ROBO Business

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Modular Robots for Rapid Development and Deployment of Custom Automation

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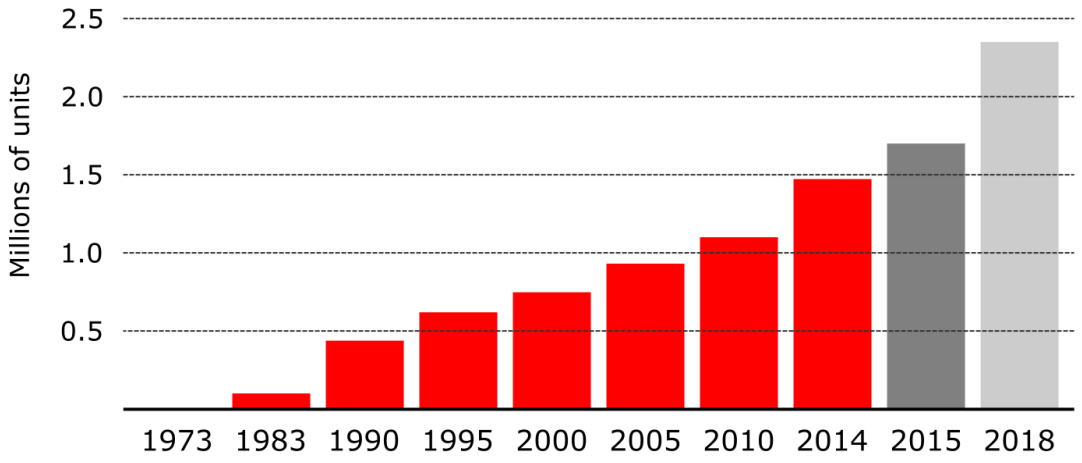
Robots enable a transition from hard to flexible automation

Hard automation
(LEGO Factory – Billund, Denmark)

Soft automation
(Pepperidge Farm Factory – Denver, Colorado)

Flexible automation
(Tesla Factory – Fremont, California)

Robots are increasingly deployed in industrial settings…



Worldwide estimated operational stock of industrial robots

Source: IFR World Robotics 2015

… but complexity leads to standard configurations

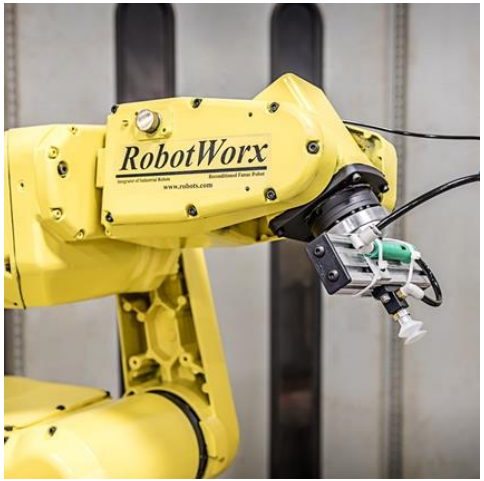
6/7-DoF Manipulators

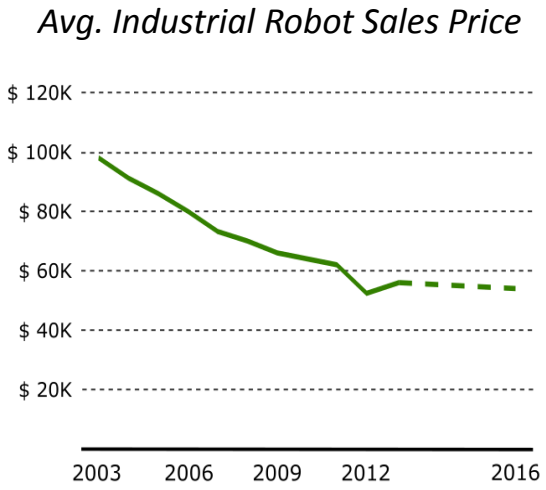
Delta Mechanisms

SCARA Arms

"Industrial Robot" Google image search results

Current robots are highly capable, but have drawbacks





Low Multi-Task Versatility

Low Ease-of-use

High Price

Source: Bishop & Associates Inc.

