Physical Swarm behaviors using evolved Behavior Trees

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Agents

Many automated processes contain the concept of an agent. Agents are autonomous, self contained units that react to the world in a convincing and predictable way.

Agent Example

An NPC (non-player character) should **fight**, unless it's *health falls too low*, at which point it should **run away** and find a safe space to **heal**.

Agent Example

An NPC (non-player character) should **fight**, unless it's *health falls too low*, at which point it should **run away** and find a safe space to **heal**.

- The **bold** statements represent behaviors
- The *italic* statement represents the control structure used to pick behaviors
- Creating and combining these components is called **agent modeling**, which is a task we can use behavior trees for

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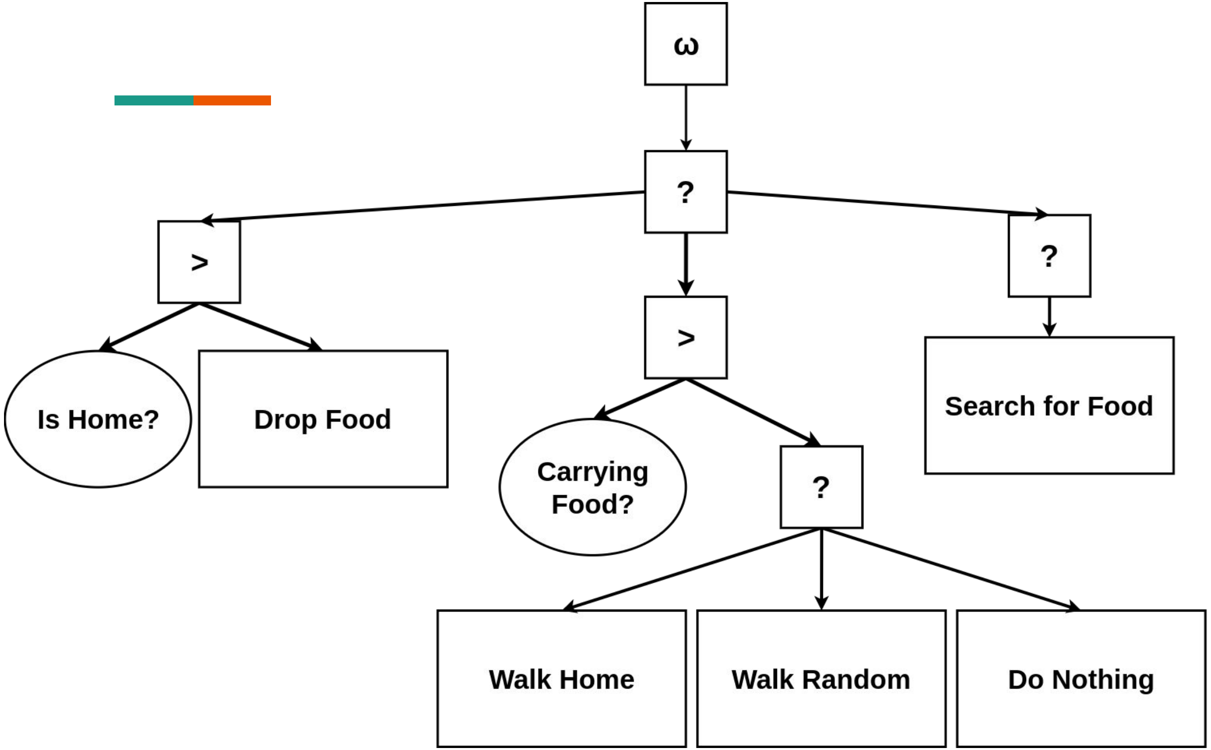
Behavior Trees

Behavior Trees

Behavior Trees are a simple, tree-based structure for modeling agent behavior.

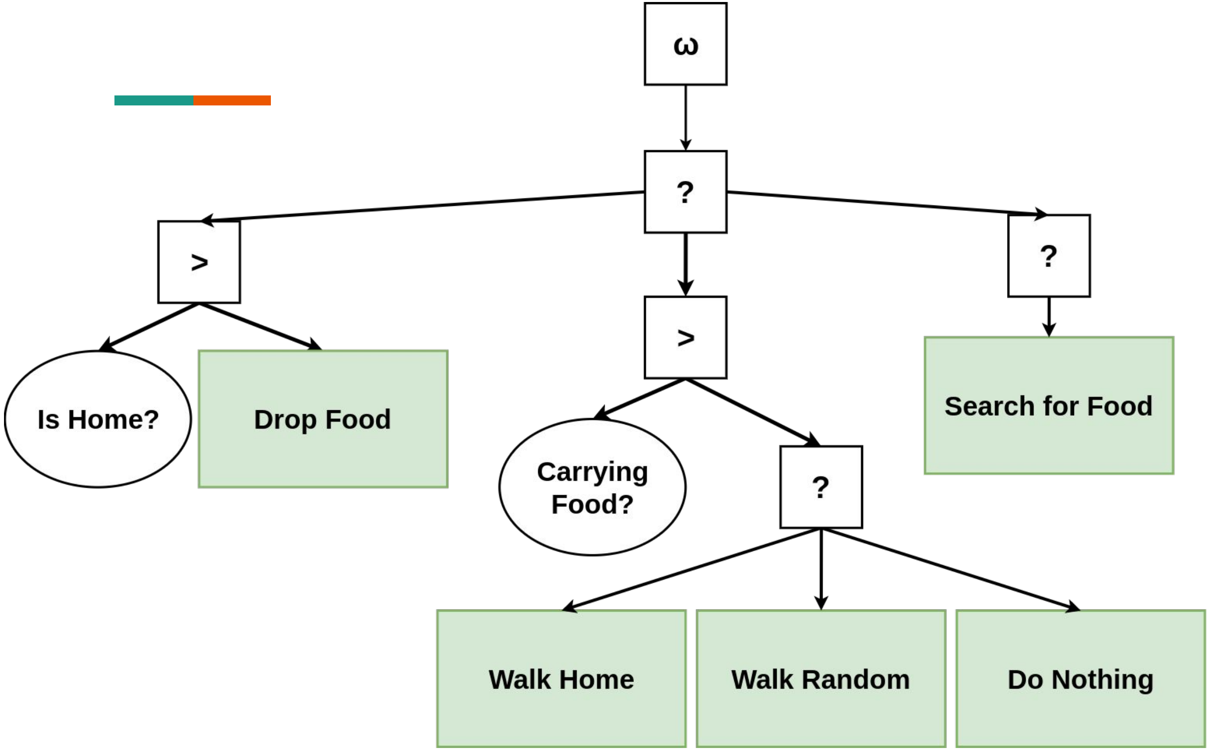
Uses include:

- Video game NPCs
- Robotics
- Swarm Modeling



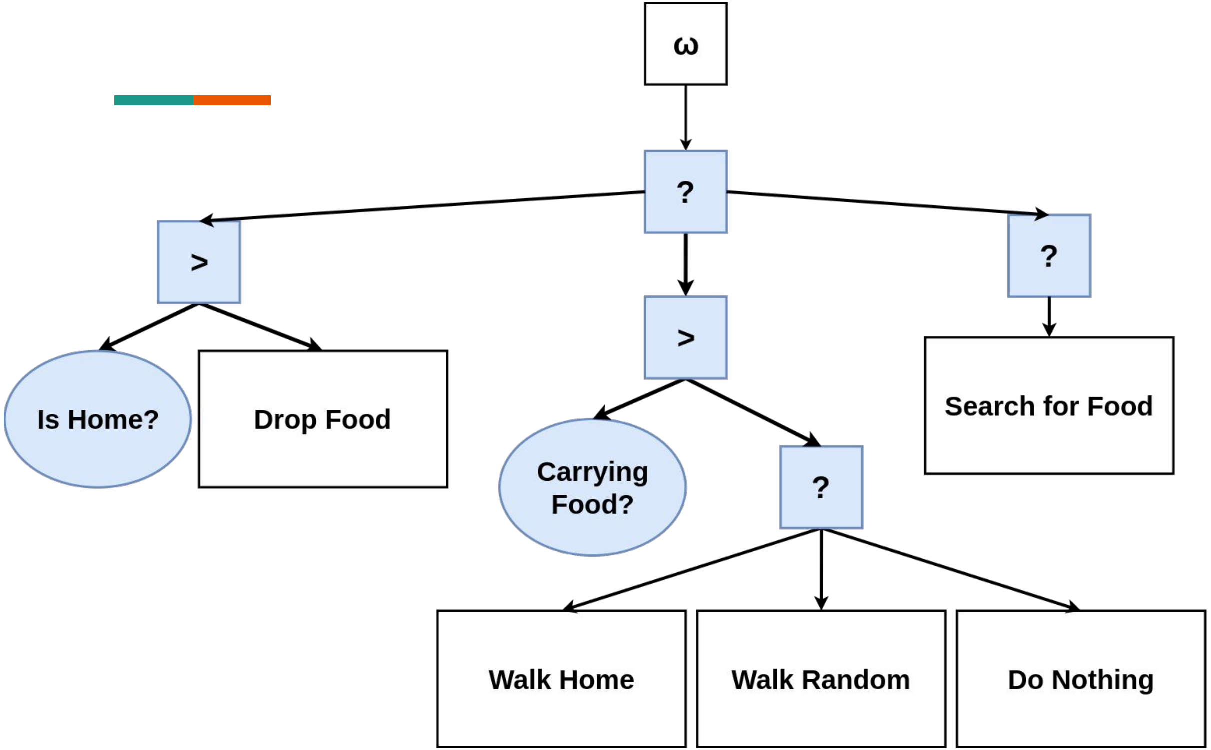
Structure:

- Tree based
- Evaluation starts at the top
- Made up of nodes of various types
- Picks behaviors



