An Introduction to Team ViGIR's Open Source Software and DRC Post Mortem

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Outline

- Intro
  - The DRC
  - Team ViGIR
- (ROS based) Infrastructure
- System Overview
- DRC Finals
- Lessons Learned

The DARPA Robotics Challenge

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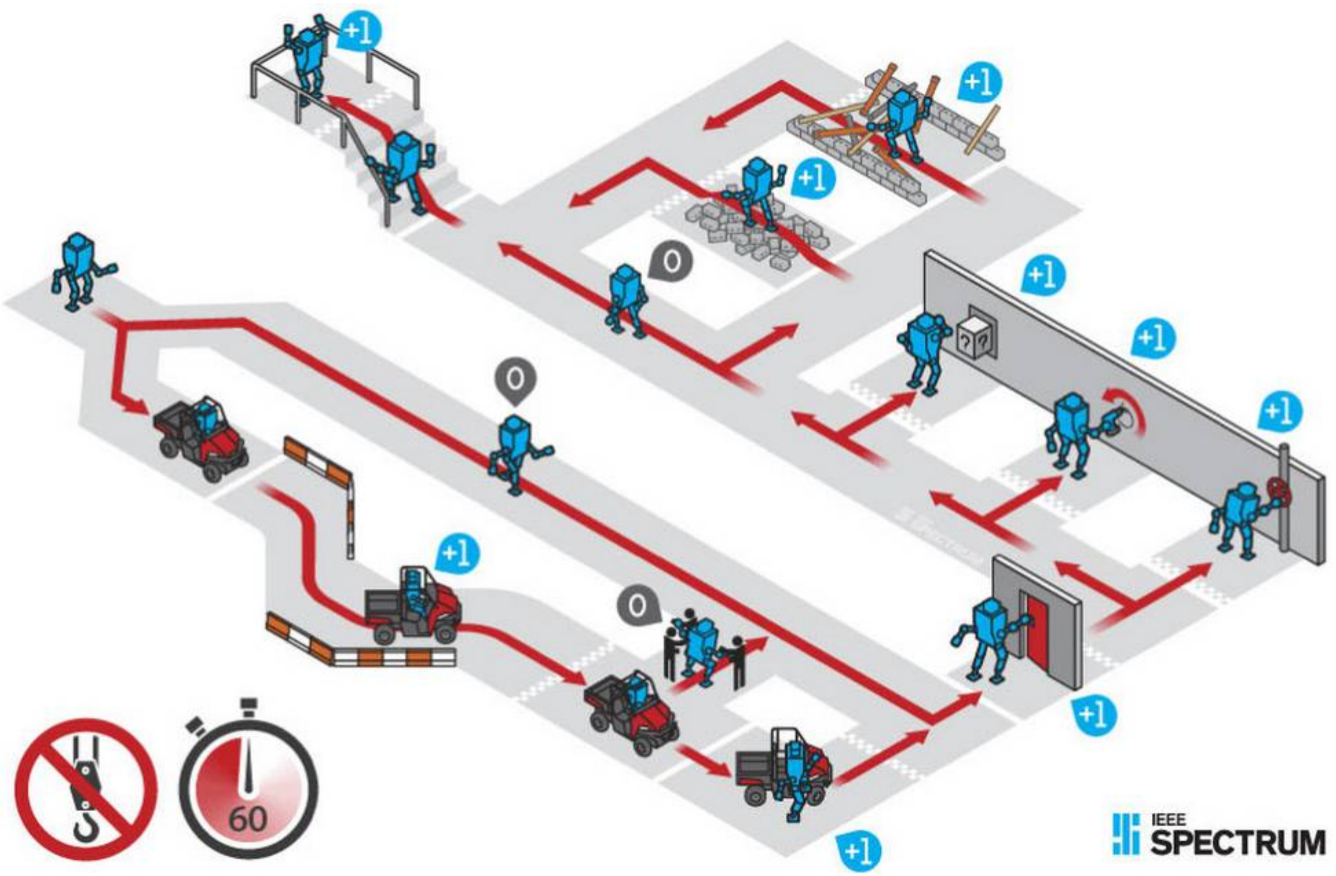
...close study of the disaster's first 24 hours, before the cascade of failures carried reactor 1 beyond any hope of salvation, reveals clear inflection points where minor differences would have prevented events from spiraling out of control.

IEEE Spectrum, November 2011 pg. 36. (online version)

DRC – Tasks and Rules



IEEE Spectrum

The “C” in DRC

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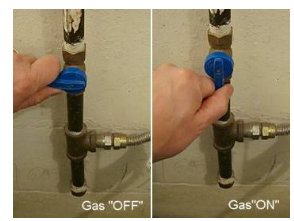
- Uneven terrain, stairs and ladders
- Motions with multiple contacts (e.g. getting out of a vehicle)

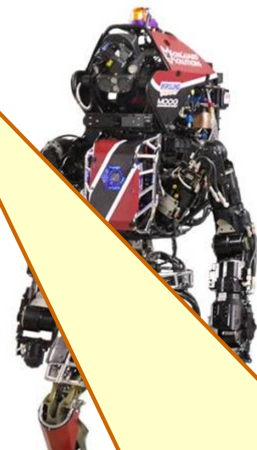
Versatile and robust

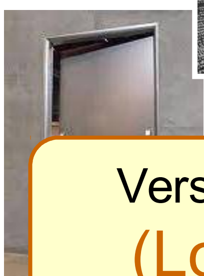
(Loco-)Motion



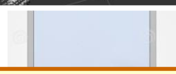
The “C” in DRC

Versatile and robust
Perception





Versatile and robust
(Loco-)Motion



- Perceive Environment for locomotion
- Perceive objects for manipulation
- Ability to acquire new objects and their potential purposes on the fly
- Robustness to different lightning conditions

The "C" in DRC

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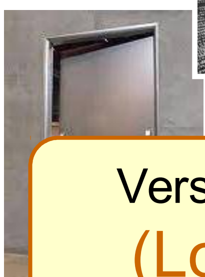
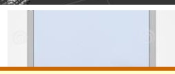
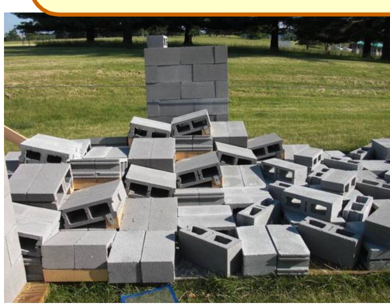



Versatile and robust
Perception

Versatile and robust
(Loco-)Motion

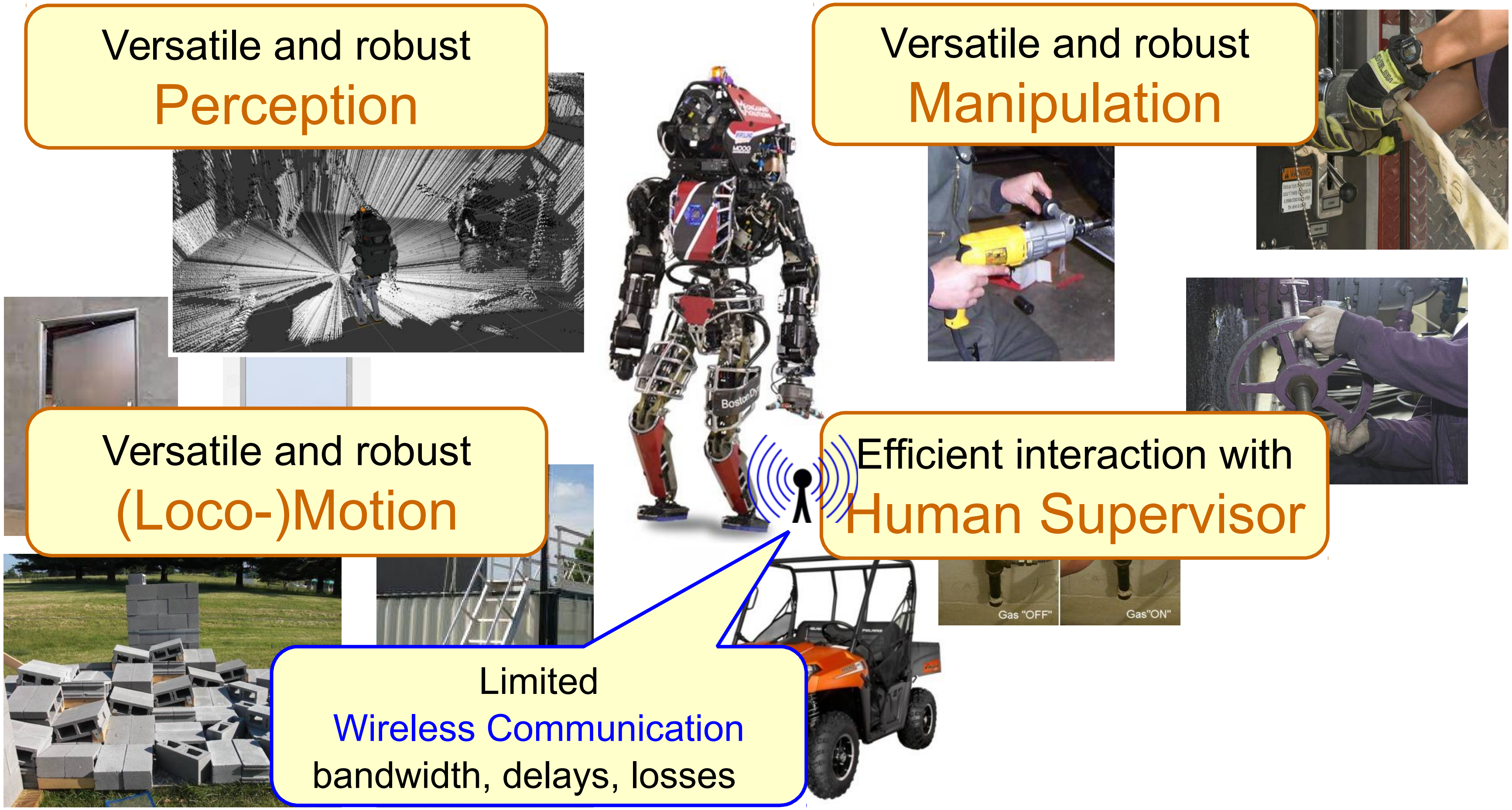



Versatile and robust
Manipulation



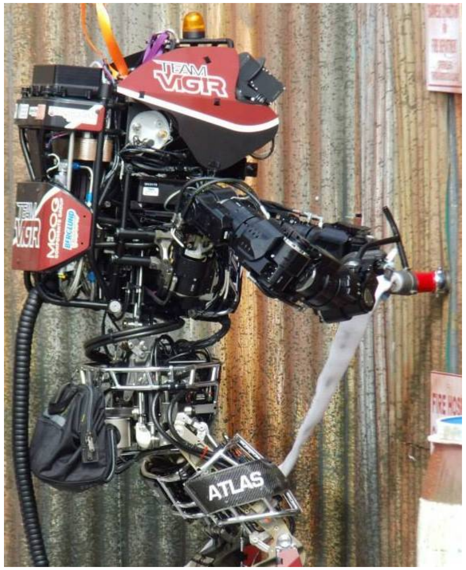
- Many different tools, only few exactly known in advance
- Acquiring new manipulation modes
- Ability to coordinate manipulation, locomotion & active perception

The “C” in DRC


Versatile and robust
Perception
Versatile and robust
Manipulation
Versatile and robust
(Loco-)Motion
Efficient interaction with
Human Supervisor
Gas "OFF"
Gas"ON"
Limited
Wireless Communication
bandwidth, delays, losses

DRC - The Meta-Challenges

- Highly compressed timeline
- Multiple competition events
  - VRC (June 2013)
  - Trials (Dec 2013)
  - Finals (June 2015)
- Systems integration
- High reliabilty
  - Only few attempts at tasks



Team ViGIR

International collaboration, Track B Atlas team. VIrginia Germany Interdisciplinary Robotics

- TORC Robotics (Blacksburg, VA)
- TU Darmstadt (Darmstadt, Germany)
- Virginia Tech (Blacksburg, VA)
- Cornell University (Ithaca, NY)
- Leibnitz Universität Hannover (Hannover, Germany)
- Oregon State University (Corvallis, OR)

Team ViGIR

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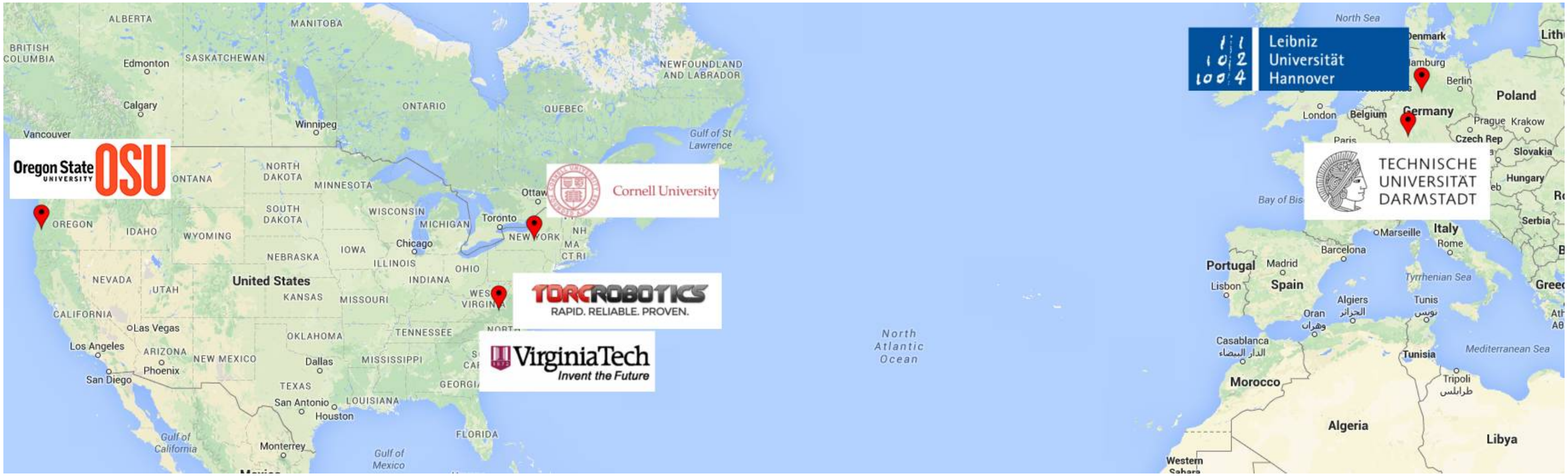

Team ViGIR

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- Track B team, DRC participation from day one
  - Virtual Robotics Challenge (VRC)
  - DRC Trials
  - DRC Finals
- Software available: github.com/team-vigir
  - Exceptions:
    - Robot controller
    - Comms bridge
- Other teams using ViGIR software at DRC Finals
  - HECTOR (SIM, TU Darmstadt)
  - VALOR (TREC, Virginia Tech)

Open Source Efforts by other DRC competitors

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- MIT:
  - Pronto State Estimator (pronto-distro github)
  - Drake Planning and Control (drake github)
  - Director UI (director github)
- IHMC:
  - IHMC Controller
  - SCS Simulator

  (ihmc_ros bitbucket)
- JSK:
  - Extensive ROS-based Software (jsk-ros-pkgs github)

Hardware

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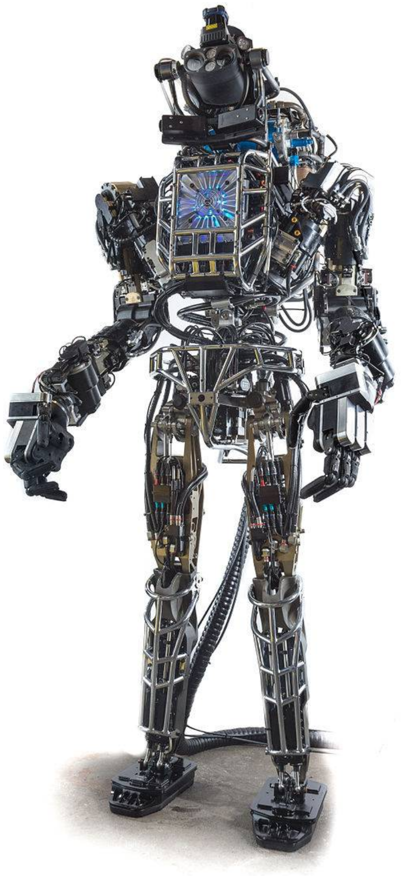
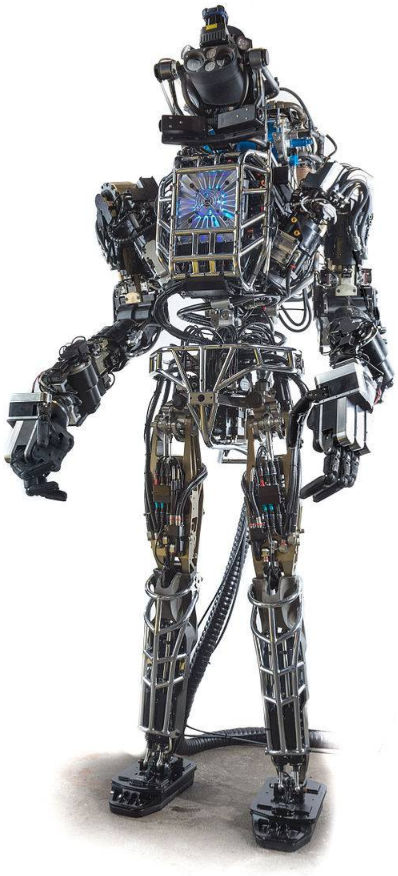
- Boston Dynamics (BDI) Atlas robot
  - Hydraulically actuated
- Our Atlas nicknamed "Florian" (after patron saint of firefighters)
- API provided by BDI
  - Walking/Stepping
  - Balancing
- → Upper body planning decoupled from low level balance control



Hardware – Atlas Versions

- Atlas V3 (2013–Nov 2014)
  - Tethered
  - 6DOF arms



Hardware – Atlas Versions

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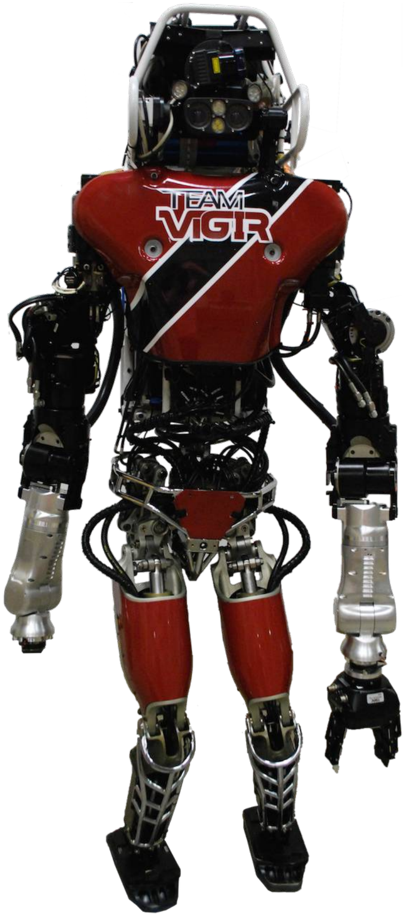
- Atlas V3 (2013–Nov 2014)
  - Tethered
  - 6DOF arms
- Atlas V4 (Feb 2015-Mar 2015)
  - Untethered
  - Onboard Computing
  - 6DOF arms

Hardware – Atlas Versions

- Atlas V3 (2013–Nov 2014)
  - Tethered
  - 6DOF arms
- Atlas V4 (Feb 2015-Mar 2015)
  - Untethered
  - Onboard Computing
  - 6DOF arms
- Atlas V5 (Apr 2015-Aug 2015)
  - As V4, but 7DOF arms (lower 3 joints electric)



Infrastructure

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- Use of ROS from the beginning
  - Prior experience
  - Great community
  - A lot of useful software
  - Integration with DRCsim
- Private git(lab) repos
  - Now moved to github
- Project management via Redmine
  - Every task in issue tracker
  - Hundreds of Wiki-pages

Timeline with a Focus on Infrastructure

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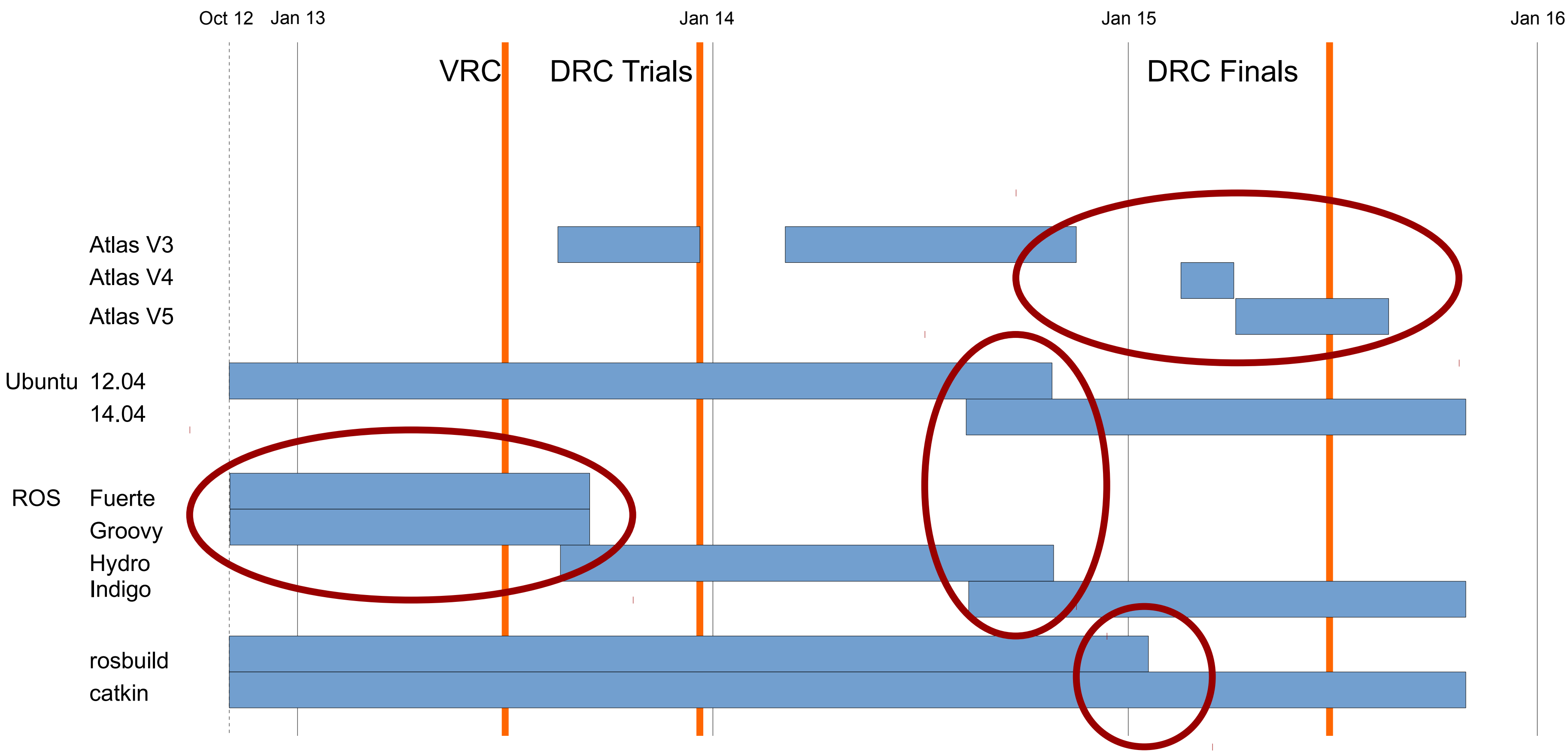