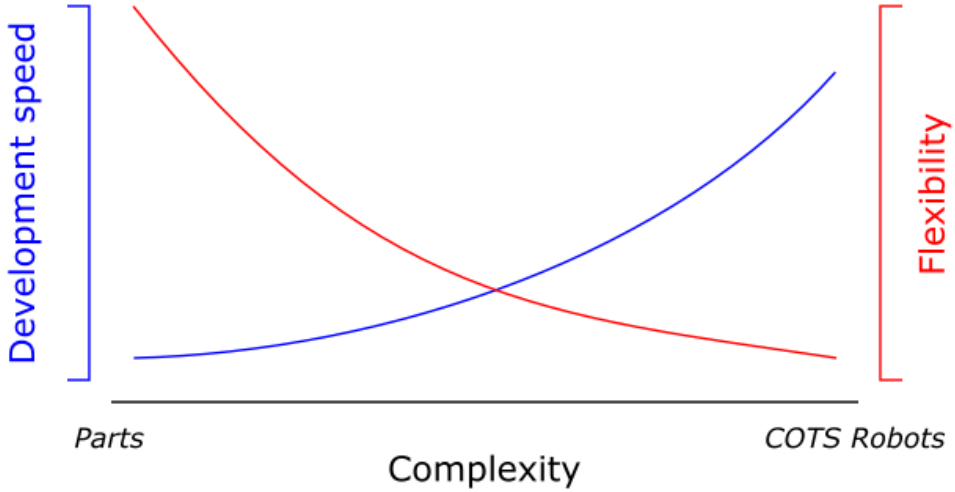
Co-Bots widen appeal, but are overkill for many tasks

Rethink Robotics' Baxter

Franka Emika's Franka

Franka manipulator arm performing a pick-and-place task

Currently, custom robots are essentially hard automation



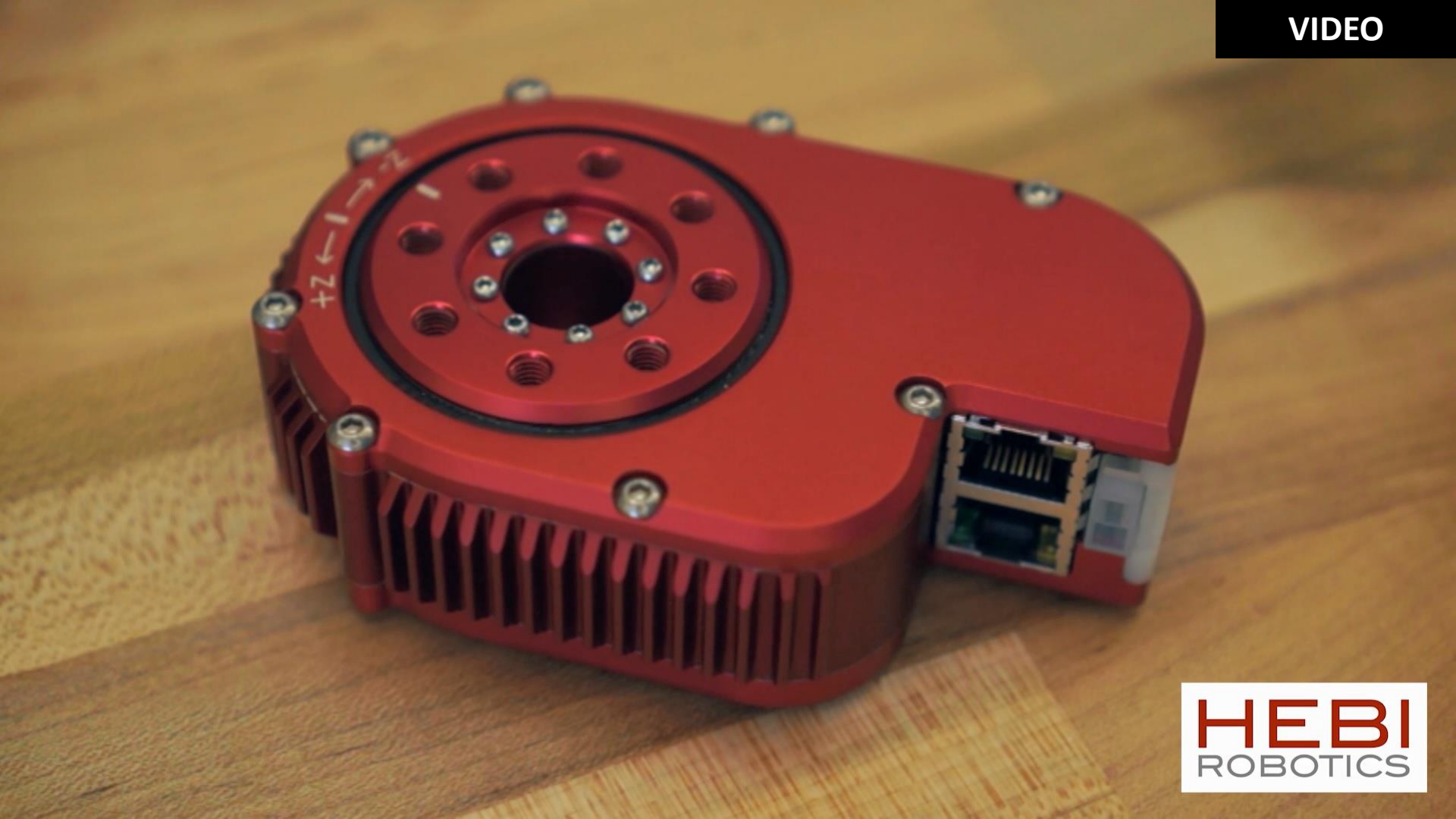
Trade-offs introduced by current starting points for automation options

