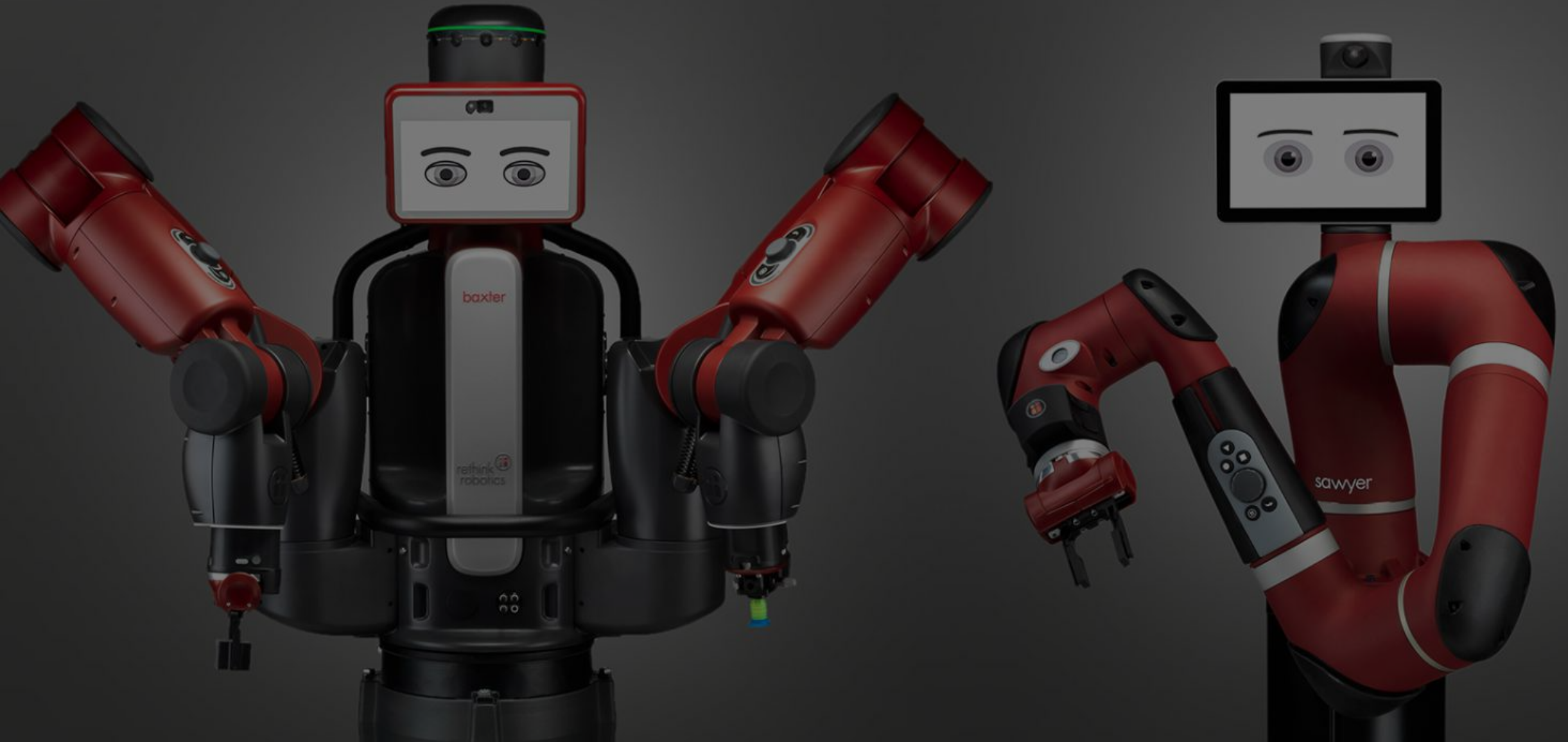




# Domo Arigato, Mr. Roboto: Calibrating Robots with Python

Nicholas Nadeau, P.Eng., AVS  
PyCon Canada 2017

# The Robots Are Coming!



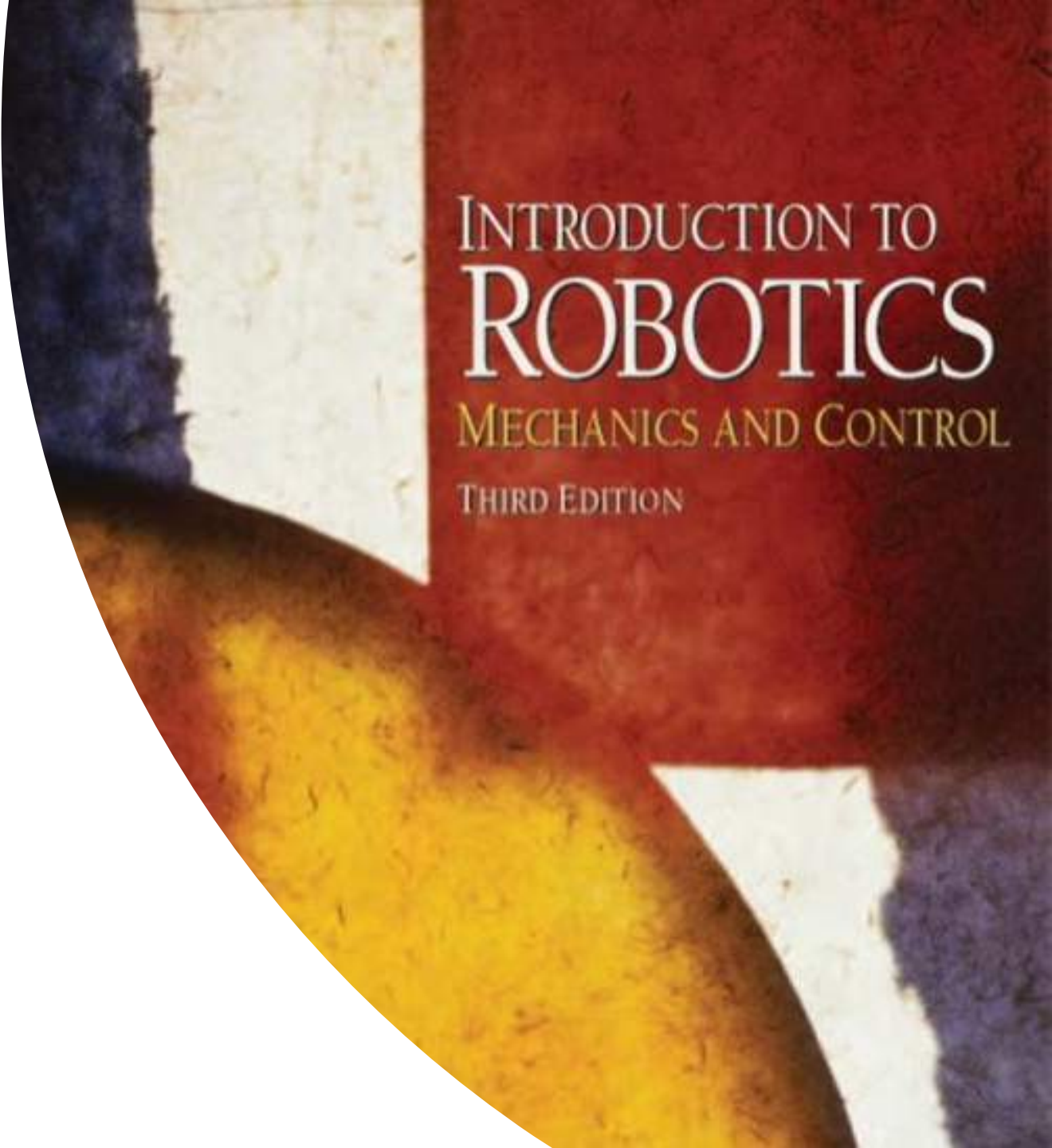


What's the difference?

