Operating Humanoid Robots:

Comprehensive Modular Open Source Software for Humanoid Avatar Robots based on ROS

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Motivation

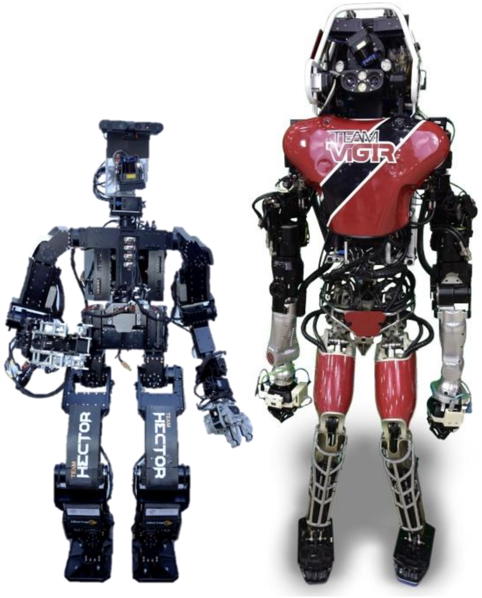
- Humanoid robots are suitable for human tasks in human environments:
  - Home
  - Industrial Environments
  - Disaster Response

Don Joven Agravante et al.
https://youtu.be/-1BcC3aEuZM

Human Environment Example
Driving Cars

Human Environment Example
Driving Cars

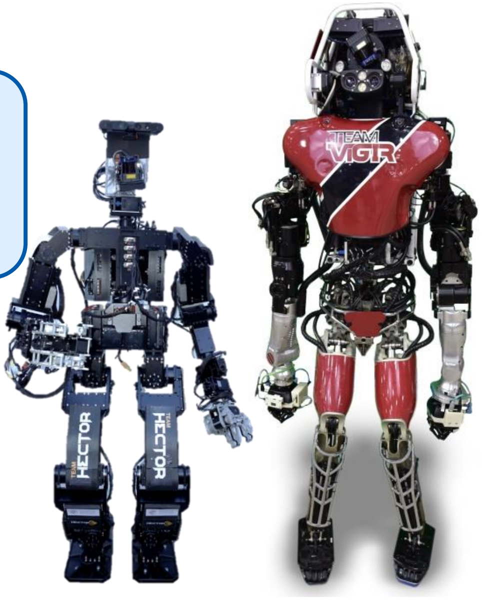
Challenges for Humanoid Robots



Challenges for Humanoid Robots

- Motions with multiple contacts (e.g. using handrails)

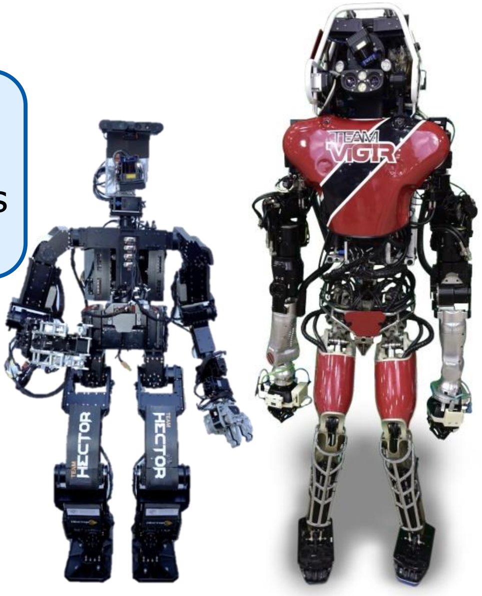
Versatile and robust **(Loco-)Motion**

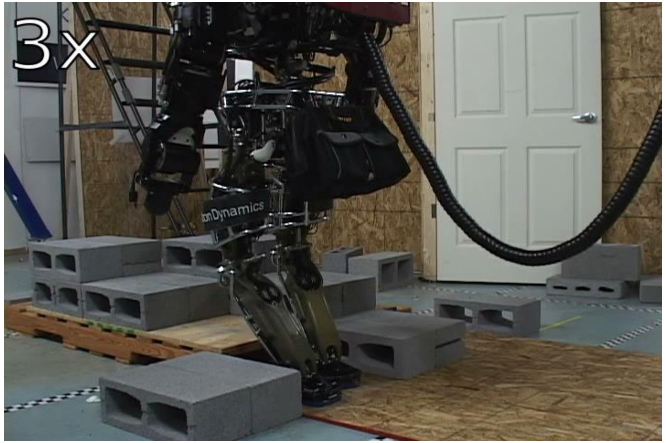


Challenges for Humanoid Robots

- Motions with multiple contacts (e.g. using handrails)
- Ladders, uneven terrain and stairs

Versatile and robust
(Loco-)Motion

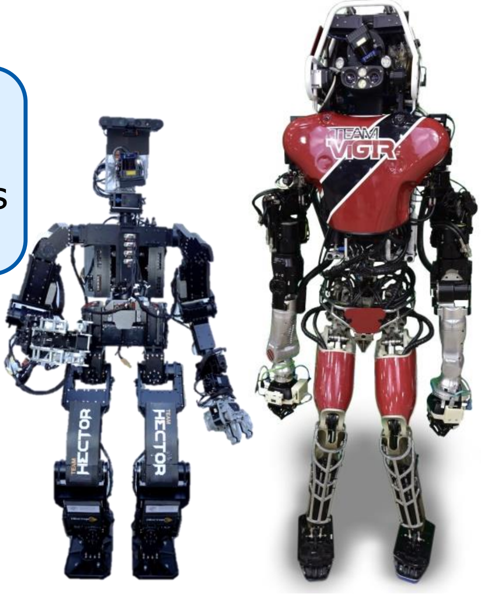


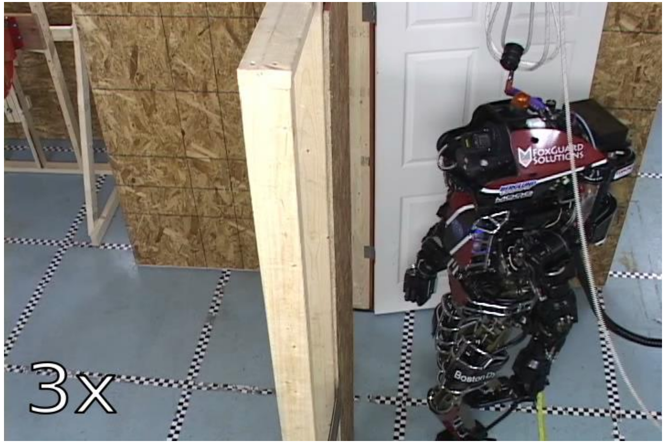


Challenges for Humanoid Robots

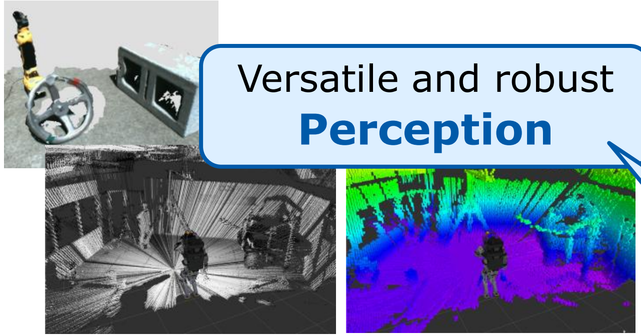
- Motions with multiple contacts (e.g. using handrails)
- Ladders, uneven terrain and stairs
- Doors

Versatile and robust
(Loco-)Motion

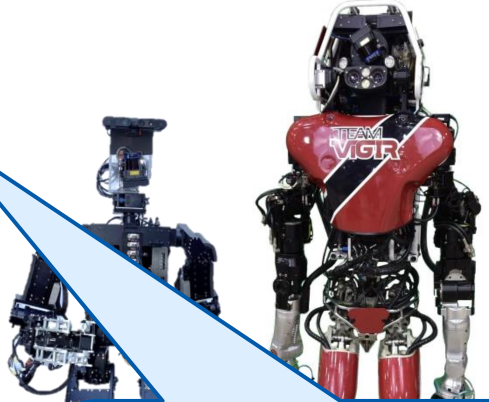




Challenges for Humanoid Robots



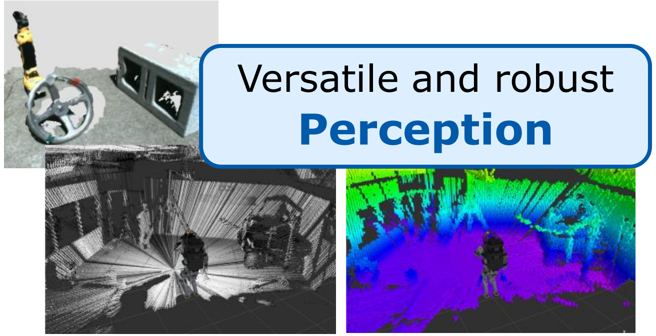
Versatile and robust
Perception



Versatile and robust
(Loco-)Motion

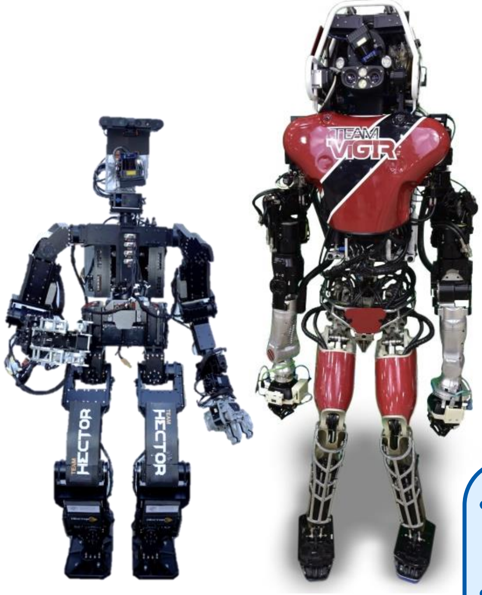
- Environment for locomotion
- Objects for manipulation
- Ability to acquire new objects and their potential purposes on the fly
- Robustness to different lightning conditions

Challenges for Humanoid Robots



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

Challenges for Humanoid Robots

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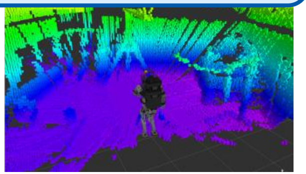


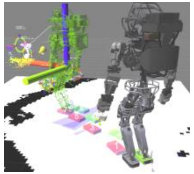
Versatile and robust
Perception

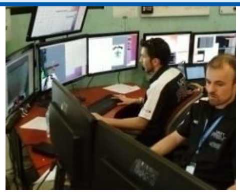
Versatile and robust
Manipulation

Versatile and robust
(Loco-)Motion

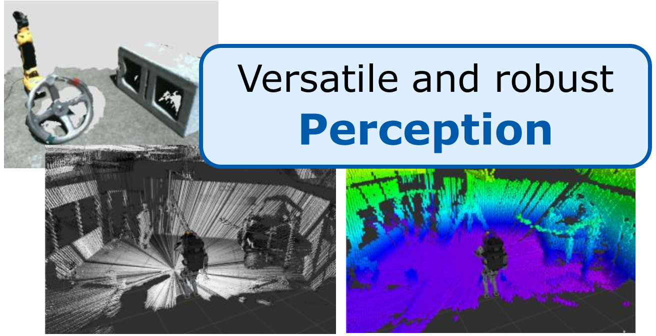
Efficient Supervision via
Human-Robot-Interaction

