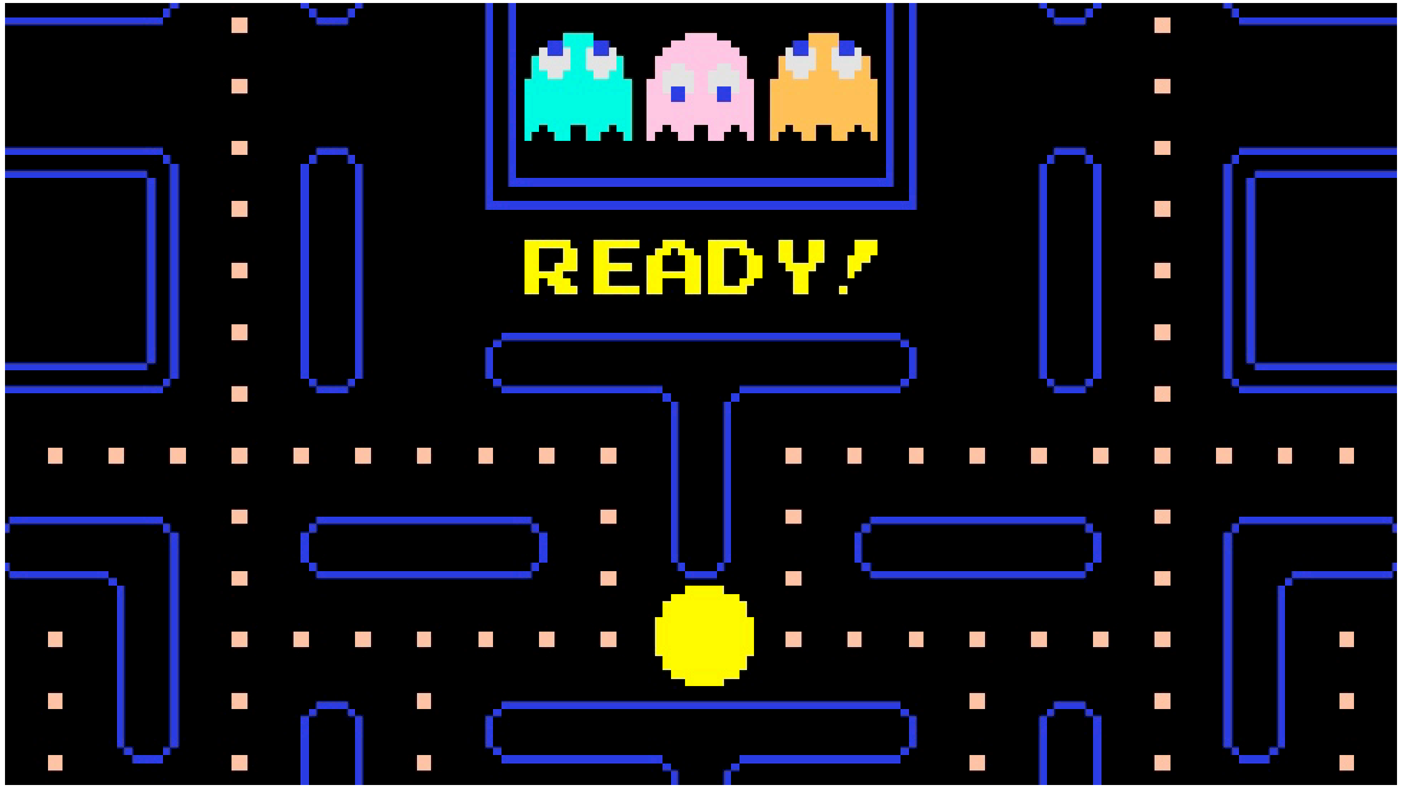
CPSC 427
Video Game Programming

Game Play and AI



Helge Rhodin

Overview

Today:

- ***Making decisions (short term)***
- ***State Machines***
- ***Behaviour Trees***
  - and their implementation

Next:

- ***Planning (long term)***

‘Modern’ AI?

Machine learning has the problem of 1. training, 2. testing

- ***Takes ages for large models***
- ***Can be real-time for small models (linear regression)***

Opportunity of large language models (LLMs)

- ***General purpose***
- ***Text is a very flexible interface***
  - *Understood by humans*
  - *Understood by machines*
  - *No need to specify the interface (what your game needs) in advance*

‘Modern’ AI?

- *Use ChatGPT?*
- https://github.com/topics/chatgpt-api?l=c%2B%2B

- ***Chat GPT provides a text-based interface***
  - *Summarise your game state as text (automatically)*
    - “User is at a distance of 10m, you have an arrow and a sword. Which one should you use? Answer with a single world.”
    - If(output == “sword”) …

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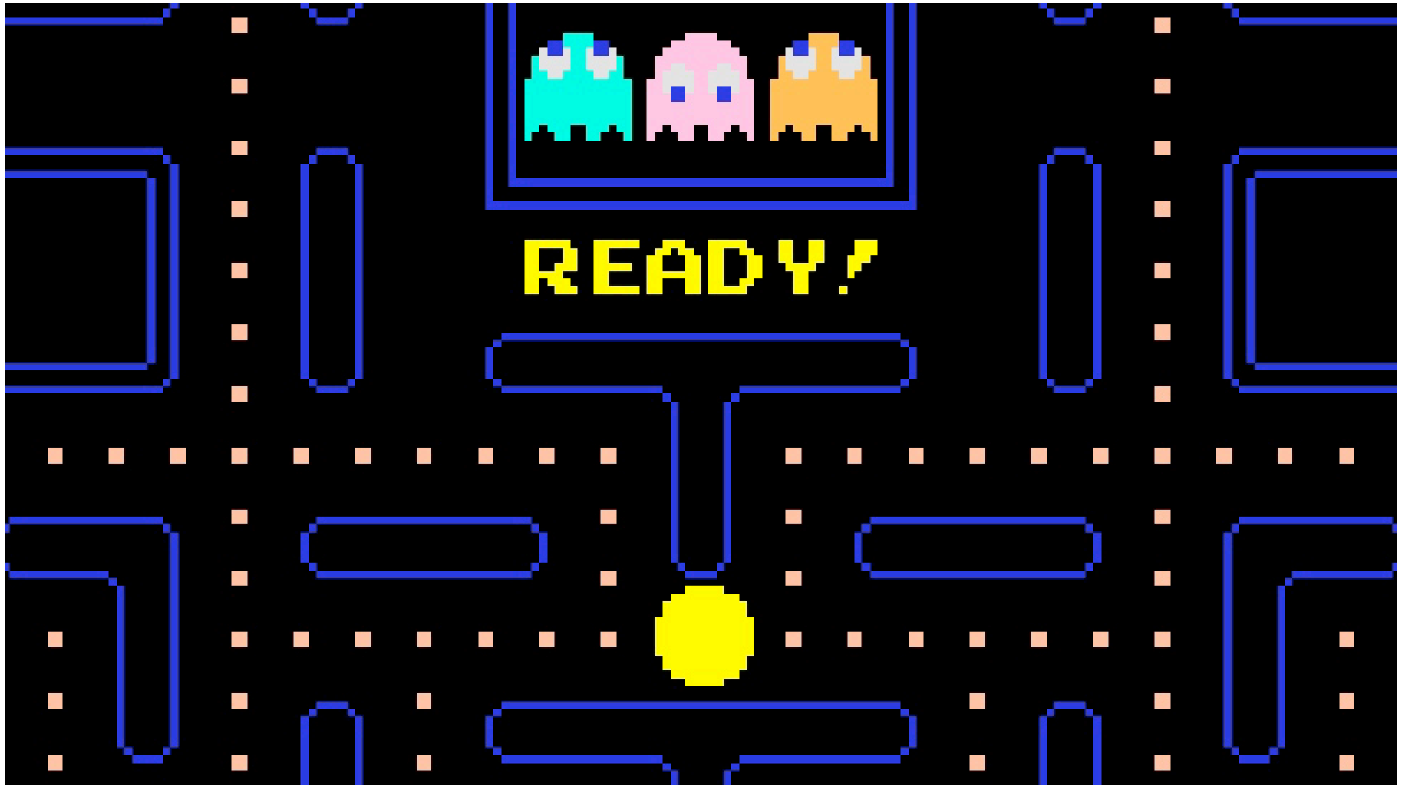
State machines



