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# Towards Design Patterns for Robot Swarms

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# Towards Design Patterns for Robot Swarms

- What are design patterns
- Our simulation approach
- Swarms in simple environments
- Information value
- Swarms in dynamic environments
- Design pattern principles and example

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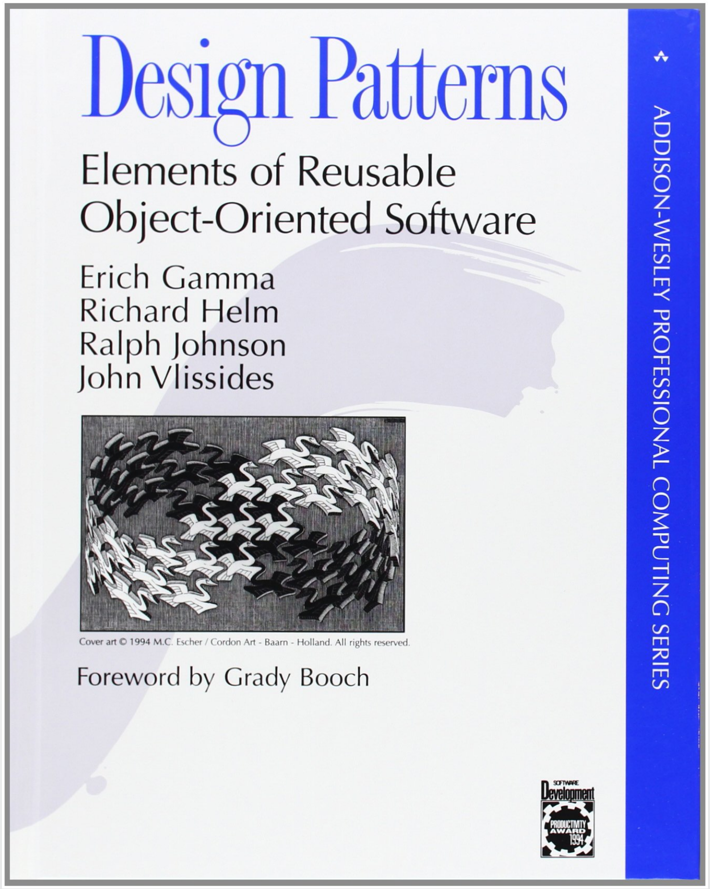
# Swarm Robotics

- Currently there is no precise method of selecting robot behaviour for swarms
- In OO software engineering, design patterns help with system design



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# Swarm Robotics

- Swarm robotics could benefit too:
  - Implicit understanding of collective intelligence
  - Modularity of behaviours
  - Mission-specific implementation

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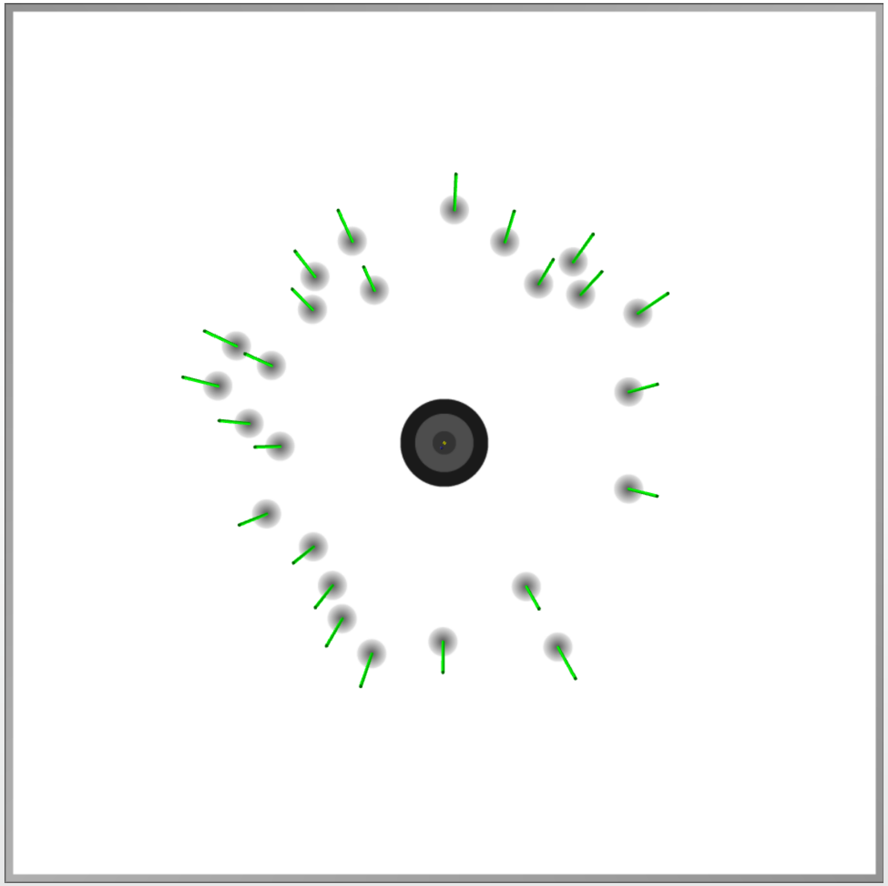
# Our Approach

- 3D simulations with realistic physics
- Parameter sweeps: robots, environment
- Detailed performance analysis
- Information flow analysis
- Information-to-work cost analysis
- Design pattern creation