Infrastructure – Managing Robot Variability

- Many variants:
  - 3+ Atlas versions
  - 4 Hand types
- Could use args/params
  - Unwieldy to forward through launch files
- Use environments variables
- Generate robot model (and onboard software setup) at launch-time

```
filename="$(find atlas_description)/urdf/$(optenv VIGIR_ATLAS_ROBOT_TYPE atlas_v5)_simple_shapes.urdf"/>
filename="$(find atlas_description)/urdf/$(optenv VIGIR_ATLAS_ROBOT_TYPE atlas_v5).$(optenv VIGIR_SIM_TYPE
filename="$(find atlas_description)/urdf/$(optenv VIGIR_ATLAS_ROBOT_TYPE atlas_v5).transmission" />

filename="$(find atlas_description)/robots/multisense/$(optenv VIGIR_ATLAS_MULTISENSE_TYPE sim)_multisense

filename="$(find atlas_description)/robots/hands/$(optenv VIGIR_ATLAS_LEFT_HAND_TYPE l_stump).urdf.xacro" ,
filename="$(find atlas_description)/robots/hands/$(optenv VIGIR_ATLAS_RIGHT_HAND_TYPE r_stump).urdf.xacro"
```

github.com/team-vigir/vigir_atlas_common/blob/master/atlas_description/robots/vigir_atlas.urdf.xacro

Infrastructure – Deployment to multiple machines

- Complex system
  - 3 Onboard Computers
  - 1 Field Computer
  - 4 OCS Computers
- Fast development cycles
  - Build and deploy quickly and consistently
- Remotelaunch scripts
  - Build using catkin (install)
  - Deploy using rsync
  - Start using ssh/screen

github.com/team-vigir/remotelaunch

Infrastructure – Deployment to multiple machines

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- 01_theoden_robot.sh
- 02_boromir_robot.sh
- 03_eowyn_robot.sh
- 04_legolas_robot.sh
- 05_pippin_robot.sh
- env.sh

Launch scripts for each machine

```
#theoden
roslaunch vigir_atlas_bringup  common_parameters.launch
roslaunch vigir_atlas_controller atlas_robot.launch
roslaunch pgr_camera sa_cameras.launch
```

Common environment setup executed on each machine

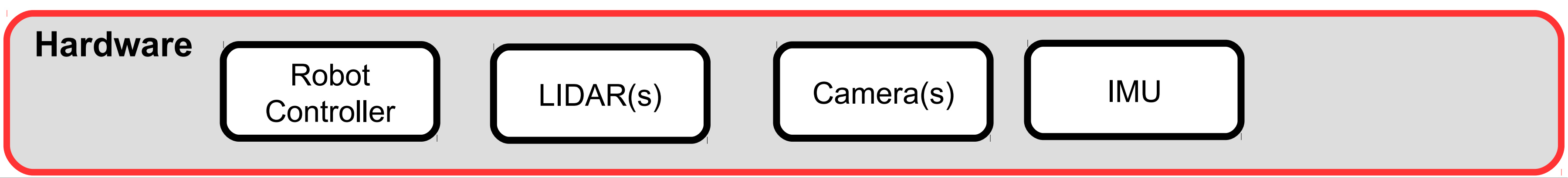
```
#!/bin/bash
# This code will be run in every screen on the remote machine. It is typically
# used to source ros and setup any other environment variables you need.
cmdline=("$@")
if [ $# == 0 ]; then
    cmdline=($SHELL -i)
fi

export VIGIR_ROOT_DIR=/home/user/vigir_repo
echo "sourcing catkin_ws................"
source "/home/user/vigir_repo/catkin_ws/install/setup.bash"
echo "sourcing scripts setup.bash.................."
source "/home/user/vigir_repo/scripts/setup/setup.bash"
shopt -s expand_aliases

exec "${cmdline[@]}"
```

Infrastructure – Simulation Options

- No single solution that can do everything currently available (as open source)
  - IHMC controller/Atlas with Gazebo integration to be released this fall

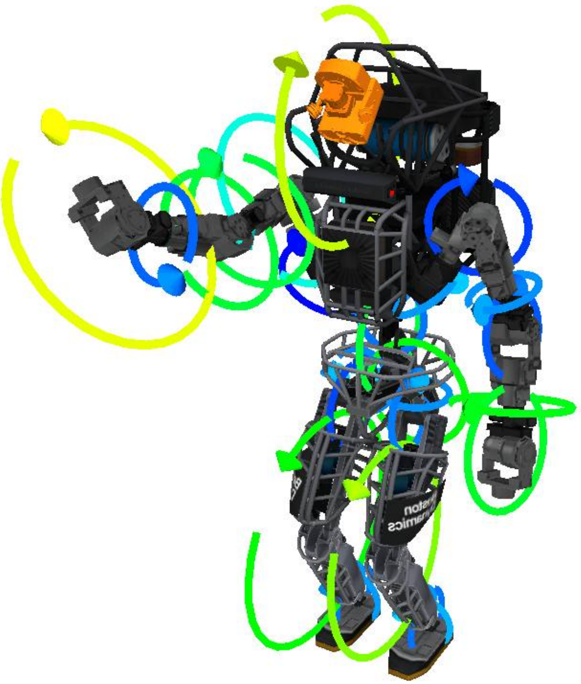
Simulator/Robot	Locomotion	Manipulation	Remarks
Atlas/BDI/DRCsim	(Yes)	No	Only with BDI lib
Atlas/IHMC/SCS	Yes	No	
Atlas/IHMC/DRCsim	(Yes)	(Yes)	Coming soon :)
Valkyrie/IHMC/DRCsim	(Yes)	(Yes)	Coming soon
Thor-Mang/Gazebo4	No	Yes	

Components - Controls

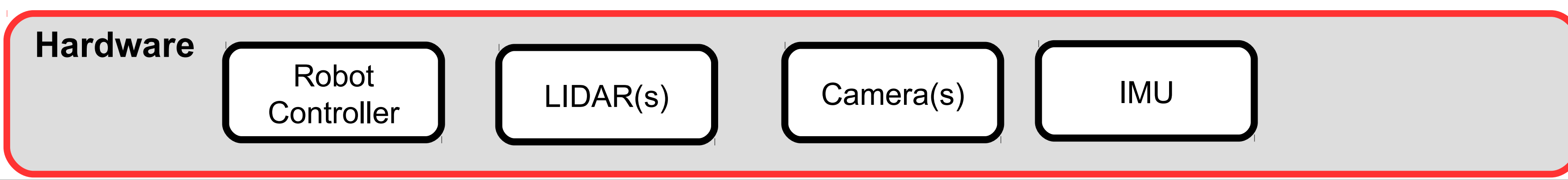


Controls

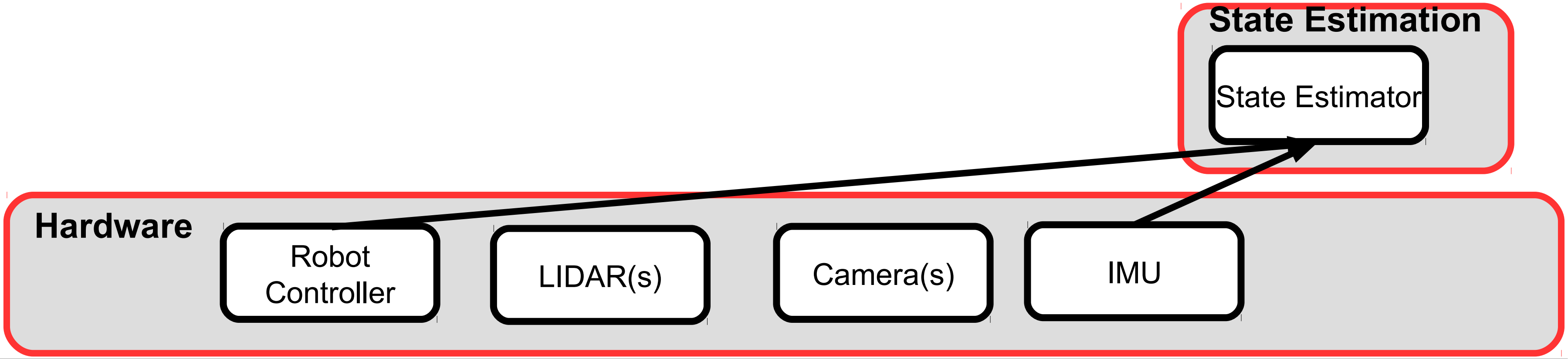
- Use of BDI supplied library
  - Walk (dynamic stability)
  - Step (static stability)
  - Manipulate (balance while standing)
- Provided as binary
  - Black box, no source (also for DRC teams)
  - Not available to general public :(
- Effort to integrate IHMC Whole Body controller
  - Use in competition prevented by time constraints/delays
  - Coming soon



Components – State Estimation



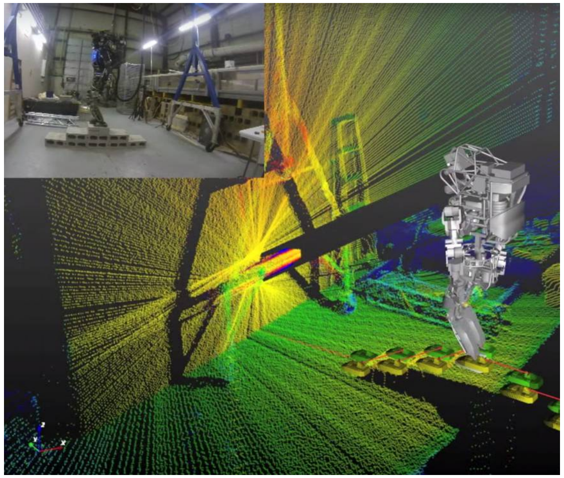
Components – State Estimation



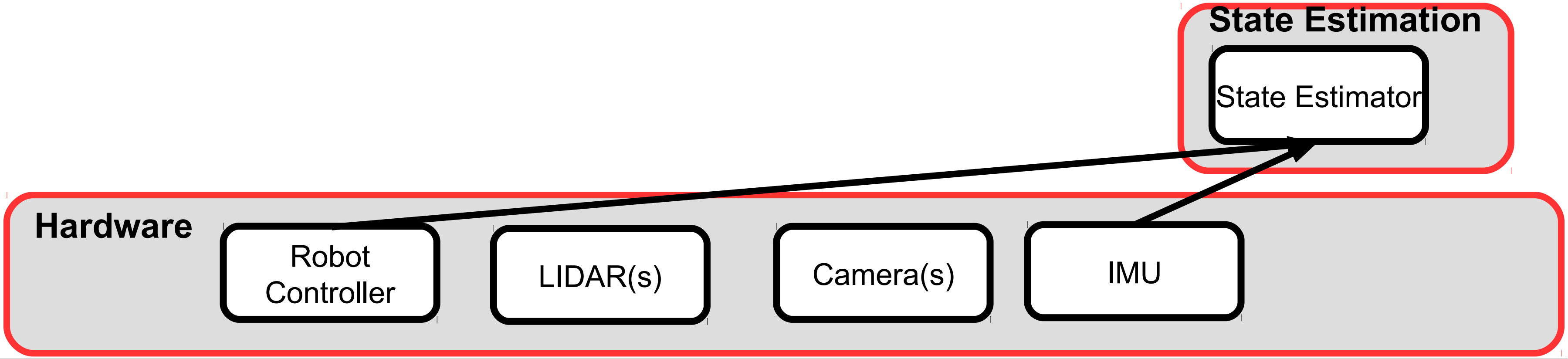
State Estimation

- Provide state (pose) estimate for robot
- Fuse
  - Leg Kinematics
  - IMU
- Continuous but drifting estimate
  - Low drift with good sensors
- Use MIT's pronto
  - Tuned for Atlas system
  - pod build system
  - LCM communications
- LIDAR use dangerous in non-static environment

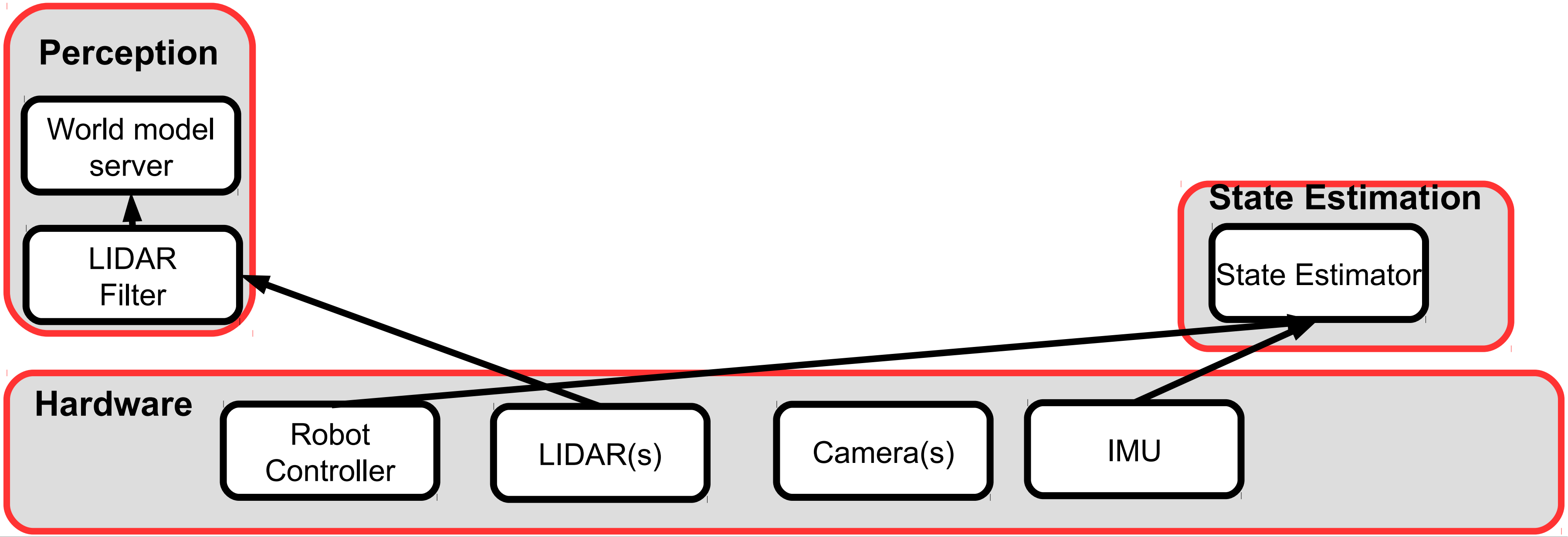
pronto-distro (ViGIR fork)



Components – Perception

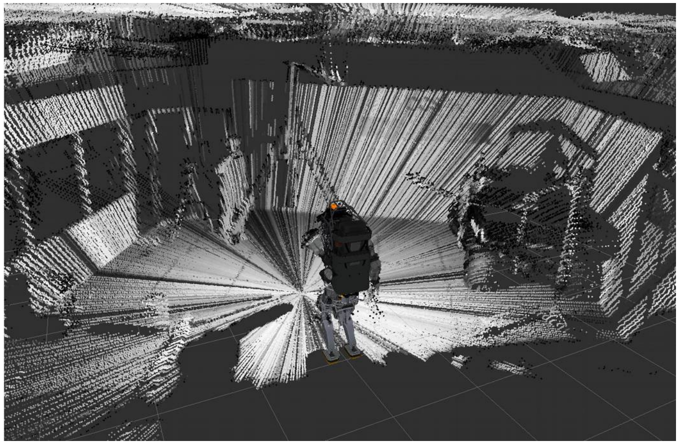


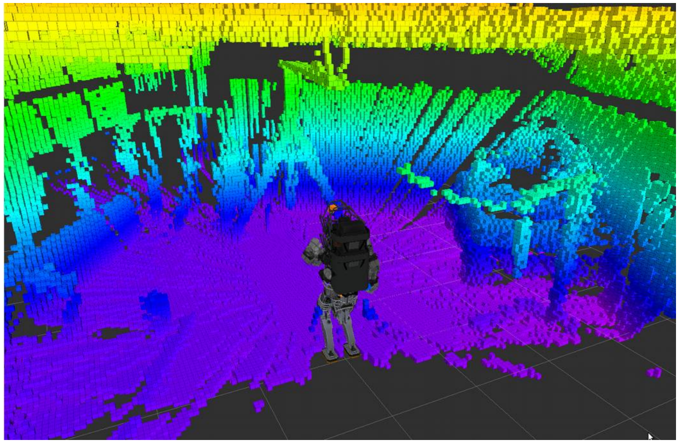
Components - Perception



Perception

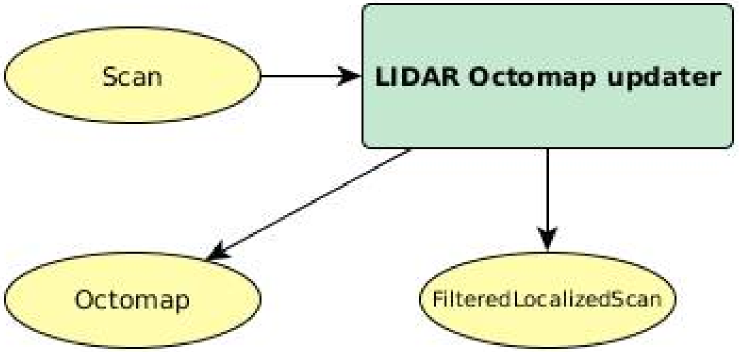
- Provide situational awareness for operator(s)
- Provide world state estimate for robot
  - Footstep planning
  - Manipulation





Perception - LidarOctomapUpdater

- Environment octomap updated in real-time
- Provide collision model for planner
- Also provide filtered LIDAR data for overall system
  - Annotate with transform information as tf prohibitive over constrained comms



github.com/team-vigir/vigir_manipulation_planning/tree/master/vigir_lidar_octomap_updater

Perception – Compressing LIDAR Data

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- Standard scan too big for 1500 Byte UDP limit

github.com/team-vigir/vigir_perception/tree/master/vigir_filtered_localized_scan_utils

Perception – Compressing LIDAR Data

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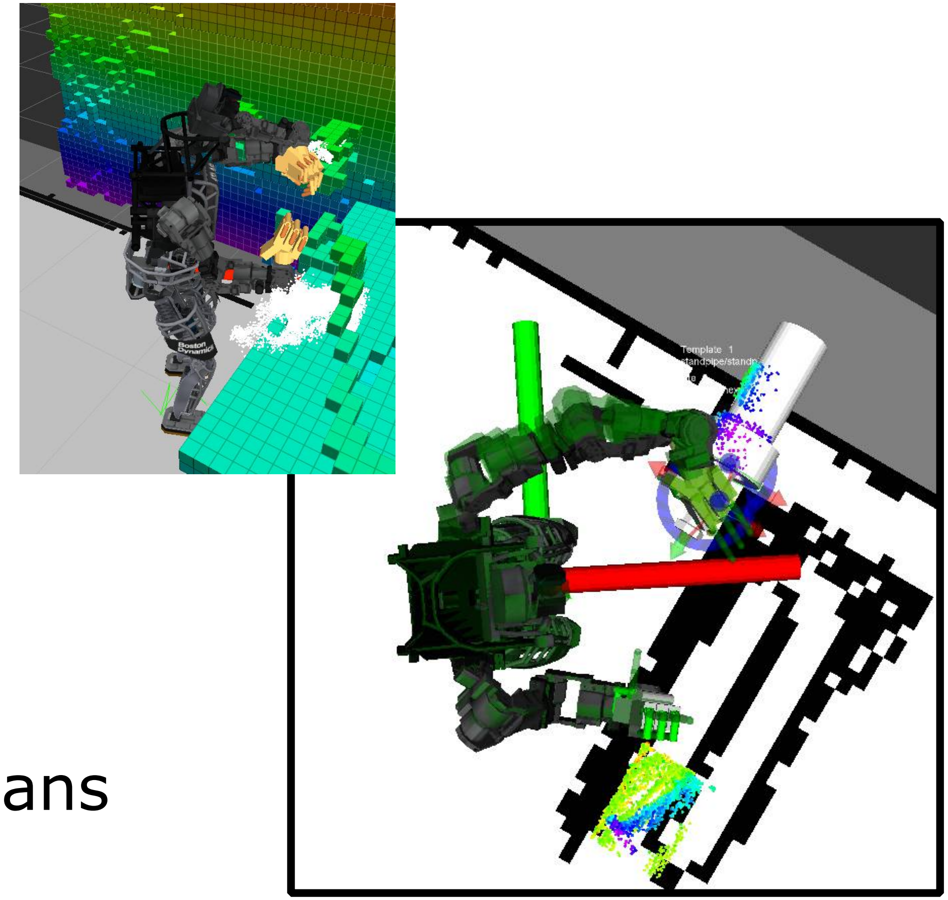
- Standard scan too big for 1500 Byte UDP limit
- Compress:
  - Split (3 separate scans)
  - Distances to uint_16
  - Intensities to uint_8
  - Self filter bit
- Add start/end global transform info
- Can reconstruct on OCS side
  - Every compressed scan usable standalone

github.com/team-vigir/vigir_perception/tree/master/vigir_filtered_localized_scan_utils

Perception – World Model Server

- Collect LIDAR data
- Provide services
  - Pointcloud ROIs
  - Octomap ROIs
  - Gridmap slice ROIs
  - Distance queries
- Two instances
  - Onboard
  - OCS
- Sync via compressed scans



github.com/team-vigir/vigir_perception/tree/master/vigir_worldmodel_server

Situational Awareness using Fisheye Cameras

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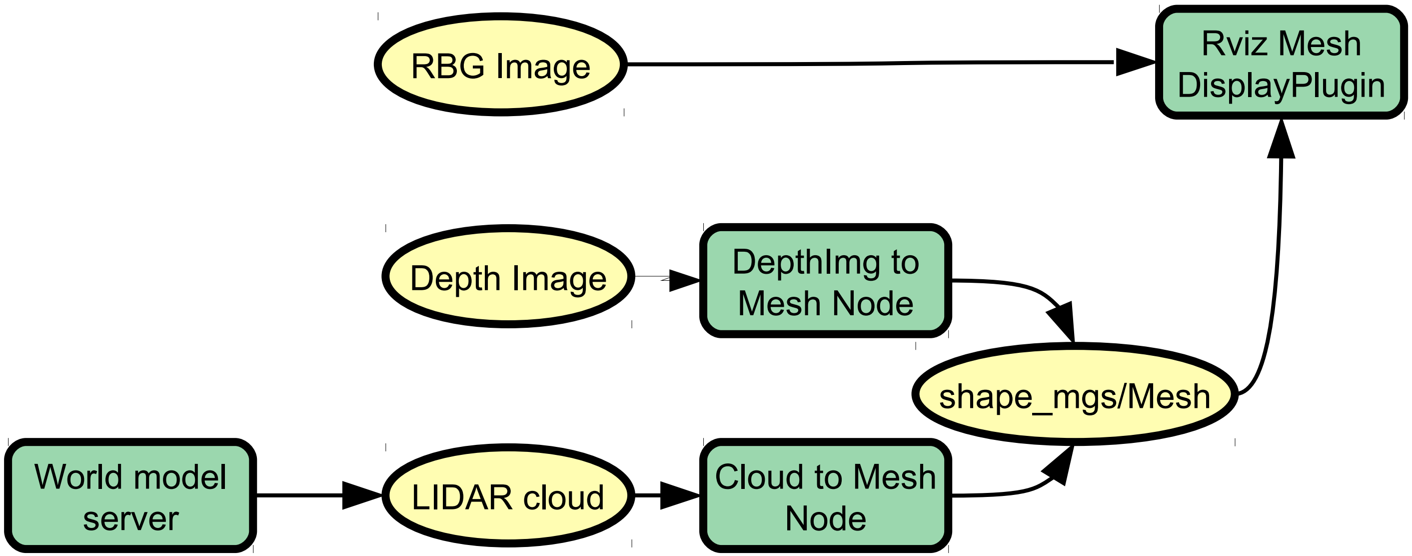
- Fisheye cameras provide high FOV
- Hard to interpret for humans
- Calibrate Fisheye cam using the ocamlib toolbox
- Virtual pinhole camera that follows tf frames

