MoveIt! Task Constructor
A framework for planning task sequences

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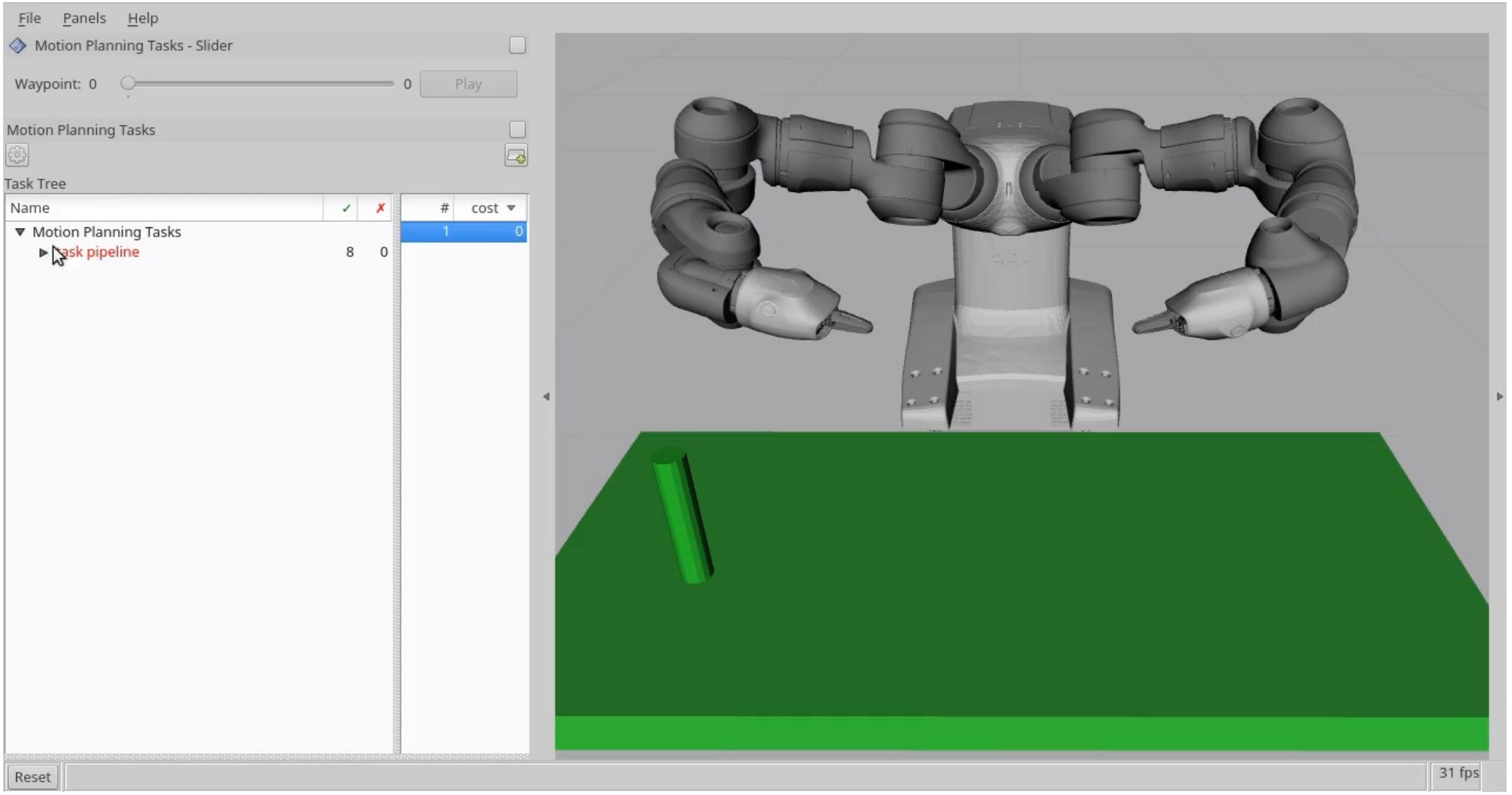
Motivation

MTC build instructions:
https://github.com/rhaschke/lecture/wiki/MoveIt-Task-Constructor