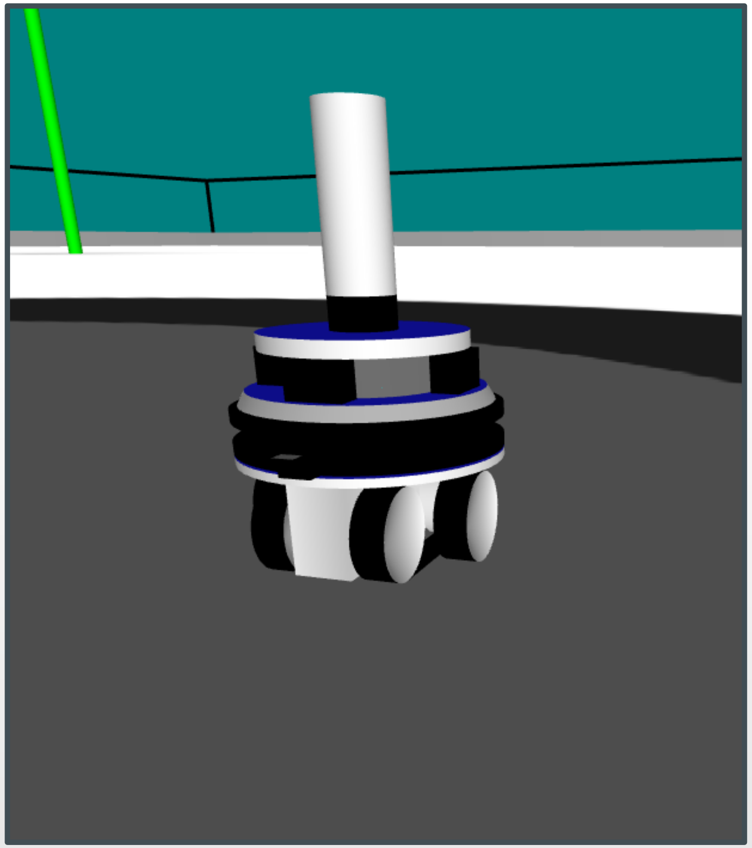
# Simulation work



- Environment variations:
  - Maintenance vs Foraging
  - Different number of tasks
    - $V_T = 100 / N_T$
  - Tasks of different utilities
  - Dynamic tasks

# Simulation work

- Swarm types:
  - Solitary: no communication
  - Local Broadcasters: recruit near tasks
  - Bee Swarms: recruit in the base
- Swarm parameters:
  - Behaviour-specific
  - Different number of robots



# Example: Simple environments

- Static tasks of the same utility
- Which swarm obtains all the reward the fastest?
- More tasks
  - -> smaller task return + easier to find
    - -> solitary foraging favoured

- Less tasks
  - -> bigger task return but harder to find
    - -> recruitment favoured

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# Example: Simple environments

Completion time, Solitary robots vs. Local broadcasters vs. Bee swarm

## Maintenance, 25 robots

| Winners | Num of tasks | Max distance | Task reward |
|---|---|---|---|
| | 25 | 5 | 4 |
| | 25 | 9 | 4 |
| | 25 | 13 | 4 |
| | 25 | 17 | 4 |
| | 25 | 21 | 4 |
| | 4 | 5 | 25 |
| | 4 | 9 | 25 |
| | 4 | 13 | 25 |
| | 4 | 17 | 25 |
| | 4 | 21 | 25 |
| | 2 | 5 | 50 |
| | 2 | 9 | 50 |
| | 2 | 13 | 50 |
| | 2 | 17 | 50 |
| | 2 | 21 | 50 |
| | 1 | 5 | 100 |
| | 1 | 9 | 100 |
| | 1 | 13 | 100 |
| | 1 | 17 | 100 |
| | 1 | 21 | 100 |

## Foraging, 25 robots

| Winners | Num of tasks | Max distance | Task reward |
|---|---|---|---|
| | 25 | 5 | 4 |
| | 25 | 9 | 4 |
| | 25 | 13 | 4 |
| | 25 | 17 | 4 |
| | 25 | 21 | 4 |
| | 4 | 5 | 25 |
| | 4 | 9 | 25 |
| | 4 | 13 | 25 |
| | 4 | 17 | 25 |
| [too difficult] | 4 | 21 | 25 |
| | 2 | 5 | 50 |
| | 2 | 9 | 50 |
| | 2 | 13 | 50 |
| | 2 | 17 | 50 |
| [too difficult] | 2 | 21 | 50 |
| | 1 | 5 | 100 |
| | 1 | 9 | 100 |
| | 1 | 13 | 100 |
| | 1 | 17 | 100 |
| [too difficult] | 1 | 21 | 100 |

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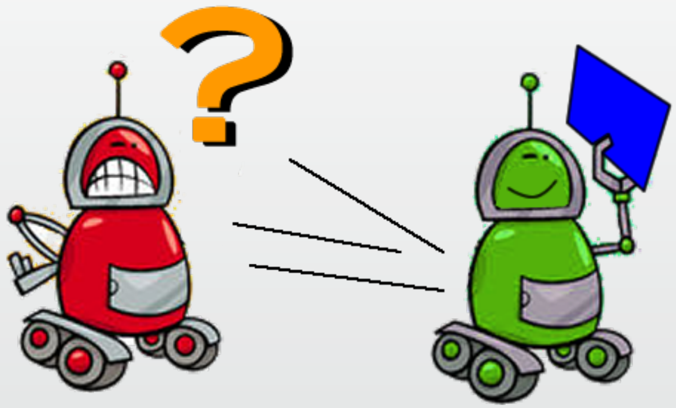
# Example: Simple environments

