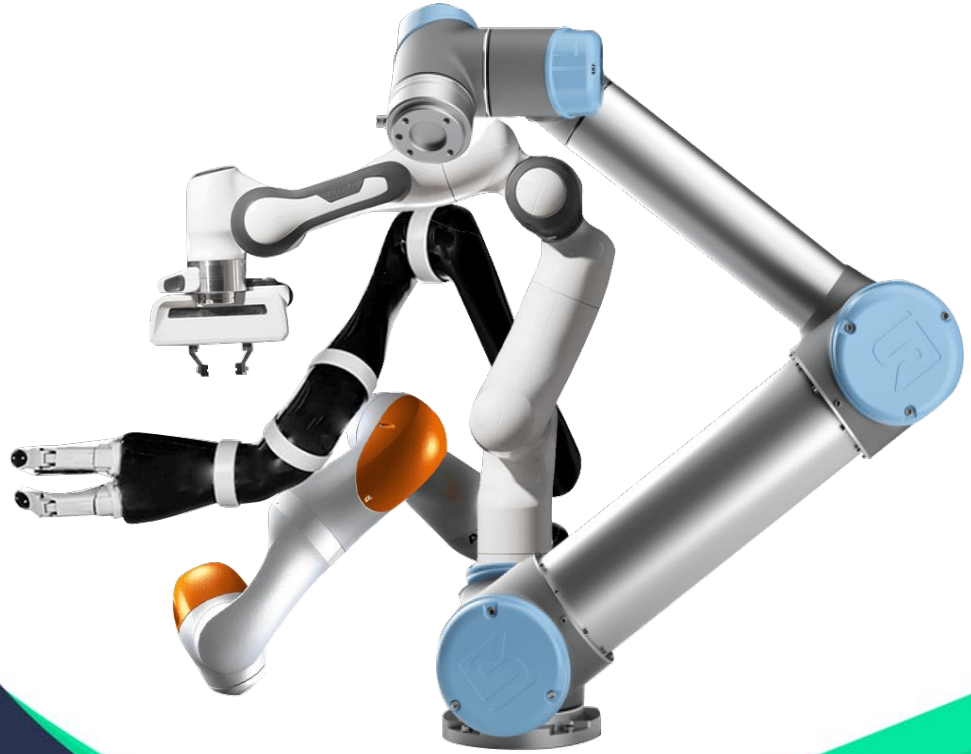
PICKNIK ROBOTICS



BehaviorTree.CPP 4.0

New features and how they make your life easier

October 21st, 2022

Davide Faconti
Staff Engineer
davide.faconti@picknik.ai

About me

PICKNIK ROBOTICS

Davide Faconti, nice to meet you

Working at Picknik (but not on Behavior Trees)

Almost 20 years in robotics doing:

- Humanoid robots design
- Bipedal Dynamic Walking
- Low hardware drivers
- Navigation and Localization
- Perception
- Manipulation
- Task planning
- Tooling and monitoring
- System architectures
- Project Management
- Product development
- But....

