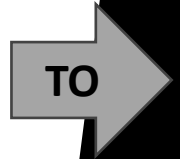


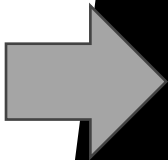
From
High-Dexterity
Tactile
Telerobots



General-Purpose
Robots with
Human-Like
Intelligence

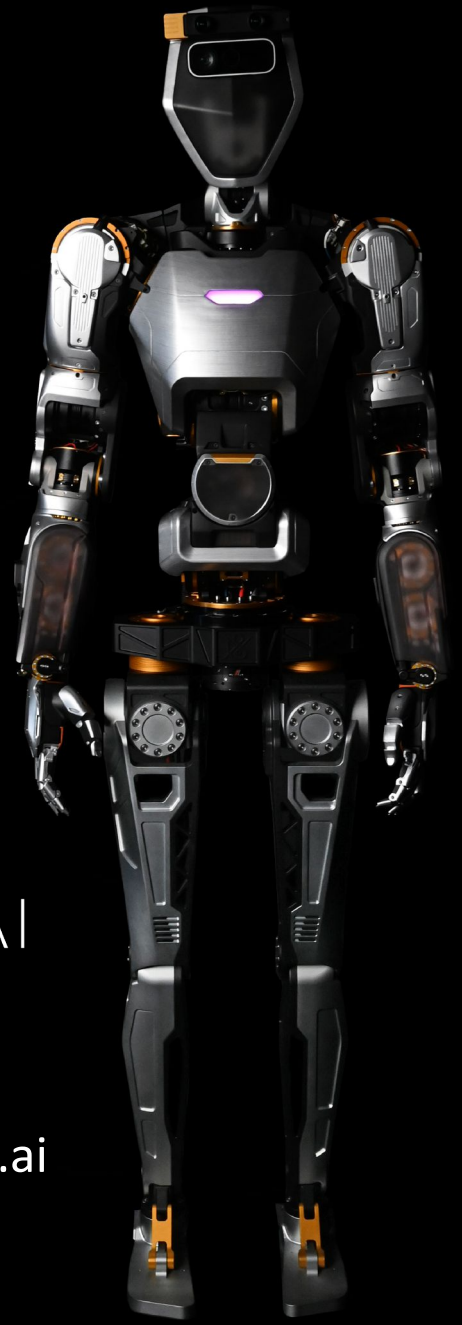
Jeremy Fishel, PhD

Founder
tangible
research



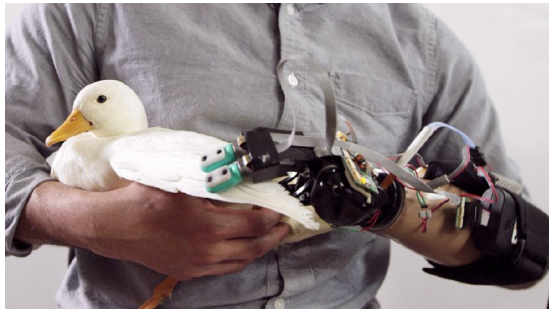
Principal Researcher
 **SANCTUARY AI**

jeremy.fishel@sanctuary.ai



How I got here...

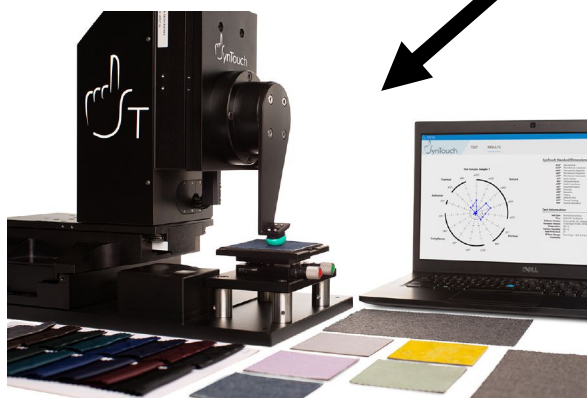
Tactile Reflexes



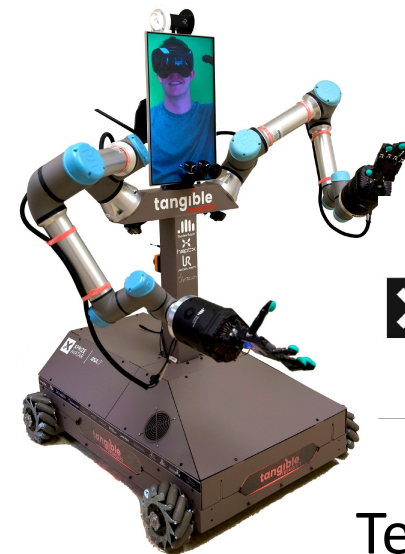
SynTouch

Telerobots?

No!



Haptic Perception



PRIZE | ANA

Telerobots?



SANCTUARY AI

Yes!

CONVERGE
ROBOTICS GROUP



Objective: Your hands. Anywhere. Safely.



Our Objective: Your hands. Anywhere.



Teleporting Skills

When an expert is needed (doctors, repair tech, etc.)