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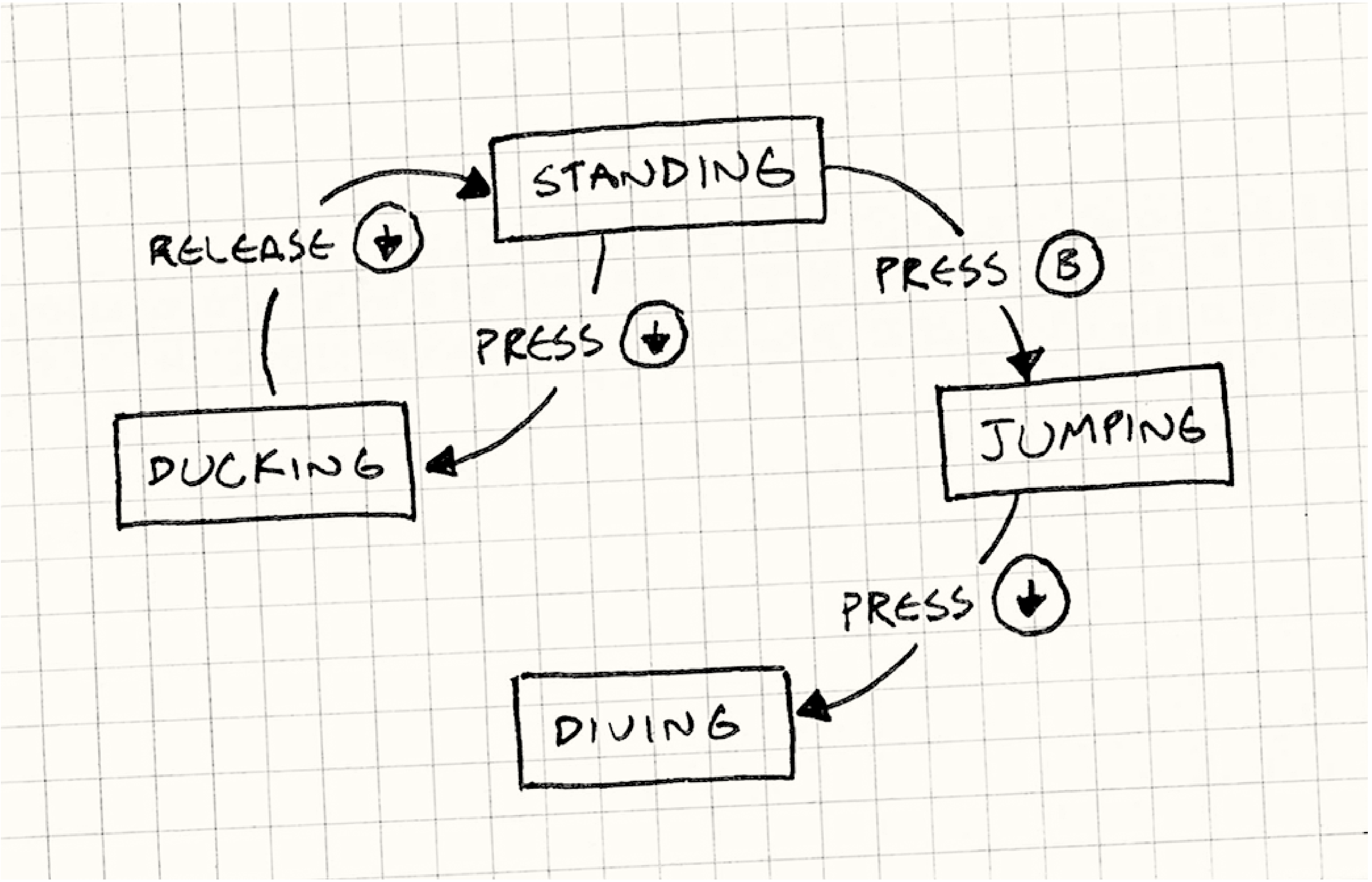
Gameplay

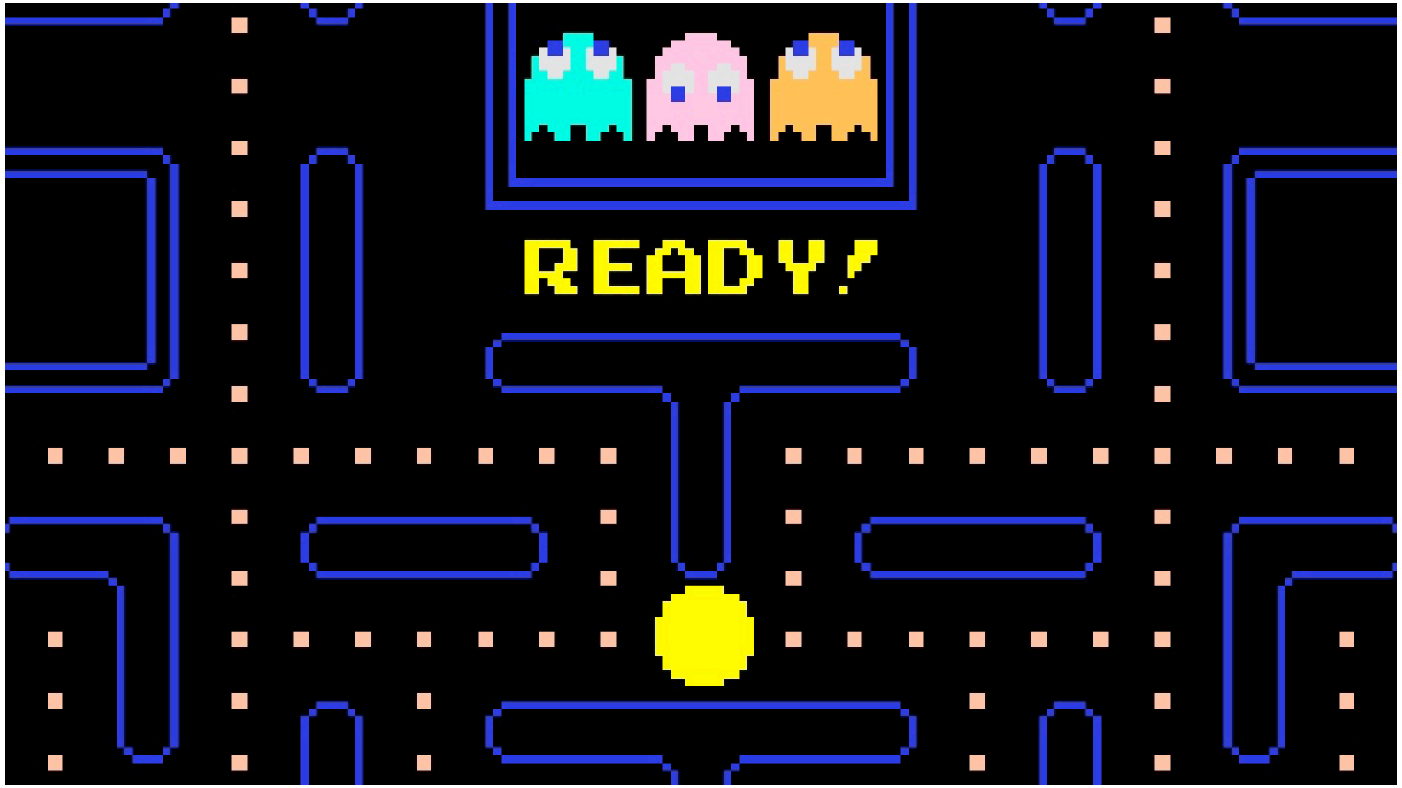
```
// start
if (!walking && wantToWalk)
{
    PlayAnim(StartAnim);
    walking = true;
}

// walk loop
if (IsPlaying(StartAnim) && IsAtEndOfAnim())
{
    PlayAnim(WalkLoopAnim);
}

// stop
if (walking && !wantToWalk)
{
    PlayAnim(StopAnim);
    walking = false;
}
```

