Course "Automated Planning: Theory and Practice"
Chapter 19: PlanSys2 - Robotic Planning System

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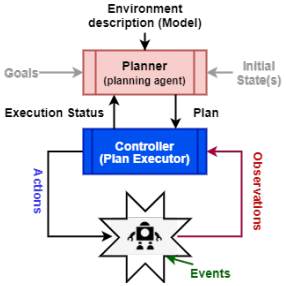
Introduction: Planning System

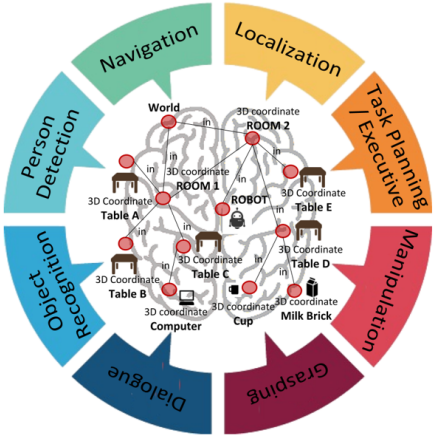
- A Planning System is a software platform to create, execute plans on an (robotic/software) agent and monitor their execution.
  - Relies on one or more models of the agents and of the environment where the agents operate.
  - Manages knowledge (instances, predicates, goals, functions)
    - Provides an interface to add/remove/update knowledge.
    - Provides validation between reality and the model.
  - Provides mechanisms to implement and execute actions
  - Provides mechanisms for monitoring execution at run-time by verifying compliance with preconditions/assumptions and action's effects.
  - Provides mechanisms to handle contingencies via fault-detection-identification and recovery (e.g. re-planning).



We are no longer in a closed world, and the knowledge must be validated with the reality

Planning System: Cortex

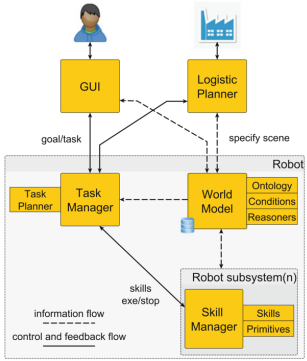
- CORTEX (by Bustos et al. [2]) is a cognitive architecture that leverages AI Planning.
- Maintains a representation of knowledge based on a graph
- Agents access the graph to fulfill their activities
  - Perception
  - Actuation
  - Deliberation/Planning
- Each agent generates task planning using Metric-FF (by Hoffmann [9])



https://robolab.unex.es/wp-content/papercite-data/pdf/luis-pablo-cortex.pdf

Planning System: SkiROS2

- SkiROS2 (by Polydoros et al. [11]) is a platform to create complex robotic behaviors through the composition of skills (software blocks modular) in Behavior Trees (by Marzinotto et al. [10]).
- Available in ROS and ROS2
- The user provides Skills, a scene and a goal
- Uses reasoning based on OWL ontologies
- SkiROS2 offers the following features:
  - A framework to organize the robot behaviors within modular skill libraries
  - A reactive execution engine based on Behavior Trees
  - An integration point for PDDL task planning using the "task planning" skill
  - A semantic database to manage environmental knowledge

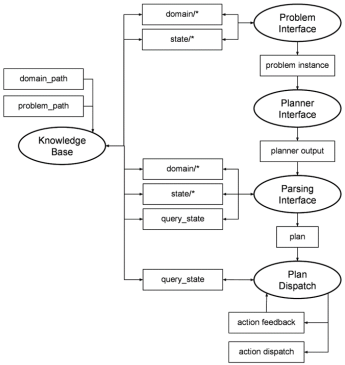


https://github.com/RVMI/skiros2

https://www.researchgate.net/publication/317753352_SkiROS-A_skillbased_robot_control_platform_on_top_of_ROS

Planning System: ROSPlan

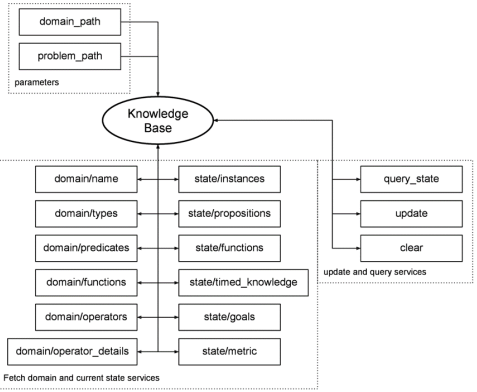
- ROSPlan (by Cashmore et al. [3]) is a framework that provides a collection of tools for AI Planning in a ROS system.
- ROSPlan has a variety of nodes which encapsulate planning, problem generation, and plan execution.
- It possesses a simple interface, and links to common ROS libraries.
  - The Knowledge Base is used to store a PDDL model.
  - The Problem Interface is used to generate a PDDL problem, publish it on a topic, or write it to file.
  - The Planner Interface is used to call a planner and publish the plan to a topic, or write it to file.
  - The Parsing Interface is used to convert a PDDL plan into ROS messages, ready to be executed.
  - The Plan Dispatch encapsulates plan execution.

