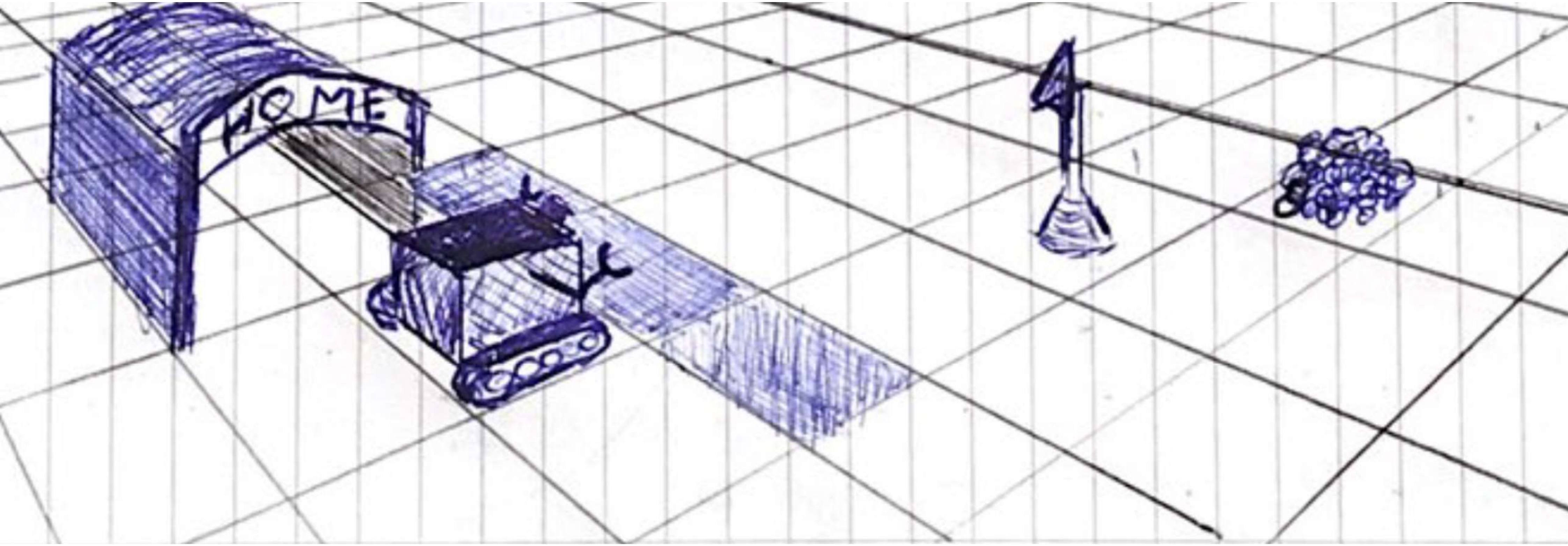


Active Walkers

Jacob Toller; Mathematical Modelling II

What are Active Walkers

- Dumb robots/creatures/thingymajigies with a very simple ruleset/decision-making process
- Exist in a 2D grid, with discrete timesteps ('turns')
- All walkers move at the same time during a turn.
- Can move into one of three forward positions:

(similarly for the other 6 facing directions.)