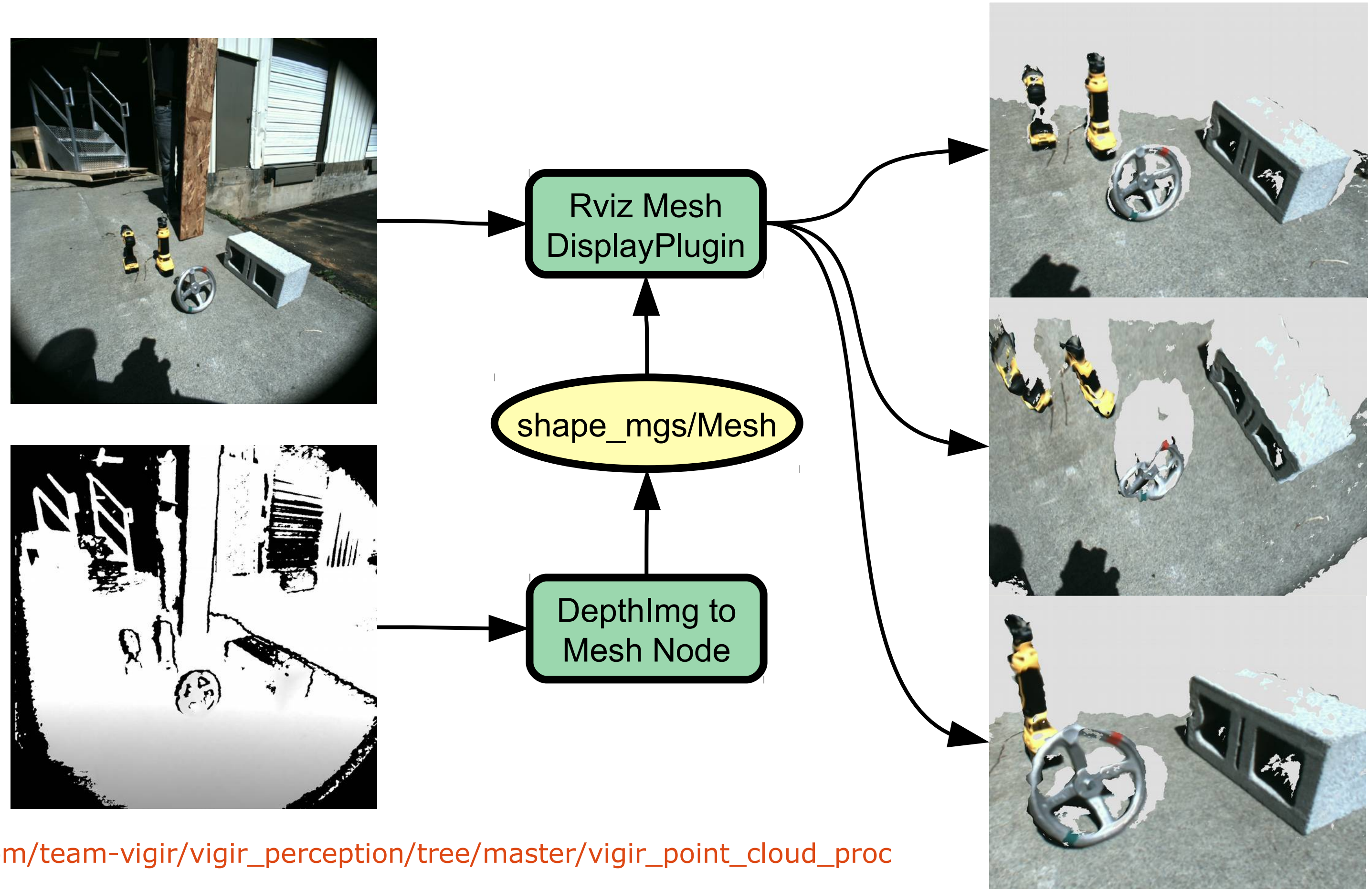
github.com/team-vigir/vigir_wide_angle_image_proc

Mesh Visualization

- Latest image data texture mapped onto mesh
  - Depth image-based: Fast update rate, low range
  - LIDAR-based: Low update rate, high range



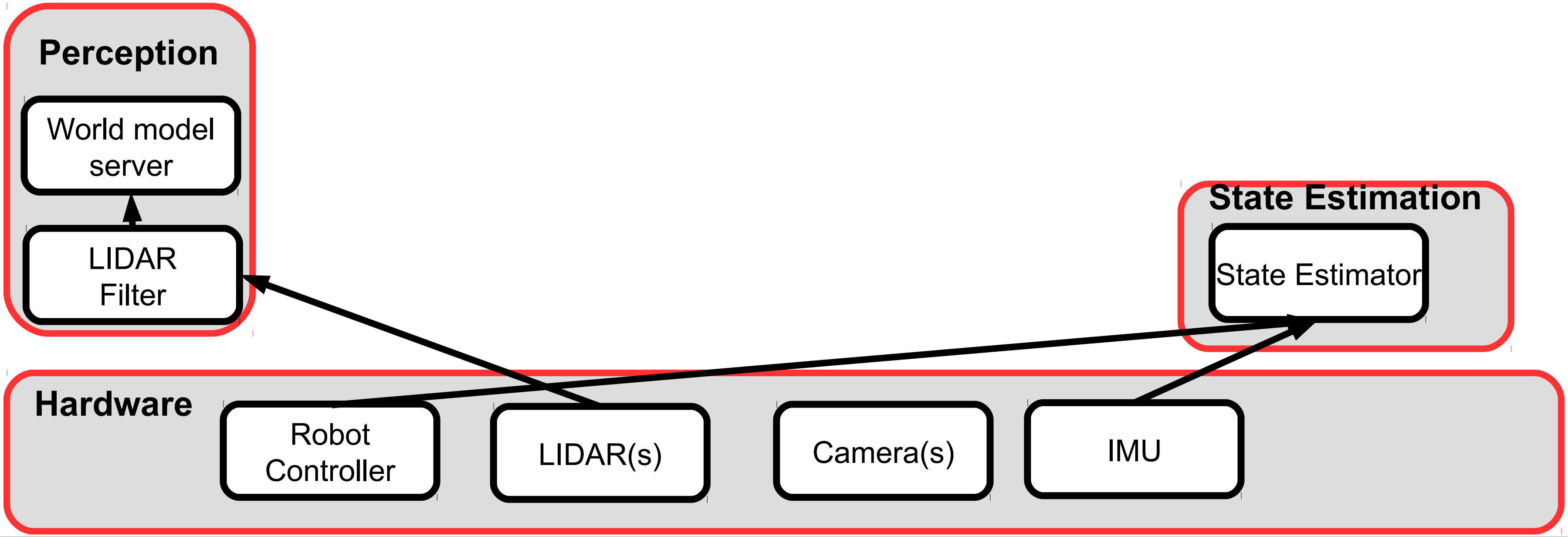
Mesh Visualization



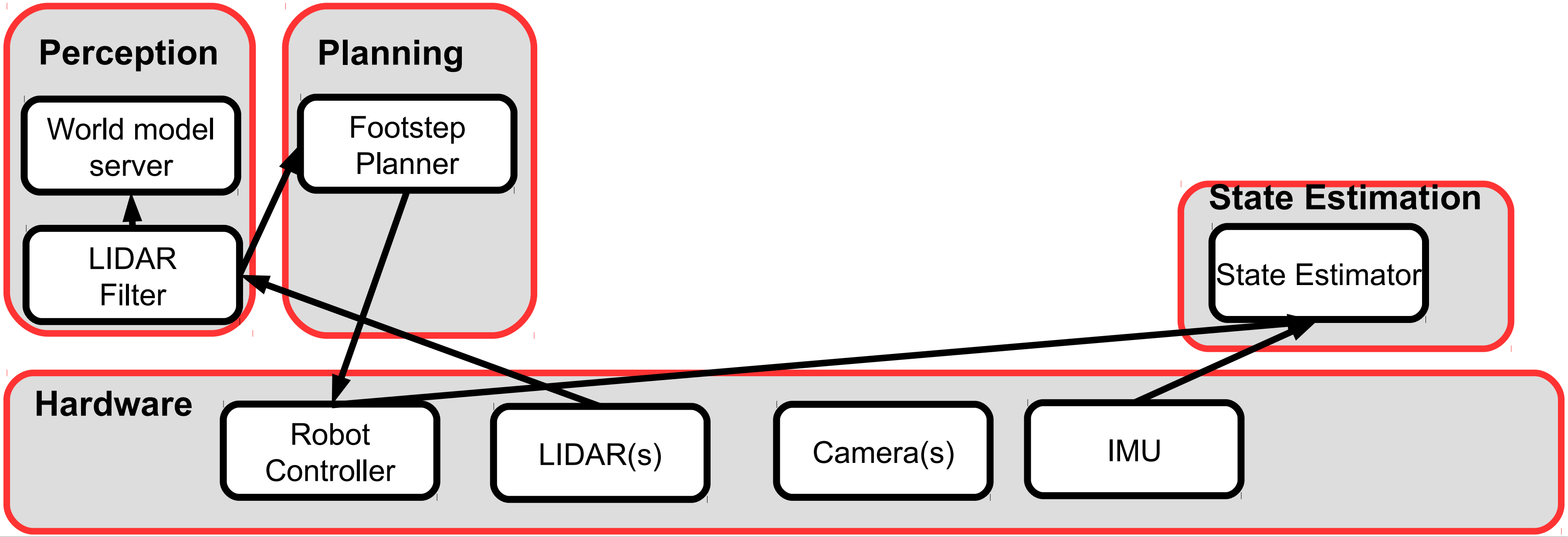
github.com/team-vigir/vigir_perception/tree/master/vigir_point_cloud_proc

github.com/team-vigir/vigir_ocs_common/tree/master/vigir_ocs_rviz_plugins/vigir_ocs_rviz_plugin_mesh_display_custom

Components – Footstep Planner

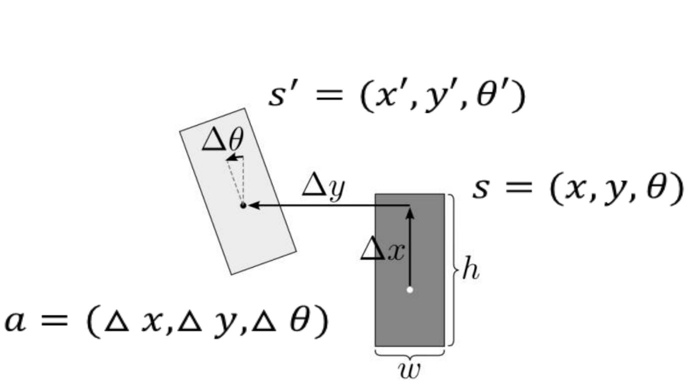


Components – Footstep Planner

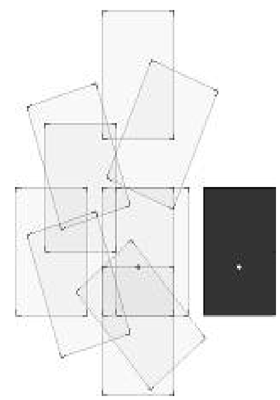


Footstep Planner

- Based on work by Hornung et. al. [1]
  - A*-search-based planning approach



Discrete Foot Placements



Successor Set

[1] Hornung et.al. Anytime Search-Based Footstep Planning with Suboptimality Bounds, Humanoids 2012

Footstep Planner

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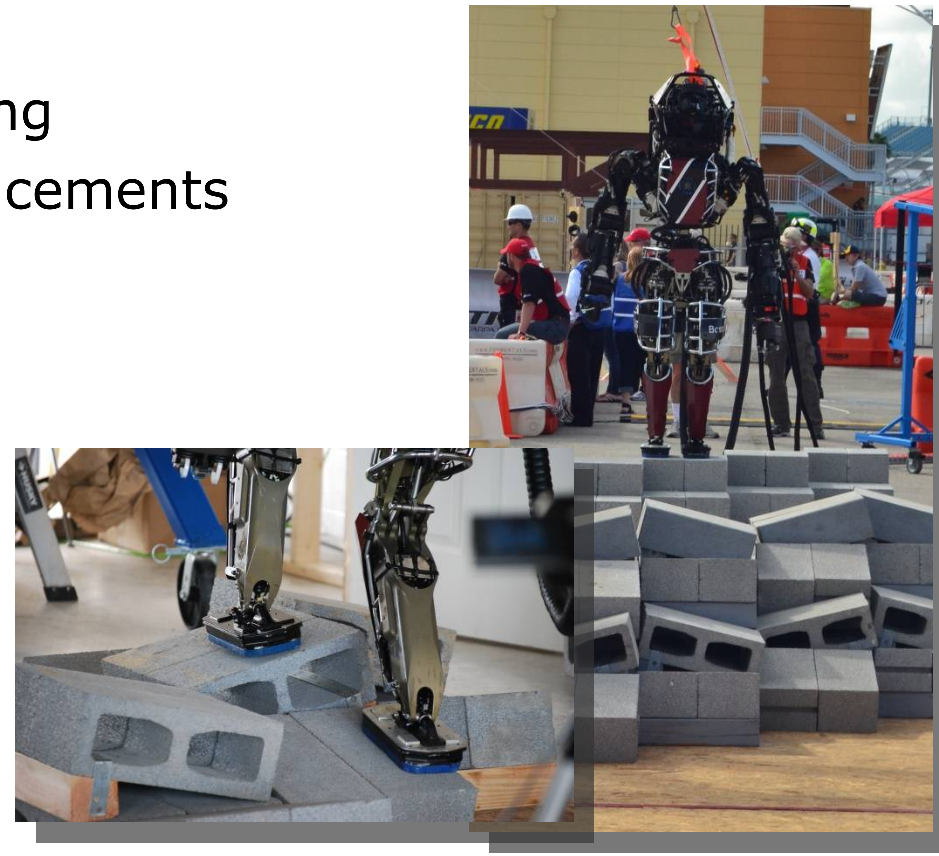
- Complex Locomotion:
  - 3D perception and modeling
  - Safe sequences of foot placements
  - 6DOF foot placements
  - Obstacle avoidance
  - Balance control
- Divide and conquer
  - Terrain Model Generator
  - 3D Footstep Planning
  - Robot Controller



github.com/team-vigir/vigir_footstep_planning_core

Terrain Model Generator

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- Only point clouds required
  - Octree as back-end
  - Incremental updates
  - Stand-alone ROS package
    - Usable in other domains

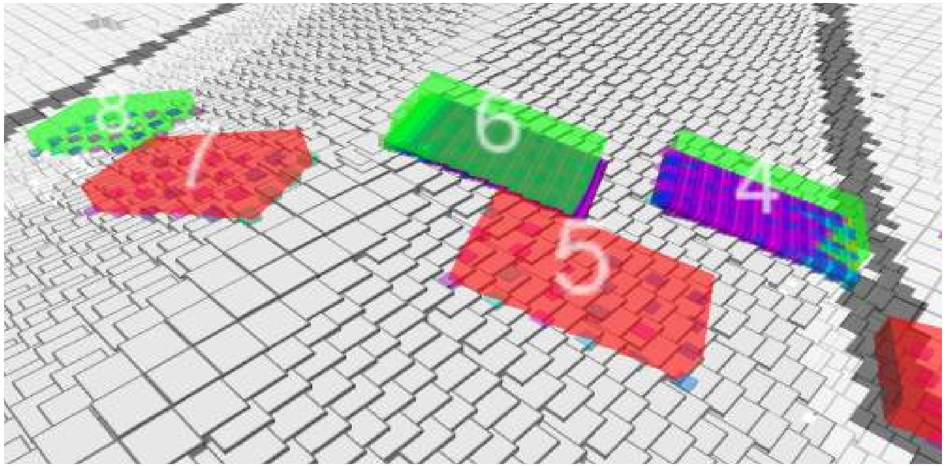
github.com/team-vigir/vigir_terrain_classifier

Terrain Model Generator

- Online Generation
  - Surface Normals (left)
  - Height Map (right)

Footstep Planner: 3D Planning

- Extension to 3D



- States: Become full 6 DOF
- Actions: Remain the same
- Roll, pitch and step height are constrained by underlying terrain
- Search space does not enlarge
- No expensive branching tree!

Footstep Planner: 3D Planning

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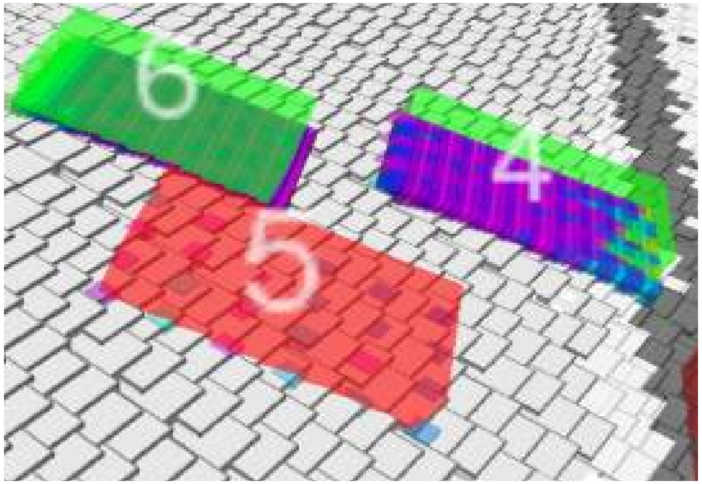
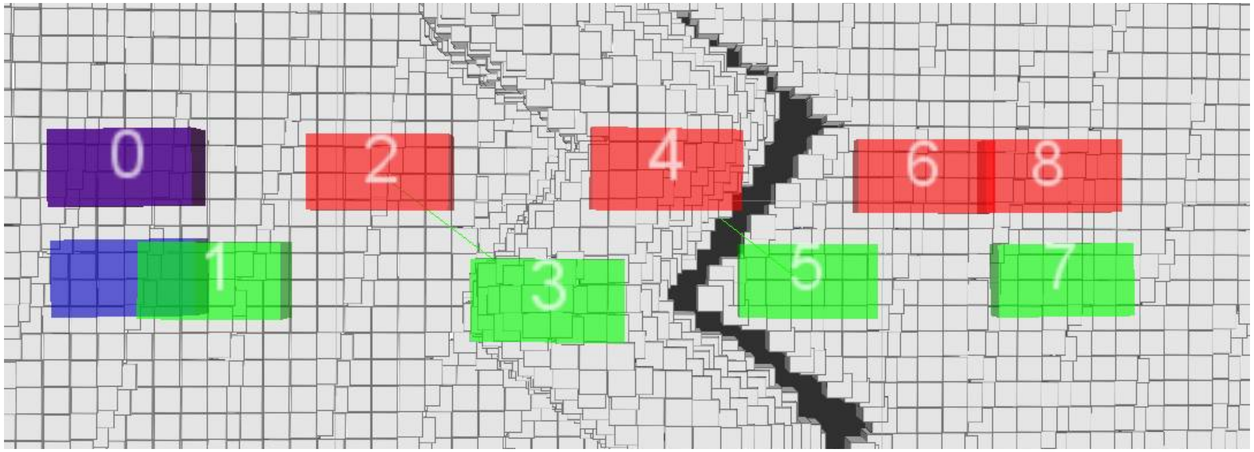
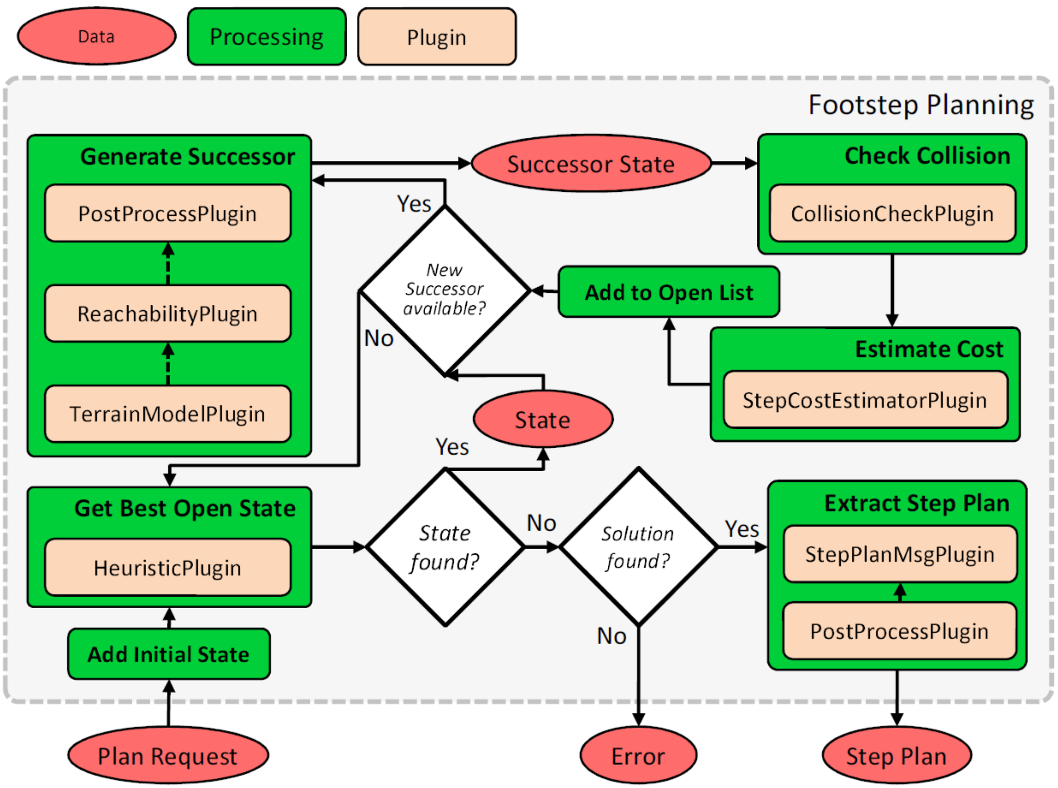
- Ground contact estimation
  - Sampling of foot surface
  - Estimate contact situation of each sample using height map
  - More flexible collision checking model
  - Allows overhanging steps



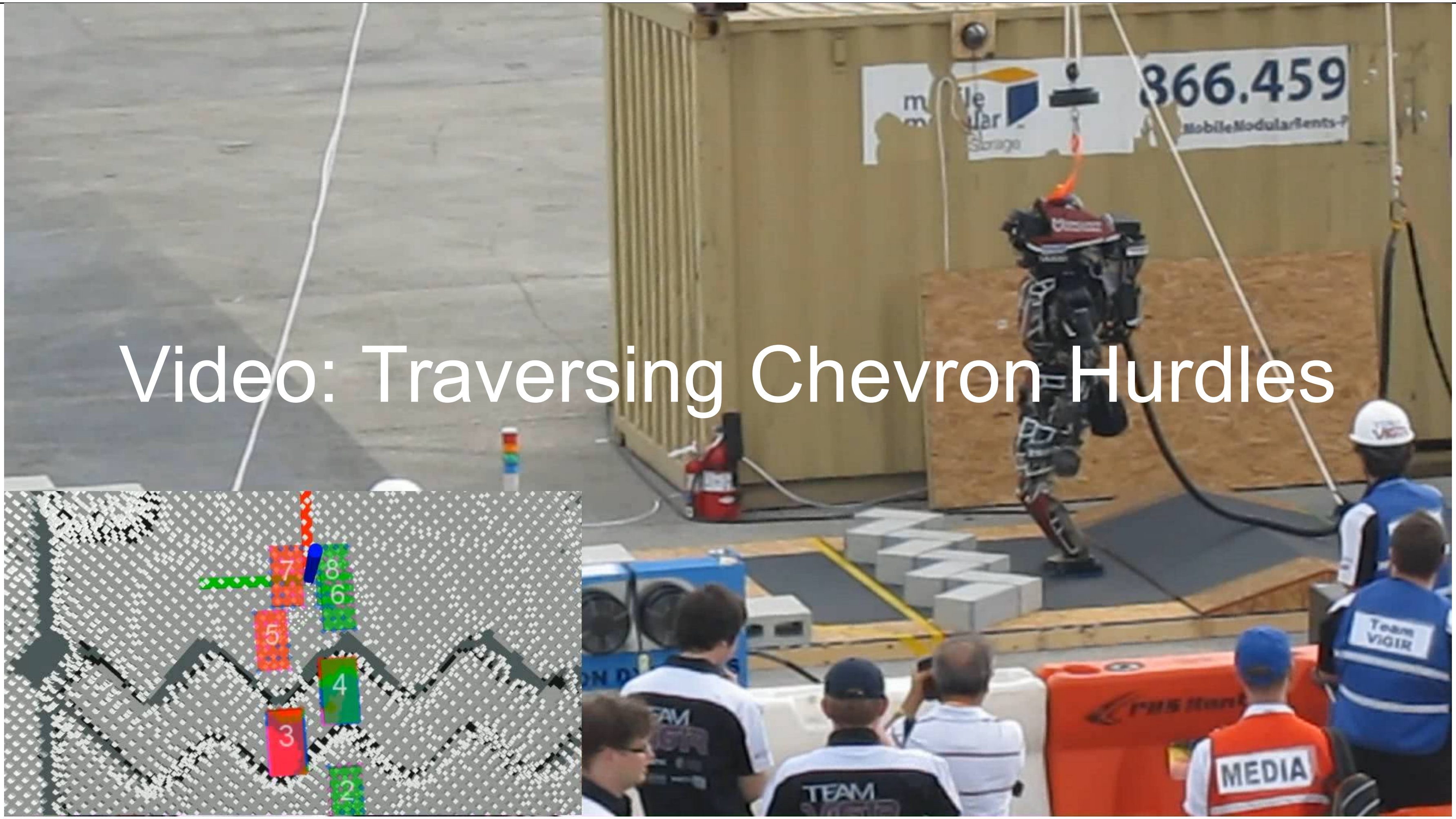


Footstep Planner: Plugins

- Plugins used for customization of all relevant system aspects
- Setups for 3 robots already available:
  - Atlas
  - Thor-Mang
  - ESCHER