From http://twvideo01.ubm-us.net/o1/vault/gdc2016/Presentations/Clavet_Simon_MotionMatching.pdf

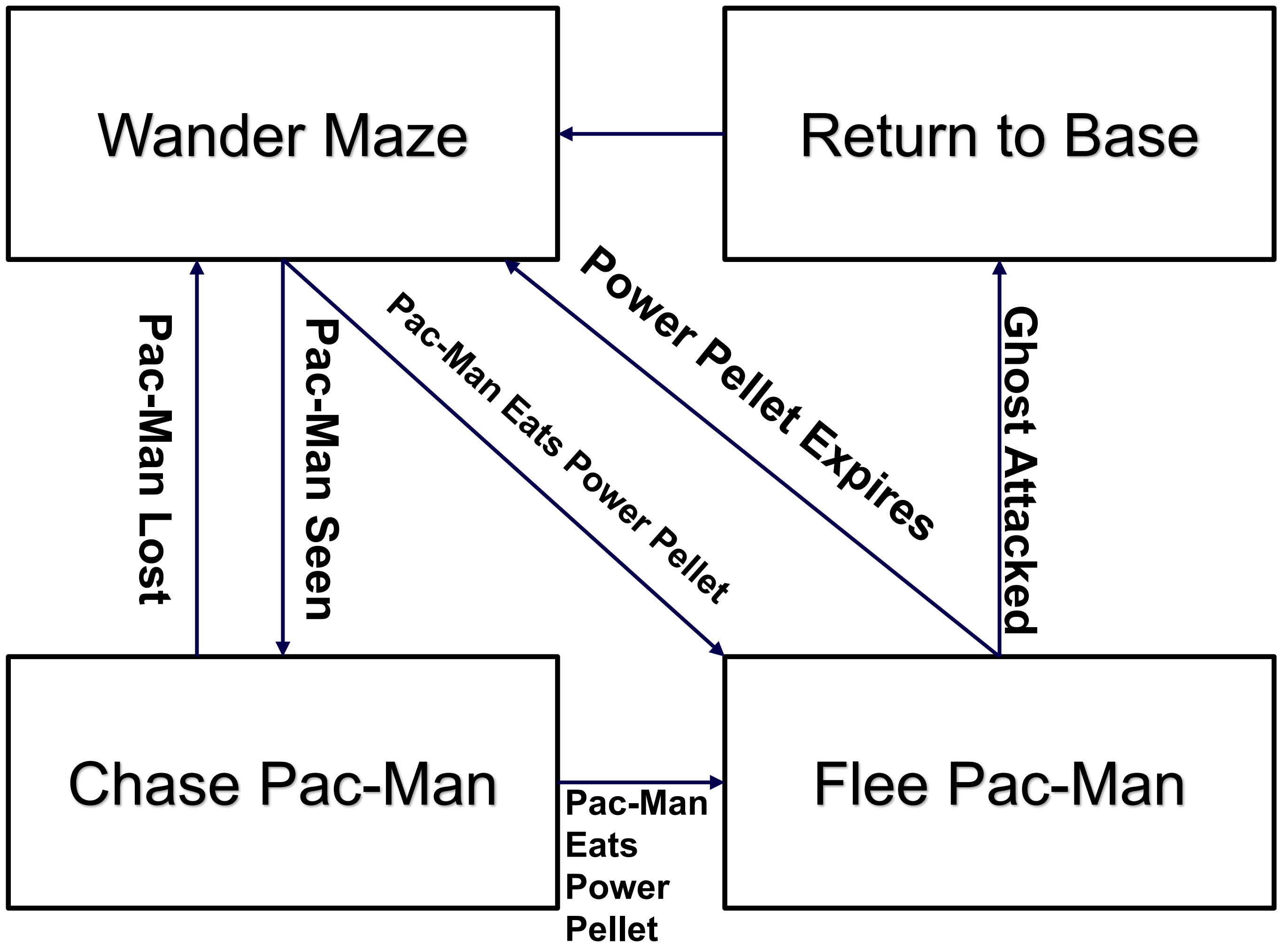
Finite State Machines: States + Transitions

