# Introduction to Robotics Manipulation

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BE BOUNDLESS

# Today

Things to cover for today's class:

- **What do I mean by "Manipulation"? (with examples)**
- **Anatomy of a manipulation system.**
- **Understand your robot arm**
- **Live demo (Gravity Compensation)**

# Matt Mason says

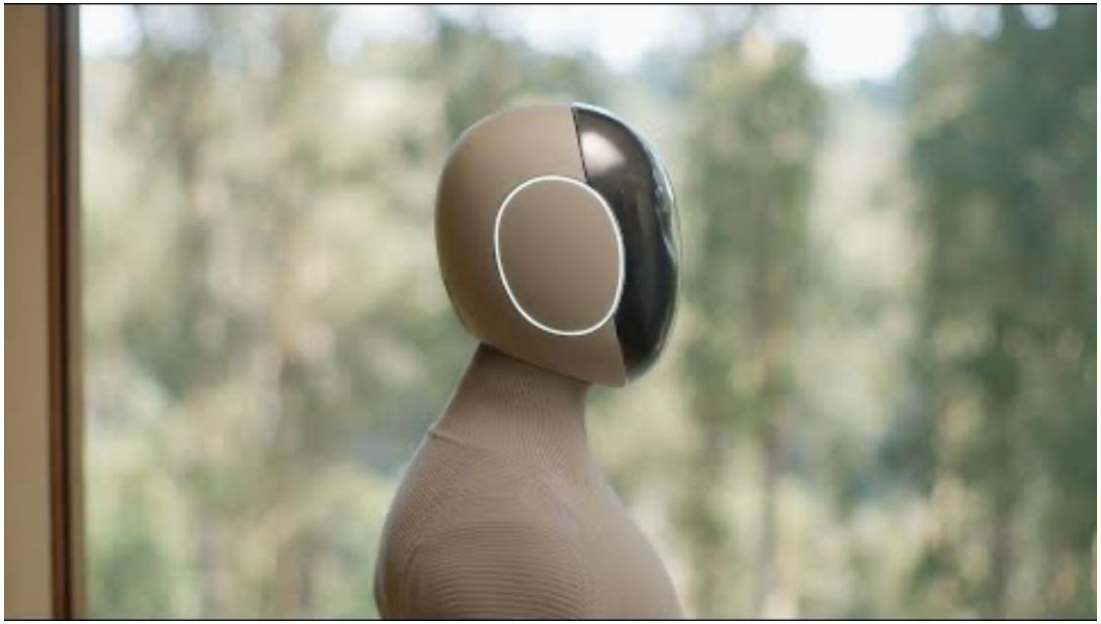
- **Definition 1: Manipulation refers to the activities performed by hands.**
- **Definition 2: Manipulation is when an agent moves things other than itself.**
- **Definition 3: Manipulation is when an agent moves things other than itself through selective contact.**
- **Definition 4: Manipulation is pick-and-place manipulation plus in-hand manipulation plus…**
- **Definition 5: Manipulation refers to an agent's control of its environment through selective contact.**



Matthew T Mason, "Toward robotic manipulation", *Annual Review of Control, Robotics, and Autonomous Systems*, vol. 1, pp. 1--28, 2018.

# What does *manipulation* mean for you?

# Autonomous “Open-world” Manipulation



“Open-world” manipulation requires:

- Semantic perceptual understanding of the world.
- Commonsense reasoning on object understanding.
- A combination of long-term (task-level) plans with fine (control level) motions.

