



Motion Planning for Industrial Robots using MoveIt!

Sachin Chitta

Associate Director
Robotics Systems and Software

SRI International

- Manager and Research Scientist, Willow Garage, (2007-2013)
 - MoveIt!, Arm Navigation, ROS Control, 3D Navigation, FCL, SBPL, OMPL, ROS, PR2
- Founding Team, Redwood Robotics, (2010-2013)
 - ❖ acquired by Google last year
- Post-doc, University of Pennsylvania (2005-2007)
- PhD, GRASP Lab, University of Pennsylvania, 2005

Robots In Industry



Need safety cages



Hard to program

Robots in automation are currently inflexible - hard to setup and hard to program.

Expensive

- Typical cost of deploying/programming a robot is 70-80% of the cost of a robotics application

Motivation

- Build state of the art software platform for robotics applications and research
- “Simple things should be easy”
 - ❖ Provide out-of-the-box experience
 - easy to setup with new robots - Setup Assistant
 - ❖ Easy to use APIs - C++ and Python
- “Allow users to dive deeper to address harder problems”
 - ❖ Flexible platform - easy to add new components
- Performance
 - ❖ design for high performance

MoveIt!

- A user-friendly platform for building FLEXIBLE industrial, research and commercial applications
 - ❖ Easy Configuration, Easy Programming, Quick switch-over
 - ❖ High Performance
 - ❖ Cross Platform

Evolution - Arm Navigation

<http://youtu.be/tzUrdvhWgx8>

[Arm Navigation - Chitta, Jones, Ciocarlie, Hsiao, Sucan, 2011](#)

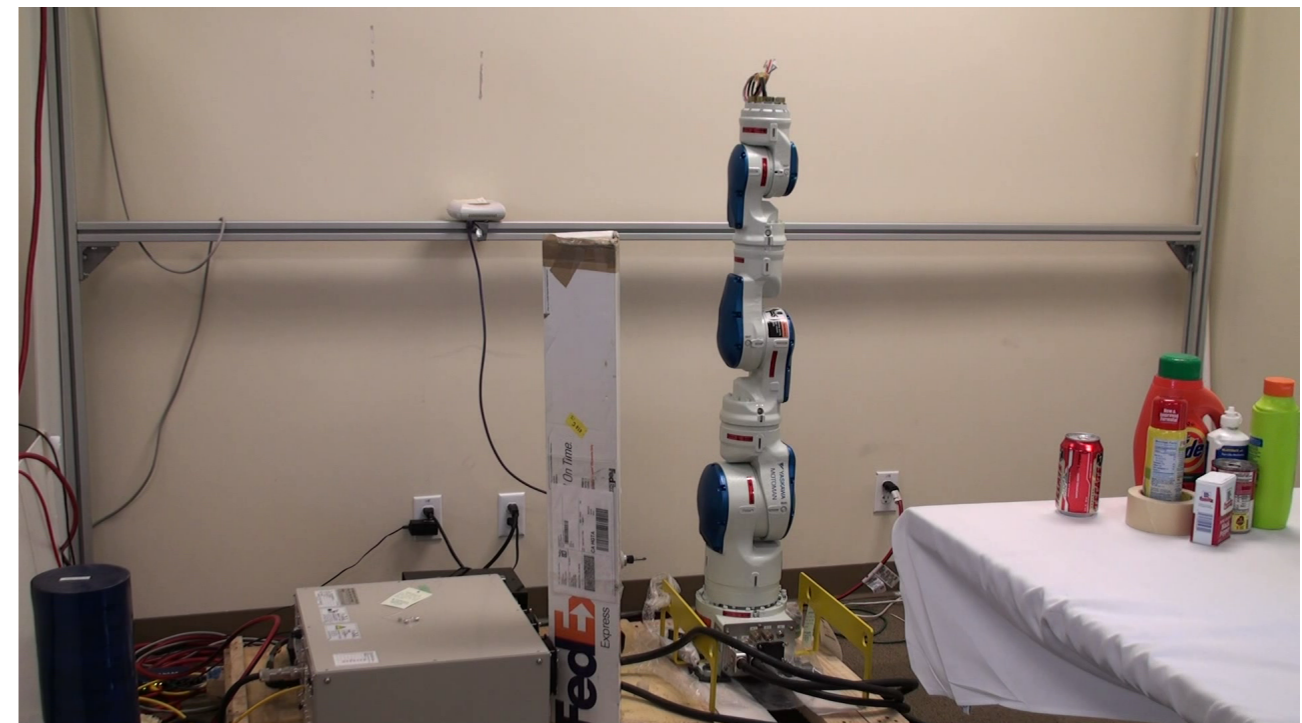
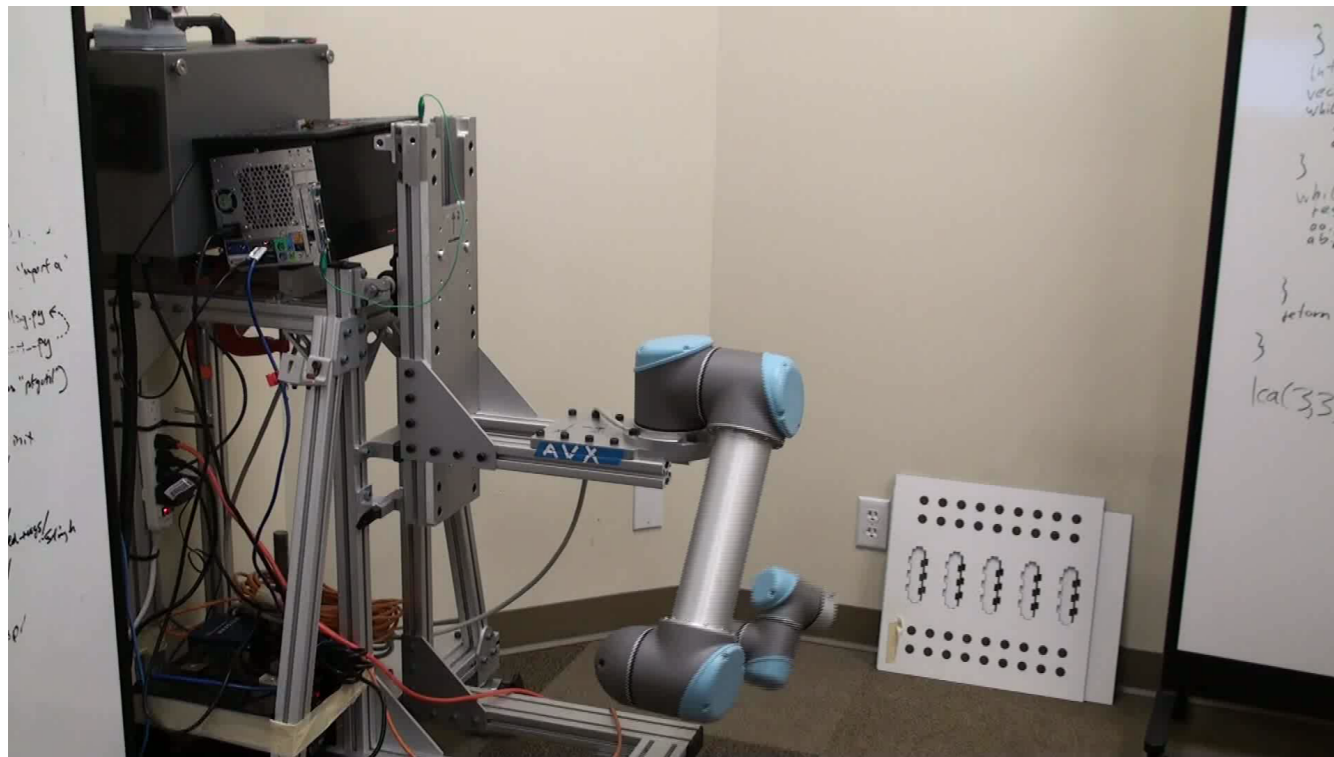
Initial Industrial Application

[http://youtu.be/ WG-45cZSUQ](http://youtu.be/WG-45cZSUQ)

