Hochschule
Bonn-Rhein-Sieg
University of Applied Sciences

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Institute for AI and Autonomous Systems

Conceptual Constraints

Uses for Cognitive Robots

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Master of Autonomous Systems

Structure

- What are conceptual constraints?
- An overview of applications of conceptual constraints
- Property-based robot testing

What are Conceptual Constraints?

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A conceptual constraint is a qualitative criterion that a robot should satisfy during learning or acting

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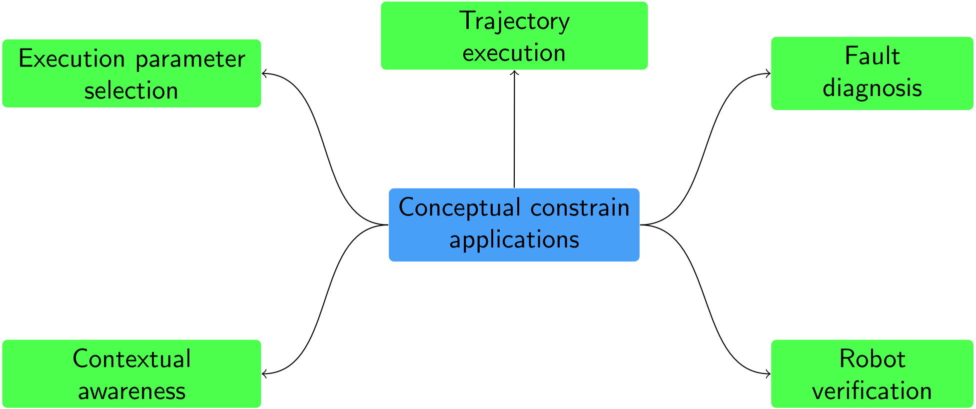
- The process of robot verification and validation is thus tightly intertwined with the use of conceptual constraints in a robot's execution process

An Overview of Applications of Conceptual Constraints

Conceptual Constrains Have Many Uses

There is a large number of problems in which qualitative constraints can be used



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  - **satisfies some explicit desirability criteria about the execution** (e.g. a glass should not be grasped too close to the rim)
- A side effect of associating the parameter selection process with conceptual constraints is that **the selection becomes explainable**
  - Explainability is particularly relevant when a robot closely cooperates with human partners

Modelling Execution Success Through Relations

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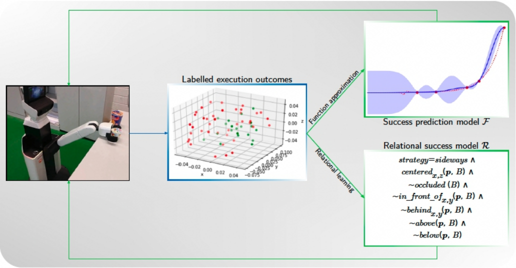

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- This is the objective of execution models:

$$\mathcal{M} = (\mathcal{R}, \mathcal{F})$$

- Here, $\mathcal{R}$ is a **conjunction of preconditions under which the execution has been observed to succeed**, while $\mathcal{F}$ models **how likely the execution is to succeed if given parameters are selected for execution**

- The precondition model is a set of constraints on the execution parameters

Parameter Sampling Using an Execution Model

Greedy execution parameter sampling

function $\textsc{sampleParameters}(\mathcal{M}, X, \boldsymbol{e}, \boldsymbol{c}, \epsilon_{\mathcal{M}}, \Sigma_{\tau}, \rho)$
    if $\boldsymbol{c} \neq \varnothing$ **then**
        $X \leftarrow \texttt{knn}(X, \boldsymbol{c})$
        $\boldsymbol{e} = \boldsymbol{e}_X$
    $\hat{\boldsymbol{\tau}} \leftarrow \varnothing$
    $sample\_found \leftarrow$ **false**
    while $sample\_found =$ **false do**
        $\hat{\boldsymbol{x}} \leftarrow \texttt{sample}(\mathcal{F}, X, \boldsymbol{e}, \epsilon_{\mathcal{M}})$
        $\hat{\boldsymbol{\tau}} \leftarrow \mathcal{N}(\hat{\boldsymbol{x}}, \Sigma_{\tau})$
        if $\texttt{verifyPreconditions}(\mathcal{R}, \hat{\boldsymbol{\tau}}, \rho)$ **then**
            $sample\_found \leftarrow$ **true**
    return $\hat{\boldsymbol{\tau}}$

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- Given an execution model, parameters can be sampled so that they (i) **maximise the execution success** and (ii) **do not violate the precondition model $\mathcal{R}$**
- The precondition model thus serves the purpose of **filtering out unsuitable execution parameters**