About me

Davide Faconti,

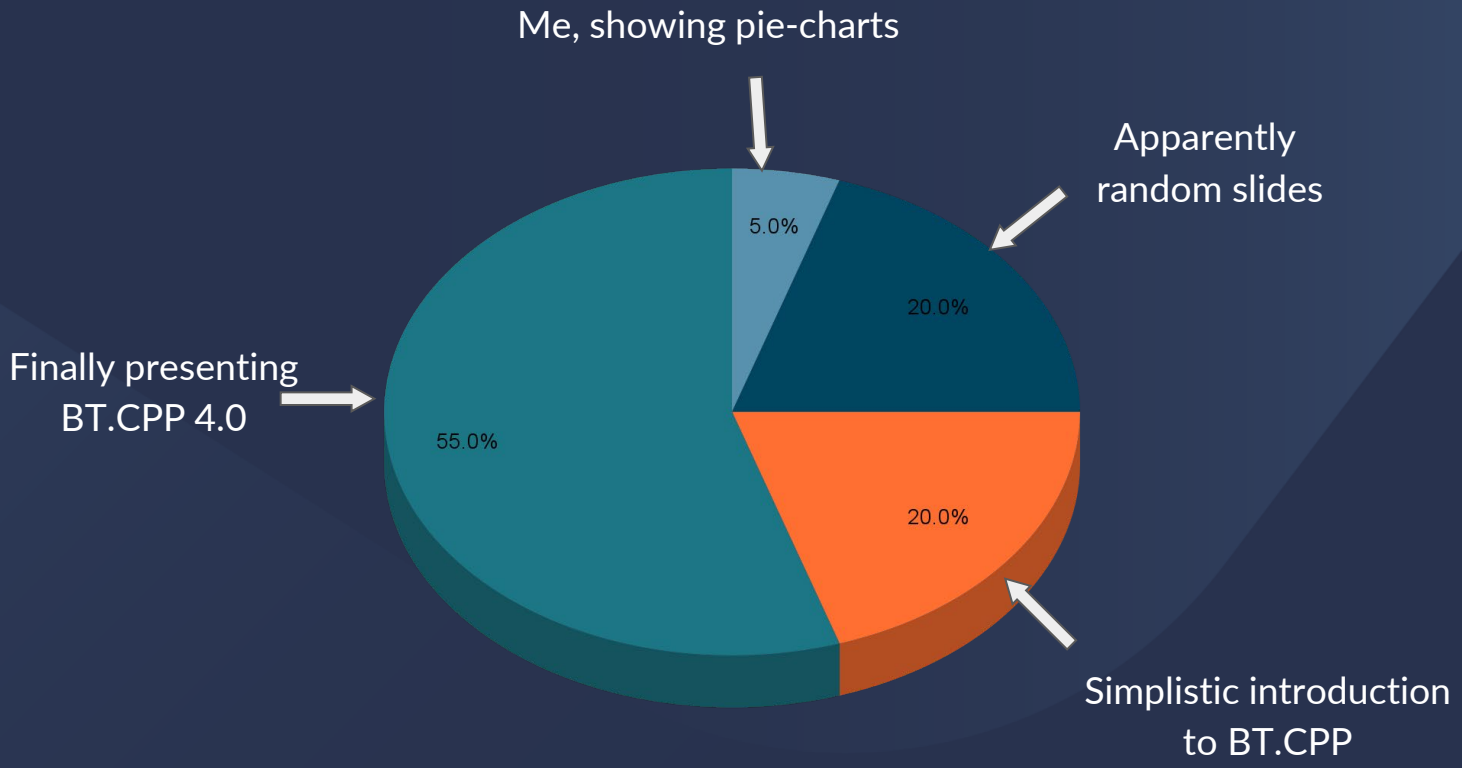
Working at Pick

Almost 20 yea

- Humanoi
- Bipedal D
- Low hard
- Navigatic
- Perception
- Manipulation

- nitoring
- ctures
- ement
- Product development
- But....

What to expect in the next 20 minutes



I am not going to explain what Behavior Trees are

What makes software “good” and why do we want that?

Good software is always about “getting things done”, but considering the human first

01 Writing software that a computer can interpret and run makes the software “correct”, but not “good”.

02 The bottleneck to scale up a software system is usually the ability of the human mind to manage complexity.

03 This is the reason why a good software is one that decreases the perceived complexity.

How do you react to the concerns of your user?

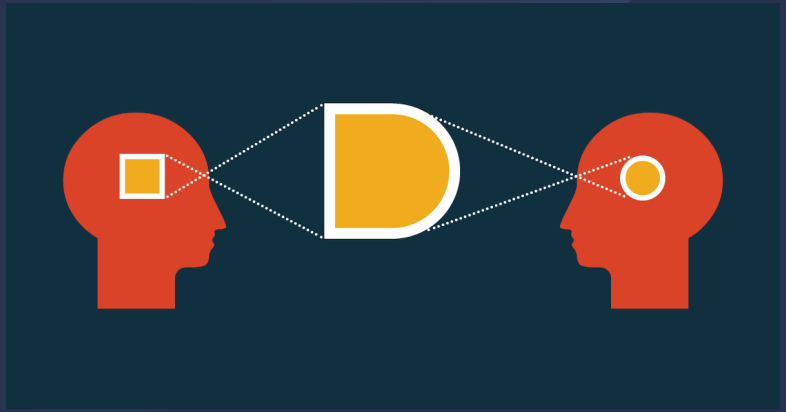
PICKNIK ROBOTICS

Option 1:

"You are..."

Option 2:

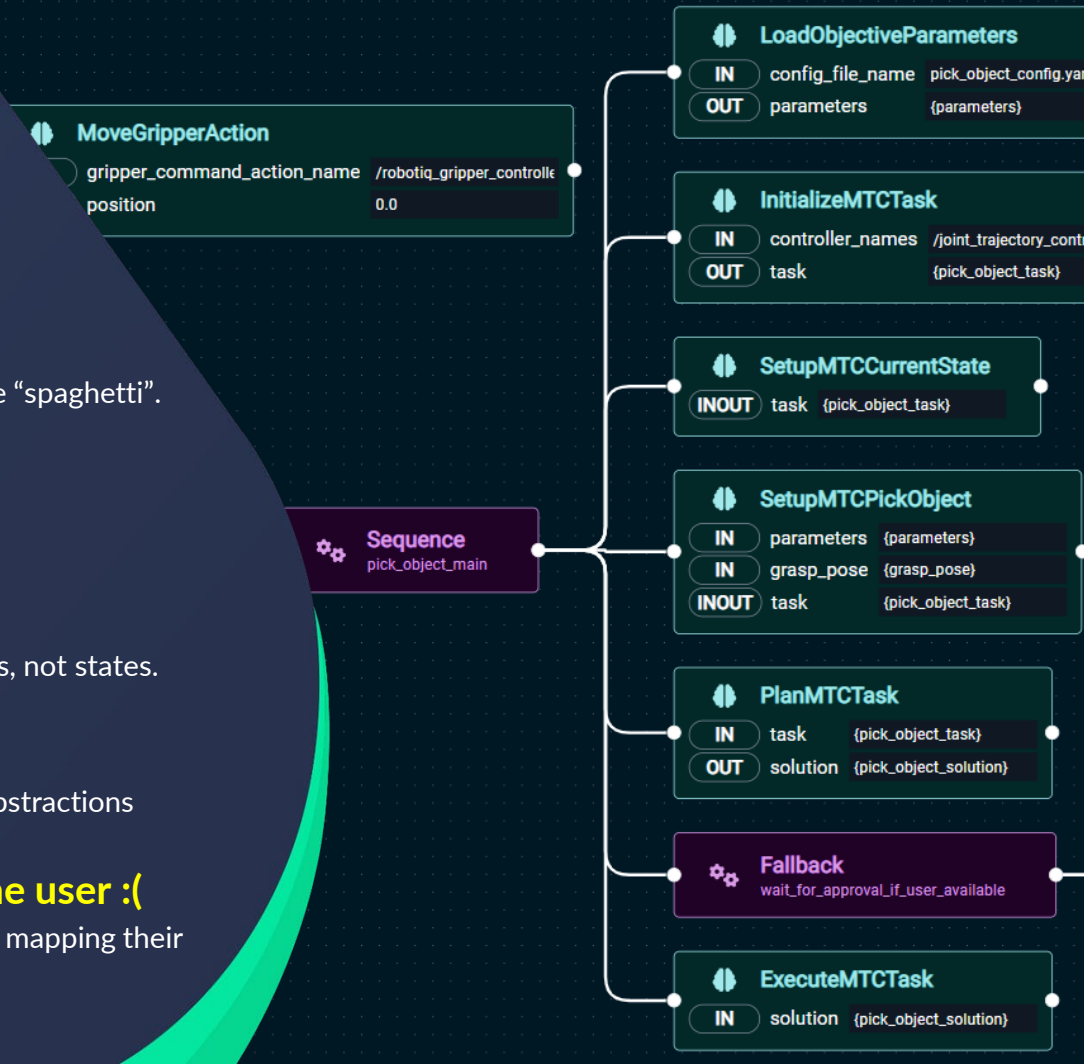
Or we can use **empathy** to understand your user's point of view