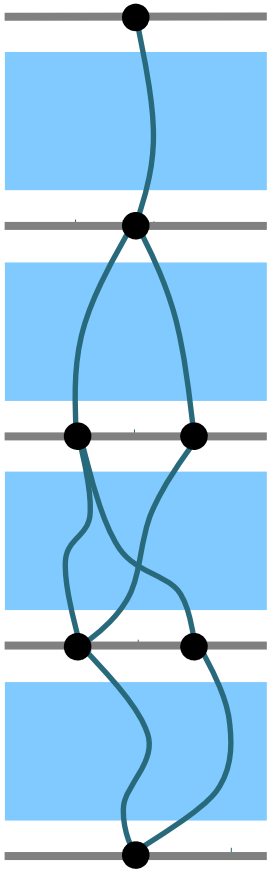
Objectives

- Definition + Planning of non-trivial manipulation sequences
  - Modular
  - Customizable
  - Multiple arms/hands (cf. Felix‘ talk)
  - Cost-ranking of alternative solutions
  - Understandable failure cases (cf. Felix‘ UX remarks)
  - Combine various planners (cf. Pilz‘ talk)

- Replace MoveIt‘s manipulation pipeline
  - Limited to single-arm pick-and-place
  - No introspection

- No Symbolic Task Planning
  - Assuming task structure is known
  - Planning on level of alternative solution paths

Overview



- **Pipeline** composed from **Stages**
- Each stage connects a *start* to an *end* **InterfaceState** via 1…n **SubSolutions**

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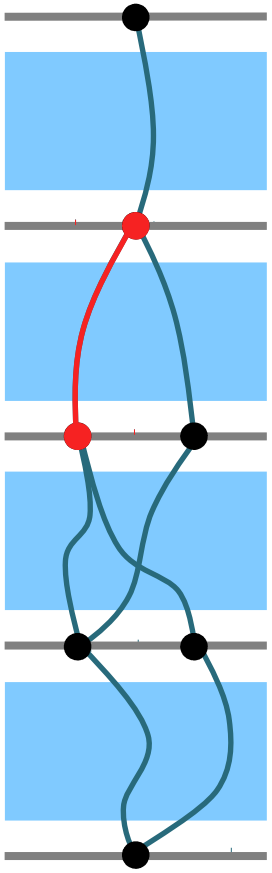

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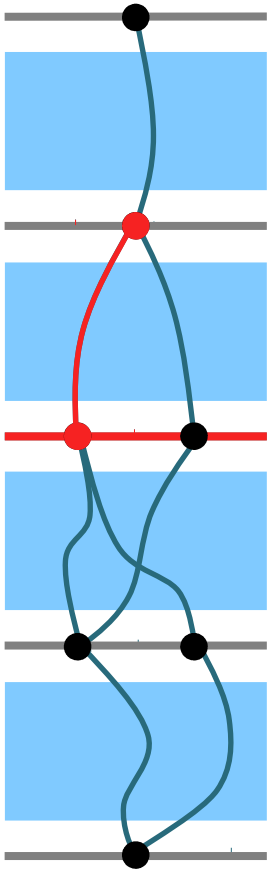

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- Stages interface each other via *list* of InterfaceStates
- Solution = fully-connected path through pipeline

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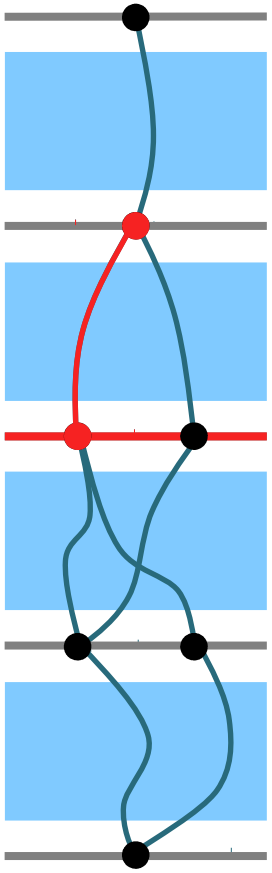

