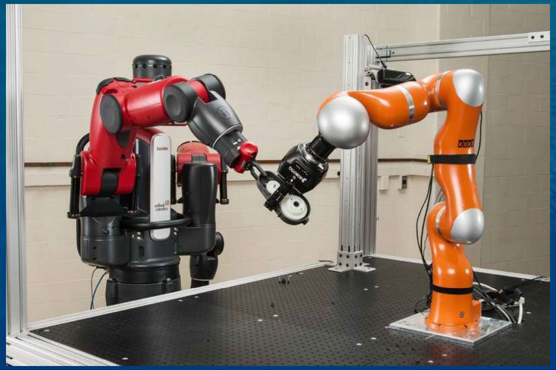
Measurement Science For Manufacturing Robotics



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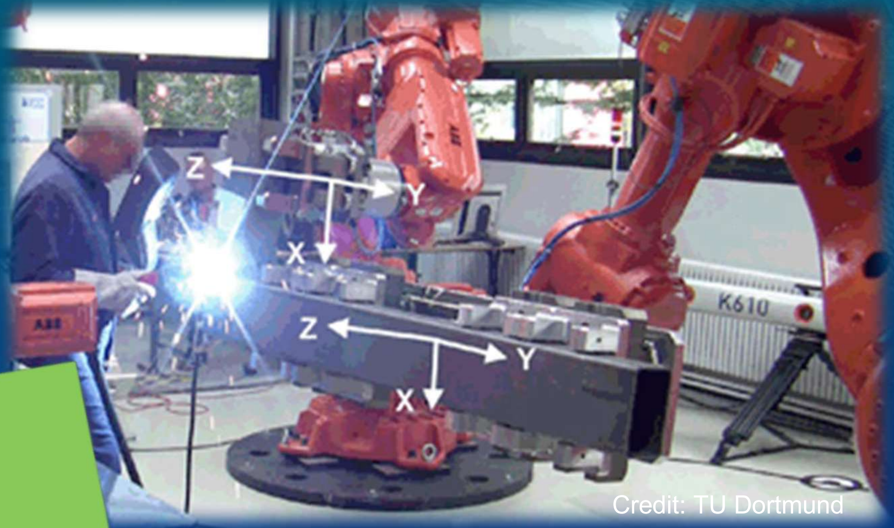
https://www.nist.gov/programs-projects/measurement-science-manufacturing-robotics
https://www.nist.gov/el/intelligent-systems-division-73500/standard-test-methods-response-robots

Disclaimer: Commercial equipment and materials are identified in order to adequately specify certain procedures. In no case does such identification imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that the materials or equipment identified are necessarily the best available for the purpose.

Enabling the Next Generation of Robots for Manufacturing

TODAY: very small percentage of potential users benefit from robots due to:

- Ad hoc, expensive custom solutions for installation, fixturing, tooling, integration
- Lengthy programming for each new part
- Limited or no tasking/replanning agility
- Separated from humans for safety; cannot collaborate/assist



Credit: TU Dortmund

Advances in Robotics Enable Future Vision:
Greater responsiveness, productivity & higher quality with collaborative robots that is achievable by small, medium, and large manufacturers