Dangerous or Inaccessible Environments

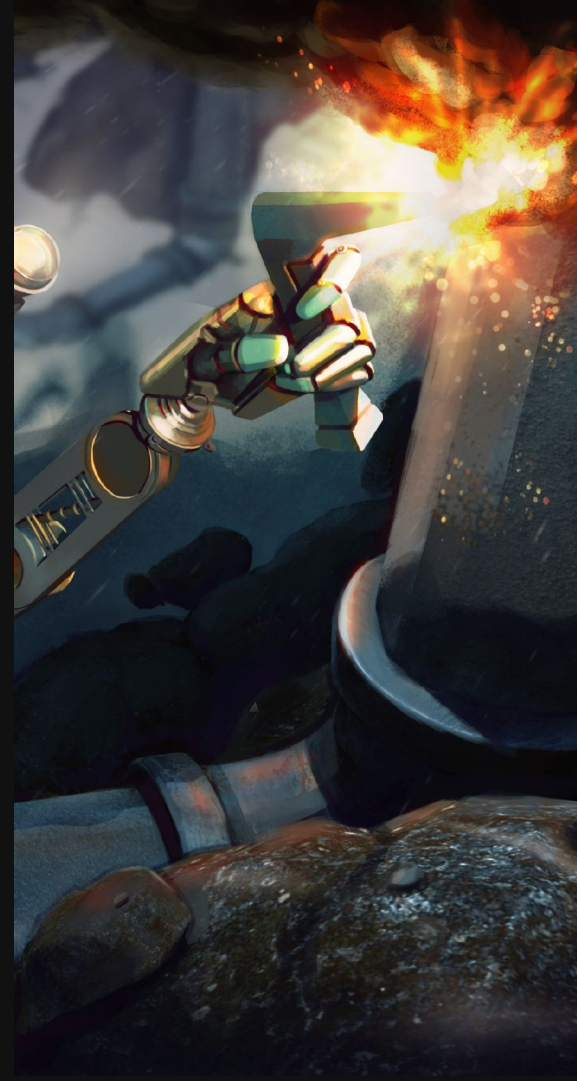
Space, deep sea, nuclear

Machine Learning

Teaching by demonstration to automate

Semi-Autonomy and Efficiency

One person, many telerobots



With Dexterous Transparency



Full Range of Motion Control

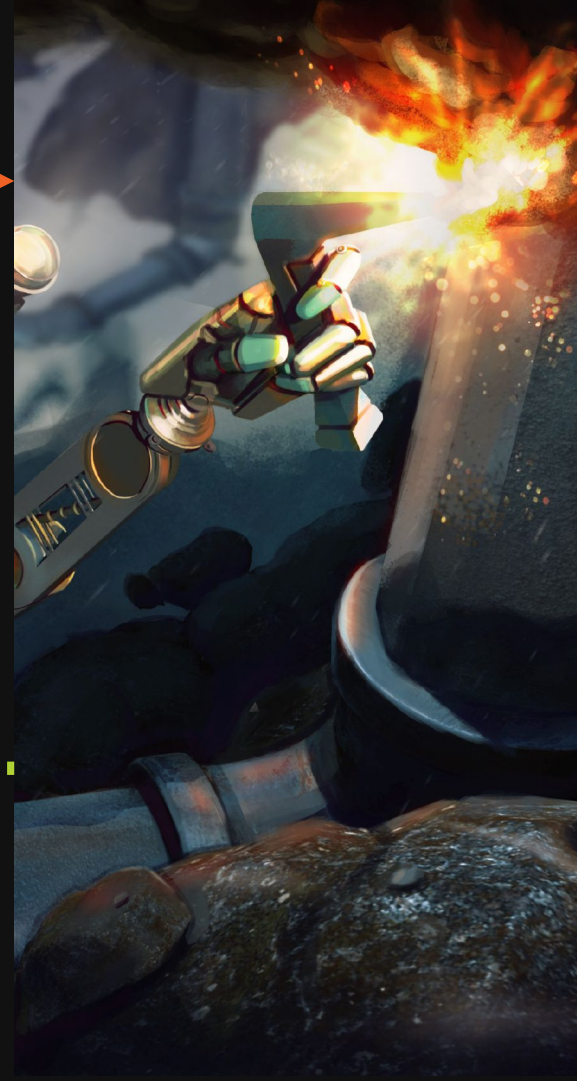
Arm+Wrist: 7 Degrees of Freedom

Hand: 22-23 Degrees of Freedom

These are Hard Problems

Complete Sensory Feedback

Vision, Sound, Force, Position, **Pressure,**
Vibration, Thermal, Pain



What Can We Do with Today's Hardware



Intelligence



Reflexes



Sight



Sound

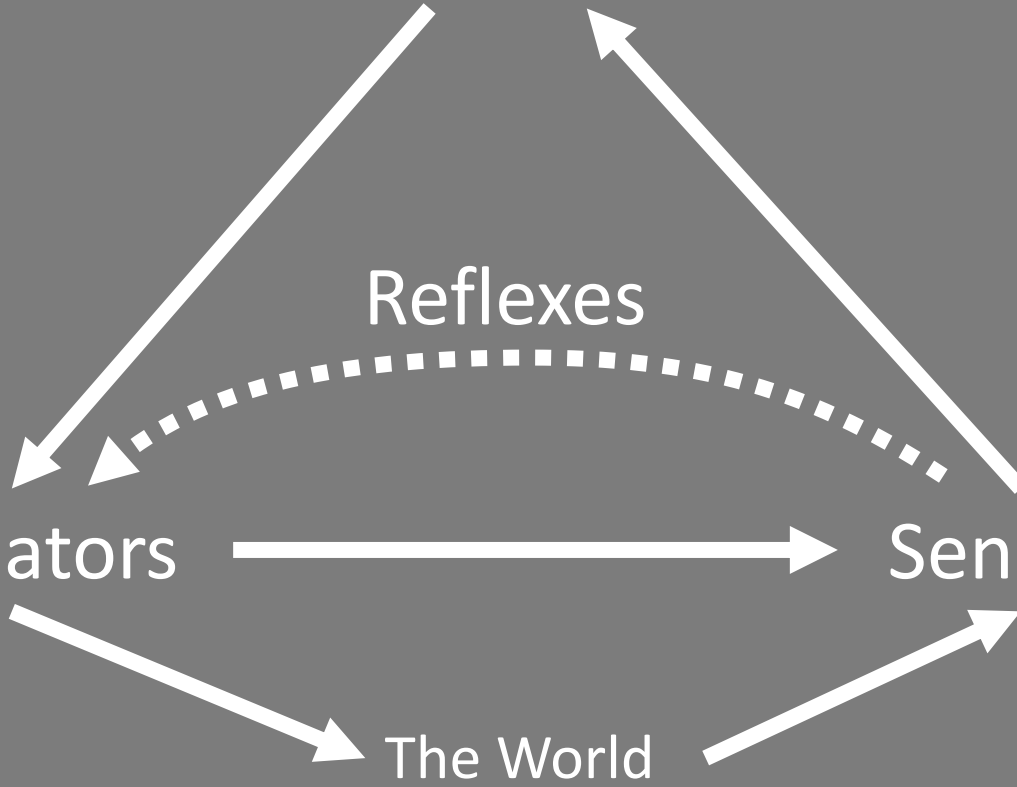


Touch

Actuators

Sensors

The World



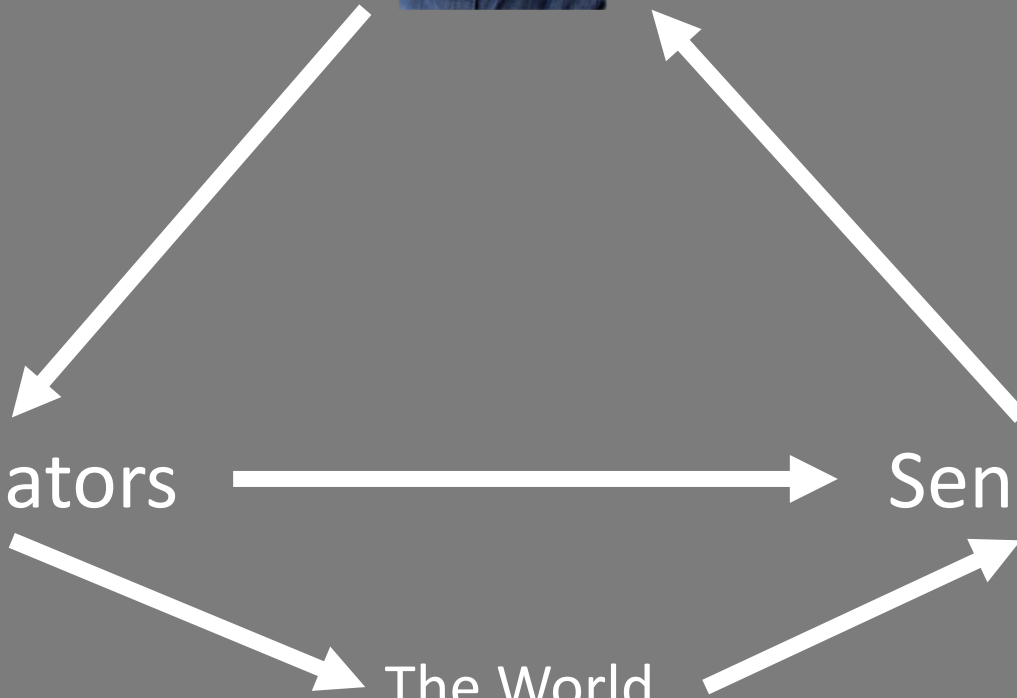
Intelligence



Actuators

Sensors

The World



The BioTac

Fingernail
(To Hold Skin
In Place)

Elastomeric
Skin

Thermistor

Incompressible
Conductive Fluid

Impedance Sensing
Electrodes

Hydro-Acoustic
Pressure Sensor
(Hydrophone)

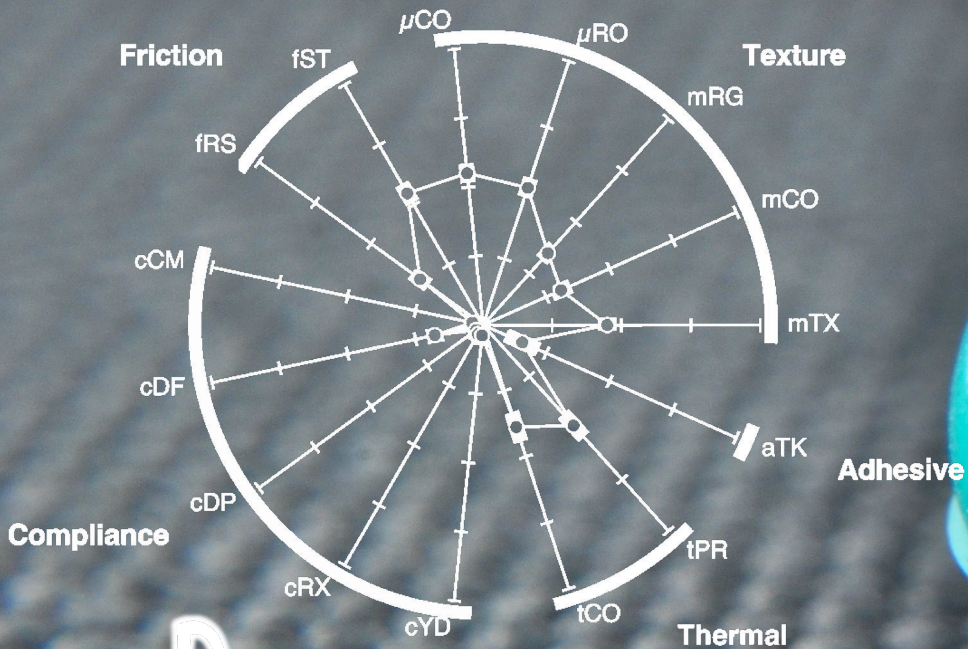
Rigid Core




Resolves forces and point of contact in three dimensions
Detects micro-vibrations for slip and object texture discrimination
Characterizes objects thermally by heat transfer properties

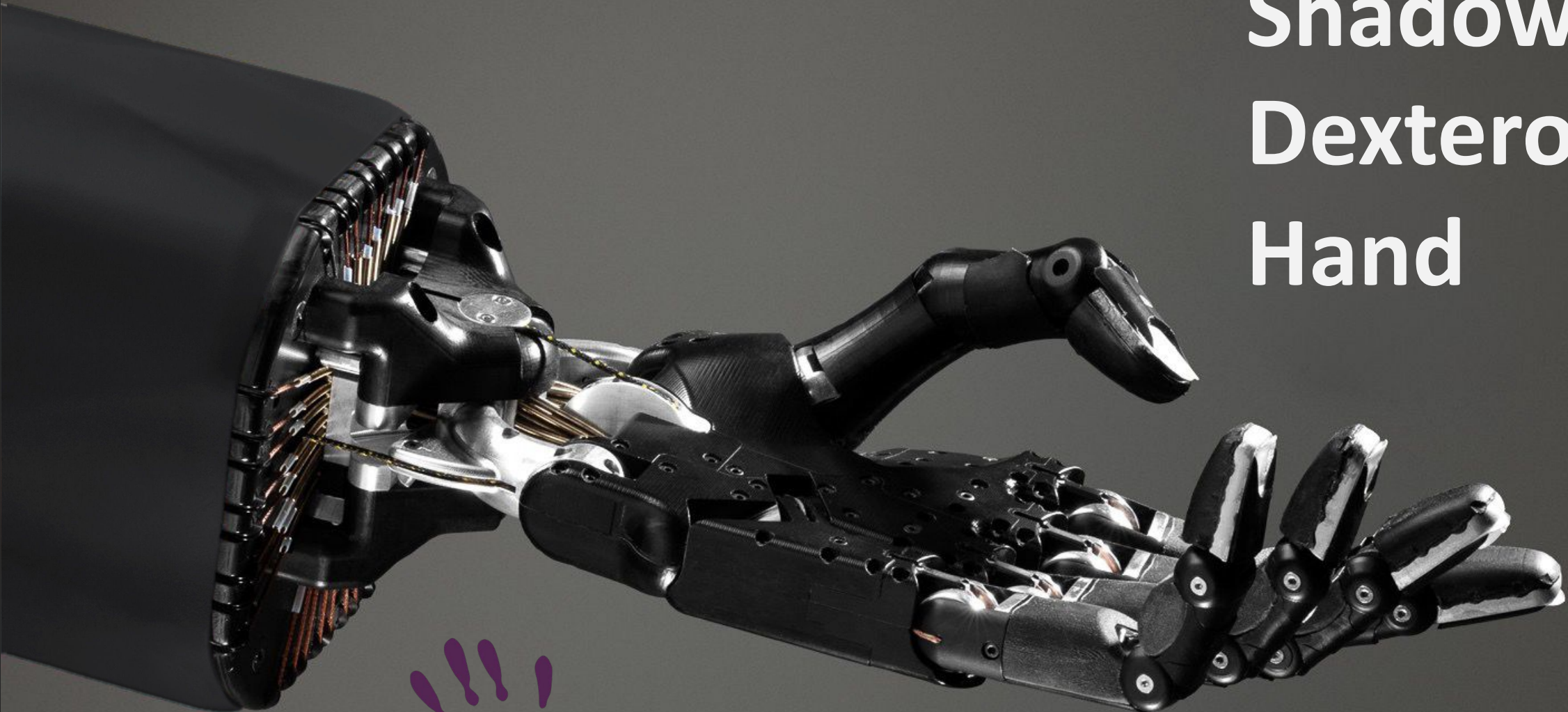
Robust: Easily replaced skin with no electronics