Robots should capture benefits of all automation types + more

Hard Automation	Soft Automation	Flexible Automation
• Easy to use • High production rate • Low cost per produced unit	• Relatively fast development • Flexible w.r.t. variations • Suitable for batch production	• Fast development • “Infinite” flexibility • Make “anything”
• Slow development • High initial investment • Inflexible	• High investment into “general purpose” equipment • Relatively slow production rate	• High investment • High cost per produced unit • Relatively slow production rate

Modular robotic building blocks help fill this automation gap

- **Hard Automation:**
  - Custom robots with low number of “targeted degrees-of-freedom”
- **Soft Automation:**
  - Rapid development/deployment/integration
- **Flexible Mechanical Automation:**
  - Agile-inspired hardware development


VIDEO
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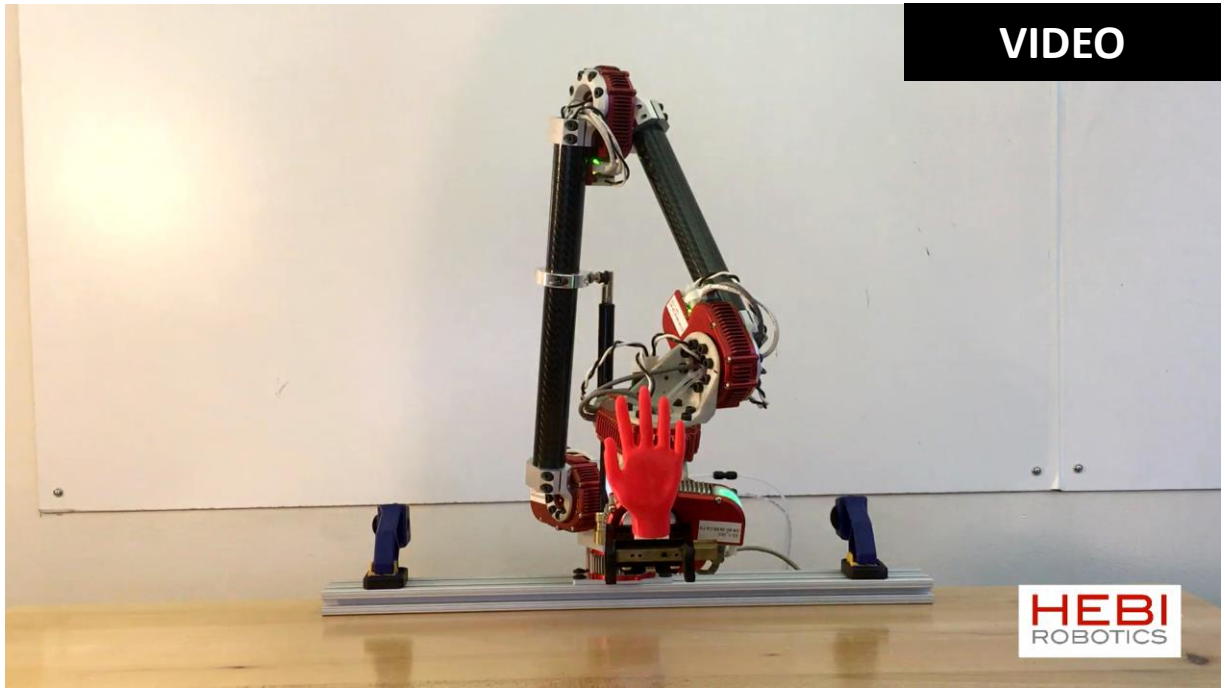
ROBOTICS