# Quest of manipulation

High-level focuses:
Scene understanding + Task-level planning (Discrete/symbolic)

Low-level focuses:
Sensory feedback in close-loop (Continuous time/state/action)

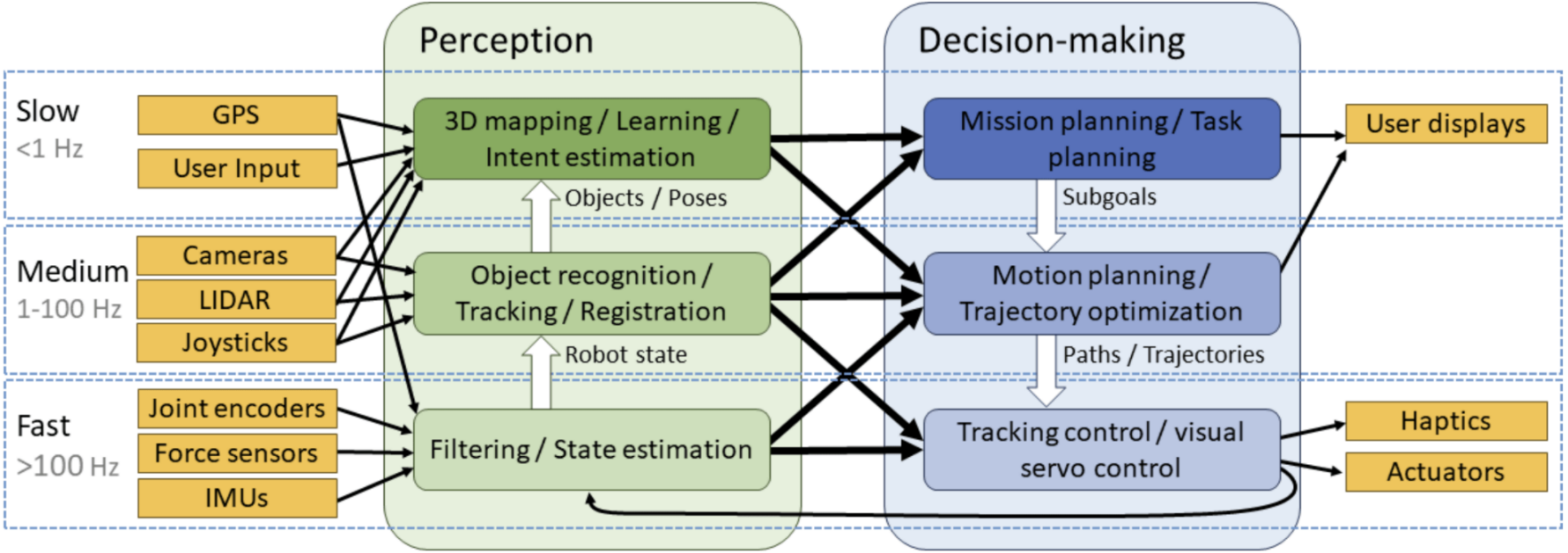
# Moving from state to stateless

# The *anatomy* of a modern manipulation system

# Modern Robot Manipulation System Overview


Each “node” is an executable.

ROS
Robot Operating System




From Kris Hauser - Robotic Systems (online)