Quantifying Touch Better than Humans



 SynTouch

Shadow Dexterous Hand

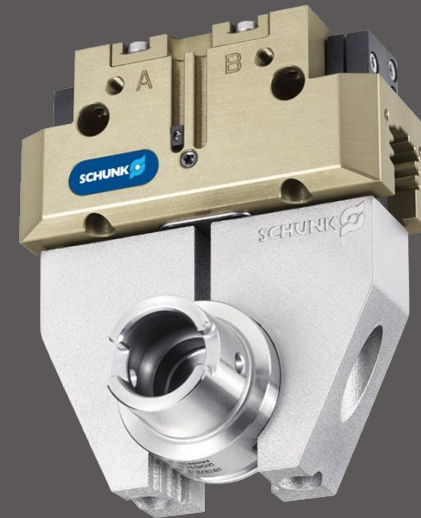
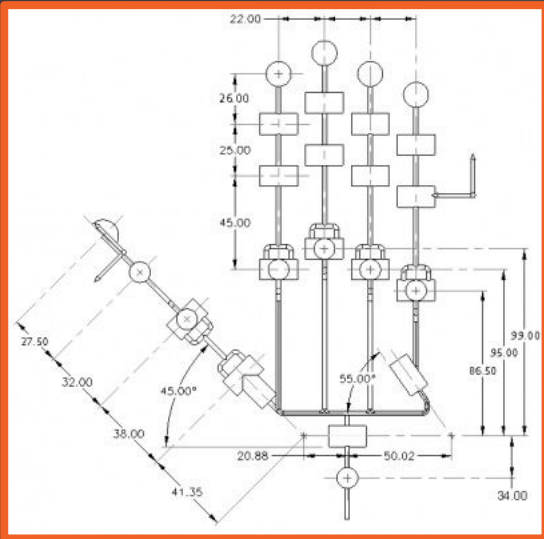
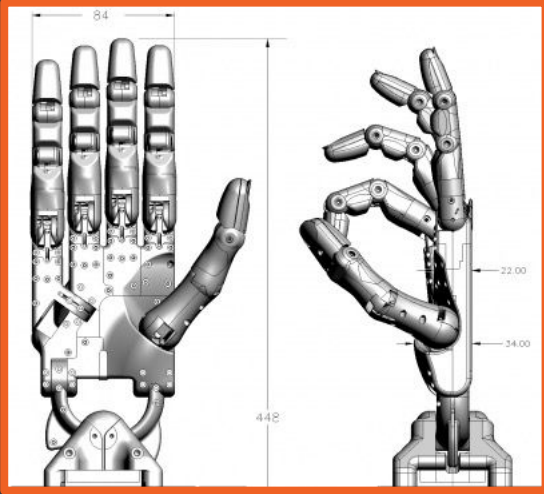


Anthropomorphic

Human Hand Size and Kinematics

20 Actuated DOF

4 Underactuated DOF



Why don't we use something simple?

Lots of Parts = Lots of Grippers

Sensor Integration

- Position sensing at each Joint (24)
- Motor Current and Temperature at each Actuator (20)
- Strain Gauges at each Tendon (40)
- Tactile Sensor Integration
- 26 Microcontrollers
- 2 CANBus Interface
- 1 EtherCAT Interface
- 1kHz Bandwidth

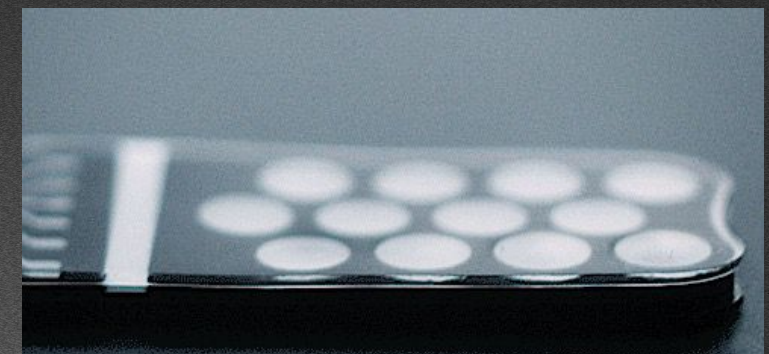
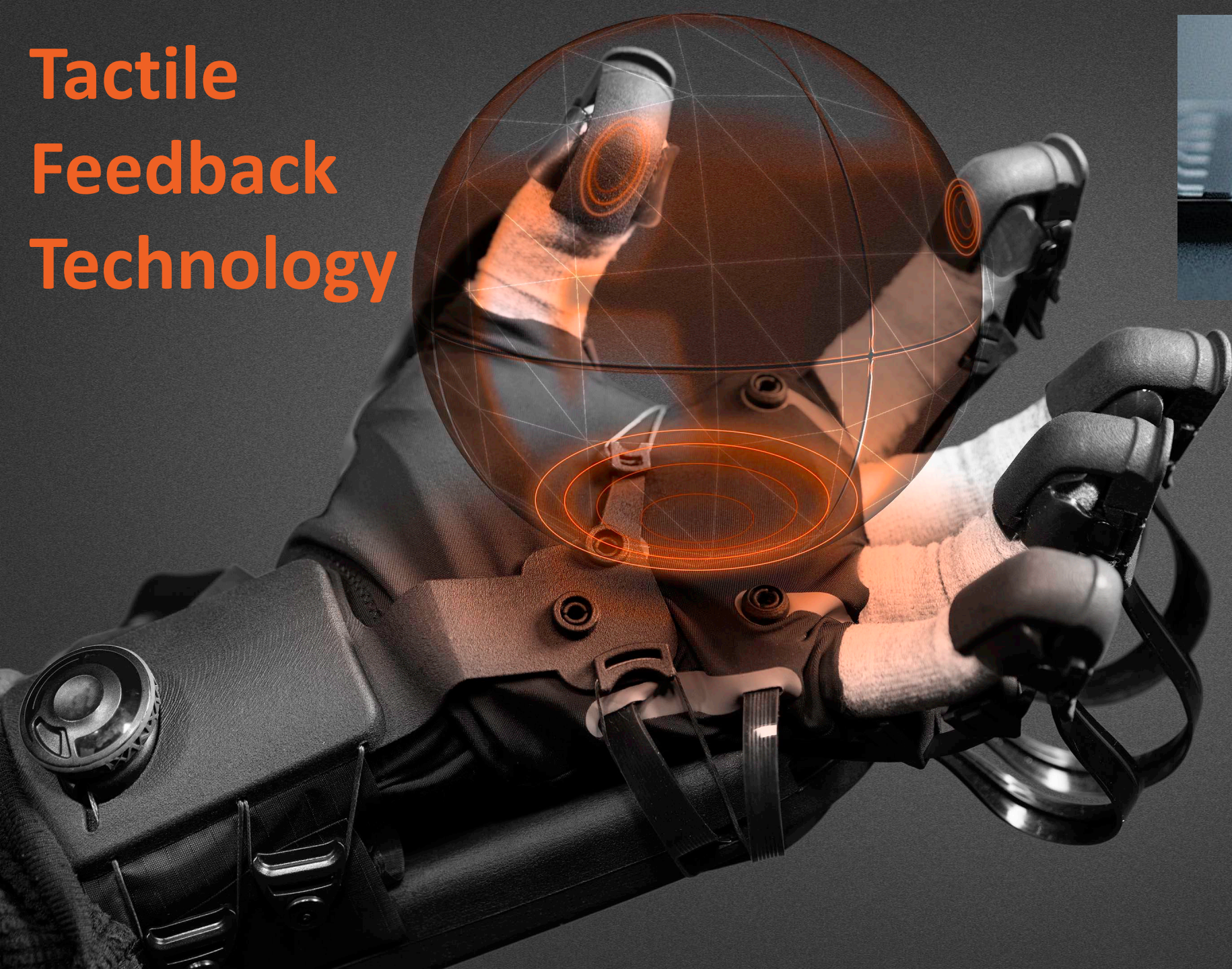




Haptic Gloves



Tactile Feedback Technology

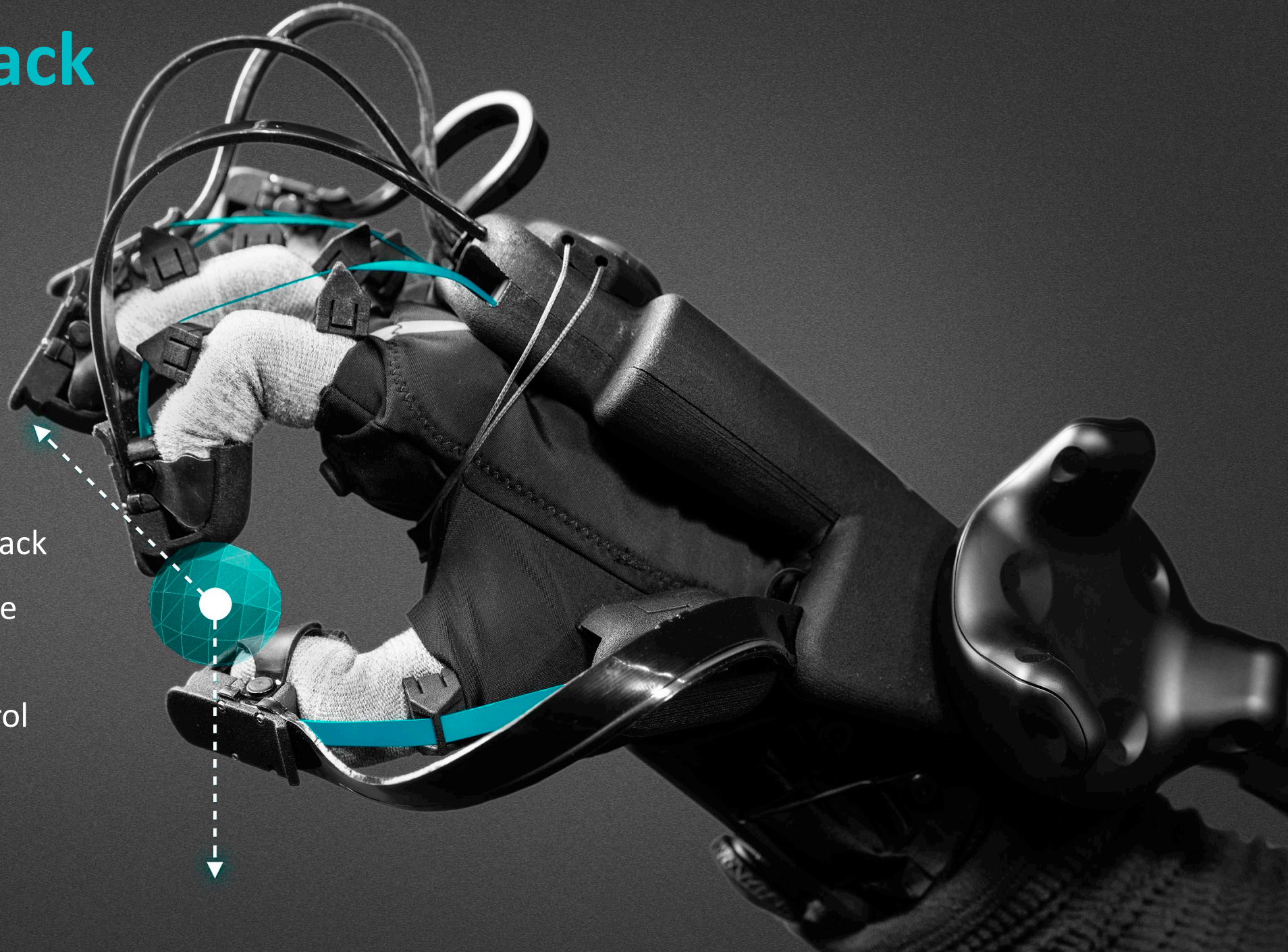


Microfluidic Silicone Skin

- 130 independently controlled points of contact over fingers and palm
- Displacement up to 2mm
- No perceivable latency
- Up to 200Hz Frequency Response
- Customizable for other regions of the body