Credit: Robotunits

NIST contributes: metrics, protocols, benchmarks, models, testbeds

Measurement Science for Manufacturing Robotics

Reducing risks in adopting new technology and helping spur innovation

PERCEPTION PERFORMANCE OF ROBOTIC SYSTEMS

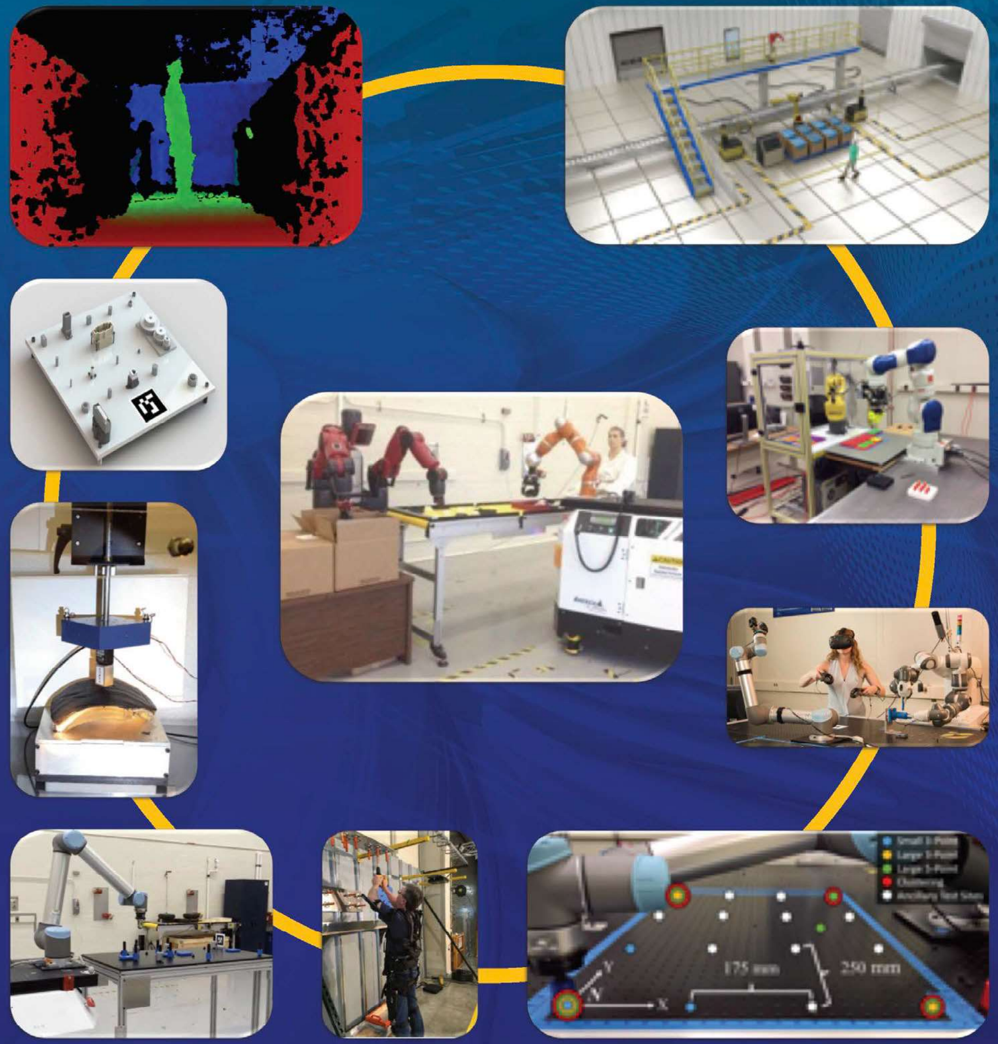
Assess and Assure Sensor & Perception Systems

GRASPING, MANIPULATION & SAFETY PERFORMANCE OF ROBOTIC SYSTEMS

Assess and Assure Dexterous Grasping & Contact Safety

MOBILITY PERFORMANCE OF ROBOTIC SYSTEMS

Assess & assure vehicles, mobile manipulators & wearables



EMBODIED AI AND DATA GENERATION FOR MANUFACTURING

Provide validated data & models for AI algorithms

AGILITY PERFORMANCE OF ROBOTIC SYSTEMS

Easily and rapidly reconfigure and re-task robots

PERFORMANCE OF HUMAN-ROBOT INTERACTION

Provide foundations for Intuitive and effective interaction methods

TOOLS FOR COLLABORATIVE ROBOTS WITHIN SME WORKCELLS

Reduce the technical barriers to adopting robots

NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Examples of NIST Products

Metrics, Test Methods

Elemental Grasp Metrics

Exoskeleton Performance (ASTM F48)

