Software Framework for Research in Semi-Autonomous Teleoperation

Peter Kazanzides
Russell Taylor

NRI 1637789
Johns Hopkins University

LABORATORY FOR
Computational
Sensing + Robotics
THE JOHNS HOPKINS UNIVERSITY

Greg Fischer

NRI 1637759
Worcester Polytechnic Institute

AIM
WPI

Blake Hannaford

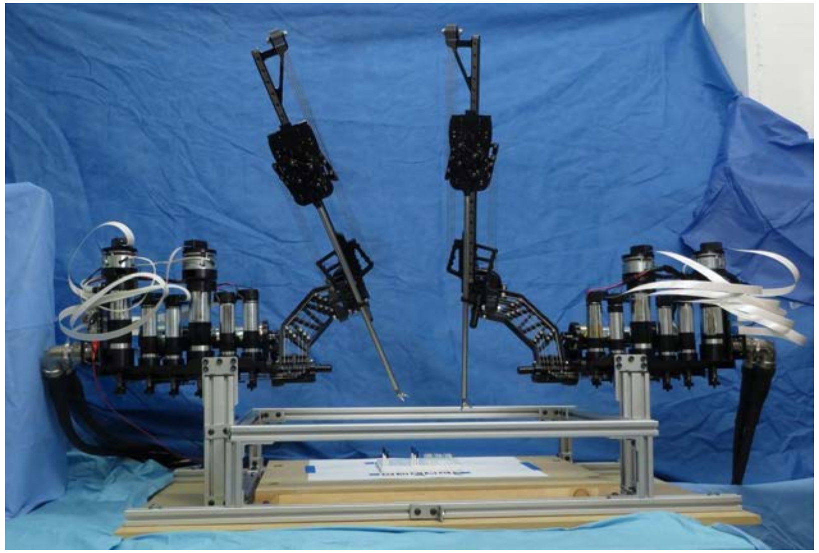
NRI 1637444
Univ. of Washington

W
ELECTRICAL ENGINEERING
UNIVERSITY *of* WASHINGTON

Background

- Open source research platforms (medical telerobotics)

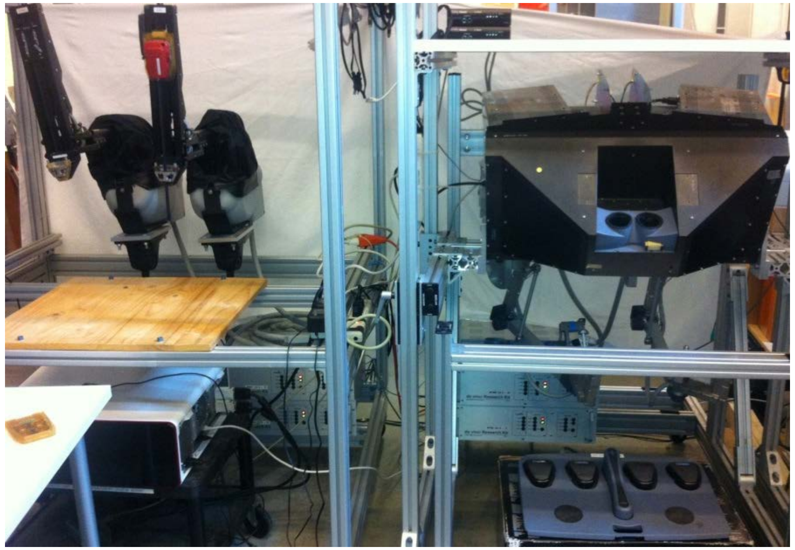
Raven II



Born:	Univ. of Washington, 2002
Raised:	UW, UCSC, 2012 Applied Dexterity, 2014

CNS 0958441

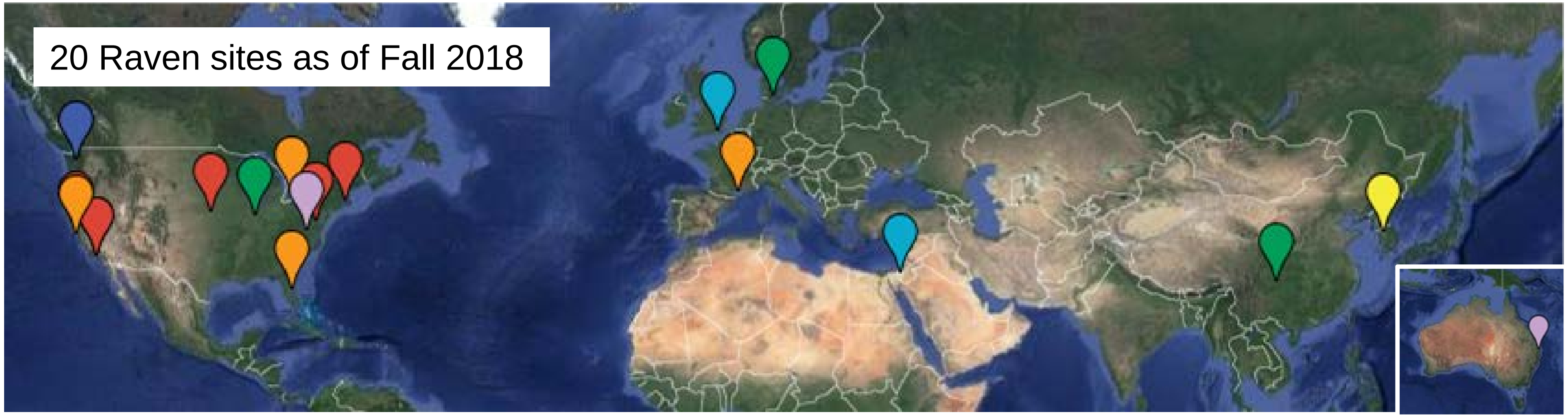
da Vinci Research Kit (dVRK)