Force Feedback Technology

- Low-profile tendon admittance force feedback
- Up to 18N resistive force feedback per digit
- Variable or binary control

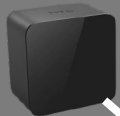


Magnetic Motion Tracking

- 6 degree-of-freedom motion tracking on each digit
- Sub-millimeter precision
- Occlusion-free motion tracking



HTC Vive Towers and Trackers



HaptX Gloves



For details:

Fishel et al., Tactile Telerobots for Dull, Dirty, Dangerous, and Inaccessible Tasks, ICRA 2020

Shadow Dexterous Hand



Motion Capture and Control

Tactile Mapping

Actuators

Sensor Integration

Sensors



UR10 Robot Arms

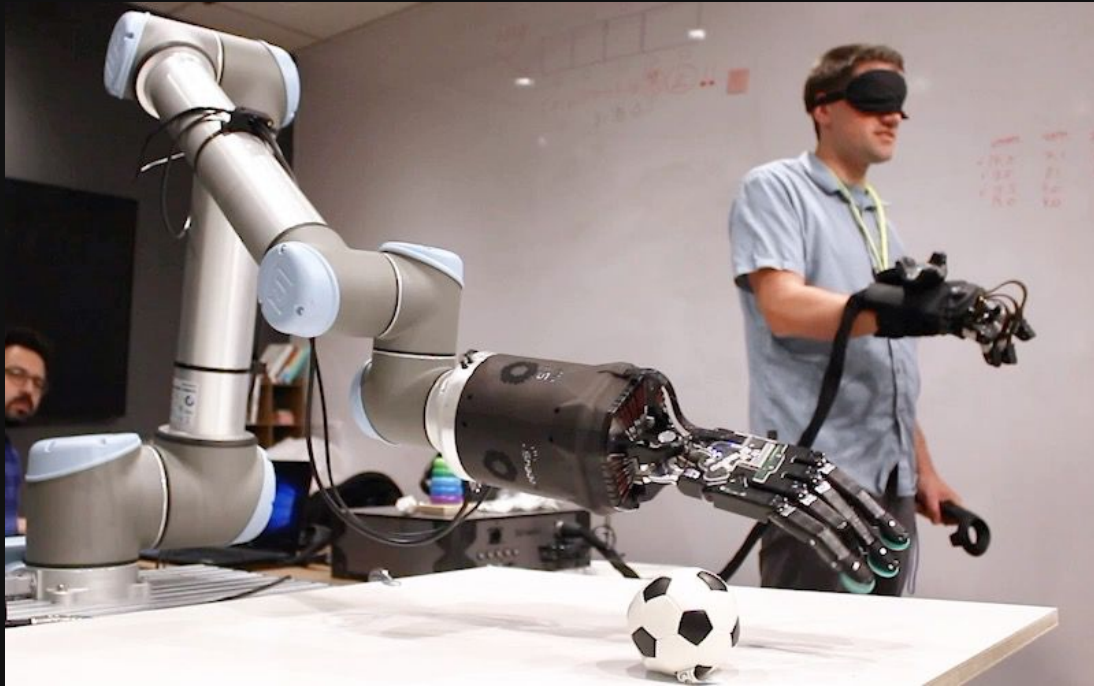
SynTouch Sensors



International Collaboration



Tactile Telerobot



Full Control of Arm, Hand and Fingertips

High-Resolution Tactile Feedback in Each Fingertip

Force Feedback on Each Fingertip



A Famous Astronaut...



“The Tactile Feedback is Tremendous”

Press

WIRED BACKCHANNEL BUSINESS CULTURE MORE SIGN IN

MATT SIMON SCIENCE MAR 1, 2019 8:00 AM

How I Became a Robot in London— From 5,000 Miles Away

Wearing a haptic feedback glove, I pilot a robotic hand from across the world, feeling what it feels. The sensation is almost too weird to be real.

IEEE Spectrum

Type to search

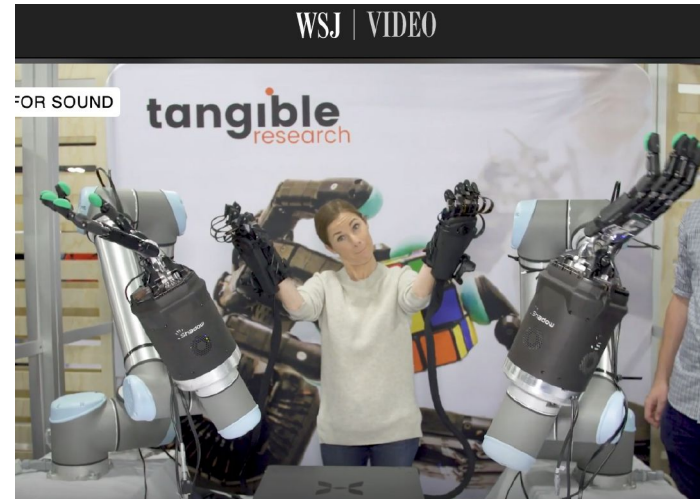
NEWS ROBOTICS

Converge Robotics Group Commercializing Immersive Telepresence > This is one of the most advanced teleoperated robots we've ever seen

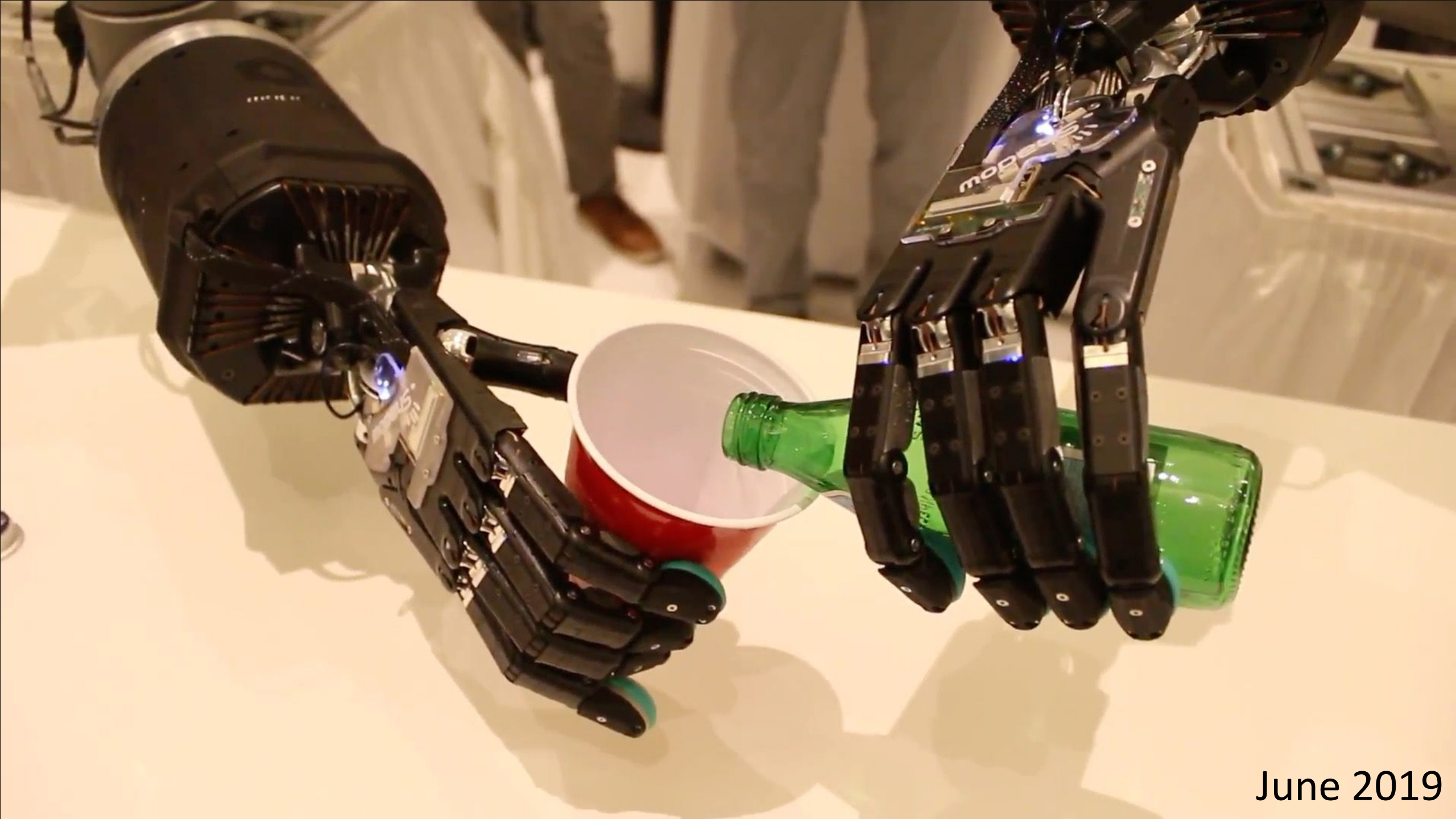
CONVERGE
ROBOTICS GROUP



Forbes Hands-On With The Tactile Telerobot At The Festo Experience Center



Adam Savage's Tested

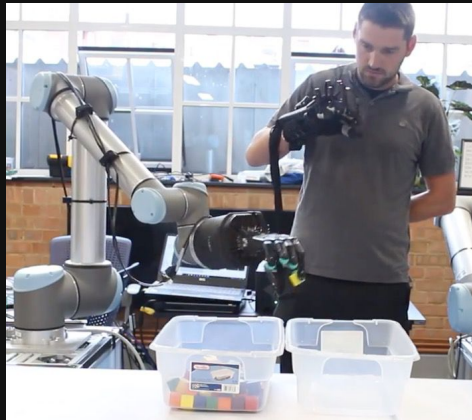


June 2019

Unimanual Performance Evaluation

Comparing performance between telerobot and direct manipulation (i.e. bare hand)

YCB Benchmarks:



Box and Blocks Test



Table-Setting

**Other benchmarks
discussed in paper:**

Peg Insertion
Pitcher-Mug

YCB Benchmark:

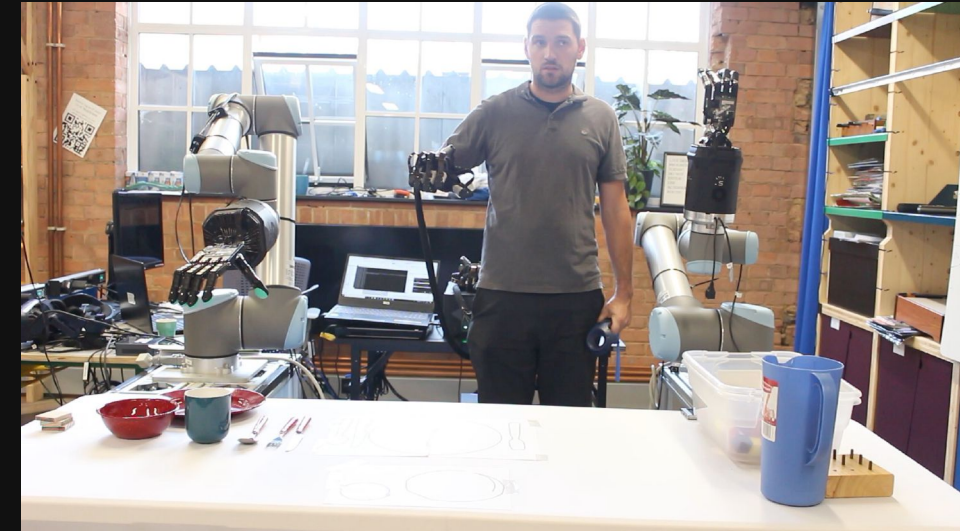
For details:

Fishel et al., Tactile Telerobots for Dull, Dirty, Dangerous, and Inaccessible Tasks, ICRA 2020

Box and Blocks Test



Table-Setting



Task Summary:

Move as many blocks as possible in 1m (blocks randomly placed in container)

Set a table by moving objects from starting position to final position

Direct Manipulation:

87.3 blocks/min

10.75s

Telerobot:

19.0 blocks/min

129.87s

Task Efficiency:

21.75%

8.28%

Performance degraded by task complexity (picking vs. pick and place) Telerobot 4.5x to 12x slower than direct (human) manipulation

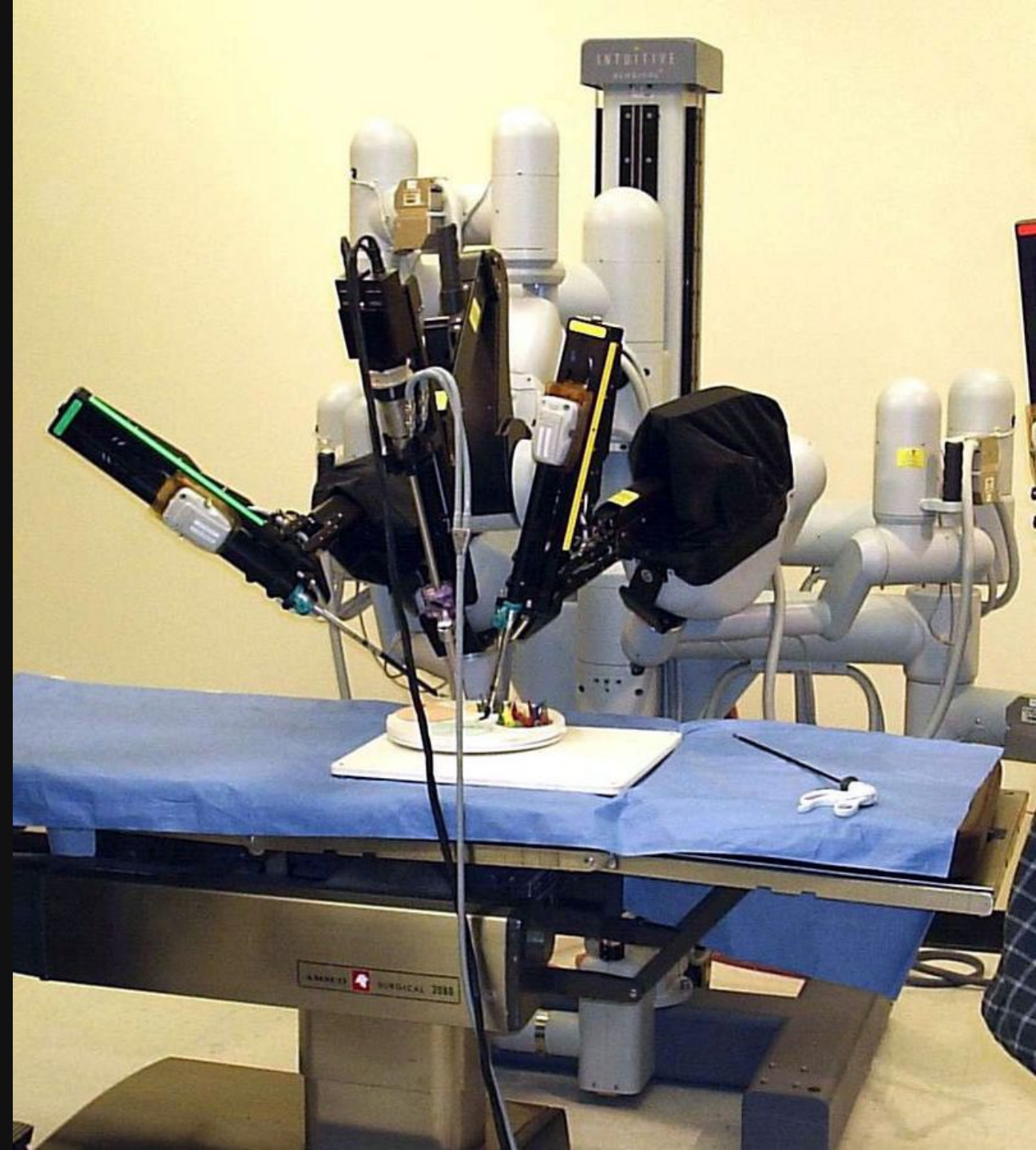
But wait, what about Surgical Robots?

Do not need touch

A lot of training and experience can create a “mind’s eye” for touch

Requires a lot of preparation and planning for each task

Slow task execution and visual re-planning instead of tactile dexterity



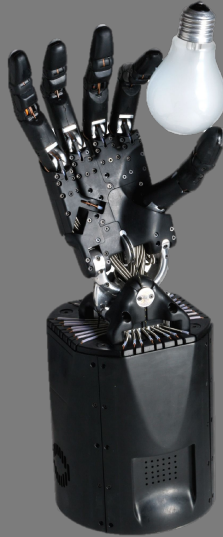
Intelligence

- Best AI Around
- Decades of Training Data



Output

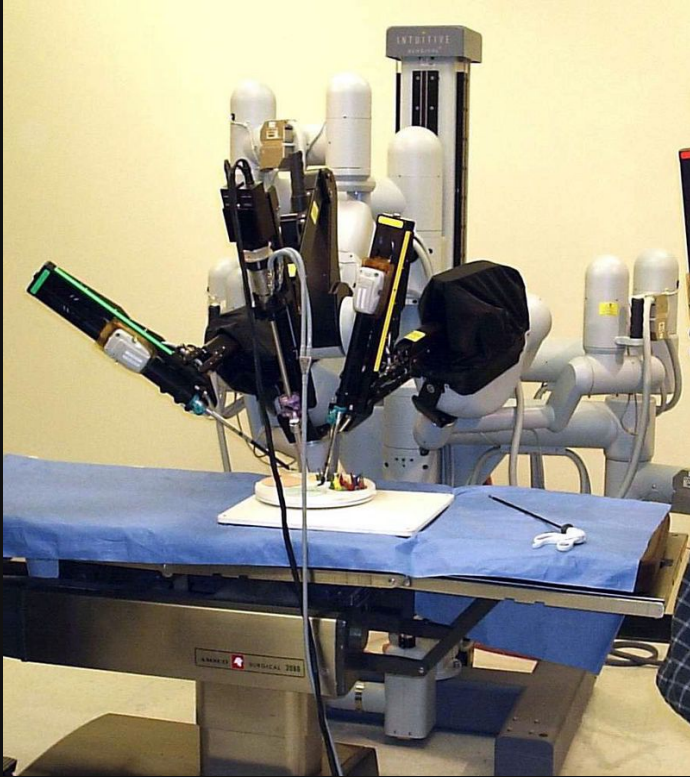
Input



Especially Touch



Telerobots Without Touch



Training + Preparation Time + Careful
and Slow = Expensive

Only makes sense for very dangerous
and inaccessible tasks

Telerobots With Touch



Intuitive + Natural

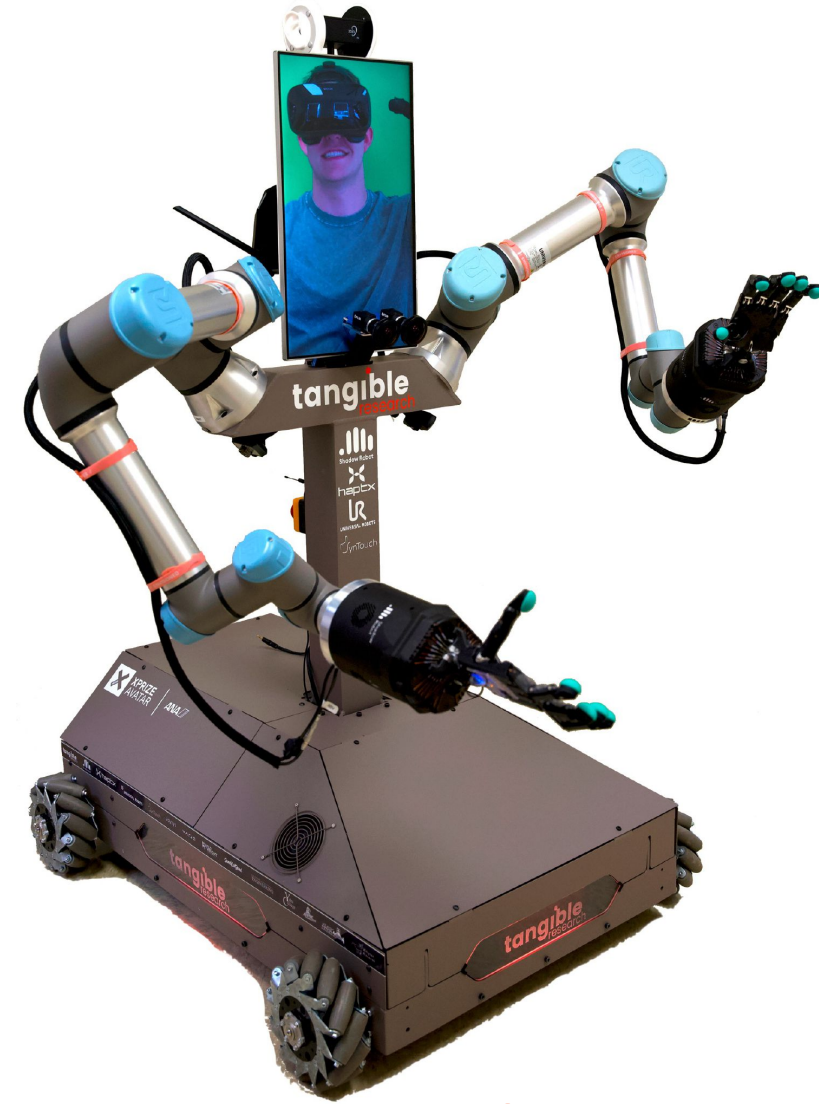
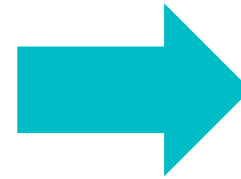
Human intelligence and dexterity
infused with robotics

Lessons Learned

- Touch is critical for manipulation and perception
- Most tasks are still possible with vision alone BUT touch makes difficult tasks easy and intuitive
- A wide range of industries applications can benefit from high-dexterity telemanipulation. We need to continue to advance this field!