Advantages of Behavior Trees

Advantages of Behavior Trees:

- **Easier to “read”**
  Graphical representation of FSMs rapidly become “spaghetti”.
- **Intrinsically hierarchical**
  Similar to Hierarchical State Machines.
- **Focus on actions, not states**
  We usually model our problem in terms of actions, not states.
- **Extensibility of the “language”**
  Decorators and Control logic provide powerful abstractions
- **But… they are not as intuitive for the user :(**
  People are very familiar with state machines, and mapping their ideas into behavior tree could be challenging



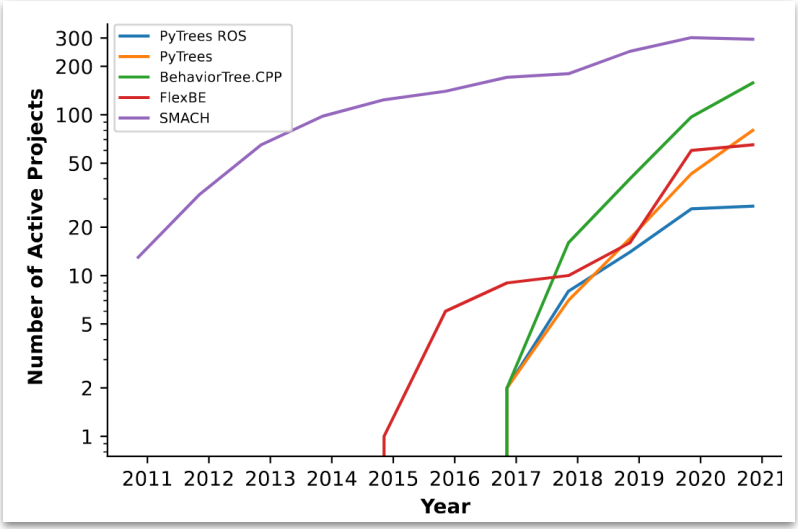
BehaviorTree.CPP

- **Nodes are defined in C++, Trees in XML**
  The best of compiled and interpreted languages together

```
<root main_tree_to_execute = "MainTree">

    <BehaviorTree ID="DoorClosed">
        <Sequence name="door_closed_sequence">
            <Inverter>
                <IsDoorOpen/>
            </Inverter>
            <RetryUntilSuccessful num_attempts="4">
                <OpenDoor/>
            </RetryUntilSuccessful>
            <PassThroughDoor/>
        </Sequence>
    </BehaviorTree>

    <BehaviorTree ID="MainTree">
        <Fallback name="root_Fallback">
            <Sequence name="door_open_sequence">
                <IsDoorOpen/>
                <PassThroughDoor/>
            </Sequence>
            <SubTree ID="DoorClosed"/>
            <PassThroughWindow/>
        </Fallback>
    </BehaviorTree>

</root>
```

BehaviorTree.CPP

- **Nodes are defined in C++, Trees in XML**
  The best of compiled and interpreted languages together
- **Increasing popularity in the ROS community**
  Driven probably by the early adoption of Nav2



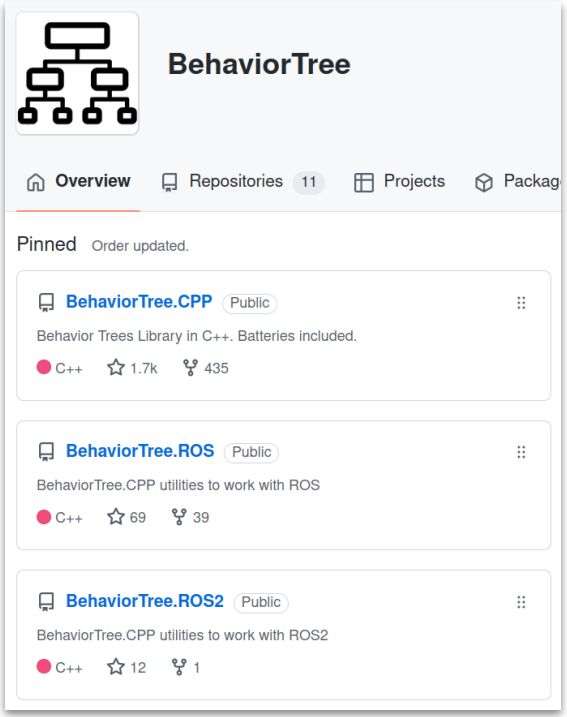
"Behavior Trees and State Machines in Robotics Applications"