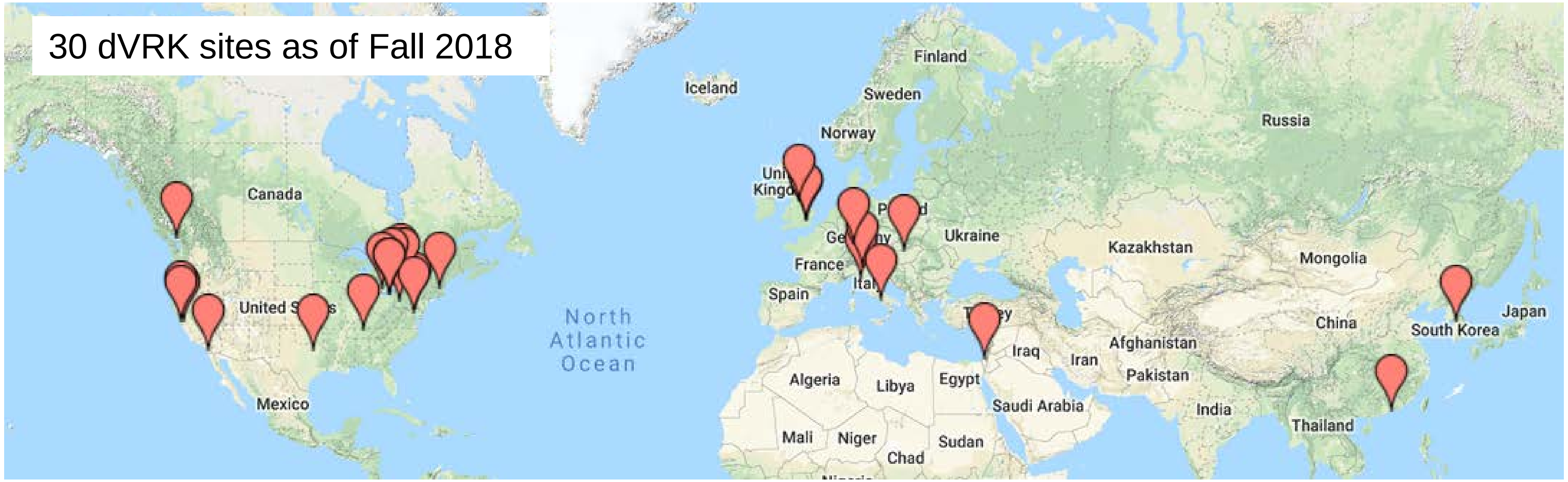
Born:	Johns Hopkins Univ., 2004
Raised:	JHU, WPI, 2012 dVRK Consortium, 2014

EEC 9731748, EEC 0646678, MRI 0722943

Raven/dVRK Community



20 Raven sites as of Fall 2018

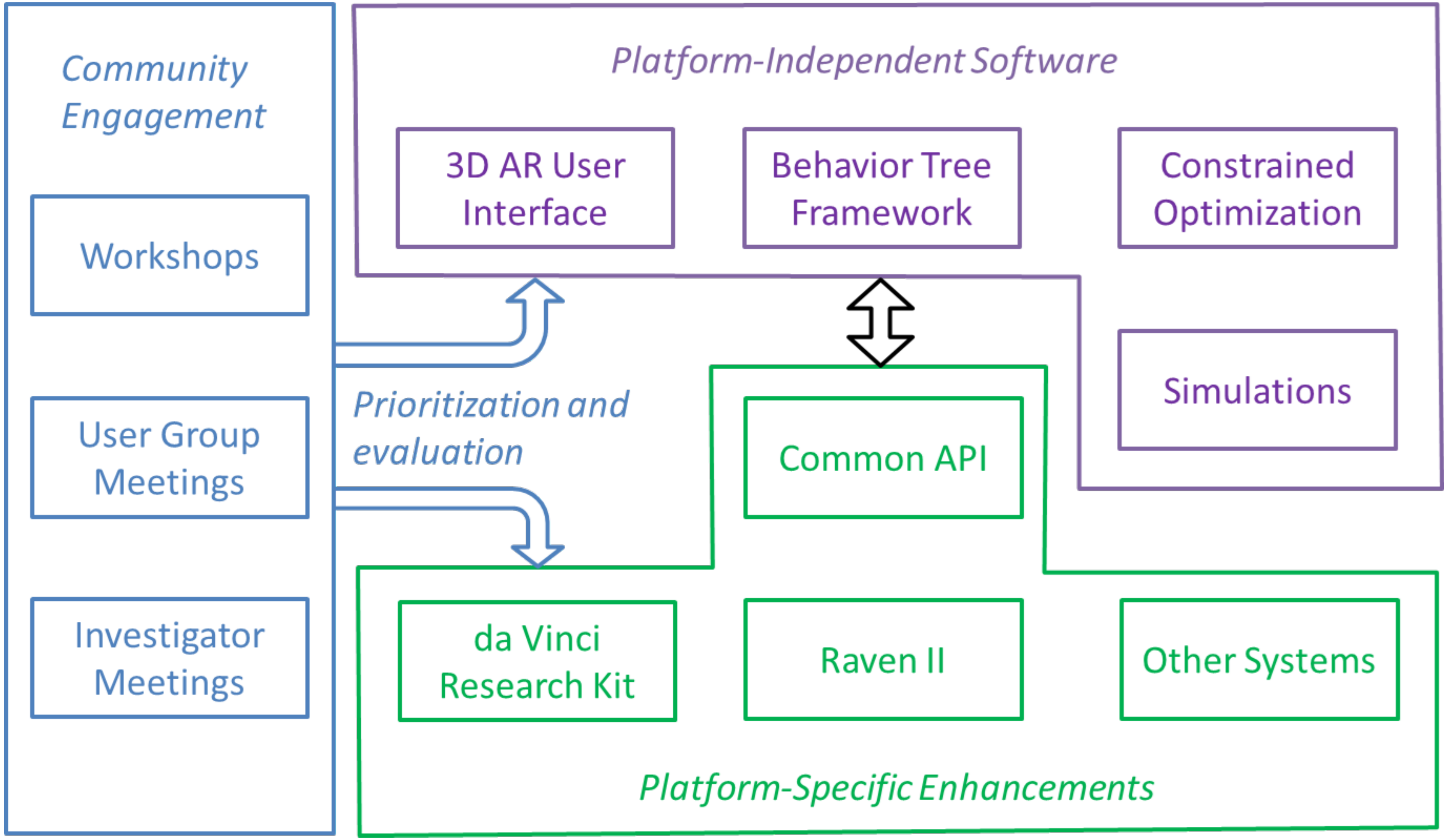


30 dVRK sites as of Fall 2018

NRI Goal

- Continue to build shared infrastructure and community around open platforms
  - Raven II and dVRK
  - Other robots (UR, Kuka, …)
  - Simulated robots
  - Haptic input devices
  - Other devices (trackers, sensors)