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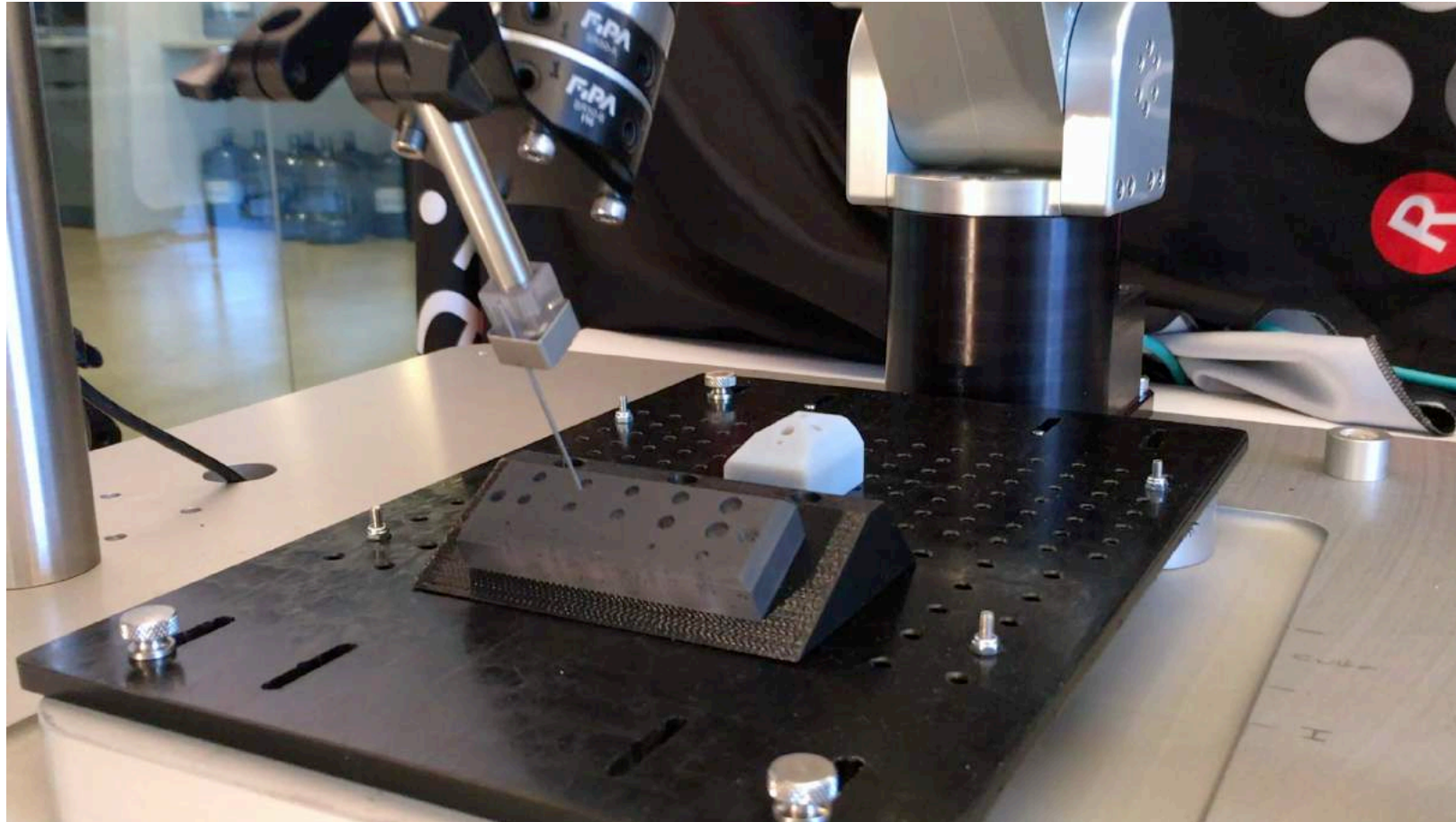
Introduction to  
Robotics: Mechanics  
and Control, 3rd Edition  
John J. Craig