Razan Ghzouli, Swaib Dragule, Thorsten Berger, Einar Broch Johnsen, Andrzej Wasowski

arXiv:2208.04211

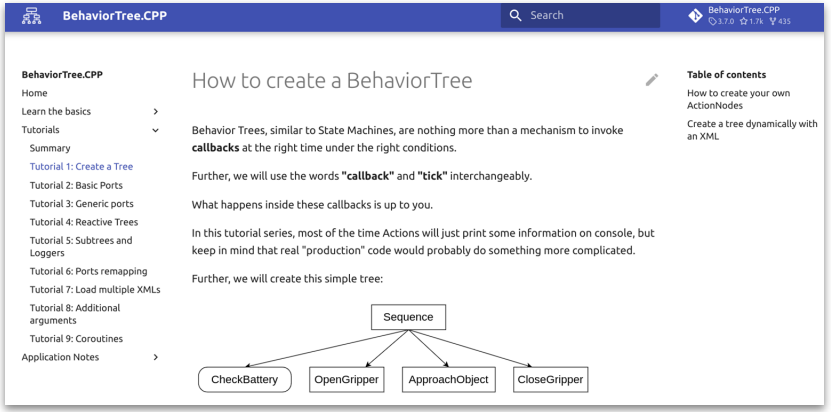
BehaviorTree.CPP

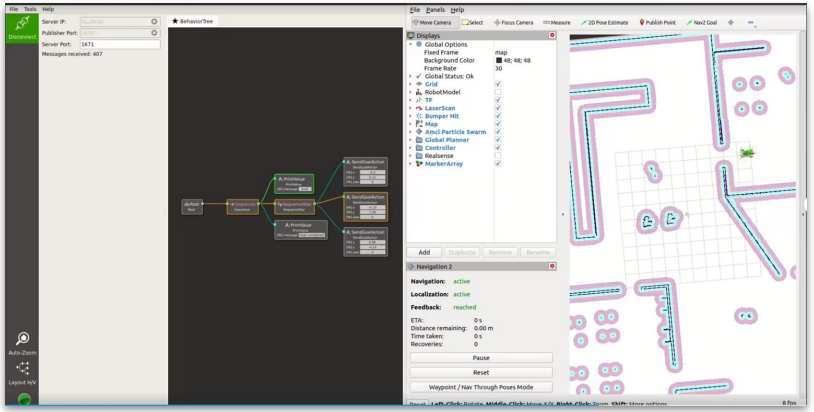
- **Nodes are defined in C++, Trees in XML**
  The best of compiled and interpreted languages together
- **Increasing popularity in the ROS community**
  Driven probably by the early adoption of Nav2
- **Technically decoupled from ROS**
  A double-edged sword: easy to include in any project, but not idiomatic in the context of ROS.



BehaviorTree.CPP

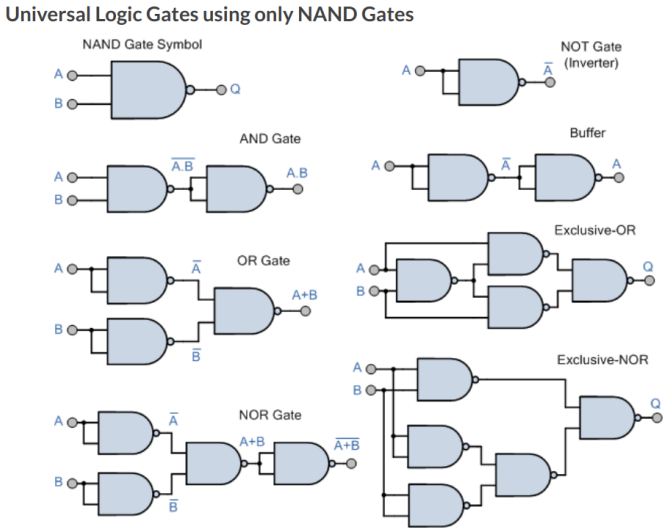
- **Nodes are defined in C++, Trees in XML**
  The best of compiled and interpreted languages together
- **Increasing popularity in the ROS community**
  Driven probably by the early adoption of Nav2
- **Technically decoupled from ROS**
  A double-edged sword: easy to include in any project, but not idiomatic in the context of ROS.
- **Tooling and Graphic interfaces**
  Groot is a useful tool that provides editing and real-time monitoring. MoveIt Studio integrates a BT editor, too.