Project Outline



Community Engagement

Workshops

User Group Meetings

Investigator Meetings

Prioritization and evaluation

Platform-Independent Software

3D AR User Interface

Behavior Tree Framework

Constrained Optimization

Simulations

Common API

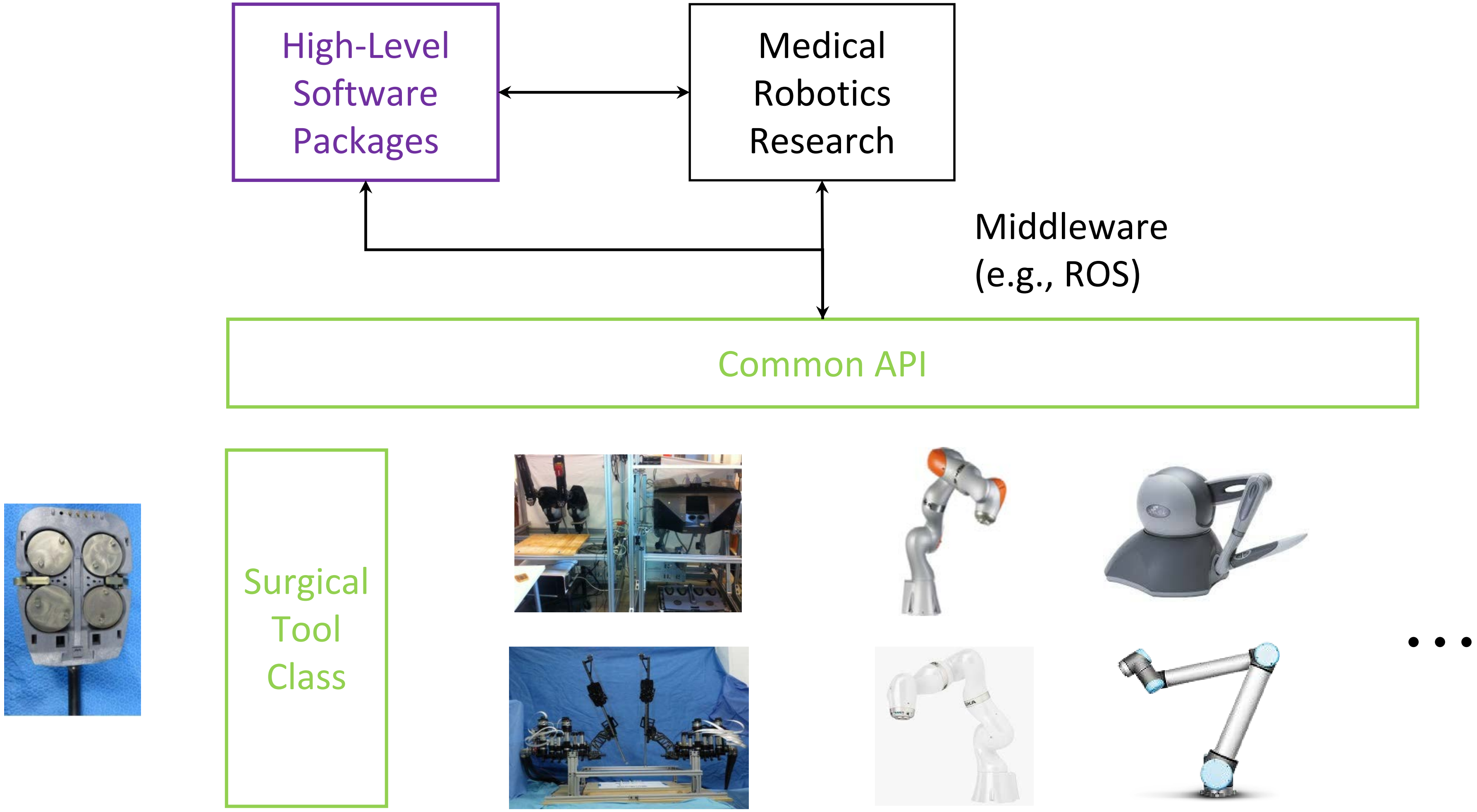
da Vinci Research Kit

Raven II

Other Systems

Platform-Specific Enhancements

Common API: Collaborative Robotics Toolkit (CRTK)



High-Level Software Packages

Medical Robotics Research

Middleware (e.g., ROS)

Common API

Surgical Tool Class

. . .

CRTK: Guiding Principles

- Based on realistic use cases
- As simple as possible
- Logical and consistent naming conventions (somewhat like part-numbering convention)
  - All robots not required to implement all commands, but should use consistent name
- Consider also that people will be keyboarding these in an interpreter (e.g., Python, Matlab)

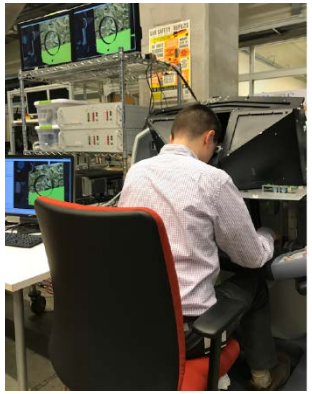
https://github.com/collaborative-robotics

Motivating Use Cases

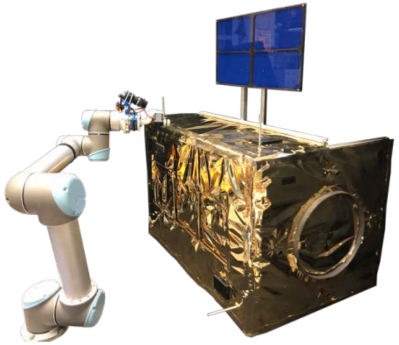
1. Teleoperation (diverse devices, communication channels, sensor feedback)
2. Autonomous motion
3. Custom kinematics/control
4. Cooperative or compliant control
5. Custom instruments

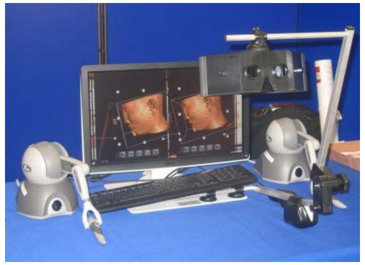
Use Case 1: Teleoperation

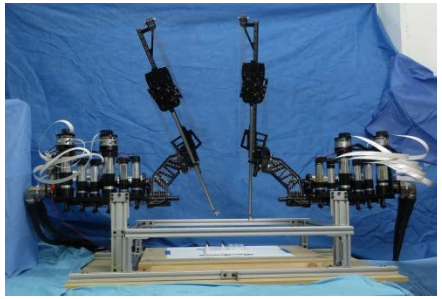
- Diverse master and slave devices
- Different communication channels (performance)
- Bilateral teleoperation, force reflection