- Matching human and robot abilities best
- Appropriate levels of human-robot-interaction for highly diverse tasks
- Distribution between work tasks robot onboard and offboard (OCS)





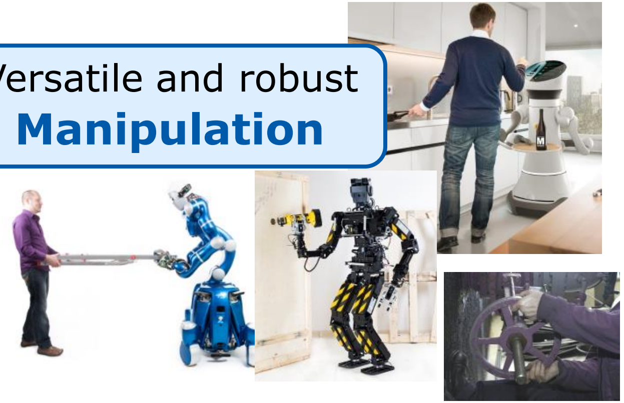
Challenges for Humanoid Robots



Versatile and robust
Perception

Versatile and robust
(Loco-)Motion

Limited
Wireless Communication
- bandwidth, latency, dropouts



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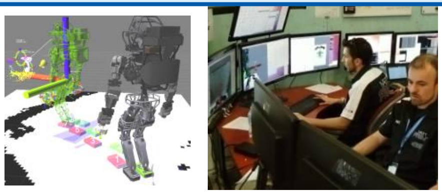

Efficient Supervision via
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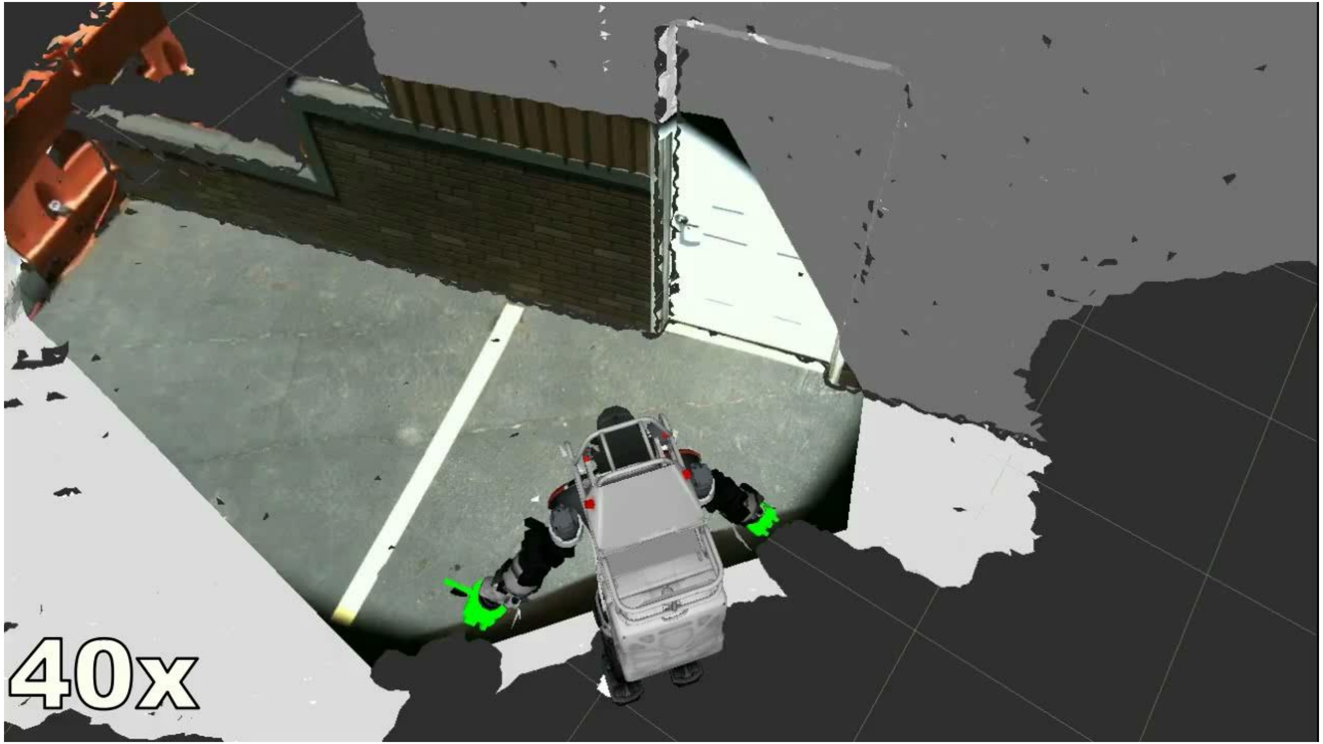
Human Operator Perspective
DRC Finals (2015) Example



Humanoid Robots Requires **Complex Software**

- Re-Inventions are the time sink #1
- Progress requires…
  - Documentation (e.g. Papers)
  - Shared Software (e.g. Open Source Code)
  - Maintainers (e.g. the Community)

Notable Open Source Efforts Usable for Humanoid Robots

- MIT:
  - Pronto State Estimator
  - Drake Planning and Control
  - Director UI
- IHMC:
  - IHMC Controller
  - SCS Simulator
- MoveIt! – Manipulation planning
- Gazebo – Simulation including physics engines
- **ROS – Robot Operating System (Middleware)**

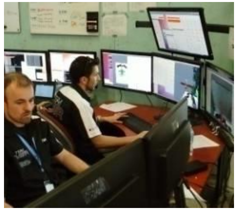
Why ROS?

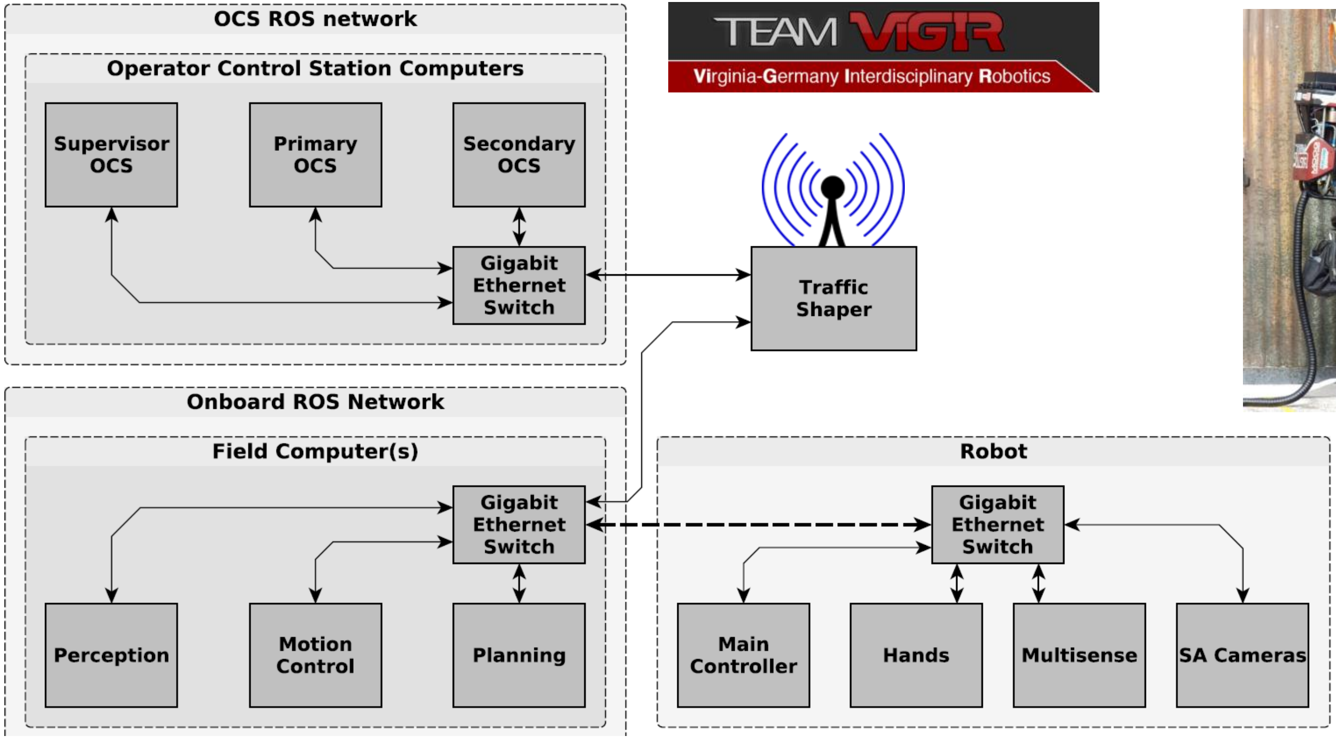
Prevent the Re-Invention of the Wheel!

- Common Ecosystem
  - Using common, well-defined interfaces
- Reusability of Software

System Architecture using ROS

Team ViGIR DRC Setup





Our Contributions (Overview)

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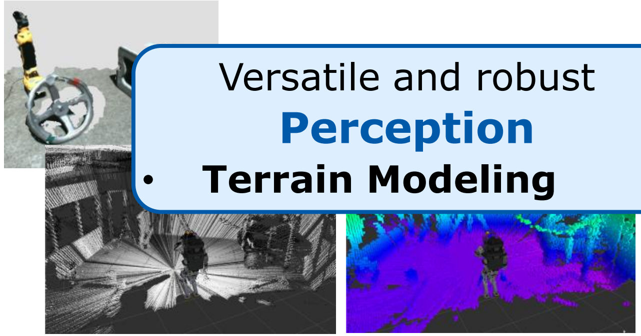
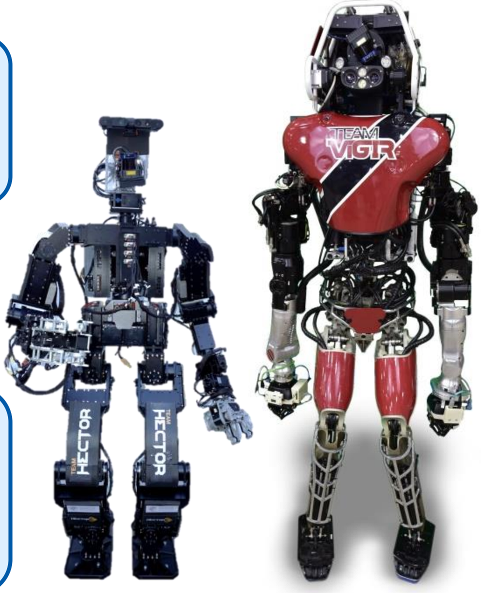
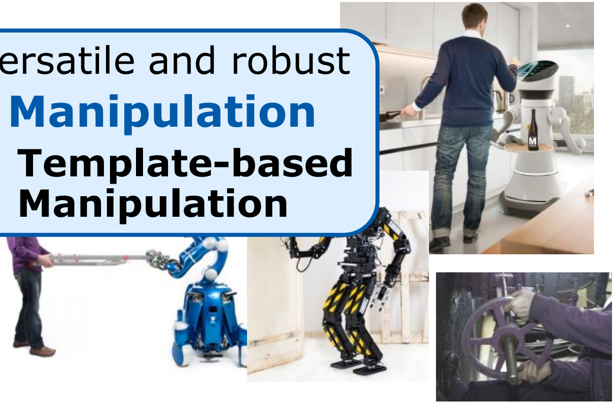