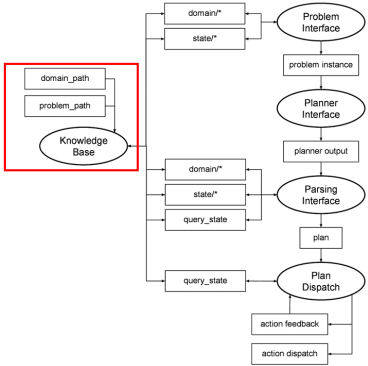


https://github.com/KCL-Planning/ROSPlan
https://kcl-planning.github.io/ROSPlan

https://www.aaai.org/ocs/index.php/ICAPS/ICAPS15/paper/download/10619/10379

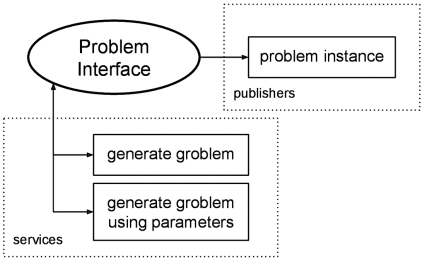
Planning System: ROSPlan (cont.)

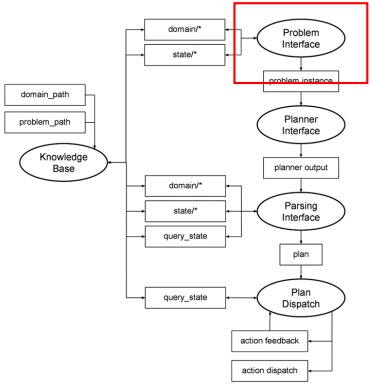




- The Knowledge Base stores the PDDL model: both a domain model and the current problem instance. It supports:
  - Loads a PDDL domain (and optionally problem) from file.
  - Stores the state as a PDDL instance.
  - Is updated by ROS messages.
  - Can be queried.

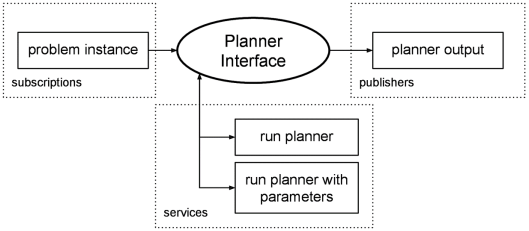
Planning System: ROSPlan (cont.)

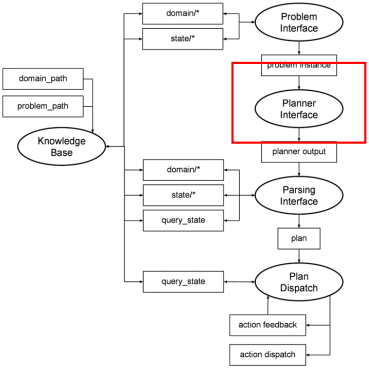




- The Problem Interface node is used to generate a problem instance.
- It fetches the domain details and current state through service calls to a Knowledge Base node and publishes a PDDL problem instance as a string, or writes it to file.

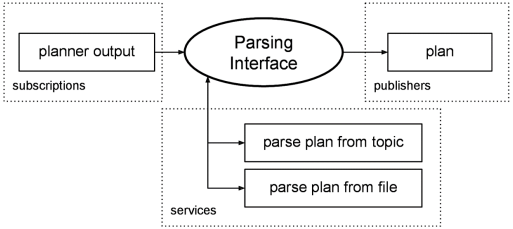
Planning System: ROSPlan (cont.)



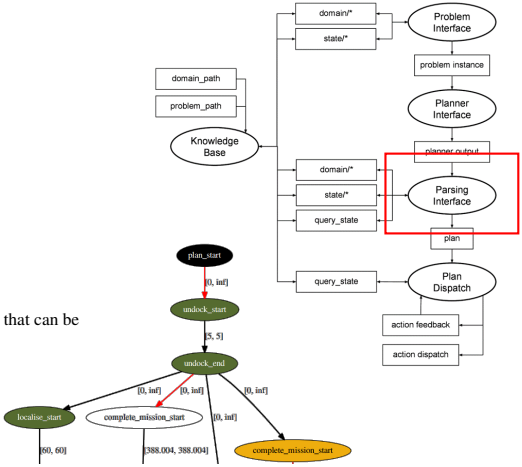


- The Planner Interface node is a wrapper for an AI Planner.
- The planner is called through a service, which returns true if a solution was found.
  - This interface feeds the planner with a domain file and problem instance, and calls the planner with a command line specified by parameter.

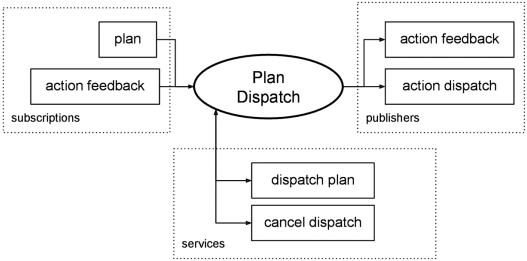
Planning System: ROSPlan (cont.)