X-Series Industrial Smart Actuator

X-Series actuator

	X5-1	X5-4	X5-9
Dimensions	43 mm x 110 mm x 73 mm, 15 mm hollow bore		
Mass	315 g	335 g	360 g
Actuation	Peak torque: 2.5 Nm Cont. torque: 1.3 Nm Max speed: 95 rpm	Peak torque: 7 Nm Cont. torque: 4 Nm Max speed: 35 rpm	Peak torque: 13 Nm Cont. torque: 9 Nm Max speed: 15 rpm
Power	18-50 V DC Cont. current: 0.8 A @ 24 V Peak Current: 2.4 A @ 24 V		
Communication	1 kHz (100 Mbps Ethernet, dual port: Daisy-chainable)		
Sensing	Angular position (multi-turn absolute, +/- 4 turns) Angular velocity, Output torque 3-Axis accelerometer, 3-Axis gyro Temperature, Voltage, Current		
Angular resolution	0.005 deg		
Backlash	+/- 0.25 deg		
API Support	Matlab (Windows / Linux / OS X), Simulink (under consideration) ROS (Linux) C/C++ (Windows (planned) / Linux / OS X) Java (in development), Python (planned)		

On-demand custom robots in hours, not months



Twenty-four minute manipulator

Modular building blocks increase versatility, decrease cost

New task requires more reach

Bigger robot ($ >40K)
vs.
Change link ($ 40)

