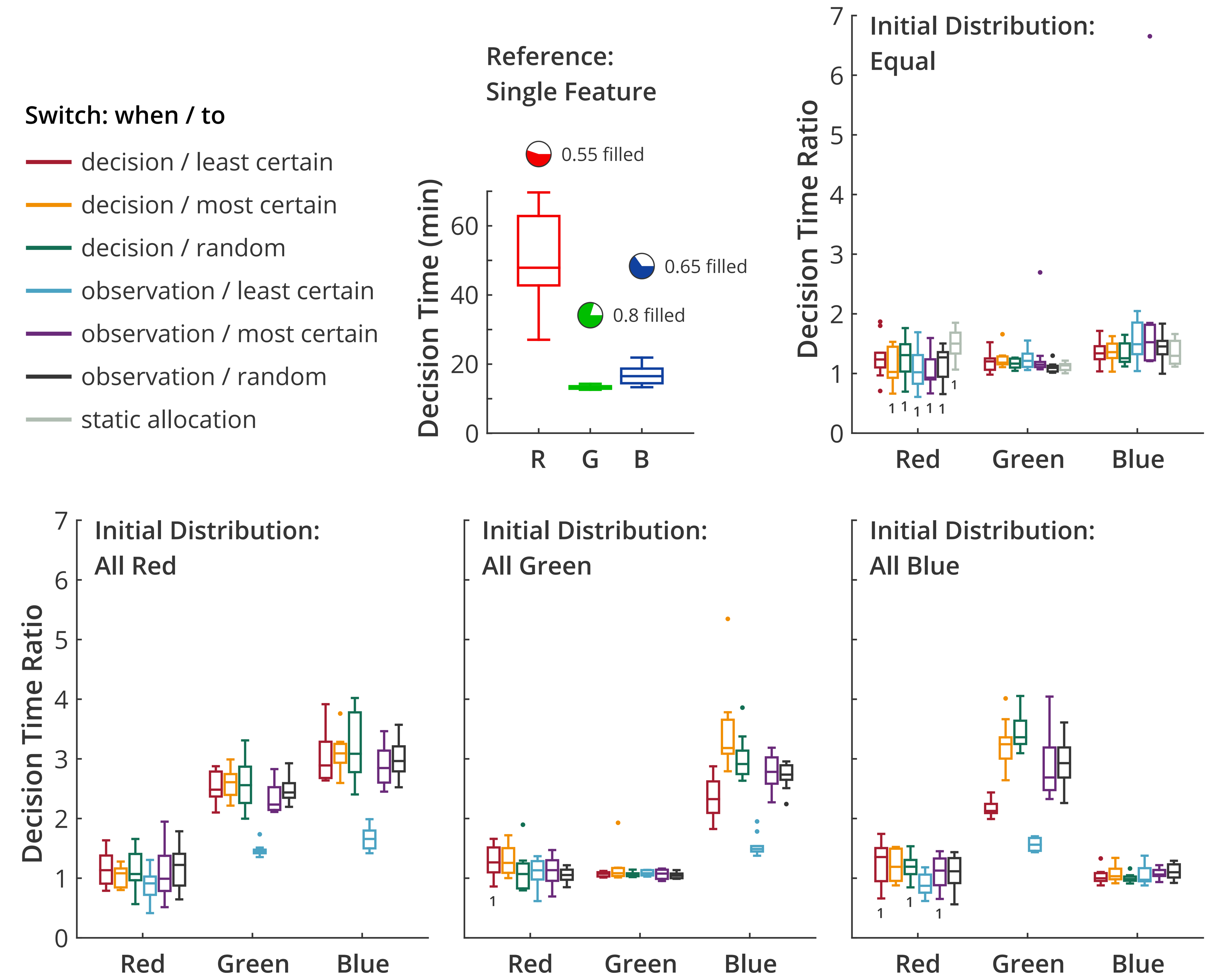
Switch **to:**
- **Least certain** feature
- **Most certain** feature
- Random feature

Multi-Feature Results

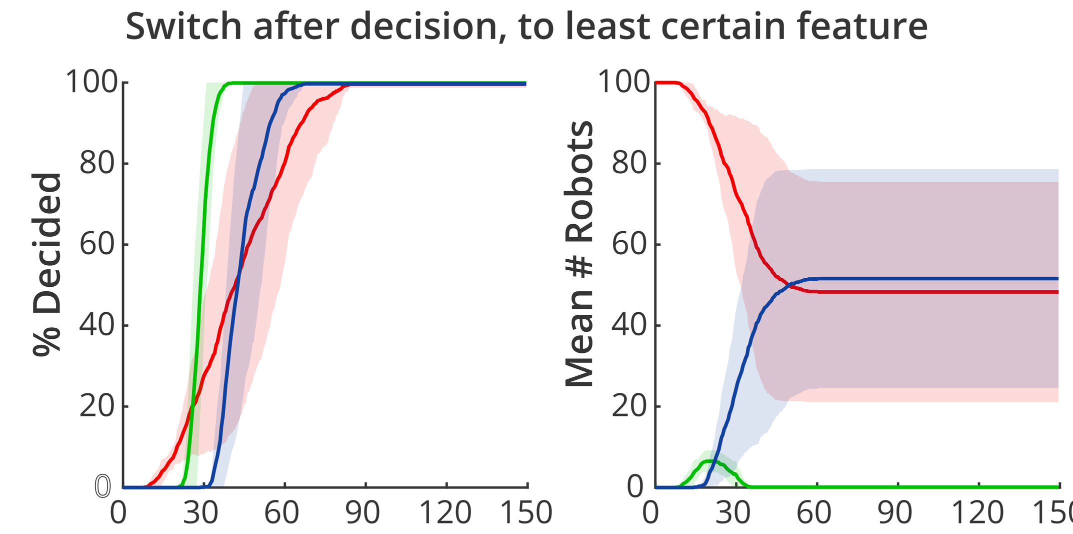
A simulated swarm of 100 agents accurately identified the majority color for 3 features of varying difficulty.