- Robot-robot interference:
  - Physical

  - Environmental



# Example: Simple environments

- More robots
  - -> more communication
    - -> communication effects (good and bad!) more pronounced
    - -> winning strategies more environment-specific

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# Example: Simple environments

Completion time, Solitary robots vs. Local broadcasters vs. Bee swarm

## Foraging, 10 robots

| Winners | | | Num of tasks | Max distance | Task reward |
|---|---|---|---|---|---|
| | | | 25 | 5 | 4 |
| | | | 25 | 9 | 4 |
| | | | 25 | 13 | 4 |
| | | | 25 | 17 | 4 |
| | | | 25 | 21 | 4 |
| | | | 4 | 5 | 25 |
| | | | 4 | 9 | 25 |
| | | | 4 | 13 | 25 |
| | | | 4 | 17 | 25 |
| | | | 4 | 21 | 25 |
| | | | 2 | 5 | 50 |
| | | | 2 | 9 | 50 |
| | | | 2 | 13 | 50 |
| | | | 2 | 17 | 50 |
| | | | 2 | 21 | 50 |
| | | | 1 | 5 | 100 |
| | | | 1 | 9 | 100 |
| | | | 1 | 13 | 100 |
| | | | 1 | 17 | 100 |
| | | | 1 | 21 | 100 |

## Foraging, 50 robots

| Winners | | | Num of tasks | Max distance | Task reward |
|---|---|---|---|---|---|
| | | | 25 | 5 | 4 |
| | | | 25 | 9 | 4 |
| | | | 25 | 13 | 4 |
| | | | 25 | 17 | 4 |
| | | | 25 | 21 | 4 |
| | | | 4 | 5 | 25 |
| | | | 4 | 9 | 25 |
| | | | 4 | 13 | 25 |
| | | | 4 | 17 | 25 |
| | | | 4 | 21 | 25 |
| | | | 2 | 5 | 50 |
| | | | 2 | 9 | 50 |
| | | | 2 | 13 | 50 |
| | | | 2 | 17 | 50 |
| | | | 2 | 21 | 50 |
| | | | 1 | 5 | 100 |
| | | | 1 | 9 | 100 |
| | | | 1 | 13 | 100 |
| | | | 1 | 17 | 100 |
| | | | 1 | 21 | 100 |

# Information value

- What is the value of new information for a robot?
  - Reward that can be extracted from a task per volume unit, compared to a reward the robot would receive using some old information

- $I = U_{new} – U_{old}$
- For scouts and unemployed robots, $I = U_{new}$
- For recruited robots, it can be positive or negative