Cartesian position, velocity, incremental position, effort (robot and tool)

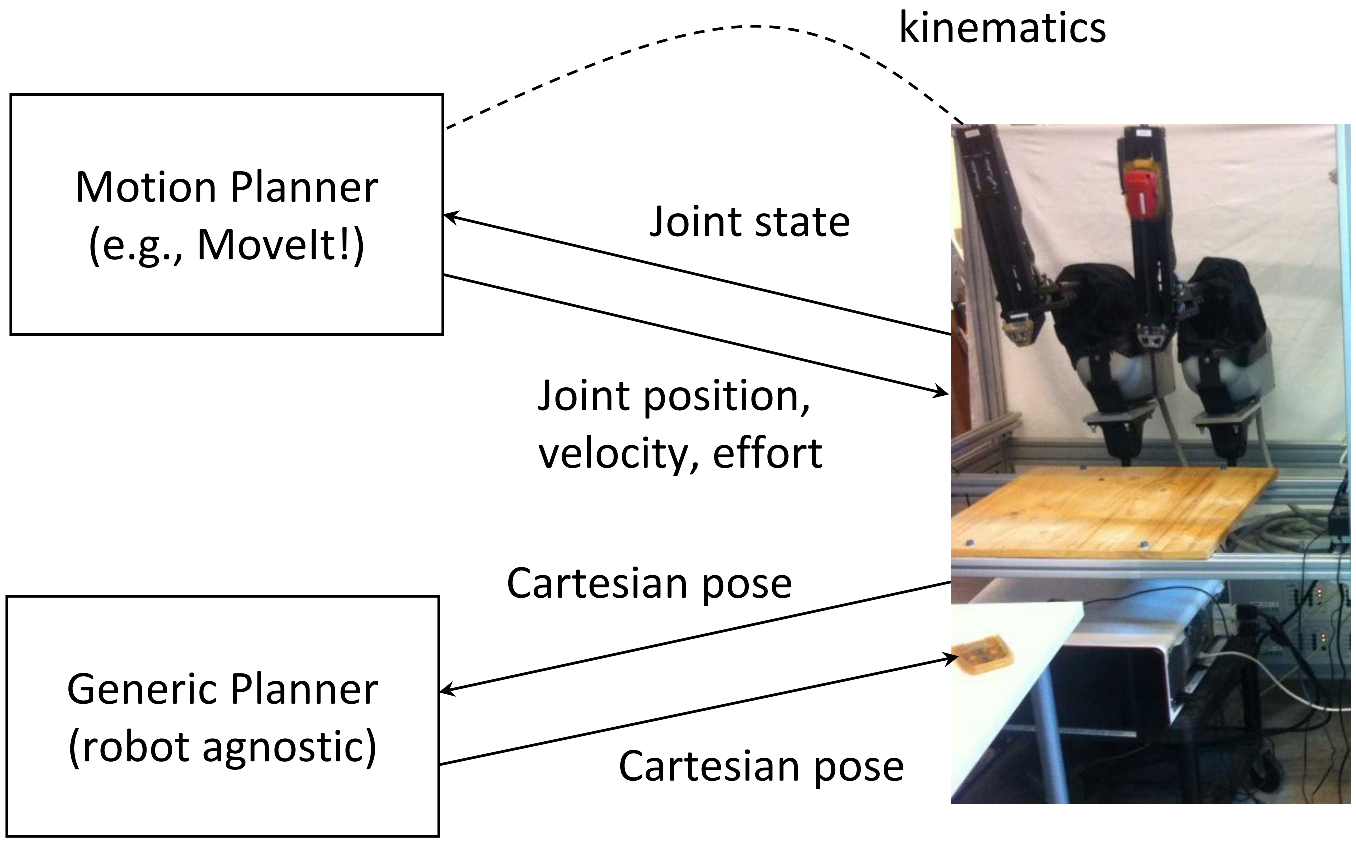






Cartesian state, joint state, generalized forces

Use Case 2: Autonomous Motion



kinematics

Motion Planner
(e.g., MoveIt!)