Versatile and robust
Perception
- **Terrain Modeling**

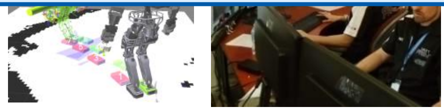


Versatile and robust
Manipulation
- **Template-based Manipulation**



Versatile and robust
(Loco-)Motion
- **3D Footstep Planning in rough terrain**

Efficient
Human-Robot-Interaction
- **“Ghost Robot”**
- **Sliding Autonomy**



[1] *Stefan Kohlbrecher et al.* “A comprehensive software framework for complex locomotion and manipulation tasks applicable to different types of humanoid robots”, Frontiers in Robotics and AI, 2016

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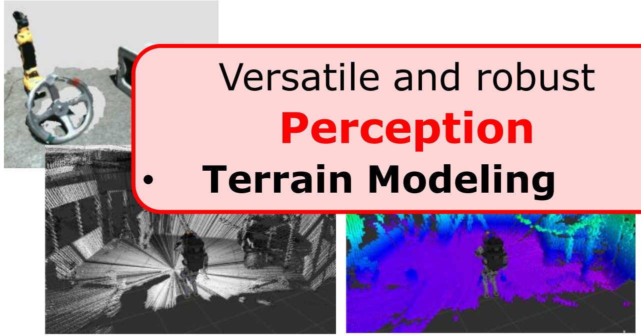

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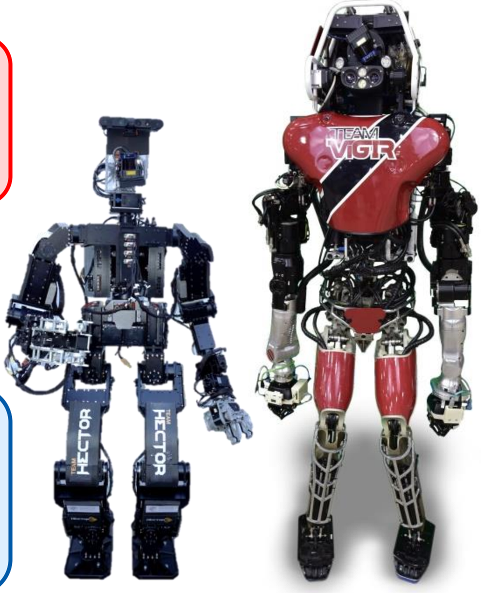

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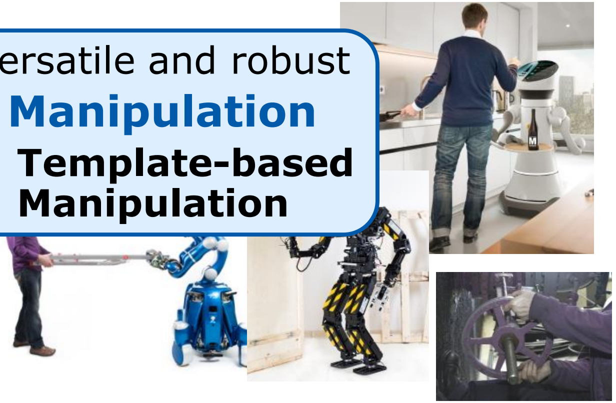

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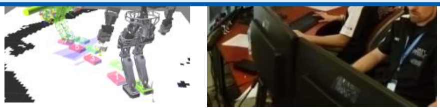


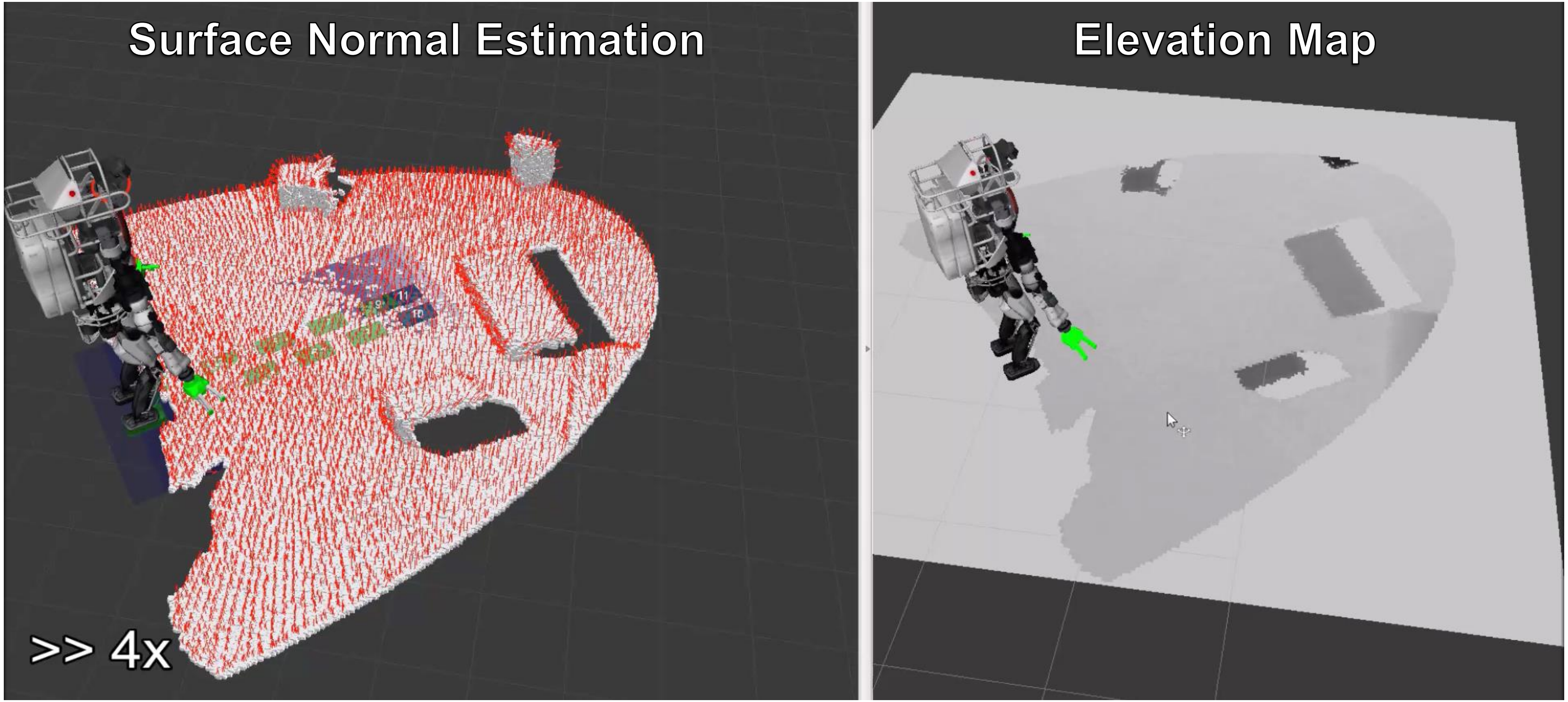
[1] *Stefan Kohlbrecher et al.* "A comprehensive software framework for complex locomotion and manipulation tasks applicable to different types of humanoid robots", Frontiers in Robotics and AI, 2016

Terrain Modeling

- Only point clouds required as input
- Uses Oct-Tree as data representation for efficient data lookup

https://github.com/team-vigir/vigir_terrain_classifier

Terrain Modeling
Online Generation



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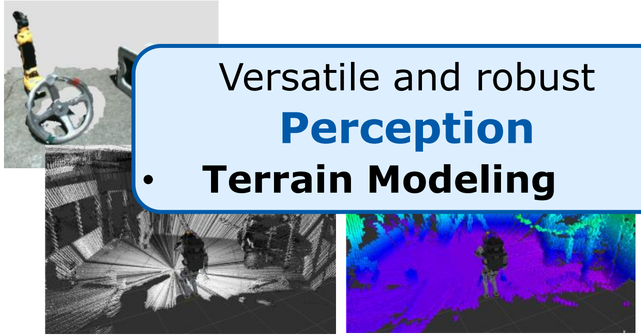

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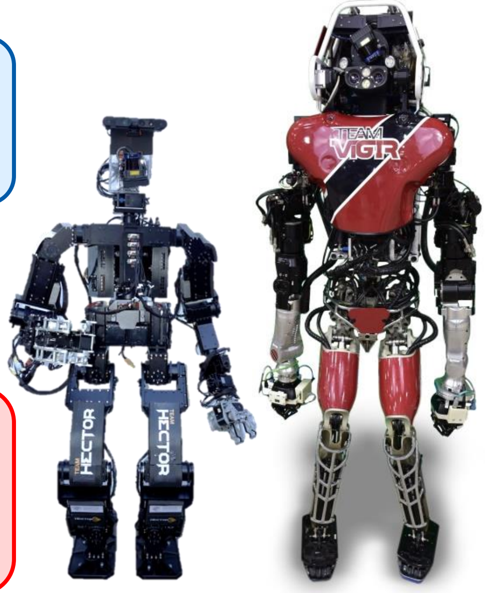

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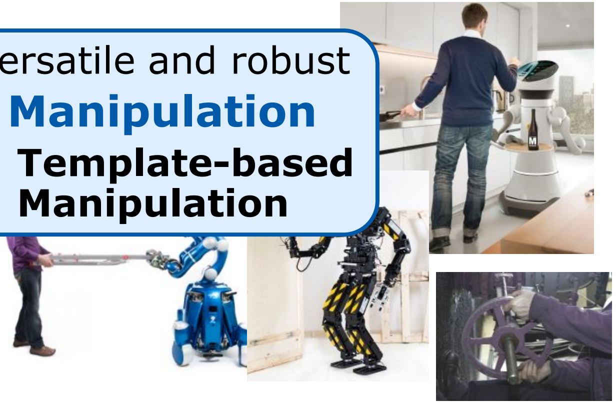

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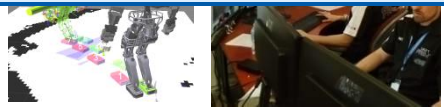

[1] *Stefan Kohlbrecher et al.* "A comprehensive software framework for complex locomotion and manipulation tasks applicable to different types of humanoid robots", Frontiers in Robotics and AI, 2016