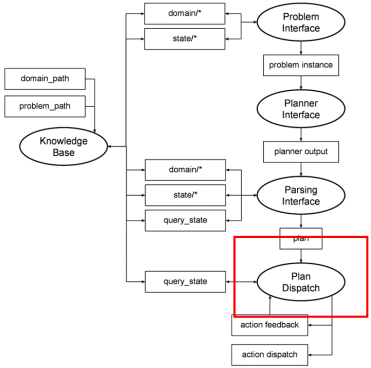


- The Parsing Interface node is used to convert planner output into a plan representation that can be executed, and whose actions can be dispatched to other parts of the system.



Planning System: ROSPlan (cont.)





- The Plan Dispatch includes plan execution, and the process of connecting single actions to the processes which are responsible for their execution.
  - An implementation of the Plan Dispatch node subscribes to a plan topic, and is closely tied to the plan representation of plans published on that topic.

Planning System: a lightweight comparison

- CORTEX and SkiROS2
  - Embed a symbolic planner, but their planners are not directly usable in other architectures, and their substitution with other planners not easy (tightly integrated).
  - No support for time based planning in CORTEX!

- ROSPlan
  - Is built on top of ROS1
    - No plans yet to move to ROS2
  - It has some limitations
    - There is no clean API for adding actions
    - There is no easy support for multiple robots
    - There is no clear interface to interact with the planning system interactively
    - It has not been designed with performance, reliability and flexibility in mind.
  - On the positive side
    - It is the first
    - It has been used in several projects in land, air, and marine applications
    - It has a reasonably good user base

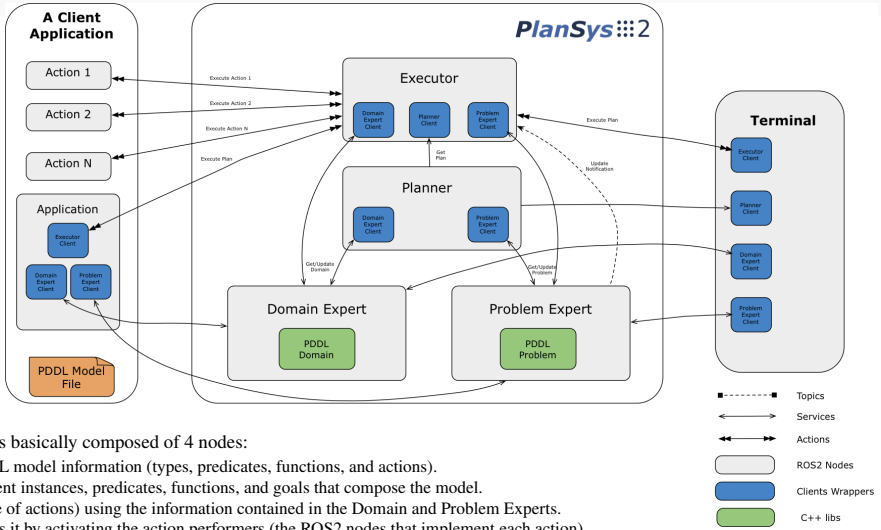
PlanSYS2: Overview I

- It has been inspired by ROSPlan
- It is an efficient, predictable, and reliable infrastructure
  - It is built on top of the ROS2 real-time capable meta-operating system, to address operational safety standards and determinism.
  - It uses the Data Distribution Service (DDS) communication standard adopted in critical systems such as spacecraft, airplanes, hyperloop, or next-generation automobiles.
  - ROS2 also introduces the concept of Managed Nodes (also known as LifeCycle Nodes):
    - These nodes have a clear life cycle based on the states and transitions from their creation.
    - The state are observable, and transitions can be triggered both internally and from outside the node.
    - They behave deterministically.
- It is modular, and each component clearly specify its interfaces, thus facilitating the substitution if needed.

PlanSYS2: Overview II

- Support for Multi-robot and Specialized Action Performers
  - The system is capable of executing plans on different robots and devices.
  - It relies on the ability of ROS2 nodes to communicate with zero-configuration (since DDS uses Multicast and in ROS2, all nodes of the same network can communicate with each other) and a new action auction protocol.
    - There can be multiple nodes in a network that implement the same PDDL action.
    - Each of them can be specialized in executing actions with specific parameters.
- It has been designed with Efficiency and Explainability in mind
  - The plans generated by the plan solver have room to be executed efficiently.
  - Executor's optimization is carried out on the generated plan by analyzing the plans to identify their execution flows, to allow for parallel executions.
  - Each update of the status of any component publishes comprehensible updates to which any visualization or monitoring application can subscribe.