Footstep Planner: Example



Footstep Planner: Interactivity

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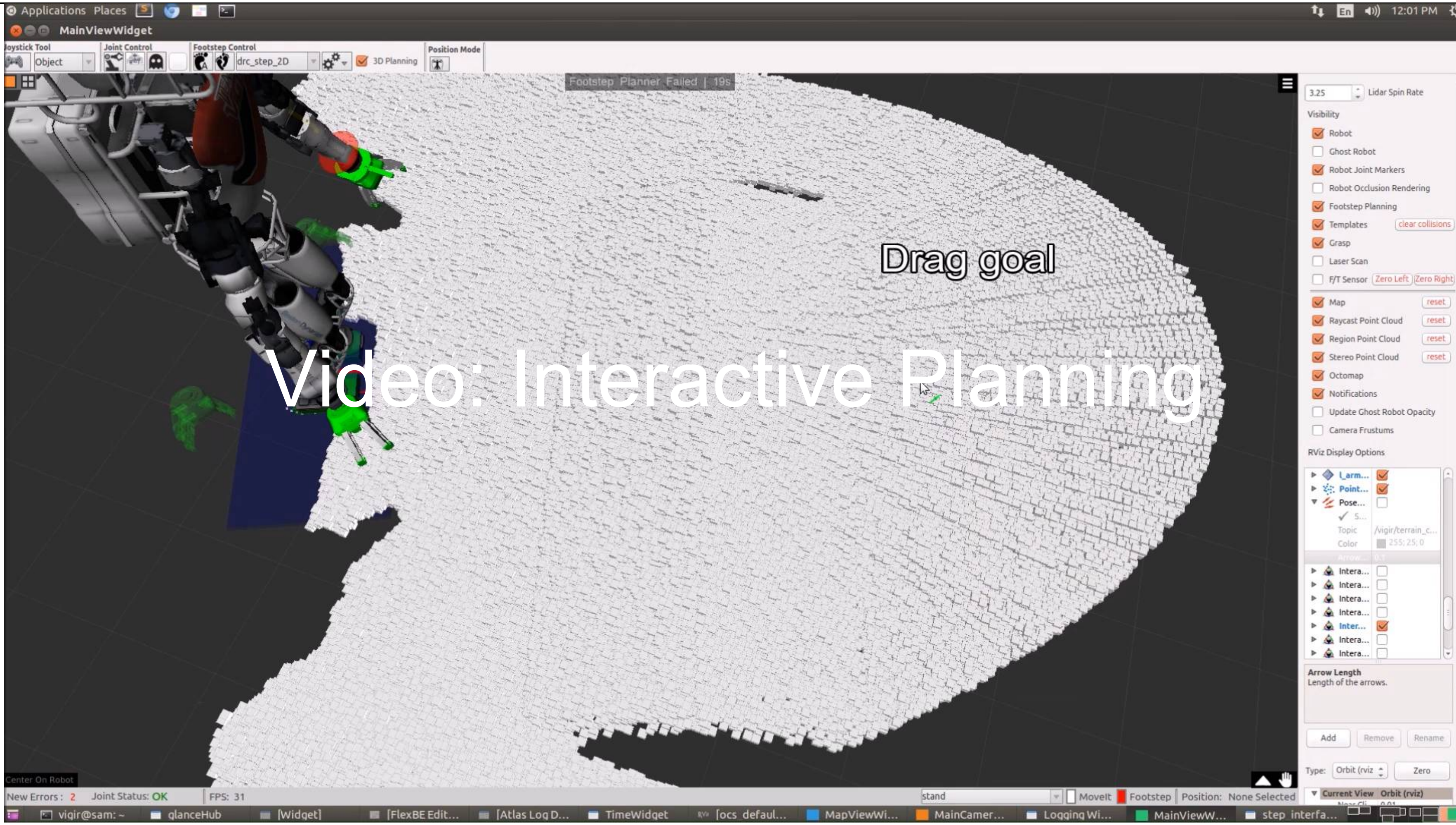
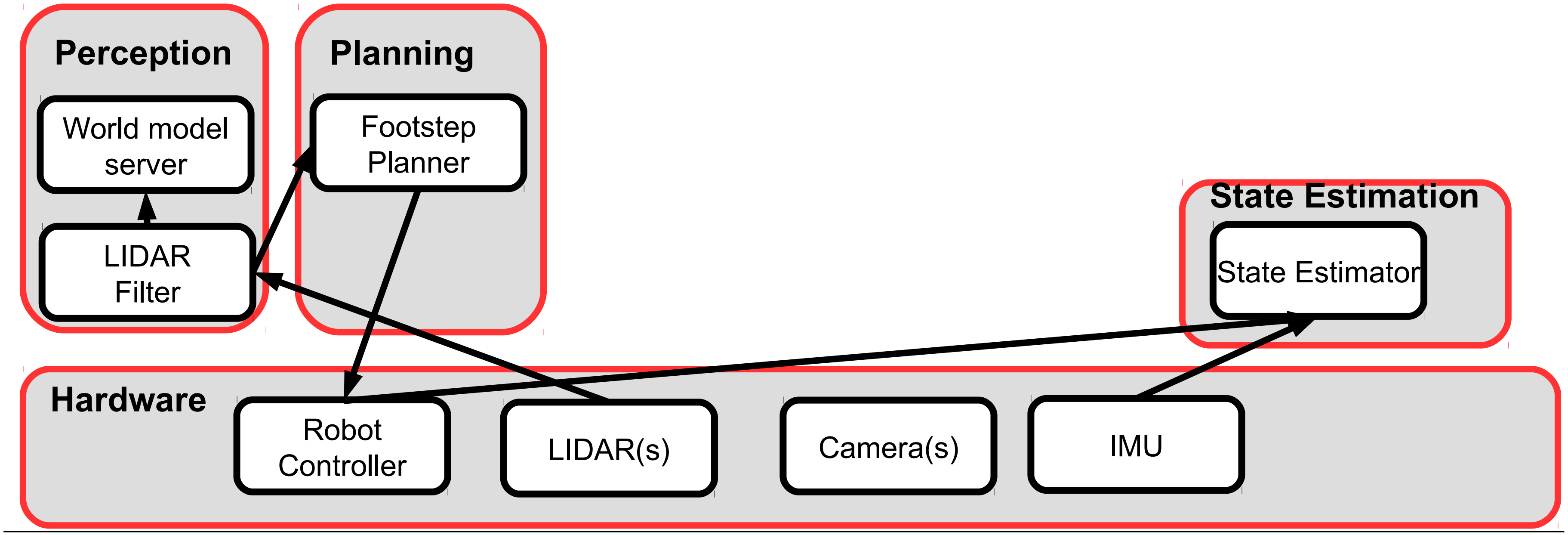
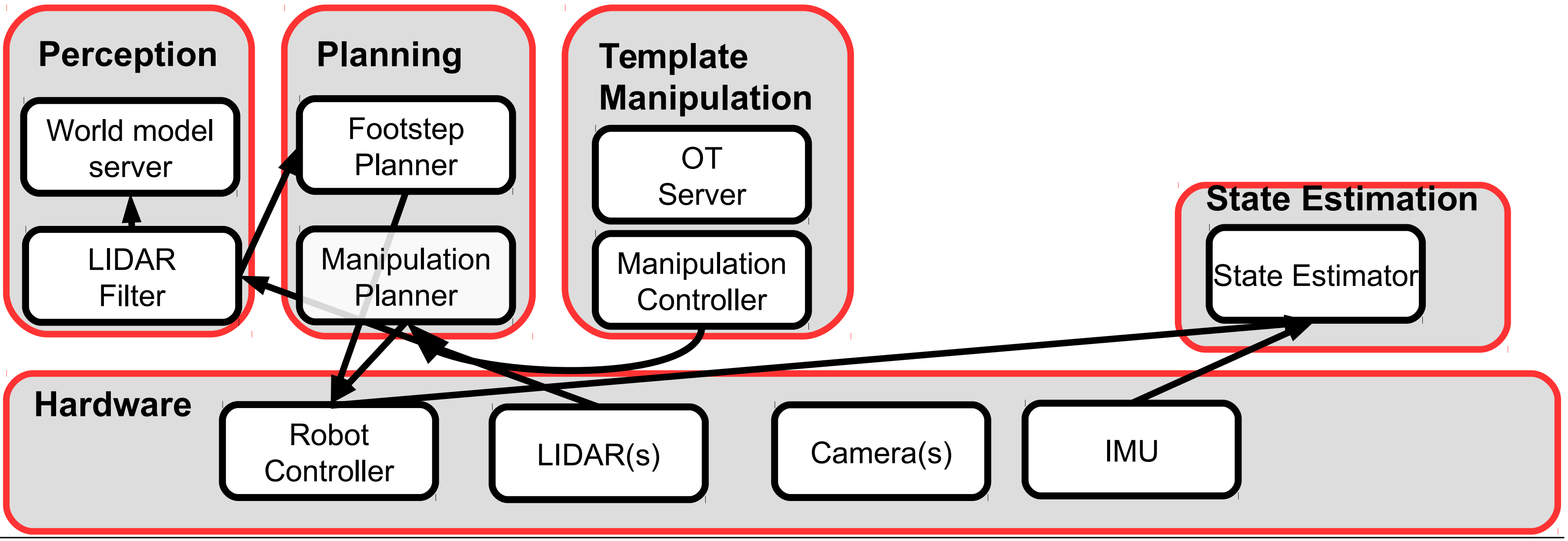


VIGIR SIM

Components – Footstep Planner



Components - Manipulation



Motion Planning - Requirements

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- Manipulation
  - Collision free planning
  - Cartesian Paths
  - Manipulation in contact with environment
  - Maintain stability
- Sliding Autonomy:
  - Operator/OCS-based (Teleop)
  - Operator/Object template based (Task level)
  - Behavior Executive (Autonomous)

→ Use MoveIt! as back-end

Motion Planning – Robot Setup

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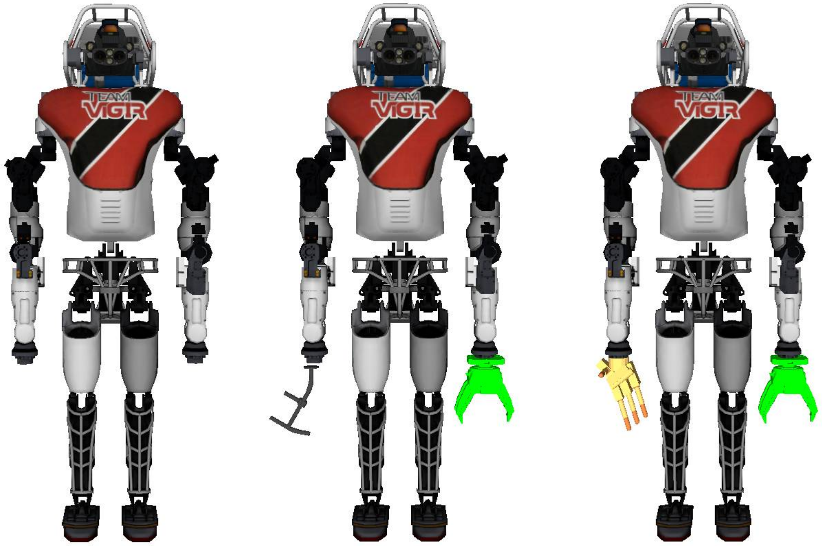
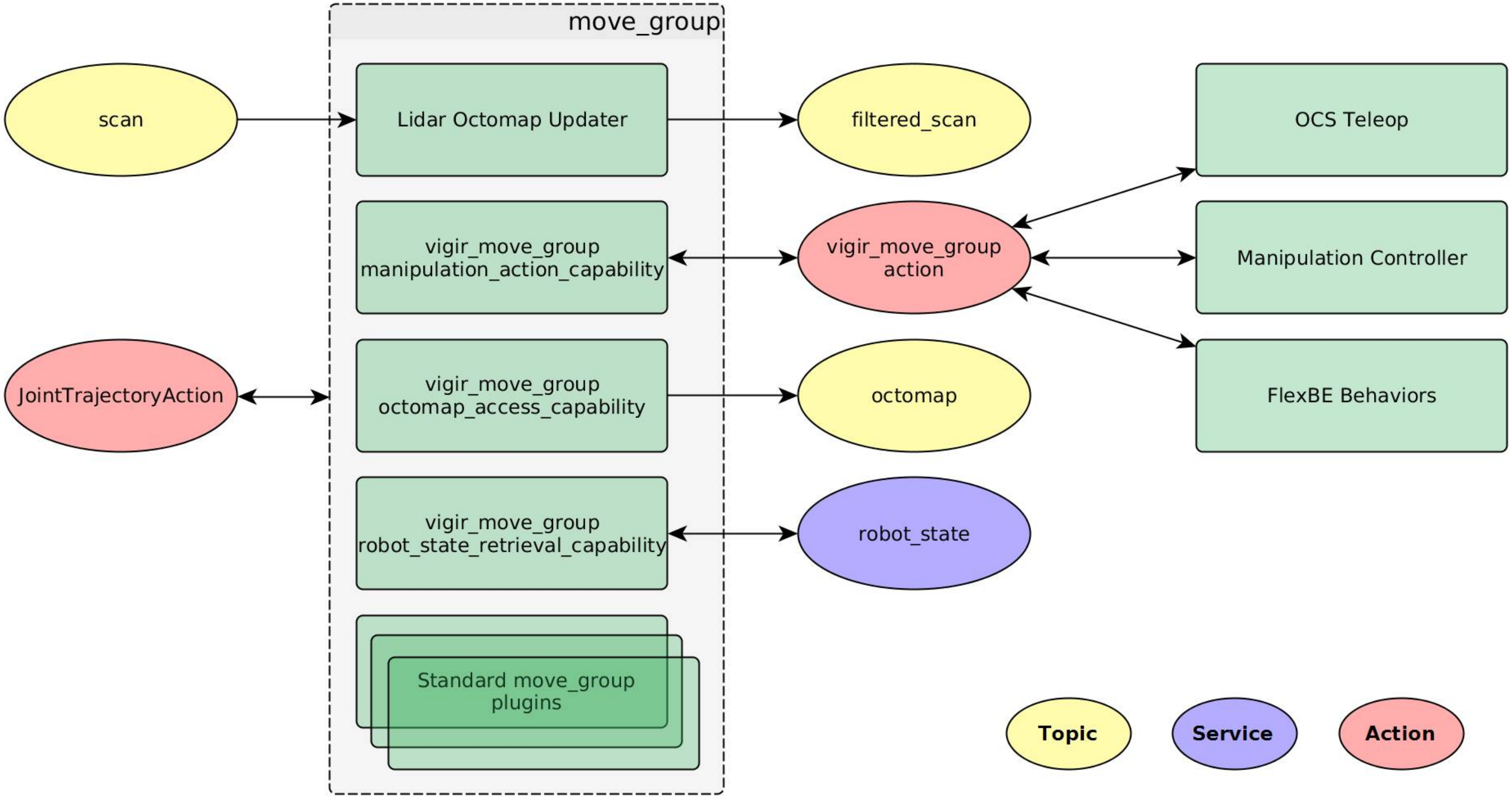
- Different robot variants
- Different hand variants
- Combinatory explosion of configs
  - Do not want to run setup assistant for every (possible) combination
- Solution:
  - Use of xacro macros to change configs



github.com/team-vigir/vigir_atlas_planning/tree/master/vigir_atlas_moveit_config

Motion Planning - Overview



Planning - Capabilities

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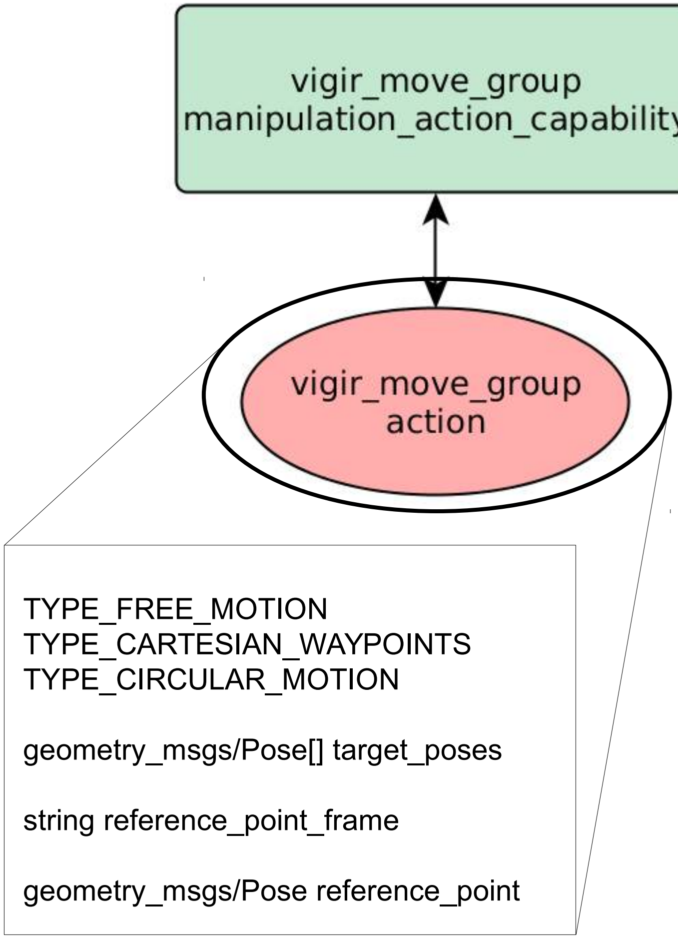
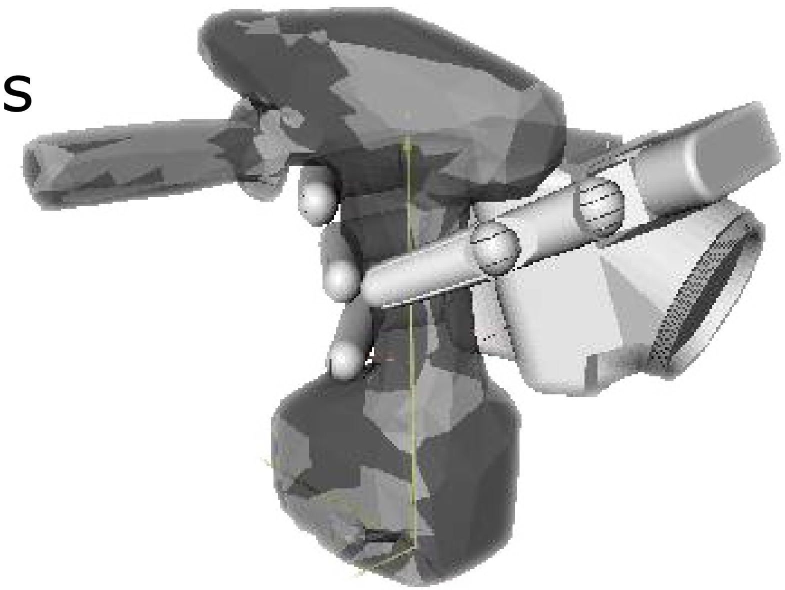
- Additional move_group capability
  - Different types of motion requests
    - Joint goal
    - Cartesian goal
    - Cartesian Path (waypoints)
    - Circular motion
  - Specify planning reference pose relative to endeffector
  - Constrain joint limits selectively at run-time



github.com/team-vigir/vigir_manipulation_planning/tree/master/vigir_move_group

Planning – Object Templates

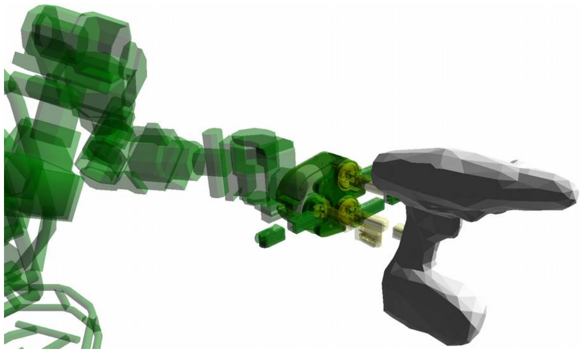
- On top of vigir_move_group
- Operator places objects
- Planning relative to instantiated objects templates
- Object template library
  - Geometry
  - Mass/Inertia
  - Grasps
  - Stand poses

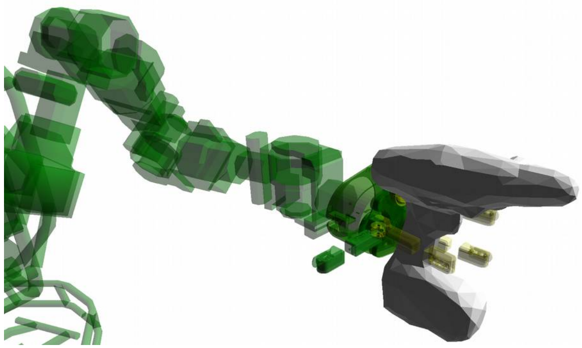


github.com/team-vigir/vigir_object_template_manager

Planning - "Ghost" robot

- Pre-plan motions with virtual "Ghost Robot"
- Additional capabilities compared to start/goal state visualization in MoveIt! Rviz plugin
  - Snap endeffectors to objects
  - Move to stand poses relative to object templates
  - Constrain IK joint limits
  - Send low-bandwidth planning request directly from OCS