# Simulation Demo

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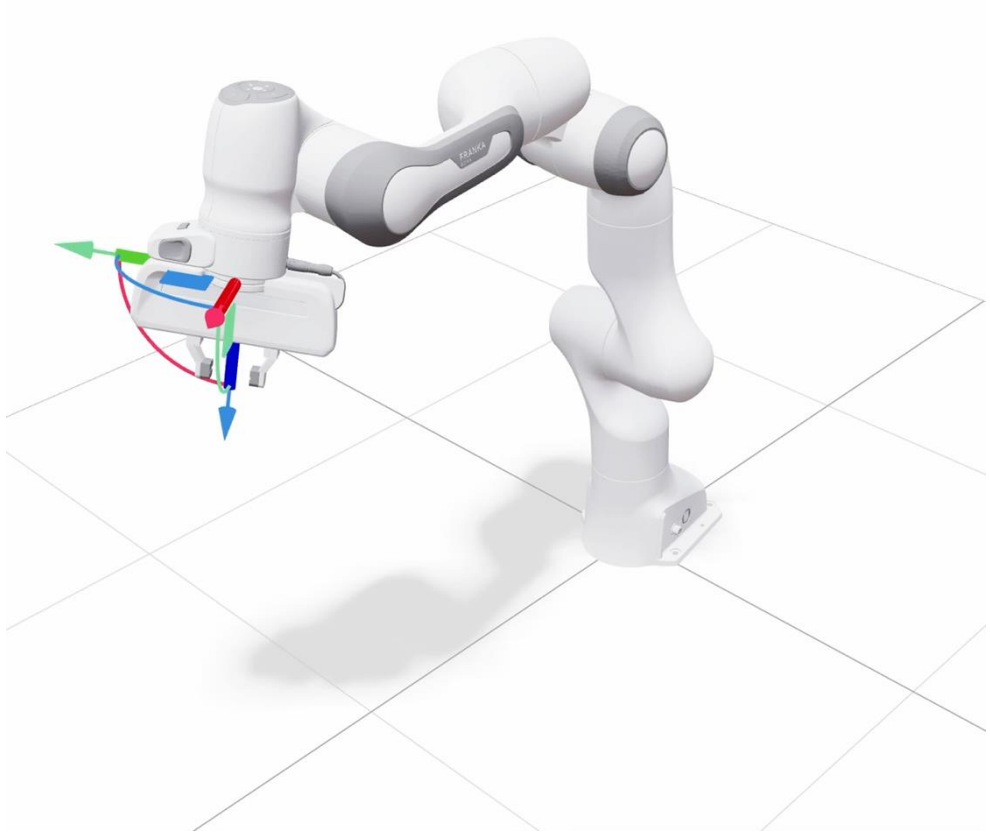