Joint state

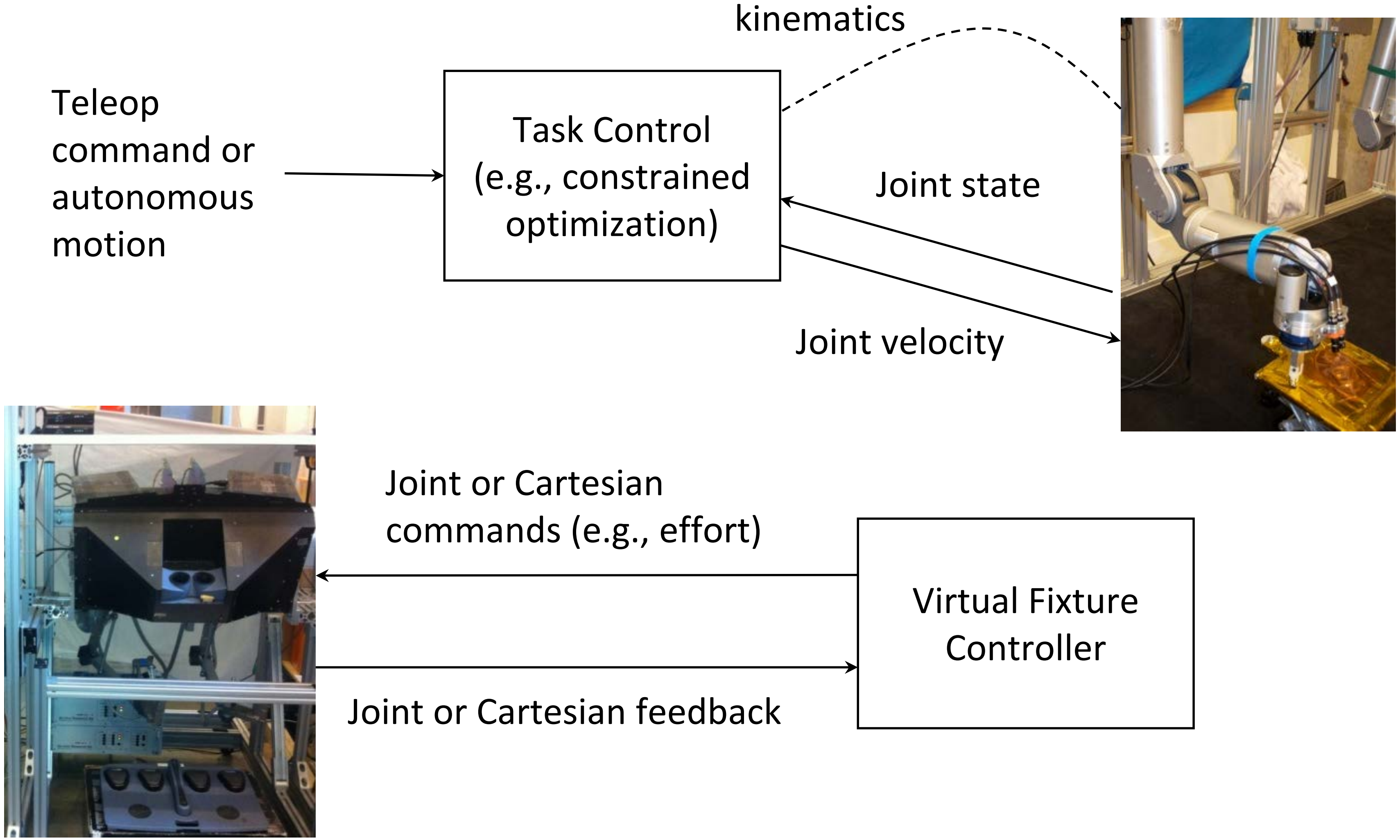
Joint position,
velocity, effort

Cartesian pose

Generic Planner
(robot agnostic)

Cartesian pose

Use Case 3: Custom Kinematics/Control



kinematics

Teleop command or autonomous motion

Task Control (e.g., constrained optimization)

Joint state

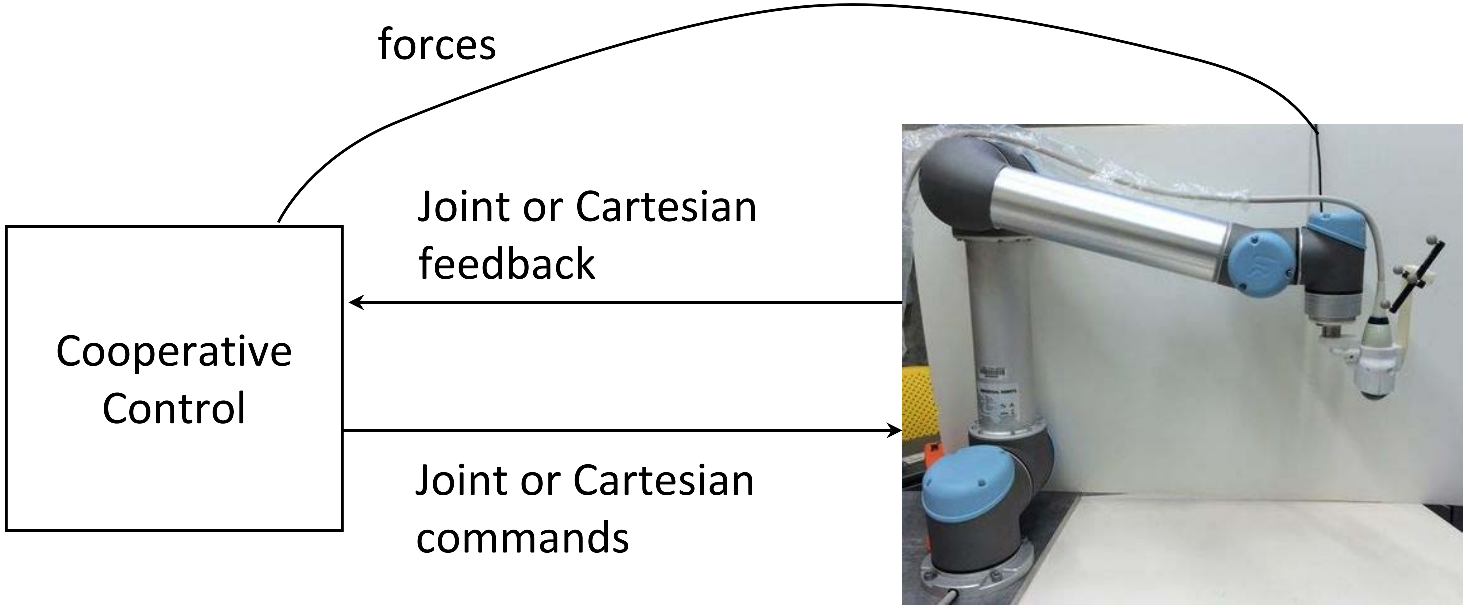
Joint velocity

Joint or Cartesian commands (e.g., effort)