3D Footstep Planning

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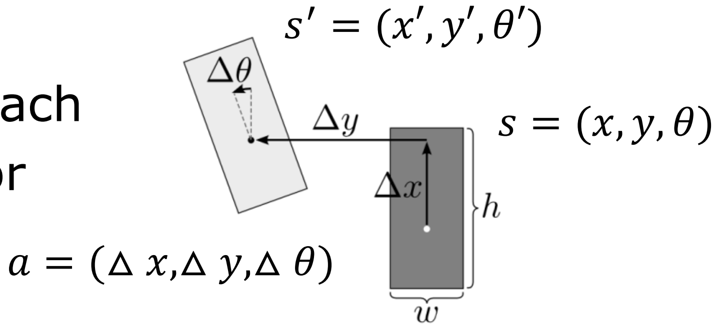
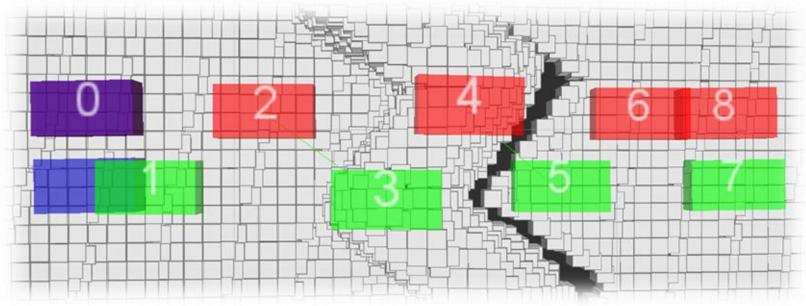
- Generates suitable sequence of full 3D (6 DoF) foot poses
  - Using A*-search-based planning approach
  - Novel collision check strategy allows for overhanging steps
- Adaptable to many bipedal robots



Discrete Foot Placements

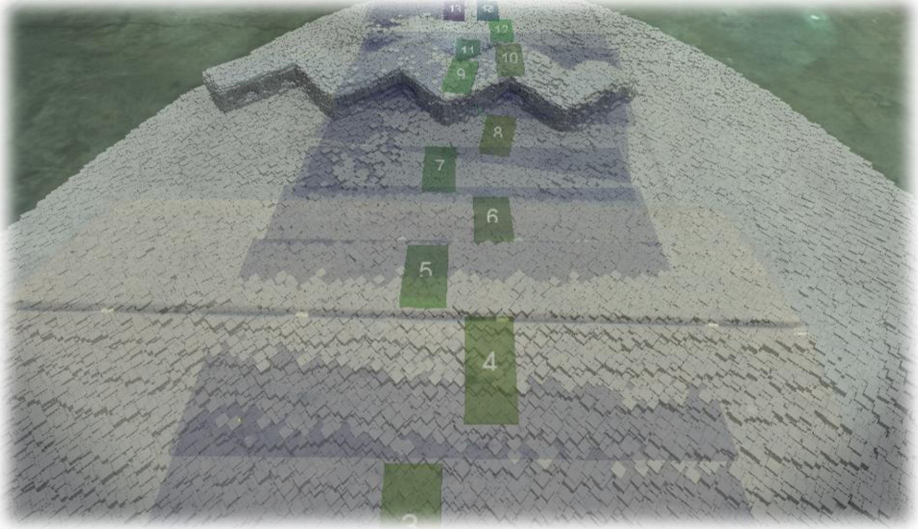


[2] Alexander Stumpf *et al.* “Supervised Footstep Planning for Humanoid Robots in Rough Terrain Tasks using a Black Box Walking Controller”, IEEE-RAS Intl. Conf. Humanoid Robots, 2014

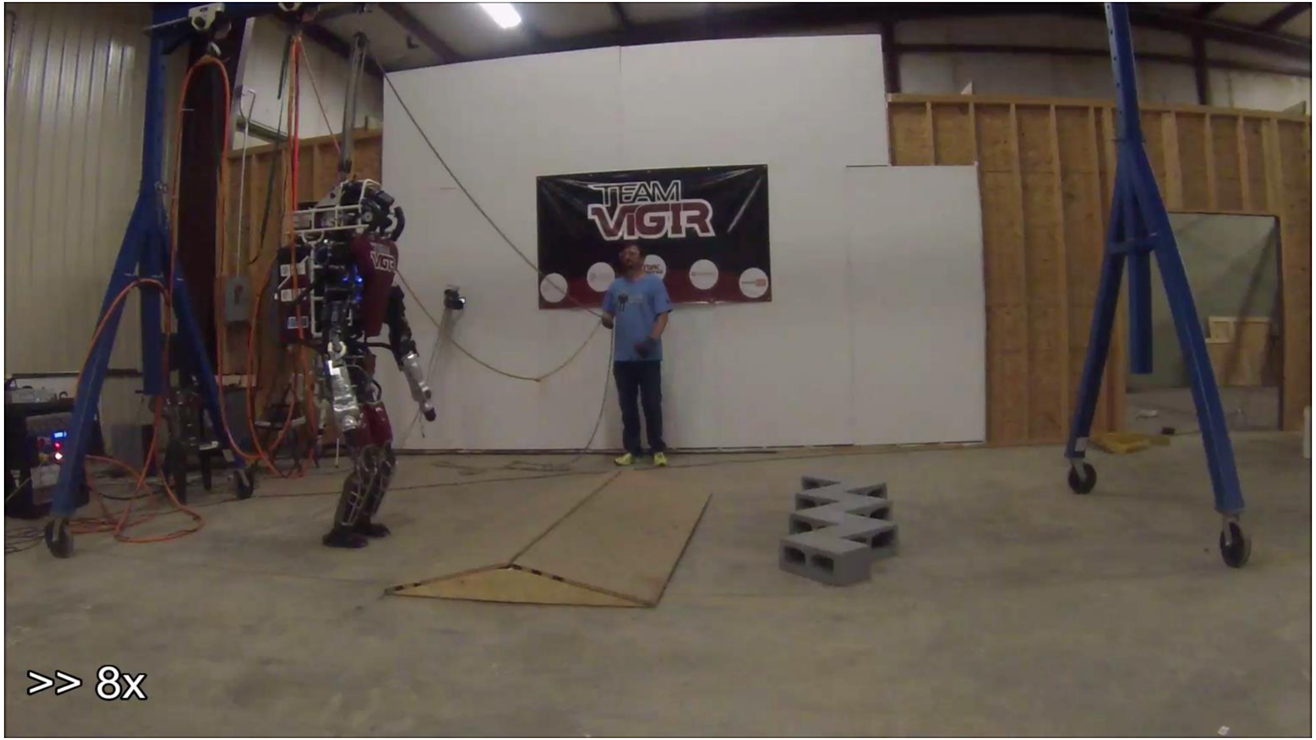
http://wiki.ros.org/vigir_footstep_planning

3D Footstep Planning
Example

- Robot‘s field of view



3D Footstep Planning
Example



3D Footstep Planning
Human Supervision

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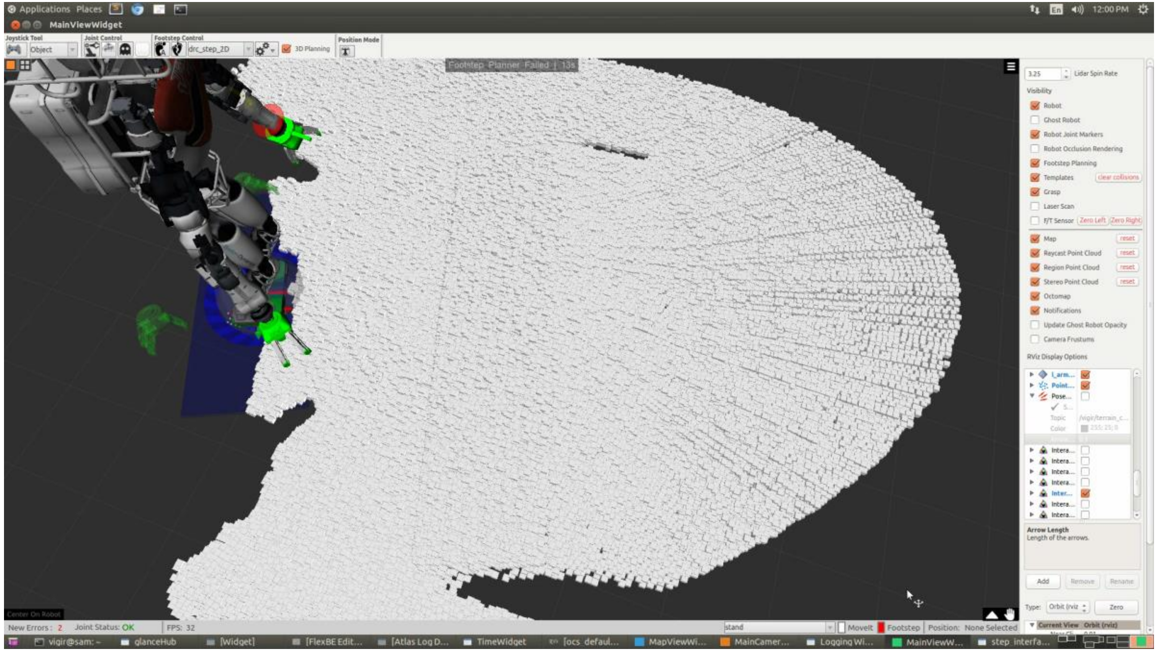
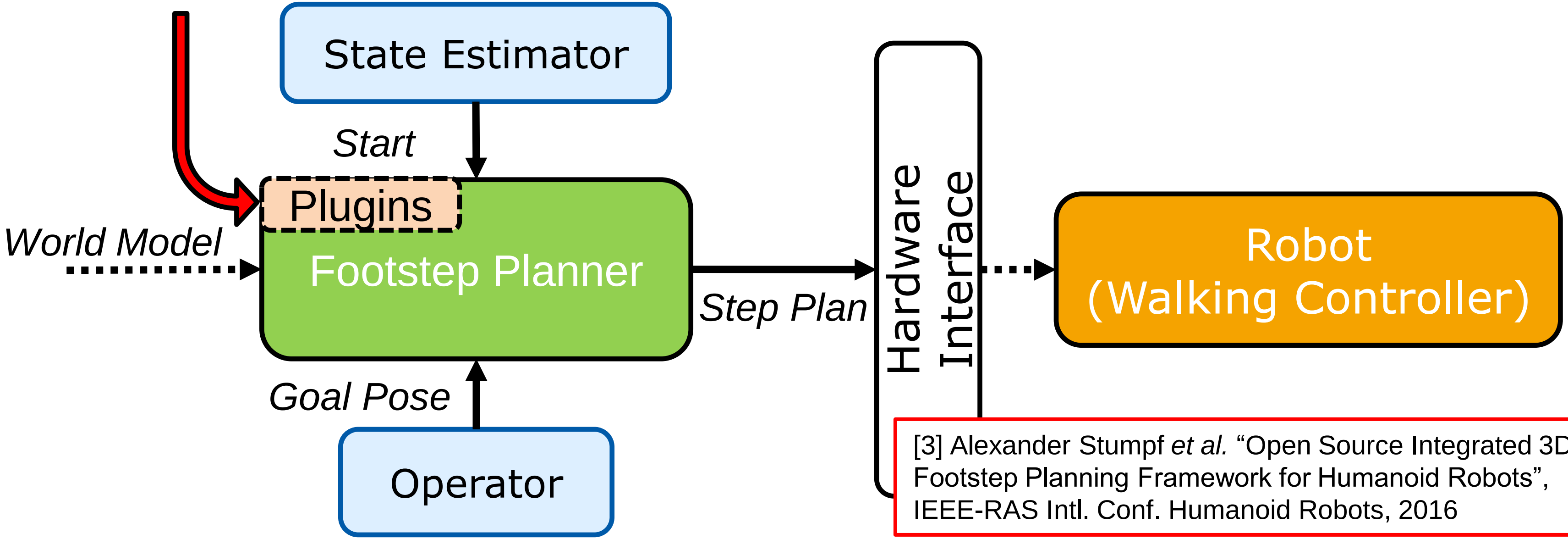
- Support for Interactive Footstep Planning