# Information value

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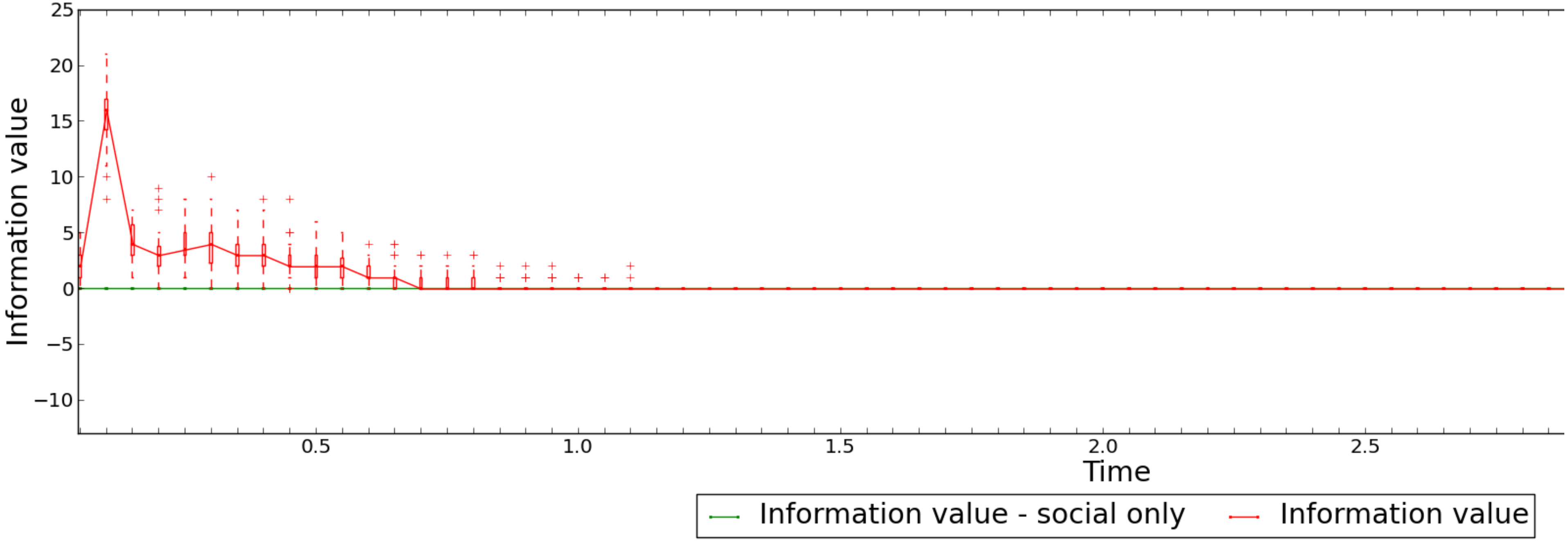
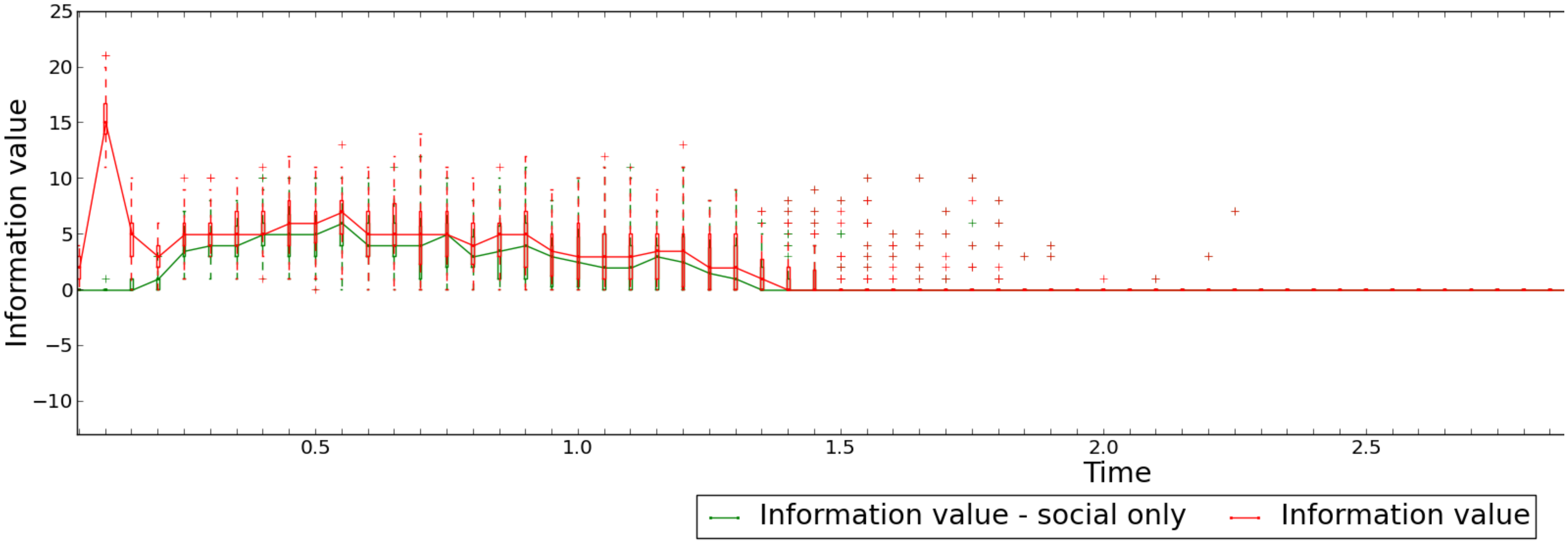



Foraging, 25 deposits, 25 solitary robots

# Information value




Foraging, 25 deposits, 25 bee swarm robots

# Example: Dynamic task utilities

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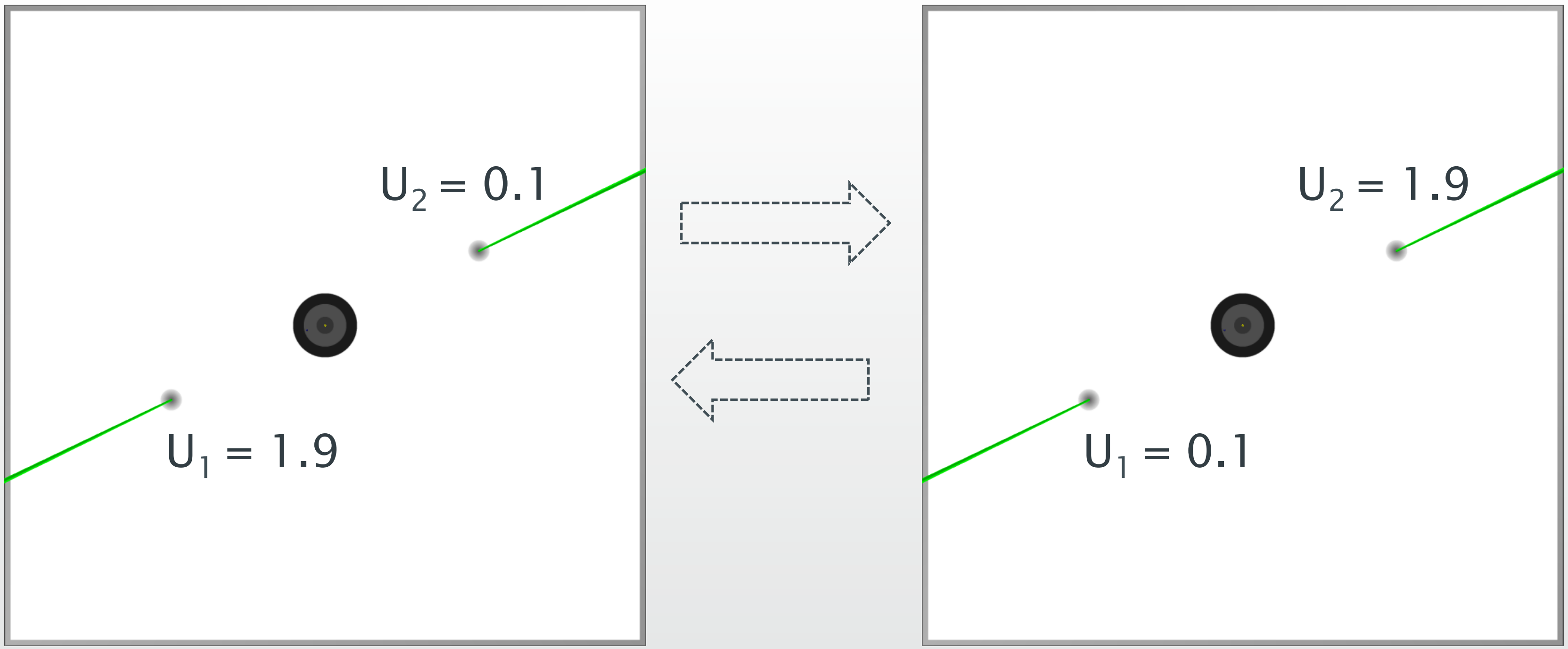
- Bee swarm able to choose between tasks of different utilities to maximise reward during foraging