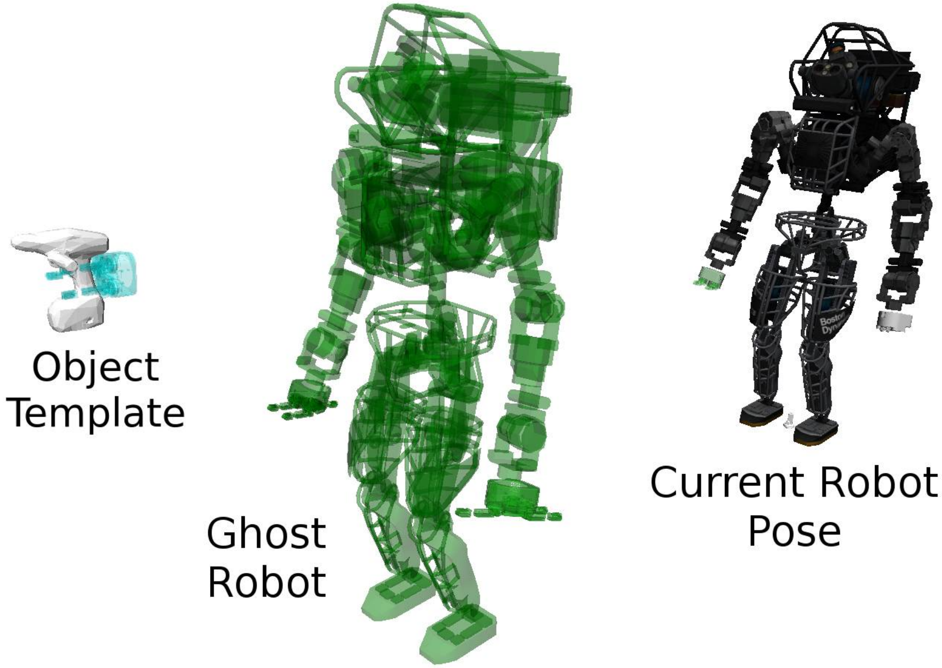
github.com/team-vigir/vigir_manipulation_planning/tree/master/vigir_ocs_robot_model

Manipulation Pipeline Example

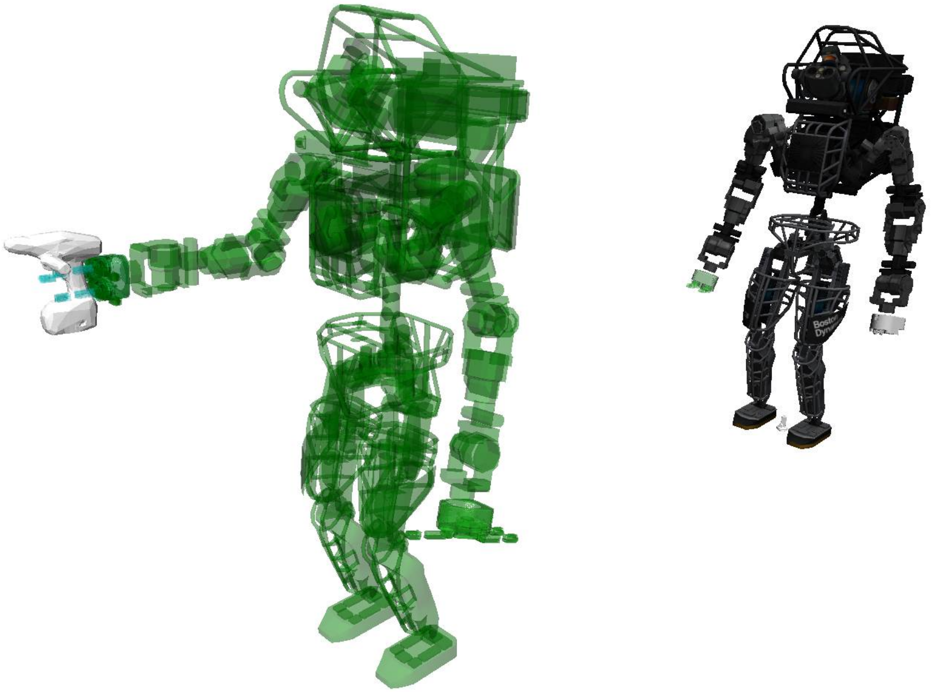
Object
Pointcloud

Current Robot
Pose

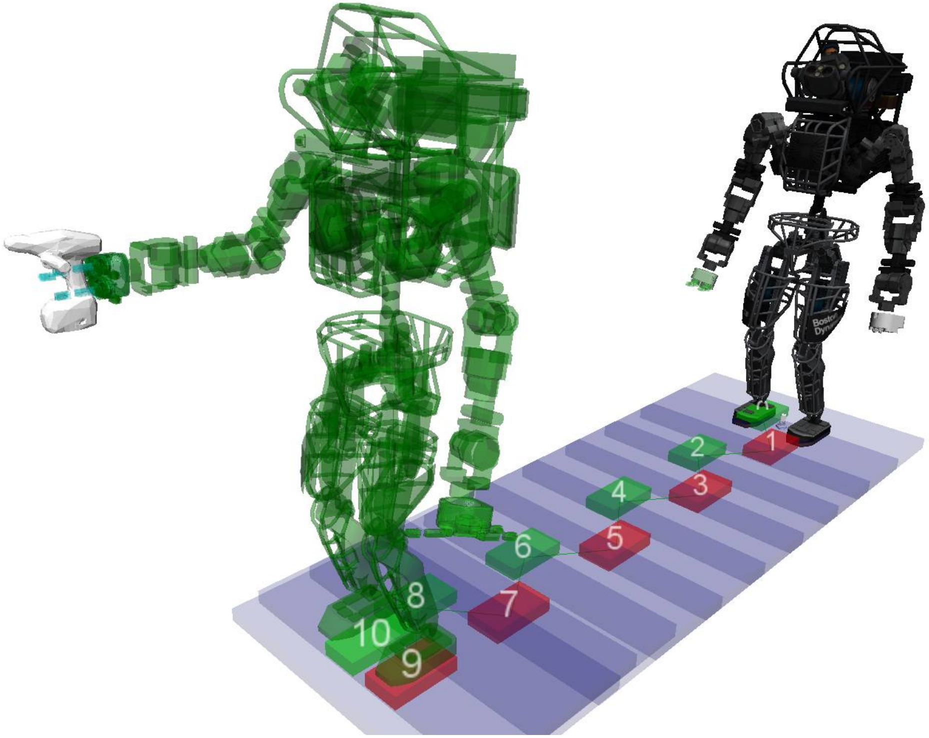
Manipulation Pipeline Example



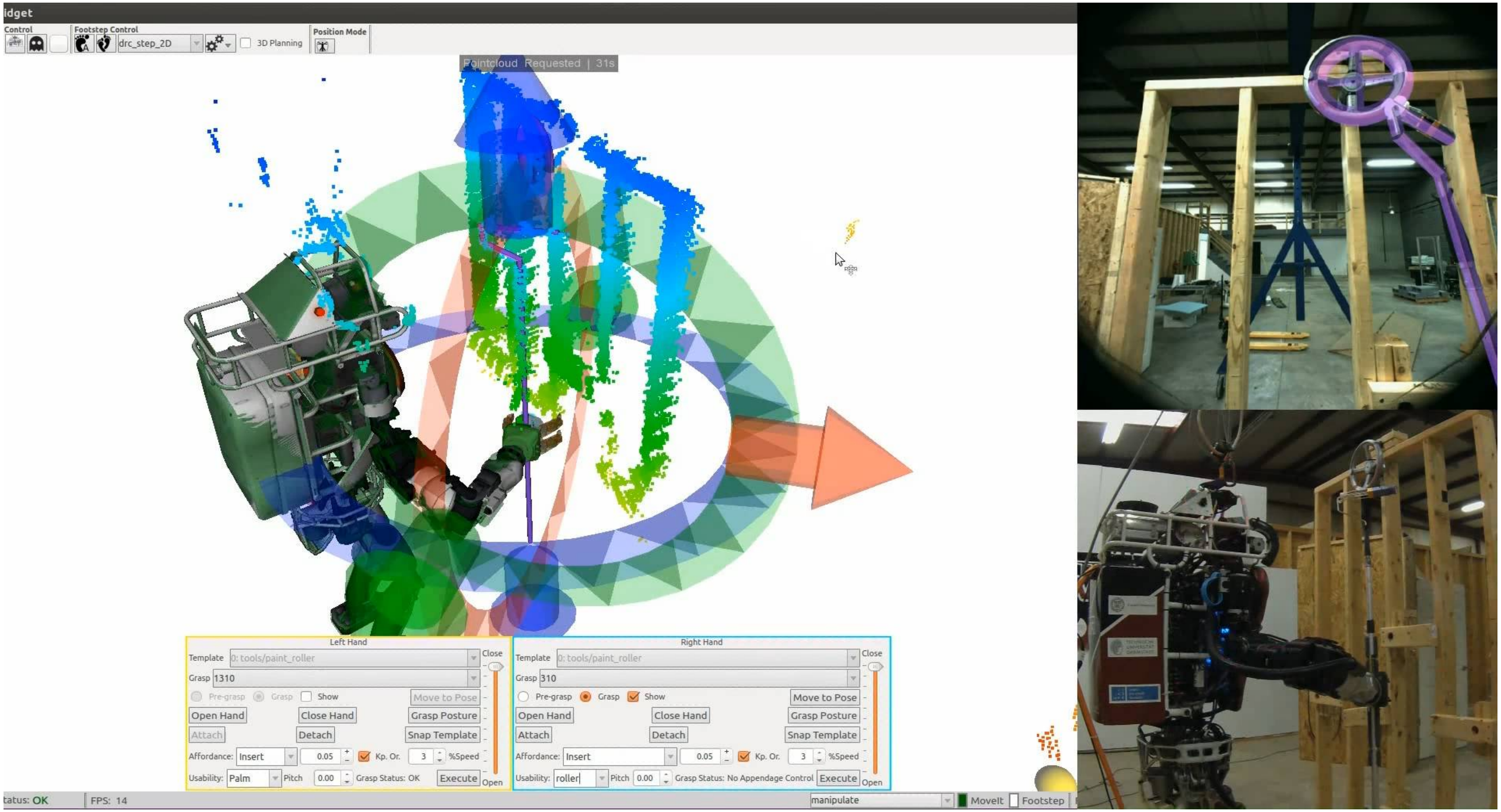
Manipulation Pipeline Example



Manipulation Pipeline Example

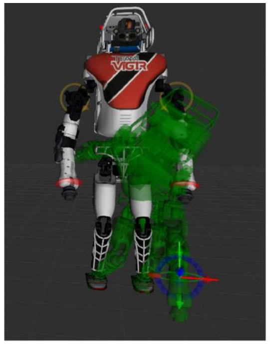


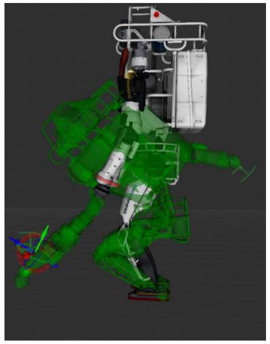
Manipulation example



Manipulation – Drake Integration

- Switch between MoveIt! and MIT's Drake planning framework on a per plan request basis
  - Whole Body Motions
  - Using github.com/tu-darmstadt-ros-pkg/rosmatlab





Manipulation – Reaching motion using Drake Integration

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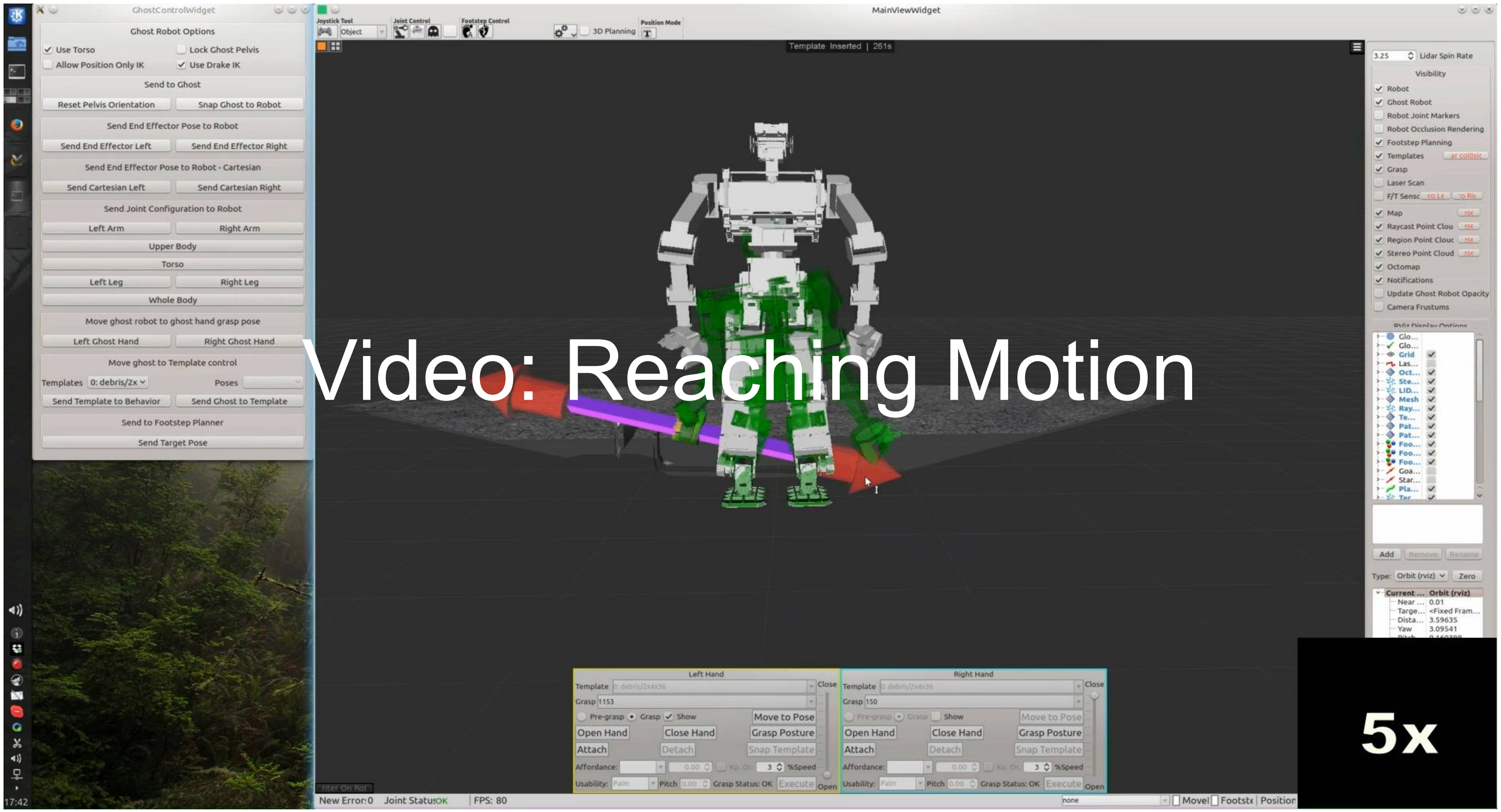

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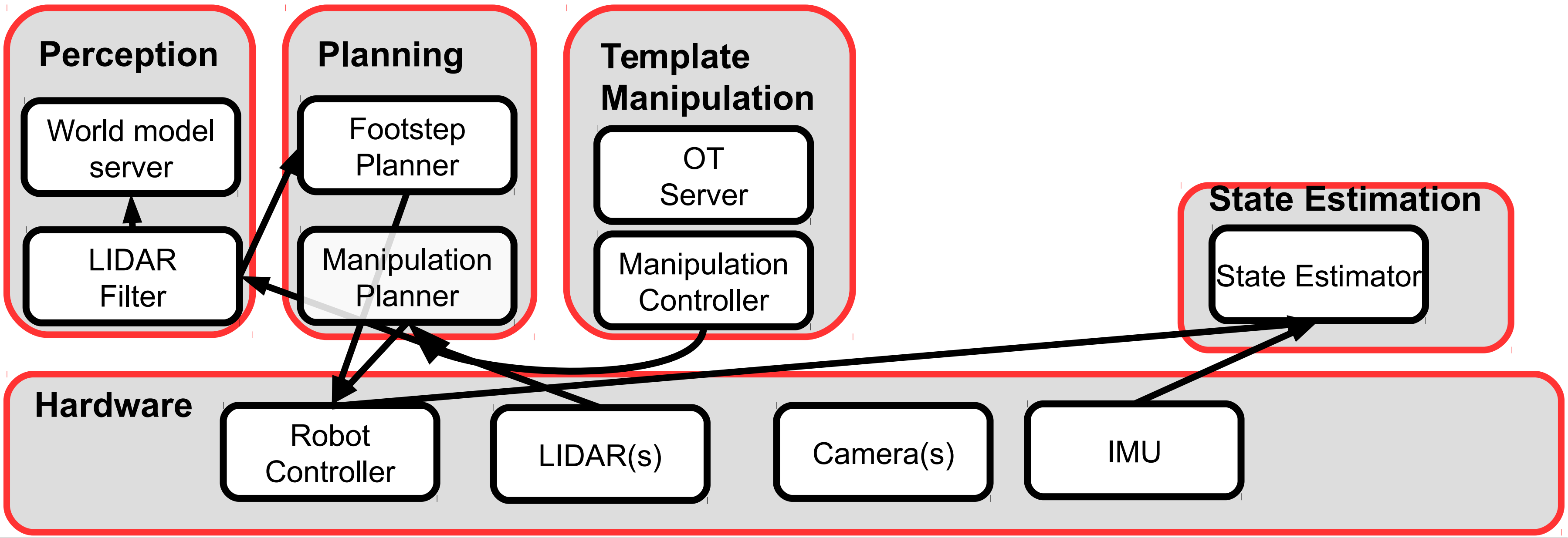
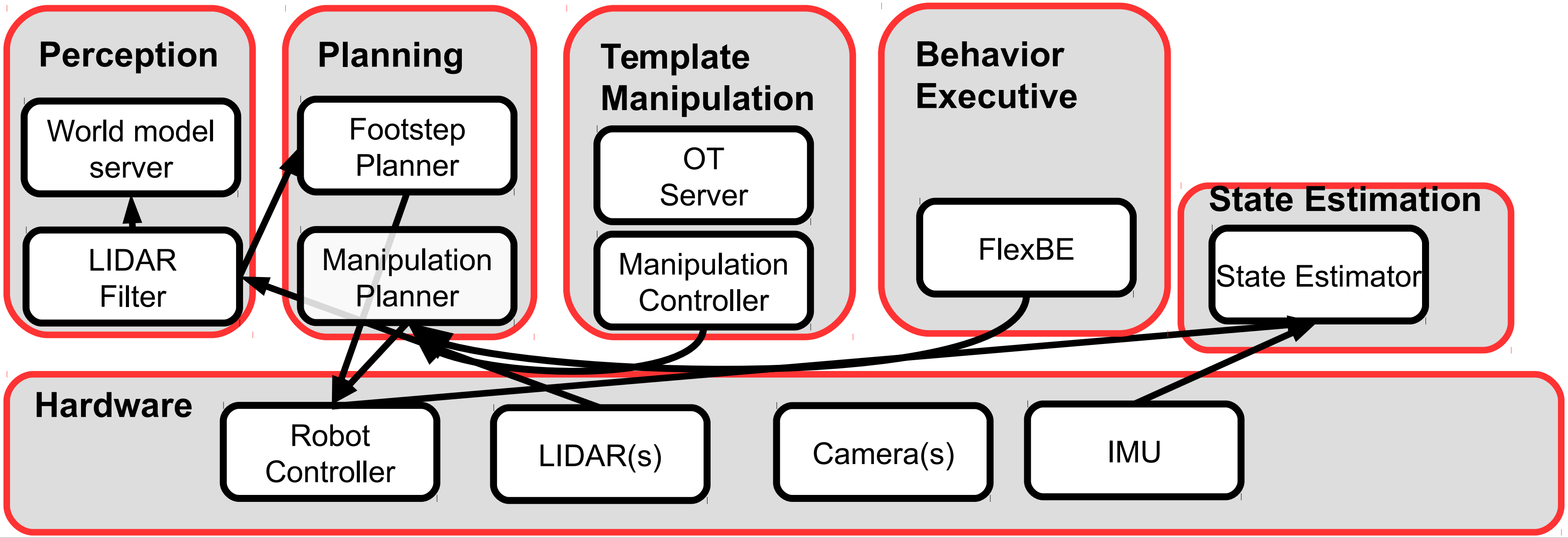
Components – FlexBE Behavior Executive



Components – FlexBE Behavior Executive



Behavior Executive - High-Level Approach

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- Communication constraints
- Limited time
- Complex robot system

Motivates high degree of **robot autonomy**

Flexible Robot-Operator Collaboration

Motivates high degree of **operator support**

- Unstructured environment
- Complex tasks
- Robustness important

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Behavior Executive - High-Level Approach

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- SMACH, XABSL, etc.
  - Focused on pure autonomy
  - Pre-defined robot behavior

- Required features:
  - Allow multiple degrees of autonomy
  - Support and restrict robot when in low autonomy
  - Adapt behavior to unforeseen situations
  - Abstraction of complex behavior design
  - Robust against runtime failure

Behavior Executive - FlexBE

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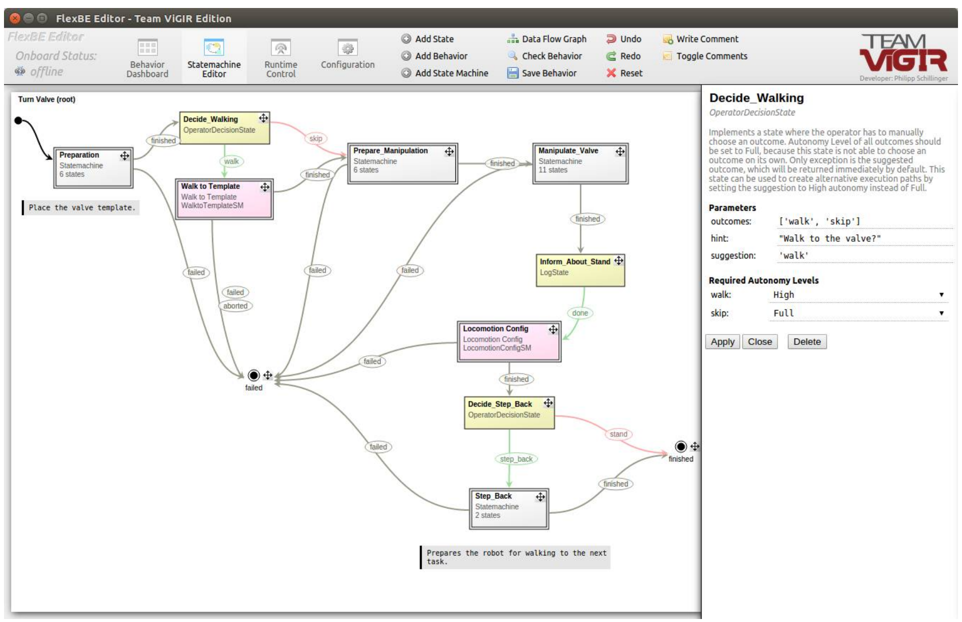
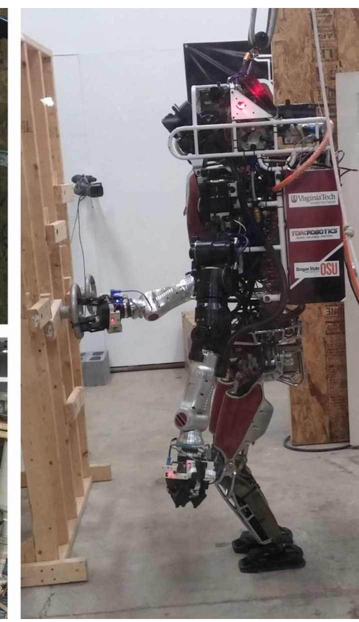
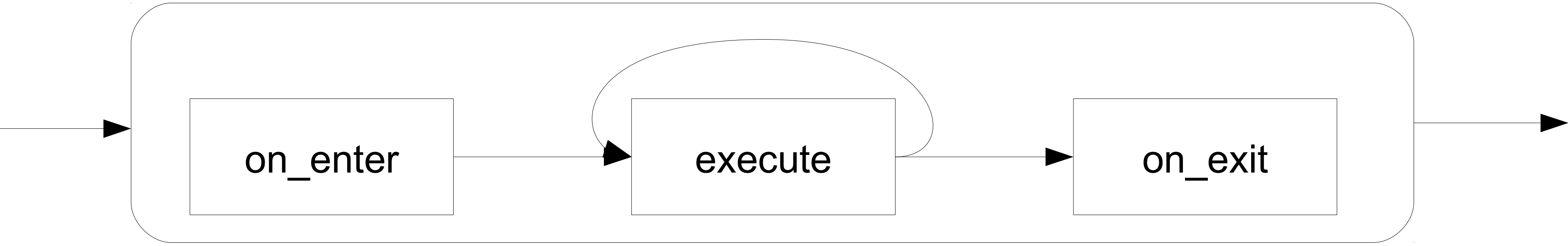
- “**Flex**ible **B**ehavior **E**ngine”
  - Based on SMACH → Hierarchical state machines
  - Adds robot-operator collaboration
  - Available on GitHub: *github.com/team-vigir/flexbe_behavior_engine*