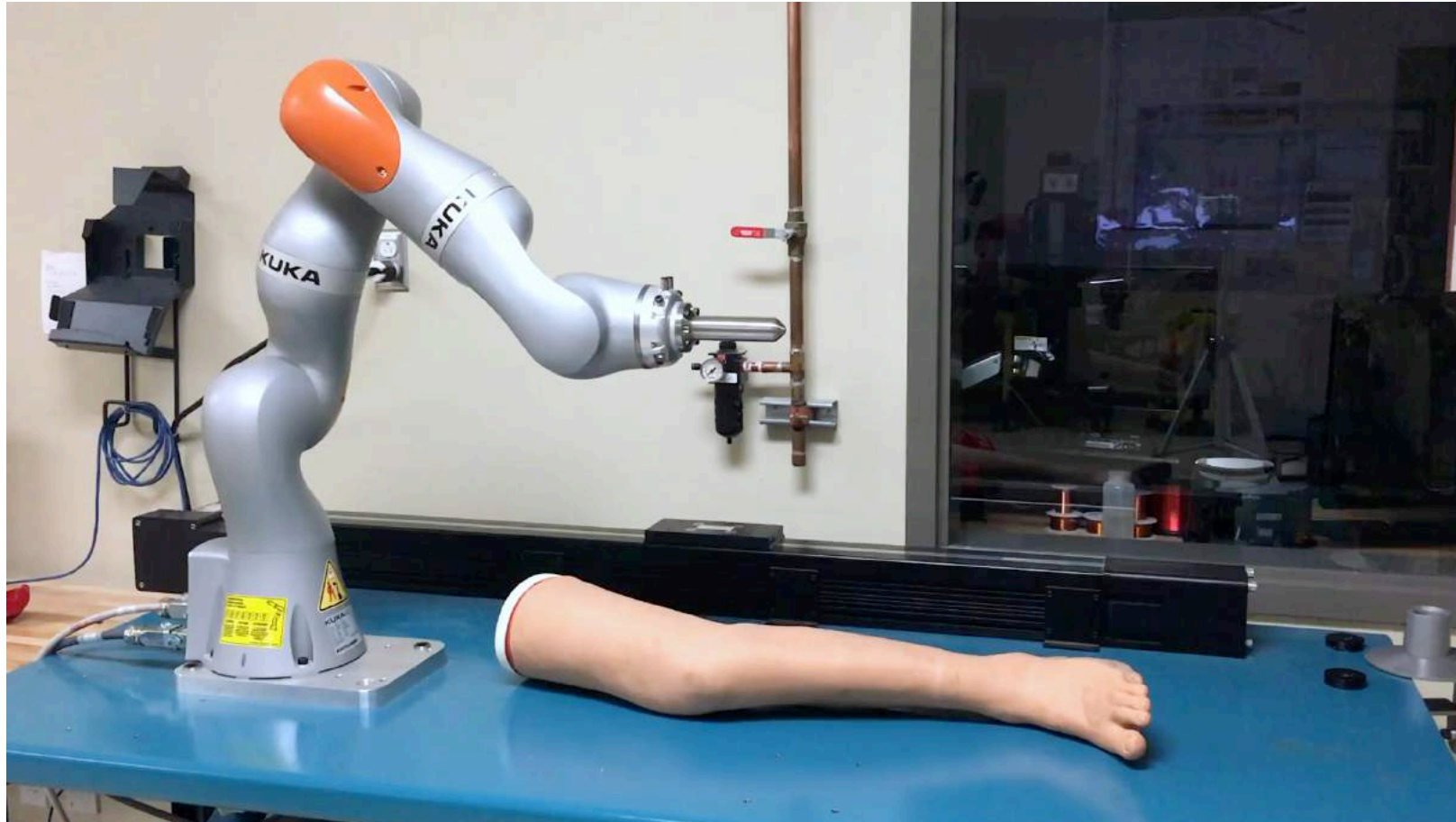
INTRODUCTION TO  
**ROBOTICS**  
MECHANICS AND CONTROL  
THIRD EDITION



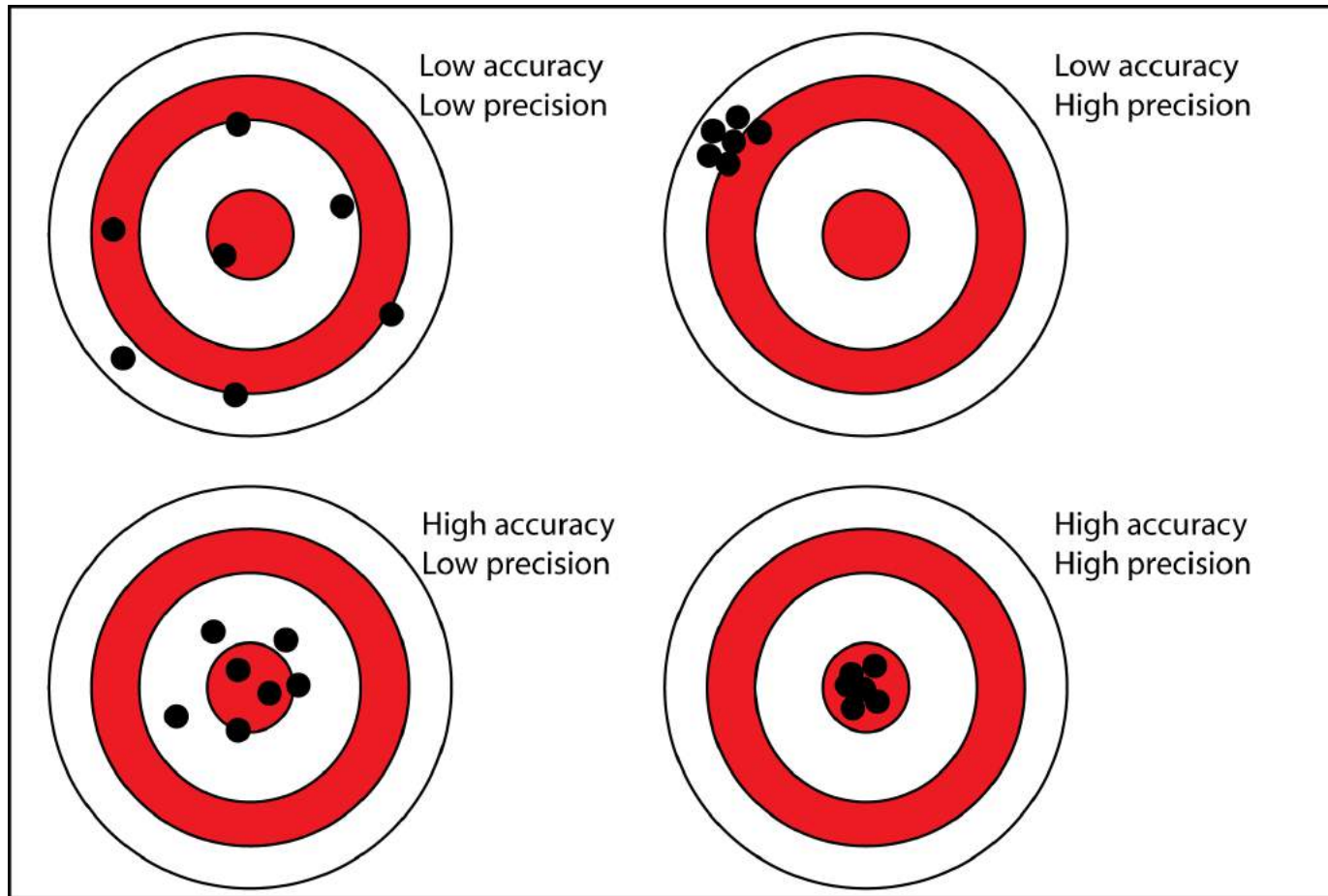
# Rogue Research Inc.