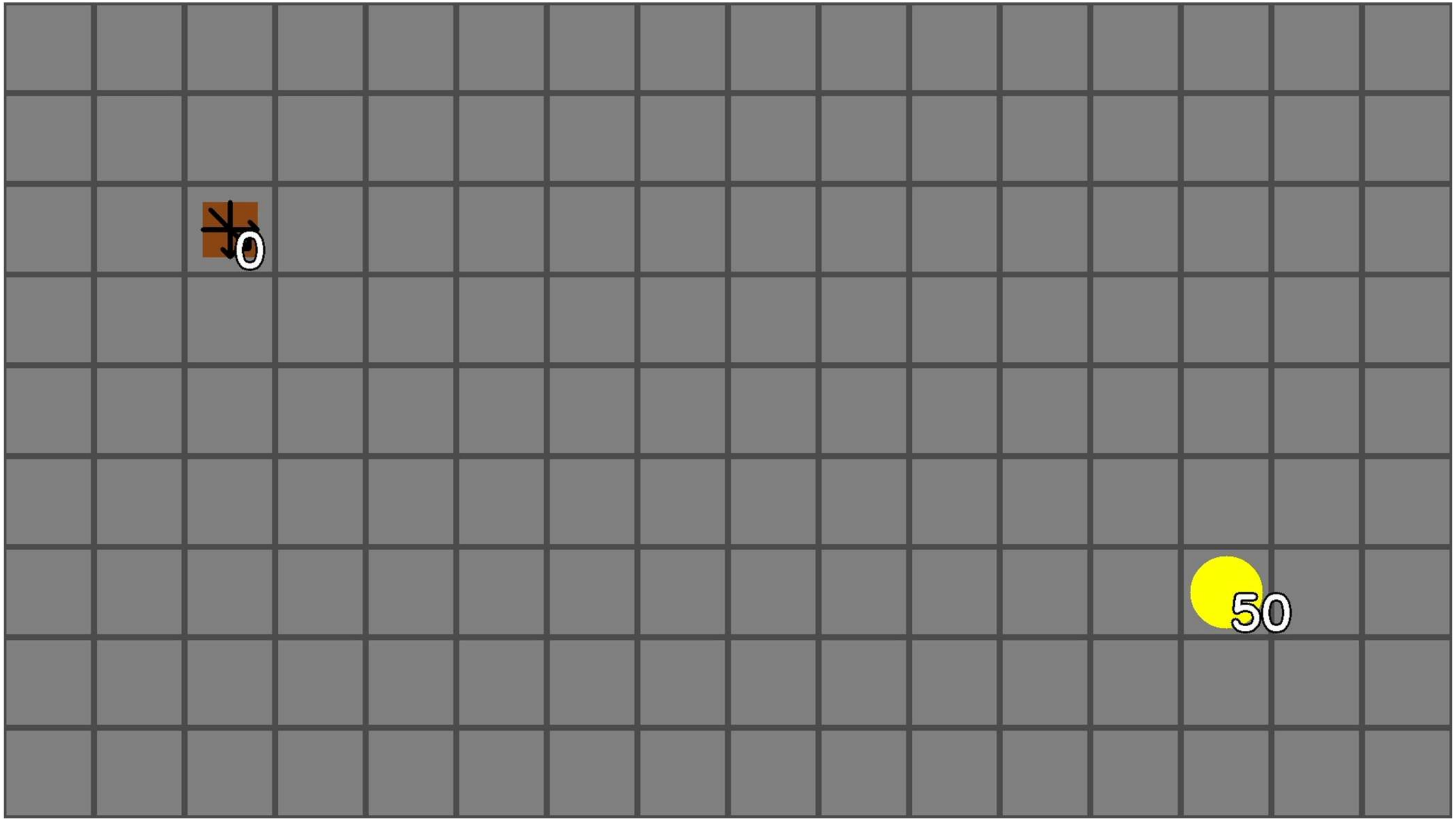
Walker Objective

- To move resources from **resource piles** in the environment; to their **home base**
- Has two possible job roles that help them do this:

	Is sensitive to:	Deposits:
Scout	Marker B	Marker A
Carrier	Marker A	Marker B

(Markers are deposited by walkers after each turn, once they have made their move)

Behaviour showcase

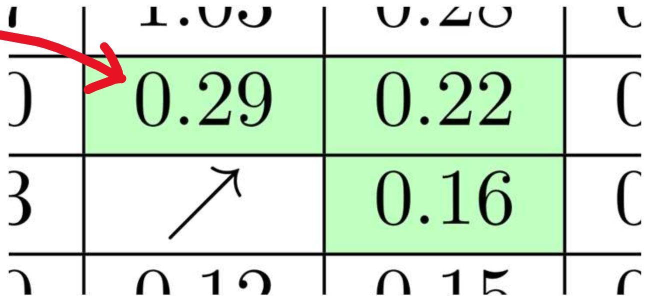


How are the markers used

- No other way to navigate/self-orient
- Each grid cell has a concentration value, per marker type.
- Markers deposited to increase the concentration in the local area.
- Walker chooses randomly from PDF; weighted so that higher concentrations ⇒ more likely.