FlexBE – States

- Interface basic robot capabilities / actions
- Executed periodically
- Event-based lifecycle (simplified):



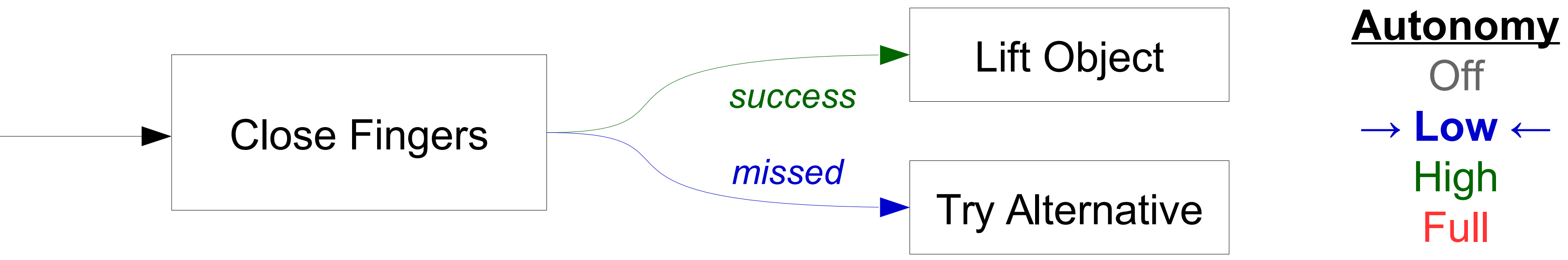
Send command(s), eg.
- publish message
- actionlib call

Check conditions and evaluate results
→ Determine outcome

Clean up

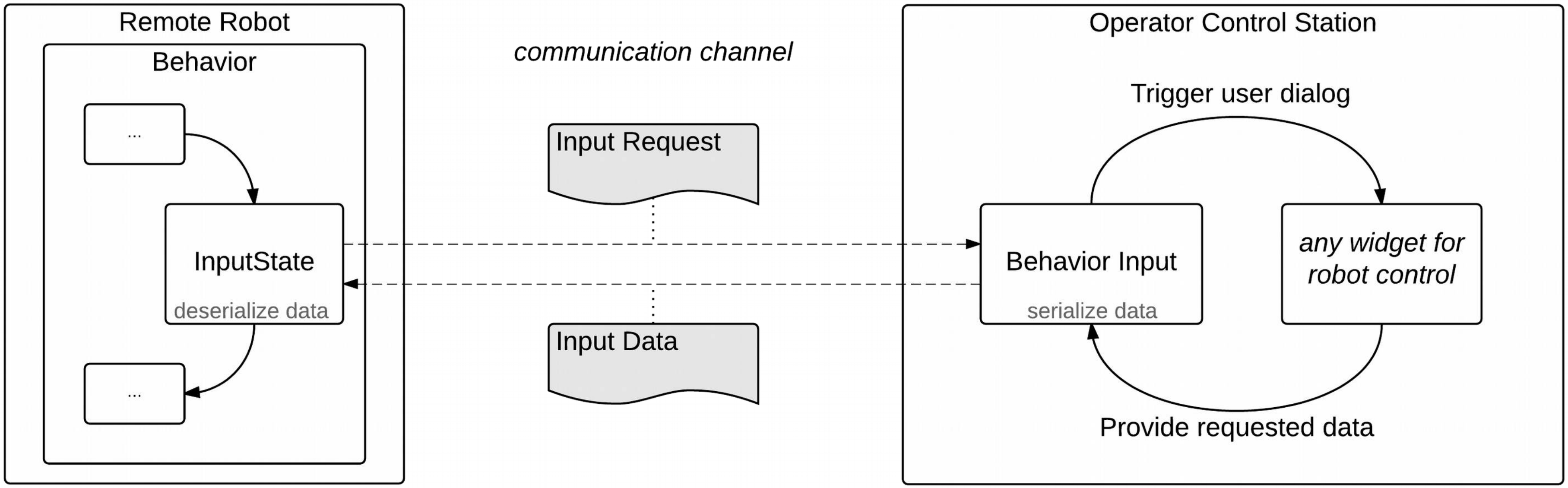
FlexBE – Autonomy Level

- Behavior runs with explicit *Autonomy Level*
  - Can be changed any time during execution
- State outcomes define required autonomy
  - High enough → Autonomous execution
  - Too low → Operator confirms or rejects
- Operator can force outcomes any time



FlexBE – Data Input

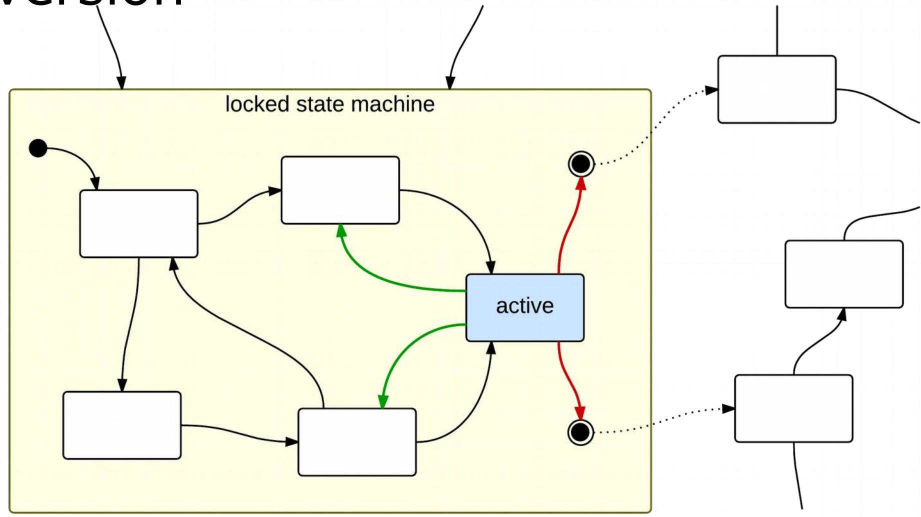
- Behavior can request required data from operator
- Integrated into operator control station



FlexBE – Runtime Changes

- Behavior is locked in a specific state
- Modifications are sent to the onboard executive
- New version is generated and imported
- Active state is transferred
  - Extracted from old, running version
  - Integrated into new version
- Old version is stopped
- New version is executed

→ Arbitrary adaptation



FlexBE – User Interface

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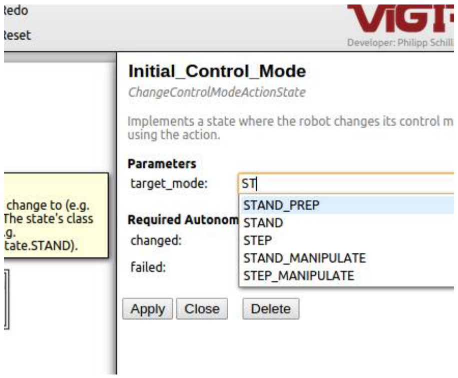
- Facilitates behavior development
- Automated code generation
- Integrated operator interaction

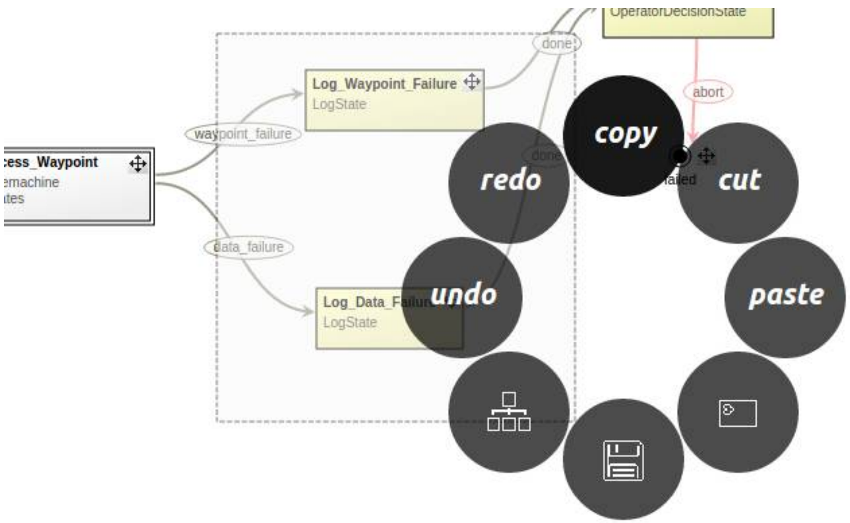
→ Is prerequisite for operator-robot collaboration

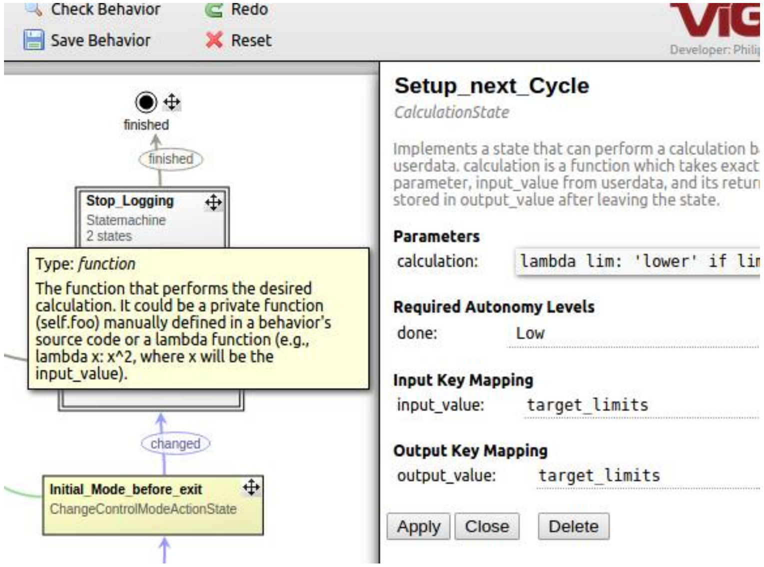
- Behavior re-definition during runtime feasible
- Transparent robot decision-making
- Send context-dependent high-level commands

FlexBE – Editor

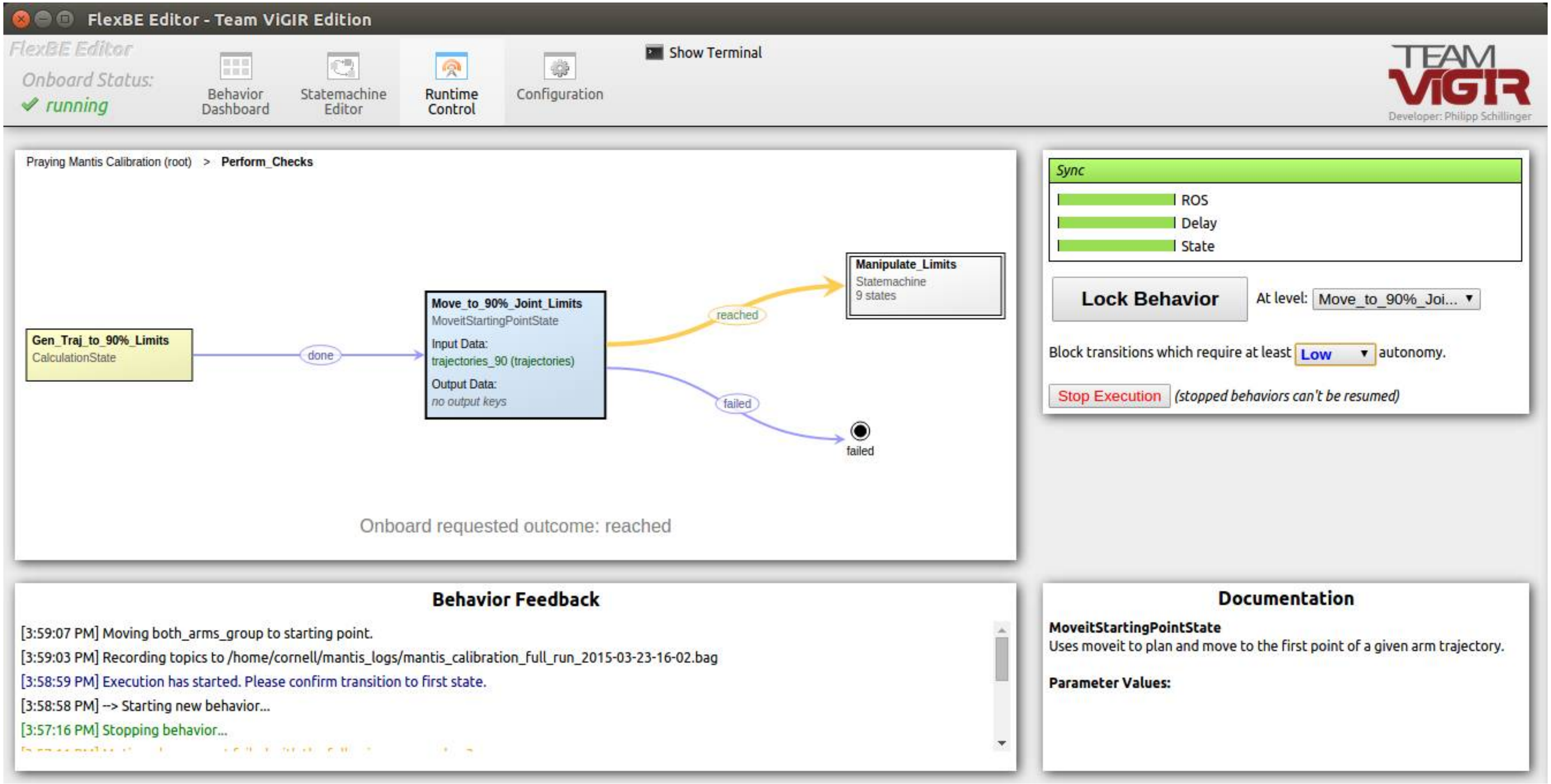
- Drag&Drop state composition
- Configuration of state properties
- Detailed documentation of states
- Dataflow graph and verification