XPRIZE System Development

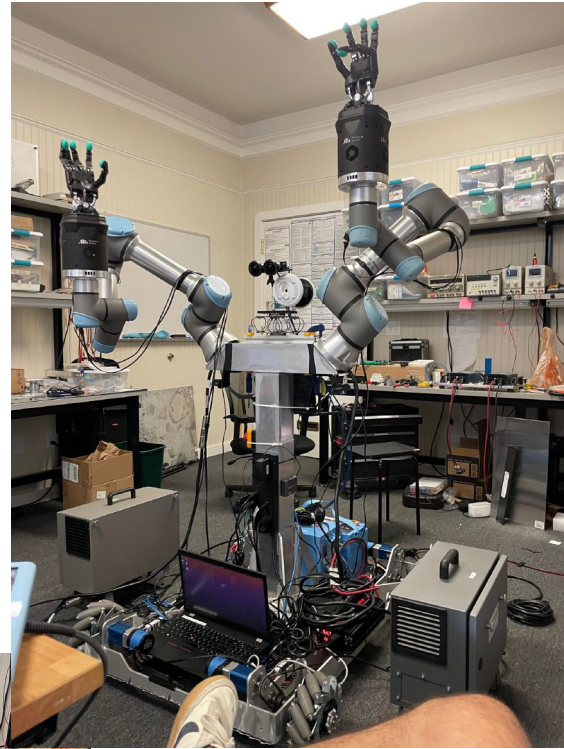
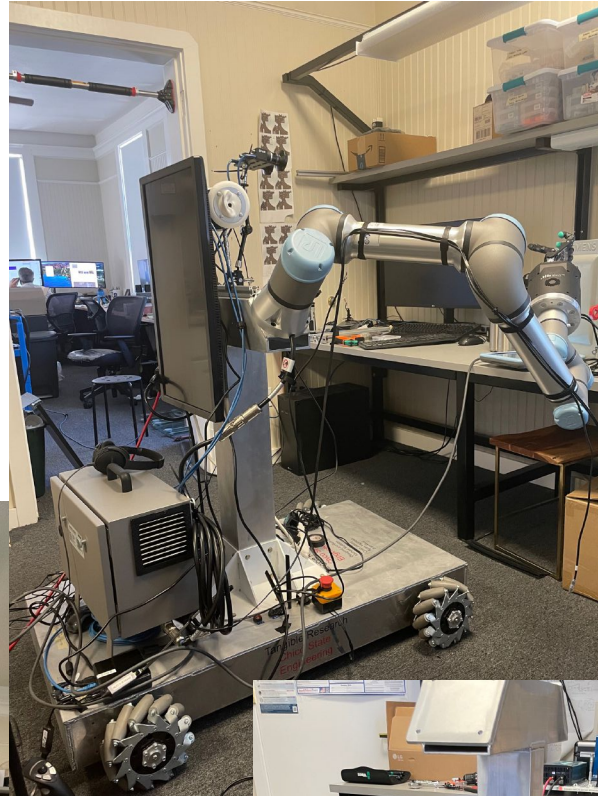


tangible
research

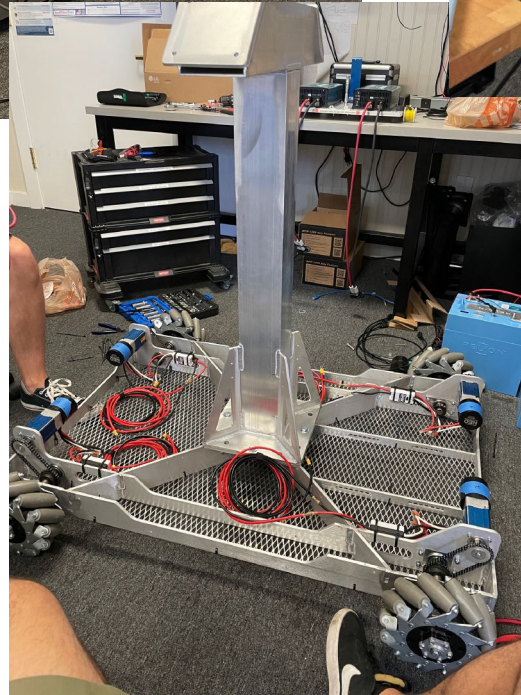
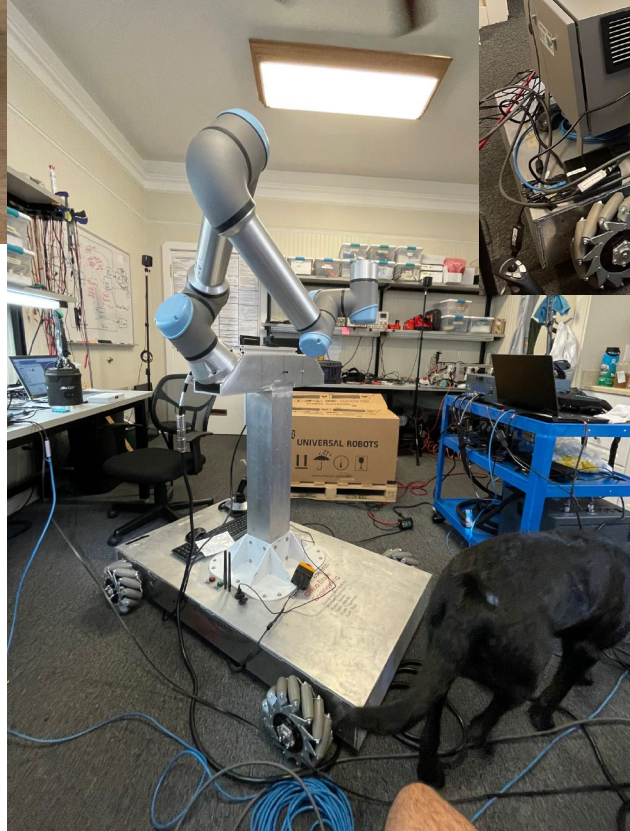
Rapid R&D



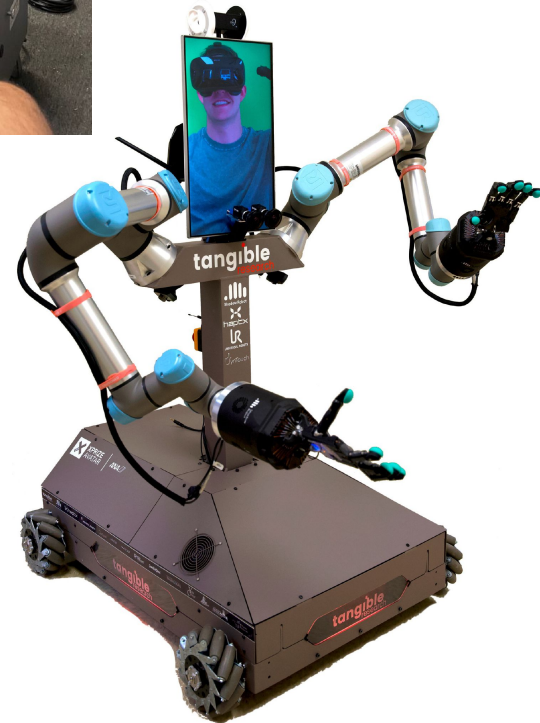
September



August



October




XPRIZE Developments

- Changed from UR10 to UR5 arms in new mounting orientation
- Detailed stability optimization for difficult competition restrictions
- Rebuilt custom lightweight mobile base and electronics housings
- Full electrical conversions of all components to run on batteries
- Extensive UI improvements to allow seamless operator control
- Several software improvements for singularity avoidance, improved AV, tactile perception enhancements, usability, etc.
- July: Design, Aug-Oct: Build and Test... pretty much a 4-month hackathon.

Finals: Cable Came Loose!

XPRIZE AVATAR ANA



RANK TEAM

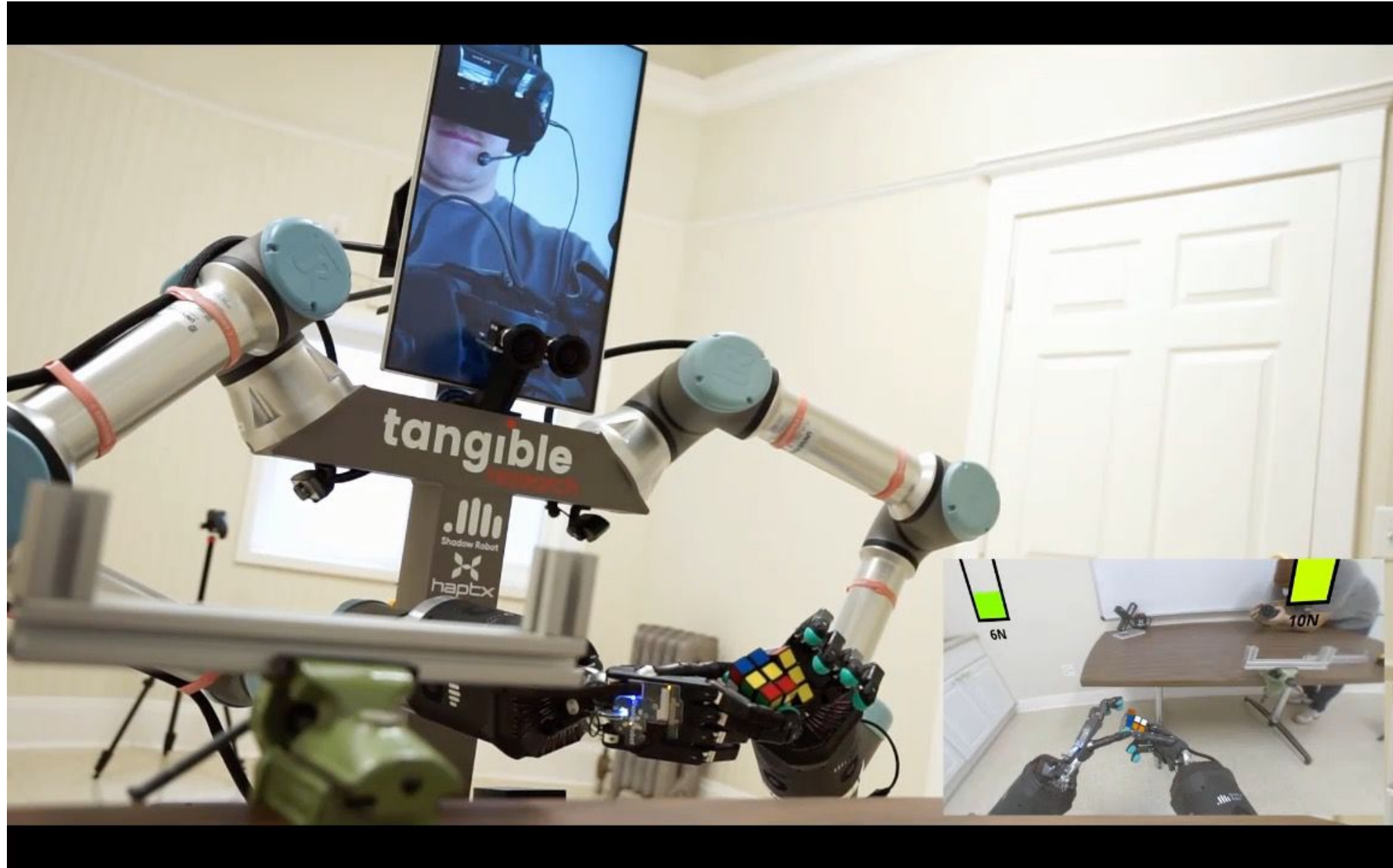
RANK	TEAM	TIME ON COURSE	TASK	POINTS JUDGED	TOTAL	LEADER STATS TO BEAT
13	TANGIBLE	05:45	3	0	3	13:20 14.5