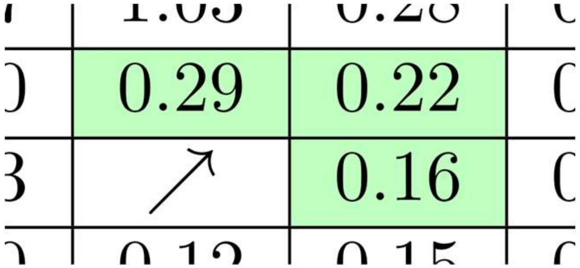
This is massively simplified; I have a more detailed explanation if requested.

Most likely choice



Probability Density Function for Decision Making

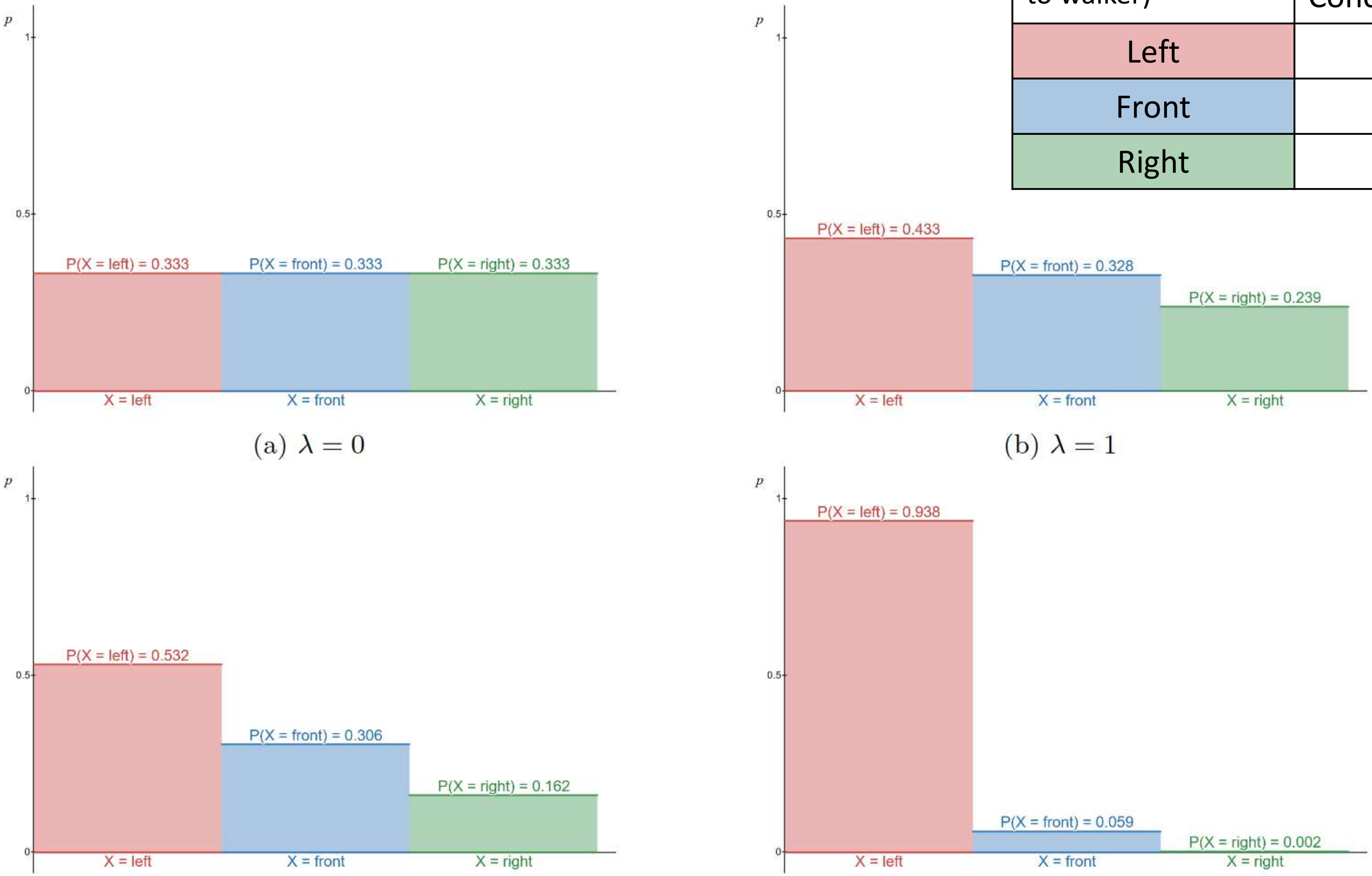
- Each concentration value raised to some power λ; as a relative weight. $C(\vec{x})^{\lambda}$
- Weights normalised to 1 to form valid PDF.
- Larger values of $\lambda \Rightarrow$ Stronger bias towards large concentrations ('less random')