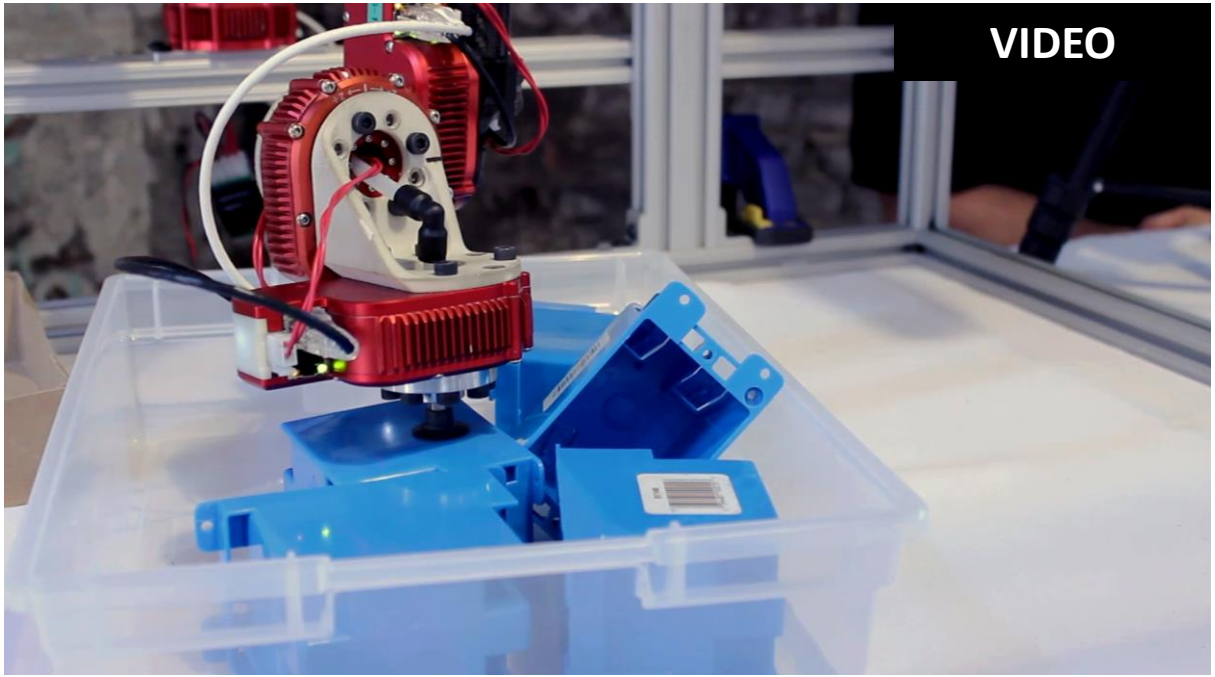
New task requires more payload

Bigger robot ($ >40K)
vs.
Gas spring assist ($ 15)

Automated button press

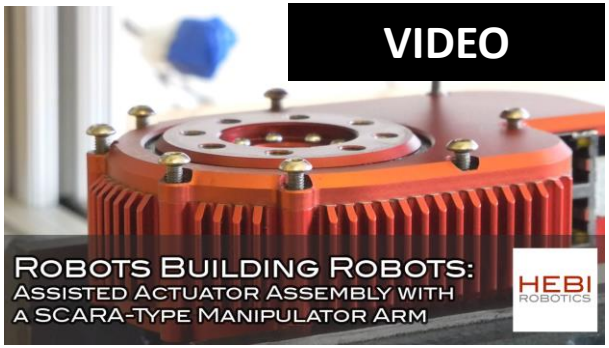
Arm w/ force sensor ($ 60K)
vs.
Targeted DoF ($ <5K)

Robust building blocks enable focus on high-level integration



Collaborative vision-based bin picking project

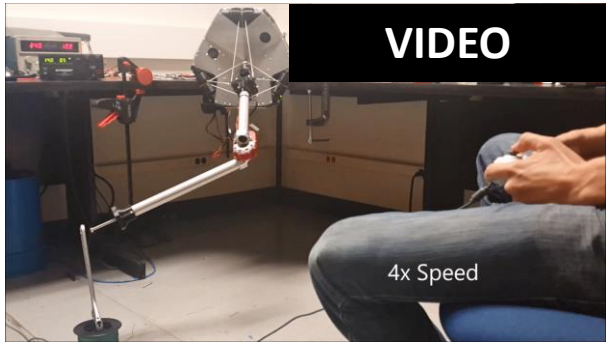
Versatility, decentralization enables automation of novel tasks



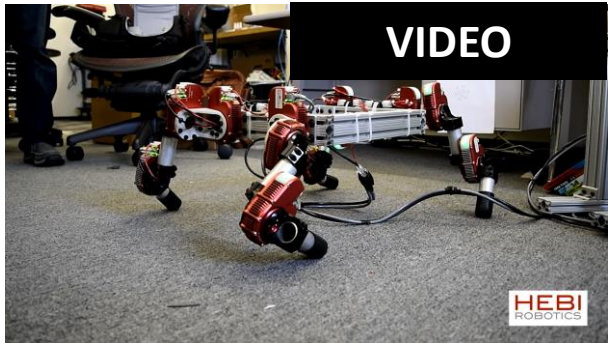
Collaborative actuator assembly

Autonomous plant stalk inspection

Tele-operated mobile base



Tensegrity-based manipulation



Legged robots

Modularity enables hands-on robot education

Carnegie Mellon University's 16-384: Robot Kinematics and Dynamics class

Conclusion

- **Takeaway 1:**
  - Modular robots enable customization and agile robot development
- **Takeaway 2:**
  - Robust robotic building blocks enable focus on high-level tasks
- **Takeaway 3:**
  - Modular robots allow targeted automation of diverse tasks

Modular robots decrease cost and increase appeal for automating new industries