# Example: Dynamic task utilities

- EE = u/d
- ‘Beggers’
  - Robots in the base compare EE of their own tasks to that of other robots and can switch
  - Deplete the best task quickly, then move to another
- ‘Checkers’
  - Robots abandon a task if its EE dropped
  - Spread across tasks more evenly
  - Faster response to environmental change

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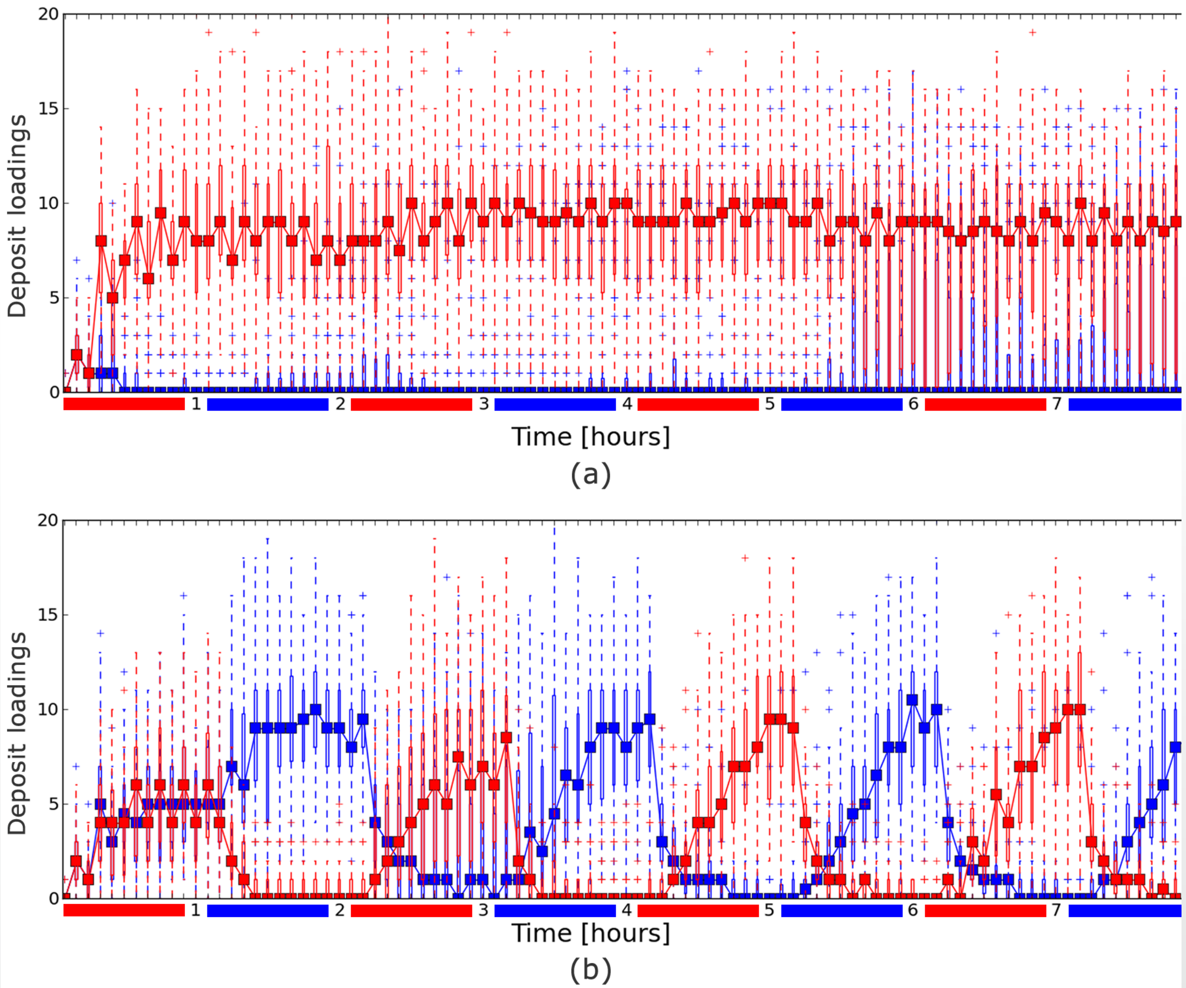
# Example: Dynamic task utilities