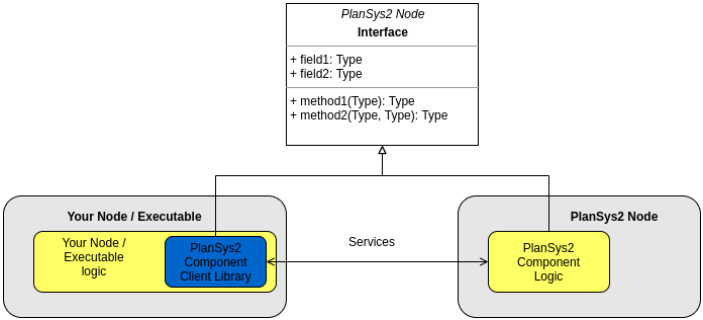
PlanSYS2: Design



- PlanSys2 has a modular design. It is basically composed of 4 nodes:
  - Domain Expert: Contains the PDDL model information (types, predicates, functions, and actions).
  - Problem Expert: Contains the current instances, predicates, functions, and goals that compose the model.
  - Planner: Generates plans (sequence of actions) using the information contained in the Domain and Problem Experts.
  - Executor: Takes a plan and executes it by activating the action performers (the ROS2 nodes that implement each action).

PlanSYS2: Design (cont.)

- Each of the Domain/Problem Expert, Planner and Executor nodes exposes its functionality using ROS2 services.
- Although, PlanSys2 offers a client library that can be used in any application and hides the complexity of using ROS2 services.

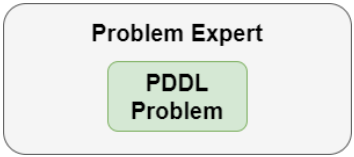


PlanSYS2: Domain Expert

- Its objective is to read PDDL domains from files and make them available to the rest of the components.
  - The PDDL files will be merged
  - Each component contributes with part of the PDDL and corresponding action implementation
    - e.g. one for movement,
    - another for object manipulation, ...

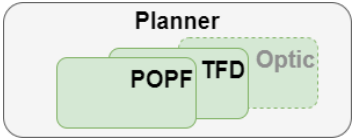
PlanSYS2: Problem Expert

- Contains the knowledge of the system: instances, grounded predicates and functions, and goals.
- Its objective is to make the knowledge available to the rest of the components.



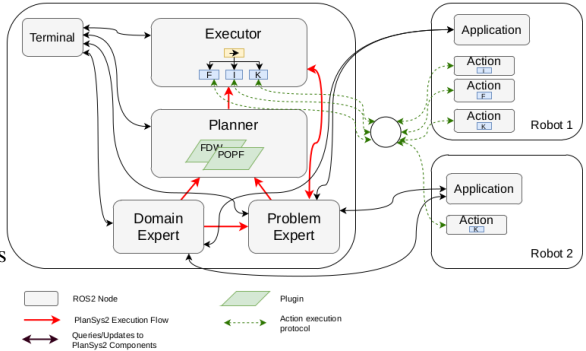
PlanSYS2: Planner

- This component computes the plan to achieve a goal.
  - A plan may be requested by providing a domain acquired from the Domain Expert and a problem acquired from the Problem expert.
  - The domains, problems and solutions are stored in proper name spaces to allow for multiple instances on the same hosting machine (E.g. `/tmp/<namespace>/`).
    - Useful for simultaneous simulation of multiple robots on the same hosting machine.
  - Run a PDDL solver (i.e. a planner) and returns the solution plan (if it exists).
- Each PDDL solver in PlanSys2 is a plugin.
  - Support for POPF by Coles et al. [4], and Temporal Fast Downward by Eyerich et al. [5]
  - POPF is the default
  - Other PDDL solvers can be used easily: OPTIC by Benton et al. [1] forthcoming



PlanSYS2: Executor

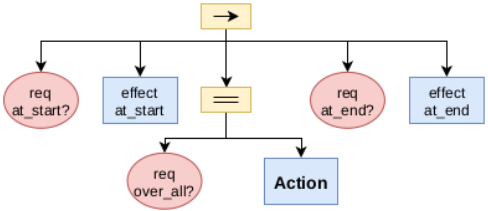
- This component is responsible for executing a provided plan.
- It is the most complex component
- Action execution involves activating the action performers.
  - This task is carried out with the following characteristics:
    - It optimizes its execution, parallelizing the actions when possible.
    - It checks if the requirements are met at runtime.
    - It allows more than one action performer for each action, supporting multirobot execution.