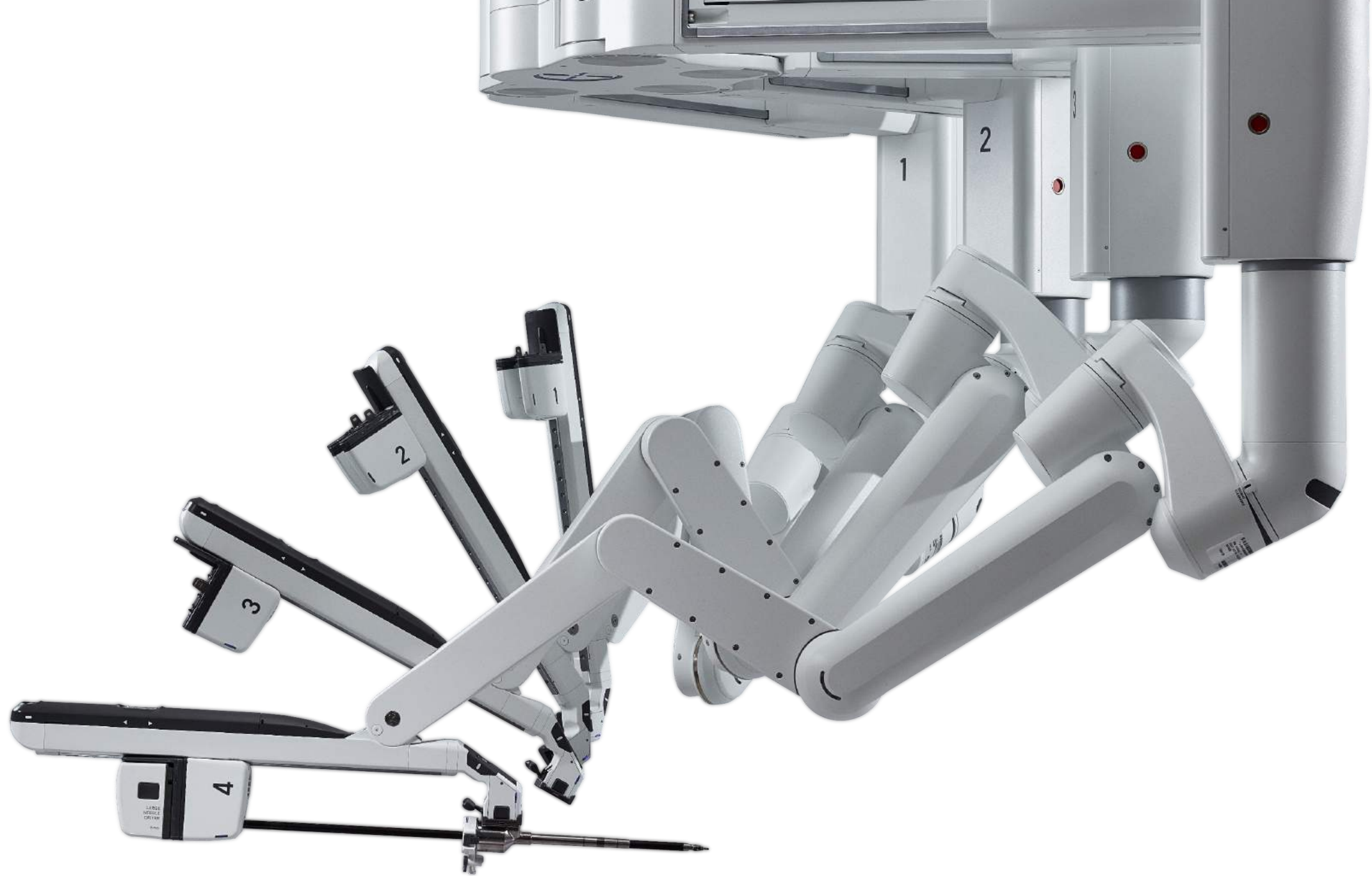


# ETS



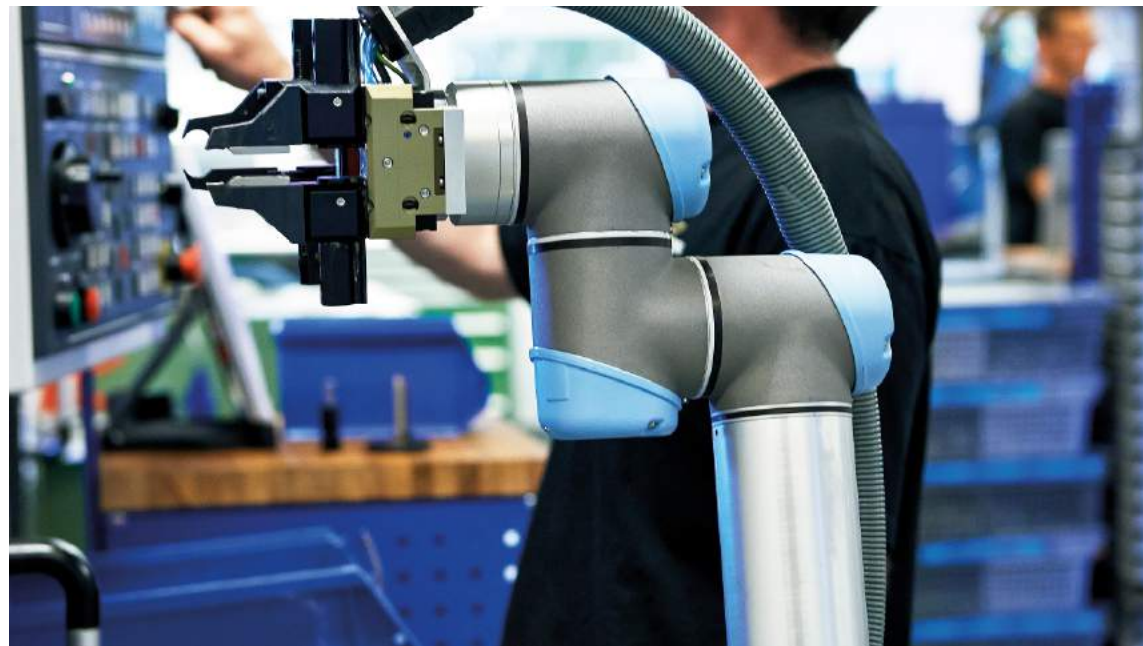
# Why Calibrate?



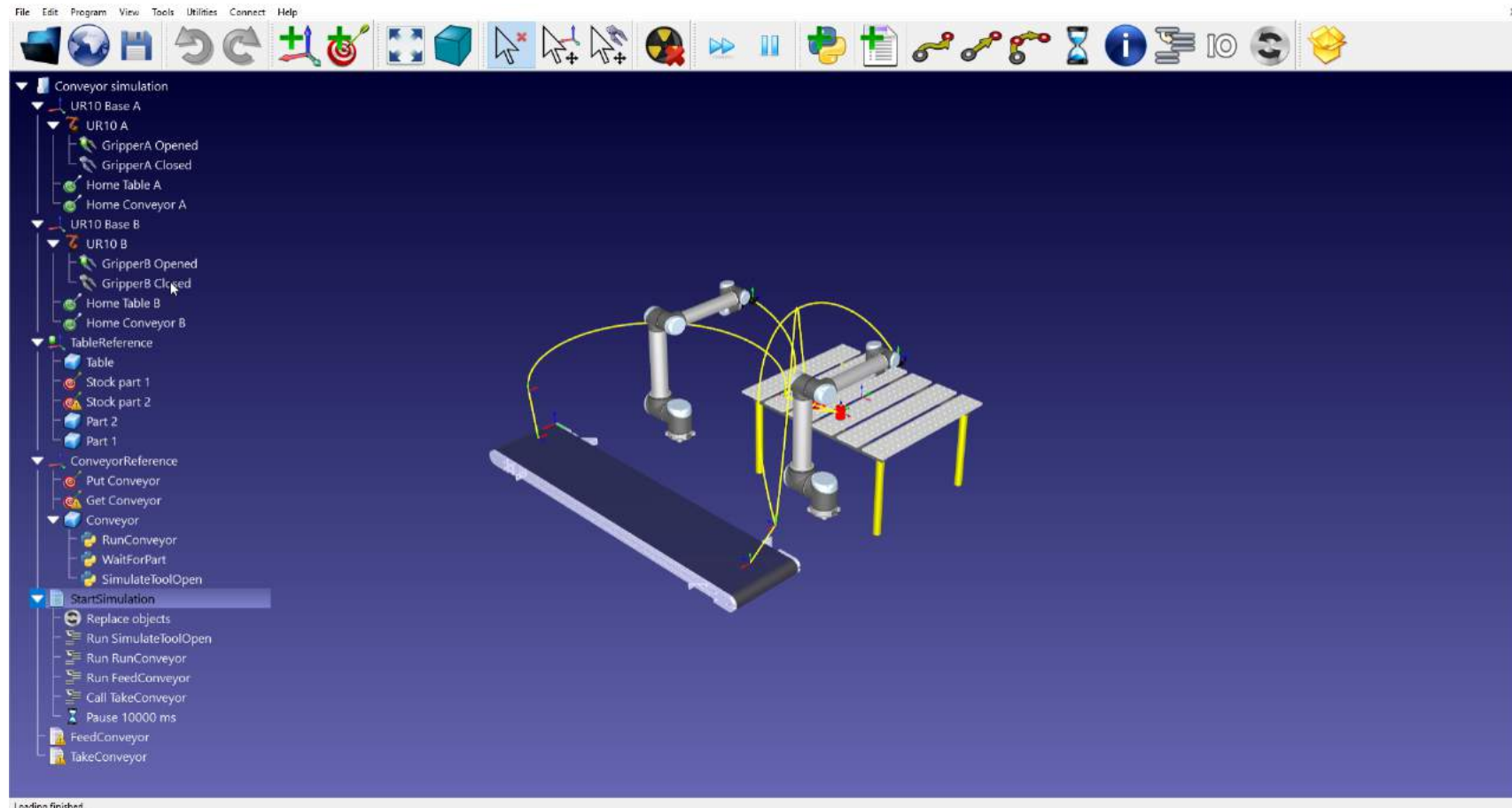


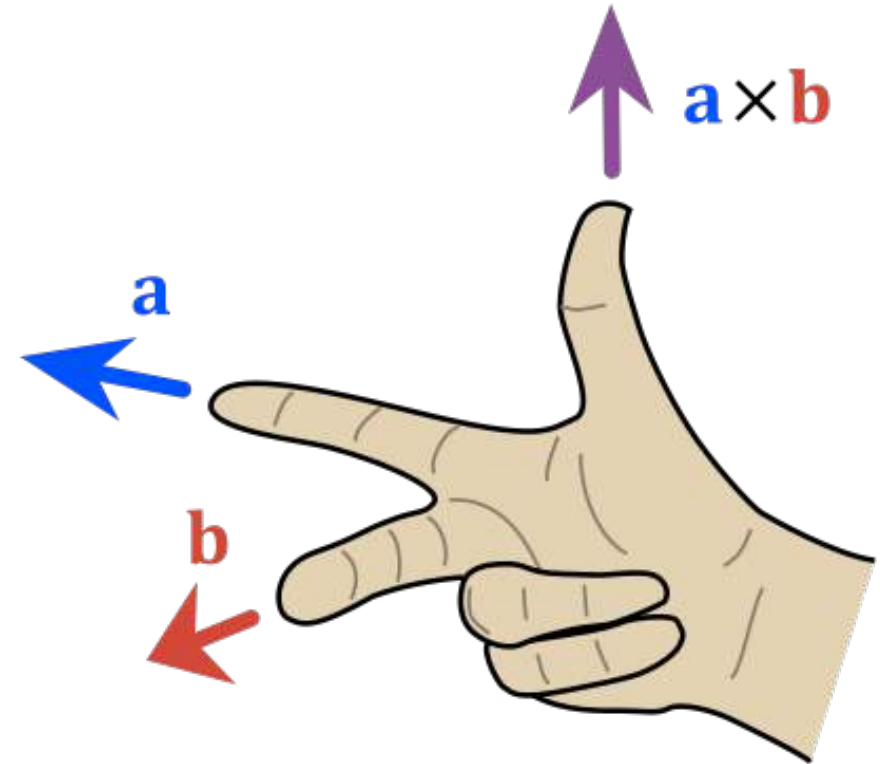
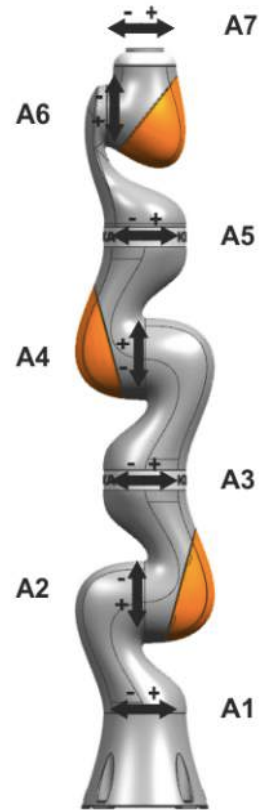