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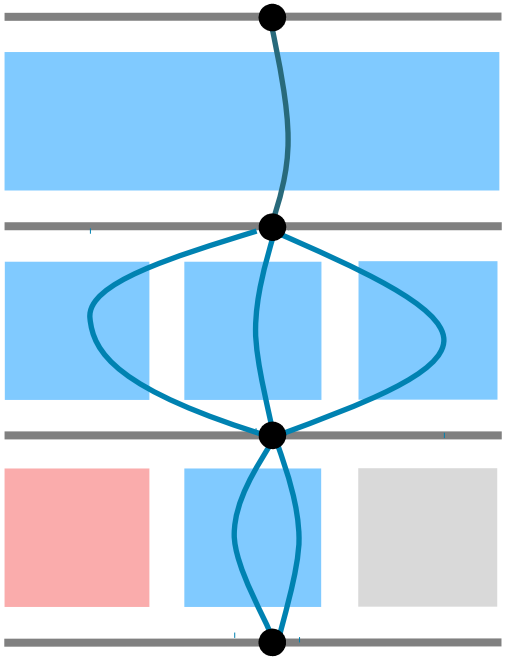
- InterfaceState
  - MoveIt's *PlanningScene*
  - Properties, e.g.
    - grasp type
    - end effector to use for grasping

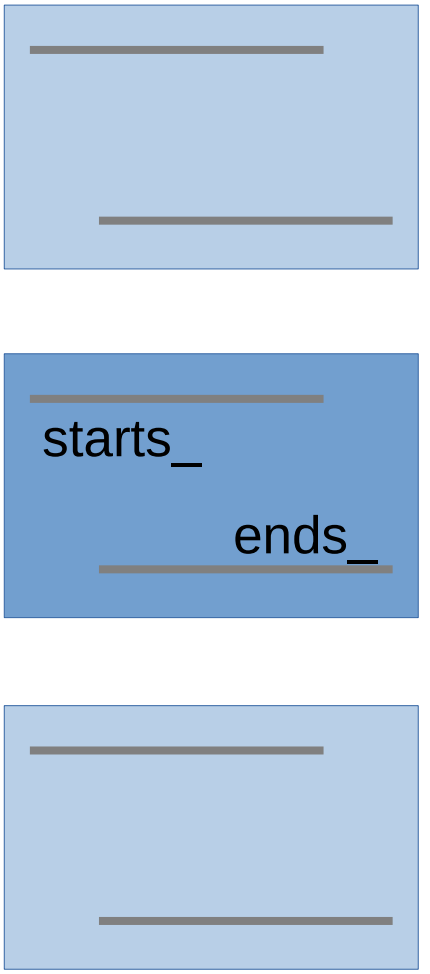
Hierarchical Structuring

- SerialContainer
  - *Sequential* chaining of sub tasks
- ParallelContainer
  - Alternatives
    - Consider all solutions of children
  - Fallback
    - Consider children one by one
  - Merger
    - Combine solutions of children for parallel execution
    - Example: arm approaching + hand opening
    - Requires extra feasibility check!
- Wrapper
  - Filter / duplicate / modify solutions



InterfaceStateLists: Implementation Details

- Each stage has its own starts/ends interface if *reading from* there
- Not instantiating the interface, indicates that the stage is *not* reading from that direction