So Many People to Thank:



Giuseppe Barbieri, Dane Barland, Joe Bauer, Georgia Blanco-Litchfield, Peter Botticelli, Gavin Cassidy, Chico SAE Baja Team, Jacopo Chiodi, Will Cortez, Rosie Curcio, Armando De La Rosa, Kirsty Dessin, Ray Dolan, Micheal Eichermueller, Hugo Elias, Jeremy Fishel, Emily Fishel, Linda and Teddy Fishel, Randy and Jenifer Fishel, Ed Foley, Ethan Fowler, Akira Fukabori, Matthew Godden, Daniel Greenwald, Jacob Grout, Radhika Gudipati, Alex Haduong, Toivo Hartikainen, Nate Hilal, Bobby Jones, Ivory Jones, Kevin Kajitani, Monika Koper, Michal Kramarczyk, Jyoti Kumar, Juan Laforga, Denise Lalonde, Beatriz León, Christy Levine, Joe Marino, Blaine Matulevich, Joe Michaels, Andrew Mitrak, Annagiulia Morachioli, Luke Moss, Kelsey Muller, Gabor Nanai, Kim Oberg, Toni Oliver, Fotis Papadopoulos, Andrew Pether, Andriy Petlovanyy, Joanna Phillips, Charlie Pooler, Jenna Prieger, Tom Queen, Caleb Rabbon, Neil and Debbie Ragsdale, Sherrine Ricketts, Bodin Rojanachaichanin, Kacper Rozanski, Jake Rubin, Dirck Sauer, Penny Scully, Rune Søre-Knudsen, Ben Starmer-Smith, Dan Turner, Roberto Valdivieso, Rich Walker, Blake Wentz, Jimmie Whitton, Alex Winning, Ian Wright, and Max Zieba.

What we wished we could have shown at XPRIZE



tangible
research



SANCTUARY AI

- Acquired by Sanctuary AI in March of 2023
- Sanctuary AI is doing a lot of exciting work in this space and shares Tangible's perspective on the challenges and opportunities.



SANCTUARY AI

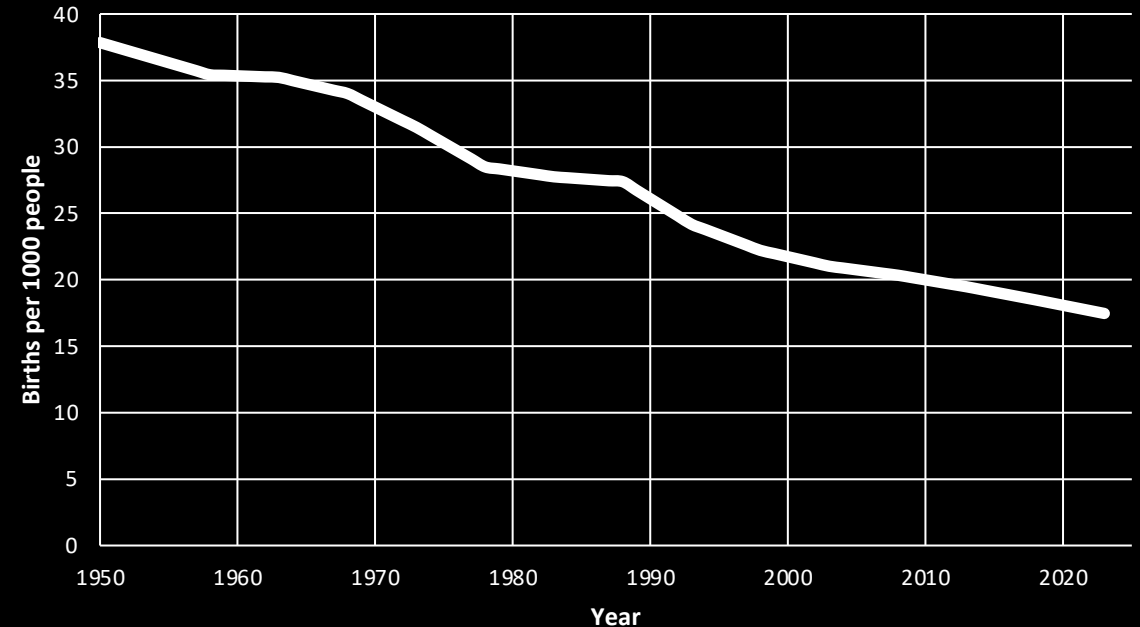
General Purpose Robots with
Human-Like Intelligence

Problem: We're going to run out of workers!

- Birth rates are declining
- People are living longer
- A larger percentage of the population is going to be retired
- There are a growing number of jobs people don't want to do *AND* fewer people to do them!

- None of the above are easy to solve, but we will have major problems in the future if we don't solve them.

Birth Rates per 1000 People Worldwide



Could
Automate
Jobs 1-by-1

or, General-
Purpose Robots
with Human-Like
Intelligence!

The Elephant in the Room



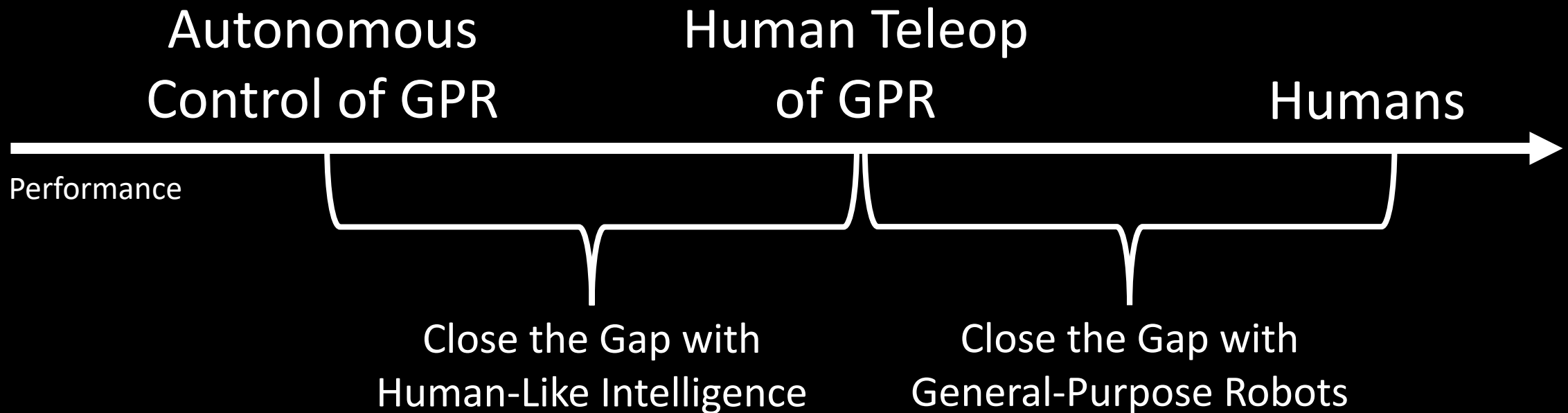
- **General Purpose** because we want a single piece of hardware that can do MOST things people can do (economies of scale, automation confidence, repurposing).
- **Human-Like Intelligence** (and human-like robotics) because they are a good design to borrow from, nothing else comes close to general purpose or human ability.

These are both incredibly difficult problems, we know.

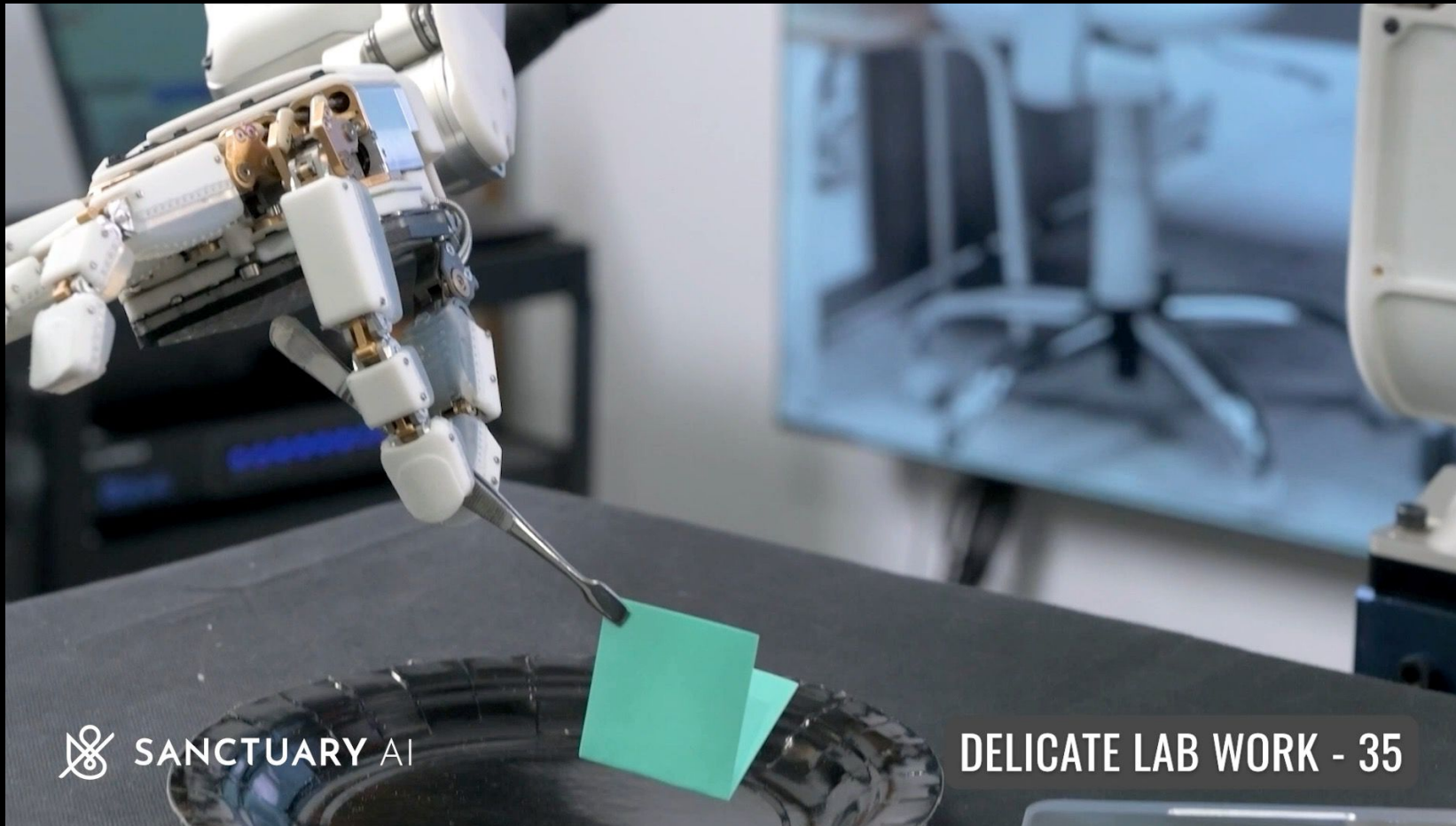
If talking about this makes your blood boil, this isn't a talk for you... sorry.

