ROS Utilization at the Intelligent Sustainable Technologies Division of the Georgia Tech Research Institute

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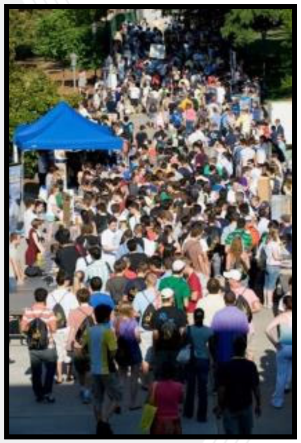
Georgia Institute of Technology









Georgia Tech Rankings

Undergraduate Engineering........ *#4*

Industrial, Manufacturing...................#1

Aerospace; Civil, Mechanical.............*#2*

Graduate Engineering................. *#8*

Industrial Engineering.................#1

Civil, Biomedical........................ #2

US News & World Report

Minority Engineering Degrees...... *#1*

Women's Engineering Degrees.... *#3*

AASE & Diverse: Issues In Higher Education

Faculty, Students & Organization

Academic Faculty......................... 1,564

Research Faculty......................... 2,427

Undergraduate Students.............16,047

Graduate Students......................16,674

Academic Colleges: Engineering, Computing, Sciences, Design, Liberal Arts, Business

Georgia Tech Research Institute (GTRI): 2,720 employees

FY19 Funded Research

Academic Sponsored Research... $408M

GTRI Sponsored Research......... $643M

Total Funded Research..............$1051M

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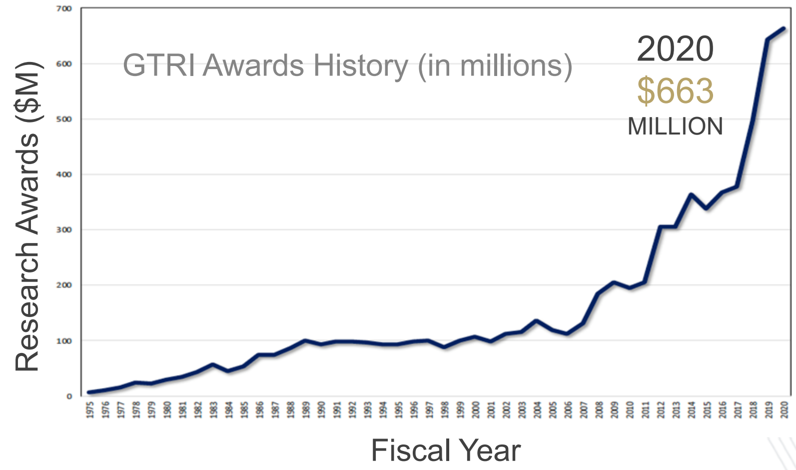
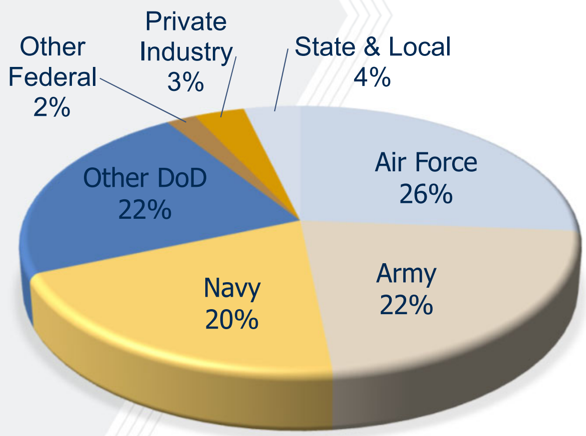
GTRI by the Numbers

Army's Largest University Affiliated Research Center (UARC)

- Second largest of 15 UARCs
- Operates under Federal Acquisition Regulation (FAR) 31.2
  - Non-profit electing to operate under cost principles for commercial organizations where fee is collected





FY20 Awards

FY20	GT	GTRI
Revenue Earned	$1.99B	$577M
Research Awards	$1.065B	$663M
Economic Impact to State	$3.35B*	$1.5B
Total Employees	9,017	2,720
Research Faculty	4,390	1,563

*FY19 number

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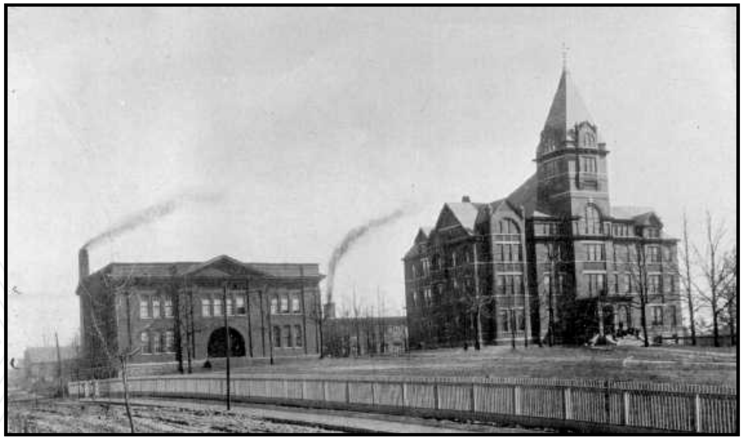
Georgia Tech History



Georgia Institute of Technology

- Founded in 1888
- Established to move the South from a purely agrarian to an industrial economy following the Civil War
- Evolved as one of the South's premier institutions for science and technology
- Origins fostered a culture of practical technology and economic development which is still pervasive today