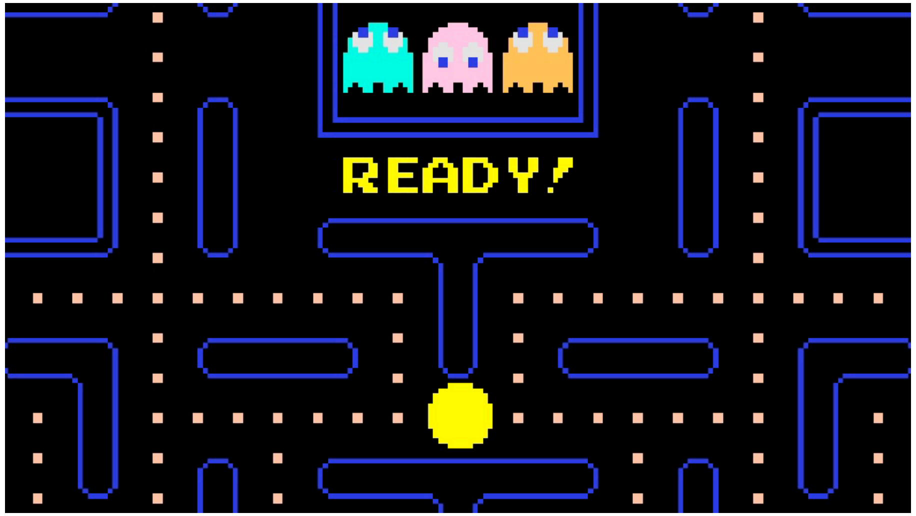


FSM Example: Pac-Man Ghosts



FSM Example: Pac-Man Ghosts





Ghost AI in PAC-MAN

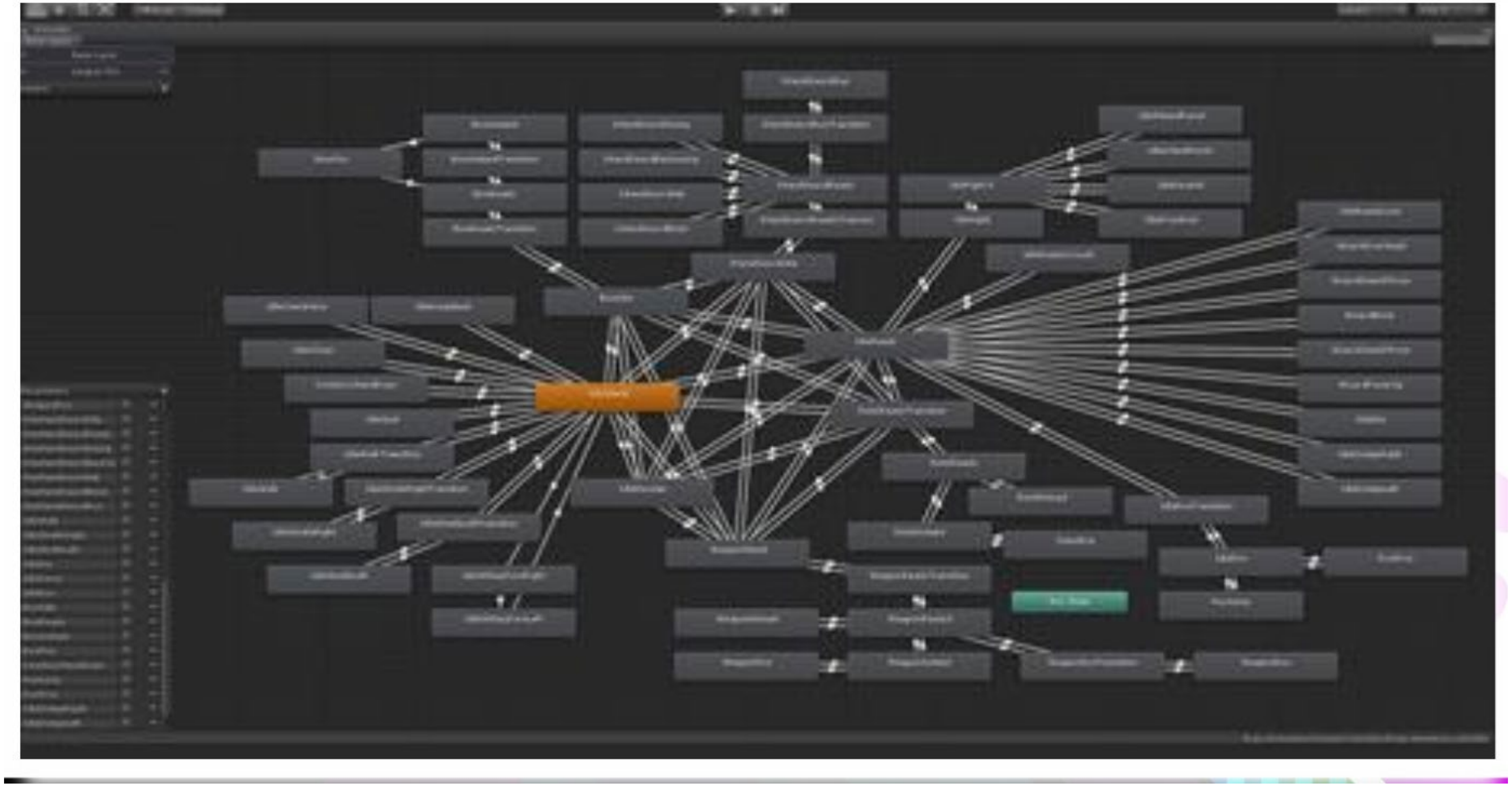
Is the AI for Pac-Man basic?

- chase or run.
- binary state machine?
- Toru Iwatani, designer of Pac-Man explained:
  "wanted each ghostly enemy to have a specific character and its own particular movements, so they weren't all just chasing after Pac-Man... which would have been tiresome and flat."
- the four ghosts have four different behaviors
  - different target points in relation to Pac-Man or the maze
  - attack phases increase with player progress
  - More details: http://tinyurl.com/238l7km

Finite State Machines (FSMs)

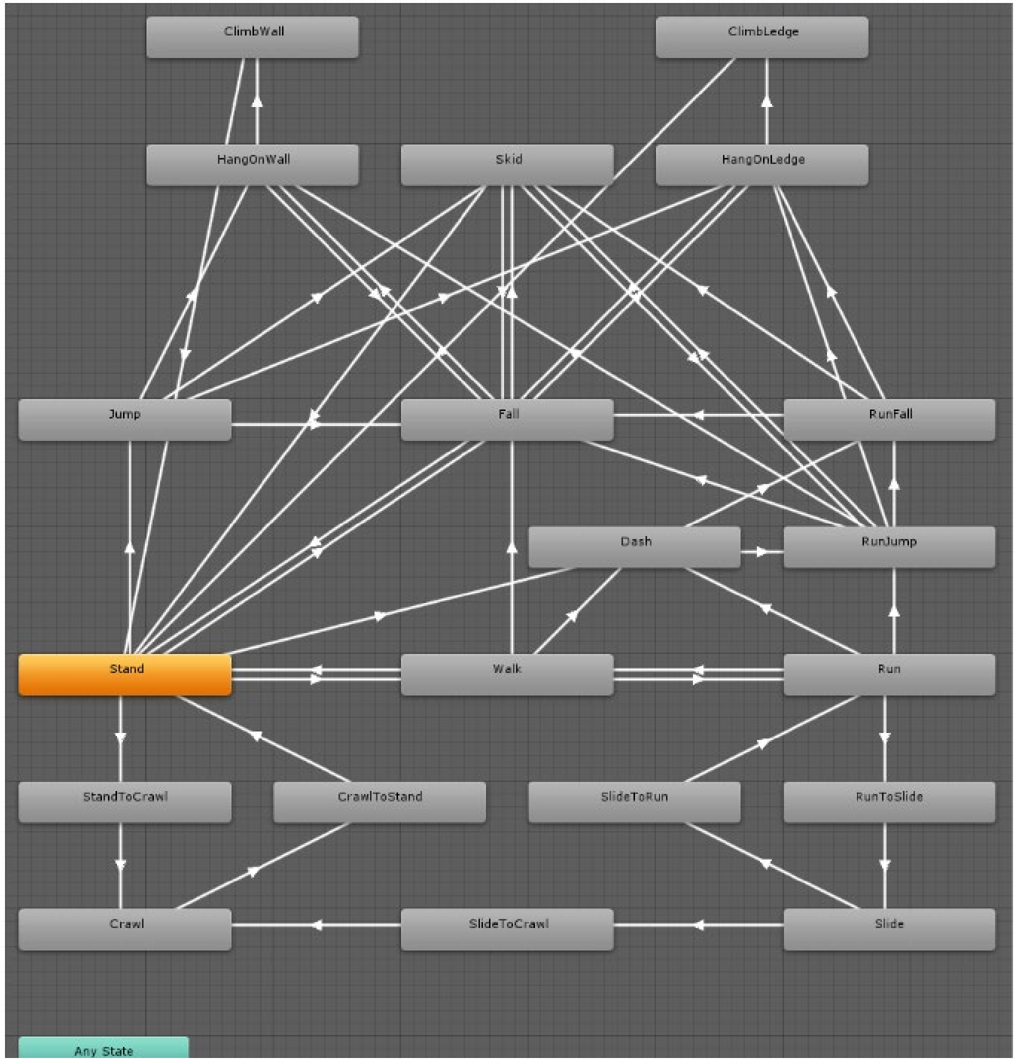
- ***Each frame:***
  - Something (the player, an enemy) does something in its state
  - It checks if it needs to transition to a new state
    - *If so, it does so for the next iteration*
    - *If not, it stays in the same state*
- ***Applications***
  - Managing input
  - Managing player state
  - Simple AI for entities / objects / monsters etc.

FSMs: States + Transitions



From http://twvideo01.ubm-us.net/o1/vault/gdc2016/Presentations/Clavet_Simon_MotionMatching.pdf

FSMs: Failure to Scale



No way to do long-term planning

No way to ask "How do I get here from there?"