# Offline Programming



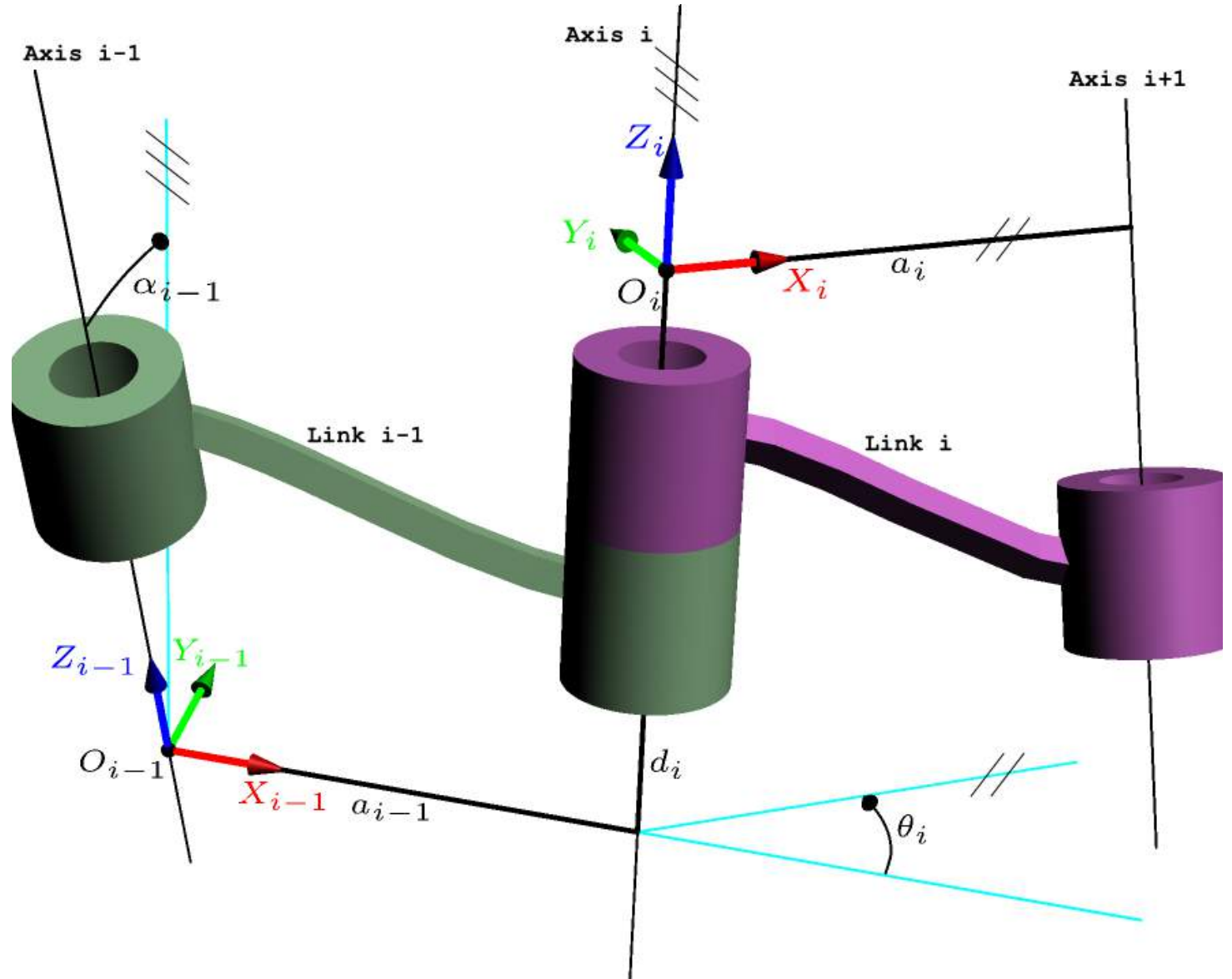


# Kinematic Parameters

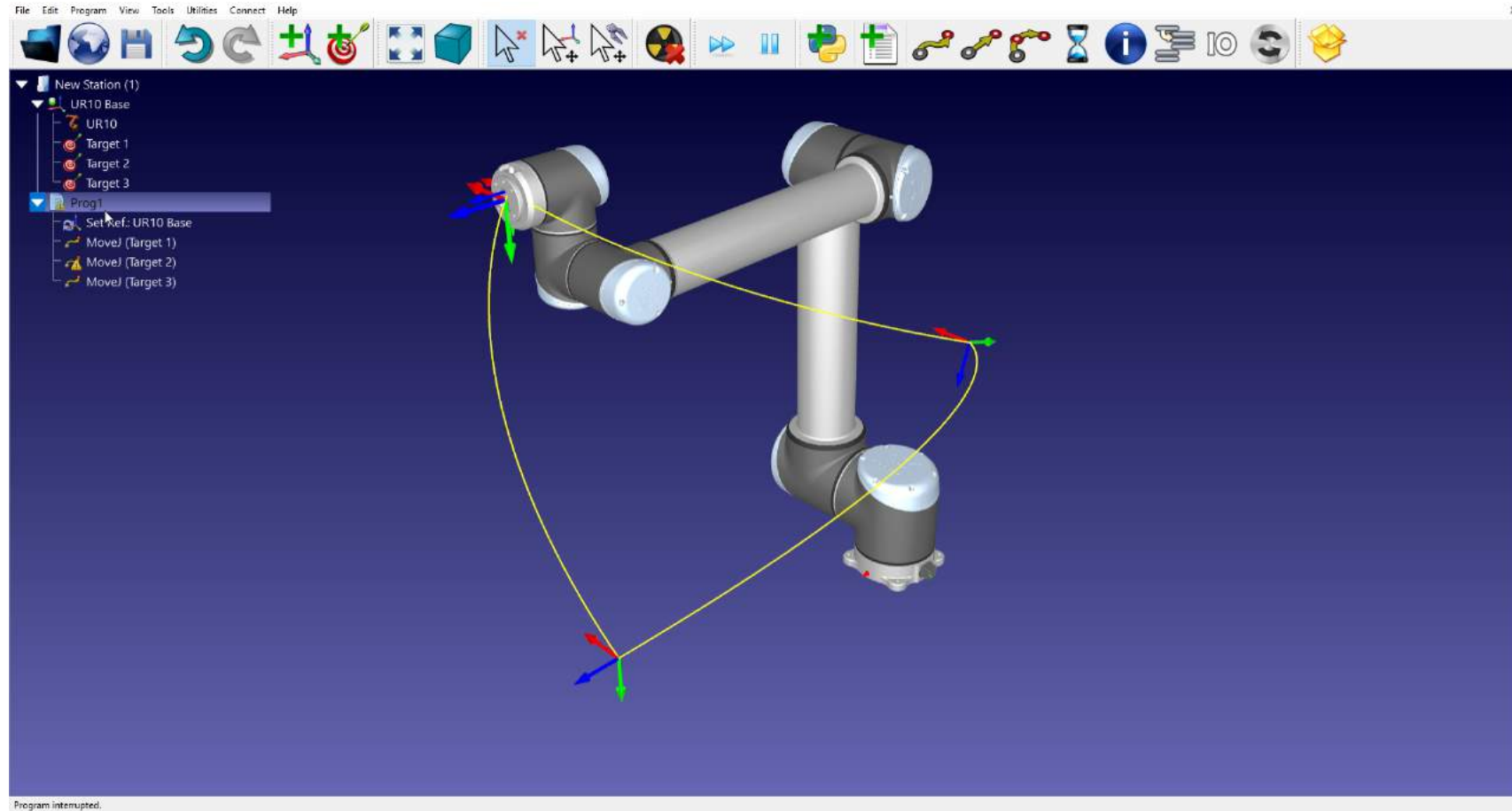


# Kinematic Parameters

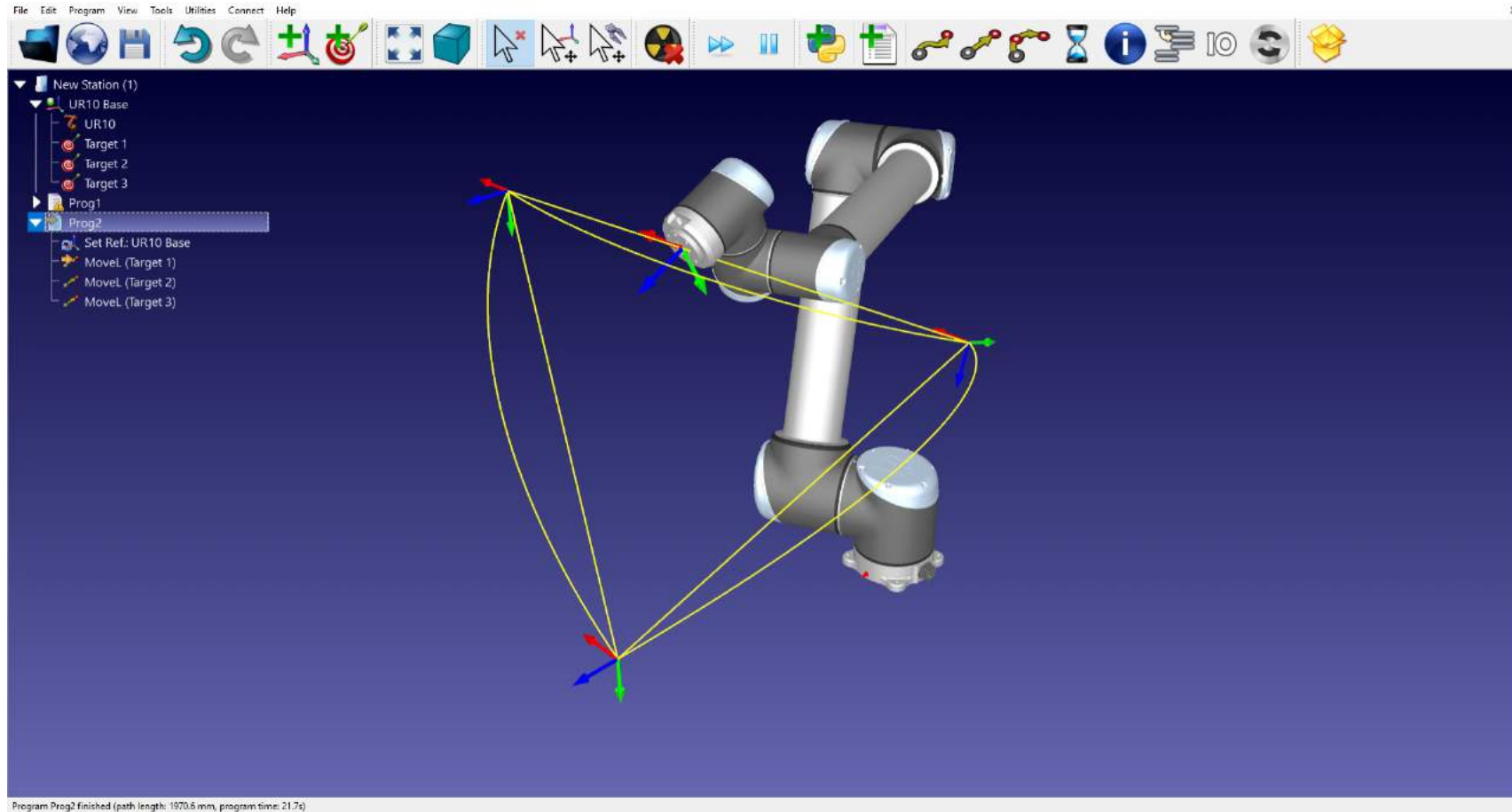
i	$\alpha$	a	$\theta$	d
0	0	0	0	118
1	$\pi/2$	0	$\pi$	0
2	0	612.7	0	0
3	0	571.6	0	163.9
4	$-\pi/2$	0	0	115.7
5	$\pi/2$	0	$\pi$	92.2



# Joint-Space Motion



# Cartesian Motion



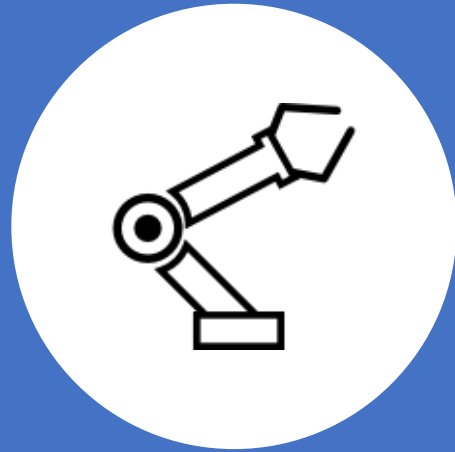
# Recap

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- Robot theory = math
- Robot simulation
  - Model robot motions and operations
  - Save time
  - Save \$\$\$
  - Improve performance
- Accuracy is very important when trying to do medical procedures
  - Else, “You're Going to Have a Bad Time”








pybotics


# Motivation #1

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## Optimization Toolbox

MAJOR UPDATE



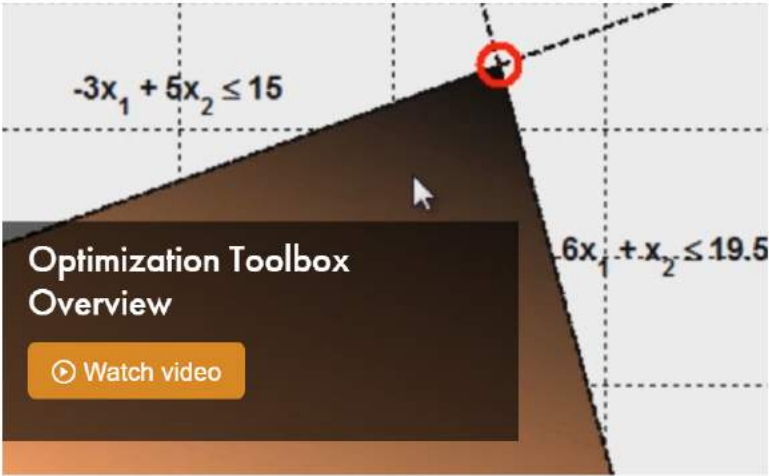
[Overview](#) [Features](#) [Code Examples](#) [Videos](#) [Webinars](#) [What's New](#) [Product Pricing](#)

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### Solve linear, quadratic, integer, and nonlinear optimization problems


Optimization Toolbox™ provides functions for finding parameters that minimize or maximize objectives while satisfying constraints. The toolbox includes solvers for linear programming (LP), mixed-integer linear programming (MILP), quadratic programming (QP), nonlinear programming (NLP), constrained linear least squares, nonlinear least squares, and nonlinear equations. You can define your optimization problem with functions and matrices or by specifying variable expressions that reflect the underlying mathematics.

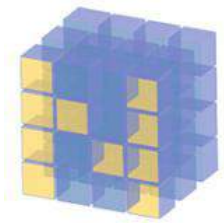
You can use the toolbox solvers to find optimal solutions to continuous and discrete problems, perform tradeoff analyses, and incorporate optimization methods into algorithms and applications.