Direction (relative to walker)	Cell Concentration $C(\vec{x})$	Relative Weight, $C(\vec{x})^{\lambda}; \lambda = 2$	Normalised Probability
Left	0.29	0.0841	0.532
Front	0.22	0.0484	0.306
Right	0.16	0.0256	0.162

Effect of the λ parameter

Direction (relative to walker)	Cell Concentration
Left	0.29
Front	0.22
Right	0.16



(a) $\lambda = 0$

(b) $\lambda = 1$

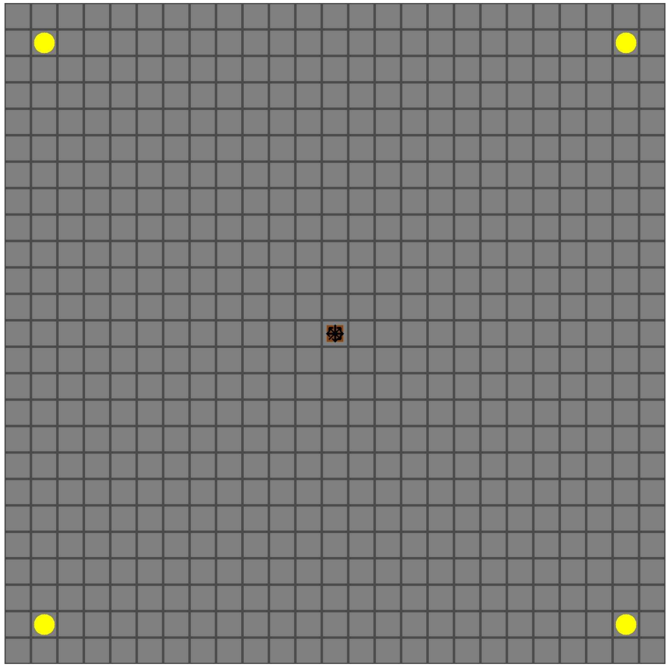
(c) $\lambda = 2$

(d) $\lambda = 10$

λ's effect on walker efficiency

- Do the walkers perform better with more randomness, or less randomness? (maybe there's a sweet spot in the middle?)

- We can measure performance by how long it takes a group of walkers to move all the resources in the environment to the nest
- Same scenario for all trials, averaged performance over 10 trials.

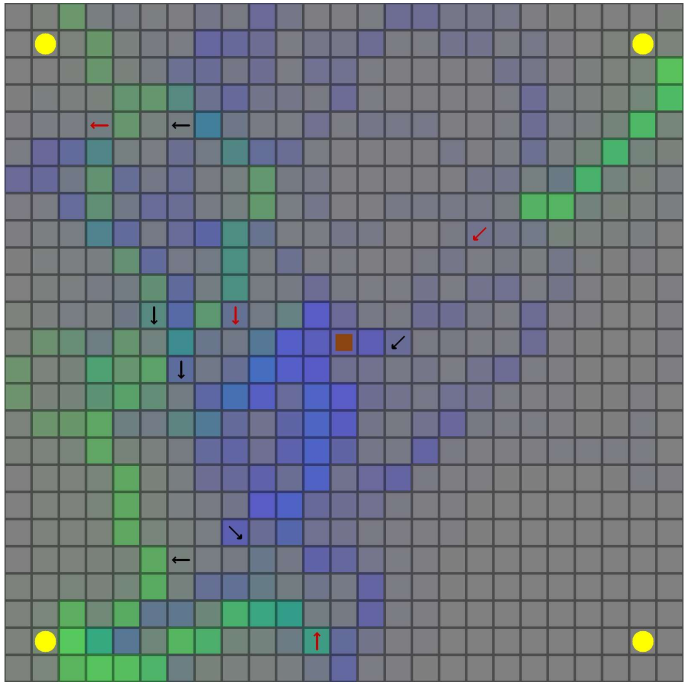


Test Scenario:

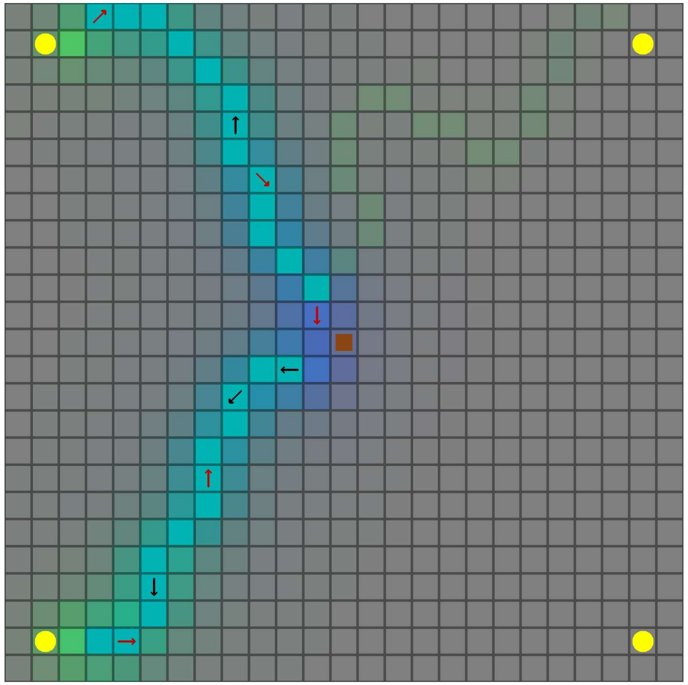
- 25x25 grid
- 10 walkers start at base in middle
- Resource pile in each corner, each with 20 units of resource
- Scenario ends once all 80 units have been moved to the base.