Ground Truth, Artifacts

Instrumented Metrology Bar for Robot Coordinated Motion Evaluation

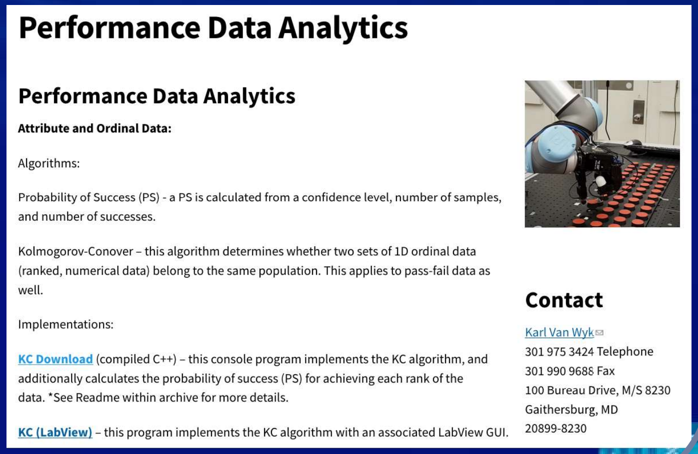
Artifacts for Dynamic 6DOF Pose Evaluation (ASTM E57)

Datasets

3D Data for the Evaluation of Point-Based, Rigid Body Registration Error

Competitions

Software Tools



Performance Data Analytics

Performance Data Analytics

Attribute and Ordinal Data:

Algorithms:

Probability of Success (PS) - a PS is calculated from a confidence level, number of samples, and number of successes.

Kolmogorov-Conover – this algorithm determines whether two sets of 1D ordinal data (ranked, numerical data) belong to the same population. This applies to pass-fail data as well.

Implementations:

KC Download (compiled C++) – this console program implements the KC algorithm, and additionally calculates the probability of success (PS) for achieving each rank of the data. *See Readme within archive for more details.

KC (LabView) – this program implements the KC algorithm with an associated LabView GUI.

Contact

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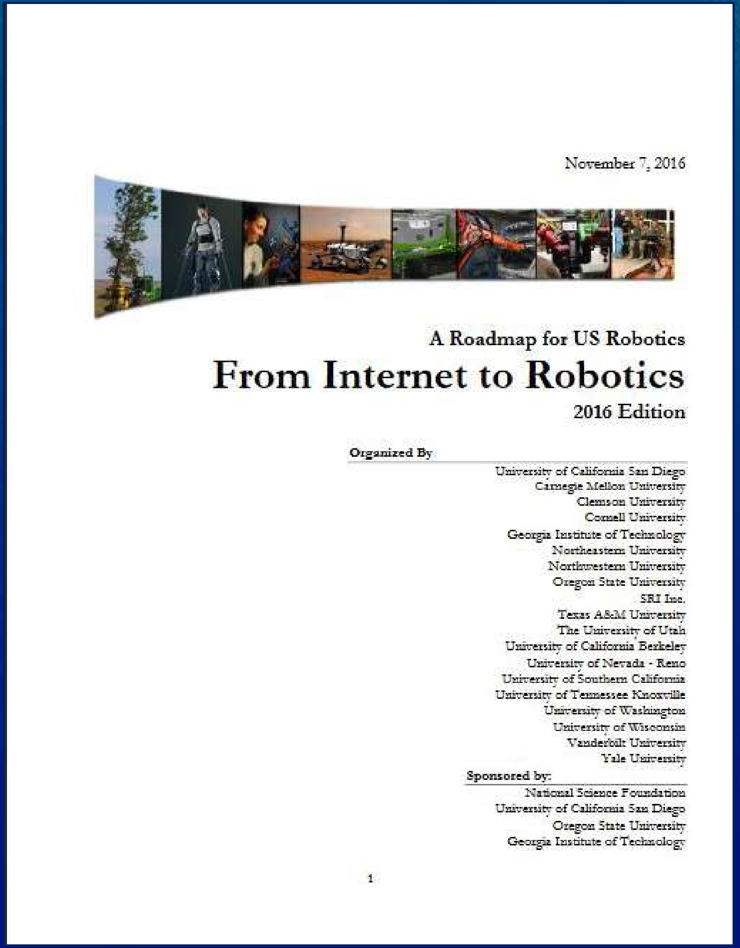
What is Robot Agility?