2 nearby deposits with changing utility, number of loadings from deposits

(a) 25 Beggers
(b) 25 Checkers

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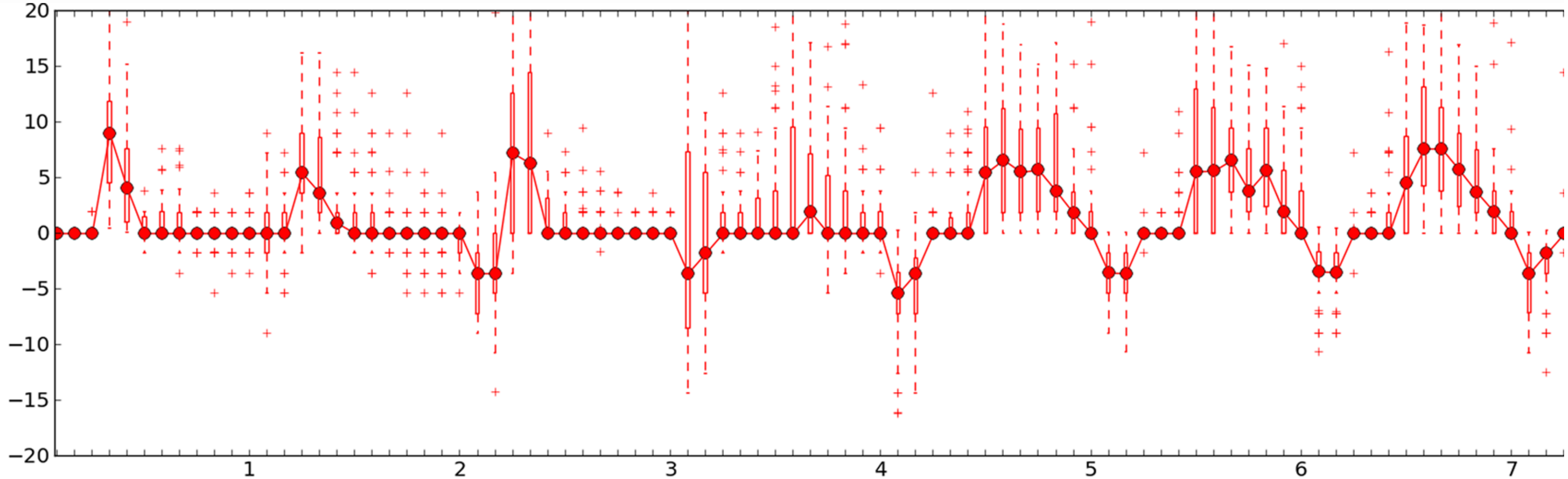
# Example: Dynamic task utilities

- Based on information value, we can identify swarm work modes




Switching (Long-range checkers, 2 deposits, 25 robots, D=9m)

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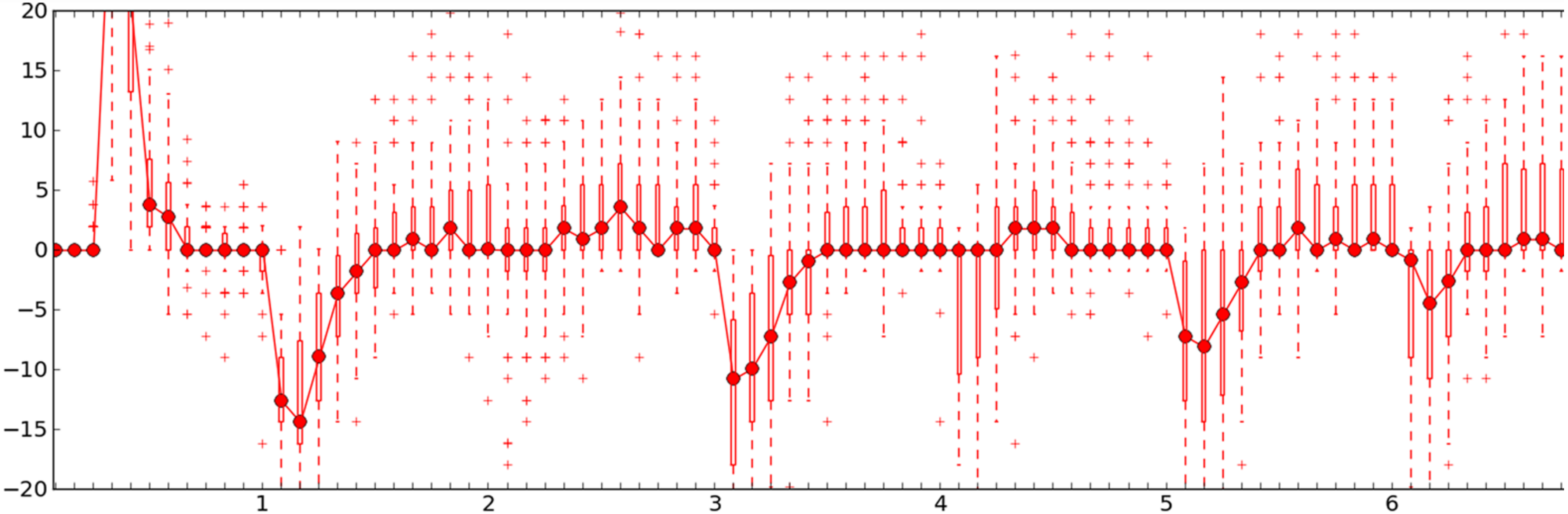
# Example: Dynamic task utilities