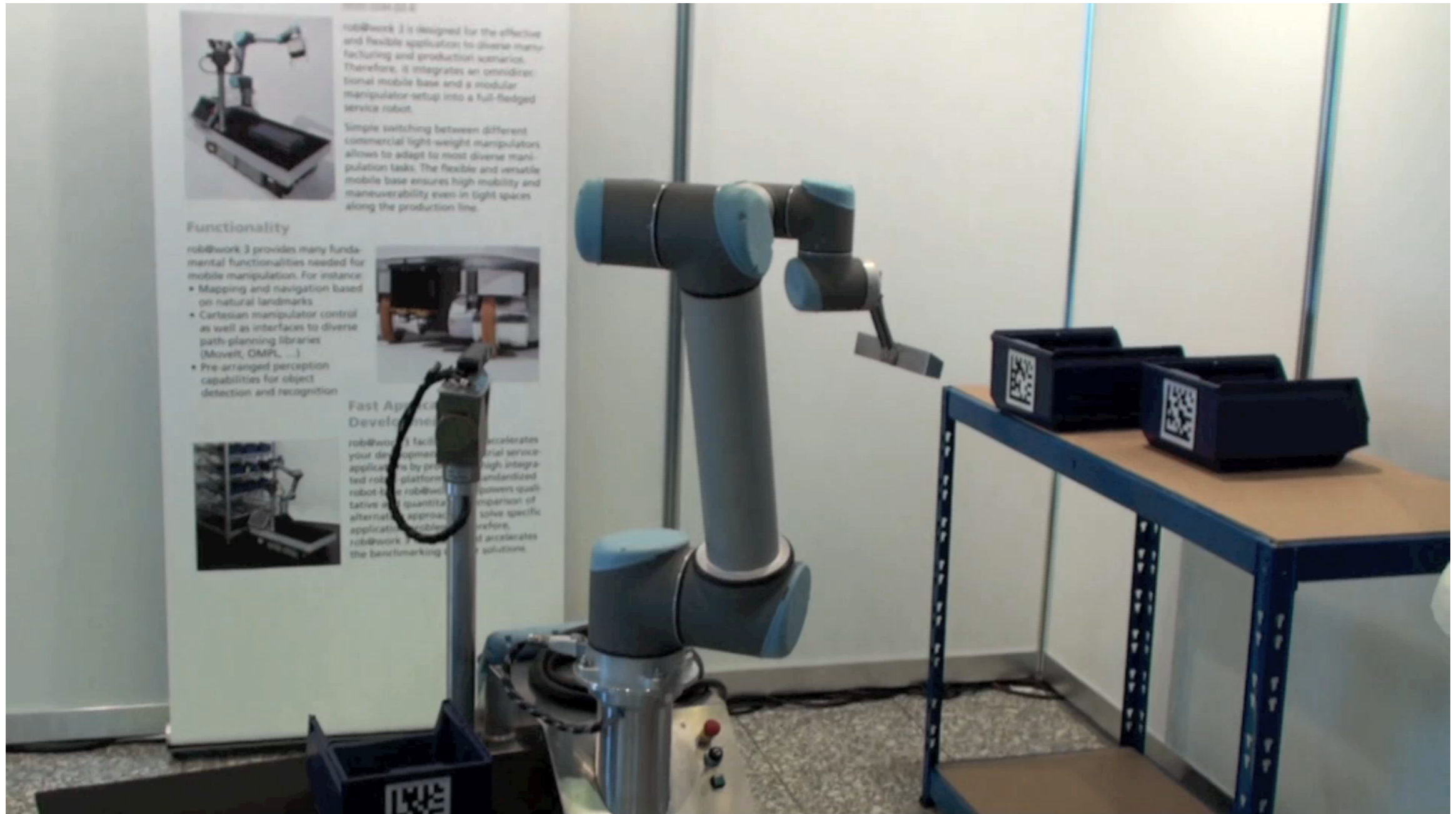
MoveIt!

- Thread-based architecture
 - Parallelize motion planners and collision checking
- GPU acceleration for 3D perception
- Script based user interface
 - designing complex programs/tasks
- GUI based interface
 - make things easier for users
- Setup Tools
 - easy to import new robots

MoveIt! - Initial Robots



ROS-Industrial

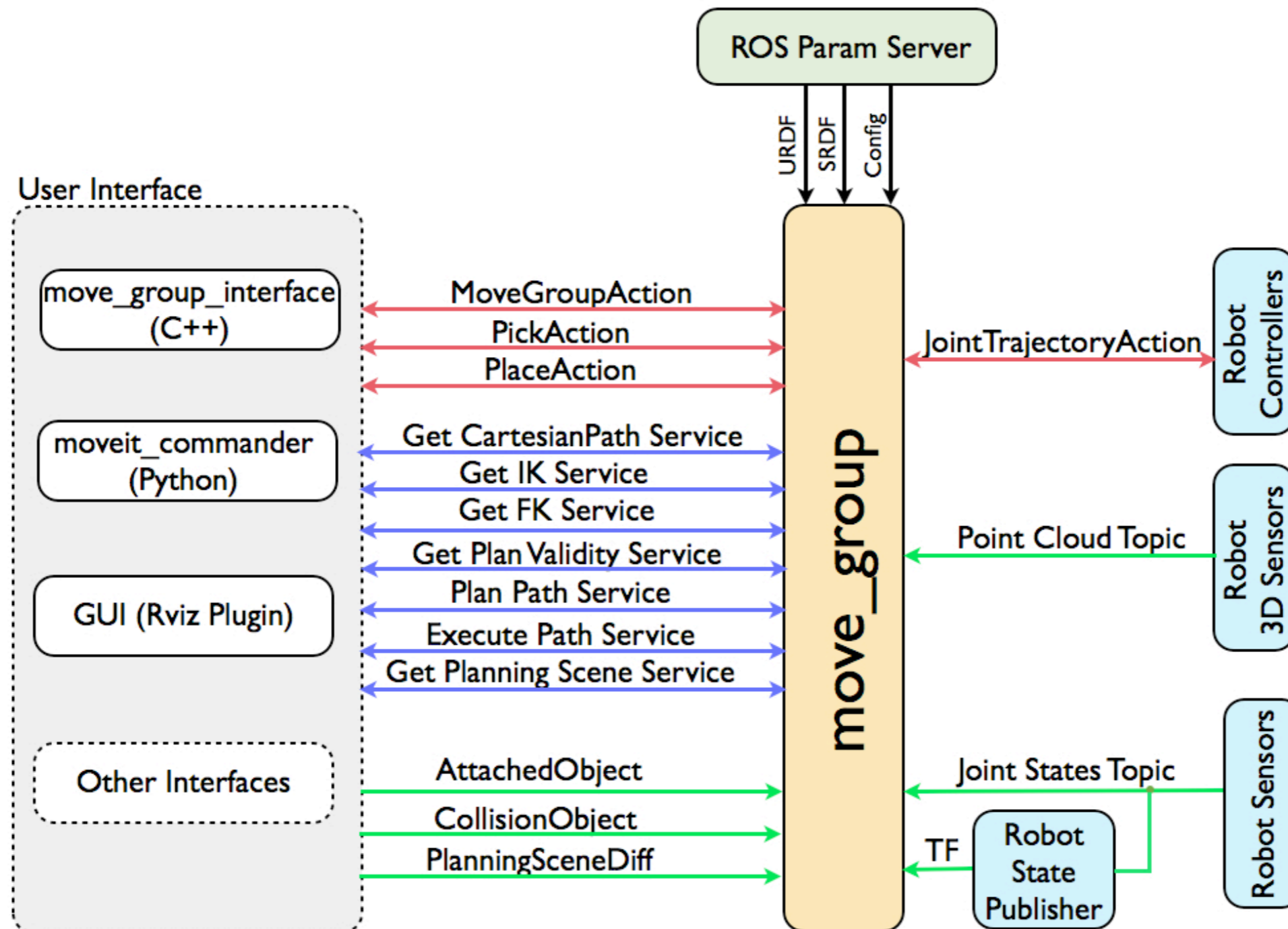


What does MoveIt! offer?