Georgia Tech Research Institute (GTRI)

- Founded in 1934
- Established to help jump-start Georgia's struggling economy during the Great Depression
- Original focus was on applied technology applicable to engineering, manufacturing, agriculture and industry
- Evolved during Cold War to a primary focus on technology for national security

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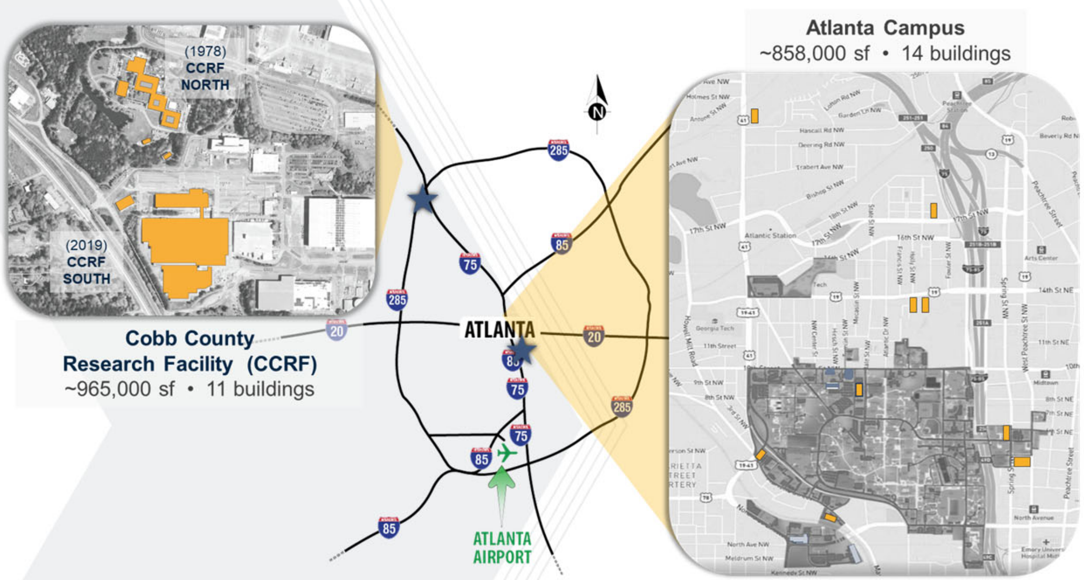
GTRI Locations and Field Offices



22 Field Offices

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Intelligent Sustainable Technology Division

ISTD develops advanced technology and systems to improve the human condition through transforming the agricultural and food systems, sustainable use and access to energy and water, and safety of people at work and from pandemics.

- 37 Research Faculty and 40 Students
- Research Focus
  - To develop and apply innovative technologies for the agribusiness, energy, and DoD in unstructured environments
    - Robotics
    - Sensing
    - Chemical sensing
    - Perception
    - Data analytics and machine learning
    - Energy capture and storage

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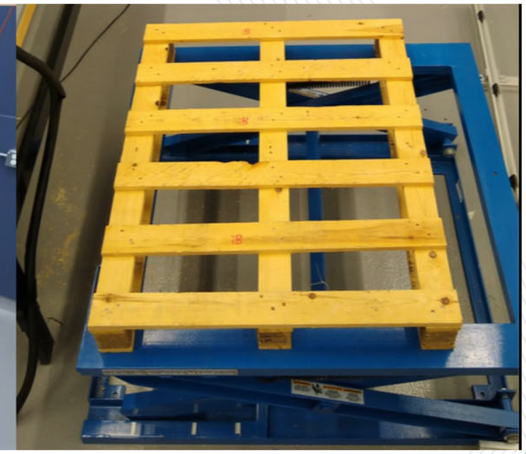
GTRI's Knowledge Driven Robotics (KDR)

Taking dumb robots and making them flexible, agile, and able to detect and correct for errors

- Many different domains and sponsors
- Two items in common:
  - Apply standardized KDR architecture and framework
  - Develop reusable components that have application across projects and domains
- Main areas of research
  - Autonomous architecture and planning systems
    - Standard interfaces for tasking and control
    - Concurrent operation of multiple systems
    - Robot/Vendor agnostic
  - Low-level controllers
    - High degree-of-freedom systems
    - Novel algorithms and control

ROS can help in many of these areas

Example System



- Environment:
  - Mix of known and unknown (but knowable elements)
  - Table with known location and dimensions
  - Randomly placed packages w/ AR-tags (unknown locations, unknown package mix)
  - Pallet of known dimensions and location (dimensions could also be unknown)
  - Mapping of AR-tag to package (includes dimensions and any constraints such as “this-side-up”)
- Ecosystem:
  - The environment plus one UR-5 and one UR-10 robot