**Optimization Toolbox Overview**

[Watch video](#)



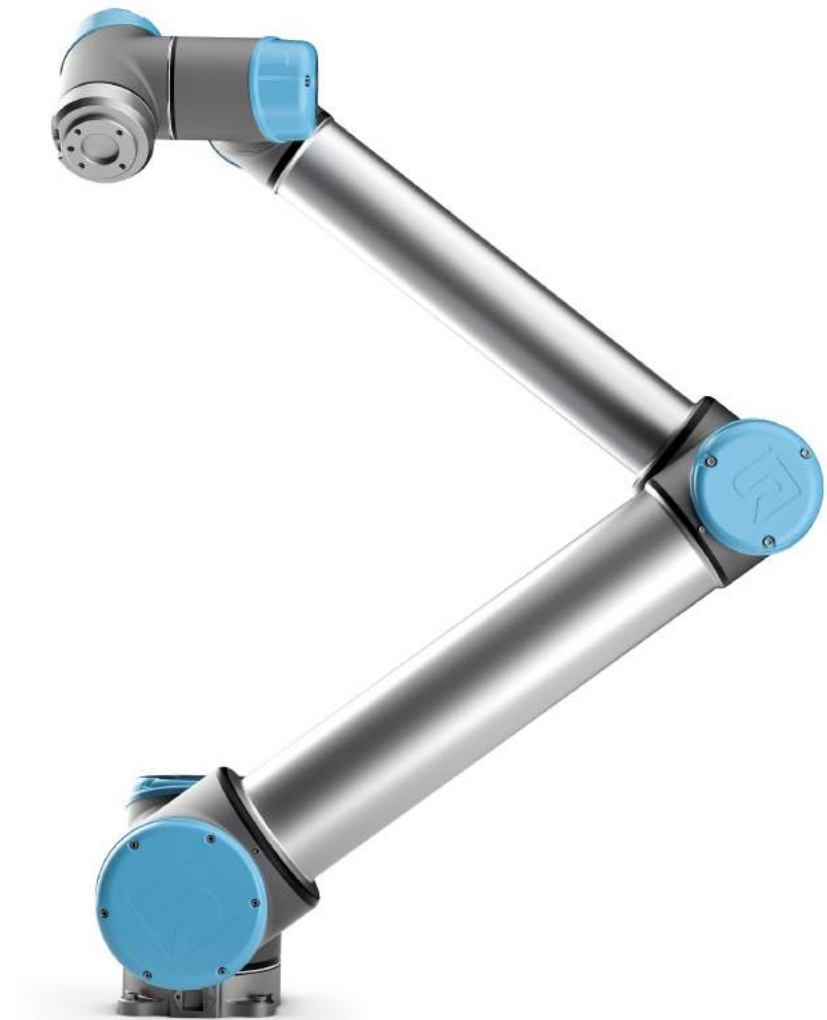


NumPy



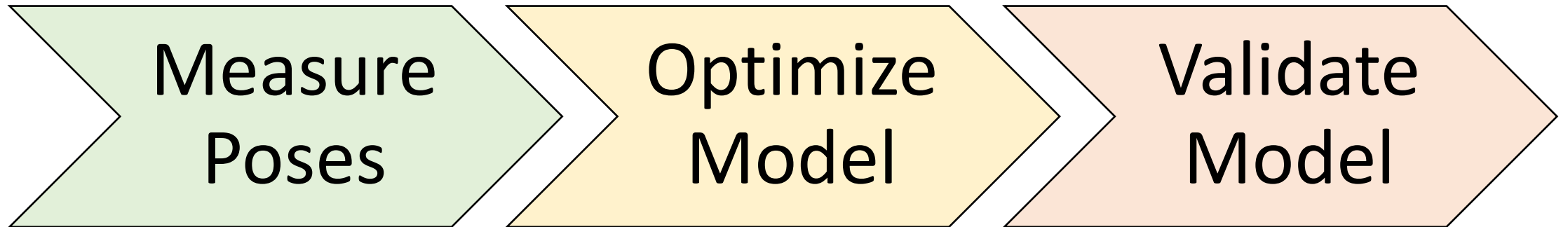
# Motivation #2

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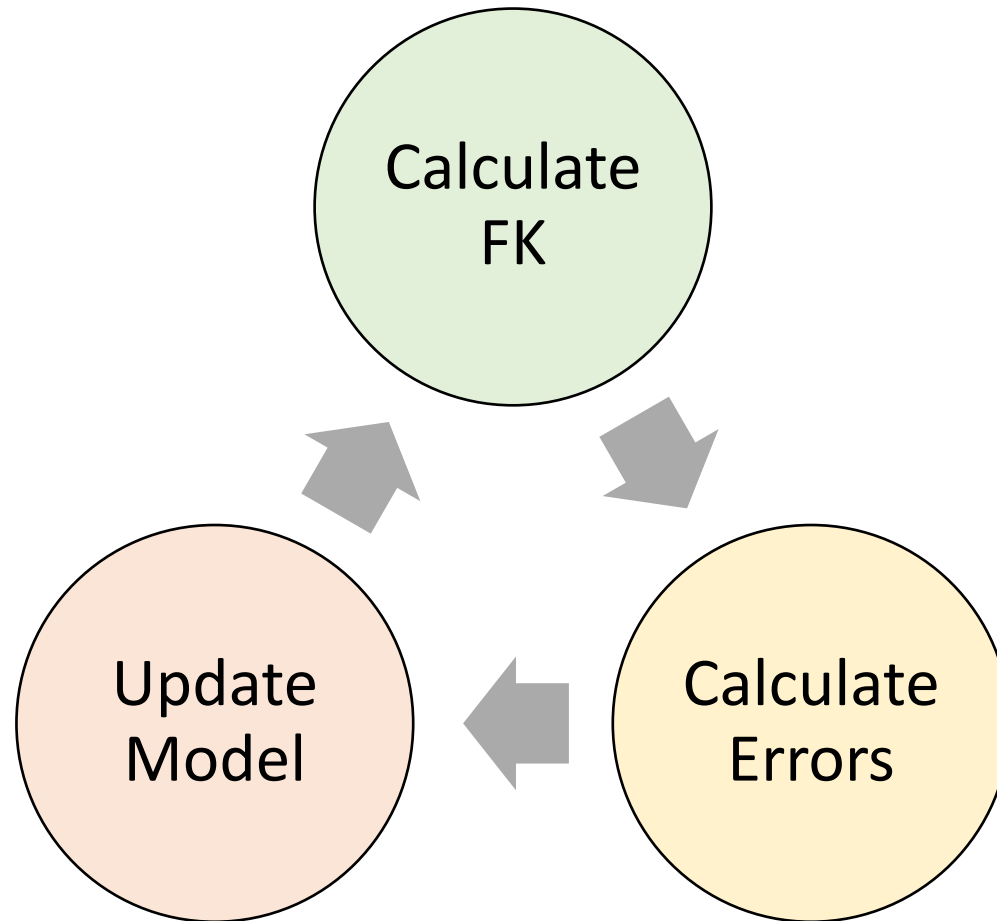