More difficult features (fill ratio closer to 0.5) took longer to decide.

Switching to the **least certain feature** for **each observation** yielded faster decisions on intermediate features for pathological initial conditions.

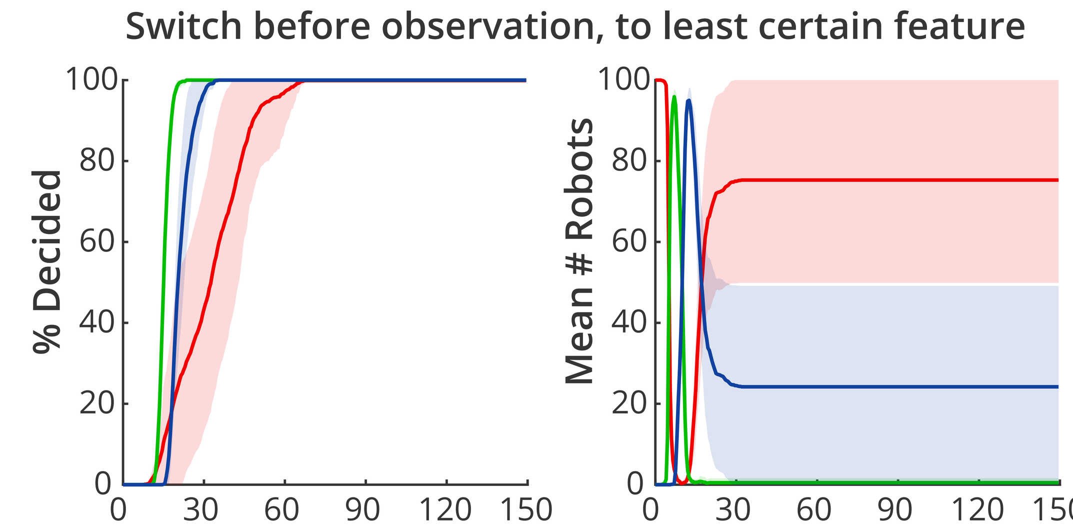


Switch after decision, to least certain feature



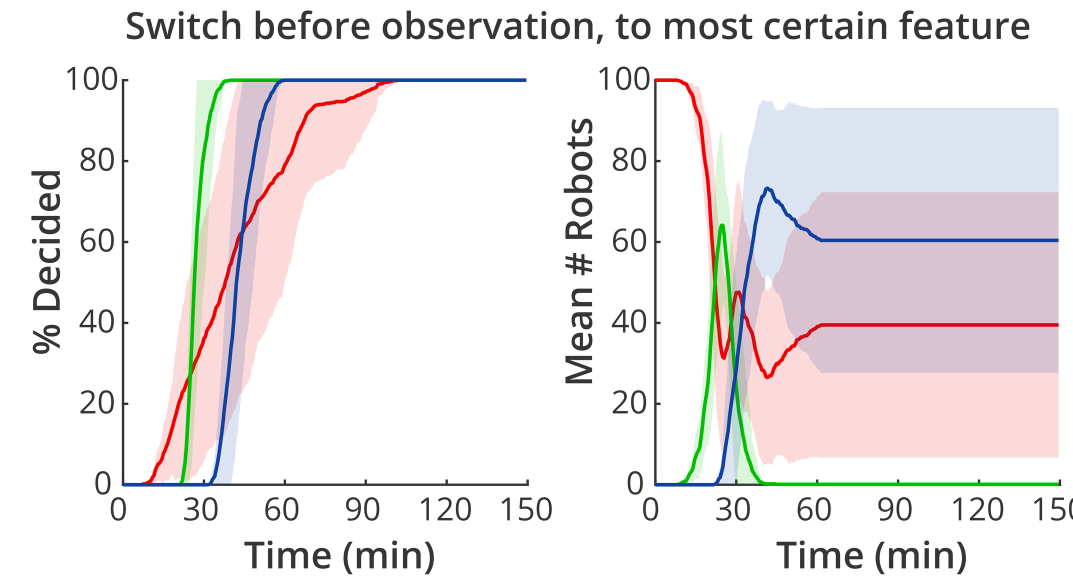
A few agents decide for red and switch to green and blue, both of which are decided faster than red.

Switch before observation, to least certain feature



Agents are more quickly reallocated to blue and green for a short periodof time, resulting in quicker decisions than when feature switching only occurs after decisions.

Switch before observation, to most certain feature



More agents are allocated to blue than when agents change the least certain feature, reducing the accuracy of beliefs about red and prolonging the feature's decision time.

Discussion

Agents made decisions with high accuracy without splitting the swarm.

Experiments on physical robots validate results of single-feature simulations.

In multi-feature decision making, the swarm distinguished between 8 possible environments in almost same time as single feature environment.

Switching features for each observation allows for faster reallocation, and switching to the least certain feature prevents over-allocation.

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References: Valentini, Brambilla, Hamann, & Dorigo. (2016) "Collective Perception of Environmental Features in a Robot Swarm"
Parker & Zhang. (2009) "Cooperative decision-making in decen-tralized multiple-robot systems: The best-of-N problem."