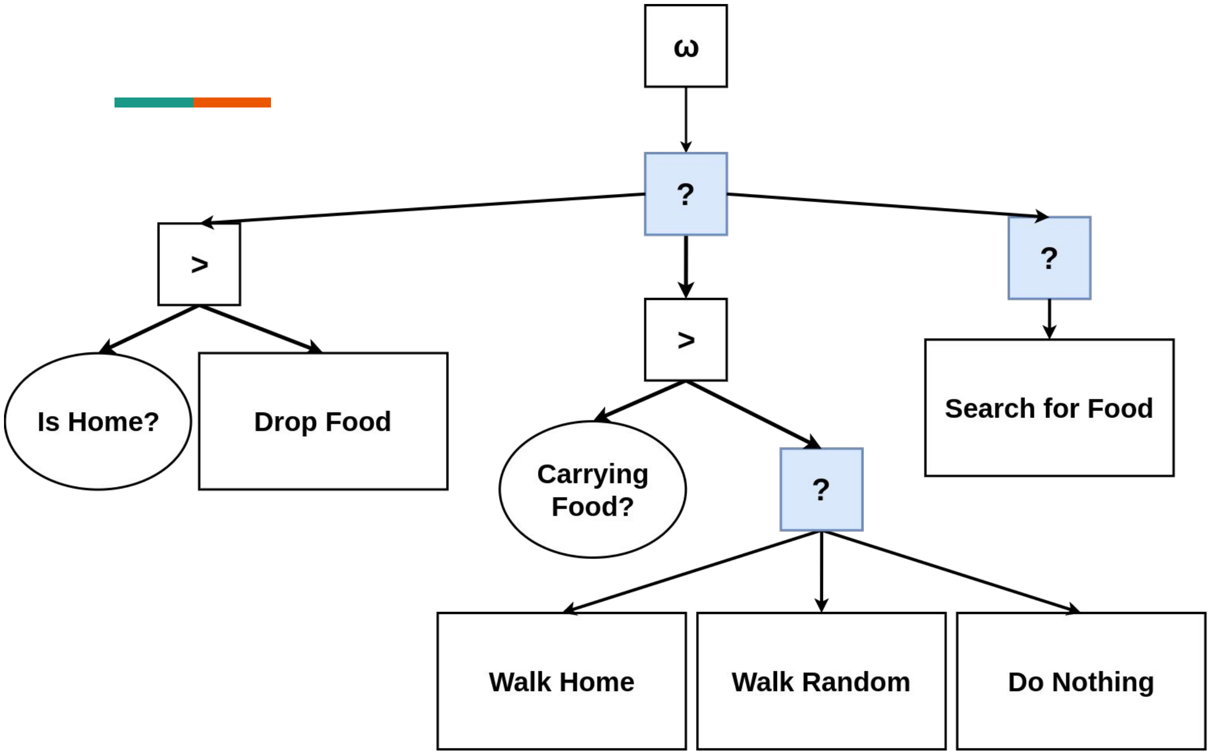
Behaviors:

- Found at the leaves
- Represent tangible actions
- When reached, the behavior will repeat until a new behavior is selected



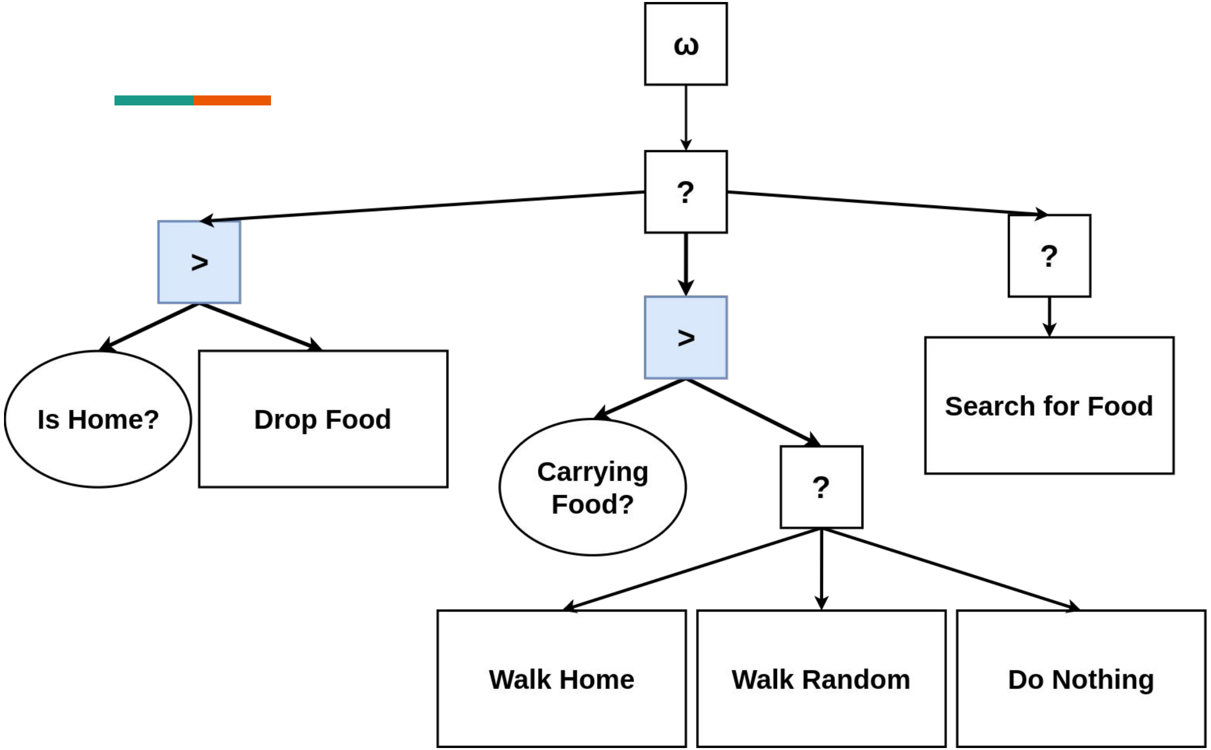
Decision Nodes:

- Represent the control structure
- Must have one parent
- Typically must have at least one child



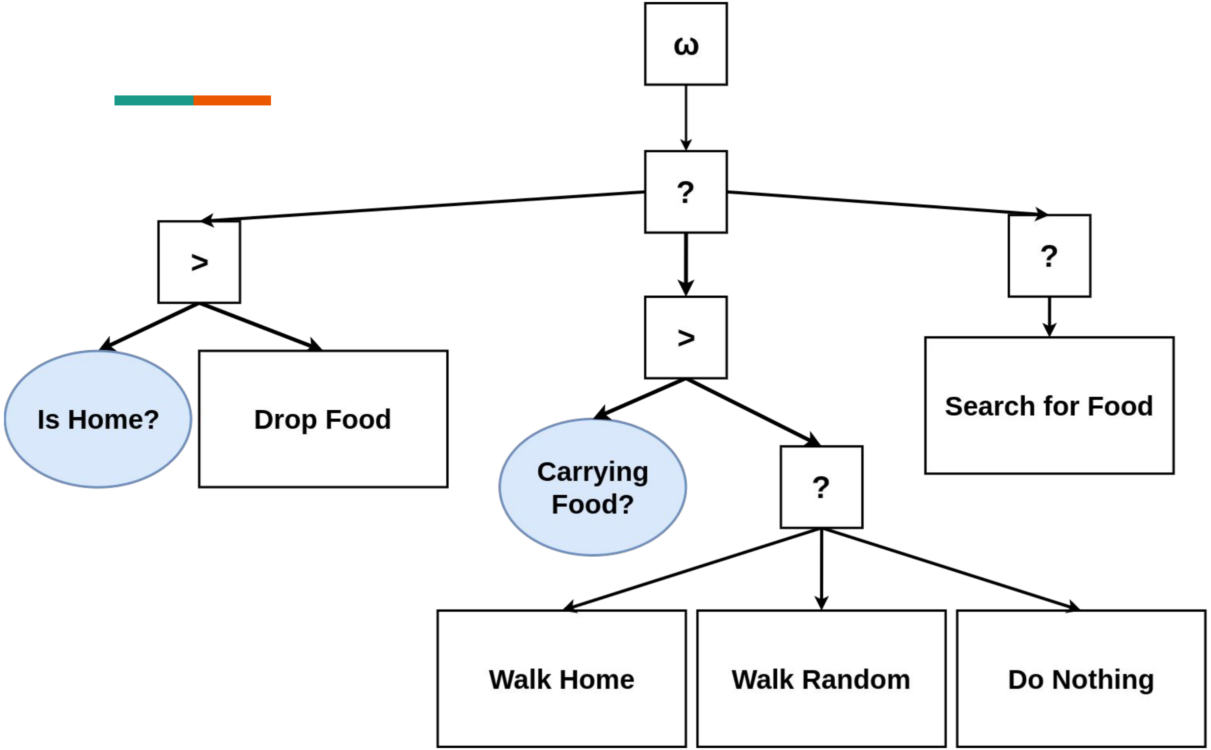
Select Nodes:

- Try each child from left to right
- Move control to the first successful child
- Return false if all children return return false
- Can be thought of as if/then/else block



Sequence Nodes

- Try each child from left to right
- Returns as soon as it hits a false child
- Can be thought of as an if/and/if/and/if statement



Blackboard Nodes:

- Come in the form of questions
- Are used to interact with the world
- Can be thought of as if statements

The blackboard:

The blackboard is how behavior trees handle memory. The blackboard is made up memory cells called blackboard values.

- Can be edited by behavior nodes
- Can be queried by blackboard nodes
- Pre-determined

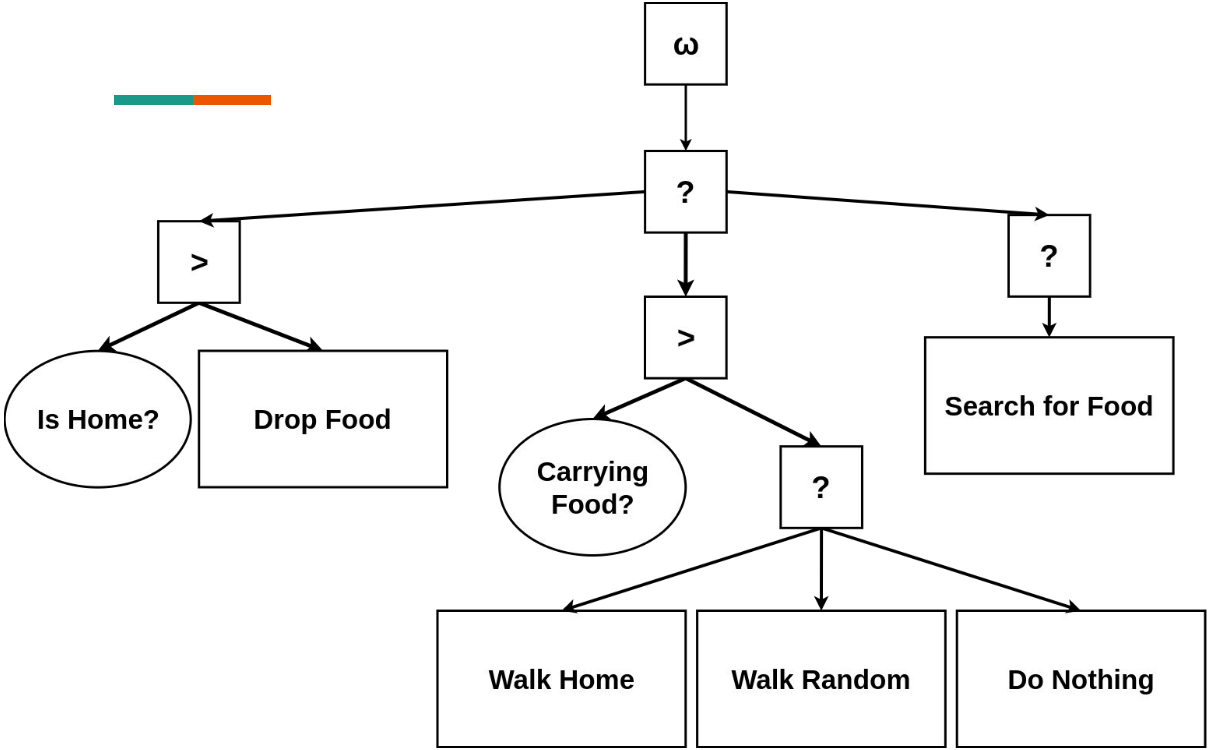
Tree traversals:

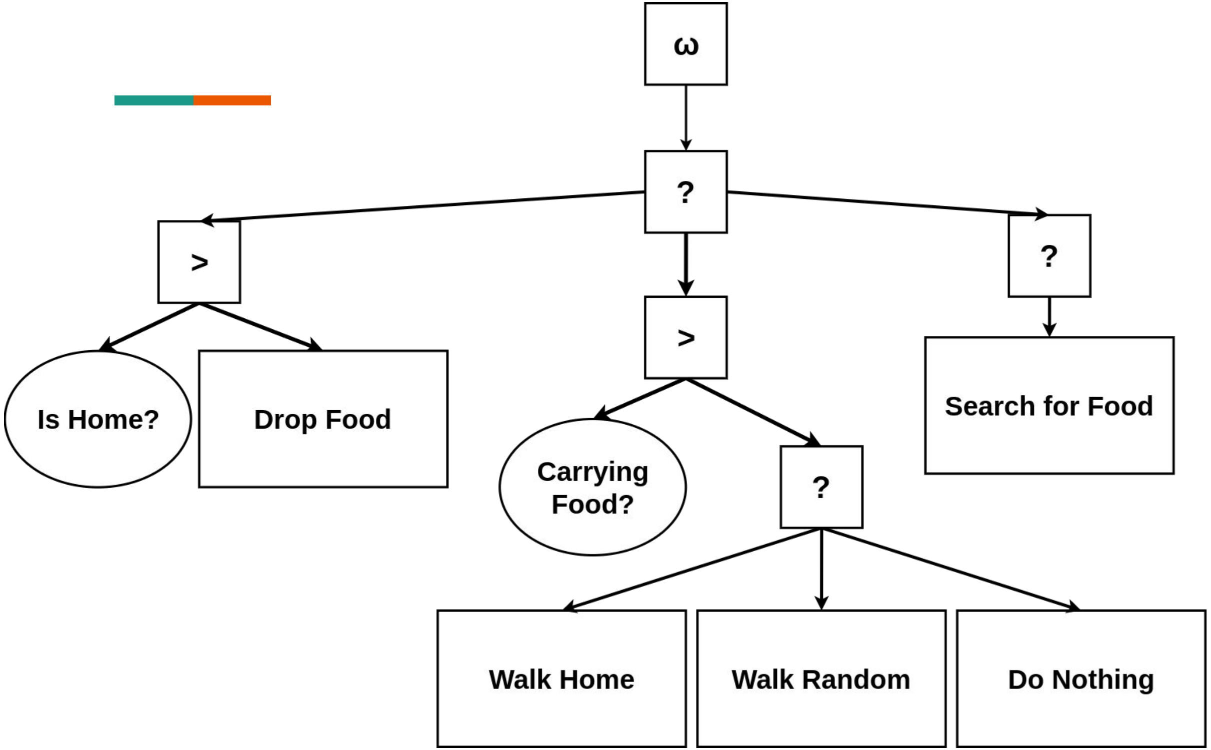
Each tick, evaluation of the BT begins at the root node, and continues recursively through the decision nodes until either a leaf is reached, or all relevant decision nodes have been queried.

- If a leaf node is reached, the leaf is queried, and the result is returned as the traversal value
- If a leaf node it not reached, the traversal will abort, and evaluation will begin again next tick

Tree states:

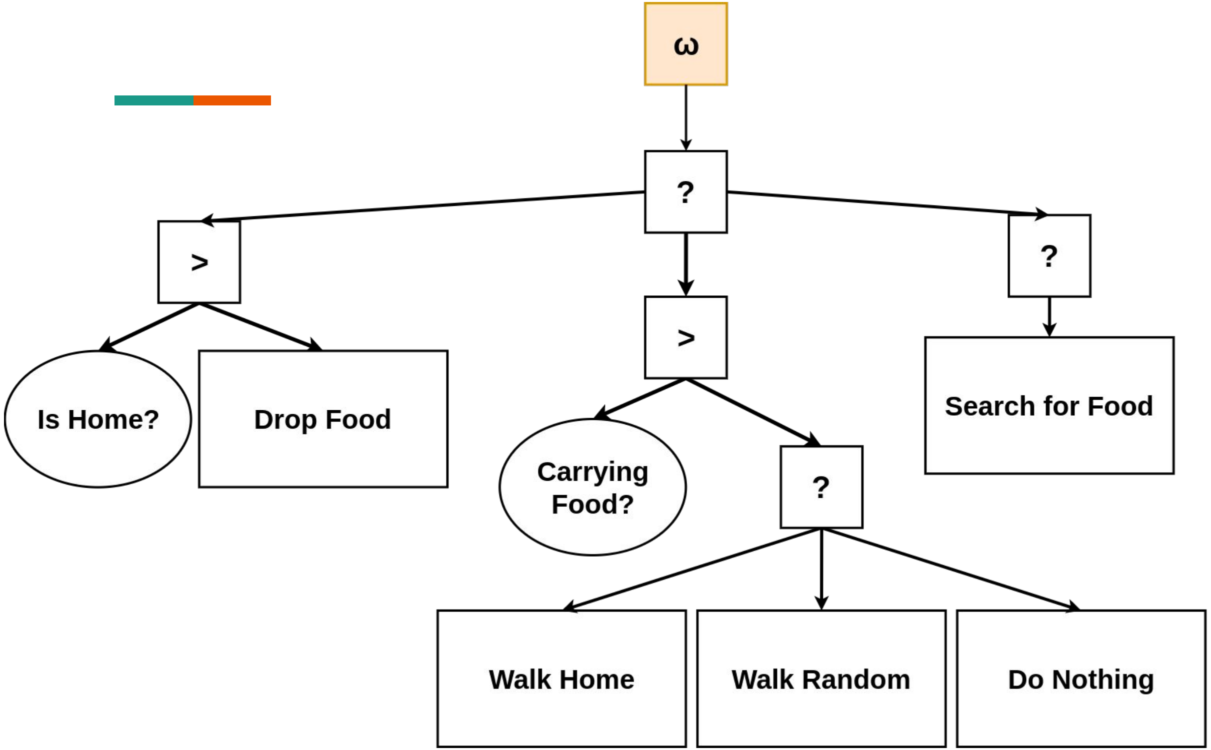
- **Running**: The behavior node will return running if it still processing its current behavior
- **Success**: The behavior node will return success, and set its internal state to running, unless it is unable to handle the behavior for some other reason
- **Failure**: Failure is a fallback state, and represents a behavior that is unable to be run at that time


ω
?
>
?
>
Is Home?
Drop Food
Search for Food
Carrying Food?
?
Walk Home
Walk Random
Do Nothing



The termite blackboard:

- Not home
- Not carrying food



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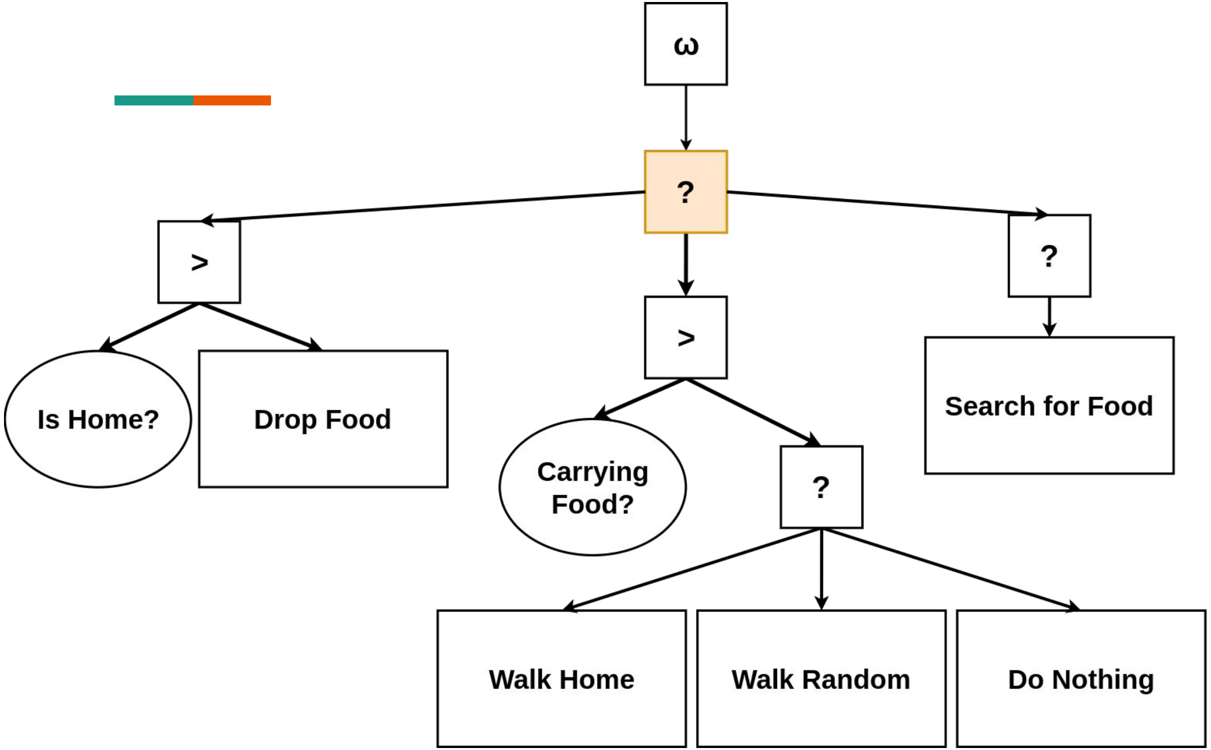