Virtual Fixture Controller

Joint or Cartesian feedback

Use Case 4: Cooperative or Compliant Control



forces

Joint or Cartesian feedback

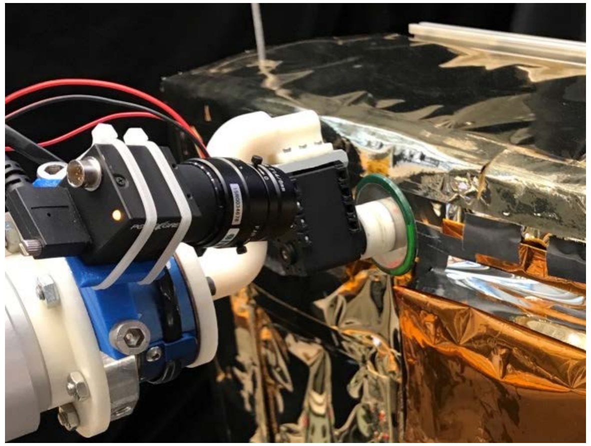
Cooperative Control

Joint or Cartesian commands

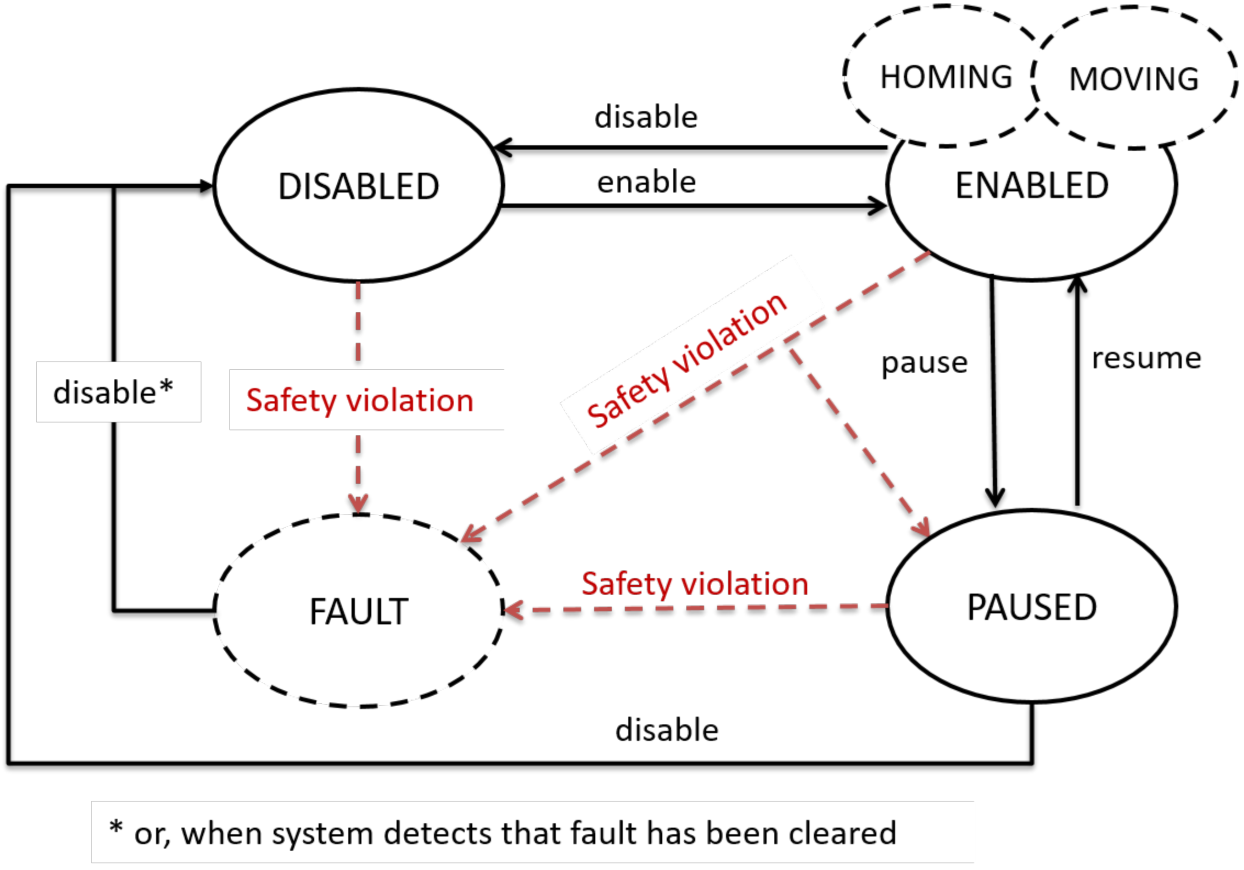
Use Case 5: Custom Instruments

- Custom instruments for Raven / dVRK
  - Interface to 4 driving disks

- Powered/sensorized tools/instruments
  - In addition to 4 driving disks
  - Grippers, end-effectors for other robots

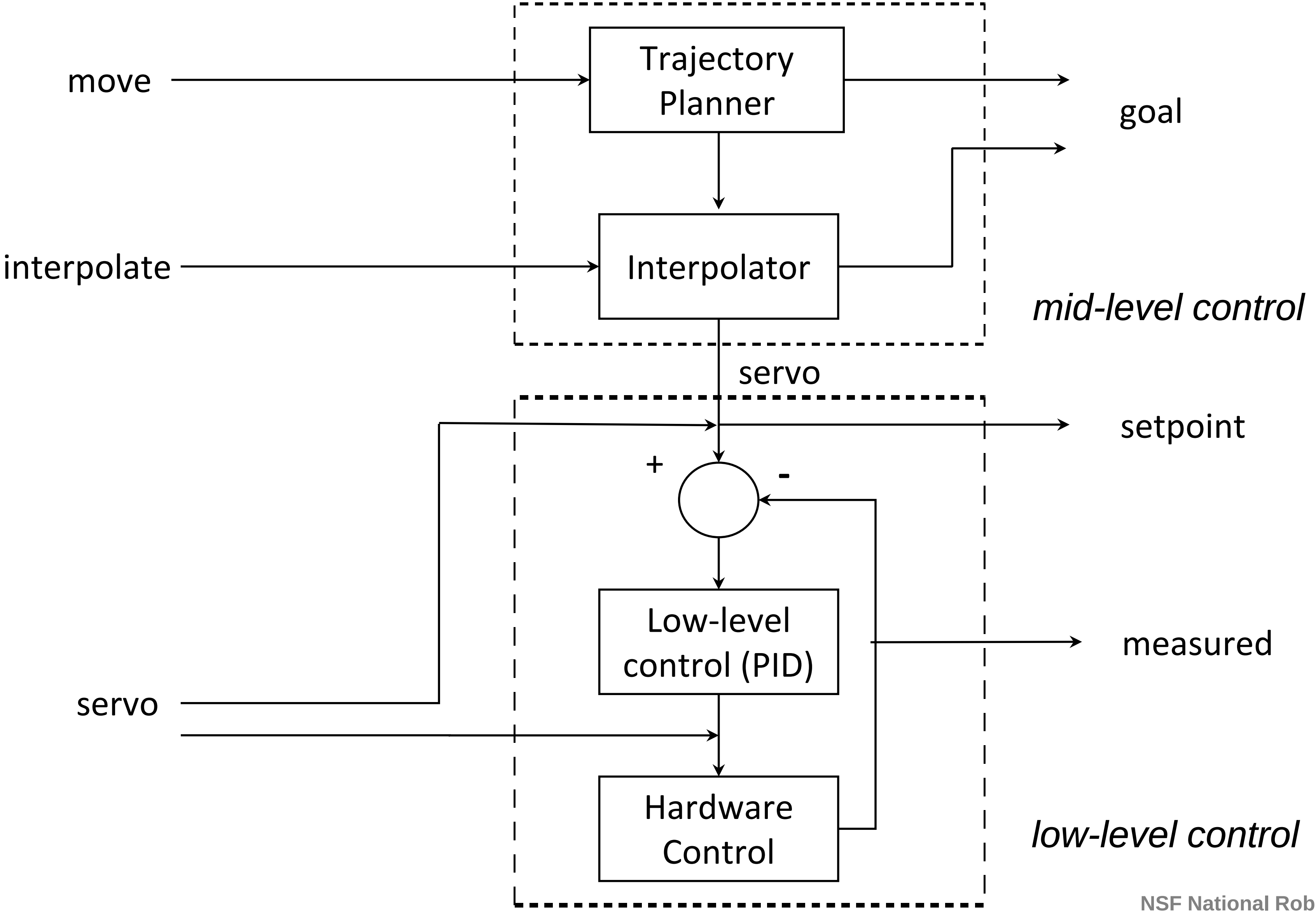


CRTK: Robot Meta-States and Modes



Meta-state queries: is_disabled, is_enabled, is_paused, is_fault
Operating mode queries: is_homing, is_moving, is_homed