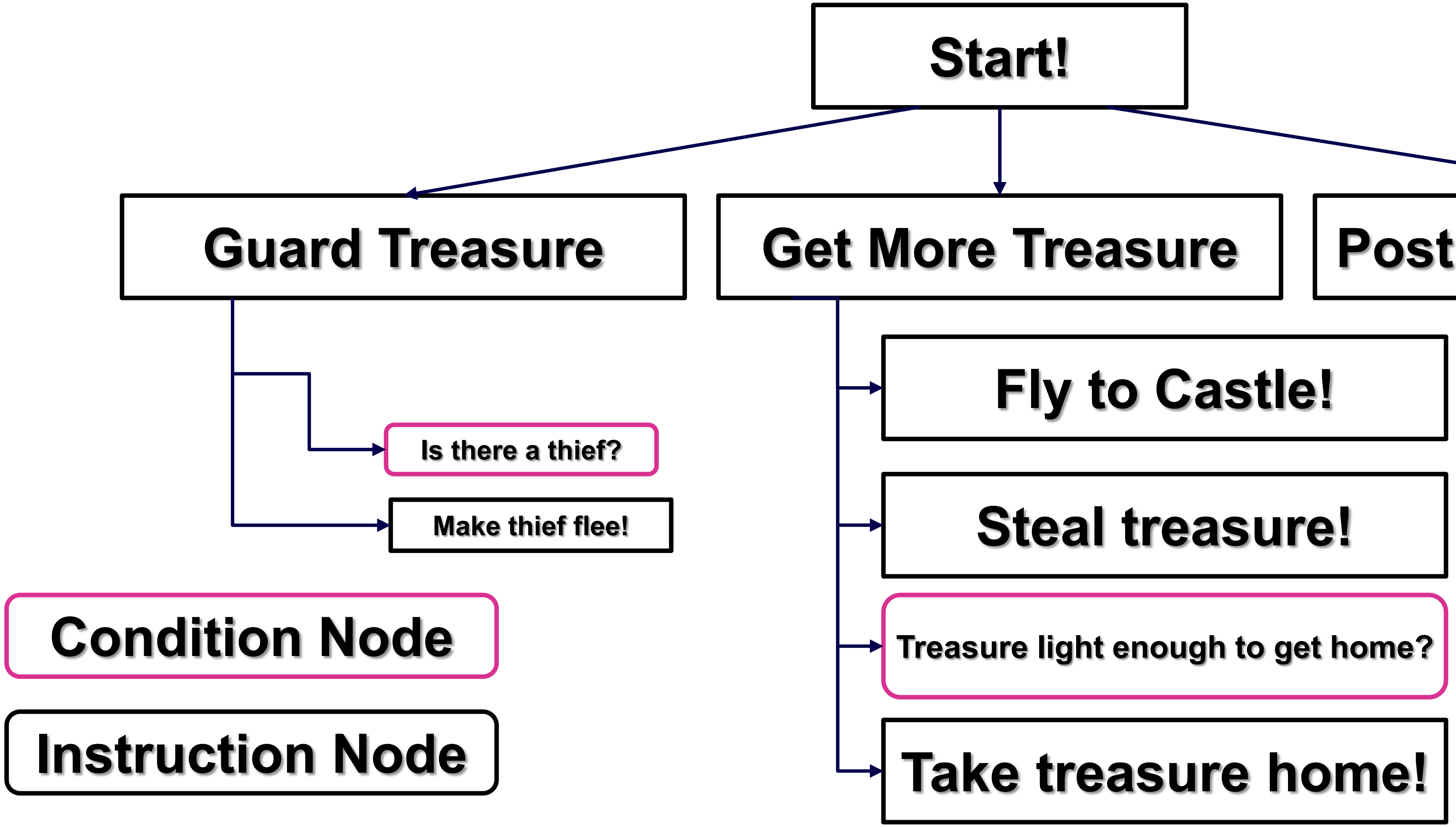
No way to reason about long-term goals

FSMs can get large and hard to follow

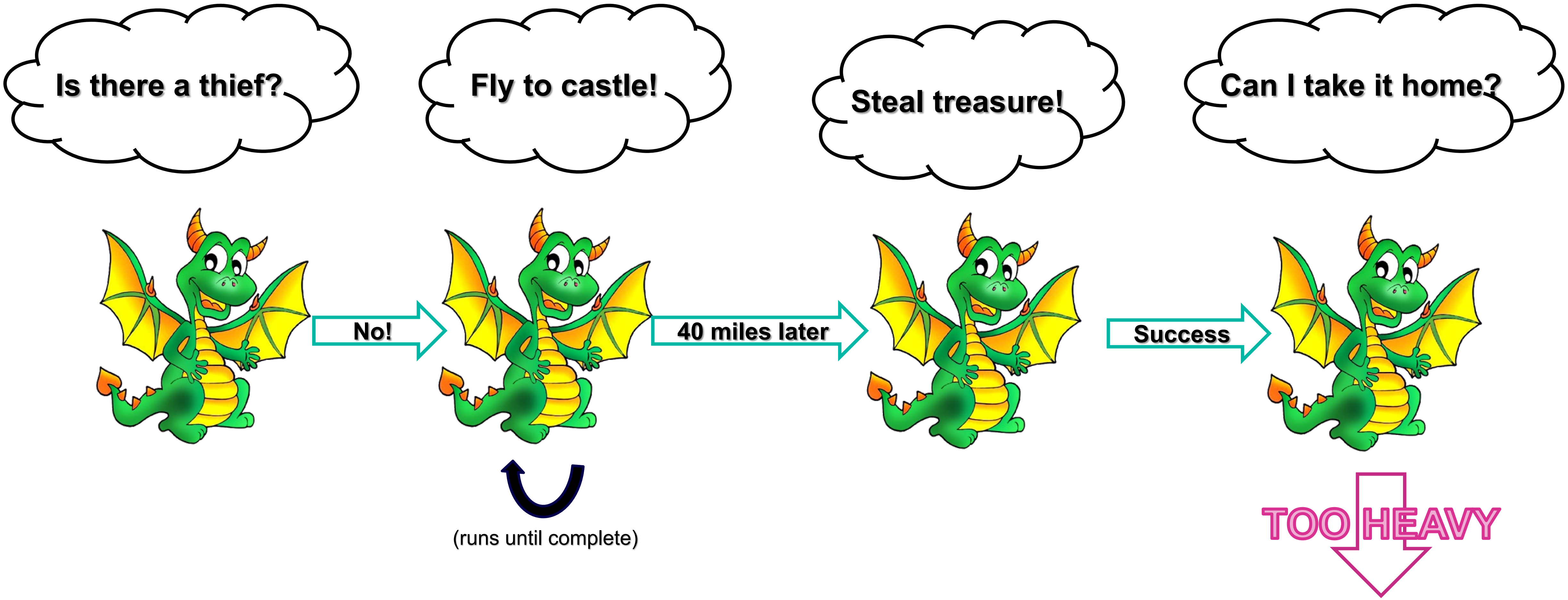
Can't generalize for larger games

From http://twvideo01.ubm-us.net/o1/vault/gdc2016/Presentations/Clavet_Simon_MotionMatching.pdf

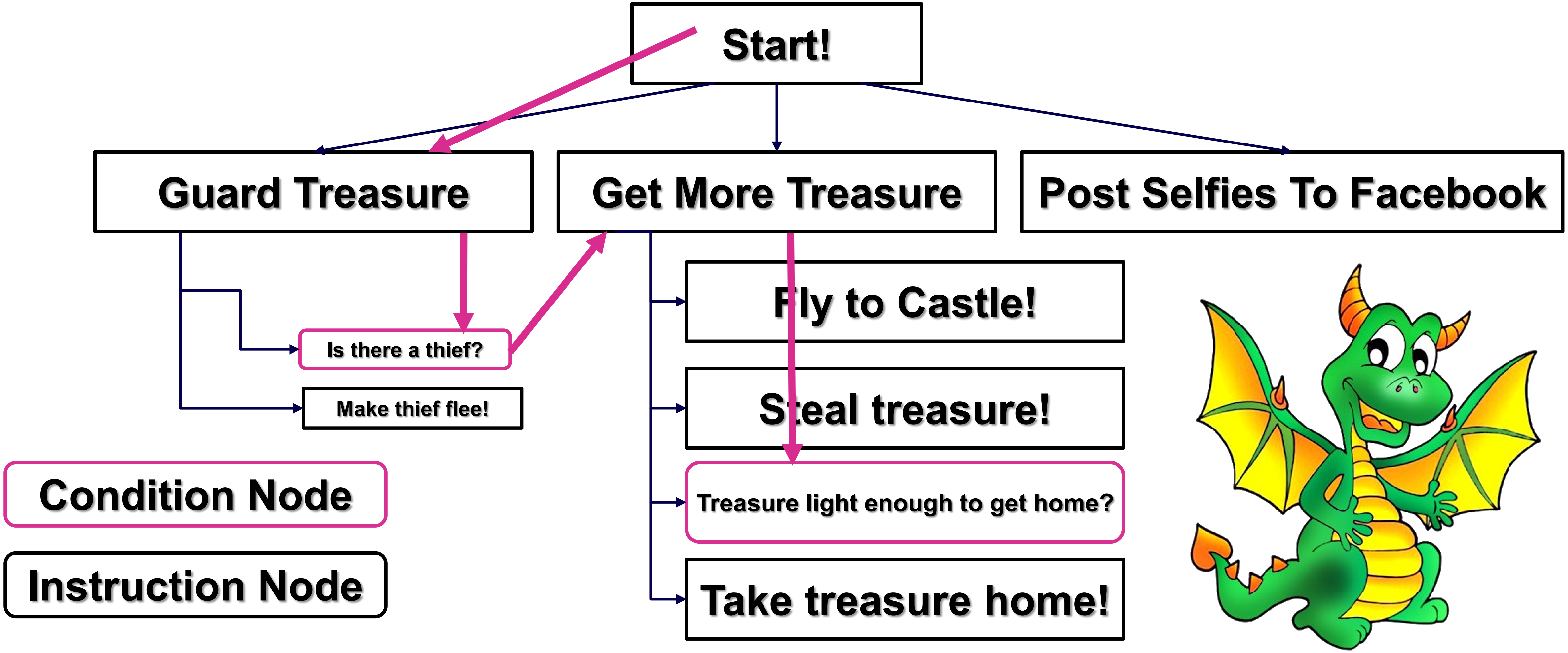
Behaviour Trees:
How To Simulate Your Dragon