- Hardware agility
  - How can different hardware configurations affect a robot's ability to accomplish a variety of tasks?
- **Software agility**
  - **How can a robot be quickly tasked to perform an operation?**
  - **How well can a robot adapt/respond to task failures?**
  - **How well can a robot re-plan when a new goal is provided to it?**
  - **How can we allow for interchangeability of robots without the need for reprogramming?**
  - **How well can a robot respond to changing environmental conditions (e.g., non-fixtured tray moves)?**

C. I. Schlenoff, S. B. Balakirsky, M. Kurwa, "Editorial: Special Issue on Industrial Robot Agility" Industrial Robot Journal, Vol. 43, No. 5, pp. 449-449, (14-Sep-2016)

Why Did We Focus on These Areas?

- Reviewed numerous roadmaps
- Numerous site visits and telecons with industry and organizations
- Feedback at conferences: ICRA, IROS, IEEE CASE
- Discussions in standards groups
- **Common themes:**
  - Robots take a long time to program
  - Robots are incapable of adapting to changing environments
  - Once a company decides on a robot brand, they are tied to that brand because of the large infrastructural cost
  - Training a robot to perform a new task (or a variation of an existing task) is very time consuming and not cost effective unless you have very large lot sizes.
    - Companies have large areas of their shop floor sitting idle because the robots were trained to develop a specific product and the demand for that product is low (even though demand for other products are high)



