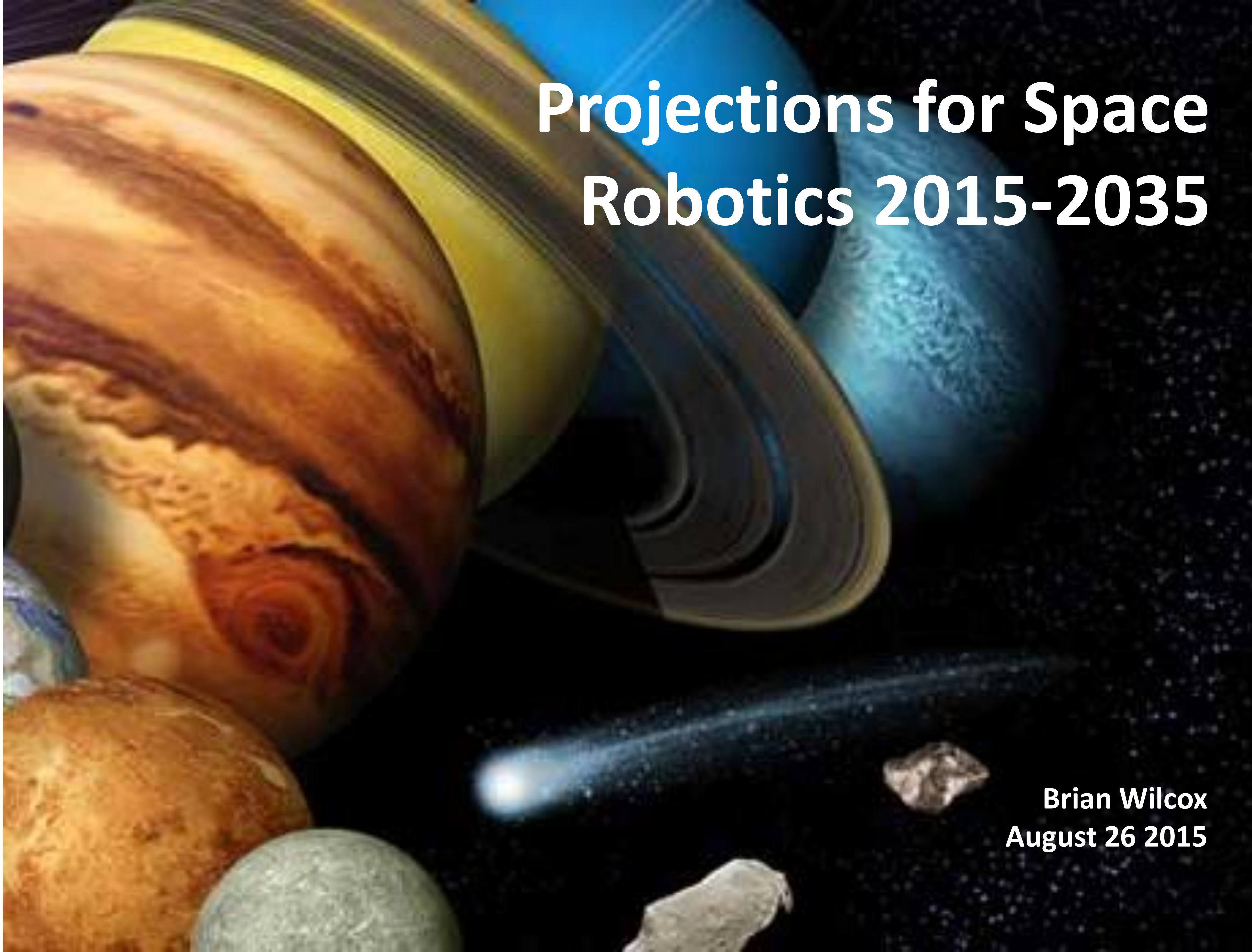


Projections for Space Robotics 2015-2035

Brian Wilcox

August 26 2015

Supervisory Control

What is the problem? Why is it hard?

Teleoperation is typically 10X slower than "shirtsleeves" rates, with zero latency.

Time-delayed robotics requires commands where force-control is managed at remote site, since forces change fast .

http://www.nola.com/news/gulf-oil-spill/index.ssf/2010/07/undersea_robots_are_heroes_of.html

What can we do now?