InterfaceStateLists: Implementation Details

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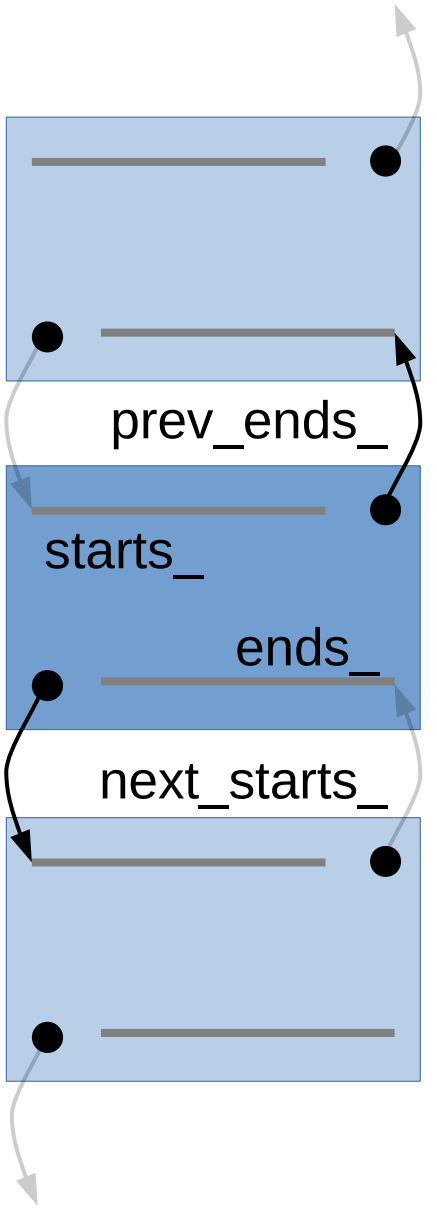
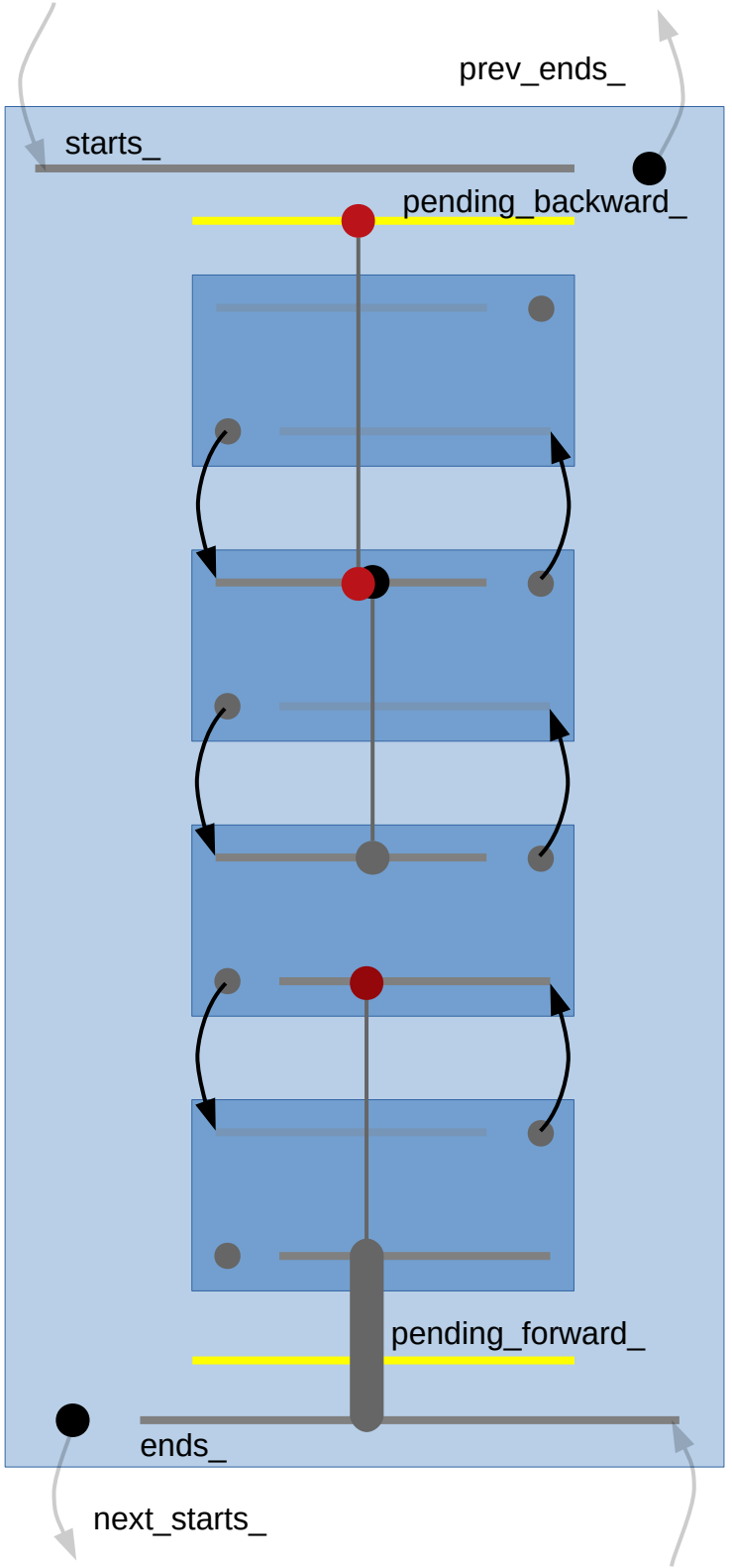
- Not instantiating the interface, indicates that the stage is *not* reading from that direction
- The pointers *prev_ends_* and *next_starts_* reference to the ends / starts interface of the previous / next stage. They indicate whether the stage is *writing* in that direction