November 7, 2016

A Roadmap for US Robotics

From Internet to Robotics

2016 Edition

Organized By

University of California San Diego
Carnegie Mellon University
Clemson University
Cornell University
Georgia Institute of Technology
Northeastern University
Northwestern University
Oregon State University
SRI Inc.
Texas A&M University
The University of Utah
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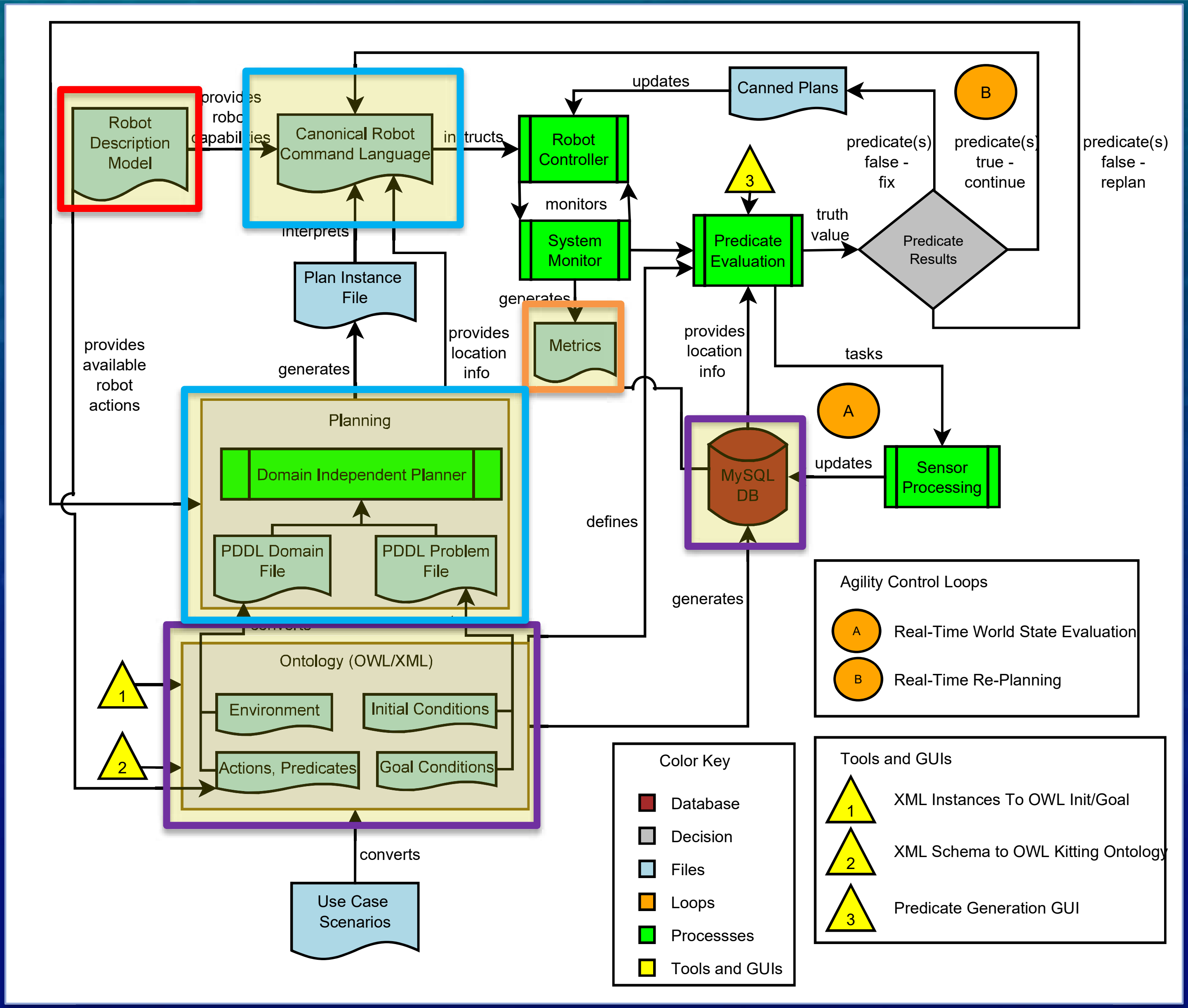
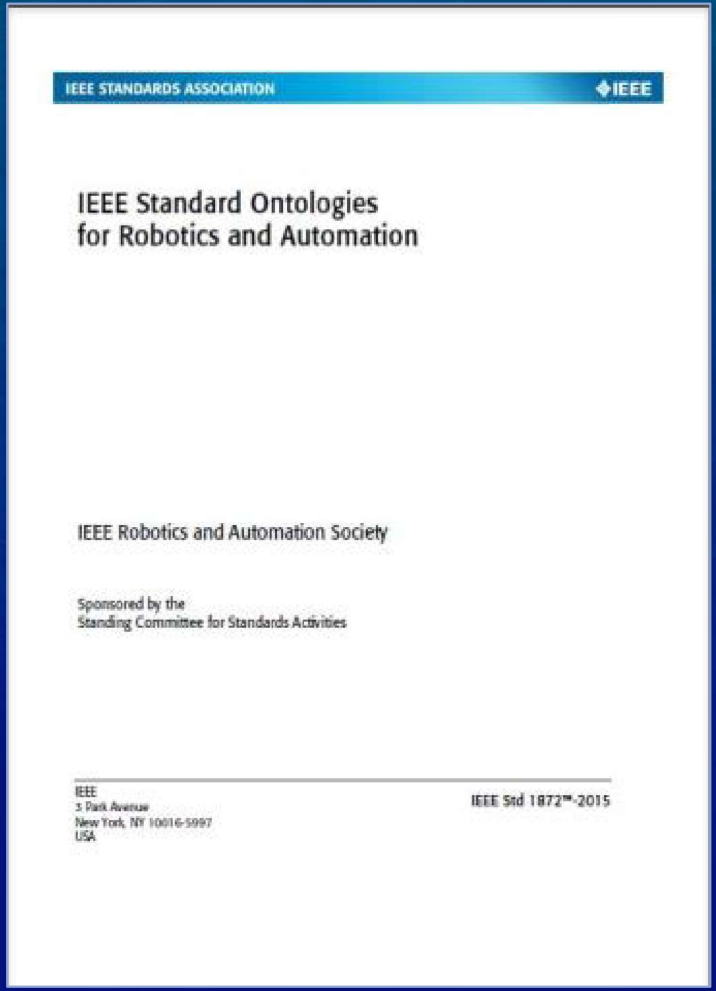
Big Picture



🟪 Knowledge representations
🟥 Robot capabilities
🟦 Planning approaches
🟧 Test methods

Core Ontologies for Robotics and Automation Standard

- IEEE 1872 -Core Ontology for Robotics and Automation (CORA)
  - "… allows for the representation of, reasoning about, and communication of knowledge in the robotics and automation domain."
  - http://standards.ieee.org/findstds/standard/1872-2015.html
  - First ontology-based IEEE RAS standard
- IEEE Ontologies for Robotics and Automation Standards Working Group
  - November 2011 – Became a working group
  - July 2014 – Initial standard applied to robots at NIST and Georgia Tech
  - April 2015 – CORA Becomes a Standard (unanimous approval from ballot group)
  - 175 members representing 23 countries
    - ~50% educational institutions, ~25% industry, ~25% government
    - ~50% US, ~50% non-US