Start!


Is there a thief?
Fly to castle!
Steal treasure!
Can I take it home?
No!
40 miles later
Success
(runs until complete)
TOO HEAVY

Behaviour Trees:
How To Simulate Your Dragon

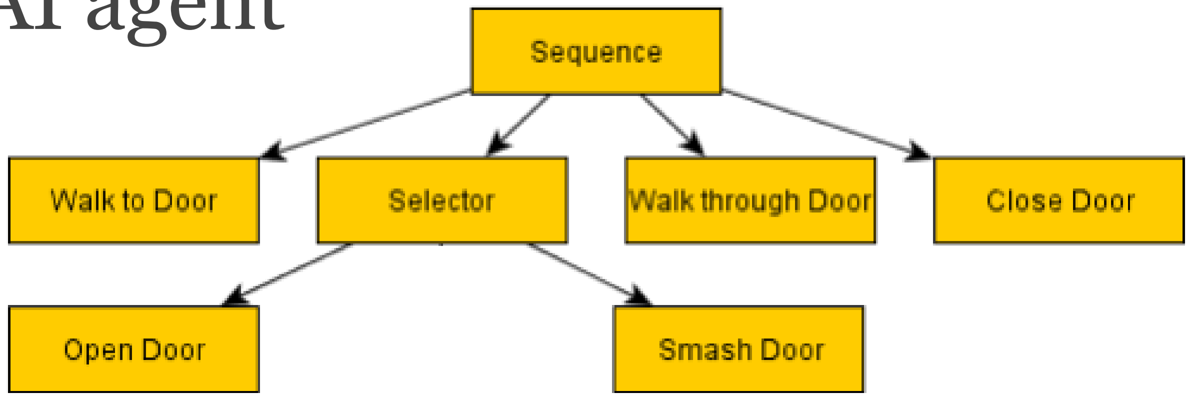


BTs are state machines

- ***With structure (tree)***
- ***With well-defined interfaces (fail-success-running)***

Behaviour Trees

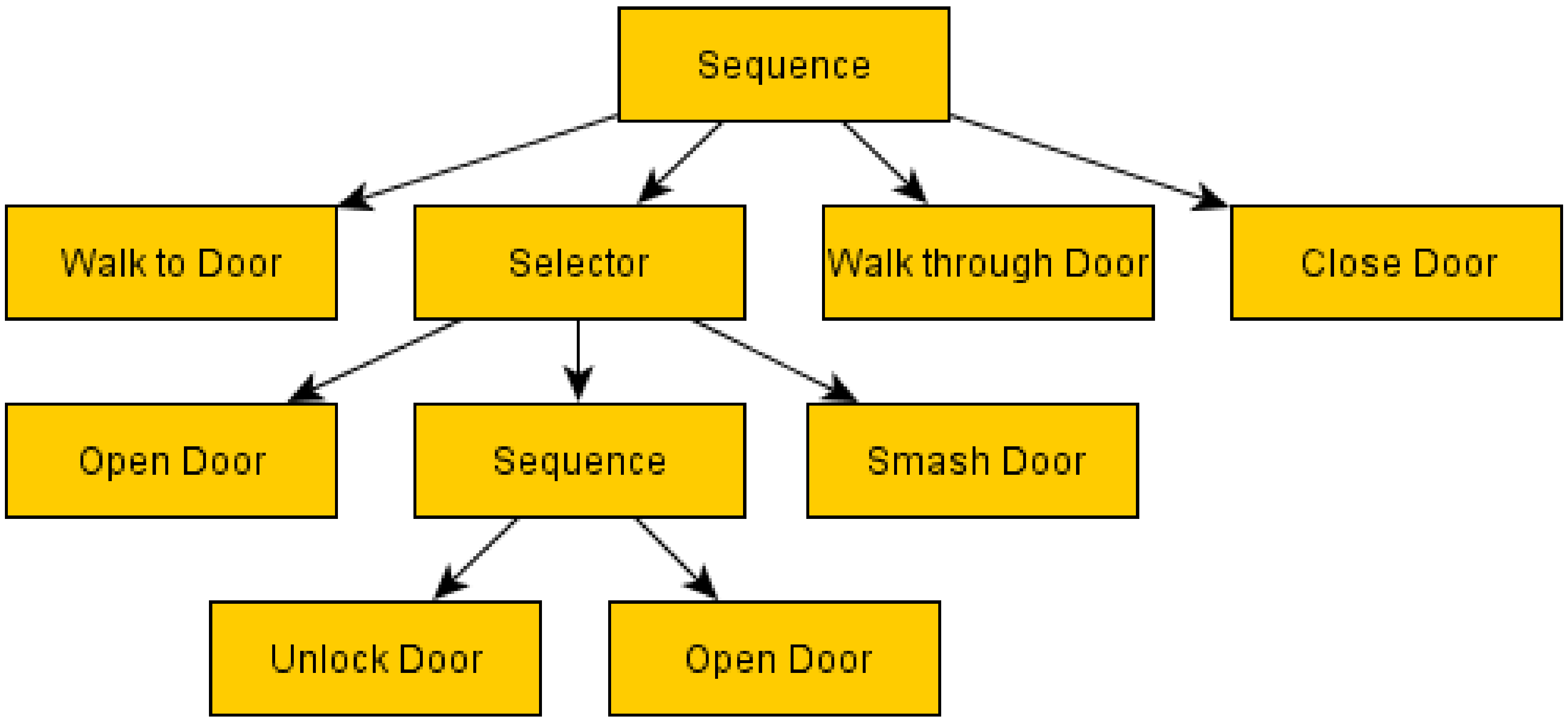
- flow of decision making of an AI agent
- tree structured
- ***Each frame:***
  - Visit nodes from root to leaves
    - *depth-first order*
    - *check currently running node*
      - succeeds or fails:
      - return to parent node and evaluate its Success/Failure
      - the parent may call new branches in sequence or return Success/Failure
      - continues running: recursively return Running till root (usually)