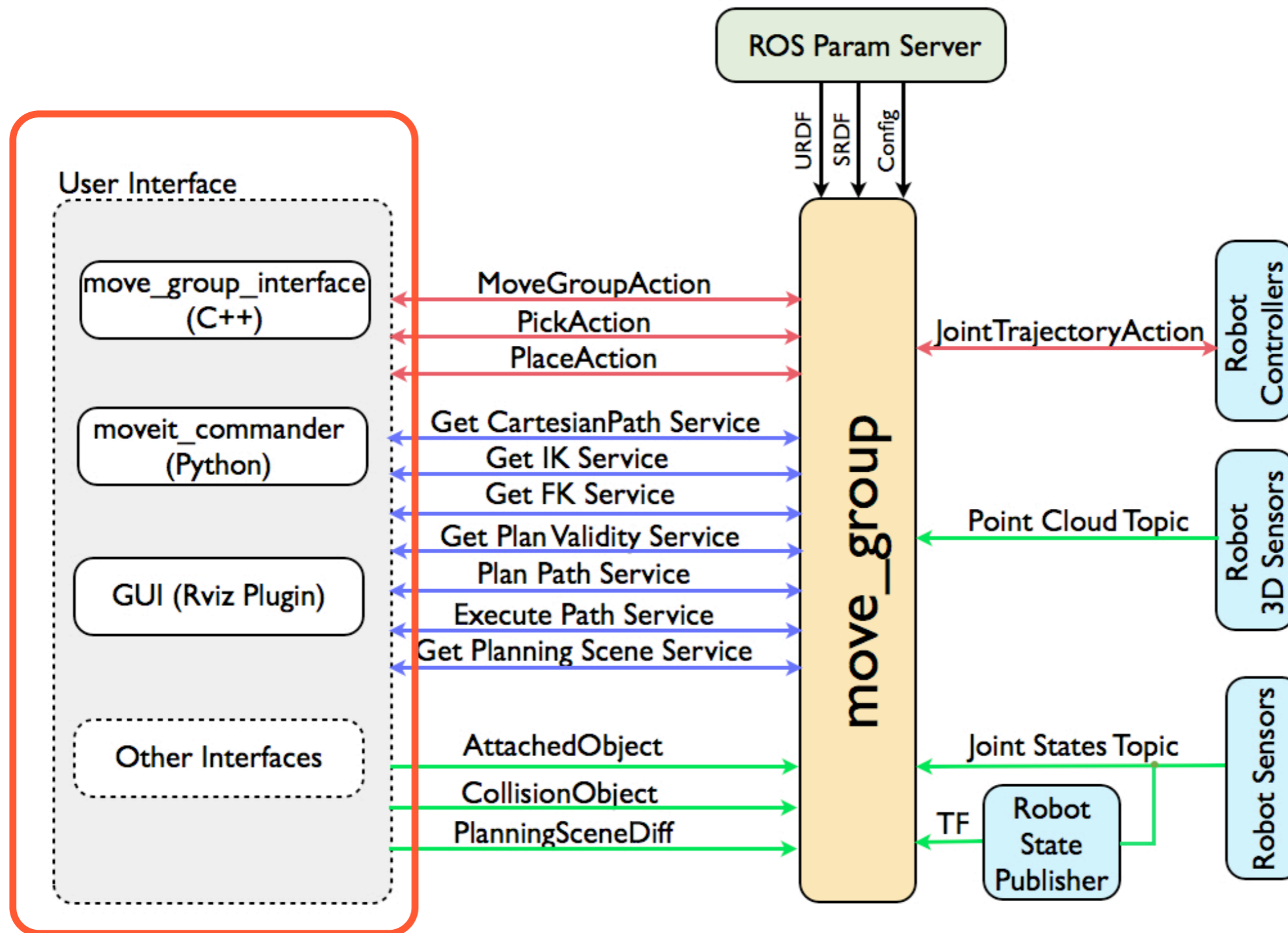
- Technical Capabilities

- ❖ Collision Checking: fast and flexible
- ❖ Integrated Kinematics
- ❖ Motion Planning
 - fast, good quality paths
 - kinematic constraints
- ❖ Integrated Perception for Environment Representation
- ❖ Standardized Interfaces to Controllers
- ❖ Execution and Monitoring
- ❖ Kinematic Analysis