IEEE STANDARDS ASSOCIATION ◆IEEE

IEEE Standard Ontologies
for Robotics and Automation

IEEE Robotics and Automation Society

Sponsored by the
Standing Committee for Standards Activities

IEEE
3 Park Avenue
New York, NY 10016-5997
USA

IEEE Std 1872™-2015

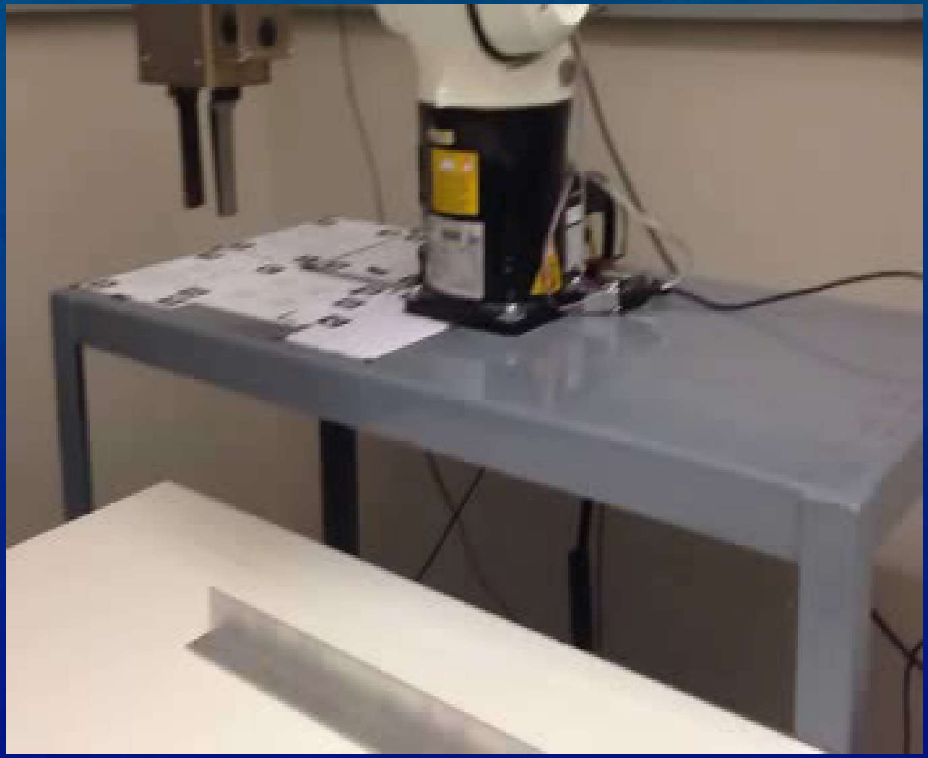
C. I. Schlenoff, "Let's Talk, Robots" Scientific Computing Magazine, Scientific Computing, 100 Enterprise Dr. Suite 600, Rockaway, NJ, 07866, United States, (21-Nov-2016)

CORA Recognition and Use

- Won the IEEE-SA Emerging Technology Award (2015) - given once a year to a working group which “advanced, initiated, or progressed a new technology within the IEEE-SA open consensus process.”
  - *“The 1872-2015 standard has and will continue to serve as a great resource to developers, users, and systems integrators in the robotics field. The resulting standard has shown value and has the support of many in the field in robotics, including representatives in the industrial, service, and healthcare fields.”* **Gurvinder Virk, ISO TC184/SC2/WG7 convener**
- Mentioned in former President Obama’s “The National Artificial Intelligence Research and Development Strategic Plan”
- Prominently featured in two journal special issues
  - Robotic and Computer Integrated Manufacturing Journal entitled “Knowledge Driven Robotics”
  - Industrial Robots journal entitled “Industrial Robot Agility”
- Featured in articles in Engadget and Scientific Computing
- Standard has been purchased over 2100 times
- Applied to research efforts in numerous institutions such as Georgia Tech and Lund University