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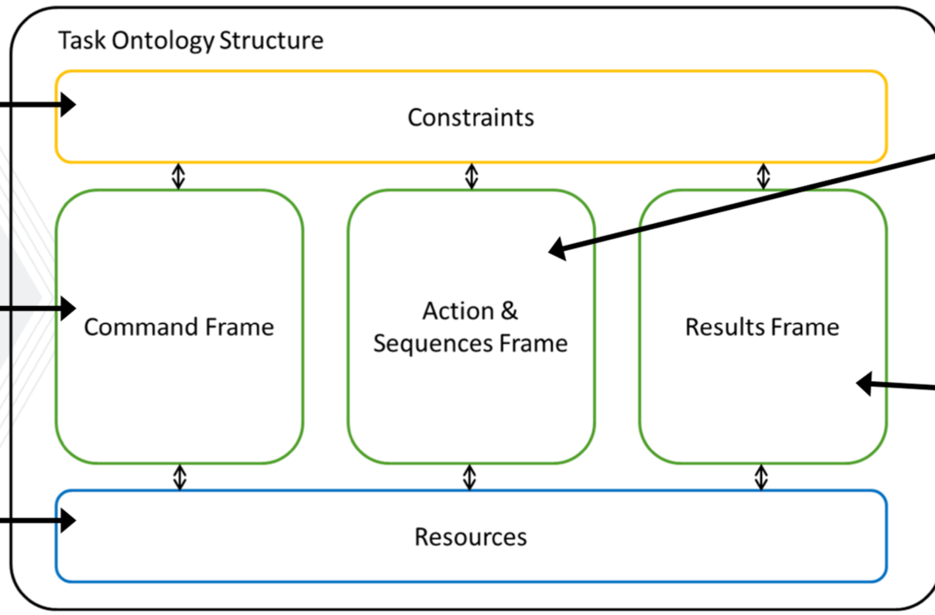
How do we task such a system: P1872.1 Task Frame Structure

Constraints specify limitations on actions that are performed in the completion of the task.

The Command Frame defines the job to be done.

Resources present the system with hardware/ software resources that may be utilized in the performance of the task.



Actions and Sequencing Frame defines the particular way the job must be accomplished.

Results Frame defines how the robot's performance of a task is evaluated.

Structure of the IEEE Robotics and Automation Society's Task Ontology

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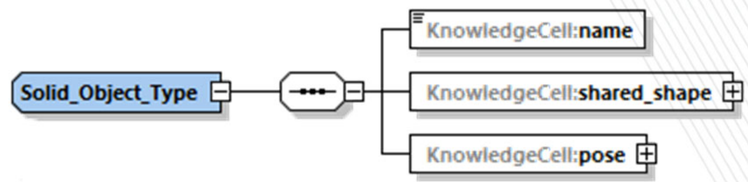
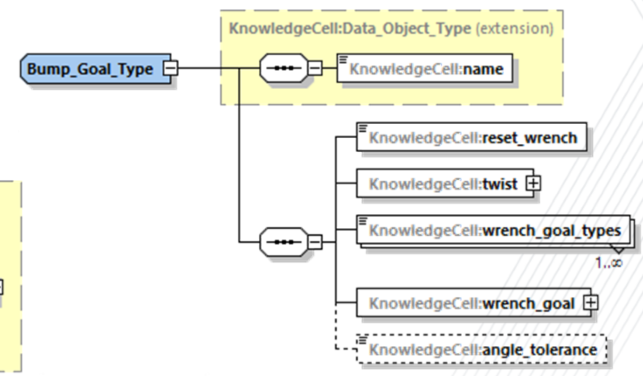
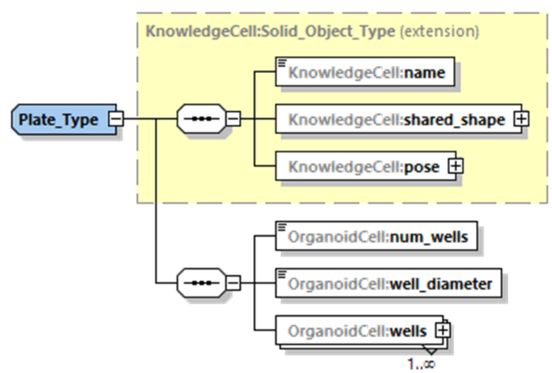
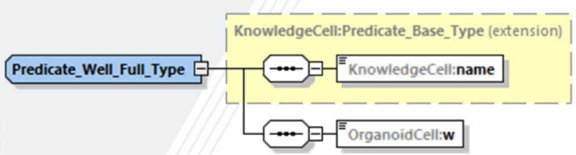
Knowledge Schemas

- Our schemas represent all of the information that is contained in the task frame
- Actions/Goals involve objects
  - Generic types that may be specialized
  - Specific types that are utilized across domains
  - Specific types that are utilized in a single domain
  - Includes predicates that are utilized as constraints and attributes