3D Footstep Planning
Available as Customizable Framework

- Modular and adaptable for any humanoid robot via plugins



[3] Alexander Stumpf *et al.* “Open Source Integrated 3D Footstep Planning Framework for Humanoid Robots”, IEEE-RAS Intl. Conf. Humanoid Robots, 2016

- **Please visit Poster on Thursday 16:30-18:00 (ThPoS.23)**

Our Contributions (Overview)

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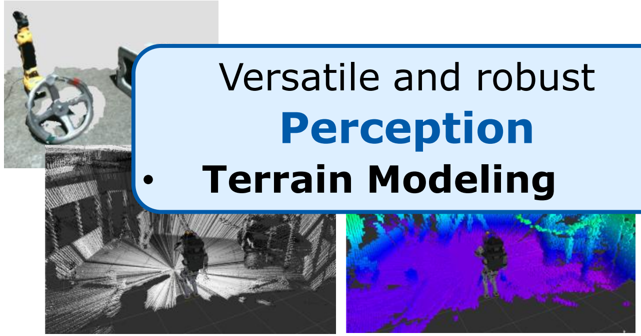

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- **Terrain Modeling**

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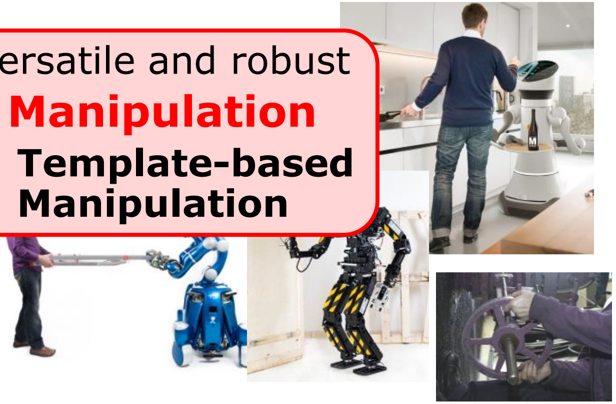
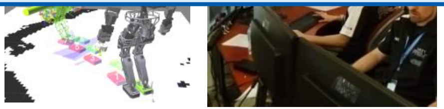


Versatile and robust
Manipulation
- **Template-based Manipulation**

Efficient
Human-Robot-Interaction
- **"Ghost Robot"**
- **Sliding Autonomy**



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Template-Based Manipulation

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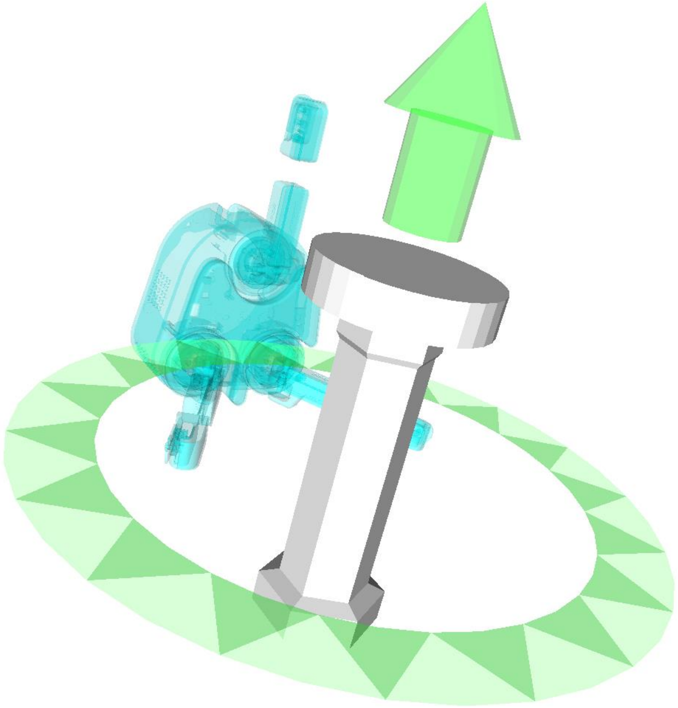
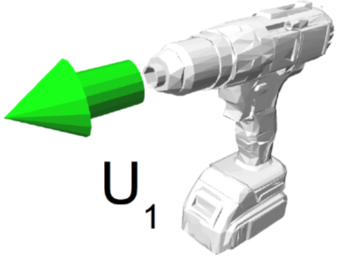
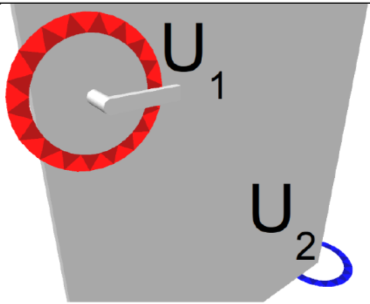
- Grasp template
  - Potential grasp poses
  - Finger joint positions
  - Type of grasp
  - Potential stand poses
- Stand template
  - Potential robot poses
- Object template

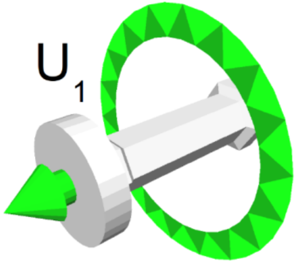


https://github.com/team-vigir/vigir_object_template_manager

Template-Based Manipulation
Actions Over Object Templates[1]

Drill Template	$U_1 = \{1, 0, 0, 0, 0, 0\}$
	The drill action possibility is a translation along the X axis (green arrow).

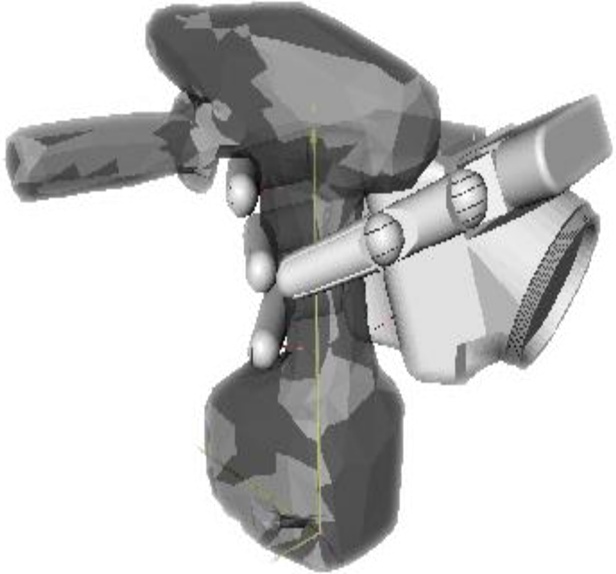
Door Template	$U_1 = \{0, 0, 0, 0, 1, 0\}$ $U_2 = \{0, 0, 0, 0, 0, 1\}$
	The door action possibilities are to rotate around the Y axis (red ring) in U_1 and rotate around the Z axis (blue ring) in U_2.

Hose Template	$U_1 = \{1, 0, 0, 1, 0, 0\}$
	The hose action possibility is a translation and a rotation around the X axis (green arrow and ring).

[4] *Alberto Romay et al.*, “Template-Based Manipulation in Unstructured Environments for Supervised Semi-Autonomous Humanoid Robots”, IEEE-RAS Intl. Conf. Humanoid Robots, 2014

Template-Based Manipulation
Example

- Operator/algorithm identifies relevant sensor data
- Overlaps template



Template-Based Manipulation
Example

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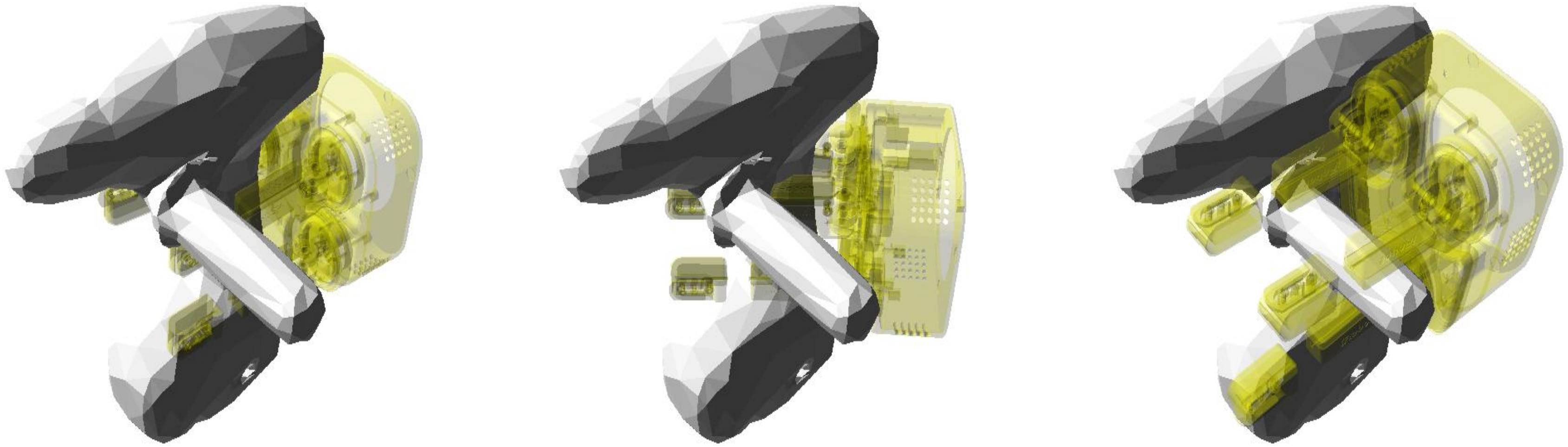
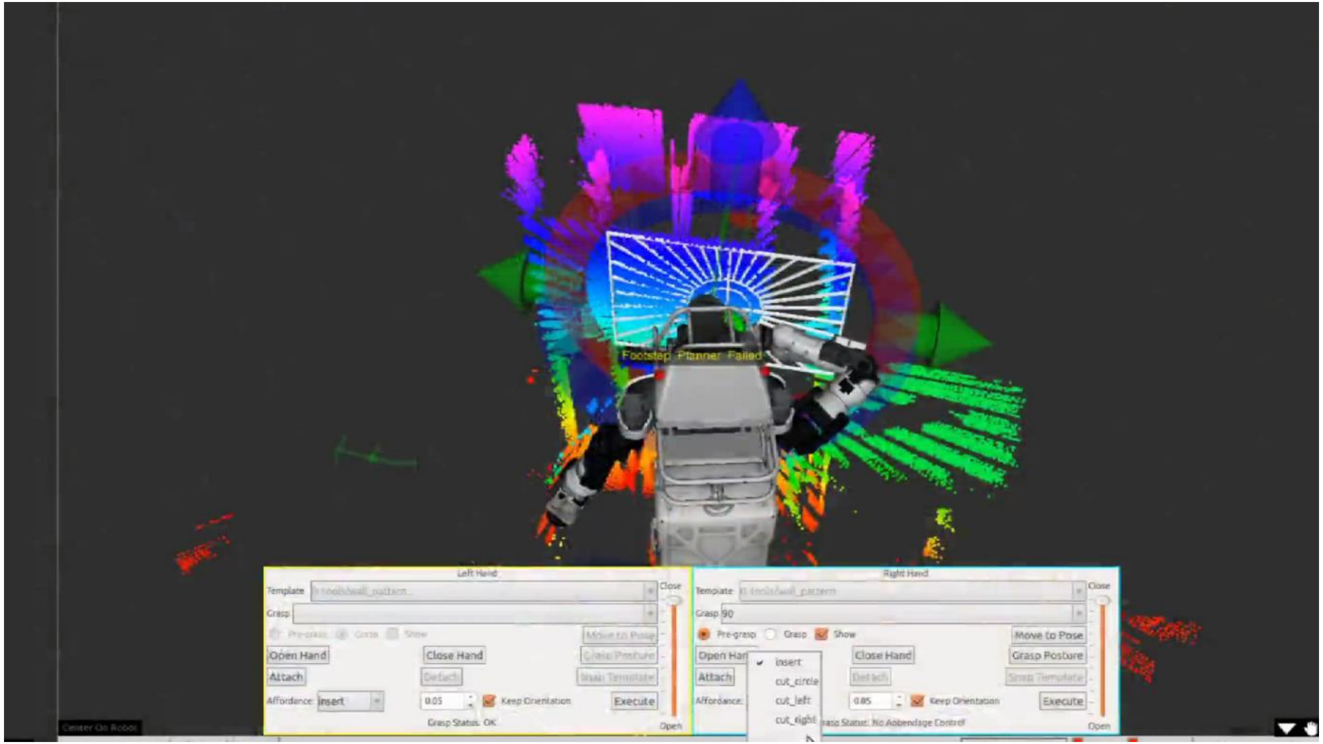
- Operator/algorithm identifies relevant sensor data
- Overlaps template
- Selects grasp