PlanSYS2: Executor - Behavior Tree Builder

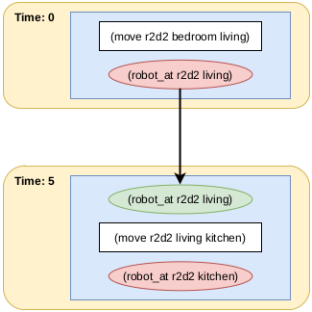
- Once a plan has been generated and it is ready for execution, the Executor converts the plan into a Behavior Tree (BT) [10] before the execution.
  - A "basic" node (corresponding to actions, blue rectangle) can be in NOTRUNNING, RUNNING, SUCCESS, and FAILURE state
  - A "condition" node to check truth of a condition: can be in SUCCESS or FAILURE state
  - There are composition nodes:
    - "=" for parallel composition
    - $\rightarrow$ for sequential composition

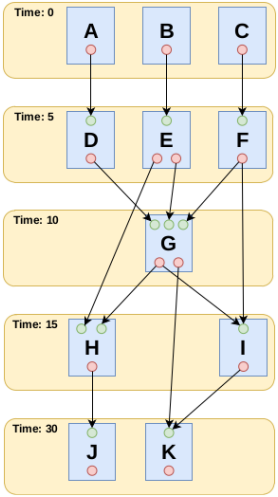
- Each (durative) action in the plan is transformed in the following subtree:



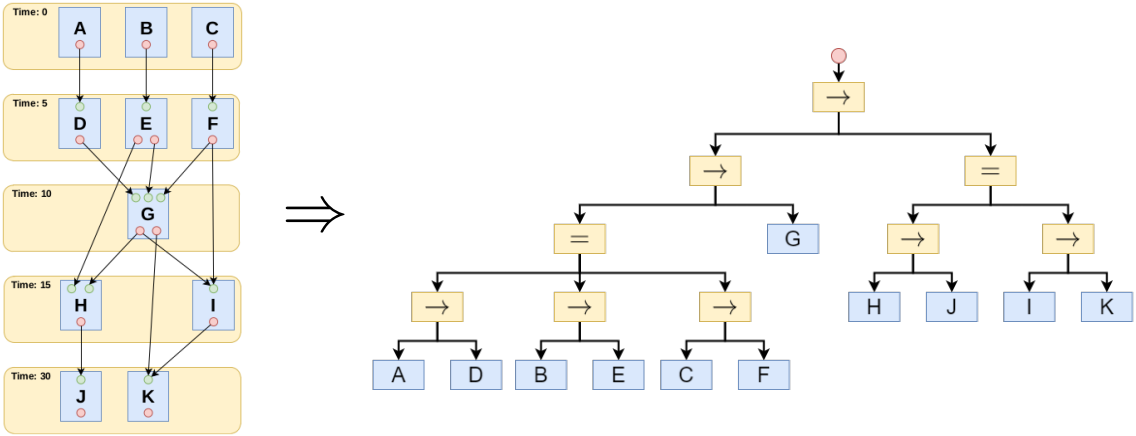
PlanSYS2: Executor - Behavior Tree Builder (cont.)

- The first step is building a planning graph that encodes the action dependencies that define the execution order.
- This is performed by:
  - pairing the effects of an action with the preconditions of a subsequent action
  - taking as reference the time of the calculated plan



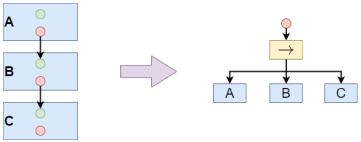


PlanSYS2: Executor - Behavior Tree Builder (cont.)

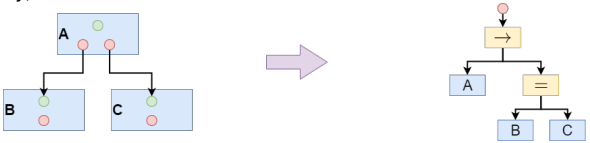


PlanSYS2: Executor - Behavior Tree Builder (cont.)

- If an action a_i in the planning graph is connected only to another action a_j and $|a_i \rightarrow| = 1$ and $|\rightarrow a_j| = 1$ (and $t_{a_i} < t_{a_j}$ is guaranteed by graph construction), this is translated to a sequence structure.

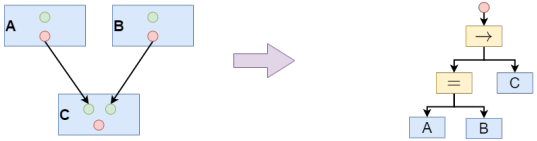


- If an action a_i such that $|a_i \rightarrow| > 1$ is connected to than actions $a_{j,k}$ such that $|\rightarrow a_{j,k}| = 1$, this is translated in a BT with one sequence that executes a_i before a parallel control node that contains all actions $a_{j,k}$.

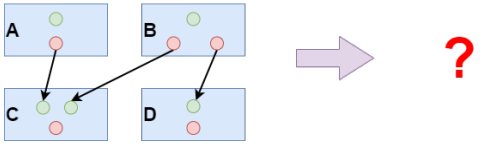


PlanSYS2: Executor - Behavior Tree Builder (cont.)

- If several actions $a_{j,k}$ such that $|a_{j,k} \rightarrow| = 1$, converge to the same action unit a_i, this is translated in a BT with one sequence that executes a parallel control node that contains action units $a_{j,k}$ before a_i.



- If an action unit a_i such that $|a_i \rightarrow| > 1$ is connected with an action a_j such that $|\rightarrow a_j| > 1$, the transformation to BT is not possible with no further information.