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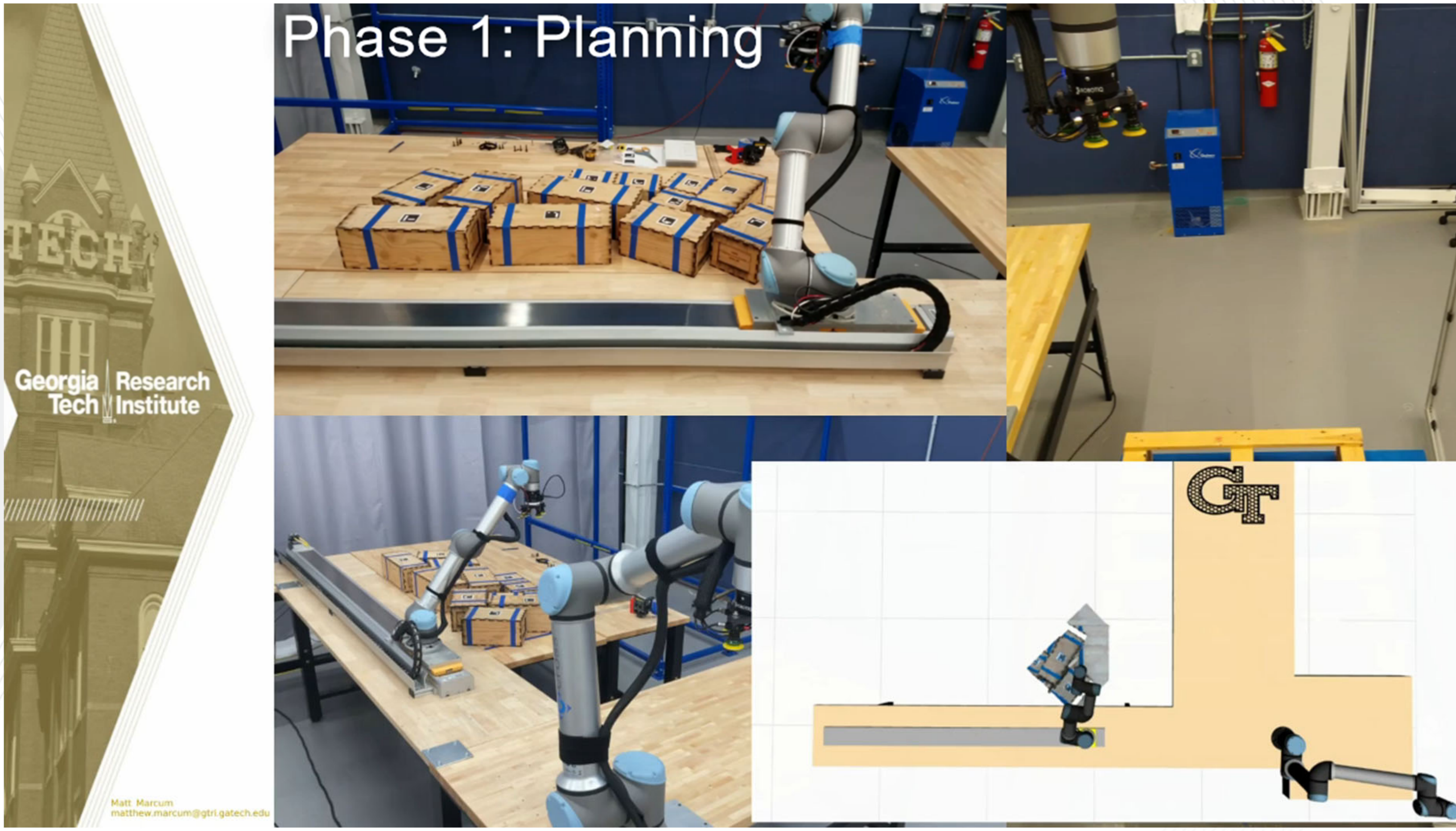
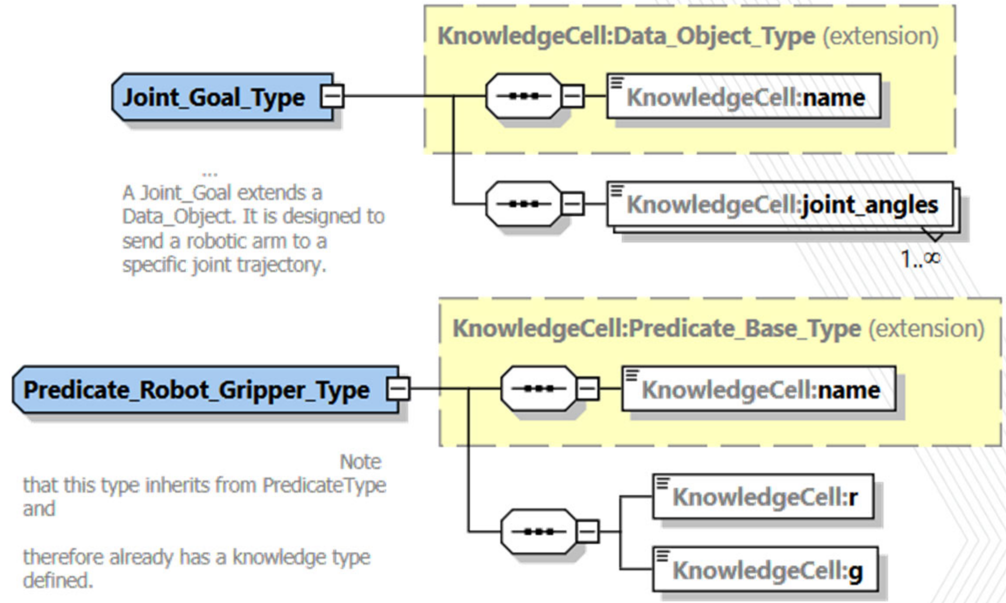
Example System

- Phase 1: Pallet Plan
  - Optimize pallet construction for given load out
- Phase 2: Knowledge Discovery
  - What boxes are available and where are they?
- Phase 3: Construction
  - Build the pallet according to the plan
  - Error detection
  - Two-arm concurrent operation
  - Coordination point utilized for arm sync



Low-Level Control: Actions



Operation(s) applied by an agent or team to affect a change in or maintain either an agent's state(s), the environment, or both.