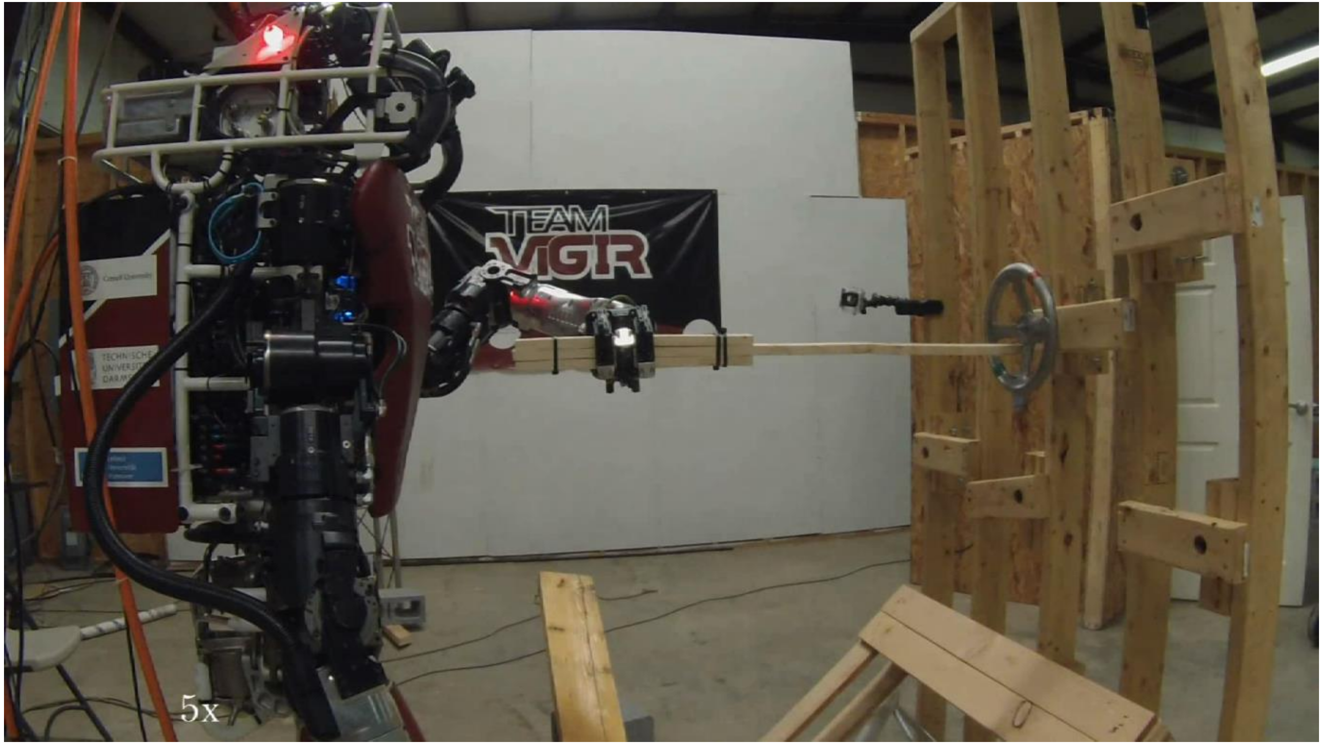
Template-Based Manipulation
Example

- Operator/algorithm identifies relevant sensor data
- Overlaps template
- Selects grasp
- Performs affordance (see videos)

Template-Based Manipulation
Versatile Manipulation with Unknown Objects



Template-Based Manipulation
Versatile Manipulation with Unknown Objects



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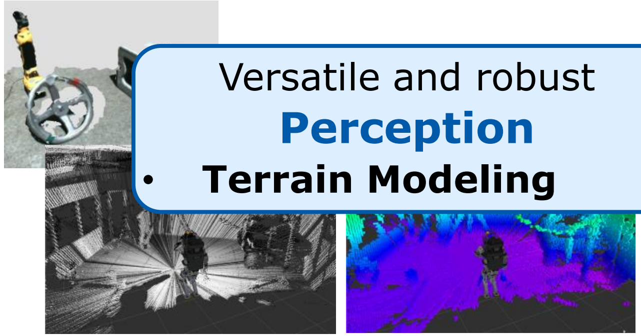

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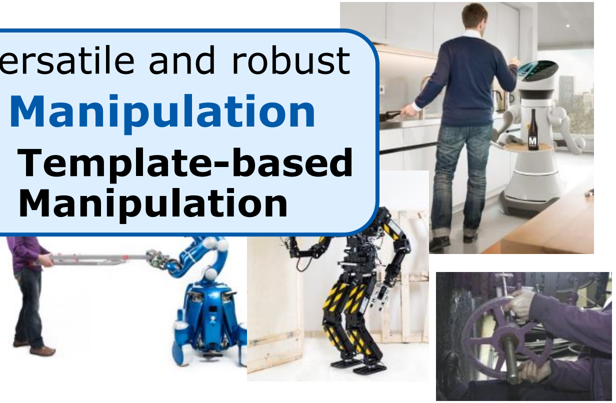

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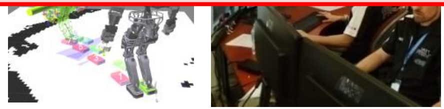
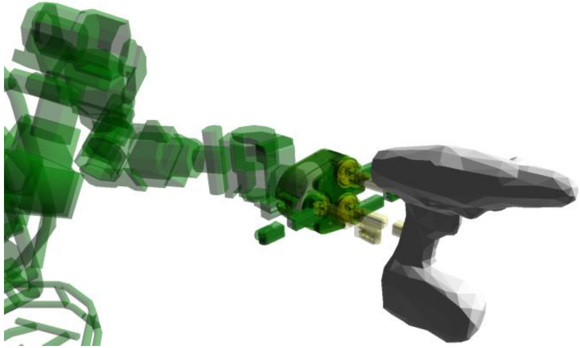
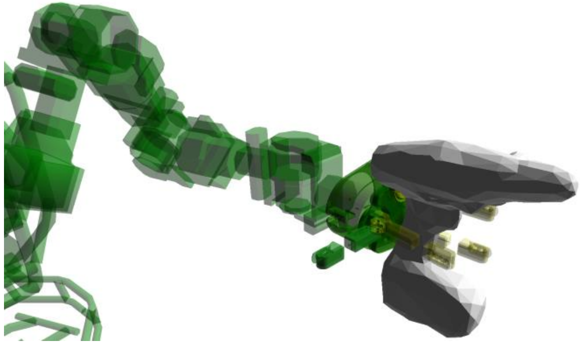


[1] *Stefan Kohlbrecher et al.* "A comprehensive software framework for complex locomotion and manipulation tasks applicable to different types of humanoid robots", Frontiers in Robotics and AI, 2016

“Ghost Robot“

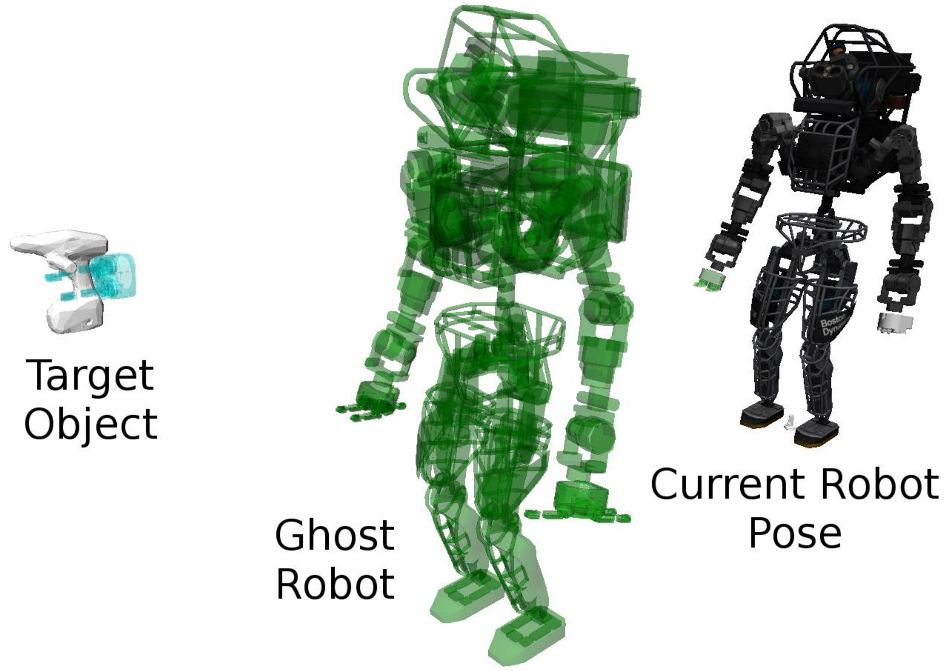
- Pre-plan motions with virtual “Ghost Robot”
- Additional capabilities compared to start/goal state visualization in MoveIt! RViz plugin
  - Snap endeffectors to objects
  - Move to stand poses relative to object templates
  - Constrain IK joint limits
  - Send low-bandwidth planning request directly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