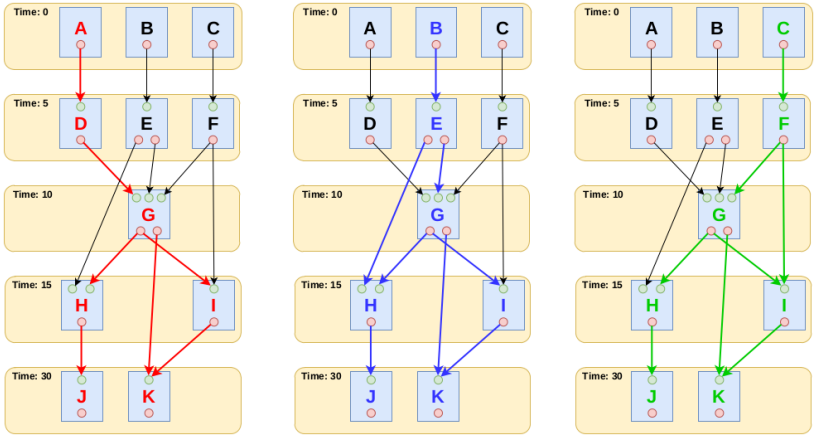


PlanSYS2: Executor - Behavior Tree Builder (cont.)

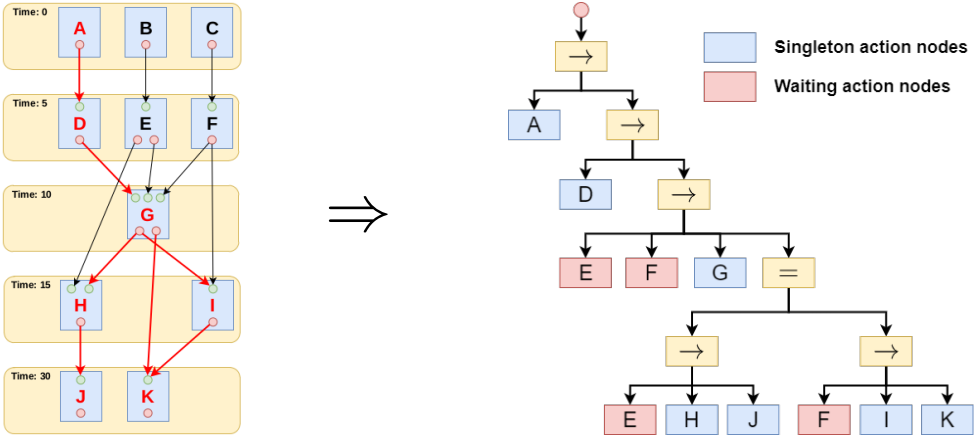
- To overcame limitations of the "simple" construction has been proposed an approach that leverages following concepts:
  - Execution flows: An execution flow starts from an action a_i such that $|\rightarrow a_i| = 0$, and add the actions in the path following the arc effect $\rightarrow$ requirement.
  - Singleton action: Each action unit a_i in the generated BT is a singleton, i.e., it can appear in different points in the BT, but it refers to the same action instance. If an action unit a_i has already returned SUCCESS when executed in one branch, it will return SUCCESS if it is ticked in any other branch.
  - Waiting nodes: This control node refers to an action instance a_i, and it returns RUNNING if a_i has never returned SUCCESS.

PlanSYS2: Executor - Behavior Tree Builder (cont.)

- Once created the planning graph, we identify the execution flows:



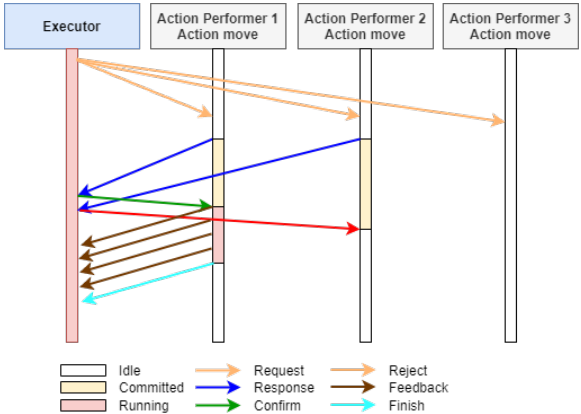
PlanSYS2: Executor - Behavior Tree Builder (cont.)



- Each flow is executed in parallel.
  - The flows can overlap, and it is not a problem since the BT that executes an action is a singleton.

PlanSYS2: Executor - Action delivery protocol

- Leverages a bidding-based delivery protocol
  - When the Executor must execute an action, it requests which action performer can execute it.
  - The Executor receives replies to his request.
  - The Executor confirms one of them (the first to answer), rejecting the others.
  - If none are found, the execution of the plan is aborted (may be after having tried some finite times to get a reply).