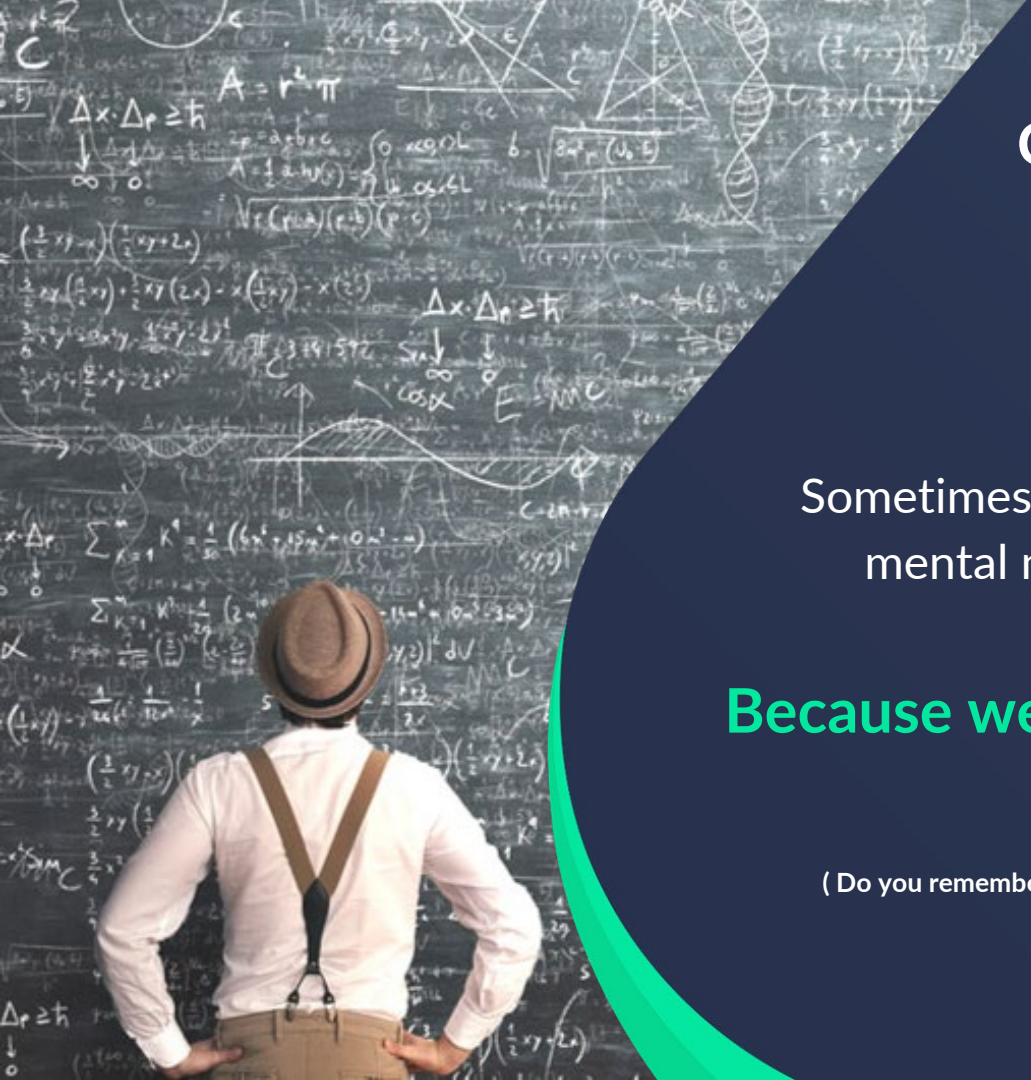
Behavior Trees as extensible Domain Specific Language

In electronics, the NAND gate is the **building block** that you can use to build the others.
Similarly, the most atomic concept of FSM is the **state transition**.



The way Behavior Trees provide **high level of abstraction** goes **beyond hierarchical compositions**:

- You can create complex behaviors by **composition of Nodes and SubTrees**
- But you can also “extend the language”, creating your own **custom** Decorators and Controllers.



Current problems with BT.CPP

Sometimes, it takes too much time to map your mental model of the problem into a tree!!

Because we still think in terms of “states”

(Do you remember what we said about “you are doing it wrong” and empathy?)

Let me rephrase...

Behavior Trees don't want you to think in terms of states.

What if that is our weakness?

Introducing…

BehaviorTree.CPP 4.0

Goals of version 4.0

01 Reduce the cognitive effort of both the person designing the tree or reviewing it.

02 Translate more effectively the “mental model” of the designer into a tree.

03 Add more expressivity to the XML code and the GUI representation.

04 In short: enhanced productivity

A scripting language inside BTs

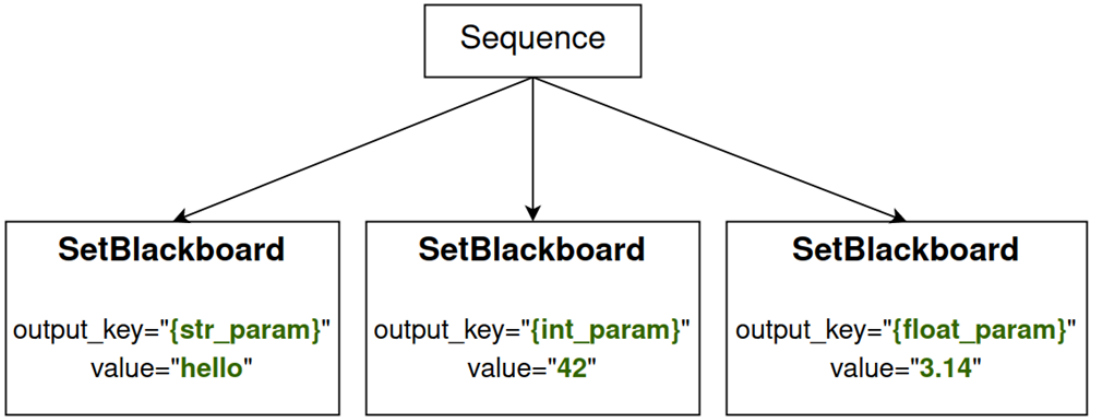
PICKNIK ROBOTICS

We can now add simple piece of code (“one liners”) to express **equality, assignment, comparison, arithmetic operations** and **if-then-else**. Our variables are the **elements of the blackboard**.