Visual comparison of high/low λ

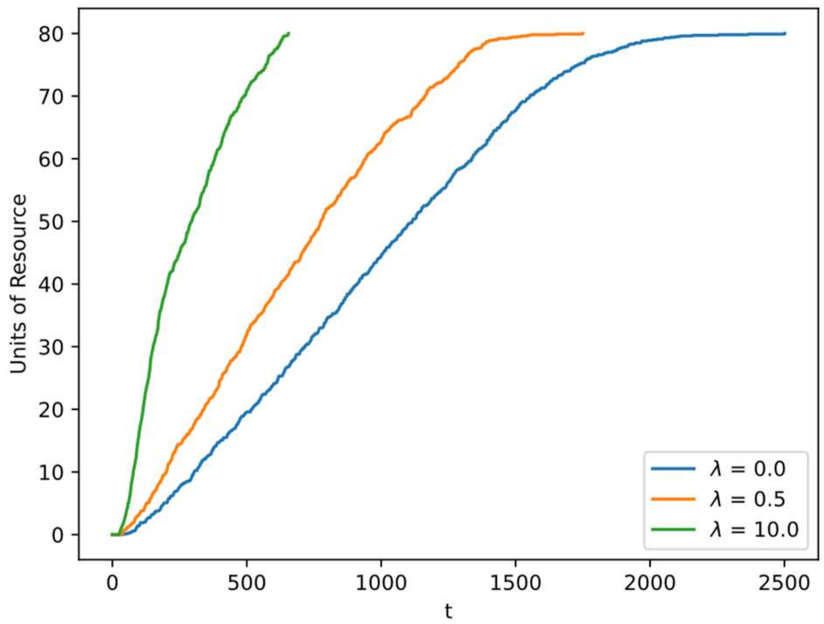
$\boldsymbol{\lambda = 0.5}$

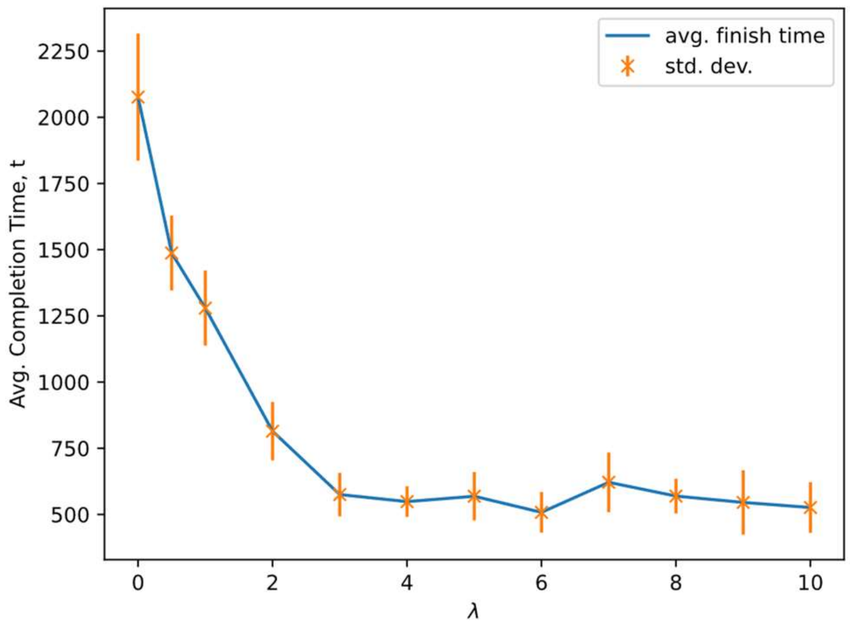


$\boldsymbol{\lambda = 10}$



Results





- Larger values of λ ('more deterministic') mean more efficiency in completing the objective.
- (Slightly) more consistent for larger λ.
- Diminishing returns at $\lambda = 3$ onwards.

Why is any of this useful?

Modelling biological processes/phenomena

- Can be used to model ants and the way they discover and transport food
- Accurately models real phenomena (Ant mills/Death Spirals)

Applications in low-performing robotics

- Replaces the use of AI/complex algorithms; with emergent behaviour from simple rules.
  - Similar applications; such as SAR
  - Power/cost efficient.
- Possible markers:
  - Sprayed chemical with a 'robotic nose'
  - LED's with small battery; sensed with a light intensity sensor.

Any Questions?

If you know what the term ‘nerd-sniping’ means; I’d advise against asking questions.

I have 8 more slides prepared…

Environment

- 2D grid; $\vec{x} = (x, y) \in [0, N] \times [0, M] : N, M \in \mathbb{Z}$
  - N wide by M tall
  - Represents a physical space, e.g. 1 cell = 1m x 1m
  - Multiple walkers can occupy a space at a time

- Timesteps; $t \in \mathbb{Z}^+ = \{0,1,2, \dots\}$
  - One turn represents however long it takes a walker/robot/ant to cross the space

Boundary conditions

0	0	0
0.07	→	0.12
0.13	0.16	0.16

- Edges of the grid act as a solid wall
- Cells 'outside of the grid' considered to have 0 probability
  - Chooses from the remaining options
- If the walker is facing into the wall with no valid options; turn around without moving

0	0	0
0.07	↑	0.12
0.13	0.16	0.16

⇒

0	0	0
0.07	↓	0.12
0.13	0.16	0.16

Concentration Sub-Model

For a given type of marker:

- Cell value calculated as sum of individual strengths of each marker.

$$C(\vec{x}) = \sum_{i=1}^{n} c_i(\vec{x})$$

Strength decay over time

$$c_i(\vec{x}) = \frac{\alpha_i(t)}{(\underbrace{\|\vec{x} - \vec{p_i}\|}_{} + 1)^{\beta}}$$

Distance from marker

Distance falloff; e.g. $\beta = 2$ follows inverse square law

Concentration Sub-Model

Effect of a single marker

0.17	0.25	0.17	0.10	0.06	0.04
0.25	1.00	0.25	0.11	0.06	0.04
0.17	0.25	0.17	0.10	0.06	0.04
0.10	0.11	0.10	0.07	0.05	0.03
0.06	0.06	0.06	0.05	0.04	0.03
0.04	0.04	0.04	0.03	0.03	0.02

Effect of multiple markers

0.19	0.27	0.20	0.12	0.09	0.06
0.27	1.03	0.28	0.15	0.10	0.08
0.20	0.29	0.22	0.15	0.12	0.10
0.13	0.16	0.16	0.16	0.16	0.13
0.10	0.12	0.15	0.22	0.29	0.20
0.08	0.10	0.15	0.28	1.03	0.27

(With $\alpha_i(t) = 1$; $\beta = 2$.)