- Based on information value, we can identify swarm work modes




Delayed switching (Long-range beggers, 2 deposits, 45 robots, D=9m)

# Example: Dynamic task utilities

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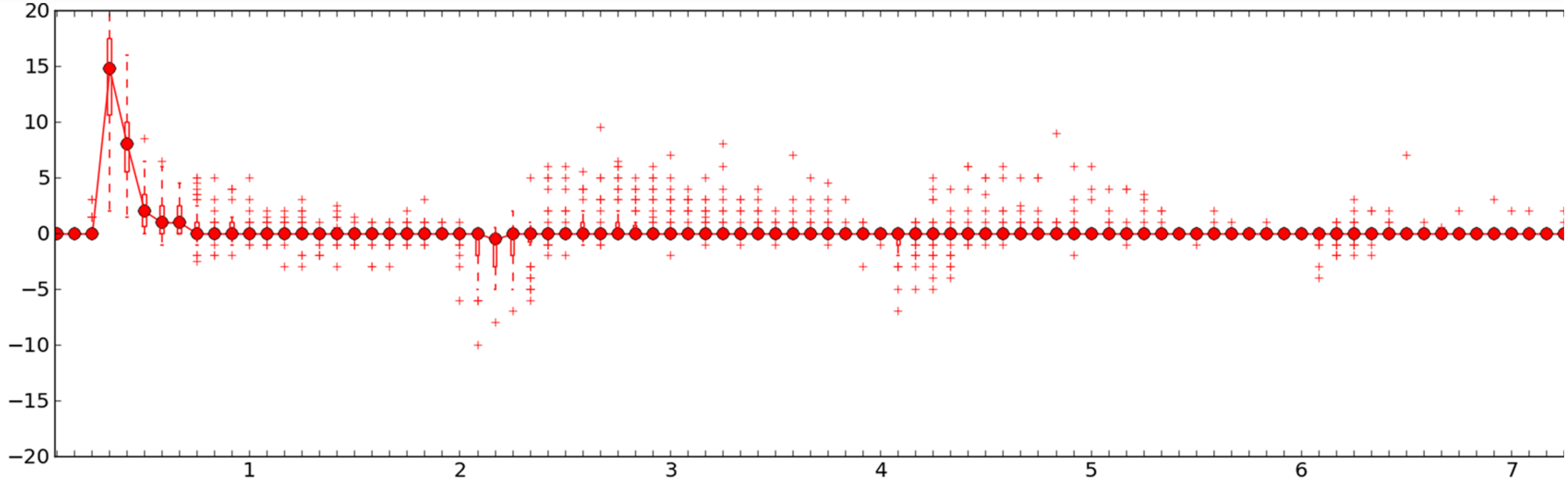
- Based on information value, we can identify swarm work modes




Locked (Long-range beggers, 2 deposits, 25 robots, D=9m)

# Example: Dynamic task utilities

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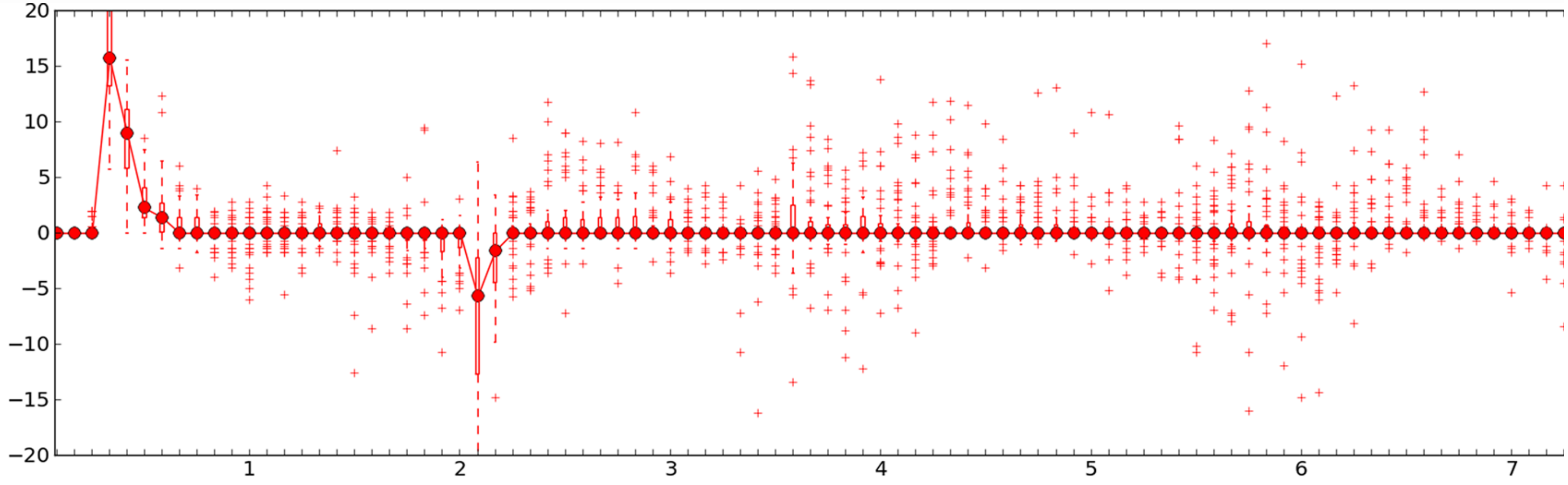
- Based on information value, we can identify swarm work modes