Examples:

- `param_A = 5.0 ; param_B = 'hello'; error_code = 42` — **Assignment**
- `(param_A != param_B) && (error_code == 0)` — **Logic operators**
- `speed = (max_speed / 2) + 4` — **Arithmetic**
- `target = (voltage < 10) ? 'recharge_pose' : 'load_pose'` — **If-then-else clauses**

Example: Initializing blackboard variables



Before

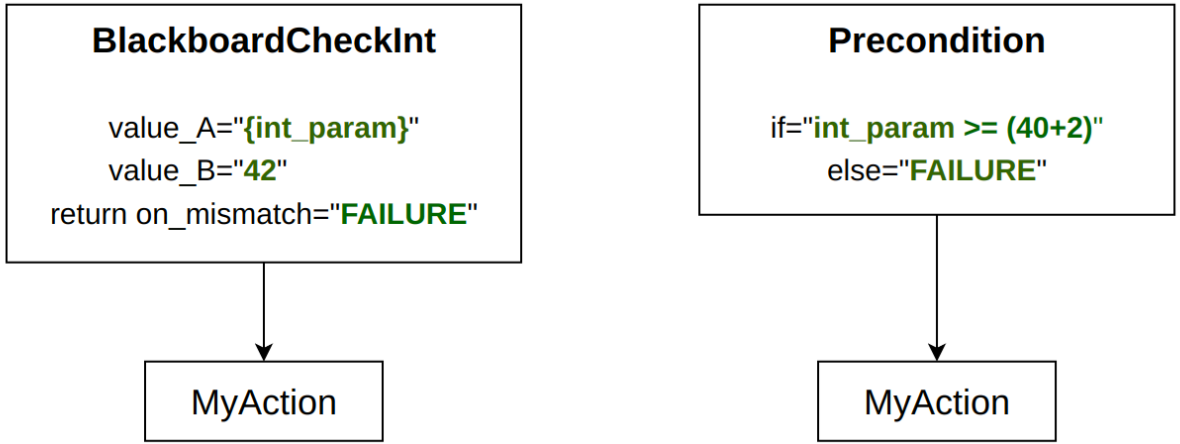
Script

code="str_param='hello';
int_param=42;
float_param=3.14"

After

(multiple commands using semicolons)

Example: the Precondition Decorator

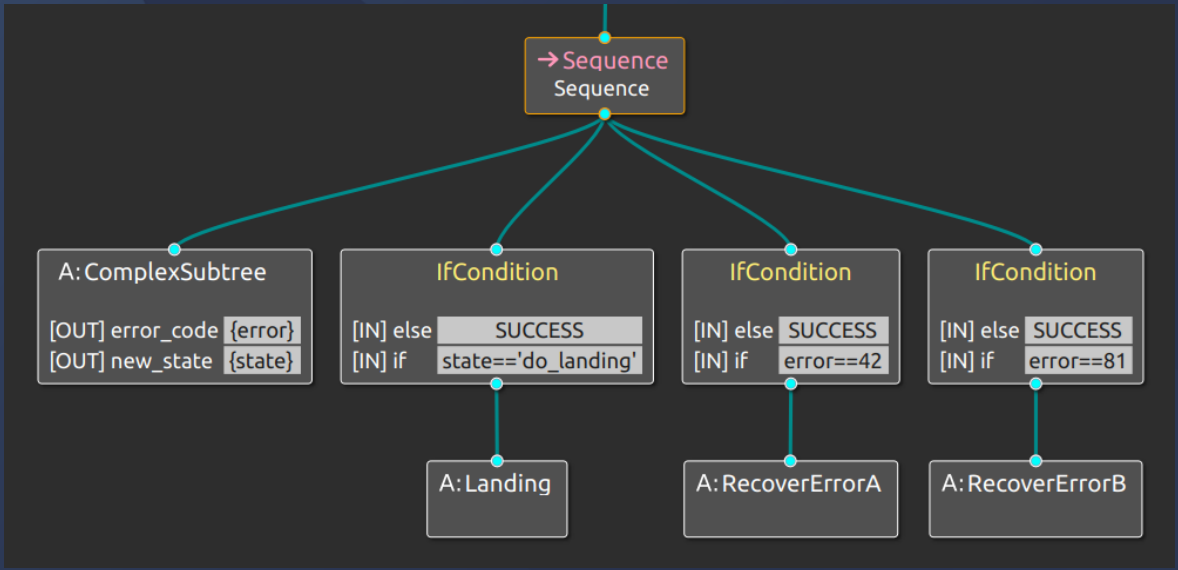


Before

After

(not just equality)