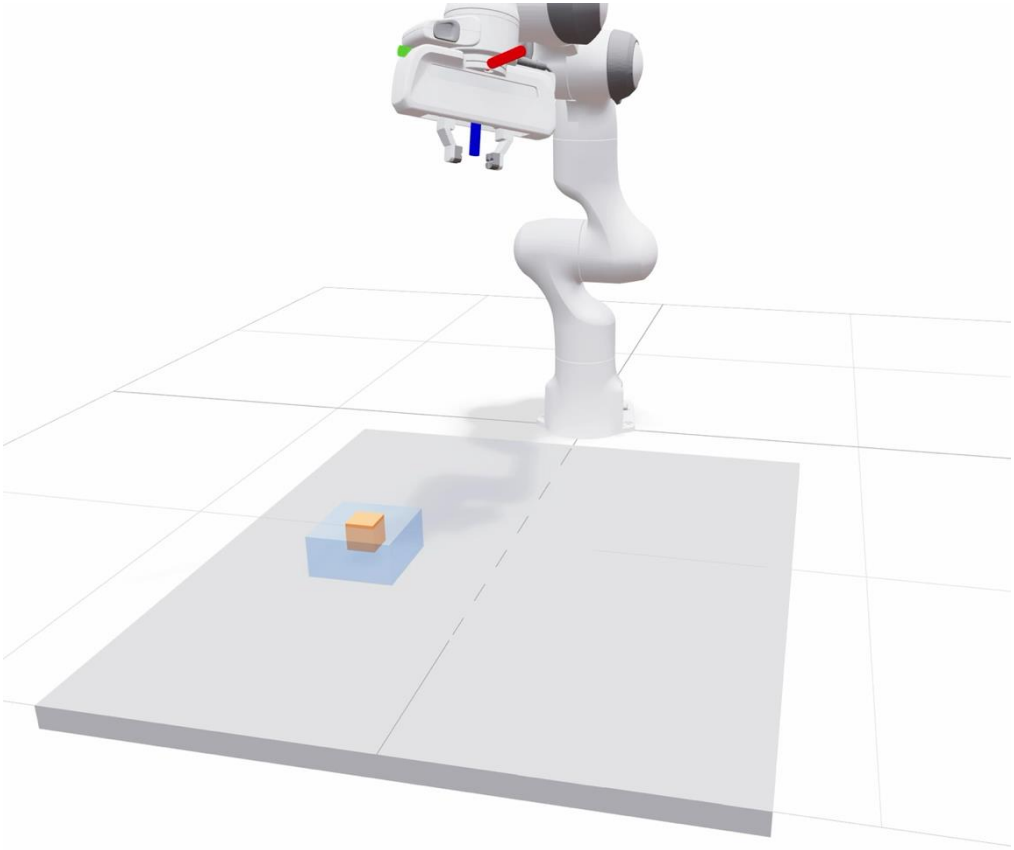

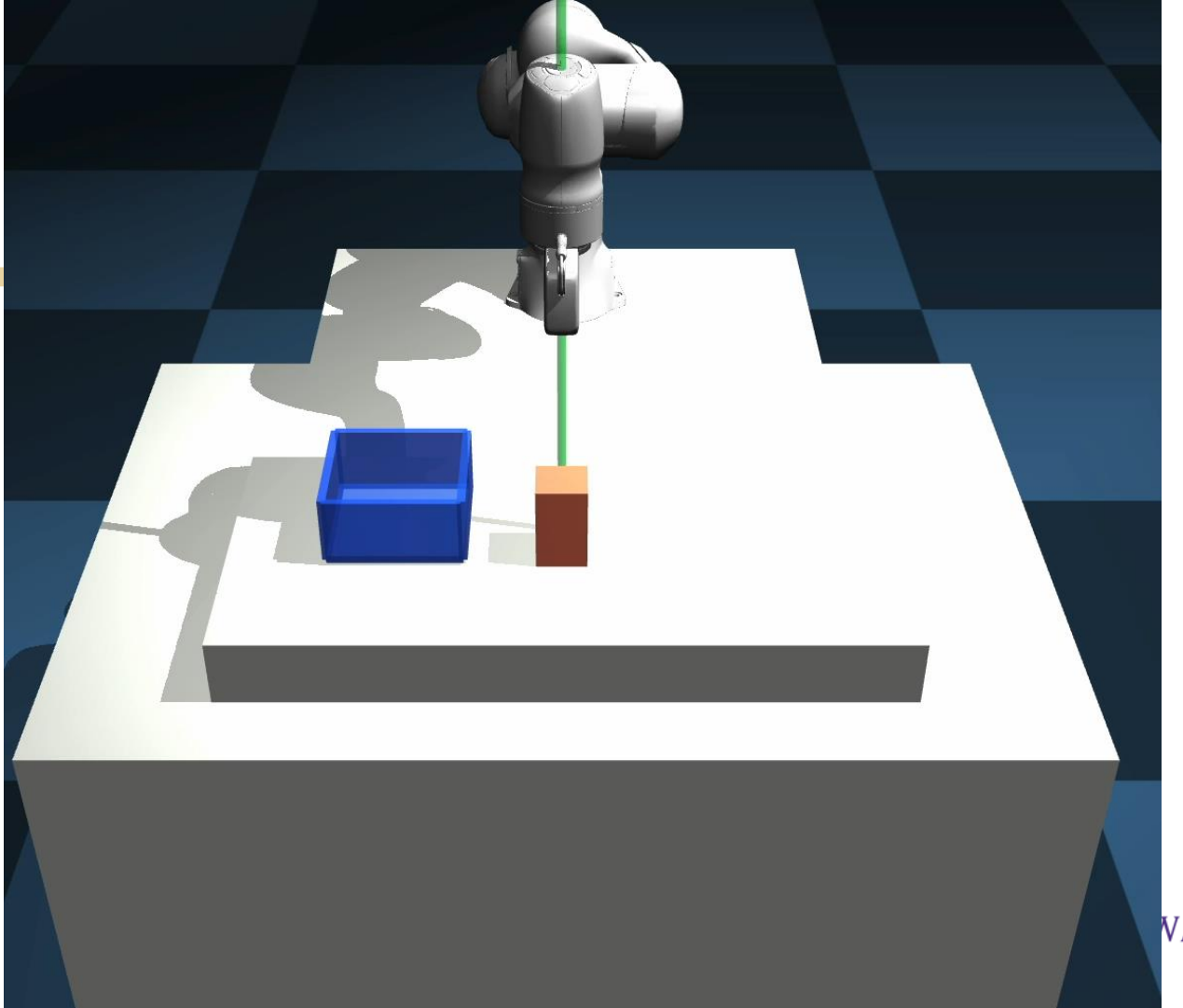

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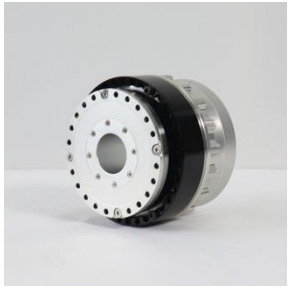
# Robotic Arms