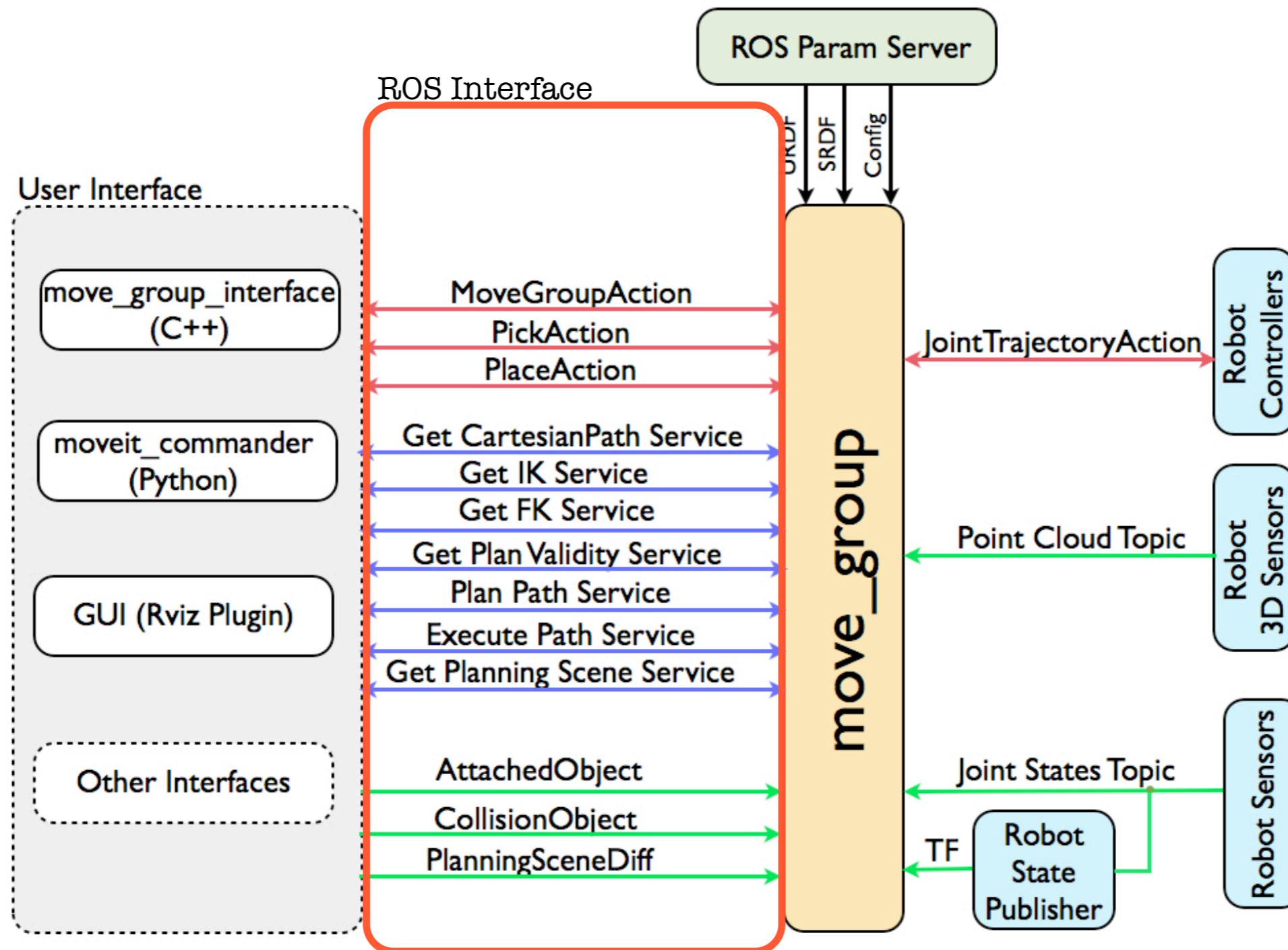
System Architecture



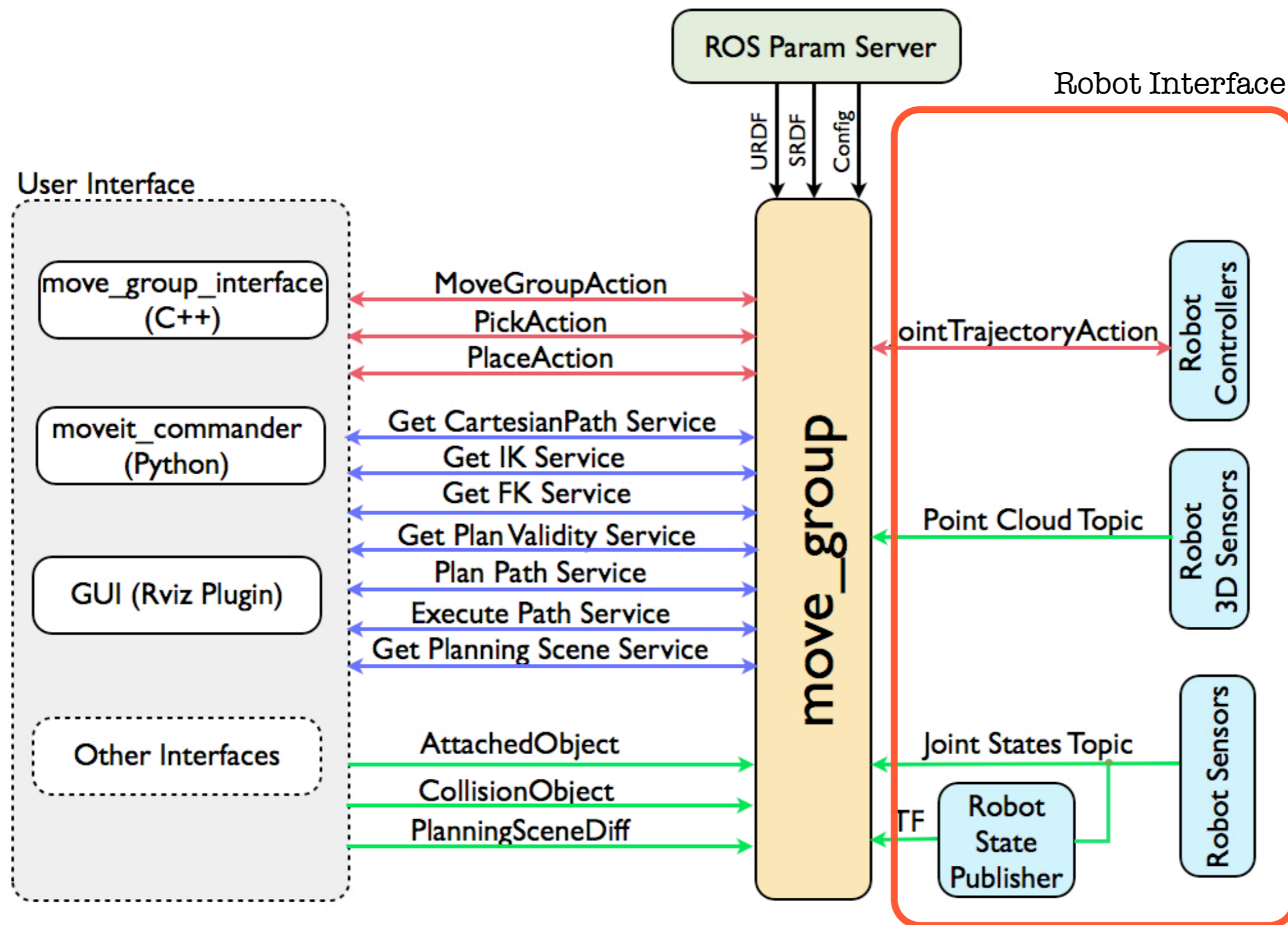
System Architecture



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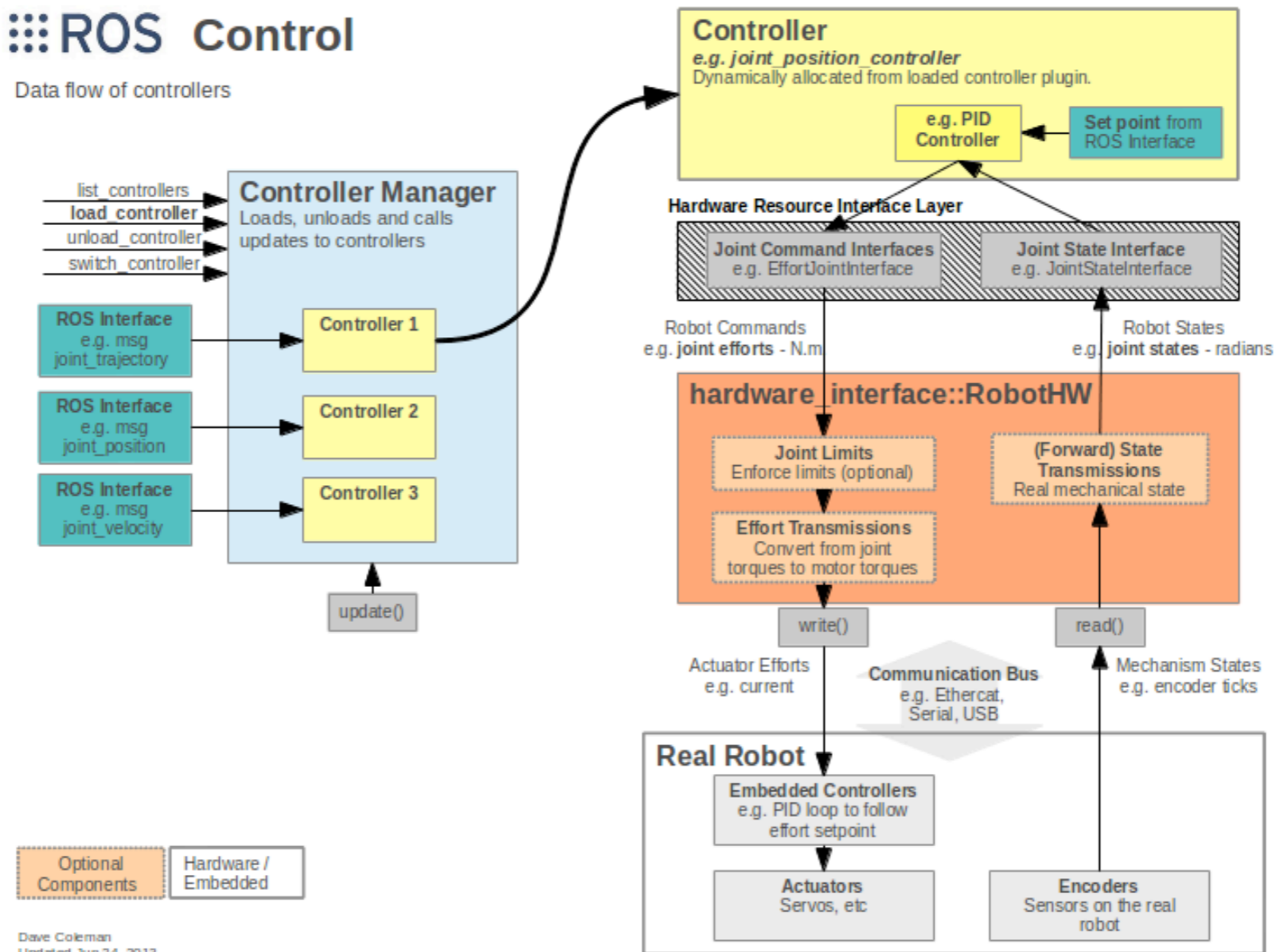
System Architecture



ROS Control

ROS Control

Data flow of controllers

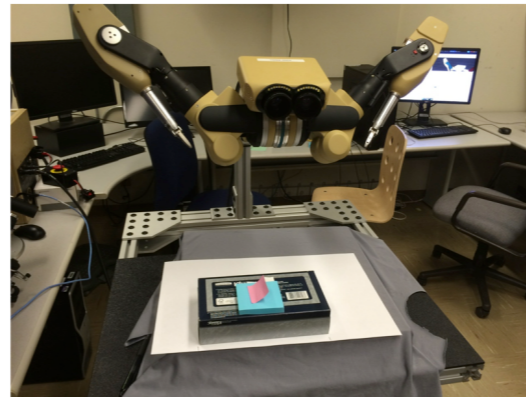


ROS-Control is based on the set of controllers originally developed for the PR2 robot

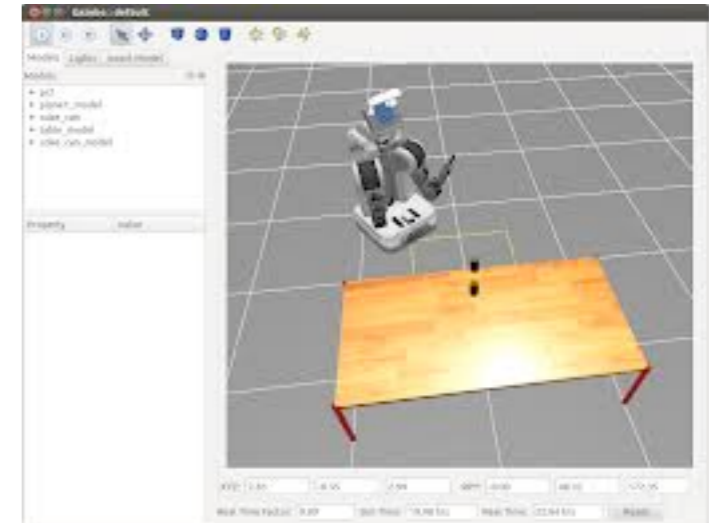
ROS Control



REEM-C (PAL Robotics)



Taurus (SRI)



Gazebo



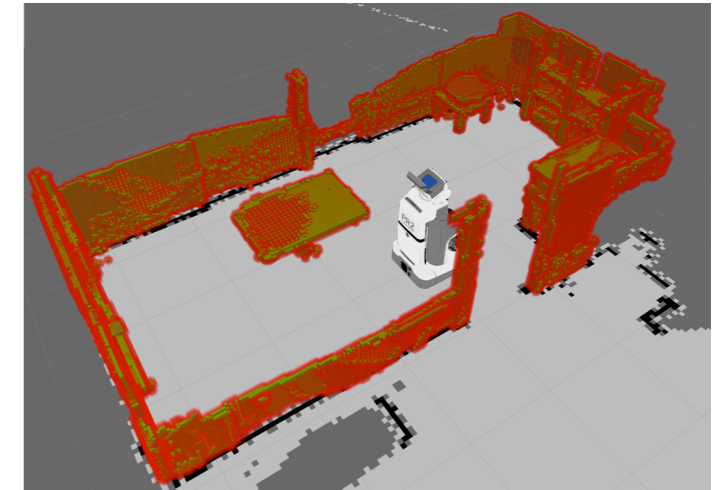
The Redwood Arm

MoveIt!