Robot Capability Model

- Robot capabilities are usually only found in the robot expert's heads
- We are trying to implant this knowledge in the robot so it can:
  - Understand what it can and can not do
  - Provide this information for automated high-level workcell planning
  - When failures happen, understand if it is able to address the failure
  - Explore alternative sequences of actions to accomplish the goal

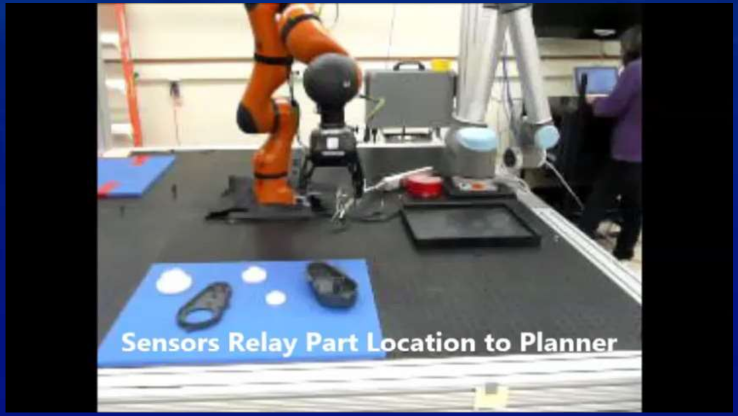


Courtesy: GTRI

M. O. Shneier, E. R. Messina, C. I. Schlenoff, F. M. Proctor, T. R. Kramer, J. A. Falco, "Measuring and Representing the Performance of Manufacturing Assembly Robots" NIST Interagency/Internal Report (NISTIR) 8090, (10-Dec-2015)

Canonical Robot Command Language (CRCL)

- A messaging language for sending commands to, and receiving status from a robot and end effector.
- Provides basic commands that are independent of the kinematics of the robot that executes the commands.
- Ability to utilize set of commands on different vendor's robots with same results
- Implemented using XML Schema for the information model and XML for the instance document



F. M. Proctor, S. B. Balakirsky, Z. Kootbally, T. R. Kramer, C. I. Schlenoff, W. P. Shackleford, "The Canonical Robot Command Language (CRCL)" Industrial Robot-An International Journal, Vol. 43, No. 5, pp. 494-502, (01-Aug-2016)

FANUC Code vs Motoman Code

FANUC Code (Karel)

```
PR[42] = PR[30]
PR[42,3] = (-80)
PR[32] = PR[31]
PR[32,3] = (-80)
PR[42] 200mm/sec FINE
PR[30] 200 mm/sec FINE
WAIT 0.10 (sec)
CALL CLOSE_GRIPPER
WAIT 0.10 (sec)
PR[42] 200 mm/sec FINE
PR[32] 200 mm/sec FINE
PR[31] 200 mm/sec FINE
WAIT 0.10 (sec)
CALL OPEN_GRIPPER
WAIT 0.10 (sec)
PR[32] 200 mm/sec FINE
END
```