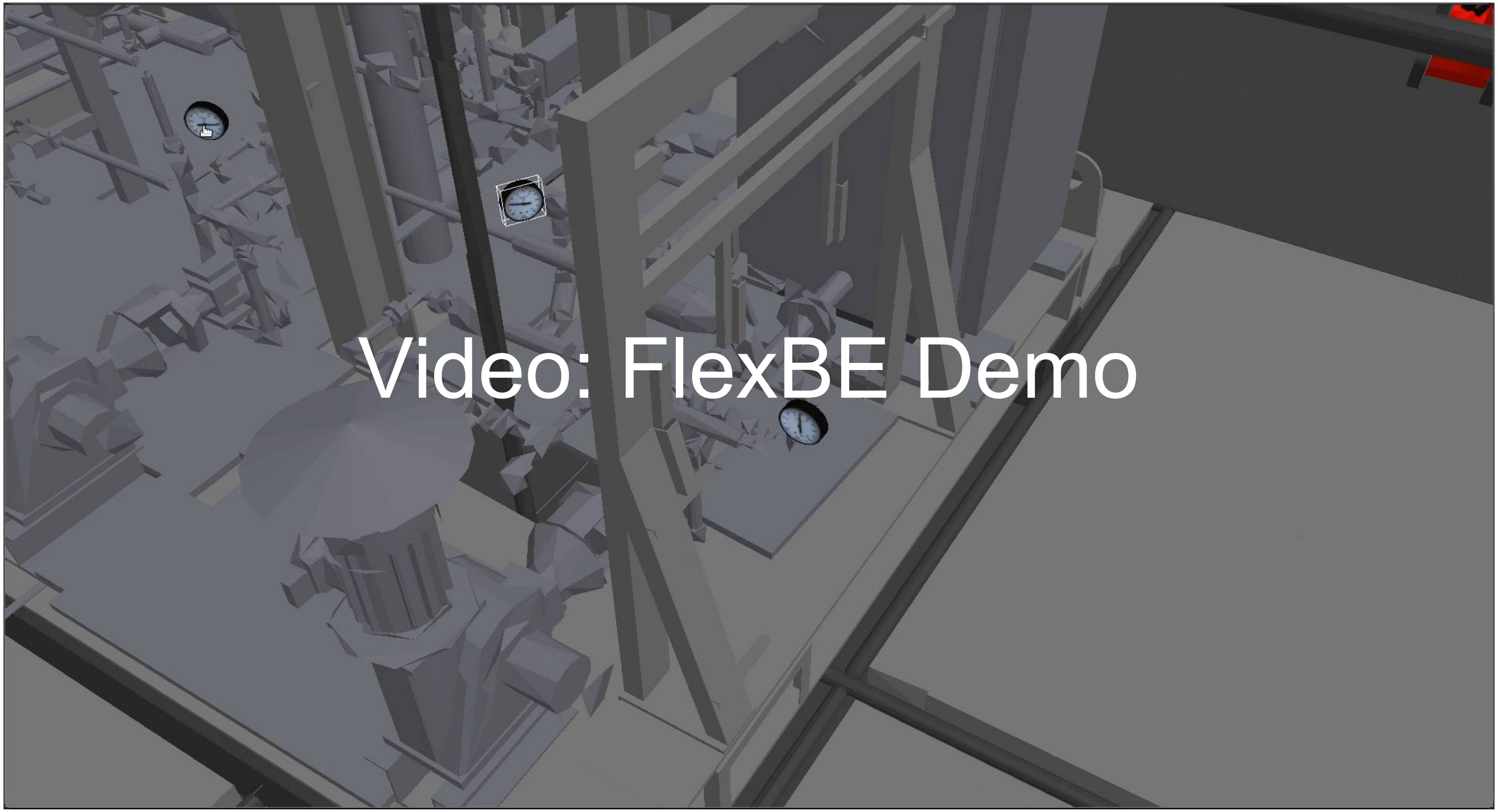




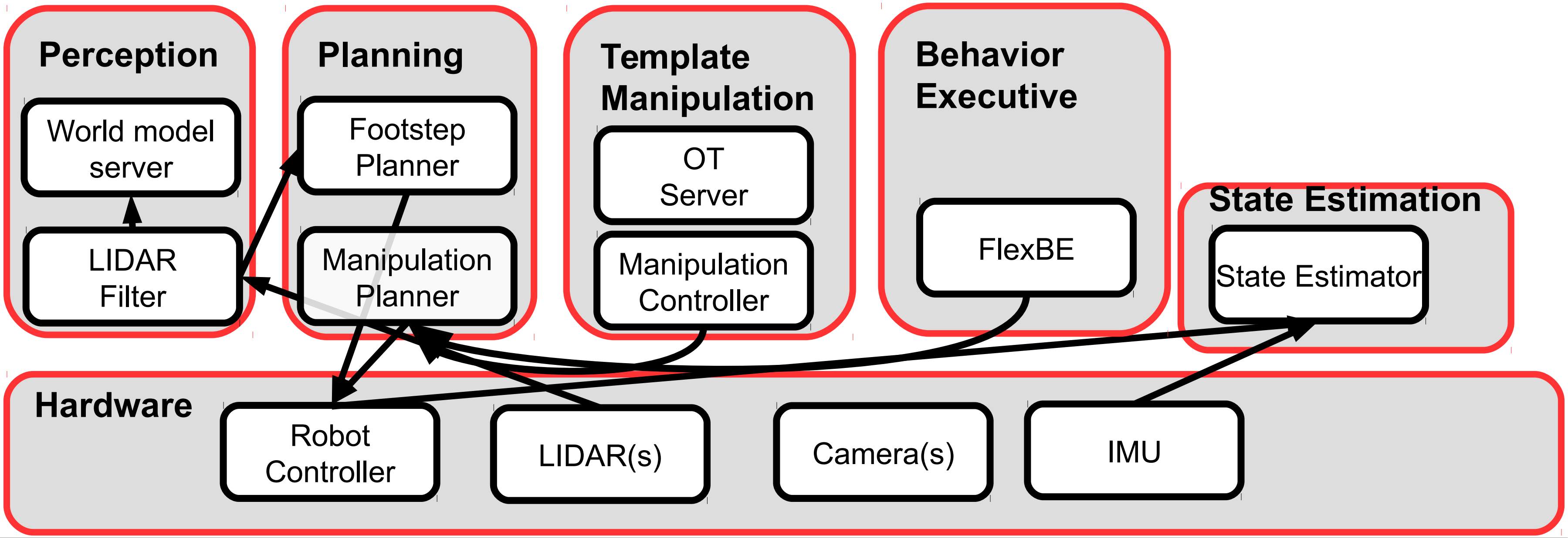
FlexBE – Runtime Control



FlexBE – Beyond DRC application



Components – Comms Bridge



Components – Comms Bridge

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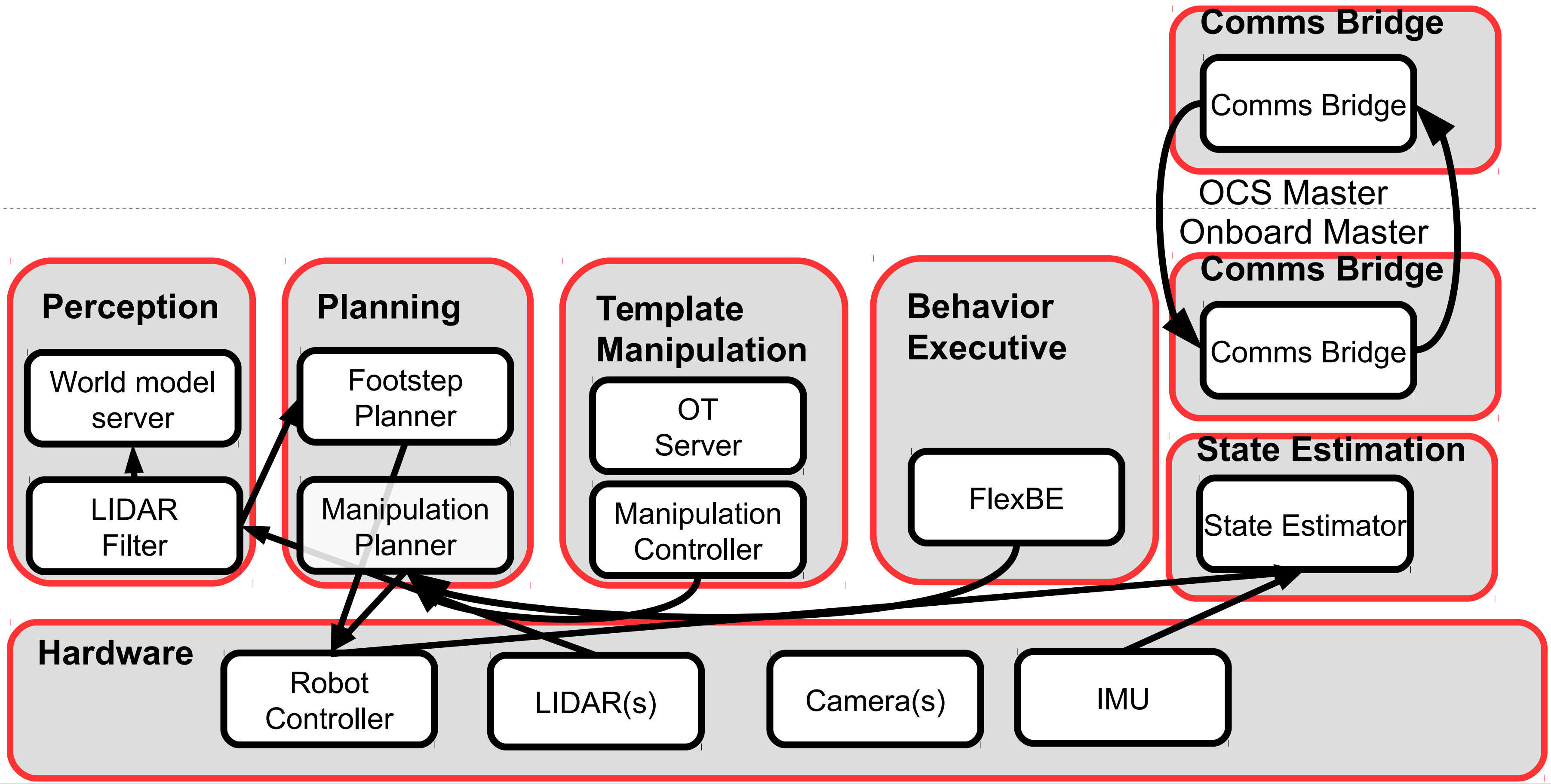
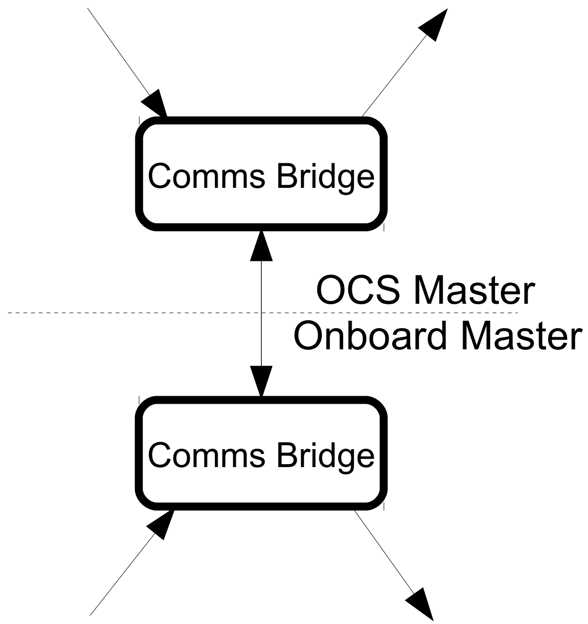
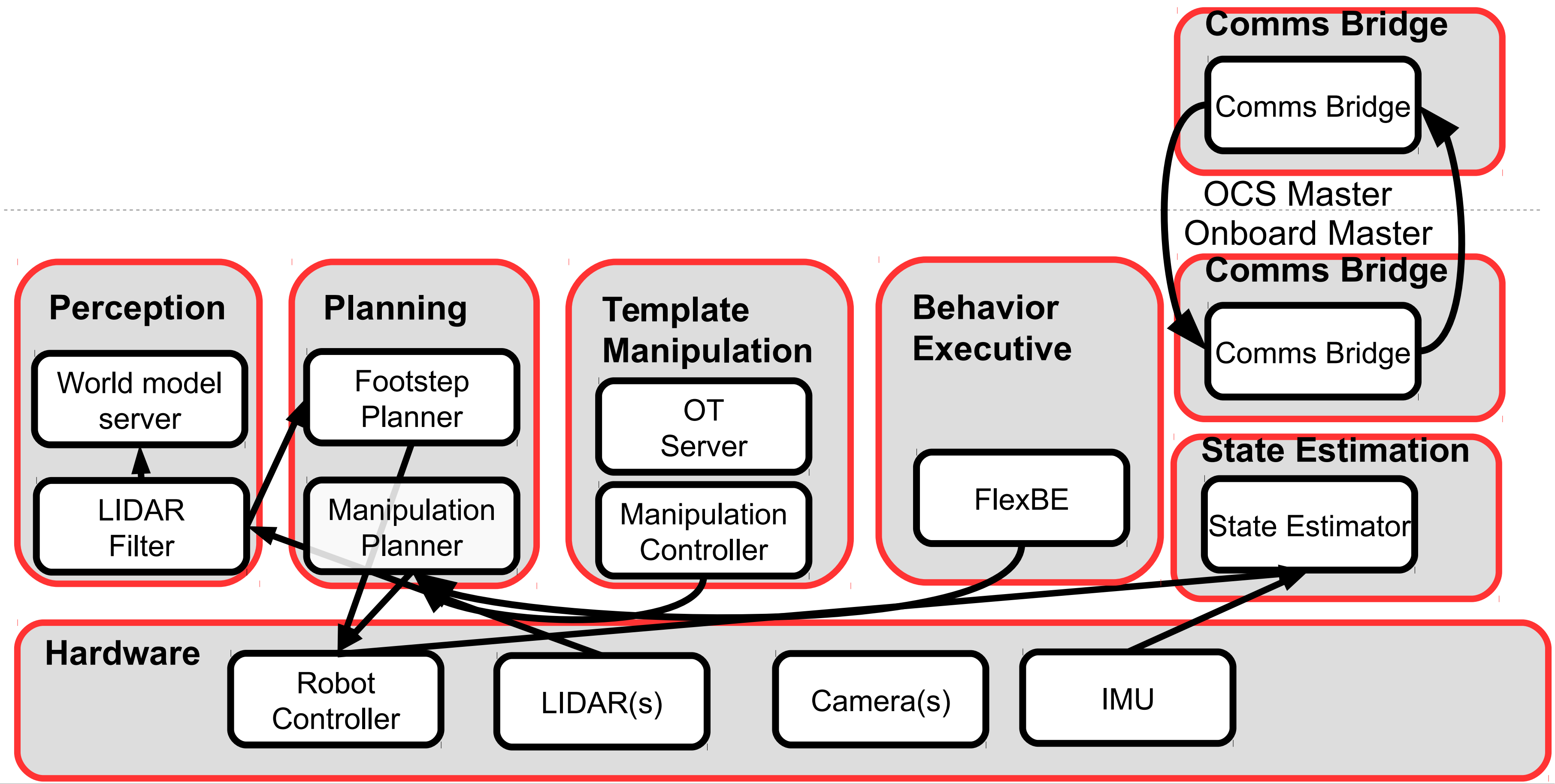


Comms Bridge

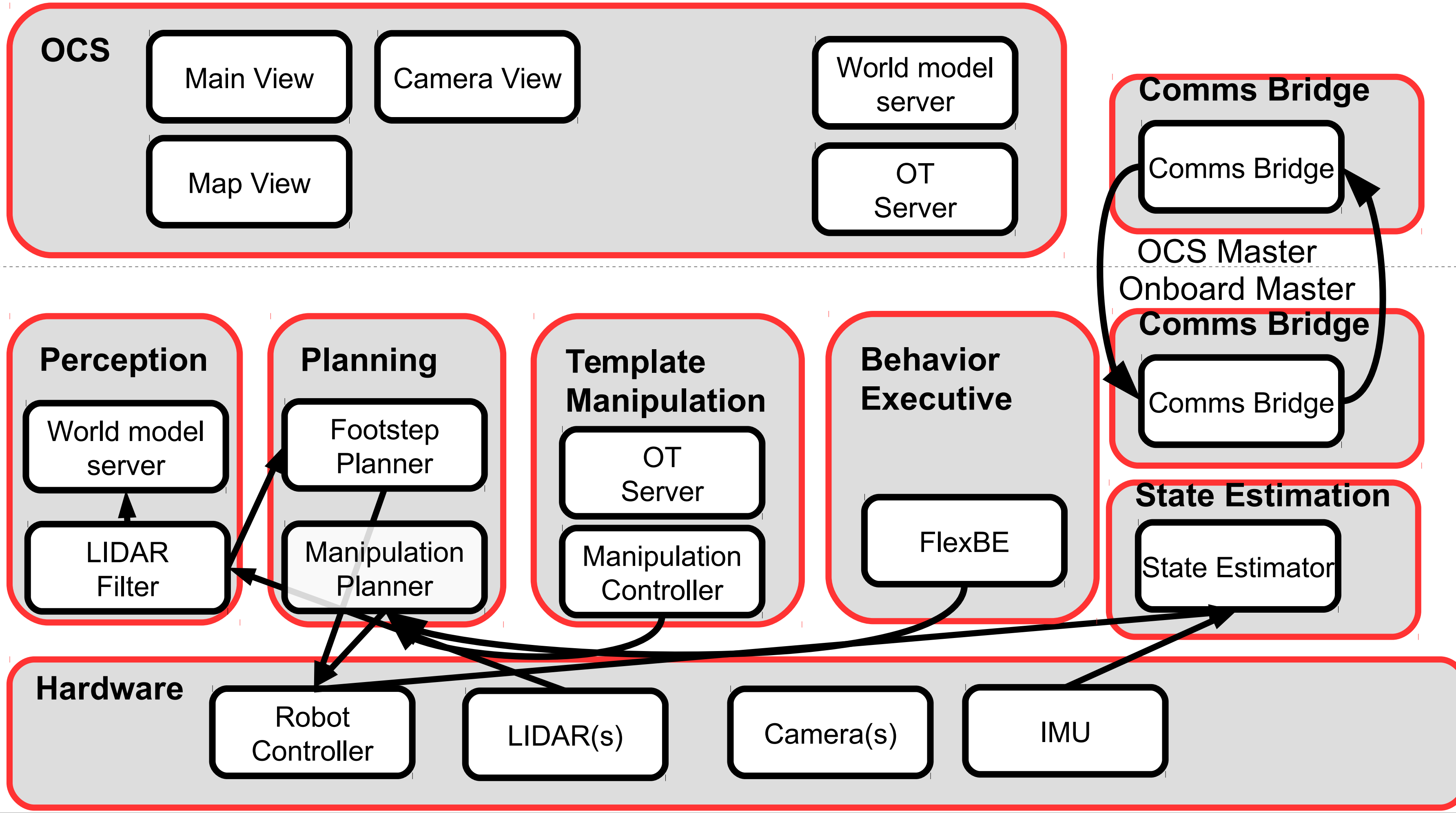
- Single ROS Master infeasible
  - Unreliable connection between operator and robot
- Dual Master approach
  - OCS
  - Onboard
- Prioritization
- Special treatment of high rate state data
  - Compress using domain knowledge
- Other data compressed using blob_tools
  - Bz2 compression per default



Components - OCS



Components - OCS



OCS

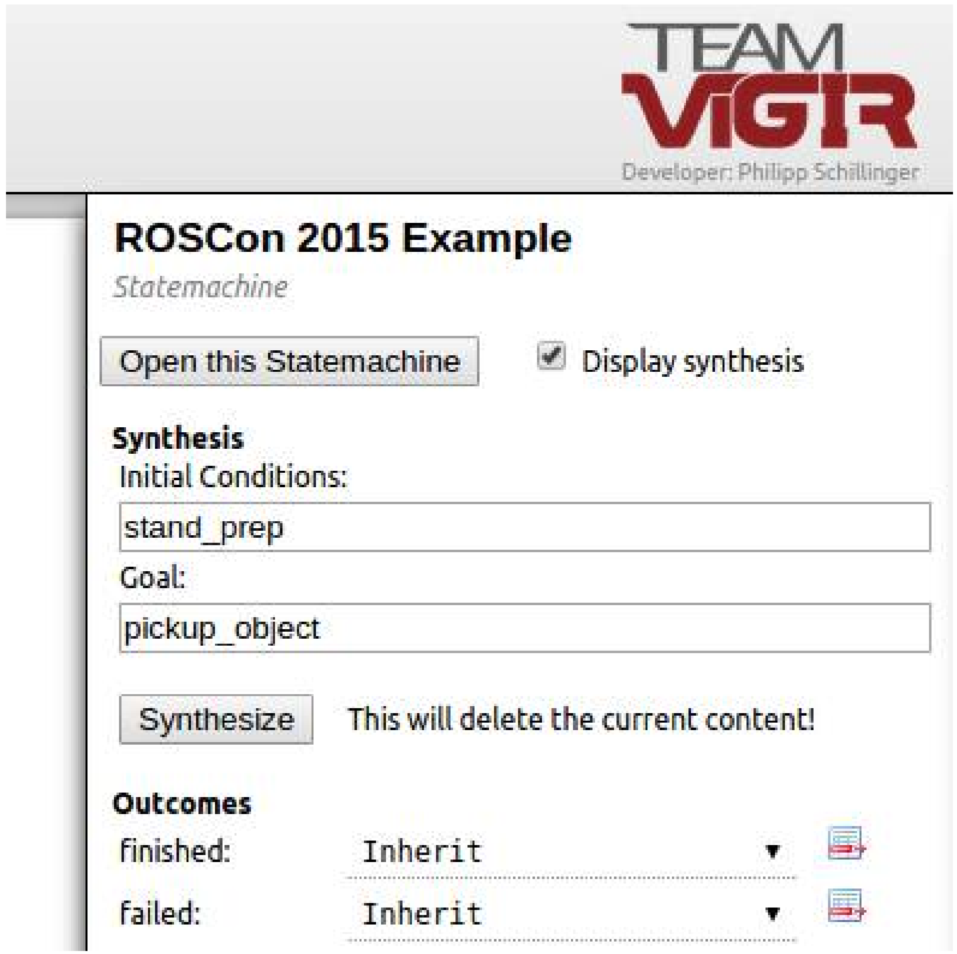
- 3D visualization based on librviz
  - Map View (Top Down)
    - Rectangle selection (query sensor data ROI)
  - Main View
  - CameraView
    - Camera data visualization
- Multiple Qt widgets for general controls
  - "Ghost Control"
  - Pre-canned joint configurations

Components – Install

- Install instructions for complete setups: github.com/team-vigir/vigir_install/wiki
  - Waiting for Atlas IHMC/Gazebo integration for full capability (walk/manipulate) Atlas example
  - Thor-Mang example available for manipulation demo: github.com/team-vigir/vigir_install/wiki/Install-thor-mang-vigir-gazebo

Components – Tutorial video

Work in Progress - Behavior Synthesis



Work in Progress - Behavior Synthesis

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- Compile formal Linear Temporal Logic (LTL) specification from:
  - High-level task (goals and initial conditions)
  - Abstract description of the robot-plus-software system, defined a priori (think config files)

- The formalism treats the outcomes of actions as an adversarial environment

github.com/team-vigir/vigir_behavior_synthesis

Work in Progress

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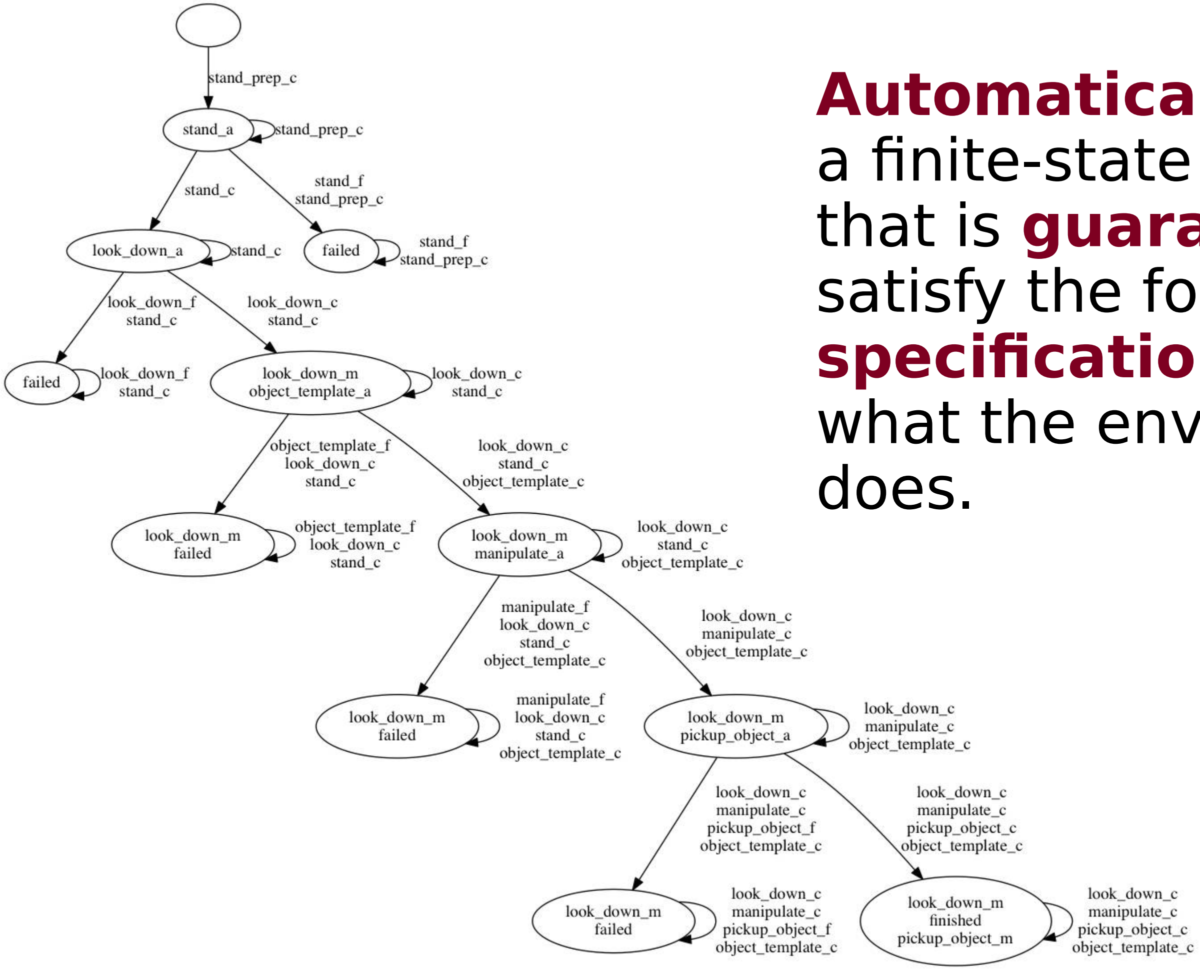
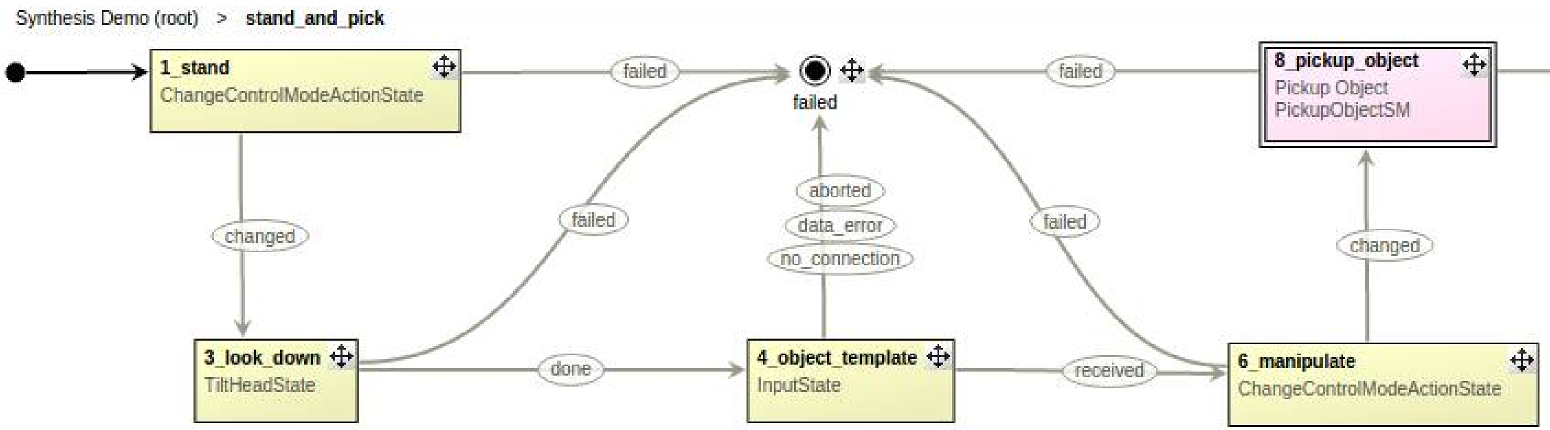


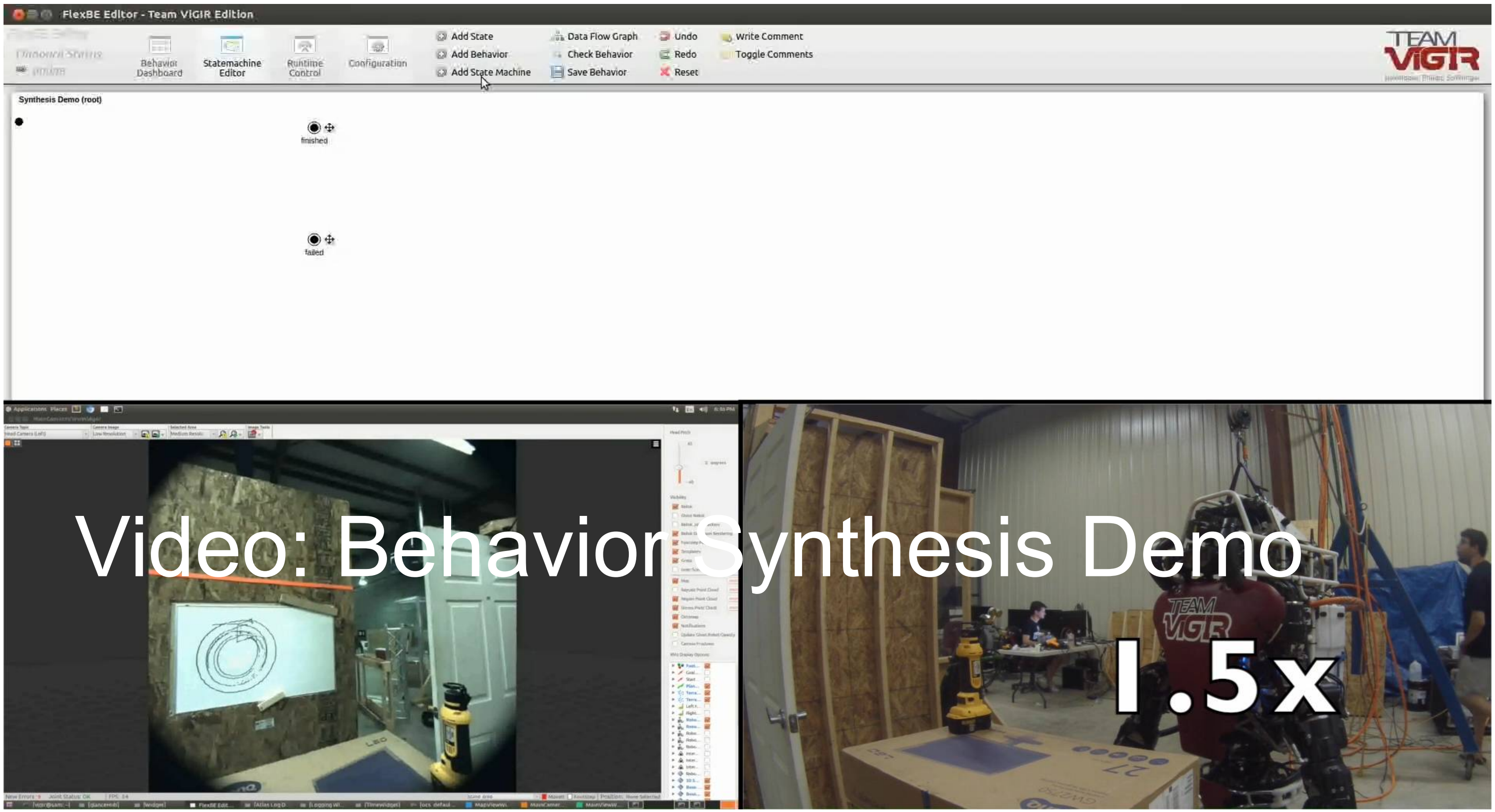
Automatically synthesize a finite-state automaton that is **guaranteed** to satisfy the formal LTL **specification** no matter what the environment does.