- MoveIt! works online
 - ❖ directly deals with perception data
 - ❖ directly talks to controllers
- MoveIt! also works offline
 - ❖ import CAD model data
 - ❖ offline programming and planning of complex multi-step paths
- MoveIt! enables full applications

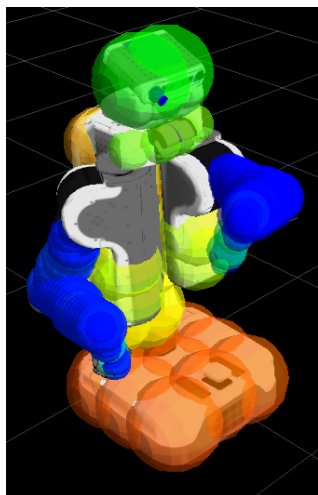
Collision Checking

- FCL - Flexible Collision Library*
 - ❖ parallelizable collision checking
 - ❖ Maximum about 2-3,000 full body collision checks for the PR2 per second
 - ✓ with realtime sensor data
 - ❖ + high fidelity mesh model

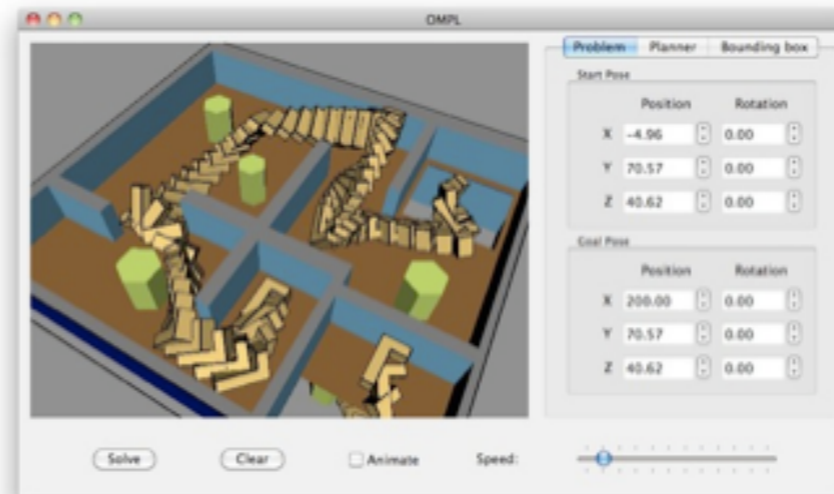
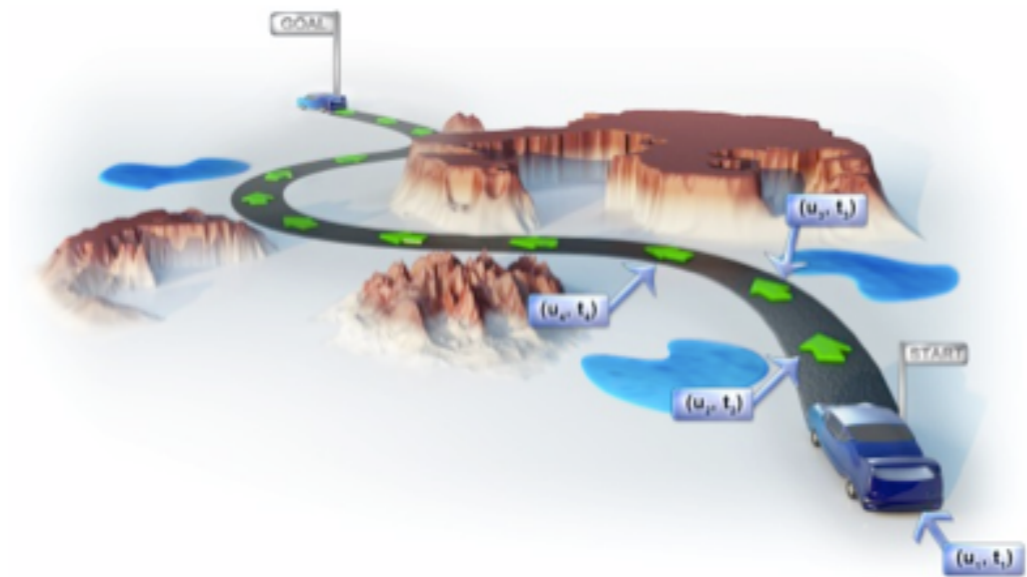


- Proximity Collision Detection

- ❖ Uses 3D distance transform to determine distance to nearest obstacle and gradient
- ❖ + very fast - 40 to 80,000 collision checks per second for the full body of the PR2
- ❖ - not as accurate

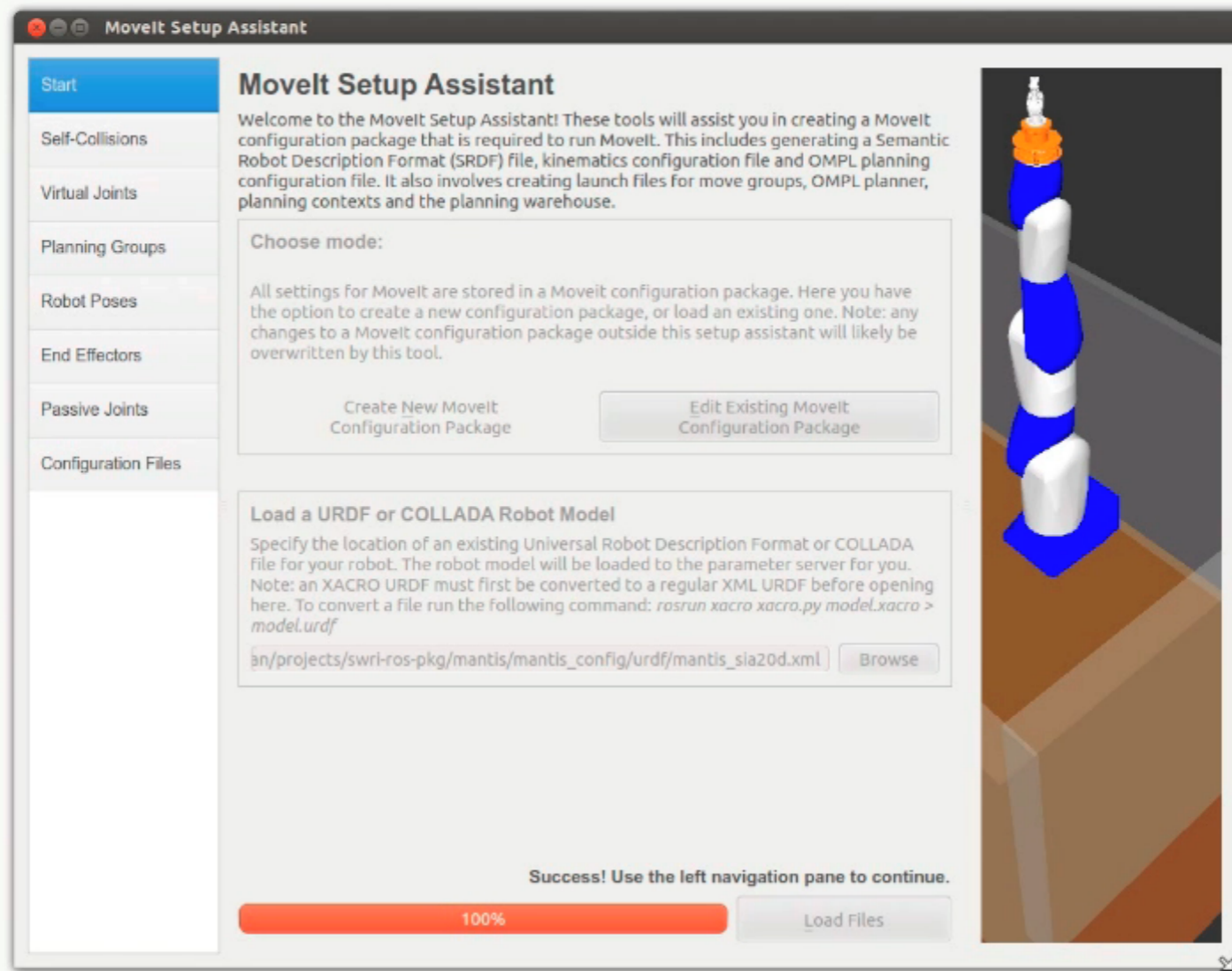


Motion Planning

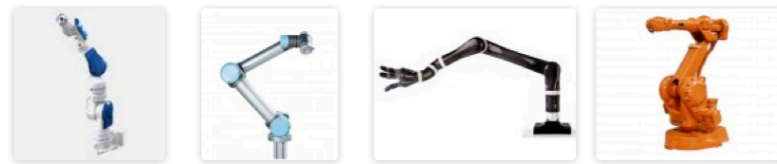


- Plugin interface for planners
- Integration with robots through MoveIt!
- Automatically configured using the MoveIt! Setup Assistant
 - ❖ Sampling based planners (OMPL) *
 - ❖ Search Based Planning Library (SBPL) ^