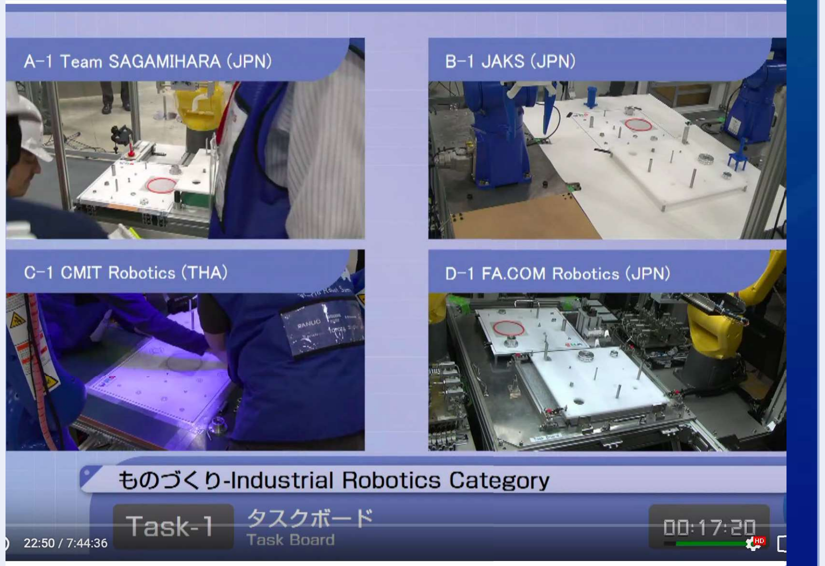
Motoman Code (Inform)

```
CALL JOB:HOME
CALL JOB:GRIPPEROPEN
SET ABOVEPART ZPLUS30
ADD ABOVEPART LGEAR1
MOVJ ABOVEPART VJ=50.00
MOVL LGEAR1 V=138
CALL JOB:GRIPCLOSE
MOVL ABOVEPART V=138
MOVJ HOMEPOS VJ=50.00
SET ABOVEPART ZPLUS30
ADD ABOVEPART SLOT1
MOVJ ABOVEPART VJ=50.00
MOVL SLOT1 V=138
CALL JOB:GRIPPEROPEN
MOVL ABOVEPART V=138
CALL JOB:HOME
END
```

Assembly Task Boards Provide Cross-cutting Impacts

Used as Competition Benchmarks

- World Robot Summit
- IEEE IROS Grasping & Manipulation



Robot Manufacturer Video

Replicated at New England Robot Validation & Experimentation (NERVE) Center and by Advanced Robotics for Manufacturing (ARM) Institute teams.

Siemens Research is publishing papers on their ML results featuring the task boards.

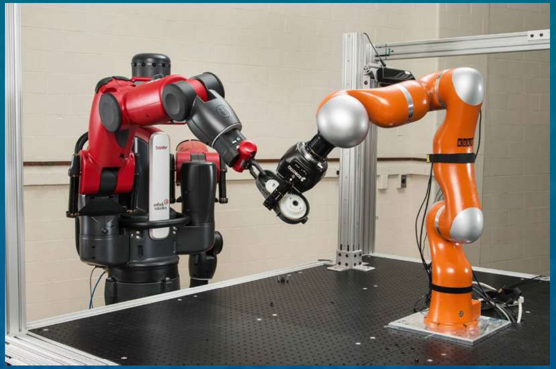
E.g., Schoettler, Gerrit, et al. "Deep Reinforcement Learning for Industrial Insertion Tasks with Visual Inputs and Natural Rewards." *arXiv; IROS & ICML conferences arXiv:1906.05841* (2019).

Agile Robotics for Industrial Automation Competition (ARIAC)

- Goal: To test the agility of industrial robot systems, with the goal of enabling industrial robots on the shop floors to be more productive, more autonomous, and to require less time from shop floor workers.
- Simulation-based competition (Gazebo and ROS)
- Year 5 of the competition just starting
- Prize Competition
  - $10,000 first prize
  - $5,000 second prize
  - $2,500 third prize
- About 50-60 teams registered each year (110 teams in 2020)
  - About 4-6 teams made it to the finals each year
- More information at www.nist.gov/ariac

How It Works

- Teams are developing robot control systems to handle agility challenges
- Teams can place sensors in the environment to track objects (for a cost)
- Teams use ROS interfaces to control actuators, read sensor information and send/receive notifications
  - Retrieving Orders
    - rostopic echo /ariac/orders
  - Querying Storage Locations of Parts
    - rosservice call /ariac/material_locations “material_type: piston_rod_part”
  - Querying Sensors
    - Beam Break / Proximity Sensor – Is there something in the proximity of the sensor? (min/max range)
    - Laser Sensor – range data
    - Camera – models detected
  - Controlling the arm (trajectory messages)
    - rostopic pub /ariac/arm/command trajectory_msgs/JointTrajectory “ [joint_names], points: [time_from_start in seconds], positions: [x,y,z, roll, pitch, yaw] …
  - Control vacuum gripper
    - rosservice call /ariac/gripper/control “enable: true”



Questions?

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https://www.nist.gov/el/intelligent-systems-division-73500/standard-test-methods-response-robots