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

Locomotion-Manipulation Pipeline



Locomotion-Manipulation Pipeline

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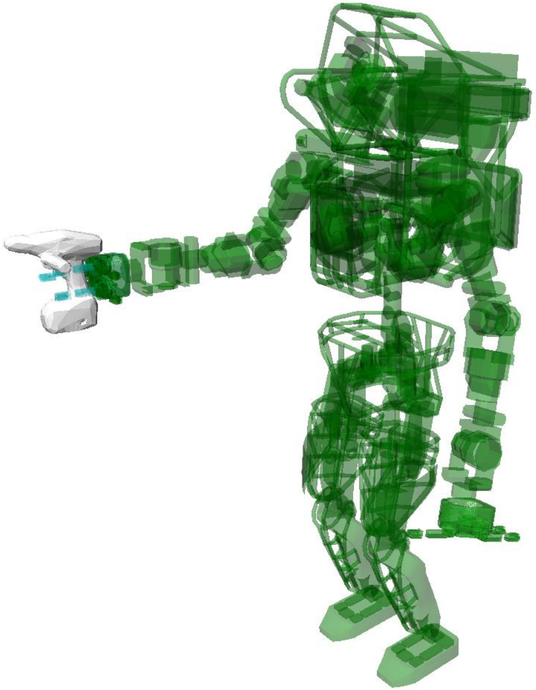

Search for suitable robot pose via inverse reachability query

Locomotion-Manipulation Pipeline

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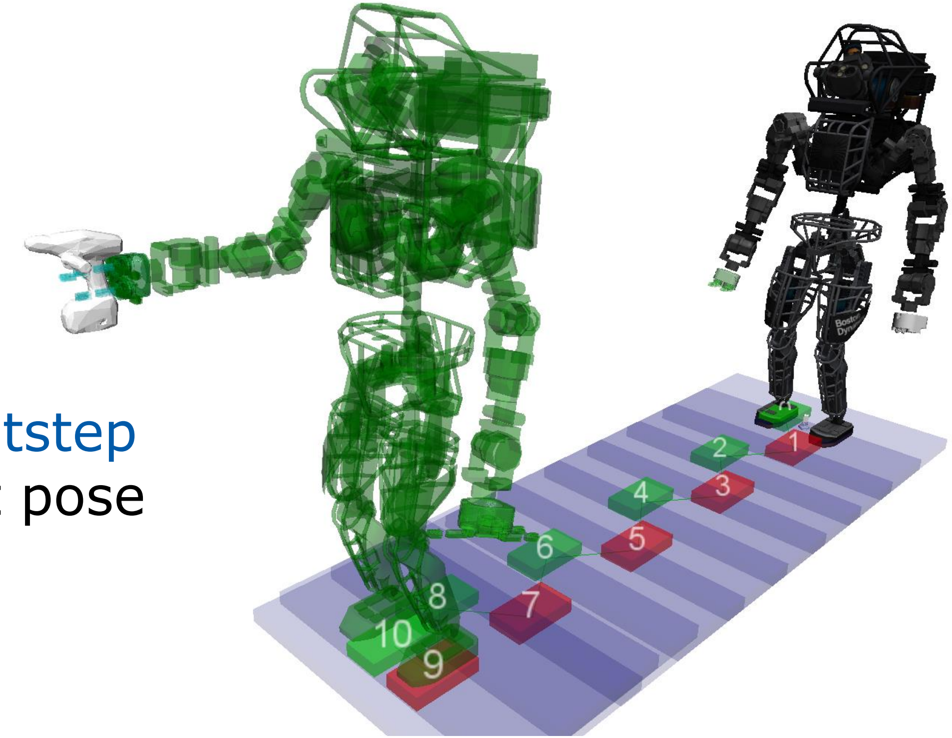
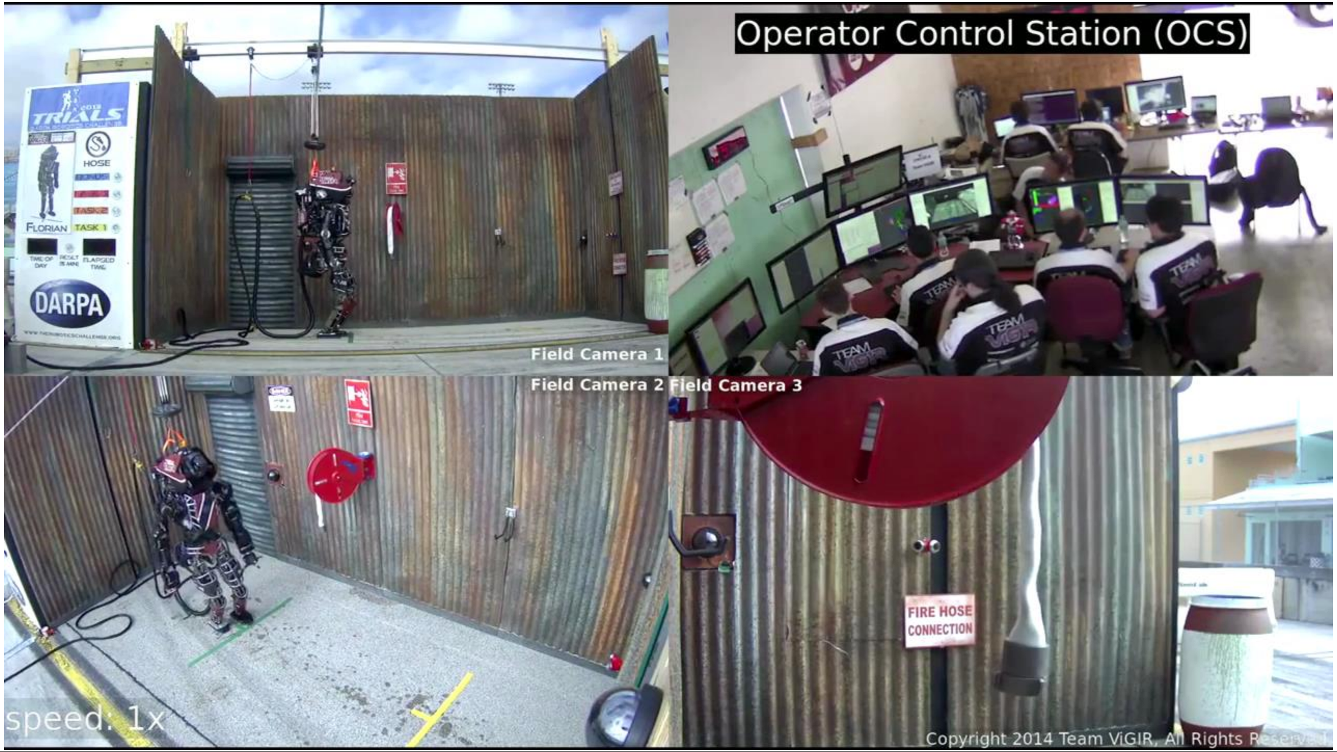


Generate footstep plan to robot pose

Locomotion-Manipulation Pipeline

Example: Hose Task (DRC Trials)



Sliding Autonomy

- Communication constraints
- Limited time
- Complex robot system

Motivates high degree of **robot autonomy**

Flexible Robot-Operator Collaboration

- Unstructured environment
- Complex tasks
- Robustness important

Motivates high degree of **operator support**

FlexBE

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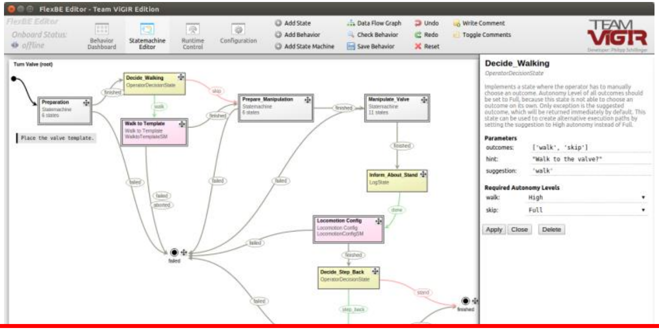
- “**Flex**ible **B**ehavior **E**ngine”
  - Based on SMACH → Hierarchical state machines
  - Adds robot-operator collaboration



[5] *Philipp Schillinger et al.* “Human-Robot Collaborative High-Level Control with Application to Rescue Robotics”, IEEE ICRA, 2016