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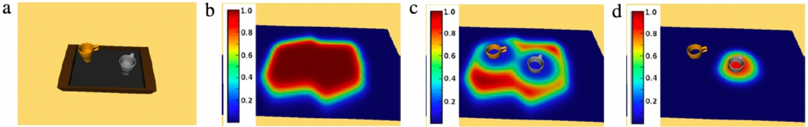
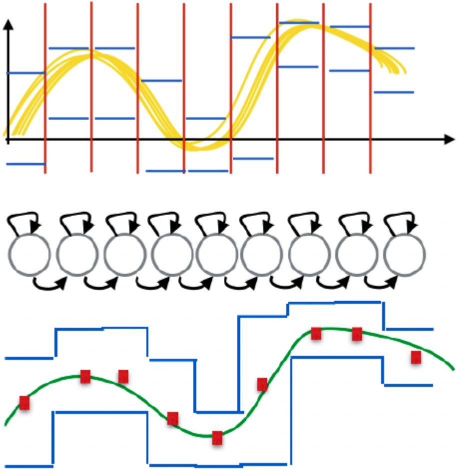


R. Dearden and C. Burbridge, "Manipulation Planning using Learned Symbolic State Abstractions," *Robotics and Autonomous Systems*, vol. 62, no. 3, pp. 355–365, 2014. Available: https://doi.org/10.1016/j.robot.2013.09.015

Trajectory Execution with Constraints



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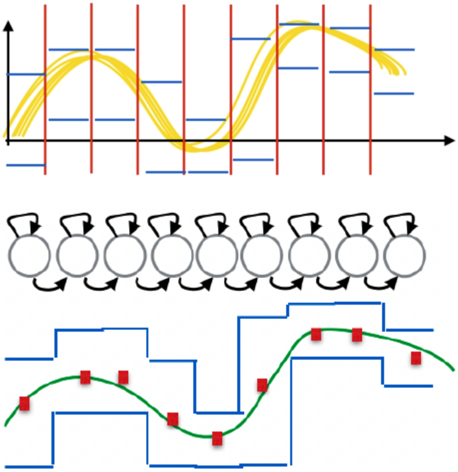

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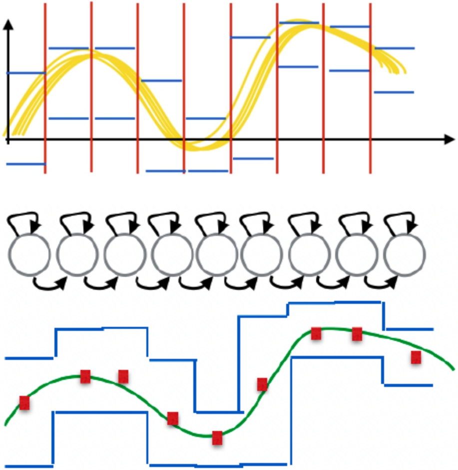

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- **Constraints can be used to detect failures during trajectory execution** — points that fall outside of the envelope can be used as indications of failures and can trigger a subsequent recovery behaviour

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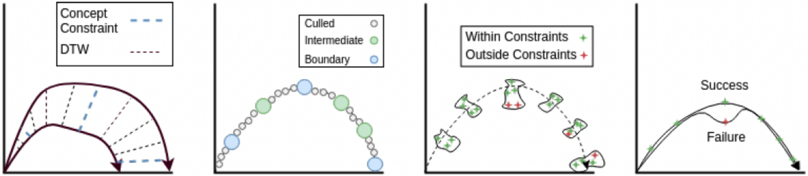

C. Mueller, J. Venicx and B. Hayes, "Robust Robot Learning from Demonstration and Skill Repair Using Conceptual Constraints," in *Proc. IEEE/RSJ Int. Conf. Intelligent Robots and Systems (IROS)*, 2018, pp. 6029–6036. Available: https://doi.org/10.1109/IROS.2018.8594133

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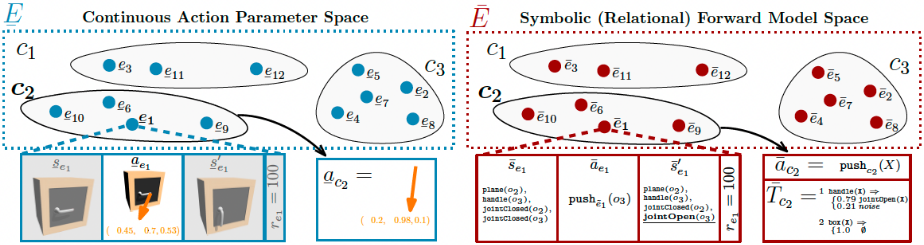

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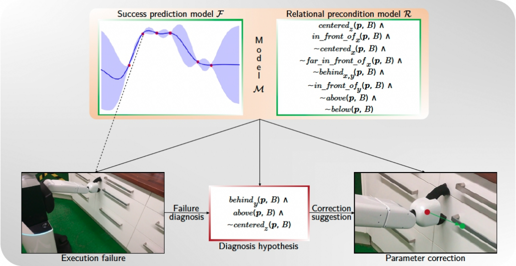

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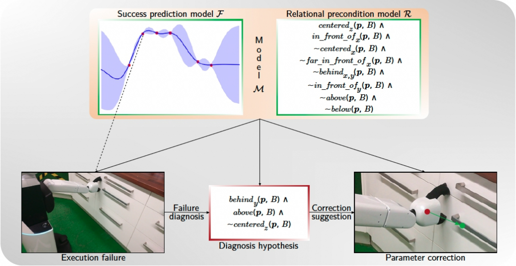