Easy Setup and Configuration



Robots Using MoveIt!



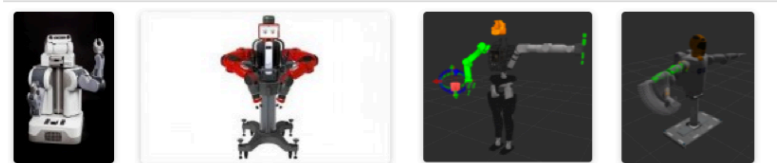
Motoman (SIA5/SIA10d/(SIA20) Universal Robots UR5/(UR10) Kinova Jaco ABB IRB 2400



Kawada Hiro Summit XL-Terobot HRP 4 Pioneer 3AT



PhantomX Pincher ClamArm HDT Arm Lynxmotion Servo Erector Arm



PR2 Baxter Research Robot BDI Atlas Robonaut/Robonaut2



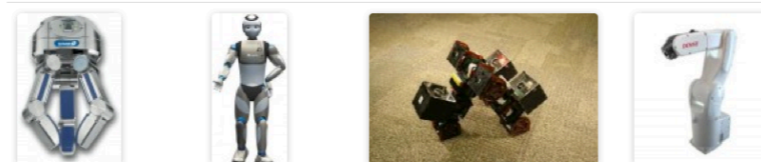
Schunk 7-DOF Aldebaran NAO Care-O-Bot HRP-2



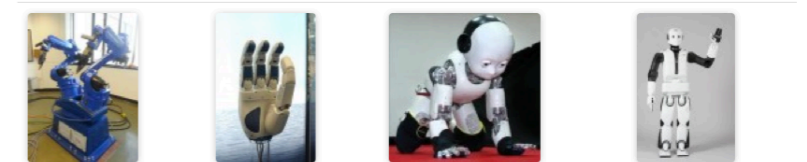
PAL Robotics REEM Schunk Powerball X-WAM Barrett WAM



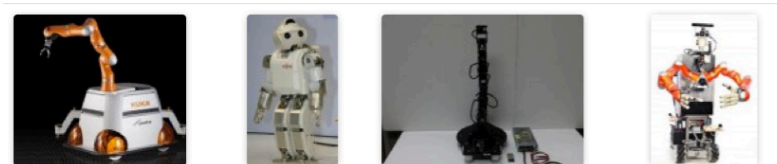
Comau NM45 Fanuc m10ia BioRob Arm KUKA LWR/LBR



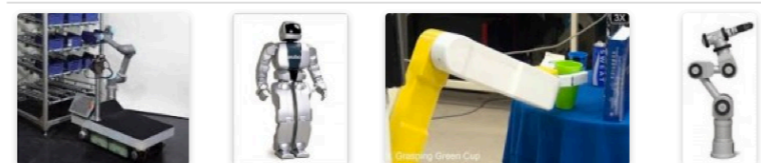
Schunk Dextrous Hand Aldebaran Romeo CKBot Denso Robot (vs060)



Clopema Robot DLR-Hit Hand iCub REEM-C



KUKA OmniROB Hoap3 Cyton Veta TUM Rosie



Rob@Work Hubo Korus Homemate Robot Katana



Shadow Robot and Hand KUKA Youbot MEKA M3

● <http://moveit.ros.org>

Industrial



Motoman (SIA5/SIA10d /SIA20)

Universal Robots UR5/(UR10)

Kinova Jaco

ABB IRB 2400

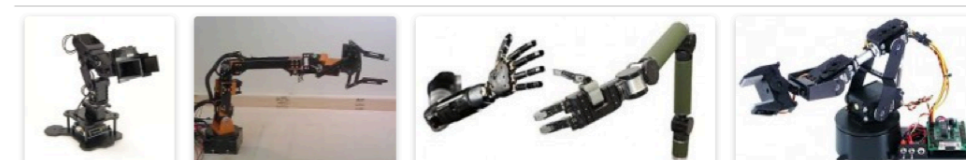


Kawada Hiro

Summit XL-Terabot

HRP 4

Pioneer P3AT

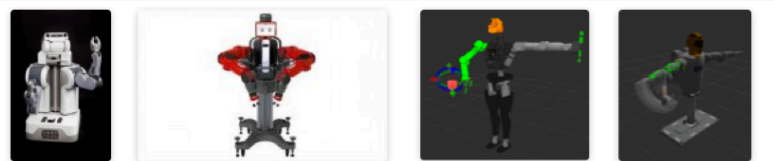


PhantomX Pincher

ClamArm

HDT Arm

Lynxmotion Servo Erector Arm



PR2

Baxter Research Robot

BDI Atlas

Robonaut/Robonaut2



Schunk 7-DOF

Aldebaran NAO

Care-O-Bot

HRP-2



PAL Robotics REEM

Schunk Powerball

X-WAM

Barrett WAM

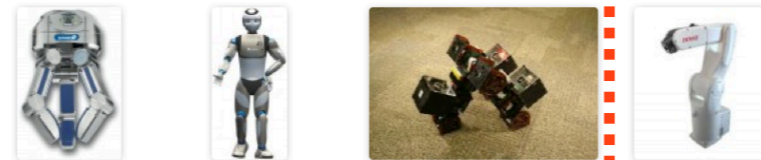


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KUKA LWR/LBR

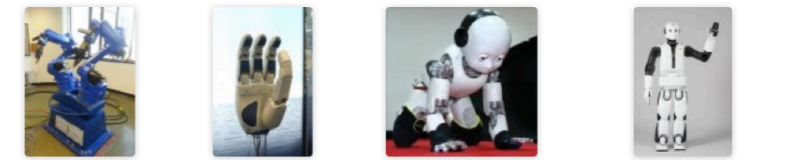


Schunk Dextrous Hand

Aldebaran Romeo

CKBot

Denso Robot (vs060)

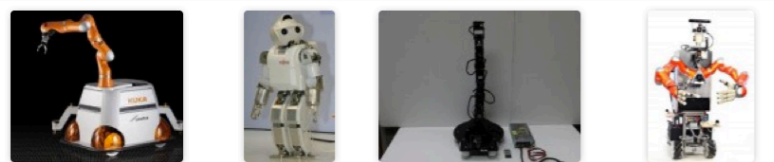


Clopema Robot

DLR-Hit Hand

iCub

REEM-C

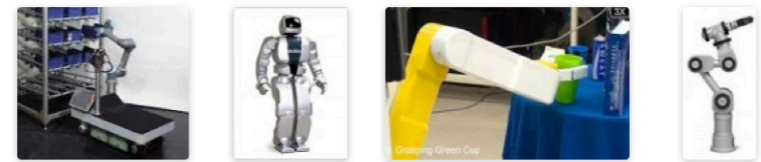


KUKA OmniROB

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Cyton Veta

TUM Rosie



Rob@Work

Hubo

Korus Homemate Robot

Katana



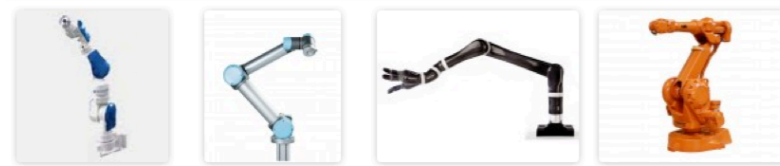
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KUKA Youbot