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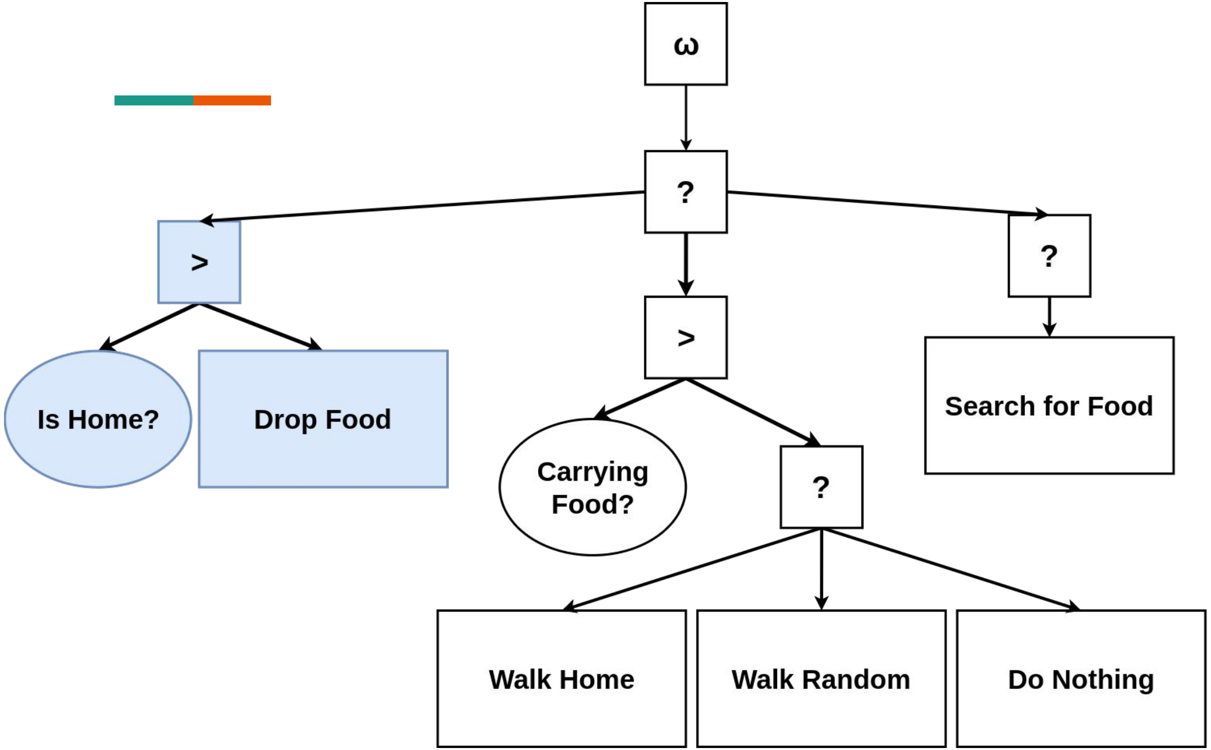

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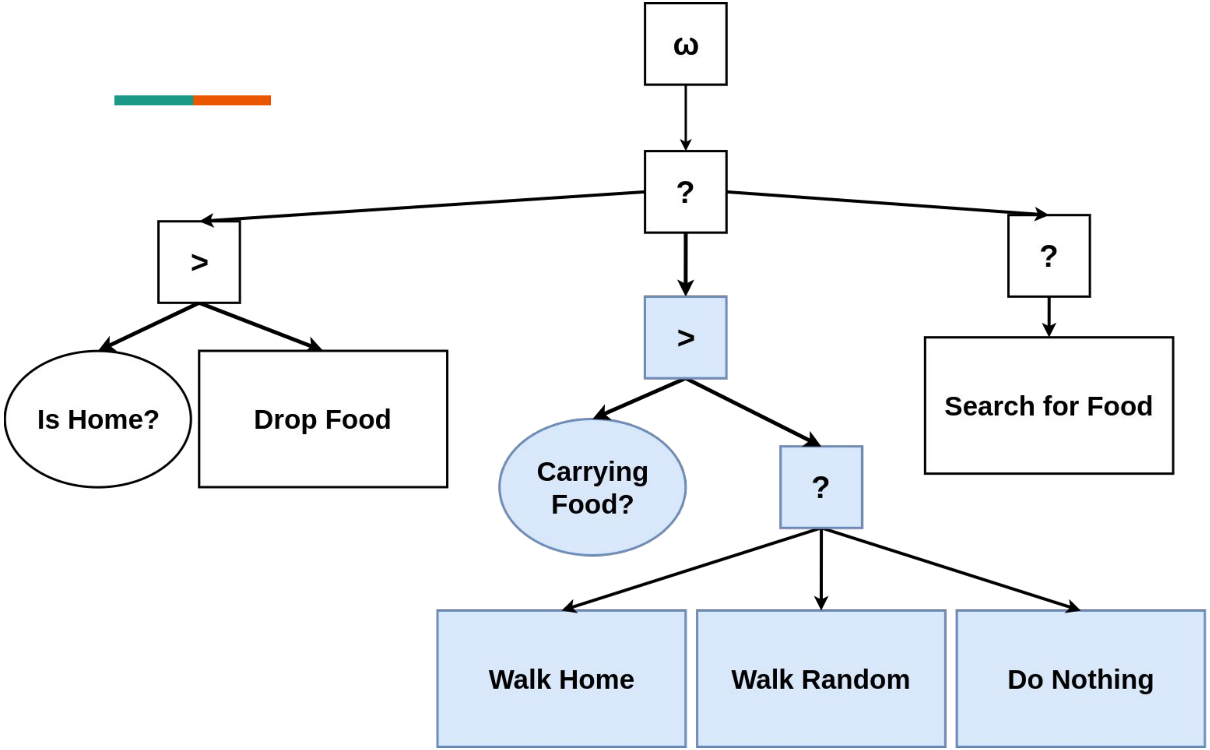

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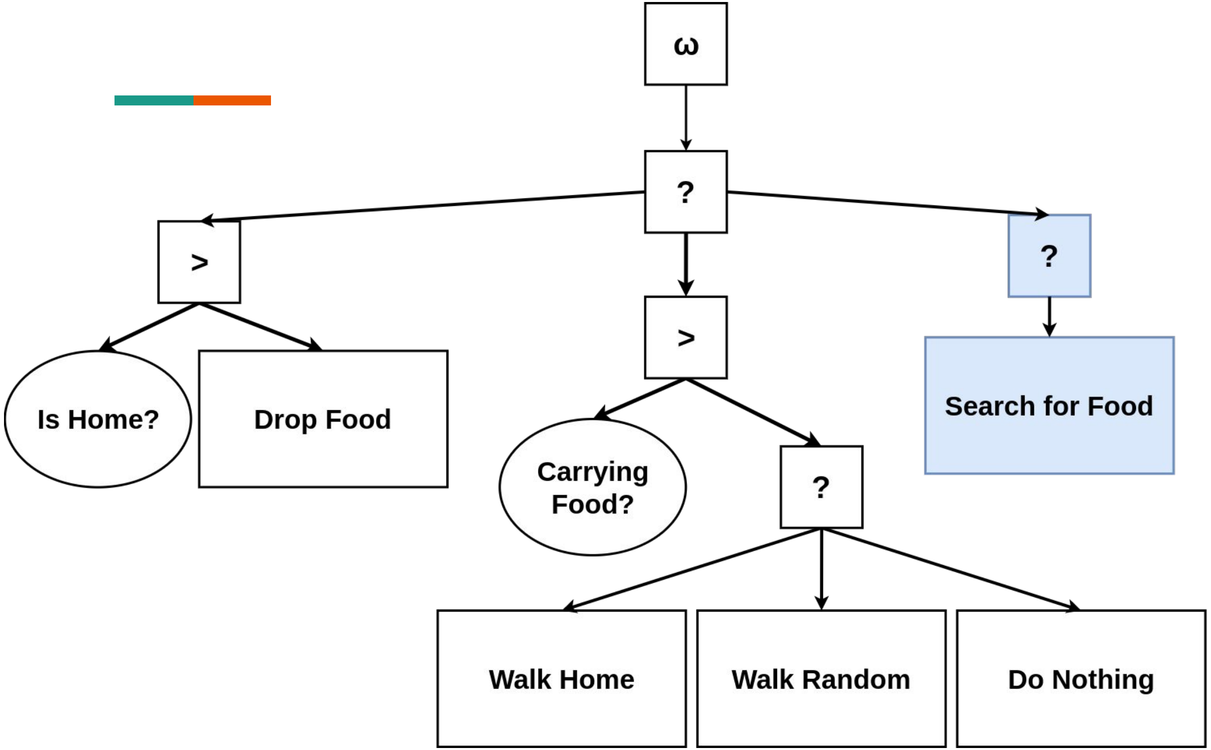

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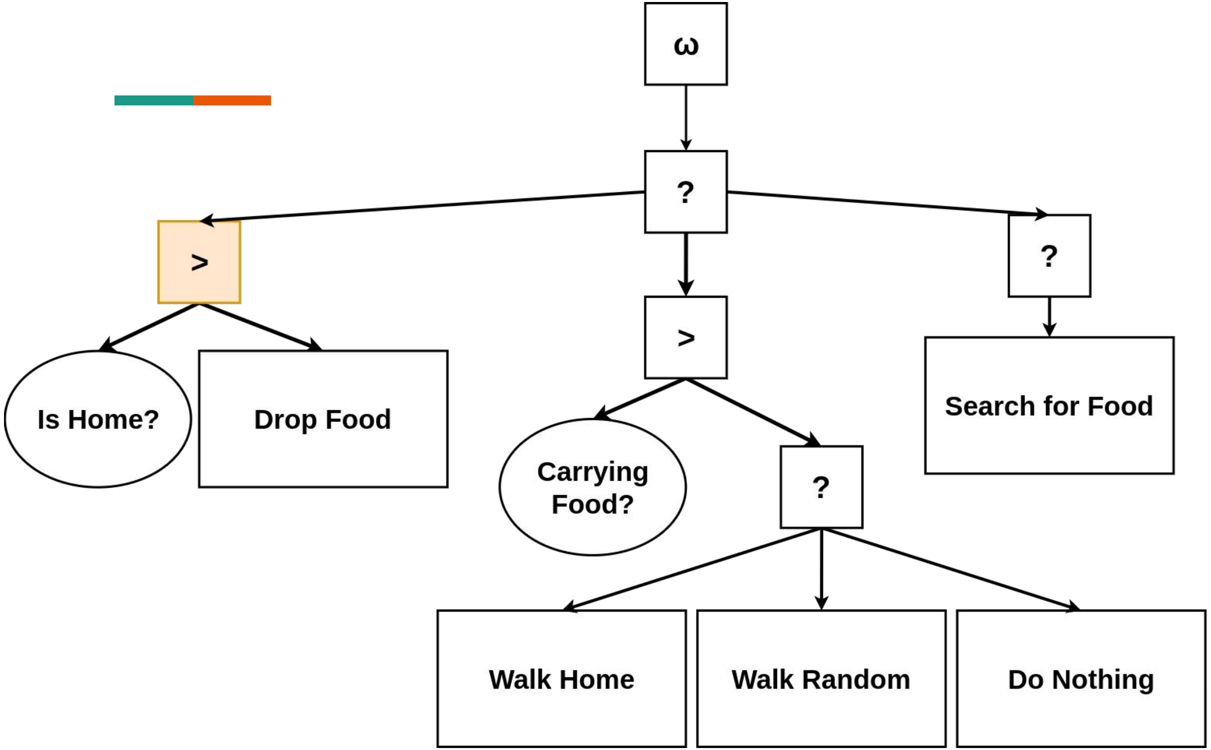