PlanSys2: Installation

- It relies on ROS2
  - Tested on Ubuntu 20.04.3 LTS
  - Tested on Ubuntu 22.04.1 LTS

- Pre-configured binaries:
  - `sudo apt install ros-<distro>-plansys2-*`
  - Example: `foxy` ROS2 distribution
    - E.g.: `command> sudo apt install ros-foxy-plansys2-*`
  - Works also for `humble` (replace `foxy` with `humble` in the following slides)

PlanSys2: Installation (cont.)

- Build from sources
  - Install ROS2 through build instructions for your distribution (e.g., `foxy`, `humble`):
    - `https://index.ros.org/doc/ros2/Installation`
  - Build sources
    - Create a workspace (e.g. `ps2-ws`):

```
command> mkdir ps2-ws
```

    - Clone the repositories (e.g. `master` or `foxy-devel`)

```
command> git clone https://github.com/PlanSys2/ros2_planning_system.git}
command> git clone https://github.com/PlanSys2/plansys2_tfd_plan_solver.git
command> git clone https://github.com/PlanSys2/ros2_planning_system_examples.git
```

    - Build the sources

```
command> rosdep install -y -r -q --from-paths src --ignore-src --rosdistro foxy
command> colcon build --symlink-install
```

PlanSys2: Using The Terminal

- Run:
  - `ros2 run plansys2_terminal plansys2_terminal`

```
command> ros2 run plansys2_terminal plansys2_terminal
[INFO] [1637759812.901738484] [terminal]: No problem file specified.
ROS2 Planning System console. Type "quit" to finish
>
```

  - Available commands:
    - `get`
    - `set`
    - `remove`
    - `run`
    - `check`
    - `source`
- One may need at least to load a domain:

```
command> ros2 launch plansys2_bringup plansys2_bringup_launch_distributed.py \
                                      model_file:=/tmp/simple_example.pddl
```

PlanSys2: Using The Terminal - commands

- `get domain|model|problem|plan`
  - `get domain`
  - `get model types|predicates|functions|actions`
    `get model predicate <pred_name>`
    `get model function <func_name>`
    `get model action <act_name>`
  - `get problem instances|predicates|functions|goal`
  - `get plan`
- `set instance|predicate|function|goal` (next slide)
- `remove instance|predicate|function|goal`
- `check actors`
- `run`
- `source <file_name> [0|1]` // 1 echo commands on standard output, 0 no echo!

PlanSys2: Using The Terminal - set command examples

- In the PlanSys2 terminal one can create the problem

```
set instance leia robot
set instance entrance room
...
set instance chargingroom room

set predicate (connected entrance dinning)
set predicate (connected dinning entrance)
...
set predicate (battery_low leia)
set predicate (robot_at leia entrance)

set goal (and (robot_at leia bathroom))
```

PlanSys2 Commands:
{ commands.txt }

PlanSys2: Using The Terminal - running planner

- One can run the planner

```
command> ros2 run popf popf /tmp/domain.pddl /tmp/problem.pddl
```

A simple Planning Package

- Types:
```
(:types  robot room )
```
- Predicates:
```
(:predicates (robot_at ?r - robot ?ro - room) (connected ?ro1 ?ro2 - room)
             (battery_full ?r - robot)        (battery_low ?r - robot)
             (charging_point_at ?ro - room))
```
- Actions:
  - move
```
(:durative-action move
  :parameters (?r - robot ?r1 ?r2 - room)
  :duration ( = ?duration 5)
  :condition (and (at start (connected ?r1 ?r2))
                  (at start (robot_at ?r ?r1))
                  (over all (battery_full ?r)) )
    :effect (and (at start (not (robot_at ?r ?r1)))
                 (at end (robot_at ?r ?r2)) )
)
```
  - askcharge
  - charge
- Simple PDDL Complete Domain:
  { simple_example.pddl }

A simple Planning Package (cont.)

- Clone the repository in your workspace (e.g. `ps2-ws`)

```
command> mkdir ps2-ws
command> cd ps2-ws
command> git clone -b foxy-devel
    https://github.com/PlanSys2/ros2_planning_system_examples.git
    example
```

- Visit directory `example/ros2_planning_system_examples/plansys2_simple_example`

```
command> tree
.
+-- CHANGELOG.rst
+-- CMakeLists.txt
+-- README.md
+-- launch
|   +-- plansys2_simple_example_launch.py
+-- package.xml
+-- pddl
|   +-- simple_example.pddl
+-- src
    +-- ask_charge_action_node.cpp
    +-- charge_action_node.cpp
    +-- move_action_node.cpp
```

A simple Planning Package: action implementation

- Action `move` (excerpt of file `move_action_node.cpp`)

```
class MoveAction : public plansys2::ActionExecutorClient
{
public:
  MoveAction() : plansys2::ActionExecutorClient("move", 250ms) {
    progress_ = 0.0;
  }
private:
  void do_work() {
    if (progress_ < 1.0) {
      progress_ += 0.02;
      send_feedback(progress_, "Move running");
    } else {
      finish(true, 1.0, "Move completed");
      progress_ = 0.0;
      std::cout << std::endl;
    }
    std::cout << "\r\e[K" << std::flush;
    std::cout << "Moving ... [" << std::min(100.0, progress_ * 100.0)
              << "%]  " << std::flush;
  }
  float progress_;
};
```

A simple Planning Package:: action implementation (cont.)