CRTK: Feedback and Control



CRTK: Feedback and Control Convention

Control level	• *servo*: direct real-time stream • *interpolate*: interpolated stream • *move*: plan trajectory to goal
Feedback	• *setpoint*: current setpoint to low-level control • *goal*: most recent interpolate or move goal • *measured*: sensor feedback • *measuredN*: redundant sensor feedback (N=2, 3, …)
Space	• *j*: joint • *c*: cartesian
Type	• *p*: position • *r*: relative (incremental) position • *v*: velocity; (t: twist) • *f*: generalized force (e: effort, w: wrench) • *s*: state (position, velocity, effort) feedback

https://github.com/collaborative-robotics/documentation/wiki/Robot-API-motion

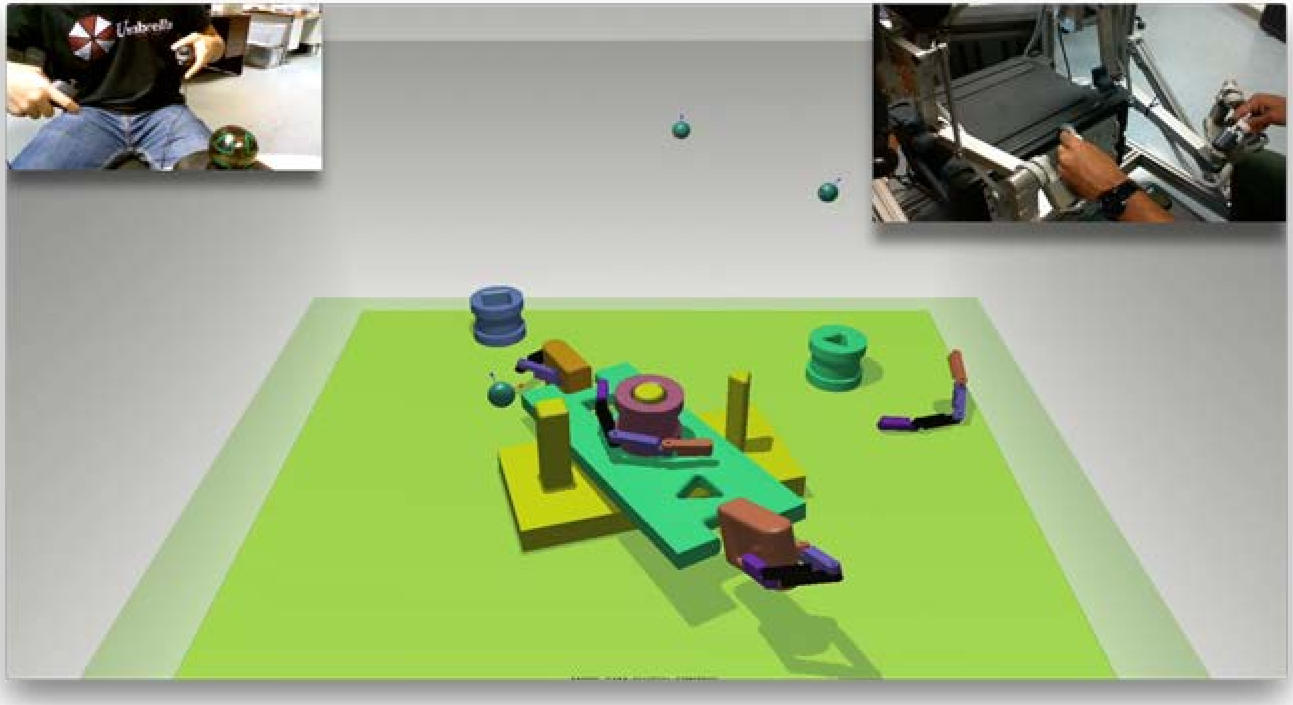
CRTK: Feedback and Control Examples

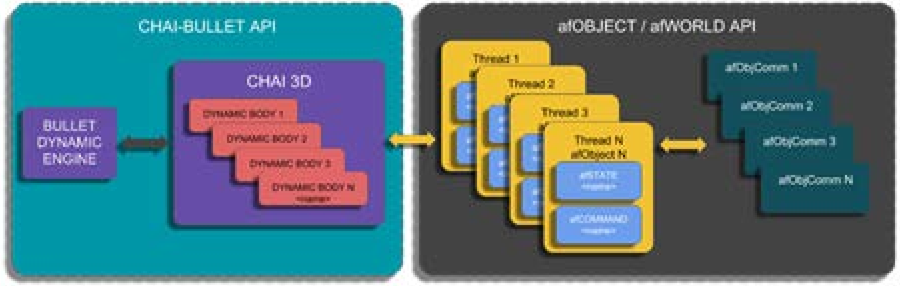
• *move_jp*	Plan trajectory and move to joint position
• *servo_jv*	Real-time update of joint velocity
• *interpolate_cr*	Interpolated relative Cartesian position move
• *servo_jf*	Real-time update of joint force (torque)
• *measured_js*	Measured position, velocity, force
• *measured_cp*	Measured Cartesian pose (position)
• *measured_cv*	Measured Cartesian velocity (twist)
• *measured_cf*	Measured Cartesian force (wrench)

Platform-Independent Software

- Leverages Common API to achieve platform independence
- Some examples:
  - 3D Mixed Reality User Interface
  - Constrained Optimization Framework
  - Behavior Tree Framework
  - Simulation Environments

Simulation Environments (Gazebo, Matlab, CHAI3D)





CHAI-BULLET API

BULLET DYNAMIC ENGINE

CHAI 3D

DYNAMIC BODY 1

DYNAMIC BODY 2

DYNAMIC BODY 3

DYNAMIC BODY N [illegible]

afOBJECT / afWORLD API

Thread 1

Thread 2

Thread 3

Thread N afObject N

afSTATE [illegible]

afCOMMAND [illegible]