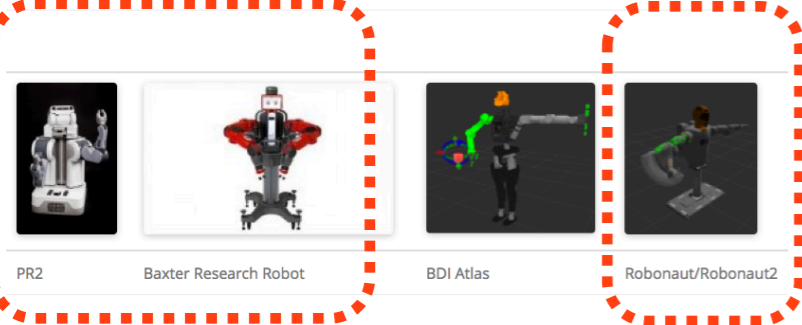
MEKA M3

● <http://moveit.ros.org>

New Generation of Robots



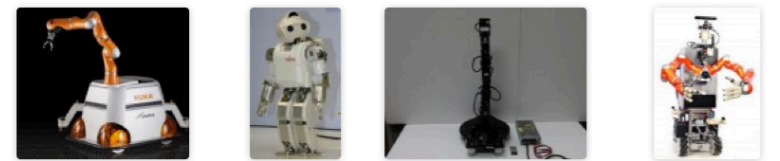
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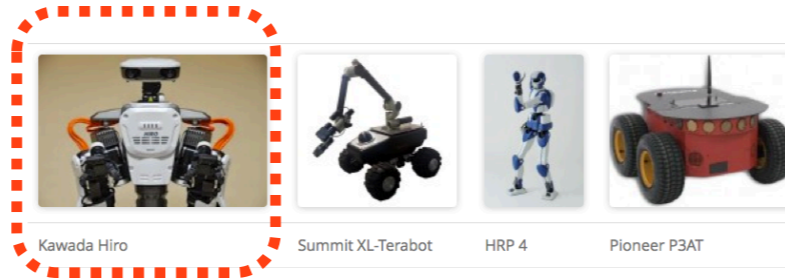
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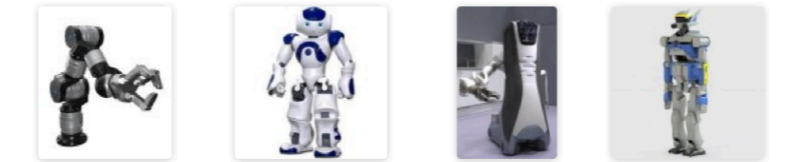
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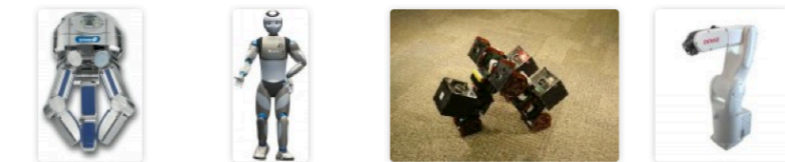
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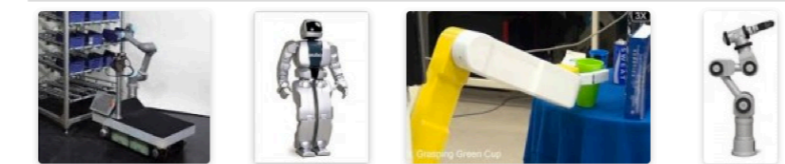
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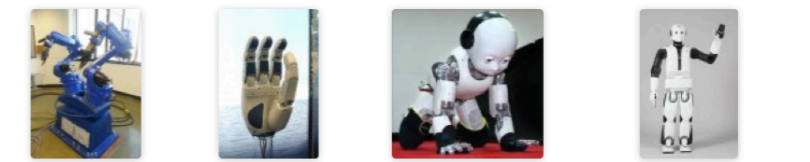
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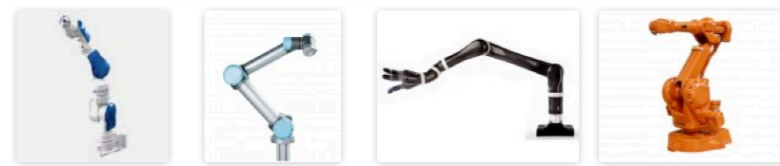
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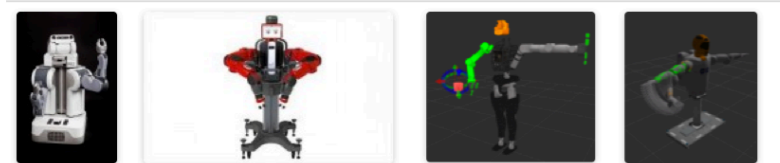
Shadow Robot and Hand KUKA Youbot MEKA M3