Indecisive (Long-range beggers, 4 deposits, 25 robots, D=9m)

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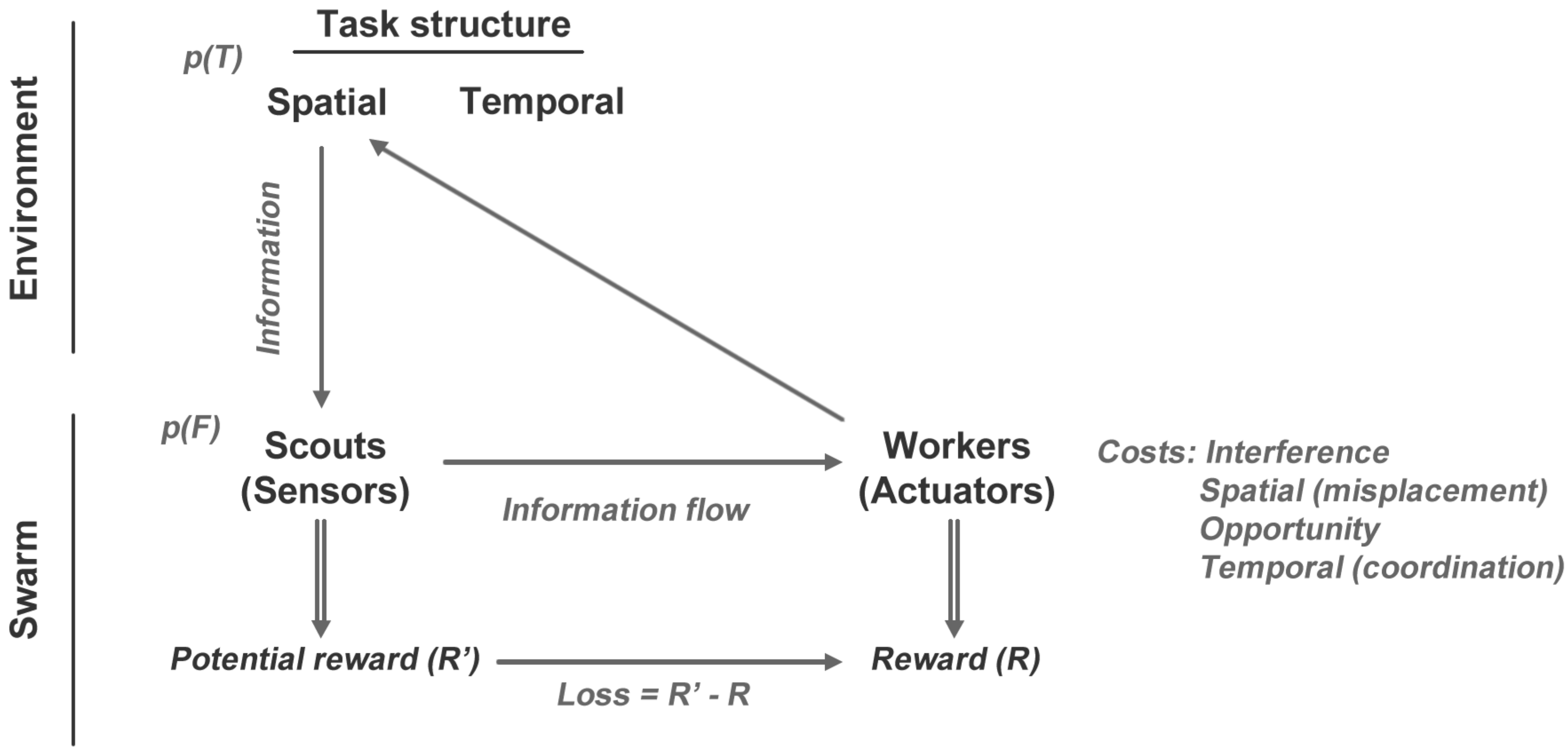
# Information value: General findings

- The correct information flow, given a particular environment, promotes swarm plasticity

- Across a range of environments, different swarm types have different likelihoods to exhibit plasticity
  - Faster information flow -> better performance but likelihood of plasticity is sacrificed

# The perception-action loop



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# The perception-action loop

- How can we match swarm behaviour to environment in order to minimise costs and maximise work?

- Design patterns

# Design patterns

- Modular
  - How to navigate an unknown environment
  - Where and when is information transferred
  - How does old information gets updated

# Design patterns

- Specified by
  - Unambiguous name
  - Problem
  - Solution
  - Parameters
  - Trade-offs
  - (Effects when combined with other patterns)

# Information exchange centre

- Problem: how to let other robots know about tasks?
- Solution: define a meeting place where robots can exchange information. Unsuccessful scouts come to this place to meet with successful scouts.

- Parameters:
  - Scouting time
  - ‘Recruitment’ time

# Information exchange centre

- Trade-offs
  - Promotes spatio-temporal synchronisation of robot work (good when tasks are hard to find, or for cooperative tasks)
  - Potential high cost of traveling to tasks if the IEC is far away (not suitable for maintenance missions)
  - Low values of scouting time and high values of recruitment time cause poor exploration of the environment (hard to calibrate for environments of unknown size)

# Current work..

- Additional experiments
  - Stigmergy-based recruitment (ants)
  - Dynamic environments
  - Tasks that require cooperation
- Visualisation of relationships between robot states, data and the environment
- Creation and classification of design patterns

# Thank you.
# Questions?

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