- Actions extend “Data_Object”
- Predicates associated with instantiated objects. Used a precondition or effect clauses for actions
- Actions are implemented as ROS action services
  - Accepts logical predicates as input variables
  - Predicates grounded through database
  - Preconditions and effect allow for error detection
  - Action servers may call additional services and hardware interfaces

Action

- Command:

```
force_traj_move(robot, traj_name)
```

- PDDL:

```
(:durative-action force_traj_move
  :parameters (?r - robot ?t - force_traj)
  :duration ( = ?duration 10)
  :condition (and
      (at start (robot_free ?r))
      (at start (robot_initialized ?r))
      )
  :effect (and
      (at start (not (robot_free ?r)))
      (at end (robot_free ?r))
      )
)
```

- This allows us to create flexible, reusable, low-level actions
- Simple call from command line or ROSPlan

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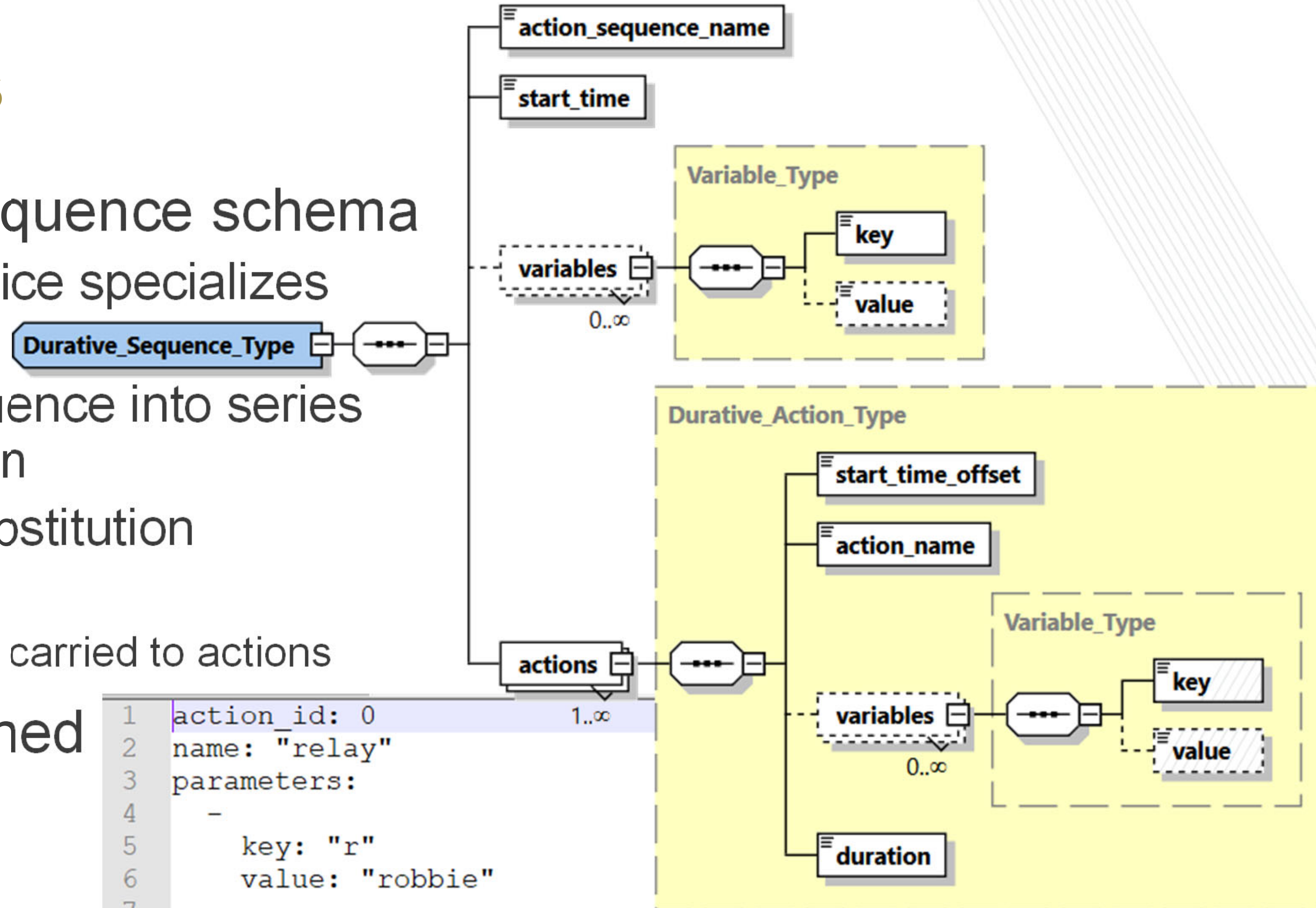
Action Sequences