Stage Types: SerialContainer

- serially chain several stages
- a solution is any path connecting any start to any end state
- container interface
  - starts_ / ends_: incoming from prev / next sibling stage
    forwarded to first / last child



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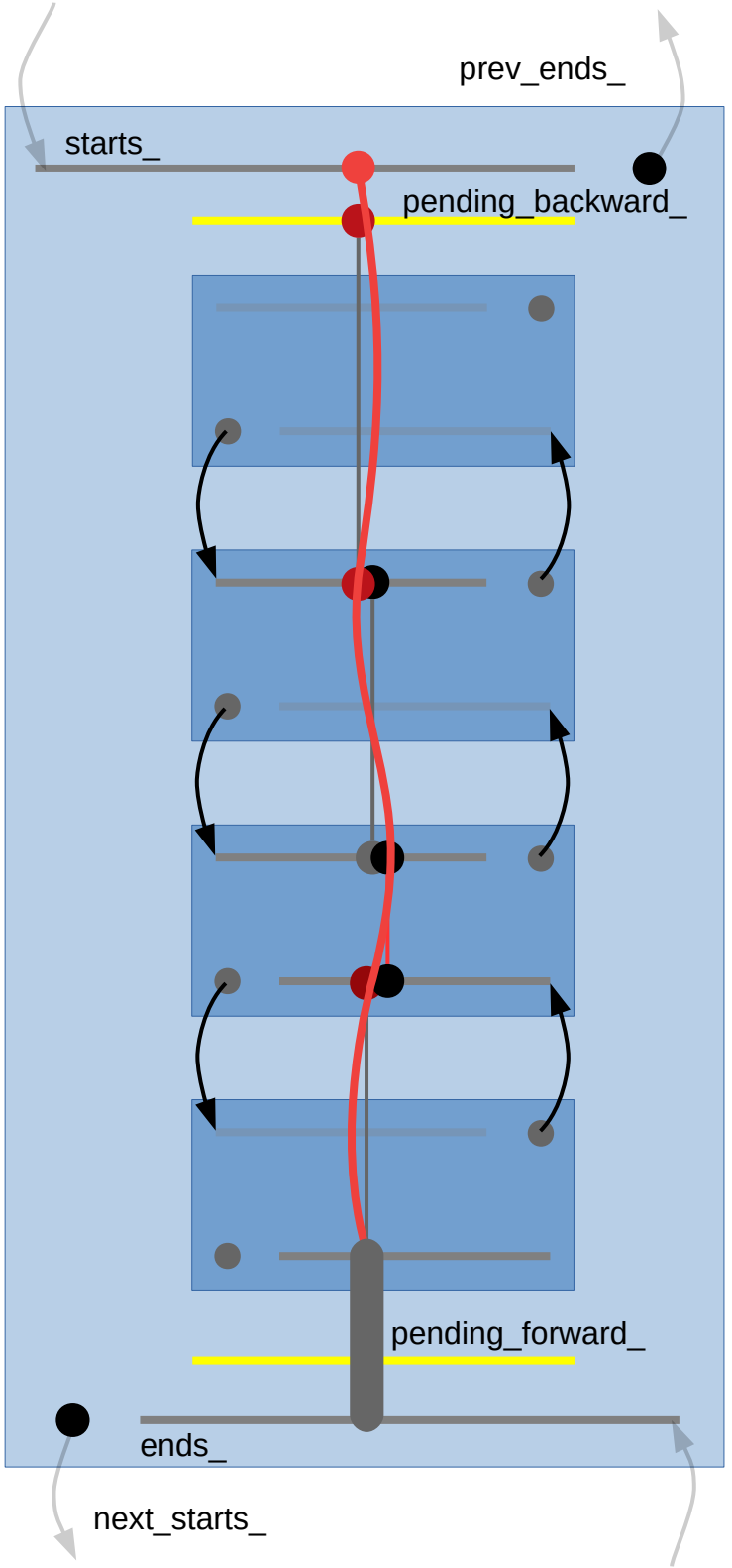
  - onNewSolution: lift full solution(s) to external InterfaceList



Semantic Stage Types

- Planning proceeds non-linearly:
  - generators: seed for planning
  - propagation: advance partial solutions
  - connectors: connect partial solutions

- Example: Pick-n-Place with Handover

↕ current state
∞ connect
↕ pick with right hand
↓ move to handover pose
∞ connect
↕ pick with left hand
↓ move to place