Sanctuary AI: Labor as a Service!

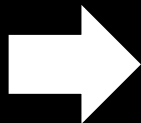
- Sanctuary AI does not sell robots, it sells work
- Fairly sophisticated “Workflow Process” to go from humans doing work to general-purpose robots doing work with human-like intelligence



Not a Sim, Our Robots Exist and Do Work Today!



Watch
Online!

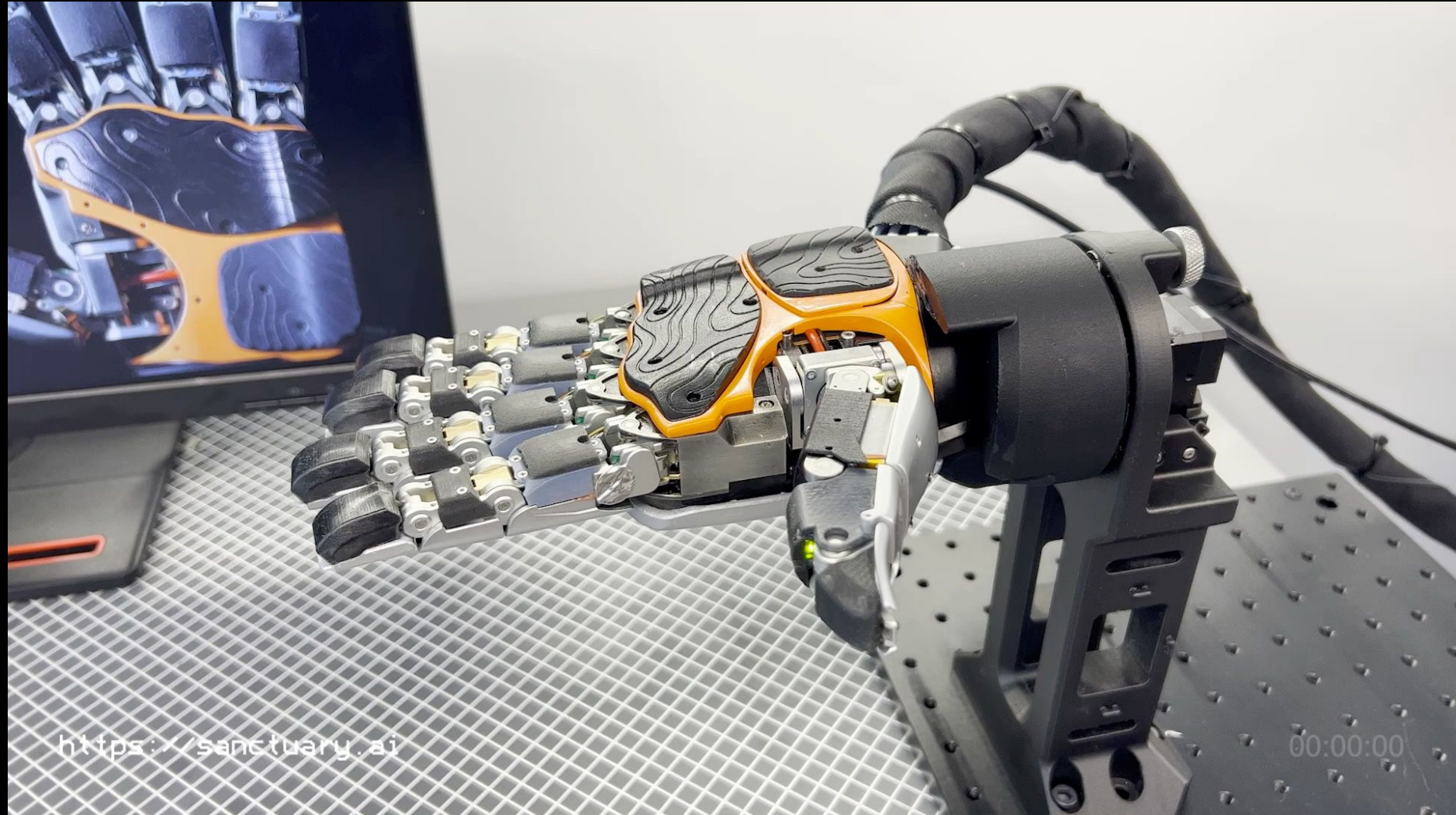


Sanctuary AI YouTube Channel: Robots Doing Stuff

https://www.youtube.com/playlist?list=PL72YzASch66WDlpqCZ_klaUBBwAPp11NT

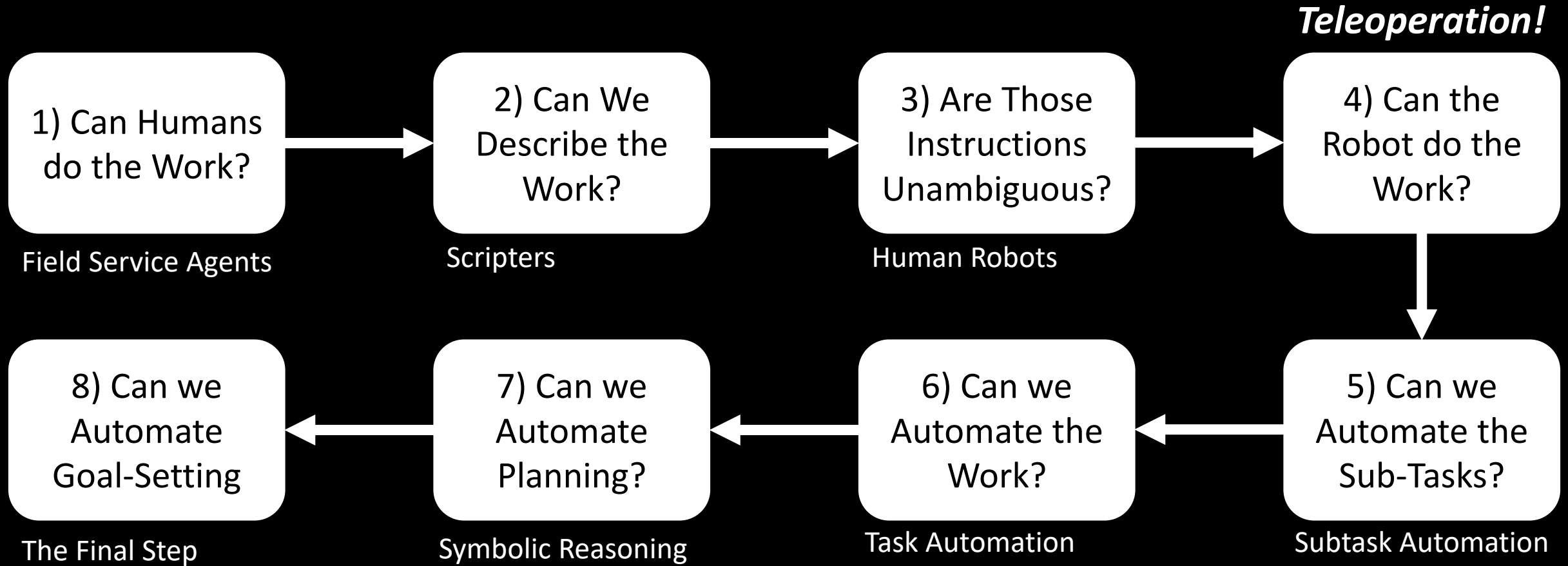
Hands First: Sanctuary Phoenix Hands v3

- 19 DOF:
 - 3 per finger
 - 5 thumb
 - 2 wrist
- Miniature Hydraulics
- Designed to Achieve all Grasps in the “Grasp Taxonomy”

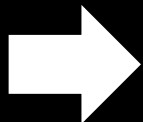


SAI Workflow Process

- *Cannot get "ChatGPT-quantity" of training data*
- *More deliberate process, changing one thing at a time*



More
Info



Sanctuary AI Ground Truth Podcast

The Future of Work and the Workflow Process | Episode 3

<https://www.youtube.com/watch?v=7QjFY763Shw>

Introducing Phoenix



Carbon™ human-like
general intelligence

human-like
full body mobility

max payload
of 25 kg / 55 lbs

human-like hands
with fine dexterity

max speed of
5 kph / 3 mph

Height 170 cm / 5 ft 7 in

Weight 70 kg / 155 lbs

*Final production specifications may vary

gen.
6

Join Our Team



Open Full-Time Engineering Roles:

- **Distinguished Technologist***
- **AI & Cognitive Platforms***
- Path/Motion Planning
- Machine Learning
- Reinforcement Learning
- Robotics Optimization
- Real-time Controls
- Systems Integration
- 3D Motion Designer
- Mechanical Design, Bipedal
- Research & Development
- Simulation
- Web Services
- ... and more!

Co-Ops / Internships:

- Electronics Engineering
- AI / Automation
- Systems Integration
- Firmware Engineering
- Controls
- Cognitive Services
- Mechanical Engineering
- Machine Learning
- Research & Development



Industrial and Academic Partnerships Too!



<https://sanctuary.ai/careers>

Thank You!