Work in Progress



- Mapping from abstract symbols to low-level system components (here, FlexBE states)
- Instantiation of symbolic automaton as an executable state machine in FlexBE

Behavior Synthesis - Example



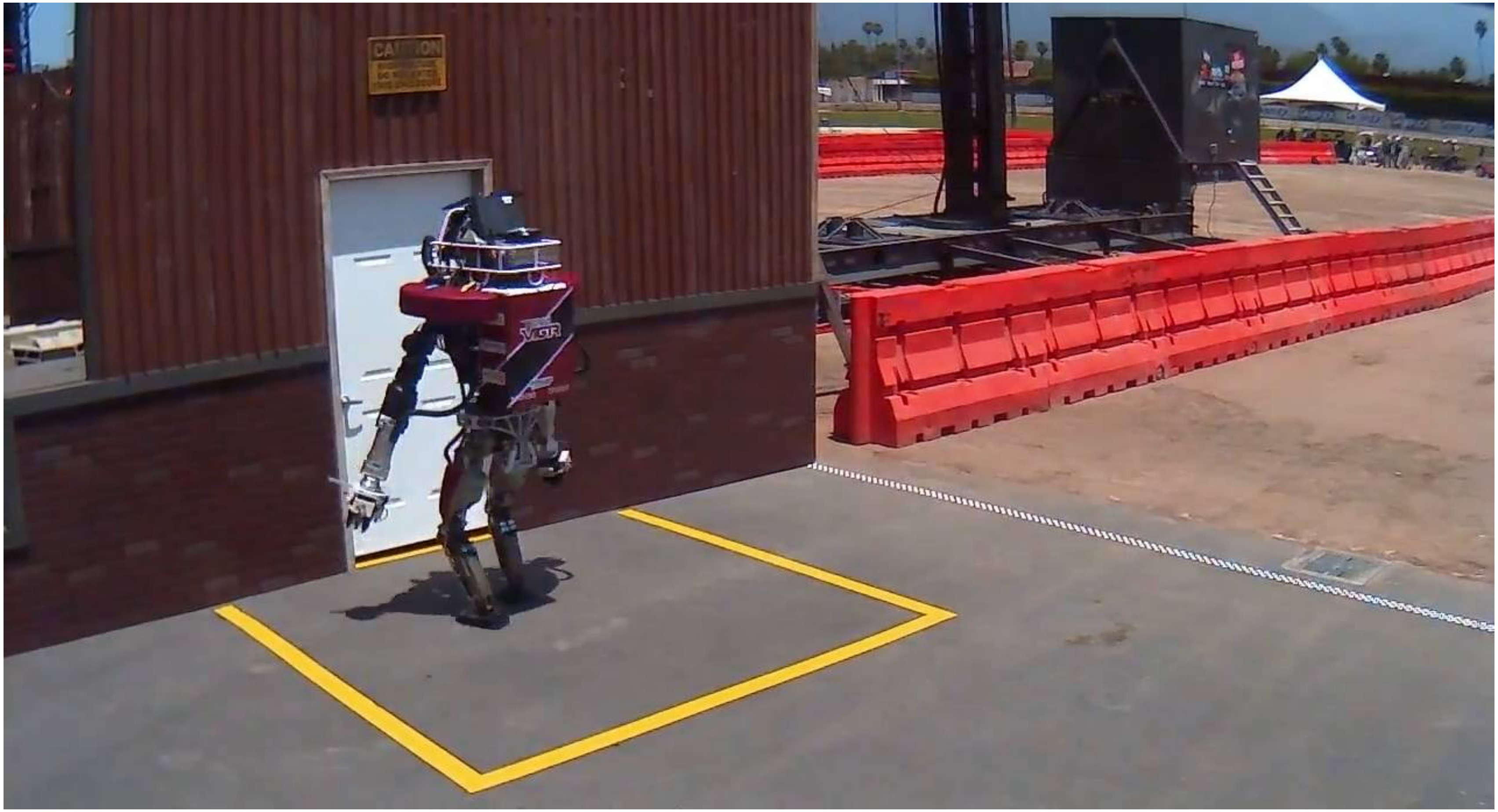
DRC Finals

- Decision not to do egress
  - Significant development effort
  - Risk of (catastrophic) damage to robot
- Limited testing under degraded comms conditions

DRC Finals – Day 1

DRC Finals – Day 1

DRC Finals – Day 1



DRC Finals – Day 1

DRC Finals – Day 1

DRC Finals – Day 1

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- Flawless Driving
- Comms bridge setup issue
  - Behavior control
  - Footstep planning
- Switch to teleop mode
- Slow but reliable

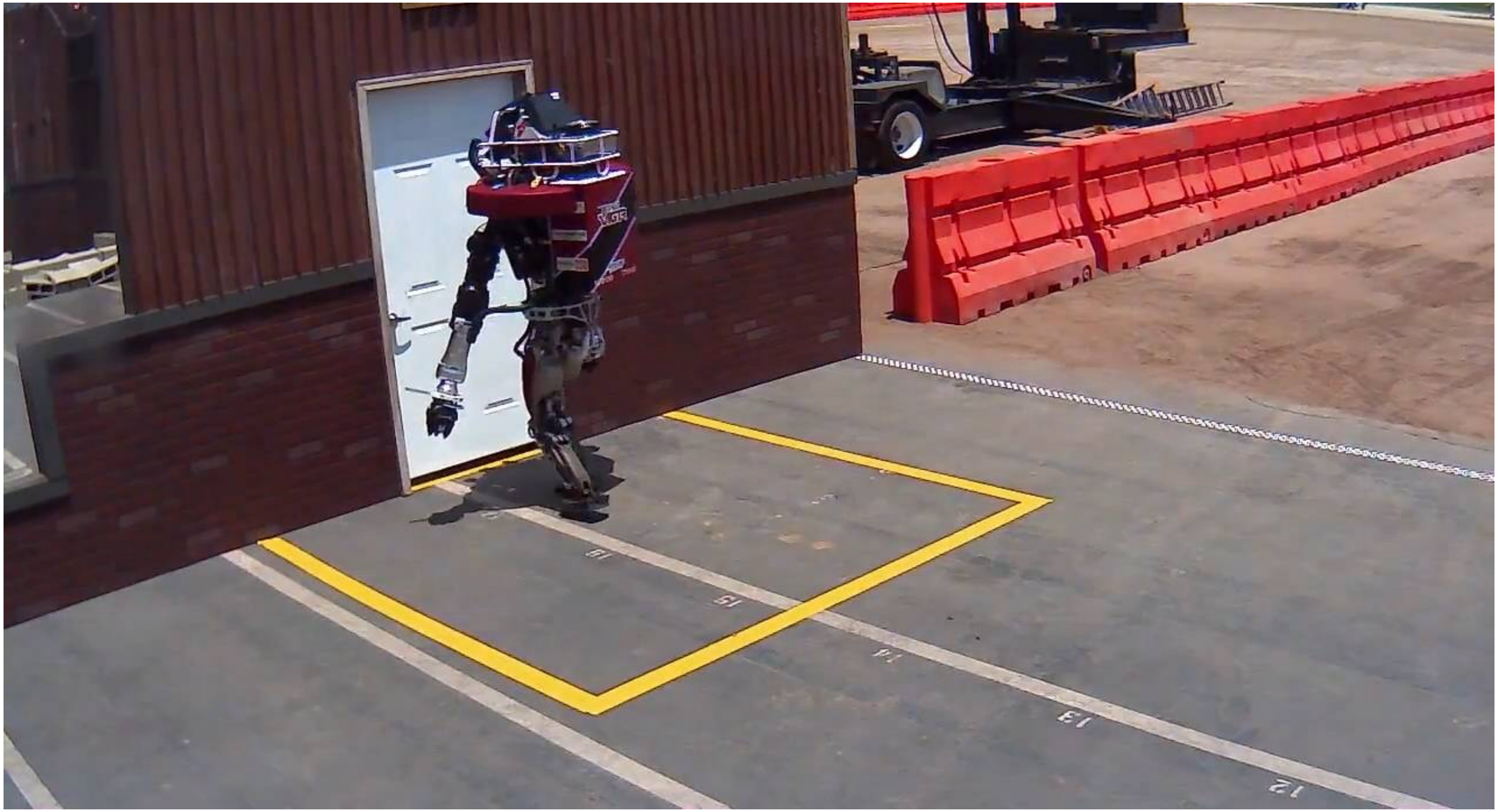
DRC Finals – Day 2

DRC Finals – Day 2

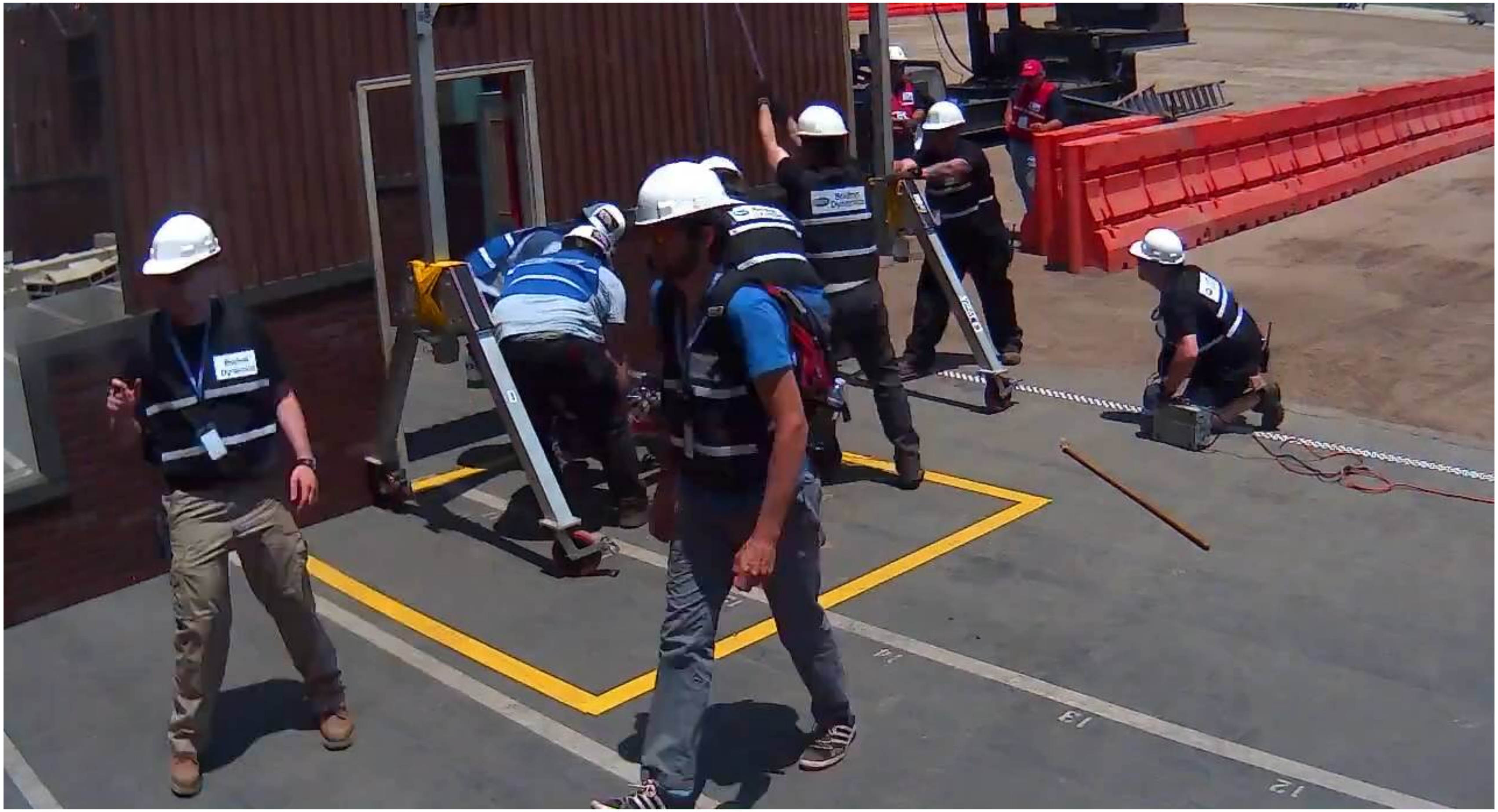
DRC Finals – Day 2

DRC Finals – Day 2

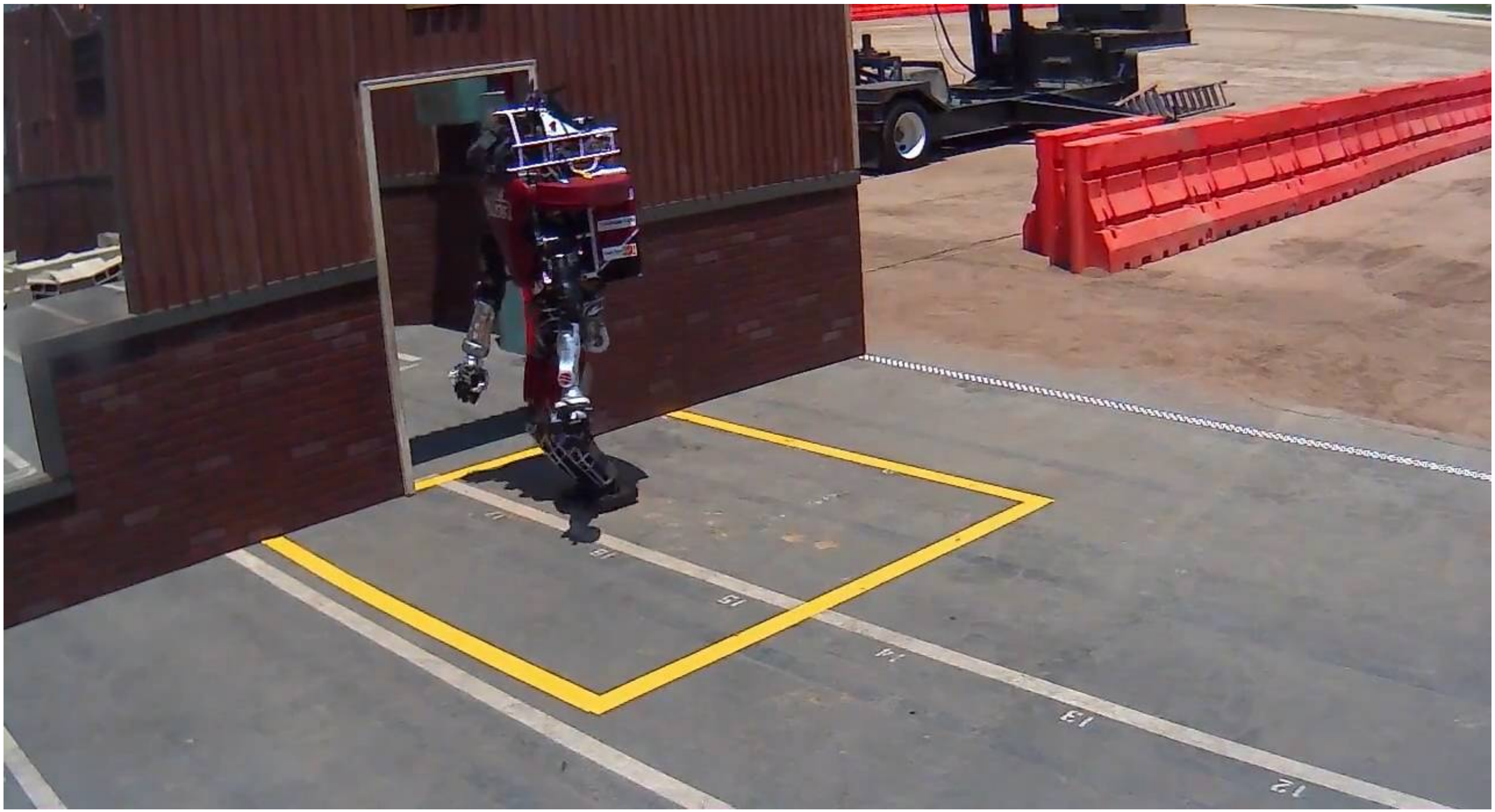
DRC Finals – Day 2



DRC Finals – Day 2



DRC Finals – Day 2



DRC Finals – Day 2

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- Start delay due to arm hardware failure
- (Too) fast driving
- Reset after touching barrier
- Successful driving
- Door opened
- Pump shutdown
  - Possibly due to overheating
- Reset
- Fall while walking through door

DRC Finals Results

- 3 Points (Day 1)
- Scored lower than would have been achievable and expected
  - Achievable: 7 points (No egress)
- Missed chance at Day 1 due to comms issues
- Unknown cause for pump shutdown at Day 2

- Driving approach worked well on both robots that used it
  - ViGIR Florian (Atlas)
  - HECTOR Johnny (Thor-Mang)

Lessons Learned - ROS

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- Workspace setup using wstool works well
  - Few convenience scripts helpful
- Keeping pace can be painful
  - From rosbuild to catkin
  - From hydro to indigo (switching ROS distro and Ubuntu version simultaneously)
- Using plain “catkin_make” in large projects bad idea
  - Use catkin_tools
- Limited constrained comms capability
- Supporting different configurations feels more involved than it should
  - Environment variables?

Lessons Learned – Big Picture

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- Having a transatlantic, nine time zone team works
  - Right mindset and people
  - Tools
- DRC showed what is possible
  - Brilliant display of state of the art capabilities
  - Still a long way to go till robots can be useful for real DRC-like tasks
- Continuous Integration
  - Simulation-in-the-loop testing desirable
- Everybody wins
  - Leap across wide range of capabilities
  - Open source developments (Gazebo, code releases..)
  - Incredible sportsmanship and cooperation across DRC teams

Conclusions

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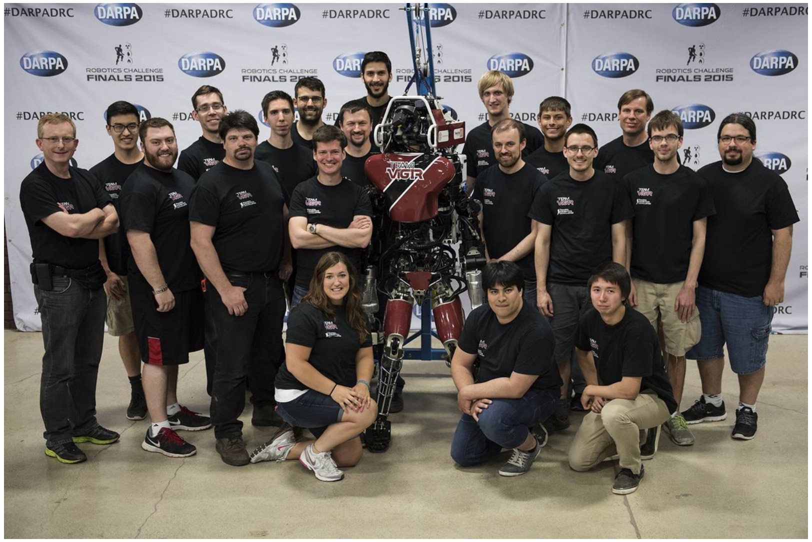
- DRC overview
- ROS infrastructure discussion
  - Useful tools
- Intro to open source components
  - Let us know what you're interested in
- DRC results discussion
- Lessons learned



Questions?

References

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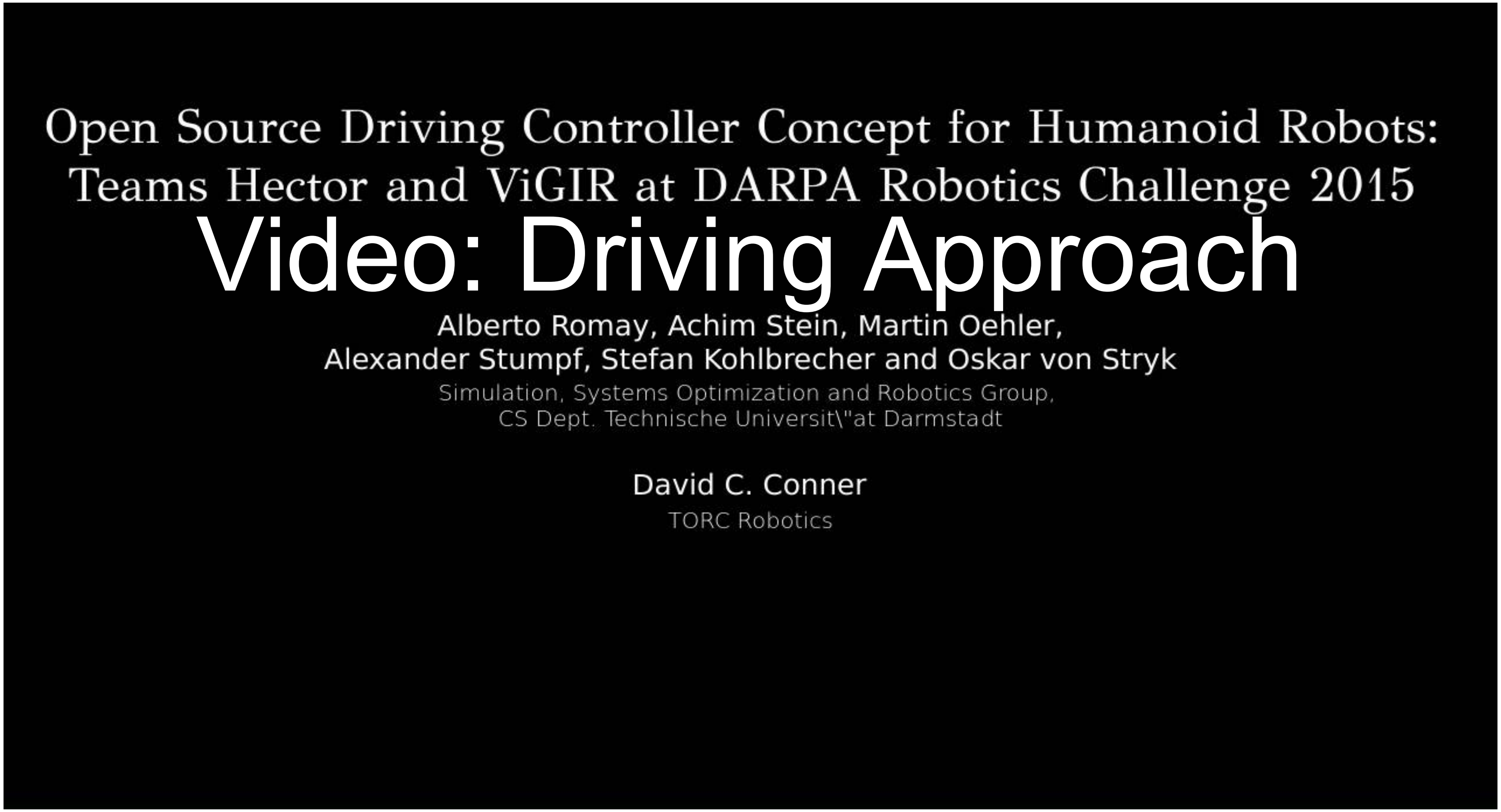
- Kohlbrecher et al. “Overview of team ViGIR's approach to the Virtual Robotics Challenge”, IEEE SSRR 2013
- Kohlbrecher et al. “Human-Robot Teaming for Rescue Missions: Team ViGIR´s Approach to the 2013 DARPA Robotics Challenge Trials” Journal of Field Robotics, 2014
- Romay et al. “Template-Based Manipulation in Unstructured Environments for Supervised Semi-Autonomous Humanoid Robots”, IEEE Humanoids 2014
- Stumpf et al. “Supervised Footstep Planning for Humanoid Robots in Rough Terrain Tasks using a Black Box Walking Controller”, IEEE Humanoids 2014

- YouTube playlist with manipulation examples

Additional Material - Driving Approach



Additional Material – DRC Communication constraints

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	Uplink (to OCS)	Downlink (to robot)	Remarks
VRC	Total ~115 kB for 30 minutes. 500 ms latency	Total, ~7 MB for 30 minutes. 500 ms latency	Worst case (20% of scenarios)
Trials	1 MB/s, 50ms latency	1 MB/s, 50 ms latency	Good comms — Switch every minute
	100 kB/s, 500 ms latency	100 kB/s, 500 ms latency	Bad comms
Finals	1.2 kB/s	1.2 kB/s	
	300 Mbit/s		Outages of 1-30 seconds after robot traverses door

VRC Rules (pdf)

Trials Rules (pdf)

Finals Rules (pdf)