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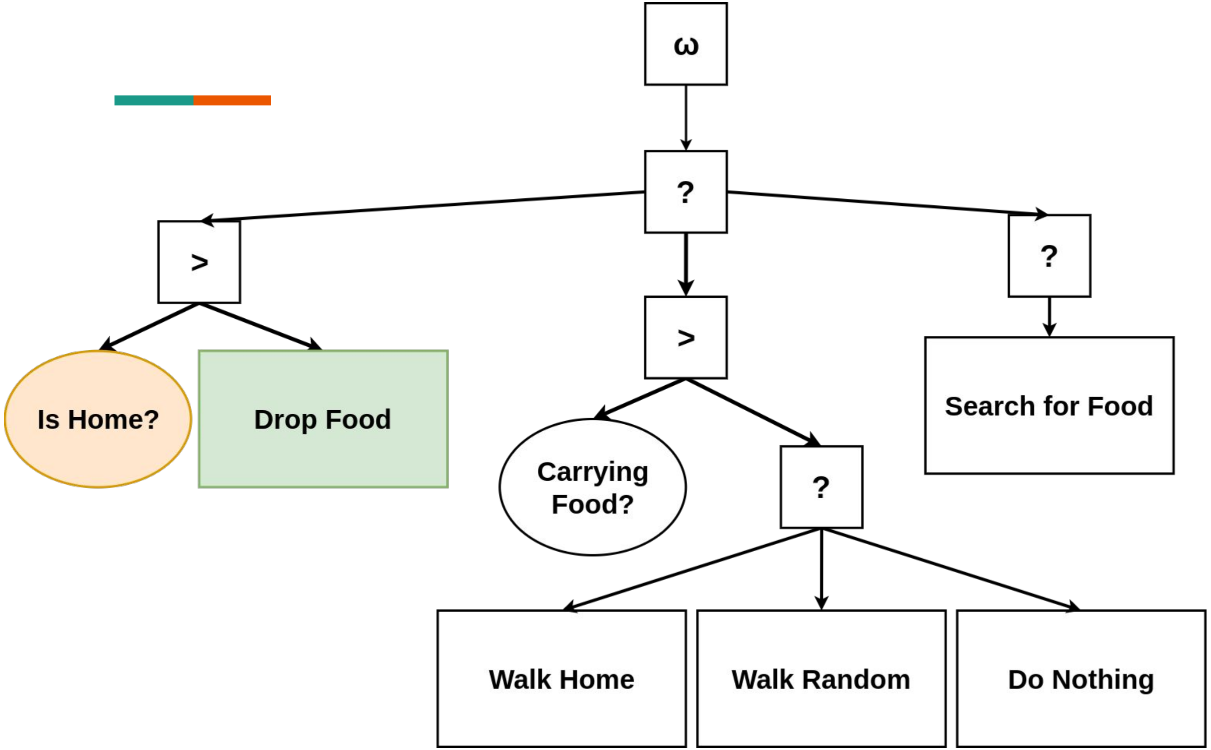

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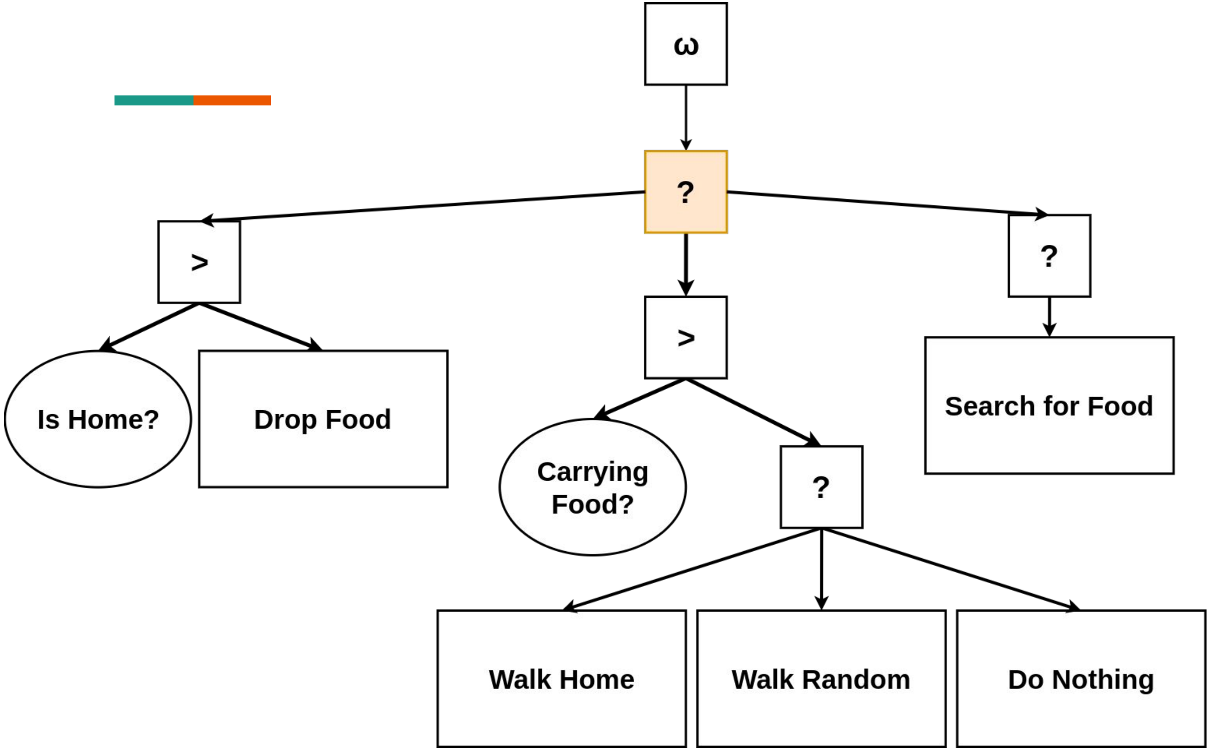

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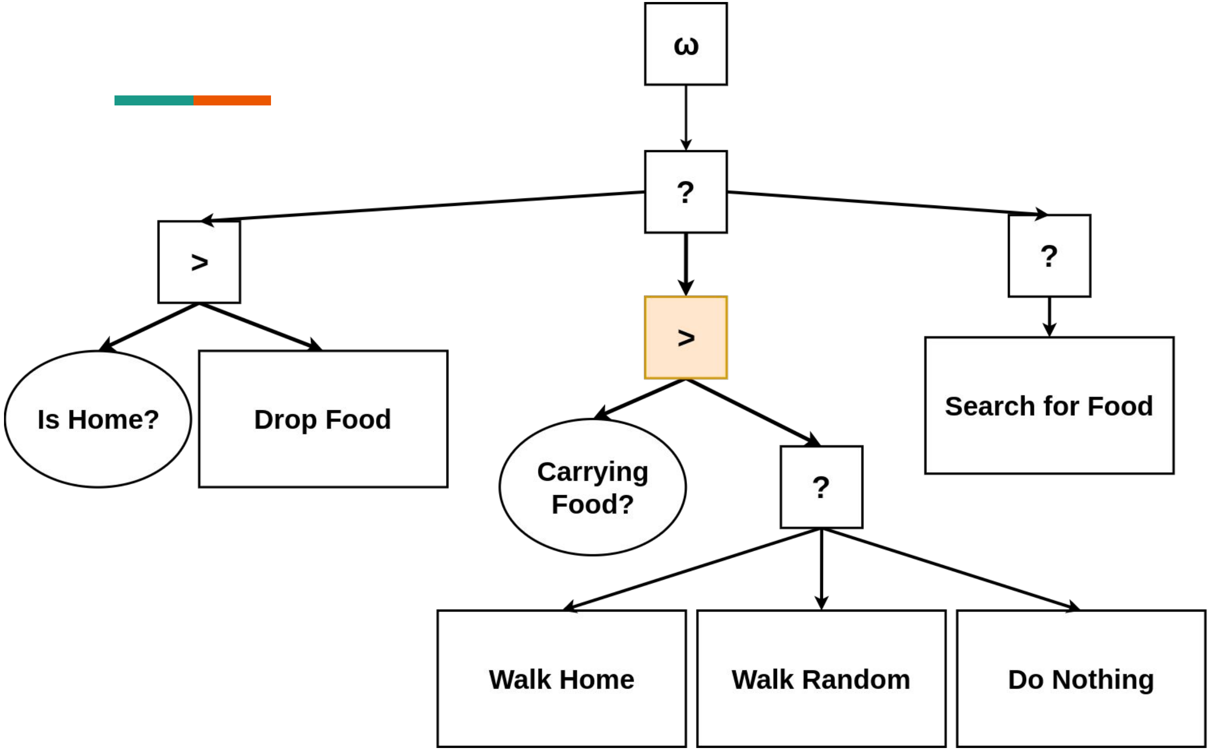