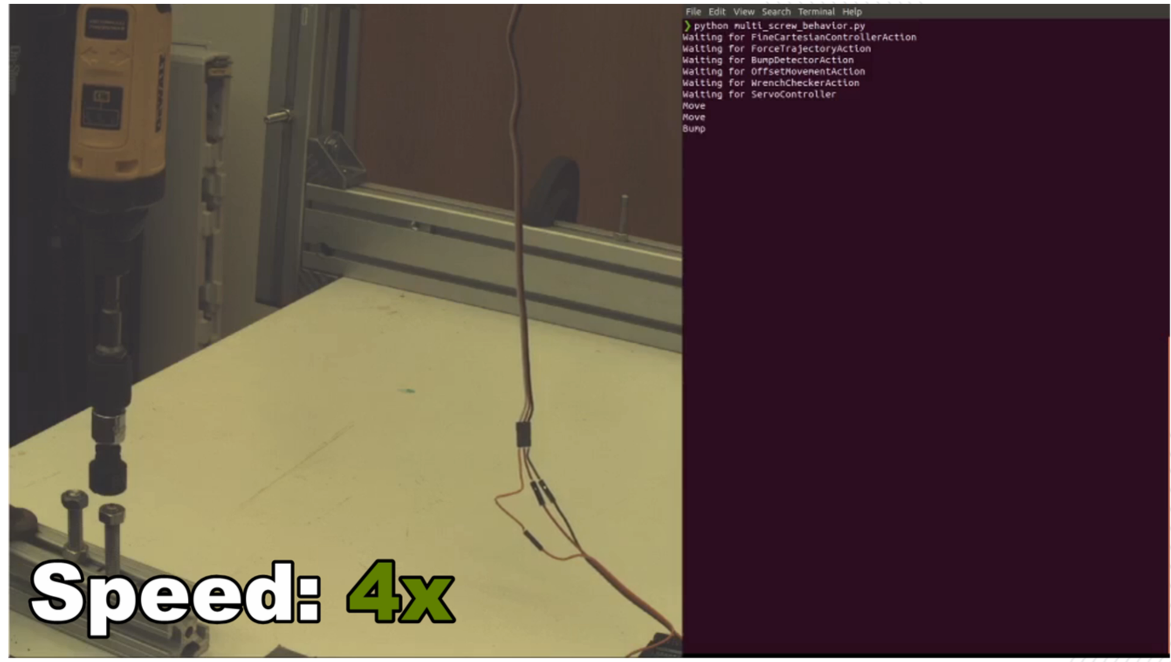
- Based off of action sequence schema
  - Templated action service specializes from schema
  - Service converts sequence into series of actions for execution
  - Automatic variable substitution
    - Constants supported
    - Sequence parameters carried to actions
- Sequences are designed to be reusable
  - May be designed by domain experts
  - May be created by a planning or AI system




```
action_id: 0
name: "relay"
parameters:
  -
    key: "r"
    value: "robbie"
  -
    key: "a"
    value: "tool_release"
duration: 1.0
dispatch_time: 1.00100004673
---
```

Action Sequences

- Low level actions provide agility
- Sequences of actions provide complex behaviors with additional agility and flexibility
- Sequences also have constraints, parameters, and evaluation criteria
- Behaviors may be modified by simply changing the XML file




```
0: (traj_move bolt_1 pos_z_offset)
1: (bump_move small_neg_z_bump)
2: (force_traj push_z_no_wait)
3: (activate_driver activation)
4: (offset_move rotate_on)
5: (wrench_check moment_thresh)
6: (force_traj push_z_wait)
7: (offset_move rotate_off)
8: (activate_drive deactivation)
9: (traj_move bolt_1 pos_z_offset)
```

Behavior: remove_bolt(bolt_1)

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Sample Action Sequence

action_sequences

action_sequence_n	pick_part
start_time	0

variables (4)

	key
1	"r"
2	"g"
3	"p"
4	"from"

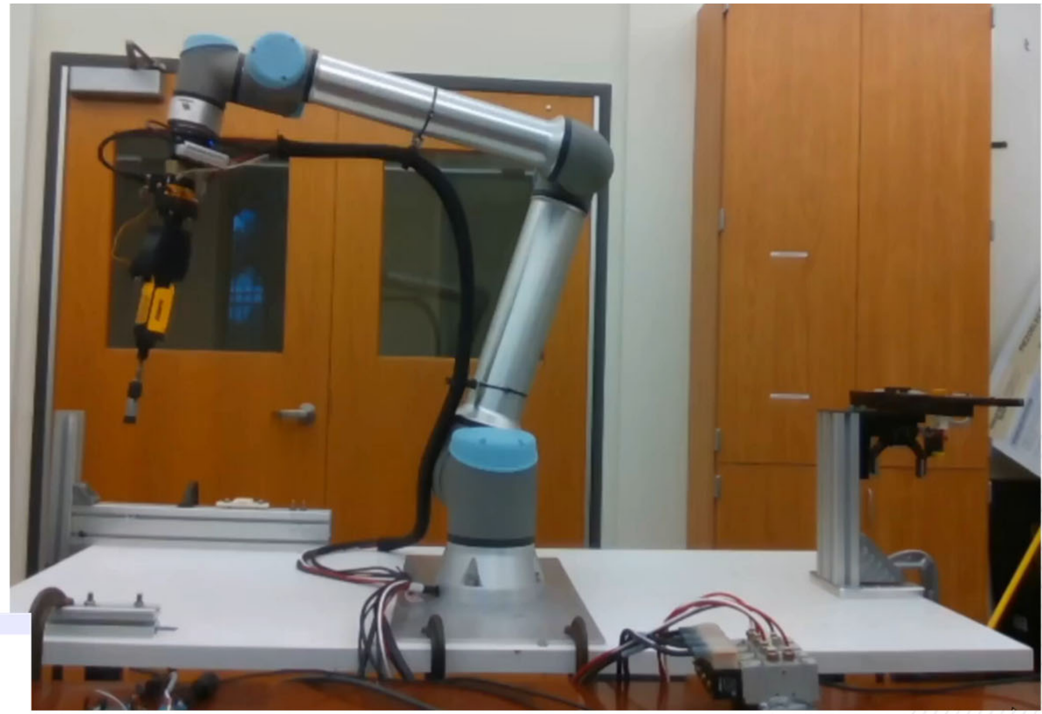
actions (4)

	start_time_offset	action_name	variables	duration
1	0	move	variables (5): 1 "r"; 2 "from"; 3 "small_pos_z_offset"; 4 "g"; 5 "motion_scaling_medium"	10.000
2	10.001	bump	variables (2): 1 "r"; 2 "small_pos_z_bump"	10.000
3	20.002	vacuum_effector	variables (2): 1 "r"; 2 "vacuum_start"	1.000
4	21.003	move	variables (5): 1 "r"; 2 "from"; 3 "large_pos_z_offset"; 4 "g"; 5 "motion_scaling_slow"	10.000