Brushless DC Motor

$$\tau = k_t \cdot i$$

- $\tau$ — motor torque (Nm)
- $k_t$ — motor torque constant (Nm/A)
- $i$ — motor current (A)

Pros:
-High Efficiency
-High Power-to-Weight Ratio
-Precise control

Cons:
-Torque control breaks after gearing
-Hard for force/impendence control

$30K USD

$400K USD

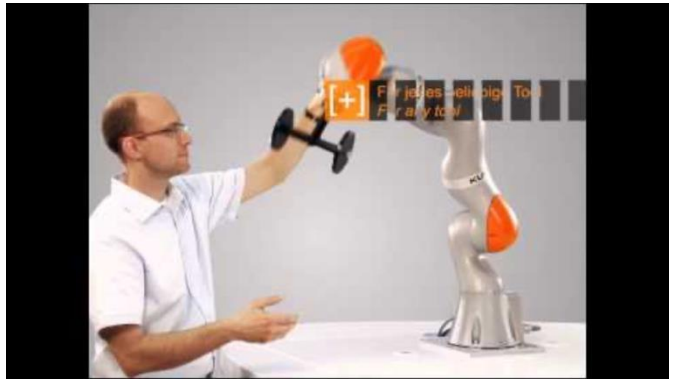

$10K USD

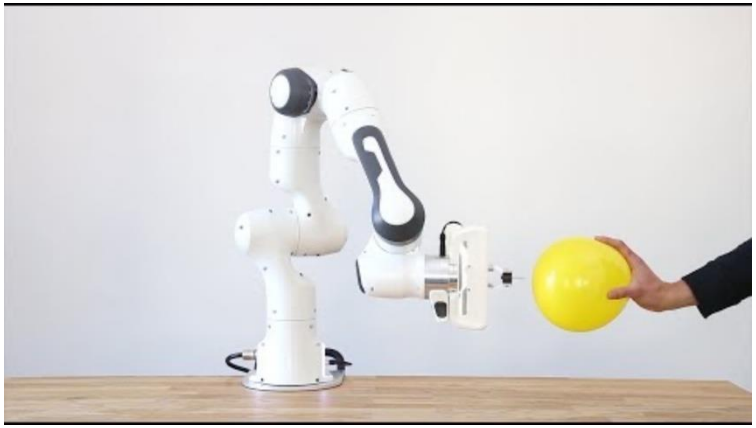
$2K USD

15 years ago

# Joint position sensor

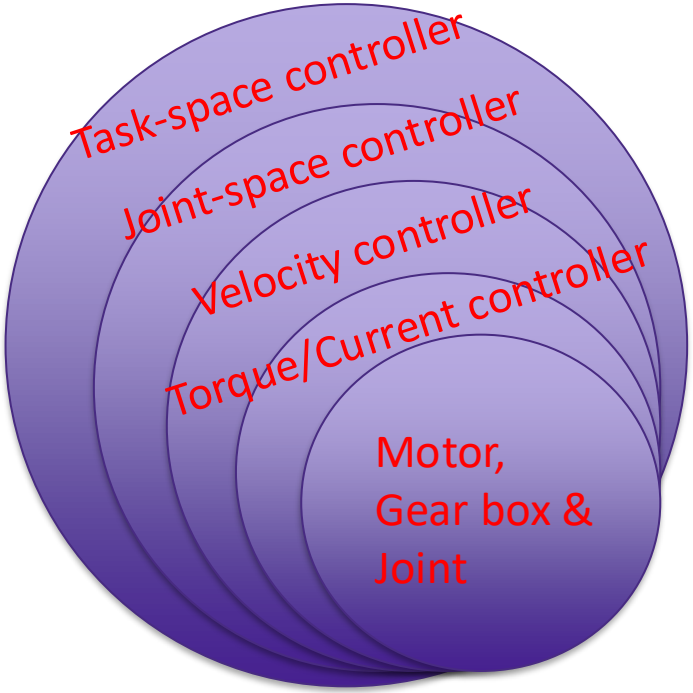
-Force/Torque sensors (often at the wrist)
-Joint Torque sensors
-Tactile skins (On gripper or joints)