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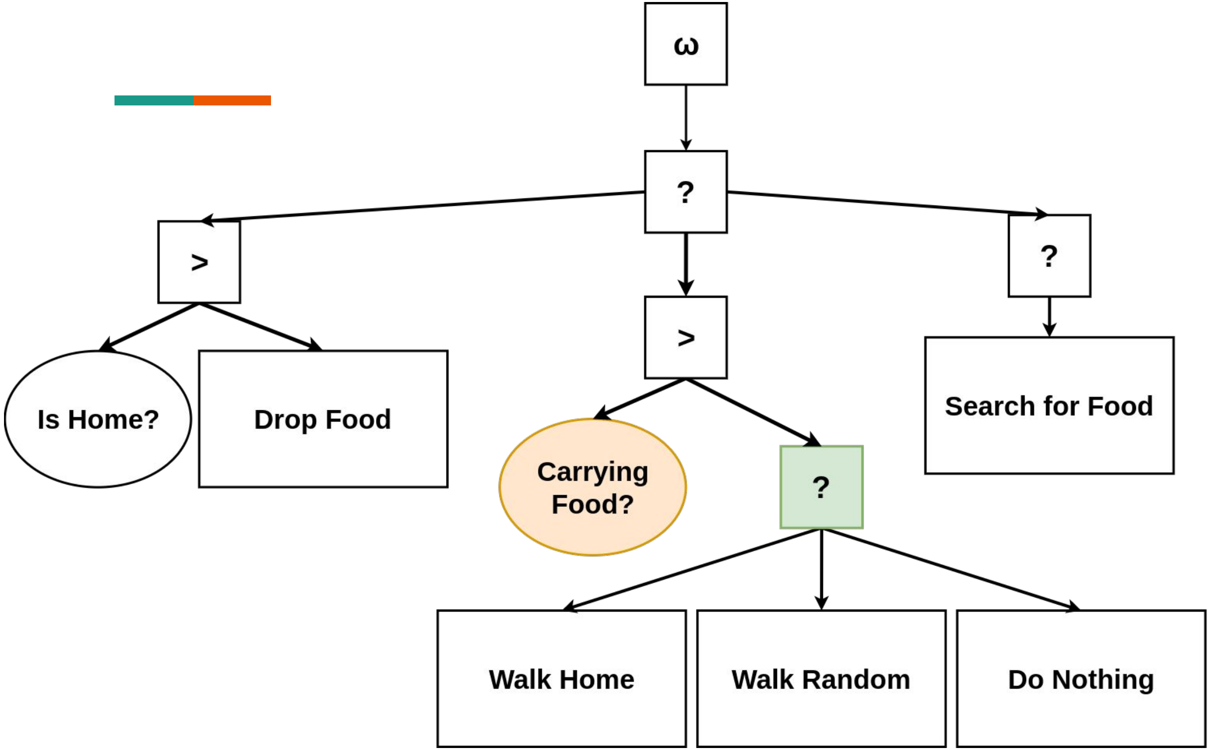

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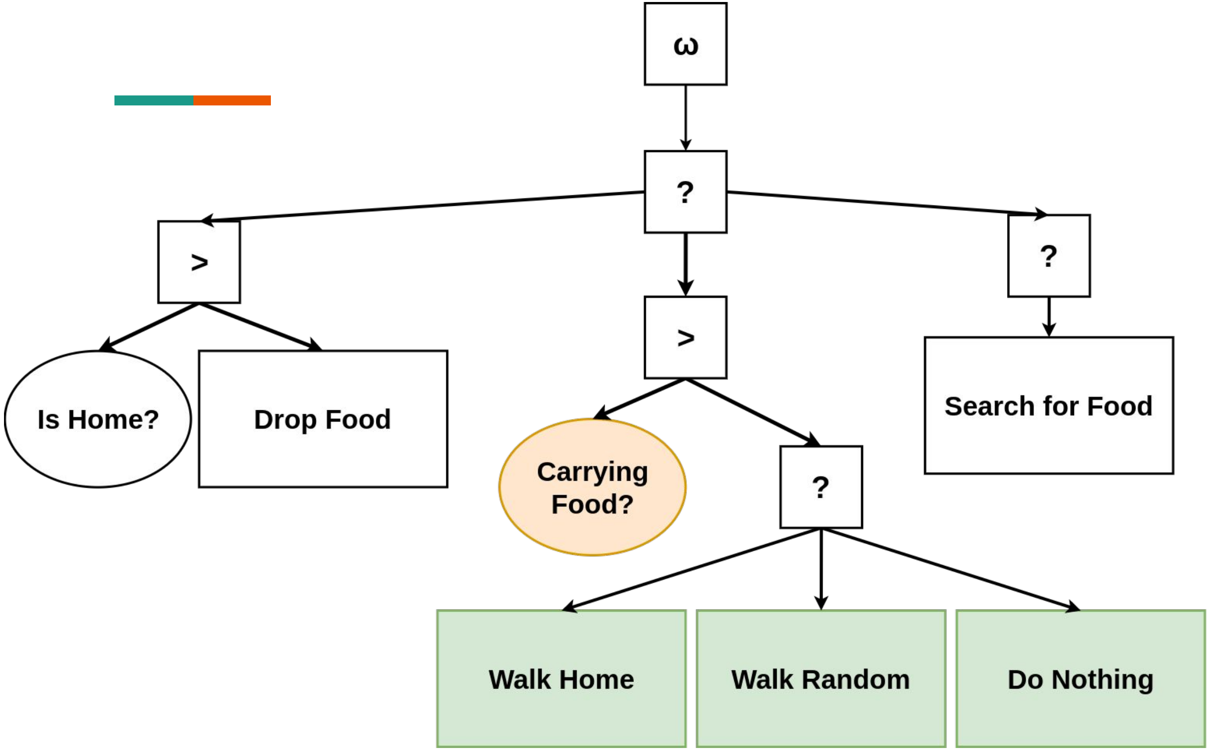

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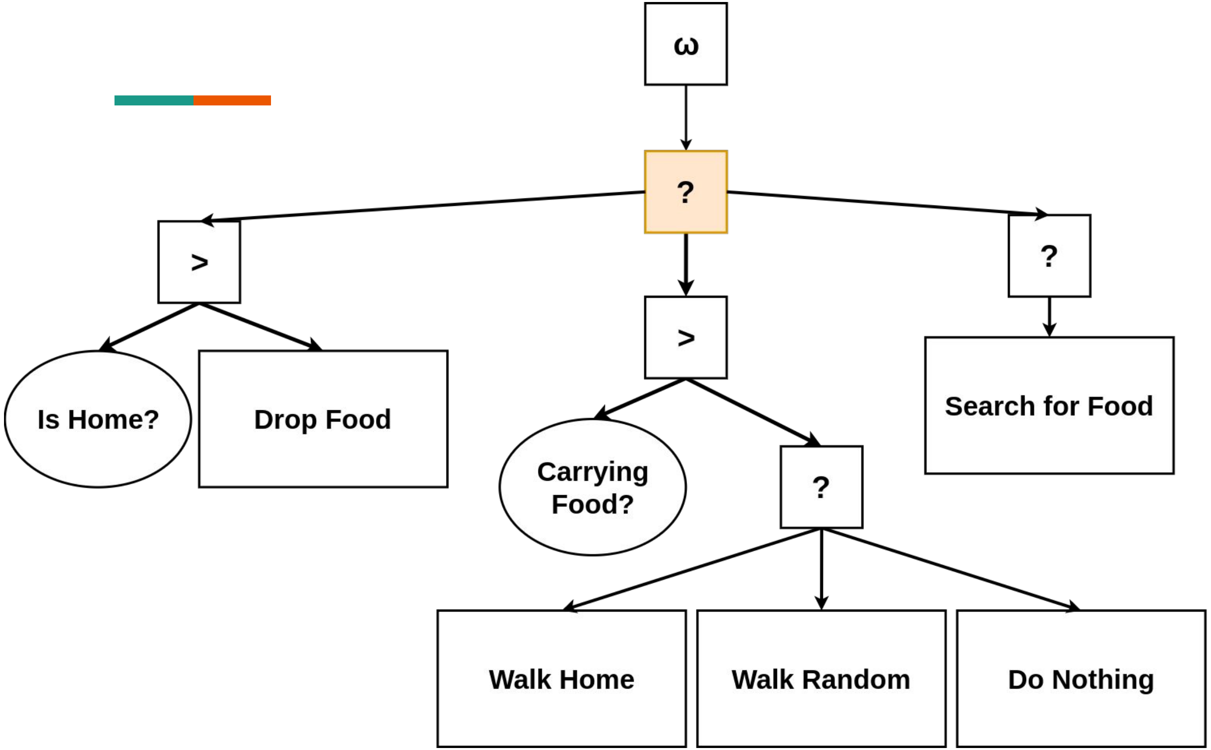

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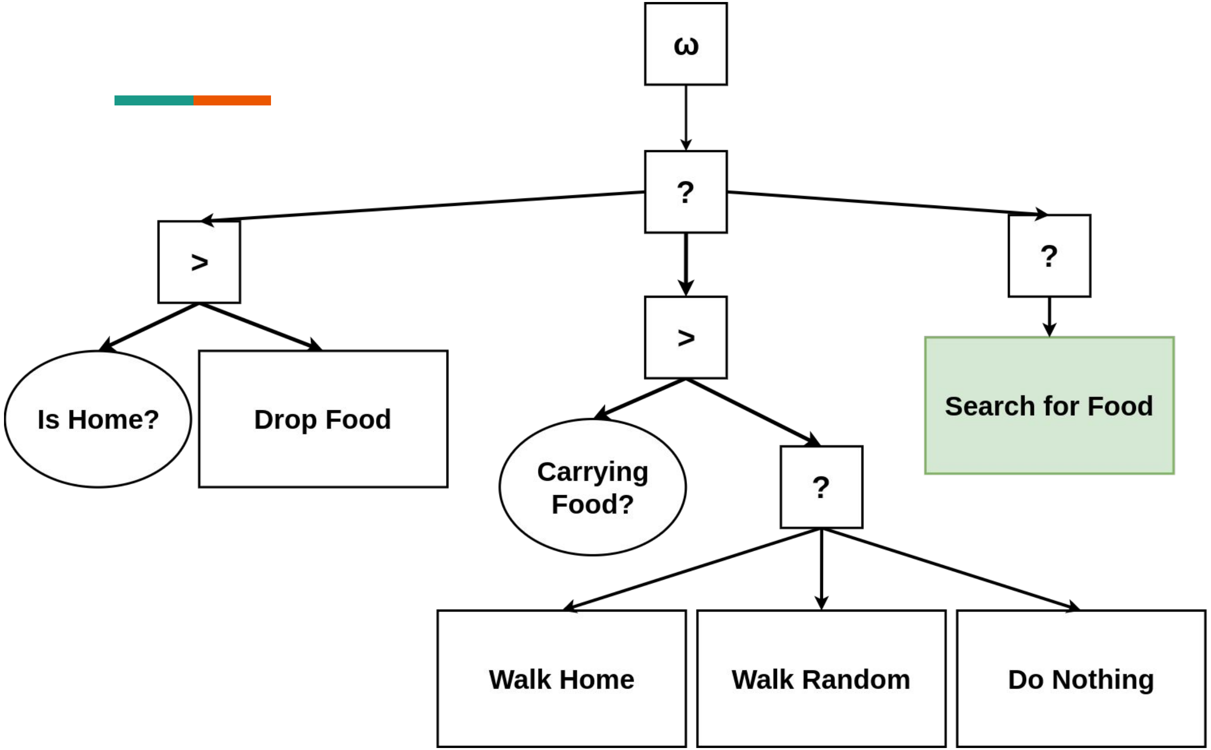