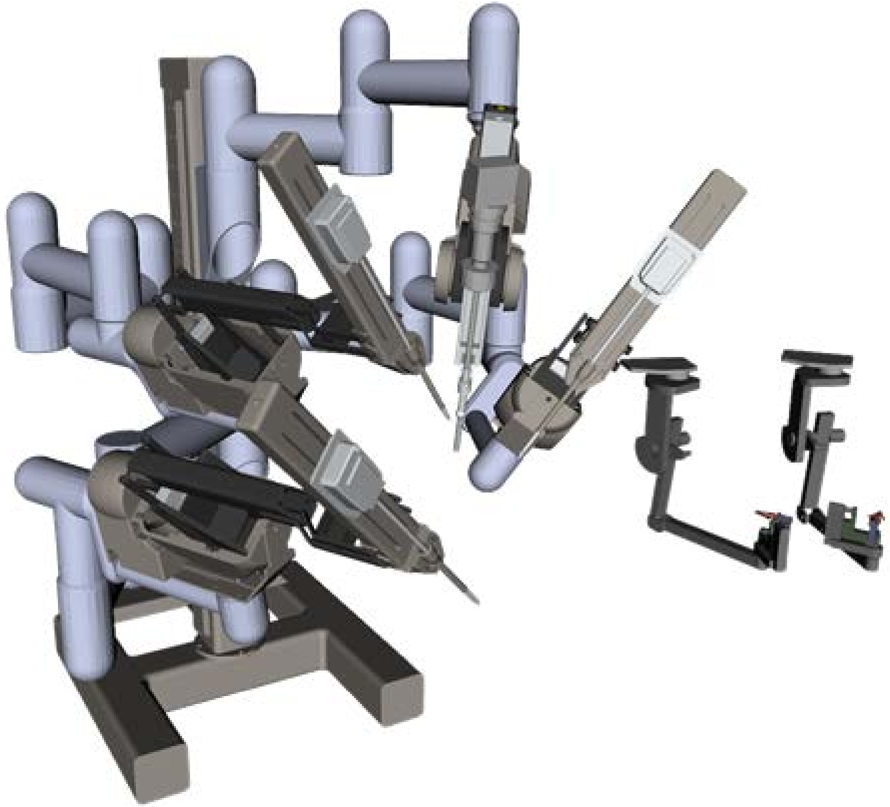
afObjComm 1

afObjComm 2

afObjComm 3

afObjComm N

https://github.com/WPI-AIM/chai_env



https://github.com/WPI-AIM/dvrk_env

Community Engagement (1/4)

- Raven/dVRK User Group Meeting at Univ. of British Columbia (UBC), Sept. 2017
  - Approx. 50 attendees for full day event
  - dVRK and Raven systems

https://smarts.lcsr.jhu.edu/events/ravendvrk-user-group-meeting-2017/

Community Engagement (2/4)

- IROS 2017 Workshop on Shared Platforms for Medical Robotics Research, Sept. 2017
  - Approx. 50 attendees for full day workshop
  - Included surgeon panel (7 surgeons)

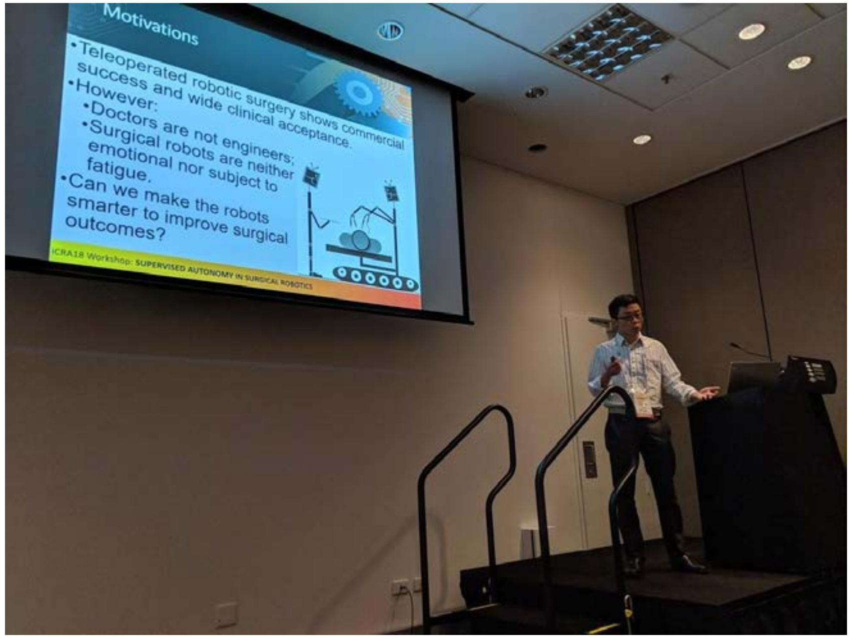
IROS VANCOUVER 2017

https://smarts.lcsr.jhu.edu/events/iros-2017-workshop/

Community Engagement (3/4)

- ICRA 2018 Workshop on Supervised Autonomy in Surgical Robotics, May 2018
  - Approx. 50 attendees

ICRA2018



Motivations

- Teleoperated robotic surgery shows commercial success and wide clinical acceptance.
- However:
  - Doctors are not engineers;
  - Surgical robots are neither emotional nor subject to fatigue.
- Can we make the robots smarter to improve surgical outcomes?

ICRA18 Workshop: SUPERVISED AUTONOMY IN SURGICAL ROBOTICS

https://sites.google.com/view/yangmingli/icra18-workshop

Community Engagement (4/4)

- IROS 2018 Tutorial on Collaborative Robotics Toolkit (CRTK) and Open Platforms for Medical Robotics Research, Oct. 2018
  - Approx. 20 attendees
  - Hands-on session

MADRID 2018 IROS

https://collaborative-robotics.github.io/iros-2018-tutorial.html

Summary

- Continued enhancement of Raven II and dVRK
- Collaborative Robotics Toolkit (CRTK) provides common API to Raven II, dVRK, and other devices
  - Satisfies common use cases in semi-autonomous teleoperation, especially for medical domain
  - Facilitates development of high-level software packages
- Community Engagement via user group meetings, workshops and tutorials
- Final year to focus on extending CRTK to other robots and devices and on release of high-level software packages