# Live Demo

# Nested control loops of modern robot arm




- Task-space controller (Cartesian control, OSC)
- Joint-space controller (Impedance control, PD)
- Velocity controller (PI, sometimes PID)
- Torque/Current controller (PI)

# PID controller

$q \rightarrow$ Joint angle $\quad q^d \rightarrow$ Desired Joint angle $\quad \dot{q}^d \rightarrow$ Desired Joint velocity

$$\tau = k_p(q^d - q)$$

Proportional term:
-Torque proportional to the position error.
-Acts like virtual spring pulling joint towards desired position.

# PID controller

$q \rightarrow$ Joint angle $\quad q^d \rightarrow$ Desired Joint angle $\quad \dot{q}^d \rightarrow$ Desired Joint velocity

$$\tau = k_p(q^d - q) + k_i \int (q^d - q)dt$$

Integral term:
-Accumulates position error over time
-Acts like a memory of past mistakes

# PID controller

$q \rightarrow$ Joint angle $\quad q^d \rightarrow$ Desired Joint angle $\quad \dot{q}^d \rightarrow$ Desired Joint velocity

$$\tau = k_p(q^d - q) + k_i \int (q^d - q)dt + k_d(\dot{q}^d - \dot{q})$$

Derivative term:
-Penalizes velocity error
-Acts like damper or shock absorber

# What does “Control” mean for robotic manipulation?

Control = *What command the robot reliably follows.*

| Dimension | Position Control | Velocity Control | Torque/Force Control |
|---|---|---|---|
| What robot obeys? | “Go *here*” (joint or Cartesian position) | “Move *this fast*” | “Push *this hard*” |
| Quantity | Joint position / trajectory | Joint or Cartesian velocity | Joint torque / force |
| Low-level controller | PID (per joint) | PI/PD (per joint) | Torque + impedance |
| Optimized for? | Precision, repeatability | Smooth motion | Contact and compliance |

# Robotic Arms

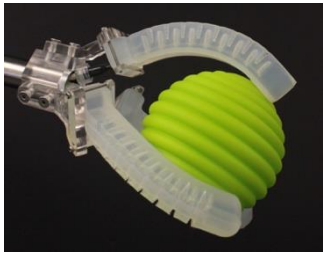
EVS industrial arm

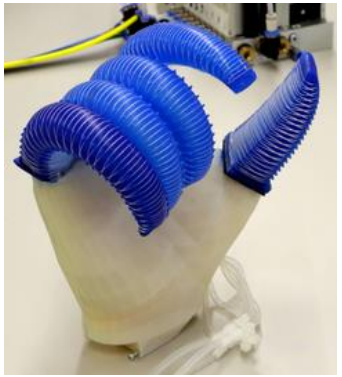

Hydraulic driven

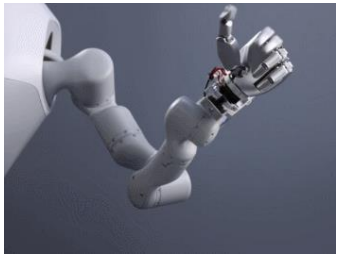
WAM arms


Cable driven

# “Hands”





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## So how many fingers do we need for manipulation?

# Mobile Manipulator

Everyday Robot


Rainbow RB-Y1

Stretch


Fetch Robot


Spot

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