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Genetic Programming

Genetic Programming:

- Genetic programming is a subset of artificial intelligence research that involves *evolving* programs
- Genetic programming works by taking a set of *unfit* programs (often randomly generated) and applying evolutionary pressure

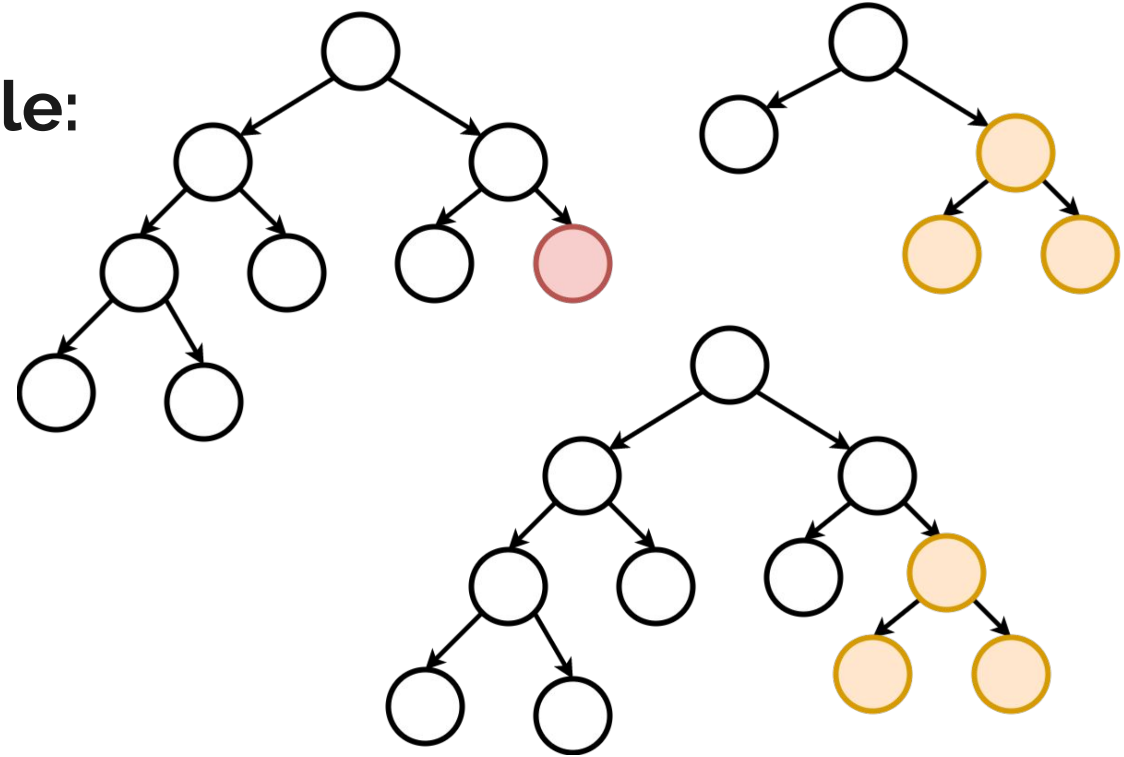
Genetic Programming & Biological Evolution:

- Programs can be thought of as organisms
- Organisms are reproduced
- There is a filter that insures the best organisms persists

Vocabulary:

- **Fitness** is the rating we give a program. It represents how well the program performed
- **Generations** are comparable to human generations
- **Crossover** is the sexual reproduction of two programs. Crossover results in new *child* programs

Crossover example:



Evolving Behavior Trees

Swarm modeling:

Swarm robotics is the field of research surrounding small, autonomous robots interacting with each other on a large scale

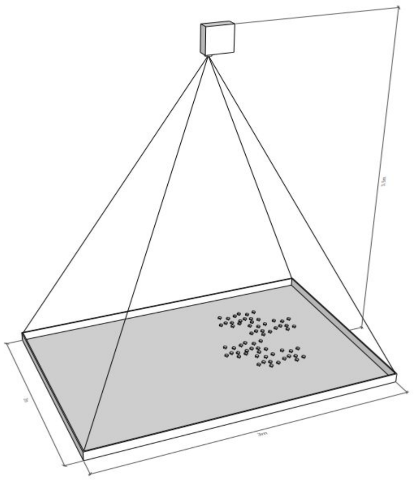
- The inspiration for swarm-robotics comes from colony-representative species such as bees, or termites
- Swarm robotics is interested in using the emergent properties of swarms to create useful robotic behaviors out of relatively simple agents
- Behavior trees can be used to model the individual agents in a swarm. These agents can then be tested or studied in a simulation environment

Why behavior trees?

"Evolved controllers are often difficult to understand, limiting our ability to predict swarm behaviour. We suggest behaviour trees are a good control architecture for swarm robotics, as they are comprehensible and promote modular reuse."

Jones et al.

Kilobots:



- A Kilobot is a small, cheap, physical robot
- Each Kilobot represents an agent in a swarm
- Each Kilobot is equipped with two vibrating motors, which allow the bot to turn and move forward
- An upwards facing photo detector for environment sensing

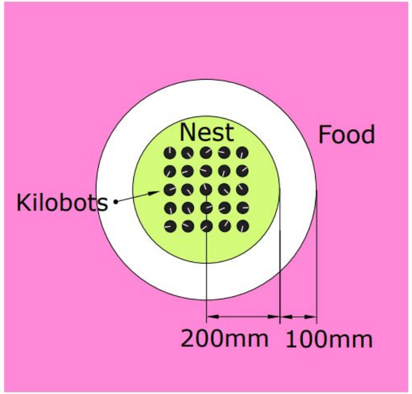
Image taken from [2]

Foraging:

A common task for modeling swarm behaviors is foraging, which is the task of moving away from a home area, collecting food and returning home.

- Includes many agent interactions
- Encourages cooperation
- Has real world applications

Foraging environment:



- At the centre of the arena is a circular nest region
- Surrounding this is a gap, then beyond that is the food region
- A kilobot which moves into the food region is regarded as having picked up an item of food, a kilobot which is carrying an item of food that enters the nest region is regarded as depositing the food in the nest

Image taken from [2]

Kilobot behavior structure:

Genetic programming works by combining a predefined set of operations in a structured way.

When evolving behavior trees, the structure is built out of behavior tree components: **decision nodes**, **behavior nodes**, and **blackboard values**. These elements are combined and trained using genetic programming.

Structure: Decision Nodes

The following decision nodes exist:

- Sequence
- Selection
- Always succeed
- Always fail
- Repeat

Structure: Behavior Nodes

The following behavior nodes exist:

- Move forward for one tick
- Turn left for one tick
- Turn right for one tick
- Always succeed
- Always fail

Structure: Blackboard

Name	**Values**:
motors	*on, off, left, right*
Δdensity	*Change in kilobot density*
$\Delta distance_{nest}$	*Change in distance to home*
$\Delta distance_{food}$	*Change in distance to food*
detected_food	*true, false*
carrying_food	*true, false*

Structure: Blackboard Queries

The Kilobot can query its blackboard values in the following ways:

- Compare two blackboard values against each other
- Compare a blackboard value against a constant

Example:

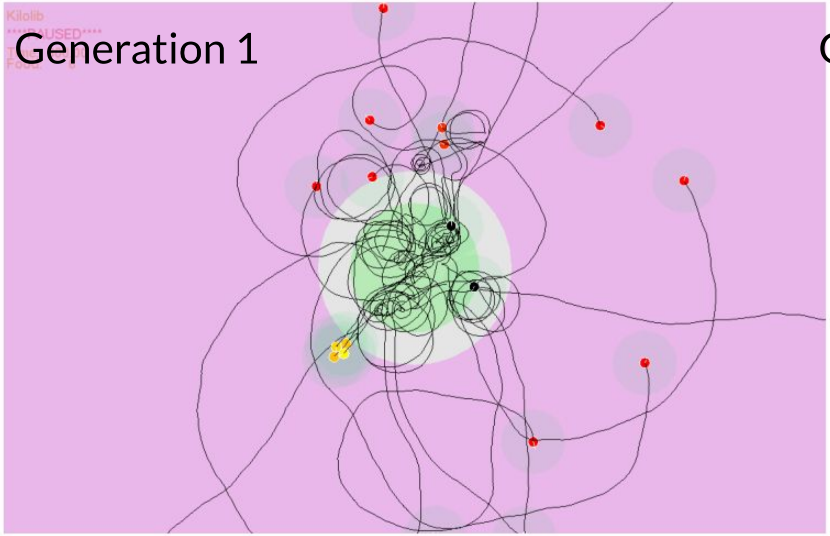
- $\Delta dist_{food} > Motors$

Evolving behavior trees

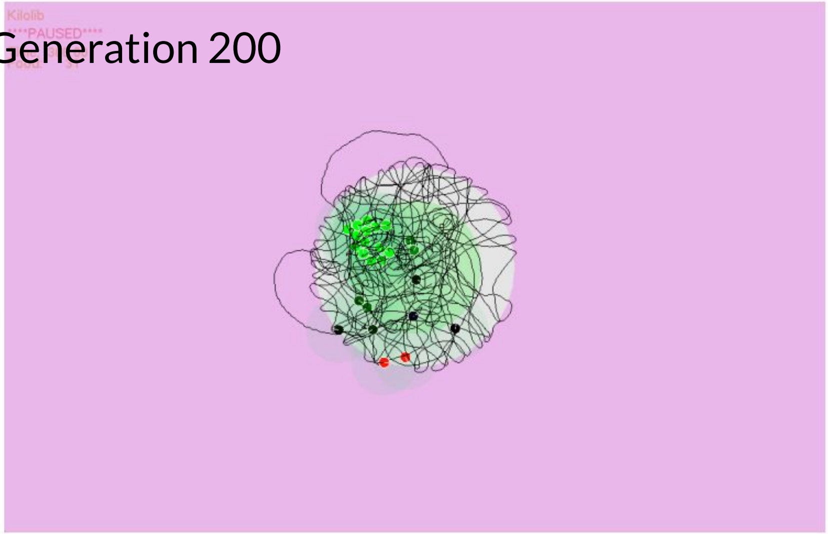
Evolution proceeds as follows:

- The population of n_{pop} is evaluated for fitness by running 10 simulations for each individual, each simulation with a different starting configuration
- The starting position is always a 5x5 grid with 50mm spacing in the centre of the nest region
- The simulation runs for 300 simulated seconds

Pathing for evolved Kilobots:



Generation 1



Generation 200

Image taken from [2]

Taken from [1]

Evolutionary discovery

- Fitness rises fast after the first generation
- The authors note that this is because Kilobots that only move forward are still collecting some food
- The best Kilobot lineage is significantly better than the rest

The best Kilobot:

- Not all of the hardwired capabilities are used
- Only *detected_food*, $\Delta dist_{food}$, and $\Delta dist_{nest}$ are used
- This is not the case for all agents: combined together, each capability was used at least once
- There is no obvious correlation between the features used and the fitness of the individual, perhaps indicating that there are multiple ways to solve this foraging problem

The best Kilobot:

- The first clause causes the kilobot to move forward as long as it is not in the food region
- If it enters the food, the second clause comes into play, performing a series of left turns and forward movements until it moves out of the food region
- Behaviour will then revert to the first clause and it will move forward again, likely hitting the nest region

```
selm3(
  seqm2(                          Move forward until in food
    ifge(0, detected_food),
    mf()),
  seqm8(                          Turn and forward until out of food
    ml(),
    ifge(Δdist_food, 0),
    mf(),
    ml(),
    mf(),
    ifge(Δdist_food, 0),
    mf(),
    mf()),
  seqm3(
    ml(),
    repeat(5,
      iflt(Δdist_nest, −0.058530)),
    ml()))
```

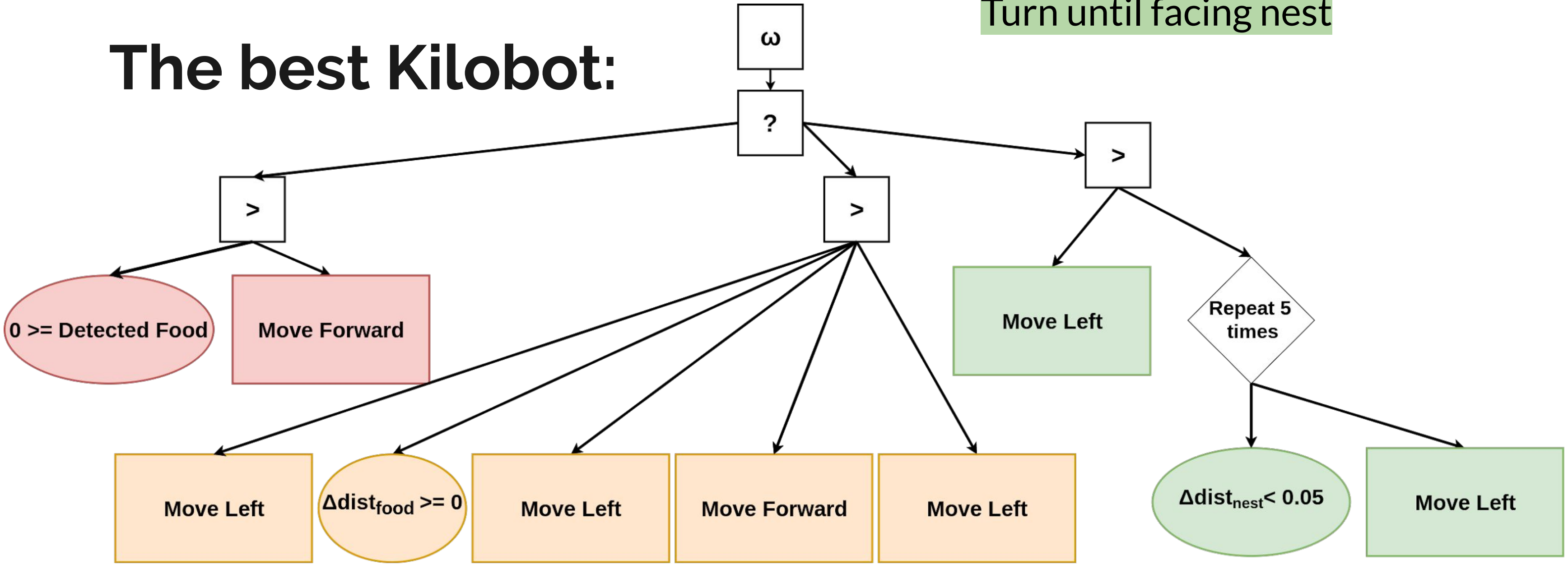
Table taken from [2]

The best Kilobot:

Move forward until in food

Turn and forward until out of food

Turn until facing nest



Results:

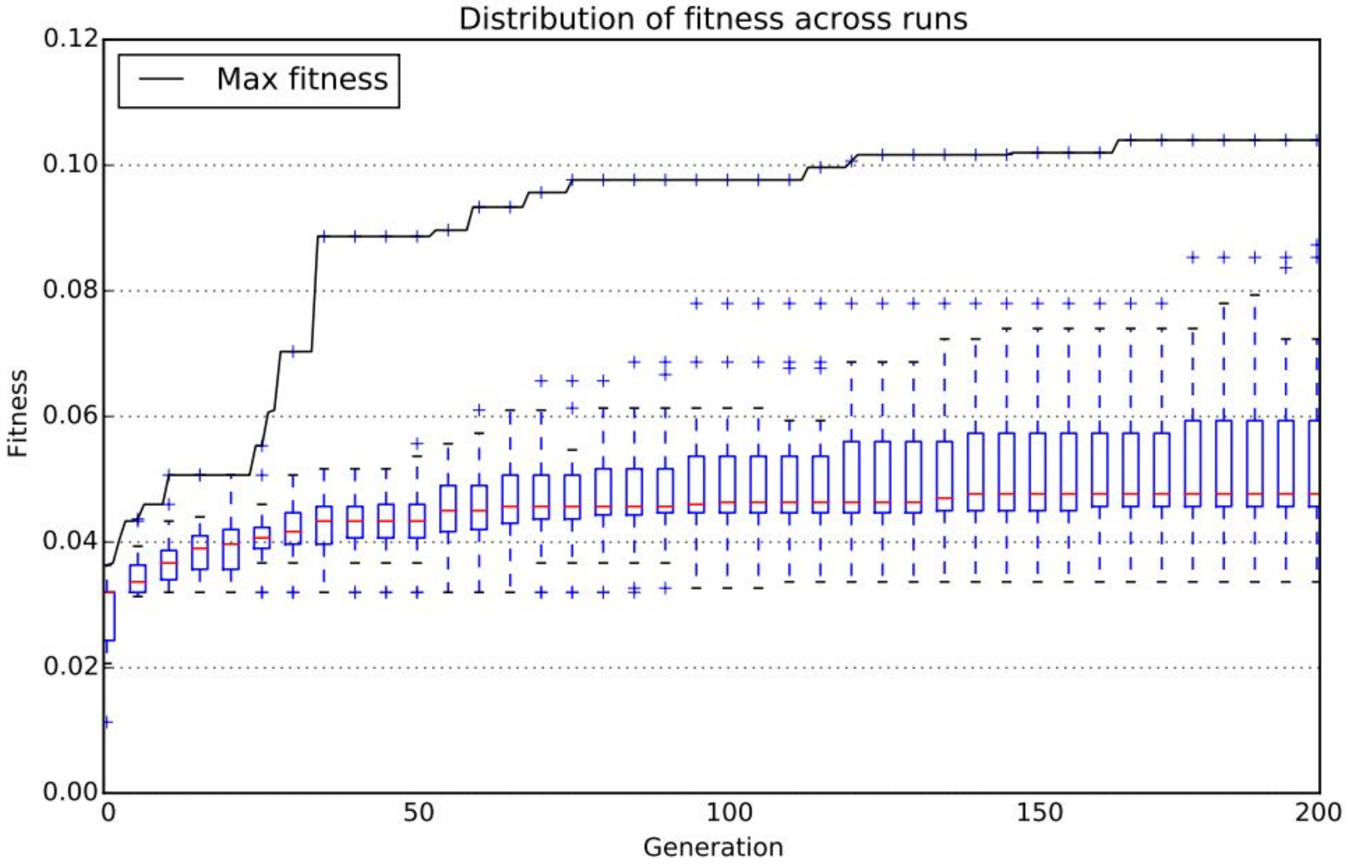


Image taken from [2]

Conclusions:

- Behavior trees are a human-readable and powerful agent-modeling solution
- Behavior trees can be evolved using genetic programming
- Evolved behaviors are viable and interesting

Questions?

Thanks to Kristin Lamberty and Nic Mcphee for making this talk possible.

Parameter	Value	Description
n_{gen}	200	Generations
t_{test}	300	Test length in seconds
n_{pop}	25	Population
n_{elite}	3	Elite
t_{size}	3	Tournament size
p_{xover}	0.8	Crossover probability
p_{mutu}	0.05	Probability of subtree replacement
p_{muts}	0.1	Probability of subtree shrink
p_{mutn}	0.5	Probability of node replacement
p_{mute}	0.5	Probability of ephemeral constant replacement

Table 3: Parameters for a single evolutionary run

Citations:

[1] M. Colledanchise and P. Ögren. Behavior trees in robotics and AI: an introduction. *CoRR*, abs/1709.00084, 2017.

[2] S. Jones, M. Studley, S. Hauert, and A. Winfield. Evolving behaviour trees for swarm robotics. In *Distributed Autonomous Robotic Systems*, Springer Tracts in Advanced Robotics, pages 487–501. Springer, 3 2018.

[3] Wikipedia. Behavior tree — Wikipedia, the free encyclopedia. http://en.wikipedia.org/w/index.php?title=Behavior%20treeoldid=922038836, 2019. [Online; accessed 15-November-2019].

[4] Wikipedia. Genetic programming — Wikipedia, the free encyclopedia. http://en.wikipedia.org/w/index.php?title=Genetic%20programmingoldid=921953038, 2019. [Online; accessed 15-November-2019].

[5] Wikipedia. Swarm robotics — Wikipedia, the free encyclopedia. http://en.wikipedia.org/w/index.php?title=Swarm%20robotics&oldid=921430950, 2019. [Online; accessed 03-November-2019].