Real World Phenomena: Ant mills

- Occur in real life when ants follow a pheromone trail that runs in a circle; constantly reinforced by the ants it's trapped.
- Is replicated by our model

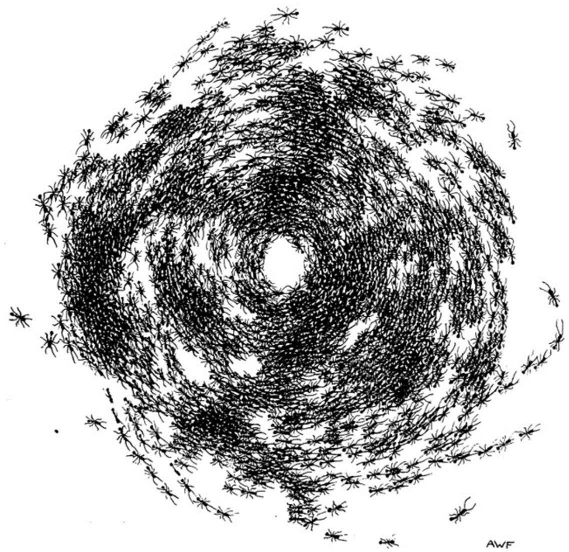
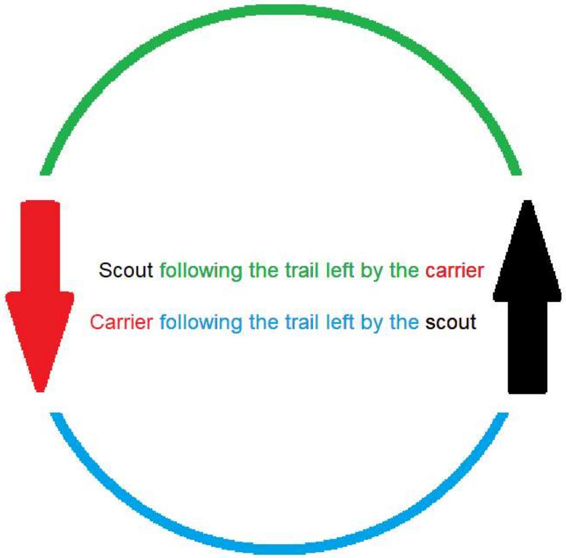
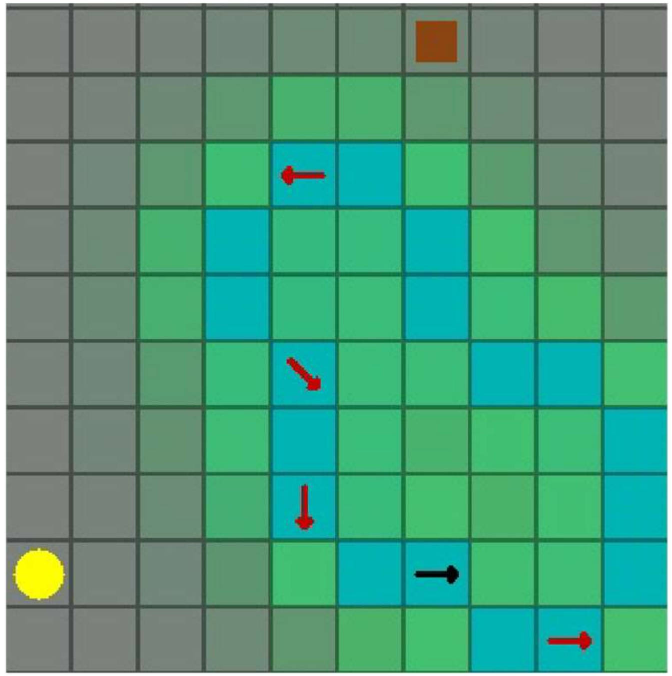


Diagram from: Schneirla, Theodore Christian et al. (1944). "A unique case of circular milling in ants, considered in relation to trail following and the general problem of orientation"

Real World Phenomena: Ant mills

- In our model; we need at least one walker of each job





Preventing Ant Mills from forming

- Make new markers weaker, relative to the amount of steps the walker has done without touching an objective (resource or home base).
- Walkers stuck in a mill cant refresh their step counter; leaving incredibly weak markers
- Walkers will eventually break free, and explore randomly until reaching an objective to lay a new marker trail at full strength.

$$c_i(\vec{x}) = \frac{\alpha_i(t)e^{-\gamma s_i}}{(\|\vec{x} - \overrightarrow{p_i}\| + 1)^\beta}$$

- γ is some small parameter, s_i as the step count of the walker *at the point when the marker is created.*

Ant Mill demonstration & prevention