● <http://moveit.ros.org>

Humanoid



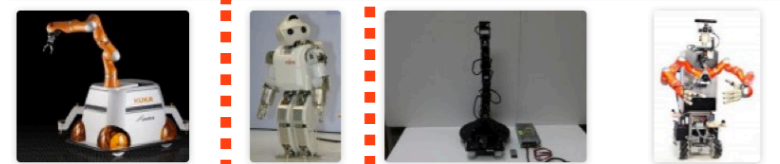
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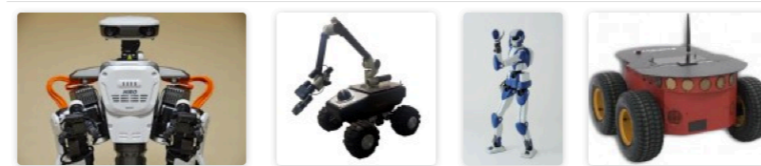
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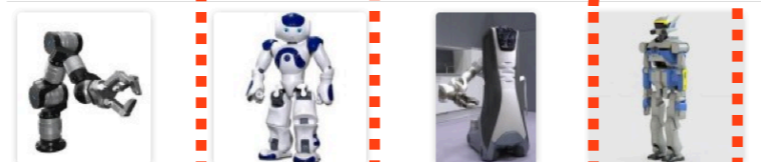
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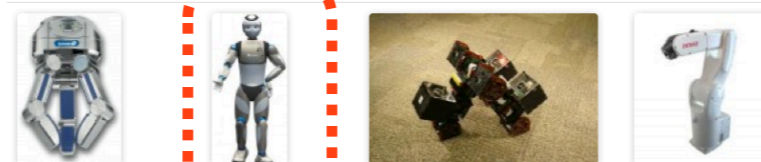
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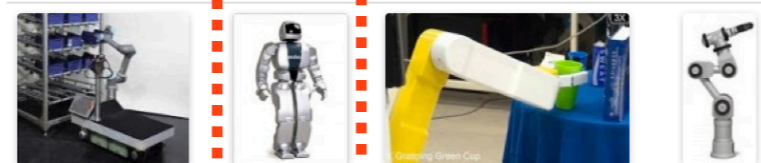
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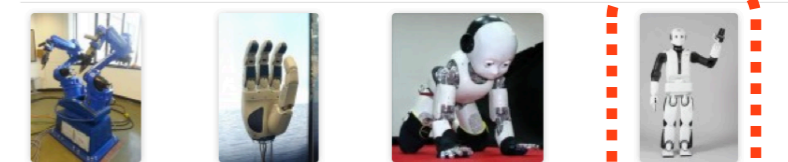
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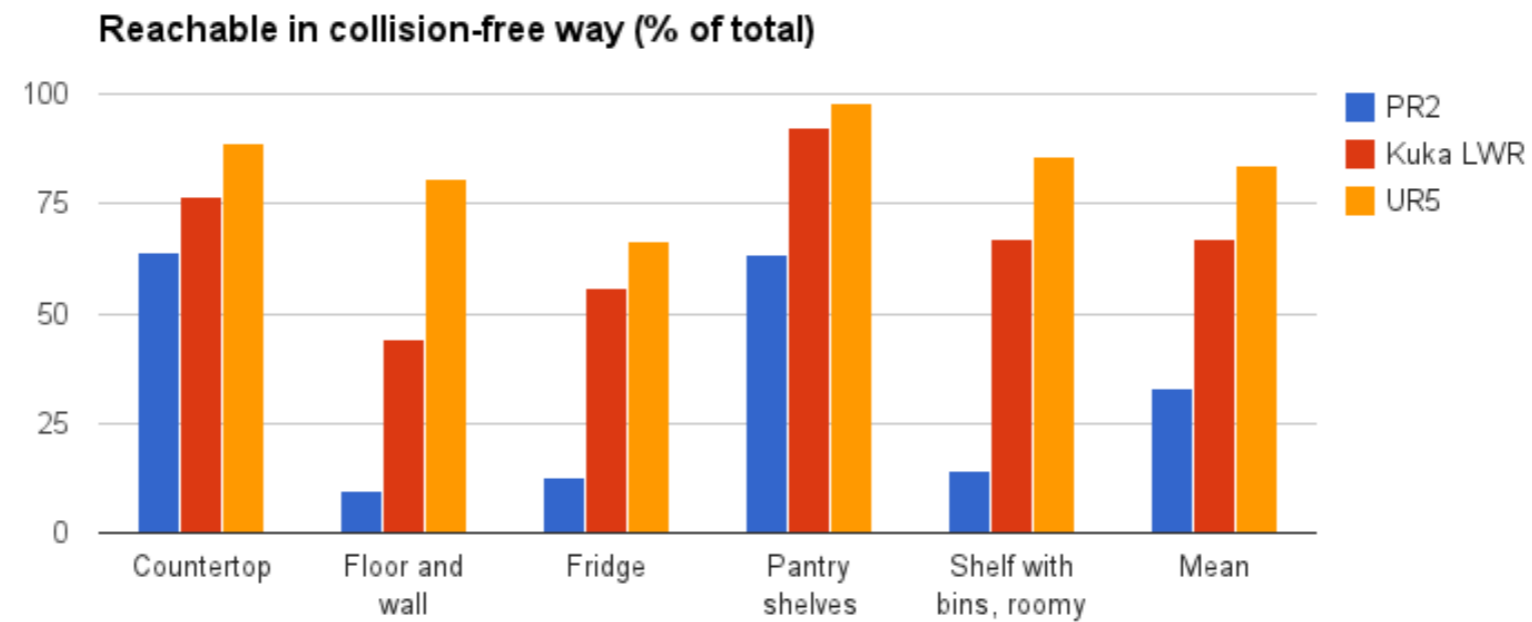
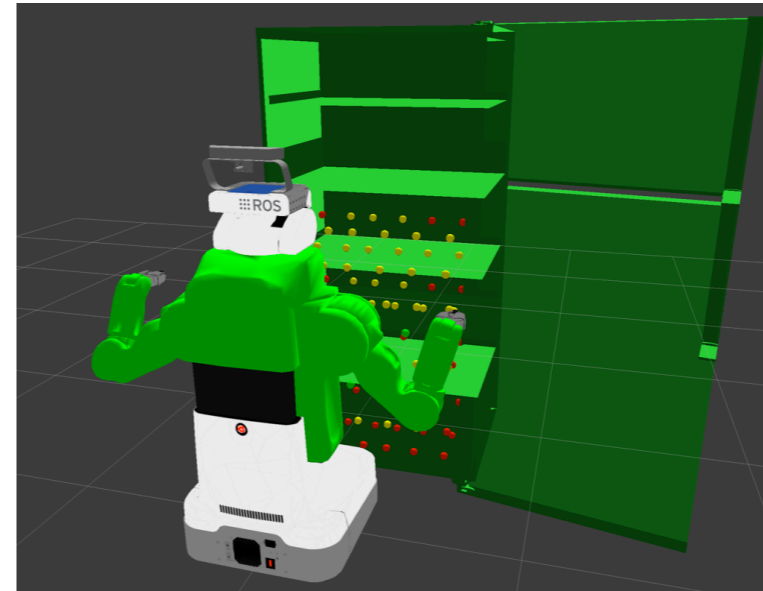
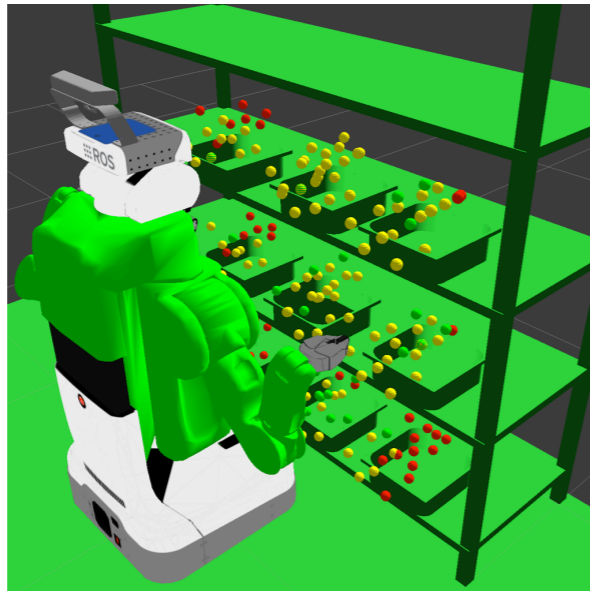
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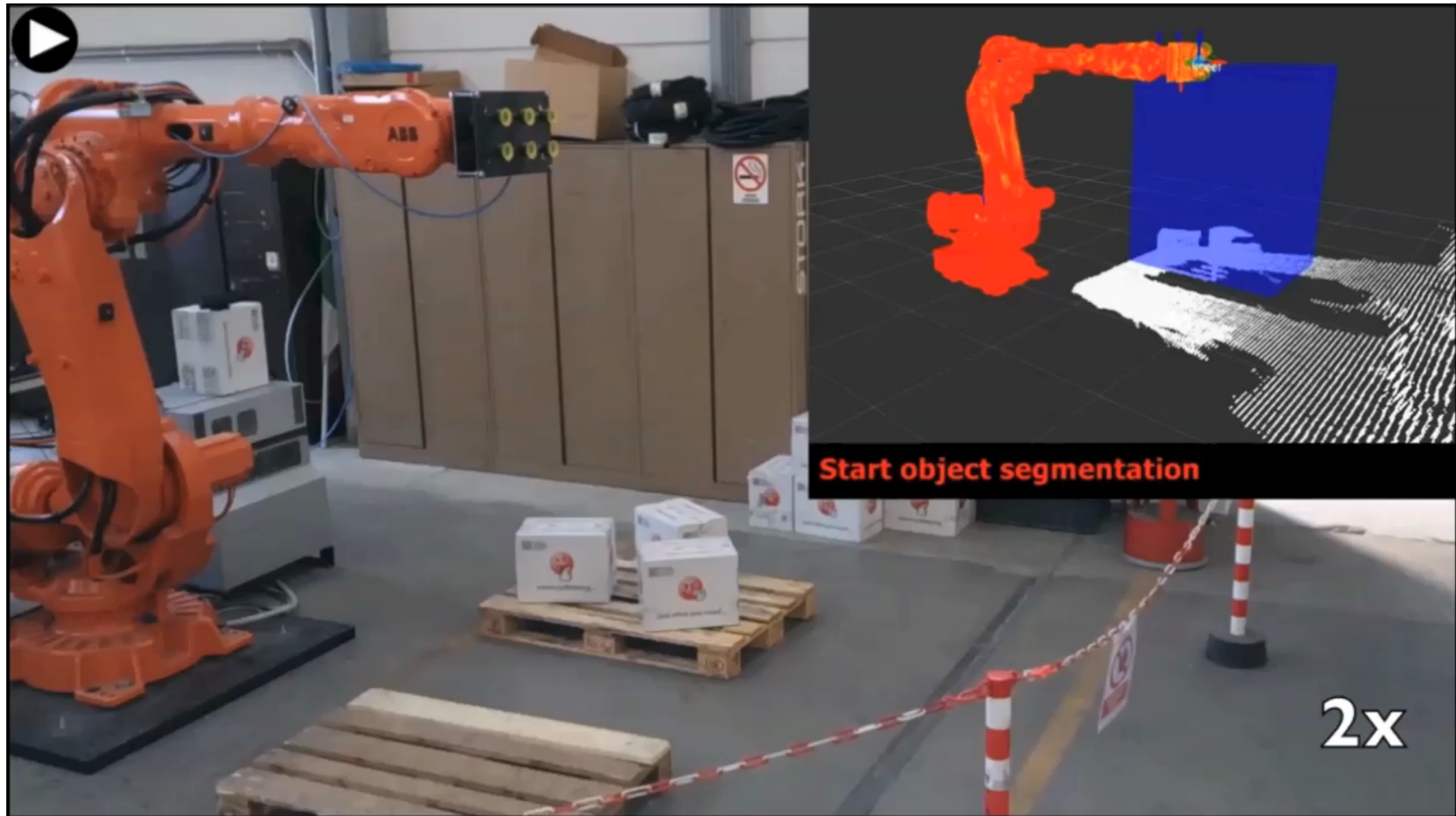
● <http://moveit.ros.org>

Kinematic Workspace Analysis



MoveIt! in Industry

Unstructured Pick and Place



MoveIt! in Industry

Workcell Programming



A Montage of Applications



MONTAGE 2013

More Info ...

- <http://moveit.ros.org>