The deep-sea robotics industry uses very robust hardware that can accept huge force overloads.

Industrial robots use compliant end-effectors without force-control, with precise fixturing and highly engineered environment for repetitive work.

https://en.wikipedia.org/wiki/History_of_robots

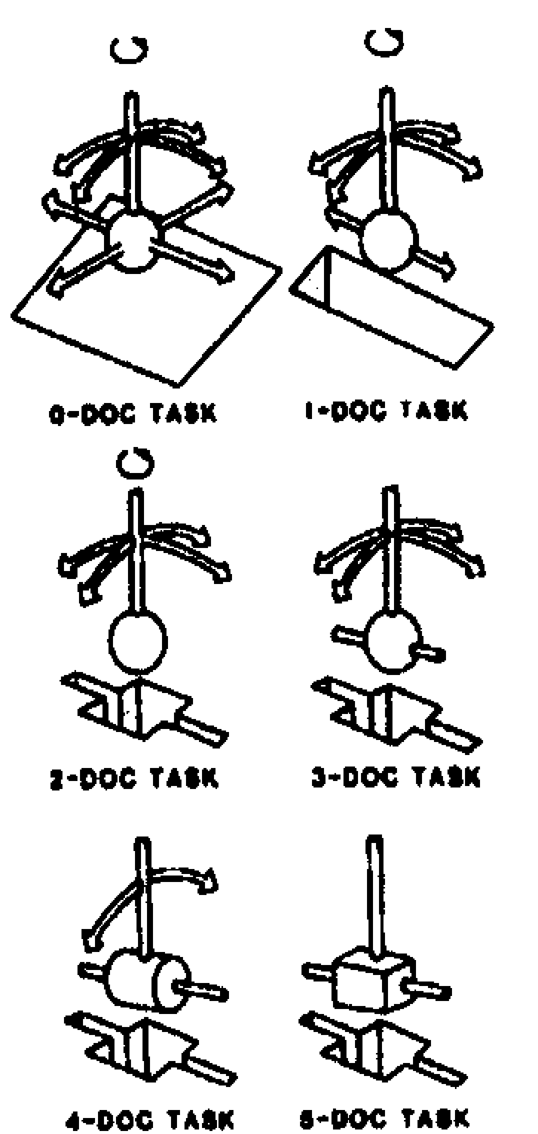
Robot Commanding using Mechanical Primitives

What's new in this approach?

- Mechanical primitives execute one-by-one force-controlled progression in degrees-of-constraint for assembly tasks, or one-by-one de-constraint for dis-assembly. Build up macros.
- Use human designation of task elements (handles, hinges, etc.) with machine-vision "snap to (stereo) picture" so robot "understands" workspace.

Who cares?

- Enables robot new-task execution at "shirtsleeves" rates - ~10X improved.



D. A. Thompson, 1977

Robot Commanding using Mechanical Primitives

What difference will it make?