https://github.com/team-vigir/flexbe_behavior_engine

FlexBE
Sliding Autonomy

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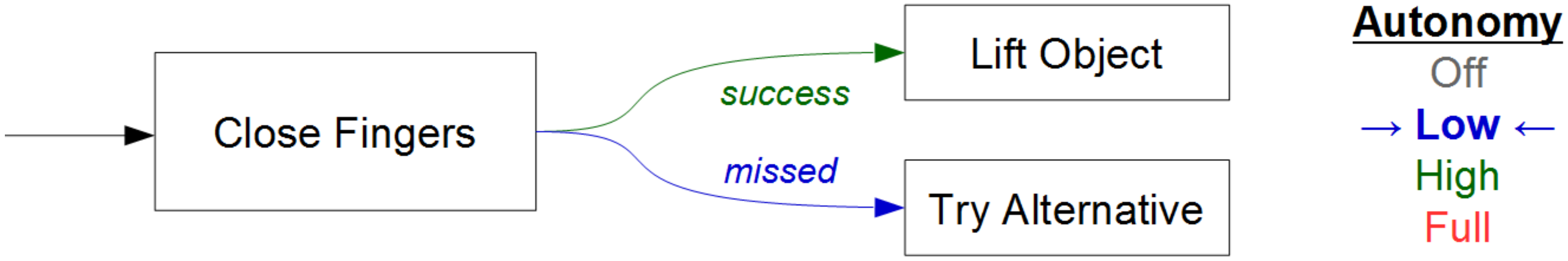
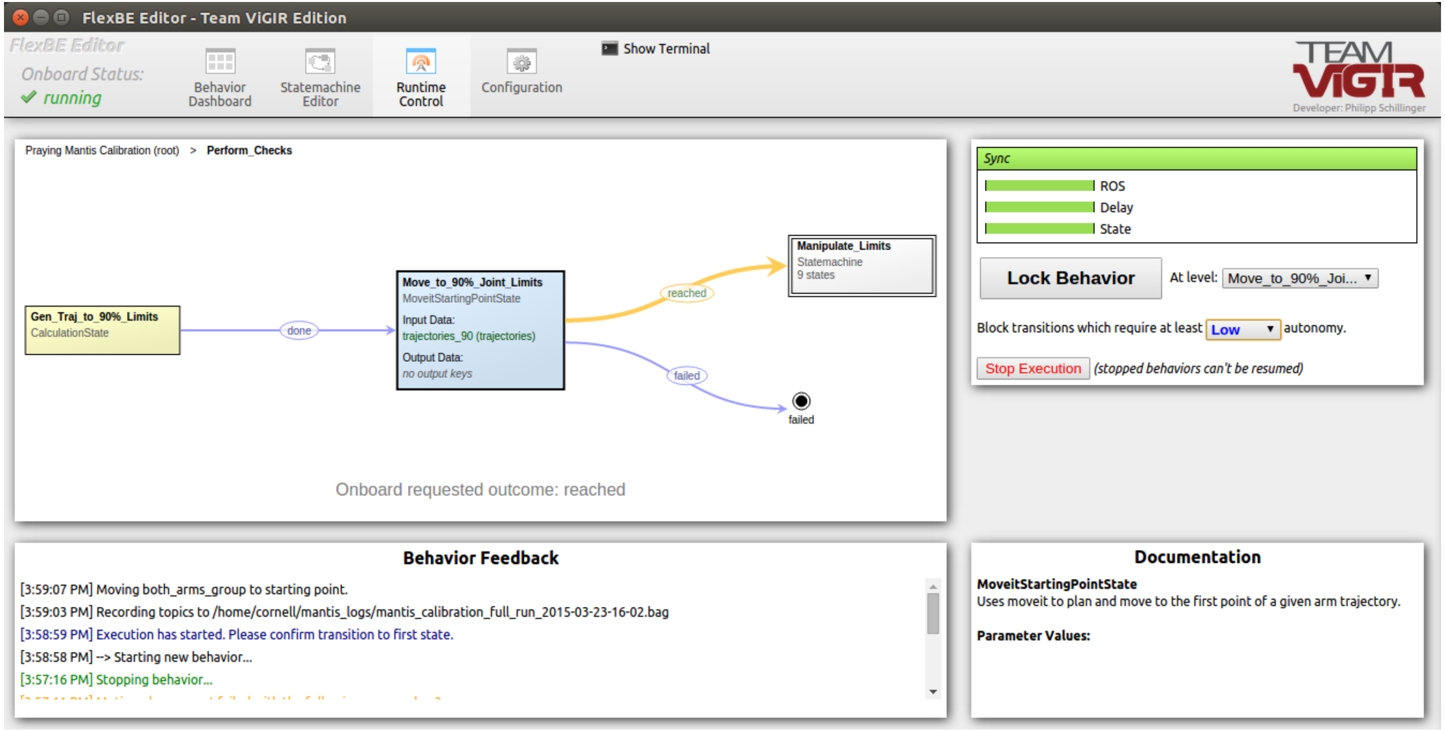
- Behavior runs with explicit Autonomy Level
  - Can be changed any time during execution
- State outcomes define required autonomy
  - High enough → Autonomous execution
  - Too low → Operator confirms or rejects
- Operator can force outcomes any time



FlexBE
Runtime Control



Synergies: Case Studies

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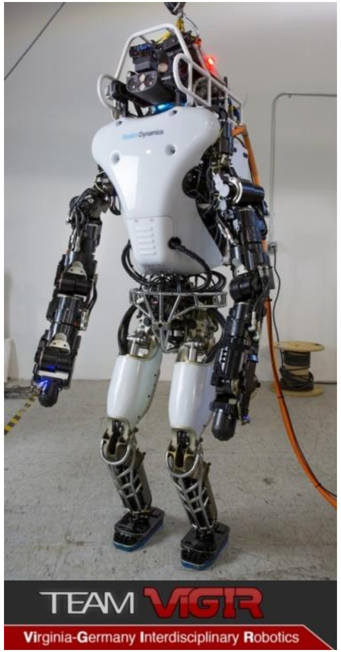
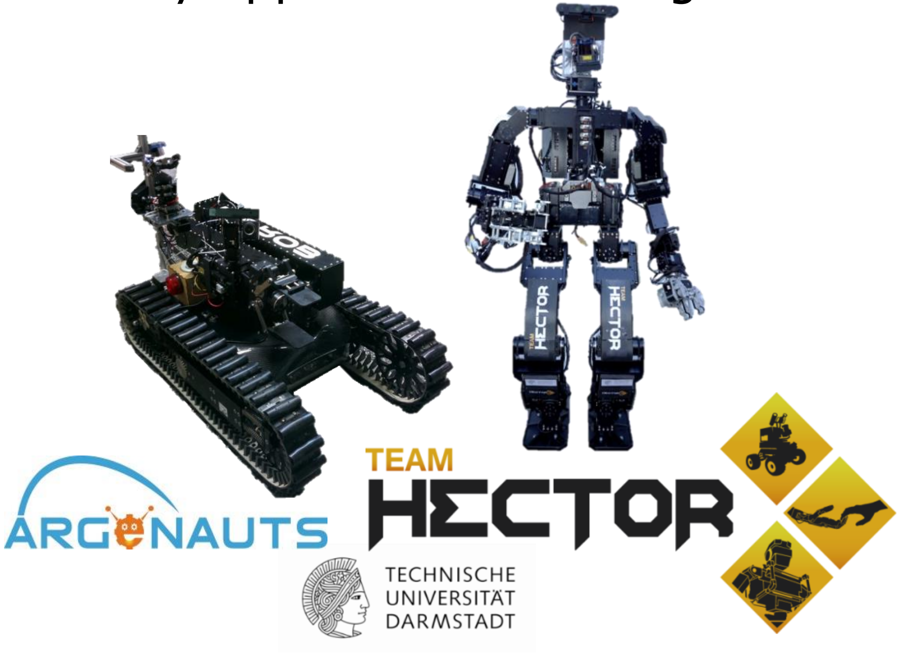
- Our software was already applied on following robots:



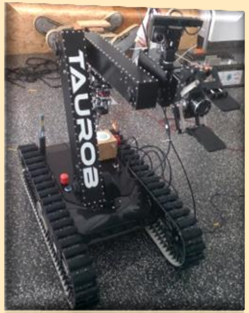


Synergies: Case Studies

- **Modularity:** Take use of synergies in **Hard- & Software** development

Tracker

- Full Autonomy
- Lattice Planning
- etc…



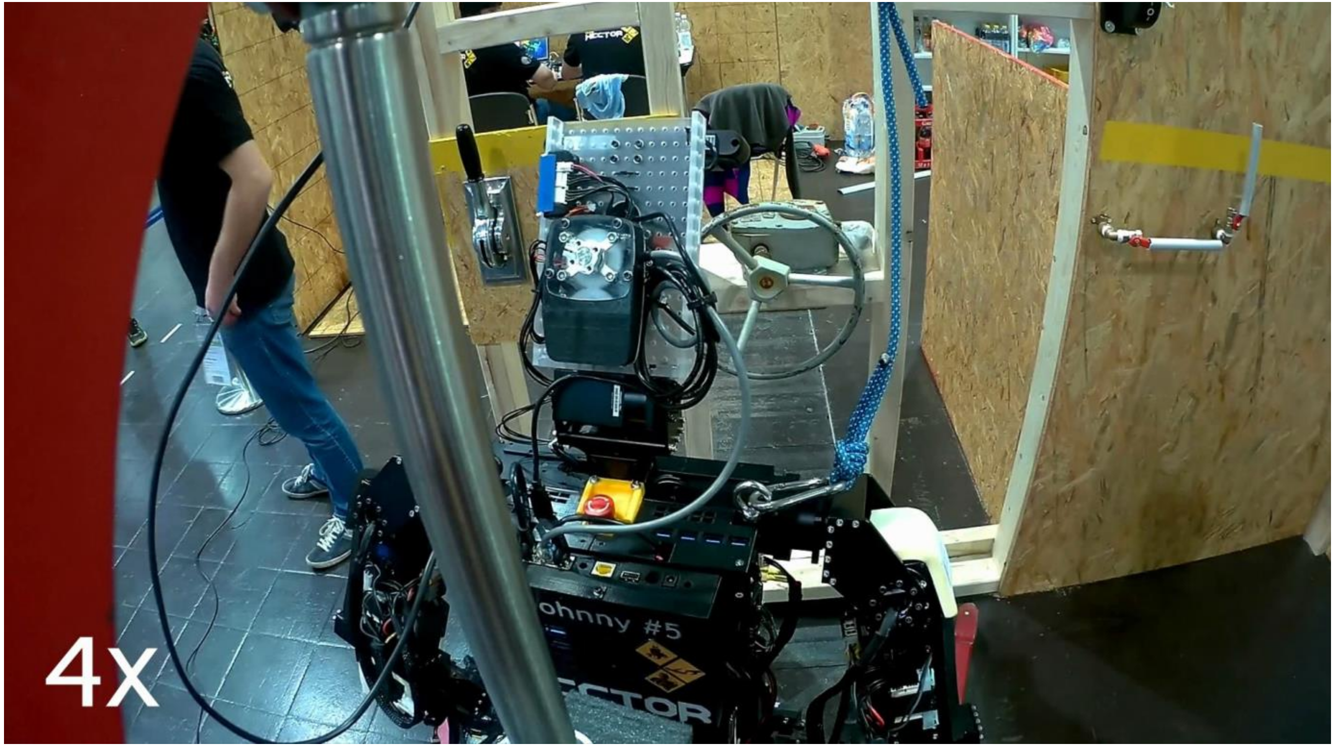
Humanoid

- Teleoperation
- Footstep Planning
- Balance Control
- etc…

Shared

- Sliding-Autonomy
- SBPL
- Manipulation
- Mapping
- Perception
- etc…

Synergies
Johnny #5 @RoboCup 2016



Publications

TECHNISCHE UNIVERSITÄT DARMSTADT

- [1] Kohlbrecher et al. “A comprehensive software framework for complex locomotion and manipulation tasks applicable to different types of humanoid robots”, Frontiers in Robotics and AI, 2016
- [2] Stumpf et al. “Supervised Footstep Planning for Humanoid Robots in Rough Terrain Tasks using a Black Box Walking Controller”, IEEE Humanoids, 2014
- **[3] Stumpf et al. “Open Source Integrated 3D Footstep Planning Framework for Humanoid Robots”, IEEE Humanoids, 2016**
  - **Presentation on Thursday 16:30-18:00 (ThPoS.23)**
- [4] Romay et al. “Template-Based Manipulation in Unstructured Environments for Supervised Semi-Autonomous Humanoid Robots”, IEEE Humanoids, 2014
- [5] Philipp Schillinger et al. “Human-Robot Collaborative High-Level Control with Application to Rescue Robotics”, IEEE ICRA, 2016

- 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

Conclusions

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- Humanoid Robots…
  - …benefit from bipedal locomotion and bimanual manipulation.
  - …are ideal choice for versatile human tasks in human environments.
  - …are just robots! Reuse of existing software is highly recommended (e.g. ROS).
- Our contribution:
  - Supervised high-level locomotion and manipulation planning working with constrained communications (bandwidth limitation, delays, packet drops)
  - All presented work is reusable due to modular design
  - Available open source GitHub
- Resources:
  - Team ViGIR www.teamvigir.org
  - Team Hector www.teamhector.de
  - Johnny #5 Simulator https://github.com/thor-mang/thor_mang_install

TEAM ViGIR
Virginia-Germany Interdisciplinary Robotics

TEAM HECTOR