Behaviour Tree Elements

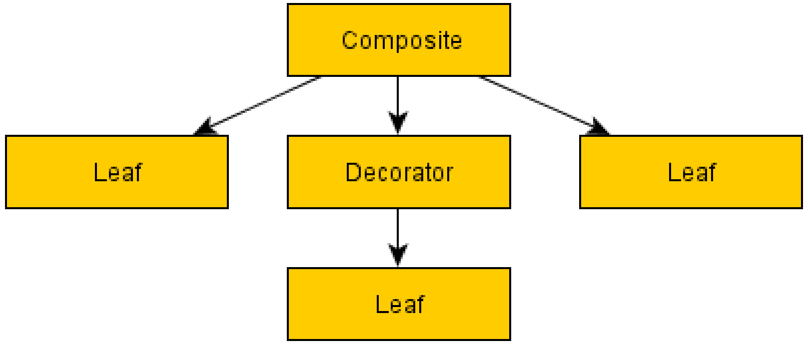
- leaves, are the actual commands that control the AI entity
  - **e.g., walk one step**
  - upon tick, return: Success, Failure, or Runnin
- branches are utility nodes that control the AI's walk down the tree
  - **e.g., door unlocked?**
  - loop through children: first to last or random
  - inverter: turn Failure -> Success
  - to reach the sequences of commands best suited to the situation
- trees can be extremely deep
  - nodes calling sub-trees of reusable functions
  - libraries of behaviours chained together

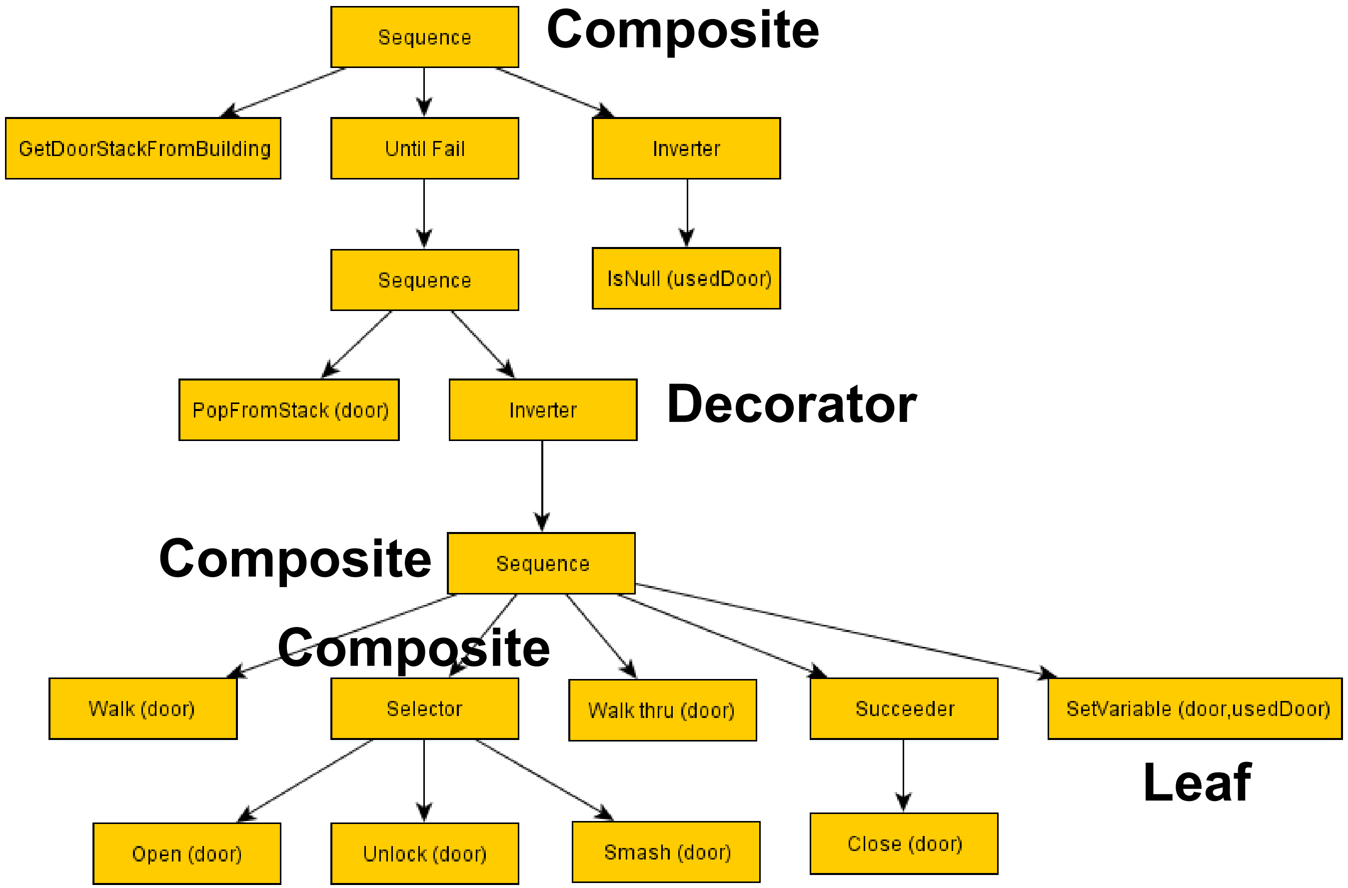
Schematic examples



https://www.gamasutra.com/blogs/ChrisSimpson/20140717/221339/Behavior_trees_for_AI_How_they_work.php

Types

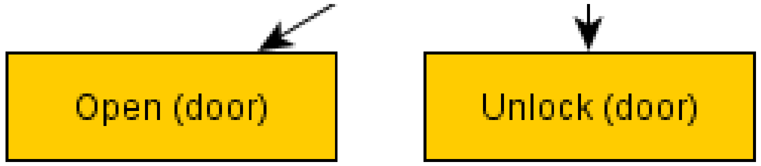

Composite
Leaf
Decorator
Leaf
Leaf


Sequence
Composite
GetDoorStackFromBuilding
Until Fail
Inverter
Sequence
IsNull (usedDoor)
PopFromStack (door)
Inverter
Decorator
Composite
Sequence
Composite
Walk (door)
Selector
Walk thru (door)
Succeeder
SetVariable (door,usedDoor)
Leaf
Open (door)
Unlock (door)
Smash (door)
Close (door)

Behaviour Tree Elements

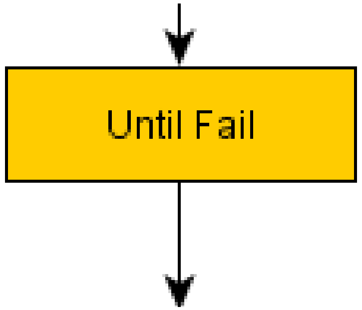
Leaf node

- A custom function, does the actual work
- Returns Running/Success/Failure



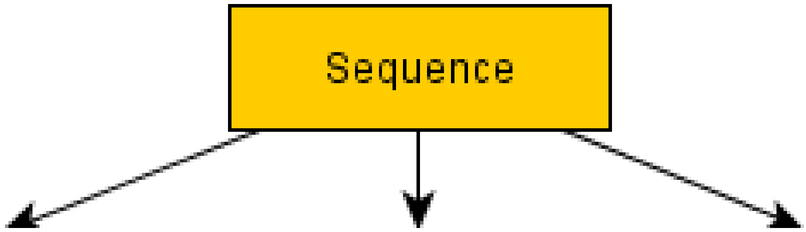
Decorator node

- has a single child
- Passes on Running/Success/Failure from child
  - may invert Success/Failure



Composite node

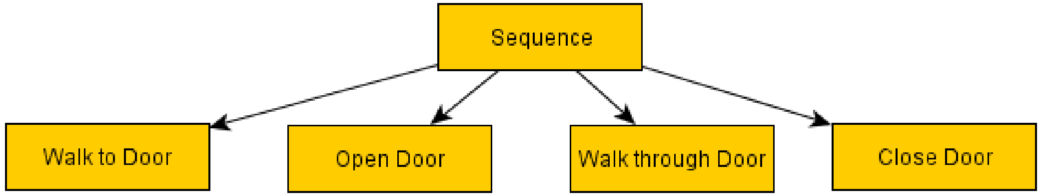
- has one or more children
- returns 'Running' until children stopped running