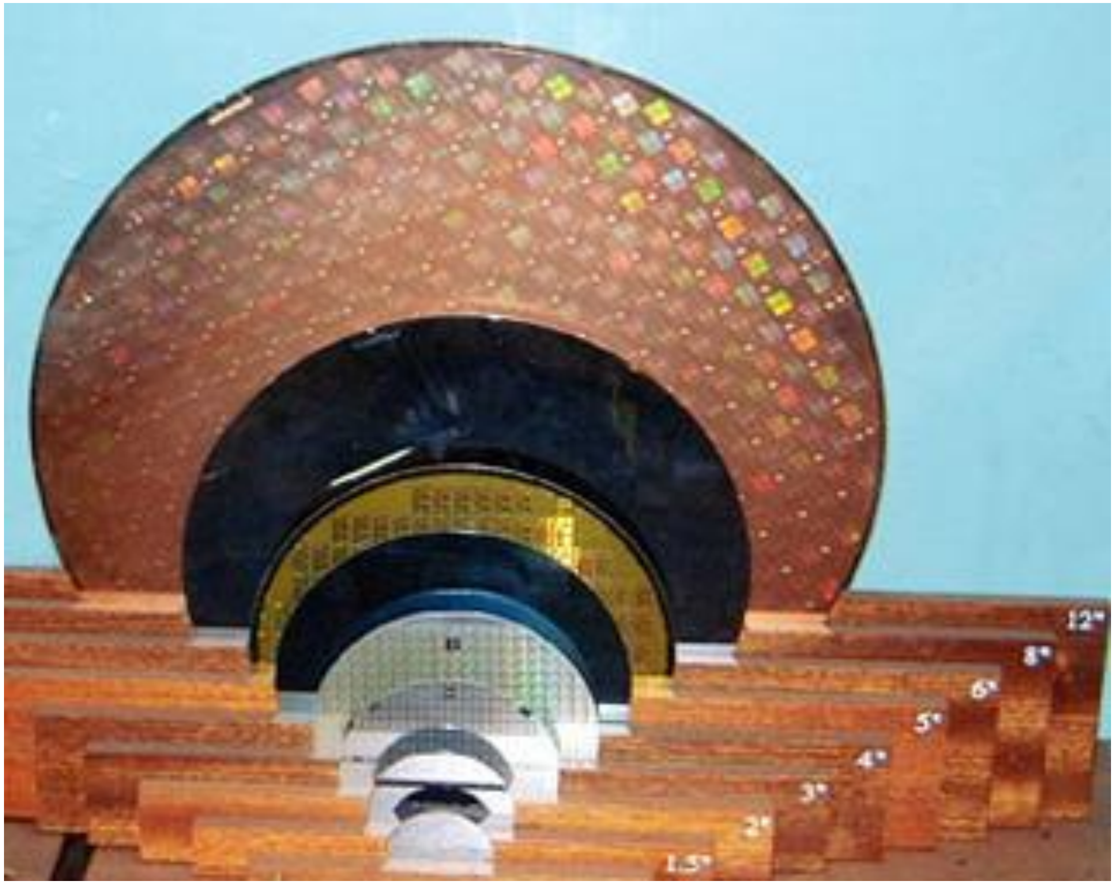
Human operator can quickly "tell" the robot about all relevant elements of work environment (workpieces, motion constraints, keep-out zones), eliminating most computation-intensive autonomous perception and planning, and give commands to perform assembly, dis-assembly, and all other manipulation within a coherent, unified framework. Macros for common tasks (e.g. array of bolts) can be debugged with extensive self-checks and recovery algorithms.

What are the risks and the payoffs?

Payoff is safe and very rapid execution of unexpected tasks in new environment, with latency only adding linearly to relatively infrequent commands.

The Coming Robot Revolution

- Moore's Law over 55 y has resulted in the computing throughput per wafer (@ constant $1-10k cost to manufacture) to increase by 11 orders of magnitude. Cost dropped from ~1 transistor per $ in 1960 to ~10^{12} transistors per $ by the end of this decade [2015 dollars].



http://www.i-micronews.com/upload/Micronews/images/Intel.jpg

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The Coming Robot Revolution (con't)

- Some lament the "software explosion" where vast resources go to writing many 100M of lines of S/W. But the human genome is only 800MB uncompressed, and it codes for only ~50k protein and RNA molecules needed to "build" a human.
- The coding for the human brain is only a fraction of the total, and each molecule presumably represents only a few lines of code. So the S/W in the brain is a few tens of thousands of lines of code. That code is almost certainly learning algorithms such as Bayes theorem and standard signal processing front-ends like the Fourier Transform.

http://ghr.nlm.nih.gov/handbook/basics/dna

The Coming Robot Revolution (con't)

- A high-performance game console now has about the same computing throughput as the most capable invertebrate animal – the octopus.

http://www.realclear.com/animals/2015/08/17/an_octopus_might_be_an_alien_and_other_astonishing_eightarmed_facts_12030.html

- In the next 15-20 years we will presumably witness computers replicating all of higher vertebrate evolution, up to and surpassing humans, by a factor of 10 every 5 years.

The Coming Robot Revolution (con't)

- An adult human brain has ~10^{17} transistors storing learned knowledge (~$3x10^{14}$ synapses each with ~300 transistors per synapse).

http://absurdwordpreferred.deviantart.com/art/Brain-FREE-Transparent-PNG-130589663

- 10^{17} transistors will cost <$100k in 2020.
- Verification and validation of learned systems would be accomplished in the same way as with humans – by getting to know and trust them as individuals. But they could be copied identically, and their learning "turned off".