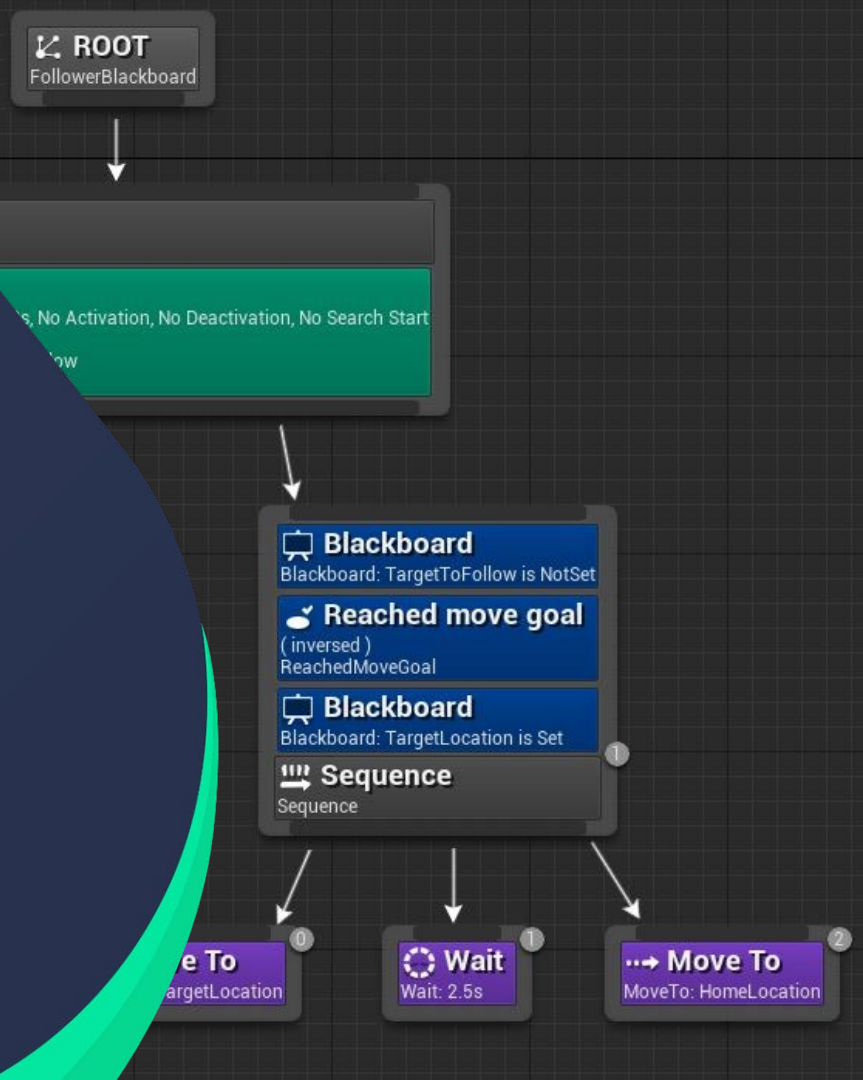
States can make your BT layout simpler



This solves the most common limitation of BTs: sometimes you DO want to think in terms of states and you need to return multiple results

Pre and Post conditions

- Now that we have unleashed the power of scripts, we can go a step further, adding Pre and Post conditions to every Node
- Shamelessly inspired by Unreal Engine BT
- It needs GUI support to become a game changer (but you will have to wait).
- Implemented as optional XML attributes



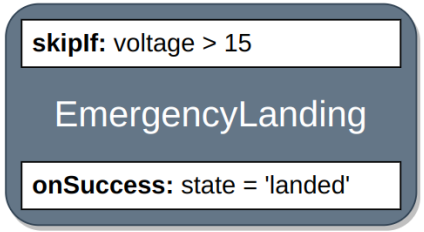
Example

This is a Node (or an entire, complex SubTree) executed only if (voltage <= 15).

Blackboard variable state changed to string “landed” if the Node return SUCCESS.

```
<EmergencyLanding
    _skipIf = "voltage>15"
    _onSuccess = "state='landed'"/>
```

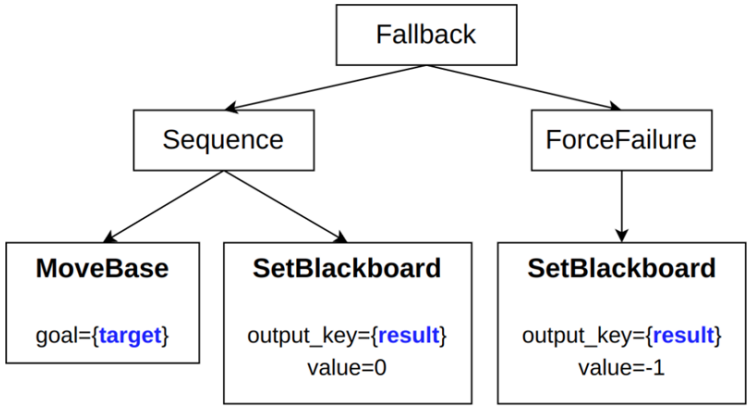
XML



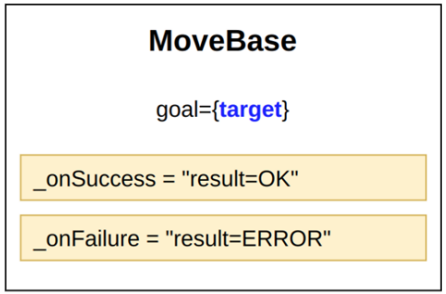
GUI

One more examples

Here, instead of recovering locally to the FAILURE of **MoveBase**, I want to do the recovery routine in another part of the tree. I use the port “results” to remember that.