Sequence Composition/ High-Level Planning

- All sequences have constraints and results
- This allows for an AI planning system to chain sequences together to move a system from the current world state to a goal state

```
0.000: (init robbie)  [1.000]
1.001: (switch_area robbie unknown_area tool_area)  [11.000]
12.002: (attach_end_effector robbie socket_driver socket_driver_pick)  [33.000]
45.003: (switch_area robbie tool_area work_area)  [11.000]
56.004: (unfasten robbie part_1 part_1_hole_1 socket_driver)  [53.000]
109.005: (fasten robbie storage_1 storage_1_hole_1 socket_driver)  [53.000]
162.006: (unfasten robbie part_1 part_1_hole_2 socket_driver)  [53.000]
215.007: (fasten robbie storage_1 storage_1_hole_2 socket_driver)  [53.000]
268.008: (switch_area robbie work_area tool_area)  [11.000]
279.009: (detach_end_effector robbie socket_driver socket_driver_place)  [23.000]
302.010: (attach_end_effector robbie vacuum_gripper vacuum_gripper_pick)  [33.000]
335.011: (switch_area robbie tool_area work_area)  [11.000]
346.012: (pick_part robbie vacuum_gripper part_1 loc_1)  [32.000]
378.013: (place_place robbie vacuum_gripper part_1 loc_2)  [32.000]
410.014: (switch_area robbie work_area tool_area)  [11.000]
421.015: (detach_end_effector robbie vacuum_gripper vacuum_gripper_place)  [23.000]
444.016: (attach_end_effector robbie socket_driver socket_driver_pick)  [33.000]
477.017: (switch_area robbie tool_area work_area)  [11.000]
488.018: (unfasten robbie storage_1 storage_1_hole_1 socket_driver)  [53.000]
541.019: (fasten robbie part_1 part_1_hole_1 socket_driver)  [53.000]
594.020: (unfasten robbie storage_1 storage_1_hole_2 socket_driver)  [53.000]
647.021: (fasten robbie part_1 part_1_hole_2 socket_driver)  [53.000]
700.022: (switch_area robbie work_area tool_area)  [11.000]
711.023: (detach_end_effector robbie socket_driver socket_driver_place)  [23.000]
734.024: (finish robbie part 1)  [1.000]
```



- This allows us to create agile, flexible, reusable, plans
- New behaviors provide new capabilities to system
- Provides error detection and correction

Novel Control: Dual Arm Path Planning

- Connect different levels of behavior in a single operating system
- Allows for easy swapping between modules that serve similar functions
  - Programs run separately
  - Communication is easily redirected

State Machine

- Dictates behavior of the system based on external stimulus

Path Planning

- Determines how the robots should move in order to achieve cooperative motion

Control

- Maintains the desired state

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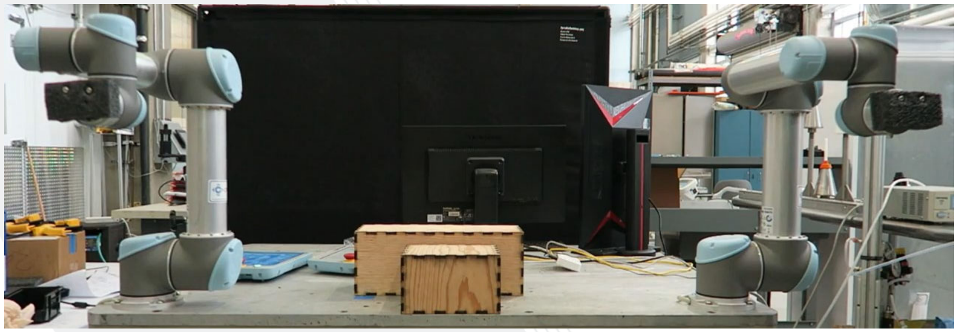
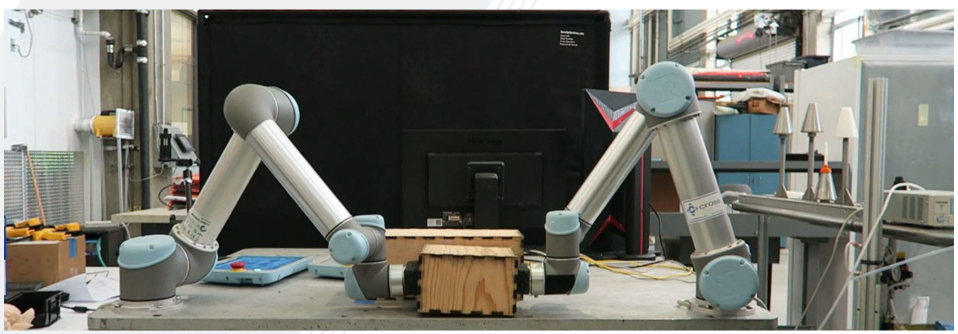
Duel Arm State Machine (One controller, multiple configurations)