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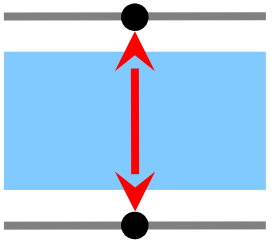
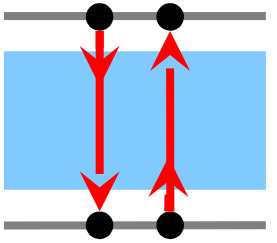
Stage Types by Interface

- Type determined by what is read from / written to interfaces

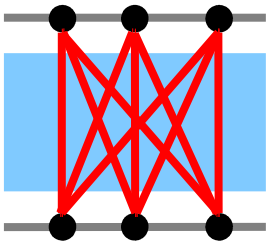
- Generator
  - No reading, Write to both interfaces
  - Examples: CurrentState, FixedState, GraspGenerator
  -



- Propagator
  - Read from one, write to opposite interface
  - Examples: Approach, Lift



- Connector
  - Read both interfaces
  - Combinatorial explosion
  - Check compatibility of states



Available Primitive Stages

- Generators
  - Fetch current Planning Scene from move_group
  - Cartesian pose generator / sampler
  - ComputeIK
  - Simple grasp generator
- Propagators
  - MoveTo: plan towards absolute goal
  - MoveRelative: plan relative motion
  - Manipulate Planning Scene
    - Attach / Detach objects
    - Modify ACM
- Connect

Connect

- Connect 2 InterfaceStates via planning
- Might involve multiple planning groups
  - Arm(s)
  - Hand(s)

- Approach:
  - List all groups with corresponding planners
  - Plan for groups in given sequence
  - Try to merge trajectories for parallel execution

Planners

- Individual stages can employ different planners
- MoveIt‘s PipelinePlanner
- OMPL
- STOMP
- CHOMP
- …
- Straight-line Cartesian path
- Straight-line Joint-space path

Basic Example: C++

```
Task task;
task.add(std::make_unique<stages::CurrentState>());

auto cartesian = std::make_shared<solvers::CartesianPath>();
// Cartesian motion along a vector in world
auto move = std::make_unique<stages::MoveRelative>("x",cartesian);
move->setGroup(„panda_arm“);
geometry_msgs::Vector3Stamped direction;
direction.header.frame_id = "world";
direction.vector.x = 0.2;
move->setDirection(direction);
task.add(std::move(move));
…
```

```
$ roslaunch moveit_task_constructor_demo demo.launch &
$ rosrun moveit_task_constructor_demo cartesian
```

Basic Example: C++

```
…
// create an arbitrary twist motion relative to current pose
move = std::make_unique<stages::MoveRelative>("z",cartesian);
move->setGroup(„panda_arm“);
geometry_msgs::TwistStamped twist;
direction.header.frame_id = "world";
twist.twist.angular.z = M_PI / 4.;
move->setDirection(twist);
task.add(std::move(move));
…
```

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Basic Example: C++

```
…
// move from reached state back to the original state
Connect::GroupPlannerVector planners = {{„panda_arm“, cartesian}};
auto connect = std::make_unique<Connect>("connect", planners);
task.add(std::move(connect));

// final state is original state again
task.add(std::make_unique<CurrentState>());
…
```

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Basic Example: C++

```
…
// move from reached state back to the original state
auto ji = std::make_shared<solvers::JointInterpolationPlanner>();
Connect::GroupPlannerVector planners = {{„panda_arm“, ji}};
auto connect = std::make_unique<Connect>("connect", planners);
task.add(std::move(connect));

// final state is original state again
task.add(std::make_unique<CurrentState>());
…
```