- Action `move` (excerpt of file `move_action_node.cpp`)

```
int main(int argc, char ** argv)
{
  rclcpp::init(argc, argv);
  auto node = std::make_shared<MoveAction>();

  node->set_parameter(rclcpp::Parameter("action_name", "move"));
  node->trigger_transition(lifecycle_msgs::msg::Transition::TRANSITION_CONFIGURE);

  rclcpp::spin(node->get_node_base_interface());

  rclcpp::shutdown();

  return 0;
}
```

A simple Planning Package: action implementation (cont.)

- `class MoveAction : plansys2::ActionExecutorClient("move", 250ms)` indicates that each 250ms (4Hz) the method `do_work()` will be called.
- `plansys2::ActionExecutorClient` has an API, with the following three relevant protected methods for the actions:

```
const std::vector<std::string> & get_arguments();
void send_feedback(float completion, const std::string & status = "");
void finish(bool success, float completion, const std::string & status = "");
```

where:

- `get_arguments()` returns the list of arguments of an action.
  - For example, when executing `(move leia chargingroom kitchen)`, it will return `{"leia", "chargingroom", "kitchen"}`
- `send_feedback(...)` sends feedback of percentage of completion.
- `finish(...)` indicates that the action has finished, and send back if it successfully finished, the completion value in [0-1] and optional info.
  Then, the node will pass to inactive state.

A simple Planning Package: ROS2 launcher

- The launcher must include the PlanSys2 launcher, selecting the domain, and it runs the executables that implements the PDDL actions:

```
def generate_launch_description():
    example_dir = get_package_share_directory('plansys2_simple_example')
    namespace = LaunchConfiguration('namespace')

    declare_namespace_cmd = DeclareLaunchArgument('namespace',
                                                  default_value='',
                                                  description='Namespace')

    plansys2_cmd = IncludeLaunchDescription(
        PythonLaunchDescriptionSource(os.path.join(
            get_package_share_directory('plansys2_bringup'),
            'launch',
            'plansys2_bringup_launch_monolithic.py')),
        launch_arguments={
          'model_file': example_dir + '/pddl/simple_example.pddl',
          'namespace': namespace
          }.items())

    ...
```

A simple Planning Package: ROS2 launcher (cont.)

- The launcher must include the PlanSys2 launcher, selecting the domain, and it runs the executables that implements the PDDL actions:

```
def generate_launch_description():

    ... # as from previous slide

    move_cmd = Node(package='plansys2_simple_example',
                    executable='move_action_node', name='move_action_node',
                    namespace=namespace, output='screen', parameters=[])

    charge_cmd = Node(...) # similar to above
    ask_charge_cmd = Node(...) # similar to above

    ld = LaunchDescription()
    ld.add_action(declare_namespace_cmd)
    # Declare the launch options
    ld.add_action(plansys2_cmd)
    ld.add_action(move_cmd)
    ld.add_action(charge_cmd)
    ld.add_action(ask_charge_cmd)
    return ld
```

A simple Planning Package: action implementation (cont.)

- The action node, once created, must pass to `inactive` state to be ready for being executed.

```
auto node = std::make_shared<MoveAction>();

node->set_parameter(rclcpp::Parameter("action", "move"));
// Move the action node to inactive/idle state
node->trigger_transition(lifecycle_msgs::msg::Transition::TRANSITION_CONFIGURE);

rclcpp::spin(node->get_node_base_interface());
```

- The parameter `action` sets what action implements the node object.

A simple Planning Package (cont.)

- Compile the repository in your workspace

```
command> colcon build --symlink-install
command> rosdep install --from-paths example --ignore-src -r -y
command> colcon build --symlink-install
```

A simple Planning Package: Running the example

- Open a terminal and run PlanSys2 framework

```
command> ros2 launch plansys2_simple_example plansys2_simple_example_launch.py
```

- Open another terminal and run PlanSys2 terminal

```
command> ros2 run plansys2_terminal plansys2_terminal
```

A simple Planning Package: Running the example (cont.)

- In the PlanSys2 terminal create the problem

```
set instance leia robot
set instance entrance room
...
set instance chargingroom room

set predicate (connected entrance dinning)
set predicate (connected dinning entrance)
...
set predicate (battery_low leia)
set predicate (robot_at leia entrance)

set goal (and (robot_at leia bathroom))
```

PlanSys2 Commands:
{ commands.txt }

A simple Planning Package: Running the example (cont.)

- In the PlanSys2 terminal compute and run the plan

```
> get plan
...
> run
```

  The shell terminals show the current actions executed and respective level of completion.

- As soon as the plan execution finish, the PlanSys2 terminal command prompt will be available again to accept new commands.

Complete Example

- https://plansys2.github.io/tutorials/docs/simple_example.html

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