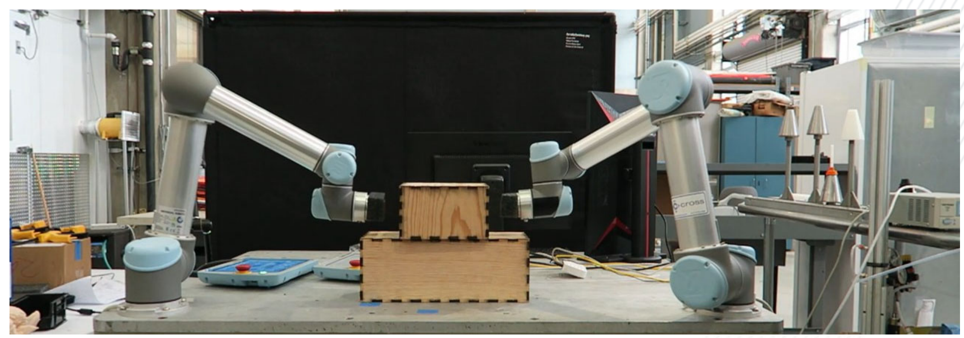


State 1: Move to approx. position (Cartesian Constraint)

State 2: Move to fixed separation (Distance Constraint)



State 3: Optimized high-DoF trajectory follow (Cartesian + Distance Constraint)



State 4: Disengage (Cartesian Constraint)

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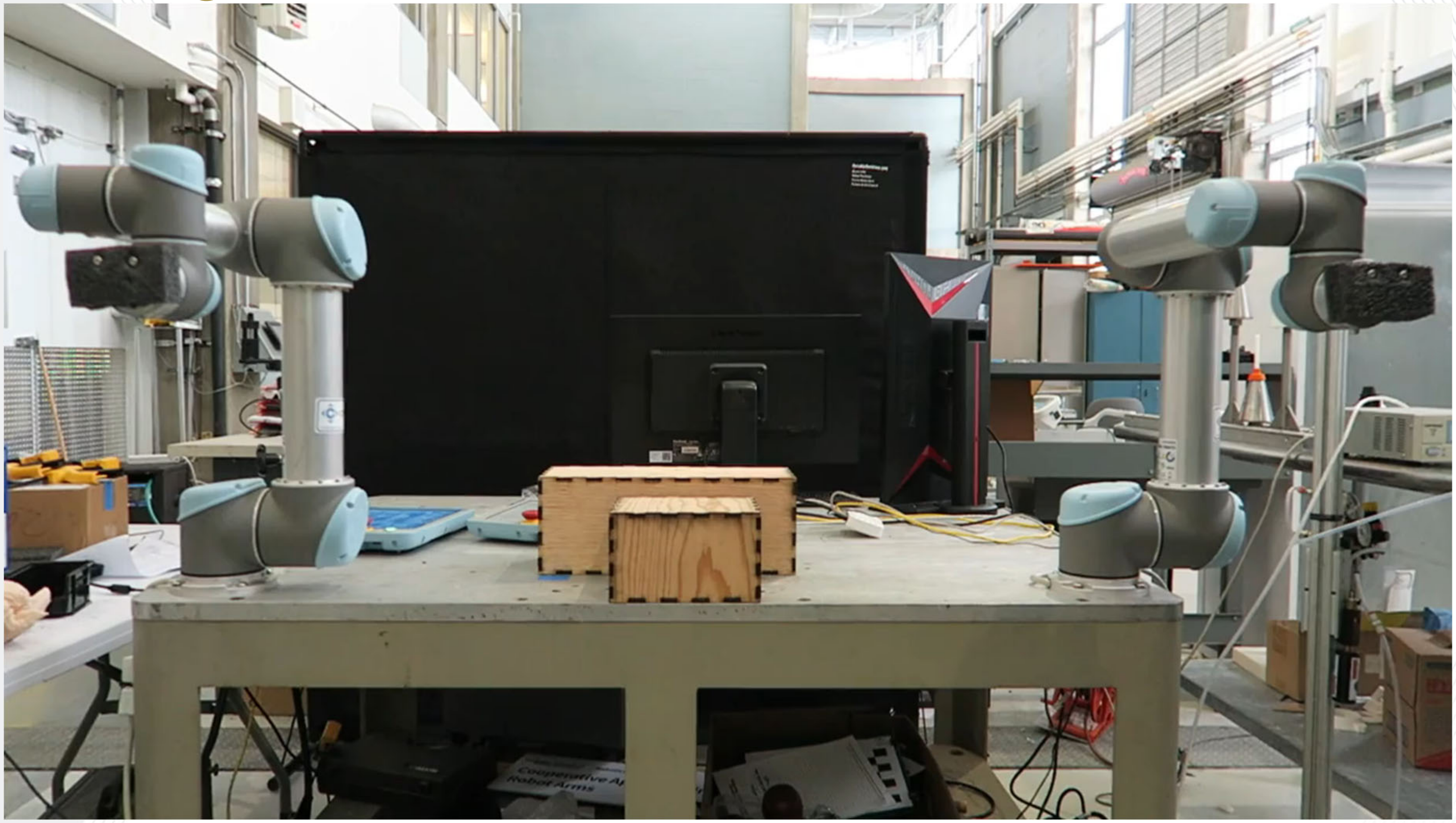
Box Moving



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Summary

- ROS has allowed:
  - Significant reuse of our services
  - Utilization of advanced open source algorithms
  - Robot agnostic implementation framework
  - The implementation of an approach that provides agility, flexibility, ease of reuse and programming, and the ability to provide for error detection and correction