Before



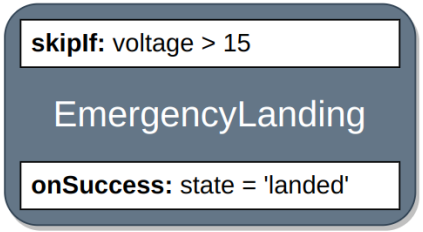
After

(with enums!)

Pre-conditions

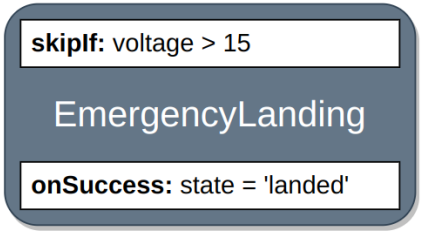
- Optional Scripts executed before the actual **tick()**
- Can be used to “skip” the execution of a Node and its children.
- Being able to halt a **RUNNING** Node, it is technically equivalent to **ReactiveSequence** (but better?)

_skipIf	Skip (don’t execute this node) if condition is true
_failureIf	Skip and return FAILURE
_successIf	Skip and return SUCCESS
_while	Don’t start, or halt a RUNNING Node, if the condition becomes false



Post-conditions

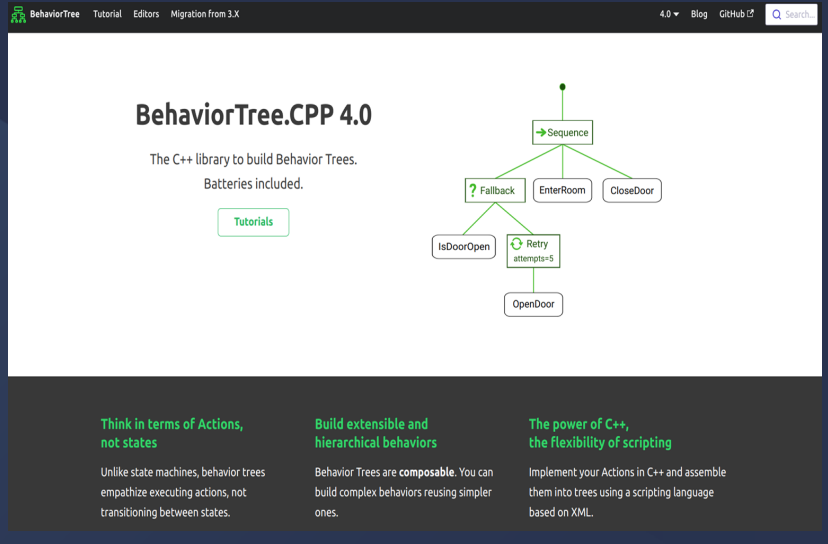
- Optional Scripts executed after the actual **tick()**
- Can be used to set variables (states, error codes, etc.)
- In 3.X it was impossible to detect if an action was halted. Now we can use **onHalted()**

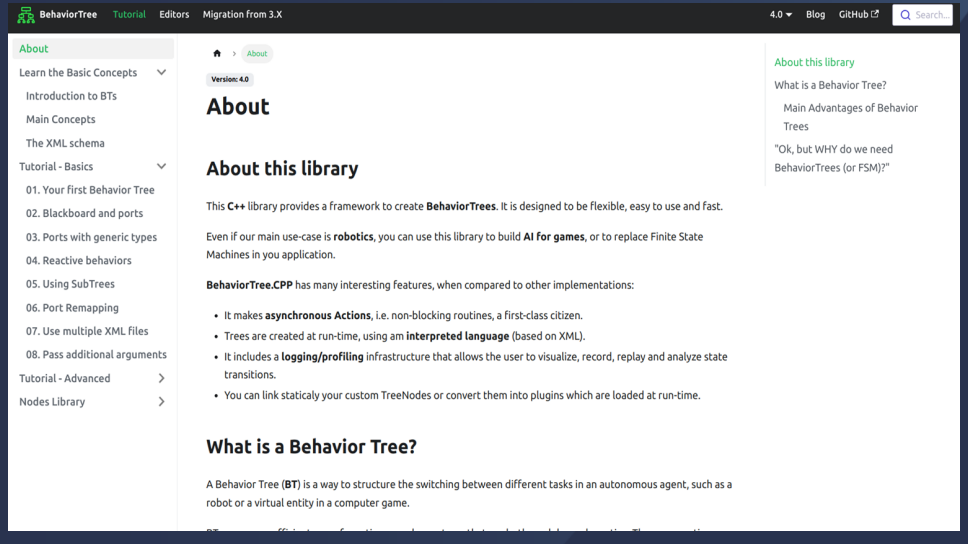


_onSuccess	Script executed if Node returns SUCCESS
_onFailure	Script executed if Node returns FAILURE
_onHalted	Script executed if a RUNNING Node was halted
_post	Script executed if Node returns either SUCCESS or FAILURE

Documentation, tutorials and Migration guide

PICKNIK ROBOTICS





I hope you enjoy reading this as much as I hated writing it ❤️

What to expect next

- **Currently in Alpha.**
  More stable releases by the end of the year.
- **Feedback from the community**
  AKA, “you”. Try it, ask questions, give ideas.
- **Editors supporting the new features**
  MoveIt Studio and Groot 2.0
- **Documentation and design patterns**
  We need to create idiomatic use of BTs

MoveIt Studio Developer Platform combines BehaviorTree.cpp with MoveIt