Useful Composites

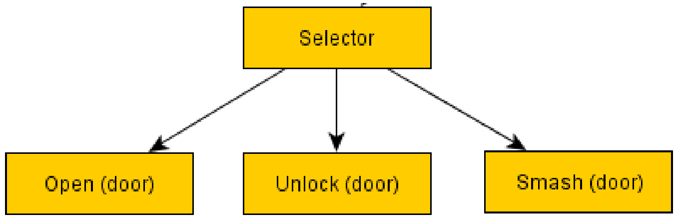
Sequence

- *execute all children in order*
- *Success if all children succeed (= AND)*



Selector

- *execute all children in order*
- *return Success if any child succeeded (= OR)*



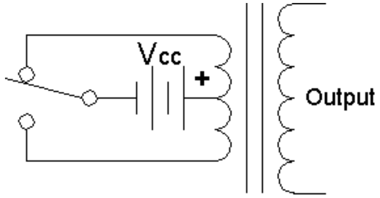
Random Selectors / Sequences

- Randomized order of above composites

Useful Decorators

Inverter

- *Negates success/failure*



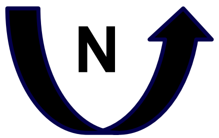
Succeeder

- always returns success

return "Success";

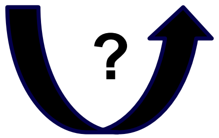
Repeater

- Repeat child N times



Repeat Until Fail

- Repeat until child fails



Leaf Nodes

Functionality

- ***init(…)***
  - *Called by parent to initialize*
  - *Sets state to Running*
  - *Not called gain before returning Success/Failure*
- ***process()***
  - *Called every frame/tick the node is running*
  - *Does internal processing, interacts with the world*
  - *Returns Running/Success/Failure*

Example: *Walk to goal location*

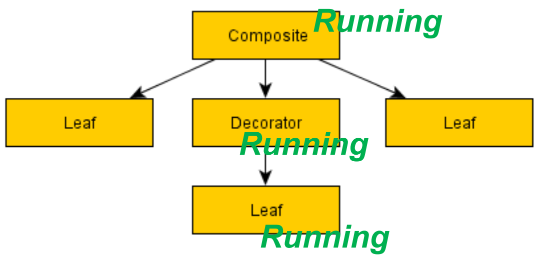
- *Sets goal position for path finding*

- Computes shortest path
- Sets character velocity
- Returns
  - success: Reached destination
  - failure: No path found
  - running: En route

Early exit?

- ***All parents of the currently running leaf node are running too***
- ***A node early in the tree can return Success/Failure***
  - Terminates children implicitly
- **Trying again?**
  - Re-initialize children with new parameters to init(…)

Example



- ***upon alarm***
- abort sleeping
- init running node
- ***try to sleep if alarm is off***
- init sleeping node

How to implement a tree in C++?

Implementation example

Basics:

```
// The return type of behaviour tree processing
enum class BTState {
    Running,
    Success,
    Failure
};


// The base class representing any node in our behaviour tree
class BTNode {
public:
    virtual void init(Entity e) {};

    virtual BTState process(Entity e) = 0;
};
```

An if condition (inflexible)

```
// A general decorator with lambda condition
class BTIfCondition : public BTNode
{
public:
    BTIfCondition(BTNode* child)
        : m_child(child) {
    }

    virtual void init(Entity e) override {
        m_child->init(e);
    }

    virtual BTState process(Entity e) override {
        if (registry.motions.has(e)) // hardocded
            return m_child->process(e);
        else
            return BTState::Success;
    }
private:
    BTNode* m_child;
};
```

Implementation example II

A leaf node

```
class TurnAround : public BTNode {
private:
    void init(Entity e) override {
    }

    BTState process(Entity e) override {
        // modify world
        auto& vel = registry.motions.get(e).velocity;
        vel = -vel;

        // return progress
        return BTState::Success;
    }
};
```

Behaviour Trees are Modular!

- Can re-use behaviours for different purposes
- Can implement a behaviour as a smaller FSM
- Can be data-driven (loaded from a file, not hard coded)
  - *JSON?!*
- Can easily be constructed by non-programmers
- Can be used for *goal based programming*

Modular design?

Modular design?

Tree construction

```
// Tree construction
// leaf nodes
RunNSteps run3(3);
TurnAround turn;

// conditional turn sub-tree
BTIfCondition turn_right = BTIfCondition(&turn,
                                          [](Entity e) {return registry.motions.get(e).velocity < 0; });
BTRunPair root = BTRunPair(&turn_right, &run3);
```

Game loop

```
Entity human;
root.init(human);
for (int i = 0; i < 100; i++)
    BTState state = root.process(human);
```

Decorators - Conditions

```
class BTIfCondition : public BTNode
{
  std::shared_ptr<BTNode> m_child;
  std::function<bool(ECS::Entity)> m_condition;
public:
  BTIfCondition(std::shared_ptr<BTNode> child, std::function<bool(ECS::Entity)> condition)
    : m_child(std::move(child)), m_condition(condition){}

  virtual void init(ECS::Entity e) override {
    m_child->init(e);}

  virtual BTState process(ECS::Entity e) override {
    if (m_condition(e))
      return m_child->process(e);
    else
      return BTState::Success;
  }
};
```

Instantiation

```
BTNode standing = BTIfCondition(child_ptr, [](ECS::Entity e) {return ECS::registry<Motion>.get(e).velocity == 0;})
```

AND Sequences

```
class BTSequence : public BTnode
{
    std::map<ECS::Entity, int> n;
    std::vector< std::shared_ptr<BTnode>> children;
public:
    BTSequence(std::vector< std::shared_ptr<BTnode>> children)
    {
        this->children = children;
    }

    virtual void init(ECS::Entity e)
    {
        n[e] = 0;
        this->children[n[e]]->init(e);
    }

    virtual BTstate process(ECS::Entity e)
    {
        BTstate state = this->children[n[e]]->process(e);
        if (state == BTstate::Failure)
            return BTstate::Failure;
        else if (state == BTstate::Running)
            return BTstate::Running;
        else // (state == BTstate::Success)
        {
            n[e]++;
            if (n[e] >= this->children.size())
                return BTstate::Success;
            else
            {
                this->children[n[e]]->init(e);
                return BTstate::Running;
            }
        }
    }
};
```

- Iterate through children until end or until child returns Failure
- Similar to ‘and’ in ‘if(child[0] && child[1] && …)’
  - Expressions following the first ‘false’ will be ignored

- Further useful composites:
  - Repeat N times
  - Repeat indefinitely
  - Negate **Success**/**Failure**
  - OR Sequence
  - If … else
  - Exit condition

  - What else???

Leaf Nodes – Generic Version

How can we apply the same BT on different entities?

- How to store internal states?
  - *store the state for every entity*
  - *use an std::map*

Minor addition to ECS::Entity

```
// Comparator to use as key in std::map
bool operator <(const Entity& rhs) const
{
    return id < rhs.id;
}
```

```
class RunThreeMeters : public BTNode
{
  std::map<ECS::Entity, int> n;
  void init(ECS::Entity e) {
    n[e] = 3;
  }

  BTState process(ECS::Entity e) {
    // update internal state
    n[e]--;

    // modify world
    ECS::registry<Motion>.get(e).position
    += ECS::registry<Motion>.get(e).velocity;

    // return progress
    if (n[e] > 0)
      return BTState::Running;
    else
      return BTState::Success;
    }
};
```

ECS solves every problem?

Entity
Component
System

When not to use ECS?

- *When information is not shared across Systems*
- ***AND*** *ECS does not fit naturally*
  - multiple components of the same type associated to the same entity
    - *previous slide: multiple class instances store the same information type in a different context*
  - Entities and Components are still be useful locally
    - *Storing Components in ECS instead of locally is equally performant. Use ECS whenever possible!*
    - *The unique Entity ID can still be useful to associate local information to a global entity!*

```
std::map<ECS::Entity, int> n;
void init(ECS::Entity e) {
    n[e] = 3;
}
```