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- Similarly, the search for parameters that correct an execution failure can be informed by conceptual constraints — by **preventing correction candidates that do not satisfy the qualitative preconditions**

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Property-Based Robot Testing

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- Property-based testing is a generalisation of unit testing, but is built with functional components in mind
- **Properties can be observed as conceptual constraints** that need to be satisfied and which are verified during the testing process

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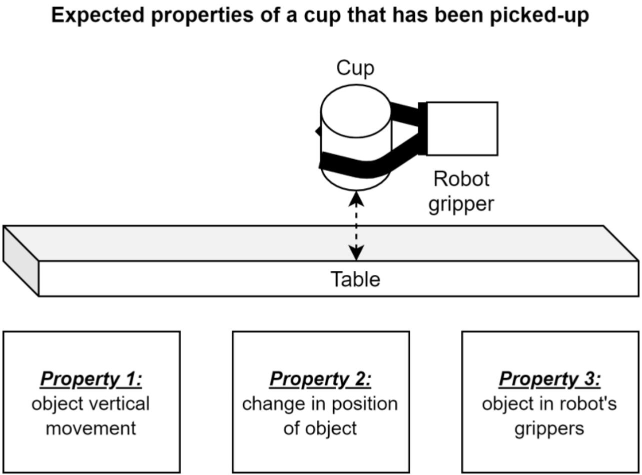
Properties Example: Object Grasping



S. O. Sohail, A. Mitrevski, N. Hochgeschwender and P. G. Plöger, "Property-Based Testing in Simulation for Verifying Robot Action Execution in Tabletop Manipulation," in *Proc. European Conf. Mobile Robots (ECMR)*, 2021, pp. 1–7. Available: https://doi.org/10.1109/ECMR50962.2021.9568837

Property-Based Testing Example

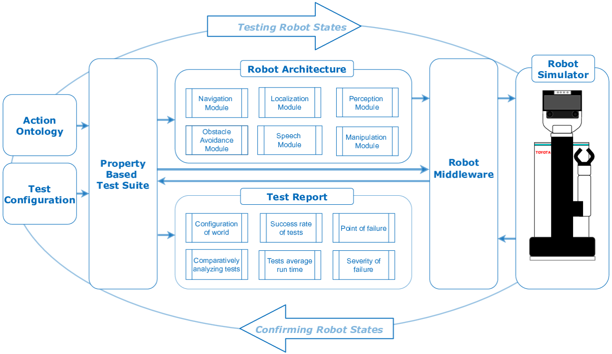
- The example[2] on the right illustrates a property-based testing program for a pick-and-place robot scenario
- Note: Programming languages have different libraries for property-based testing, but most of these are derived from the QuickCheck[3] library in the Haskell programming language

```
from hypothesis import given, strategies as st
@given(generate_placing_problem(generate_surface(),
                                st.integers(1, 10)),
       generate_grasping_problem(generate_surface(),
                                 st.integers(1, 10),
                                 choose_grasping_object()),
       position_robot())
def test_pick_and_place(placing_surface, objects_on_placing_surface,
                        grasping_surface, objects_on_grasping_surface,
                        object_to_grasp, robot_pose):
    localise_robot(robot_pose)

    grasp_result = grasp(object_to_grasp)
    assert object_in_gripper(grasp_result)
    for x in objects_on_grasping_surface:
        assert object_on_surface(x, grasping_surface)

    move_to(placing_surface)
    assert robot_at(placing_surface)

    place_result = place(object_to_grasp)
    assert object_on_surface(object_to_grasp, placing_surface)
    for x in objects_on_placing_surface:
        assert object_on_surface(x, placing_surface)
```

[2] Example using Hypothesis: https://hypothesis.readthedocs.io/en/latest/index.html

[3] QuickCheck: https://hackage.haskell.org/package/QuickCheck

Property-Based Testing in Simulation



S. O. Sohail, A. Mitrevski, N. Hochgeschwender and P. G. Plöger, "Property-Based Testing in Simulation for Verifying Robot Action Execution in Tabletop Manipulation," in *Proc. European Conf. Mobile Robots (ECMR)*, 2021, pp. 1–7. Available: https://doi.org/10.1109/ECMR50962.2021.9568837

- Property-based testing can be used to **facilitate simulation-based testing of robots** — for instance, to verify the successful execution of robot actions
- **The informativeness of testing depends on the ability to generate representative and exhaustive test scenarios**

Summary: Conceptual Constraints

- Conceptual constraints are criteria that are expressed qualitatively and which convey information about certain aspects of a robot's execution process
- There are a variety of uses of conceptual constraints, such as for execution parameter selection, trajectory execution, context-aware acting, as well as fault detection and diagnosis
- Conceptual constraints can also be used for robot testing, concretely in the case of property-based testing, in order to verify that a robot satisfies particular execution requirements