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Basic Example: Python

```
task = core.Task()

# start from current robot state
task.add(stages.CurrentState("current state"))

# Cartesian motion along x
move = stages.MoveRelative("x +0.2", core.CartesianPath())
move.group = group

dir = Vector3Stamped(header=Header(frame_id = "world"),
                     vector=Vector3(0.2,0,0))

move.setDirection(dir)

task.add(move)

…
```

```
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```

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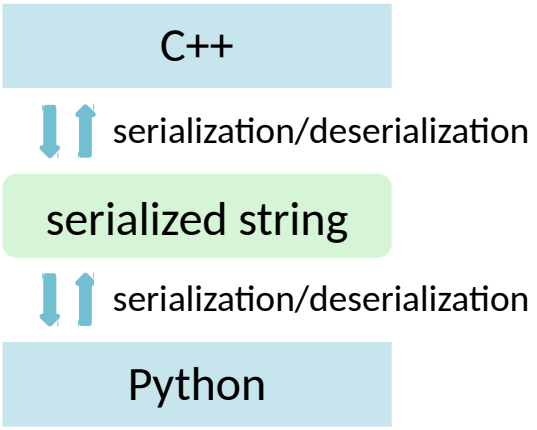


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task.add(move)

…
```

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$ rosrun moveit_task_constructor_demo cartesian.py
```

Basic Example: Python

```
…

# moveTo named posture
move = stages.MoveTo("moveTo ready", cartesian)
move.group = group
move.setGoal("ready")
task.add(move)


if task.plan():
    task.publish(task.solutions[0])
```

```
$ roslaunch moveit_task_constructor_demo demo.launch &
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```

Containers as Wrappers for reusable sub tasks

- Combine stages into reusable sub tasks
- Examples: Pick / Place or Grasp / Release

Pick
- Approach
- Grasp
- Lift

Place
- Place
- UnGrasp
- Retract

Grasp
- ComputeIK
  - GraspProvider
- Allow Object Collision
- Close Gripper
- Attach Object

UnGrasp
- ComputeIK
  - PlaceProvider
- Detach Object
- Open Gripper
- Forbid Object Collision

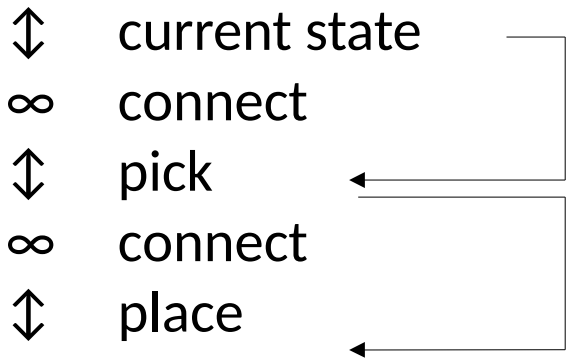
Property Inheritance

- Need a method to derive stage properties
  - from parent
  - from passed-in solution
- Explicit property handling
  - declared with name and type
  - explicit inheritance or forwarding
- `Property::configureInitFrom(source, const InitializerFunction& f);`
- `Property::configureInitFrom(source, other_name);`
- `PropertyMap::configureInitFrom(source, names);`
- `source = PARENT | INTERFACE`

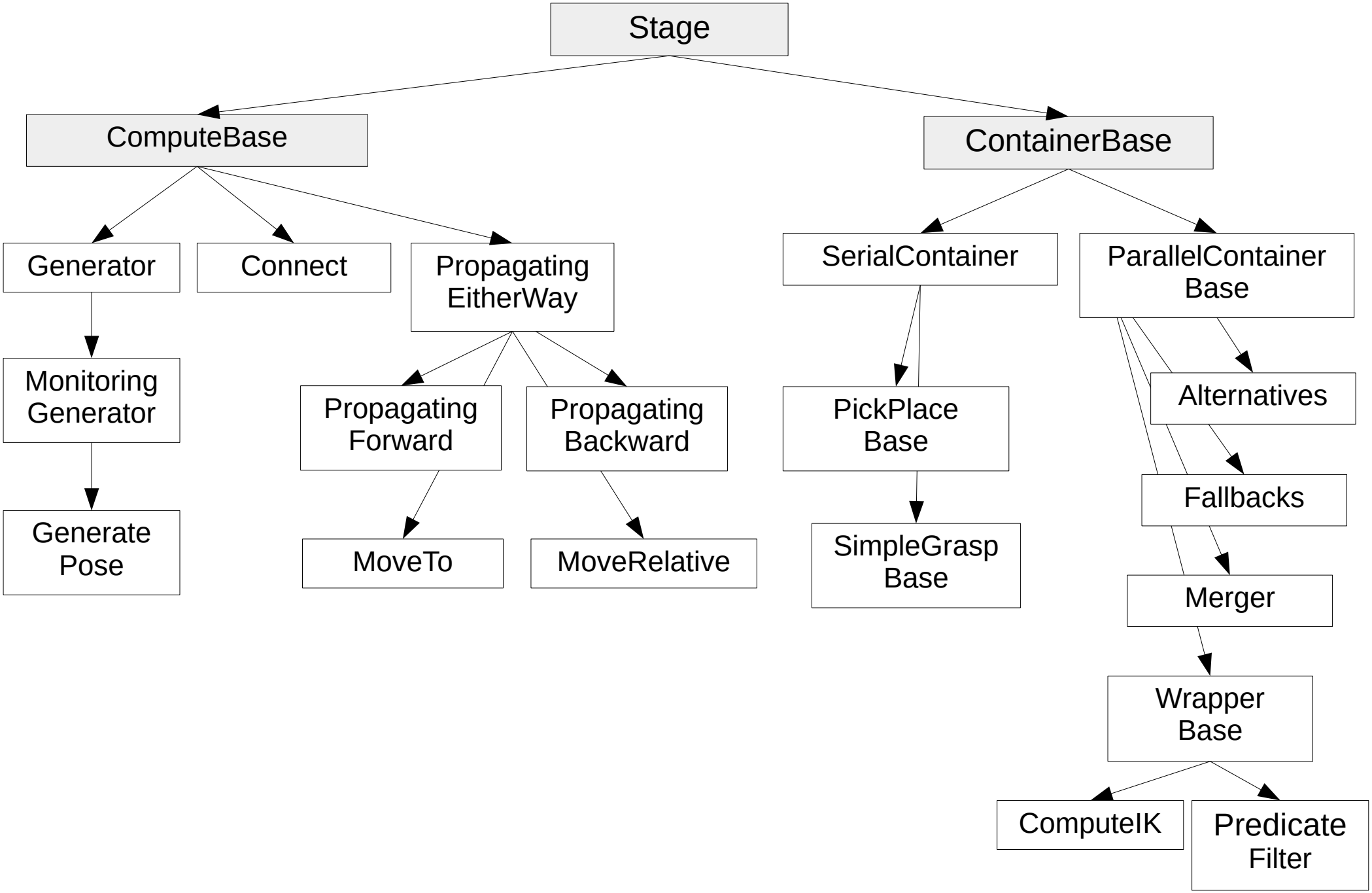
```
$ roslaunch moveit_task_constructor_demo demo.launch &
$ rosrun moveit_task_constructor_demo modular
```

MonitoringGenerator

- Generator might need input from a remote stage
- Grasp/Place an object at the current position
- MonitoringGenerators
  hook into solutions of another stage



Stage Type Hierarchy



Providing Custom Stages

```
class MyStage : public PropagatingForward {
public:
   MyStage(string name);

   void computeForward(const InterfaceState& from) override
   {
      ...
      SubTrajectory solution(trajectory, cost, comment);
      solution.markers().push_back(marker);
      sendForward(from, move(end_scene), move(solution));
   };
};
```

Outlook: Envisioned Features

- Drop-In replacement for MoveIt‘s Pick+Place capability
- Interactive GUI
  - Configure + validate task pipeline in rviz
    - Save / load YAML
    - C++ / python code generation
- Execution Handling
  - Premature execution of planned sub tasks
  - Choose controllers for sub tasks (force control, servoing)
- Failure handling
    - Replan from current situation
    - Revert to previous stage

Scheduling

- Find „good“ solutions fast!
- Priority queues @ different levels
  - InterfaceState: remember best solution only
  - InterfaceStateList: sort by length and accumulated cost of partial solution
  - Stage scheduling (TODO)
    - Interface type
    - success rate
    - estimated computation time
- Compute stages in parallel threads

Cost Functions

- Currently costs explicitly computed in stages
- Future: Provide set of cost functions to choose from
  - accumulated amount of joint-space / Cartesian motion
  - distance from preferred pose
  - clearance to obstacles
  - …
- Generic mechanism to set cost functions per stage
- Plugins?
- What are stage-specific useful defaults?

More Advanced Examples

- Pick + Place

```
$ roslaunch moveit_task_constructor_demo demo.launch &
$ roslaunch moveit_task_constructor_demo pickplace.launch
```

- Bimodal Pick + Place
  - Choose left or right arm based on costs
- Long-Distance Pick-and-Place with Handovers

  https://github.com/ubi-agni/mtc_demos
- Pouring

  https://github.com/TAMS-Group/mtc_pour