# Calibration Overview



# Optimization Cycle



Optimization Vector

**Robot**

**World  
Frame**

**Kinematic  
Chain**

**Tool  
Frame**

# Optimization Mask

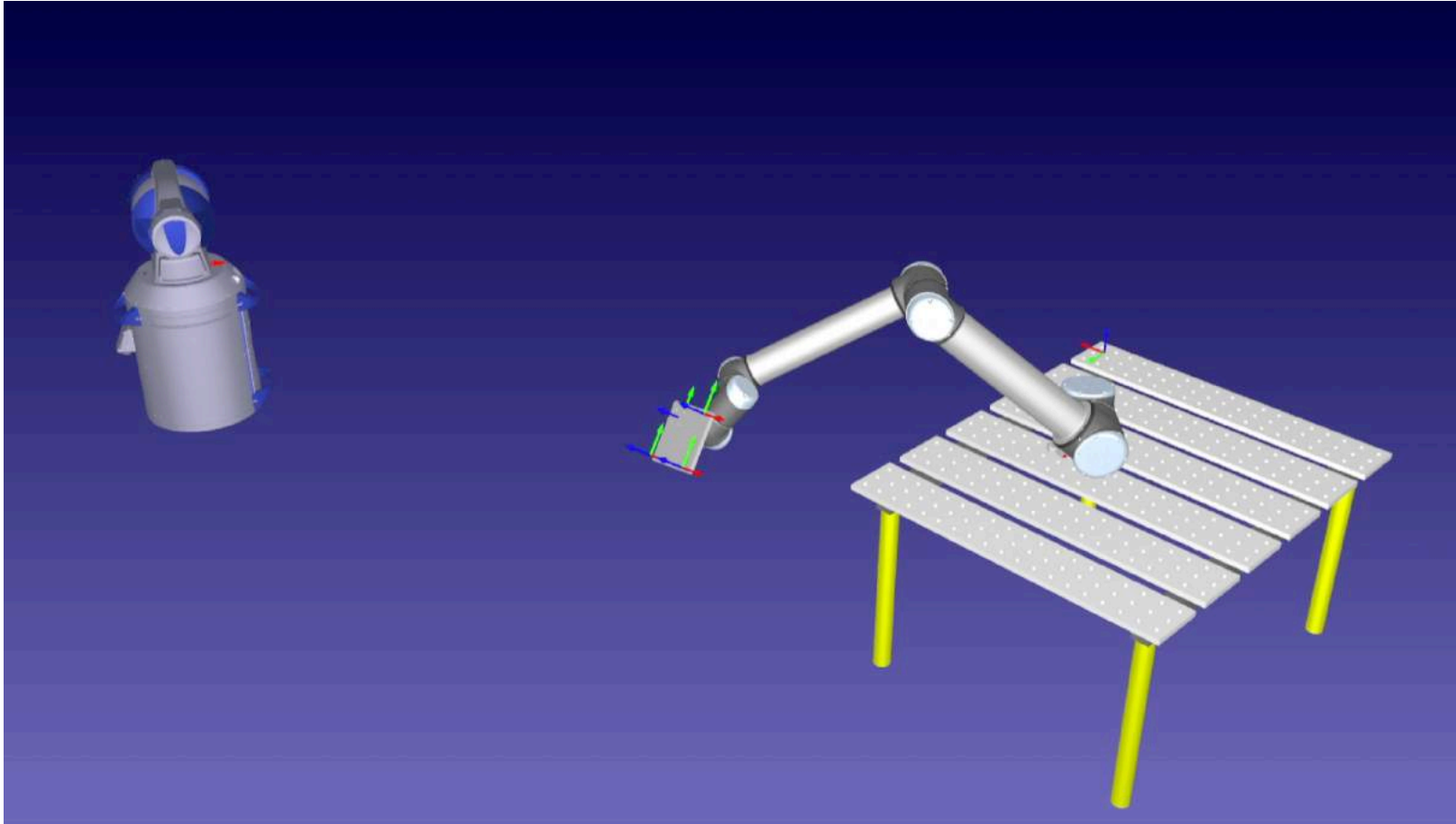
Model	$X_1$	$X_2$	$X_3$
Optimization Mask	True	False	True
Optimization Vector	$X_1$		$X_3$



# FARO ION



# UR10 Measurements



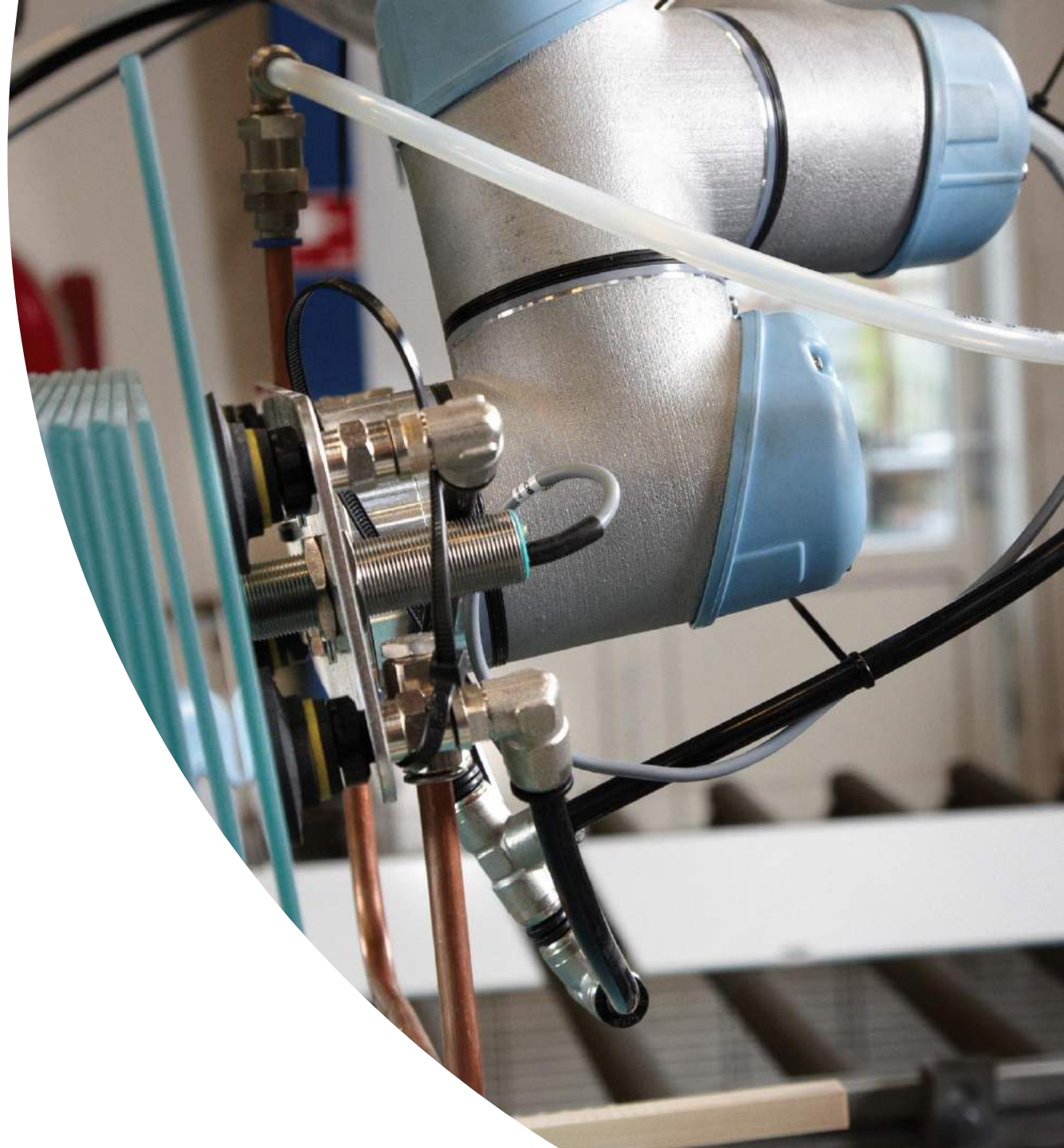
# Calibration Demo

Jupyter Notebook!

# Recap

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- Scientific Python Ecosystem are fundamental building blocks for the community
  - Bridge the gap between science, engineering, and software development
- Robots are not very accurate out-of-the-box
  - But we can fix that!





# I ♥ Robots Now What?

- Hardware continuous integration!
  - Continuous calibration
  - Robot performance forecasting and machine learning
- Contribute!
  - Robots & devices
  - Wrappers, server-client interfaces, drivers
  - Frameworks and toolboxes
- Graduate degree!
  - Control and Robotics Laboratory (CoRo) @ ÉTS







Thank You!

- @EngNadeau
- nicholasnadeau.me
- github.com/nnadeau

# Third-Party Media

- KUKA Aktiengesellschaft
  - <https://www.kuka.com/en-ca/press/media-library>
- Courtesy of Rethink Robotics, Inc
  - <http://www.rethinkrobotics.com/press/>
- uArm Swift Pro
  - <https://www.sparkfun.com/products/14342>
- Introduction to Robotics: Mechanics and Control, 3rd Edition
  - <https://www.pearson.com/us/higher-education/program/Craig-Introduction-to-Robotics-Mechanics-and-Control-3rd-Edition/PGM11887.html>
- Precision and accuracy
  - <http://www.antarcticglaciers.org/glacial-geology/dating-glacial-sediments-2/precision-and-accuracy-glacial-geology/>
- da Vinci Xi
  - <https://www.intuitivesurgical.com/company/media/images/da-vinci-xi/>
- Universal Robots
  - <https://www.universal-robots.com/media/>
- KUKA LBR Joints
  - [https://www.kuka.com/-/media/kuka-downloads/imported/48ec812b1b2947898ac2598aff70abc0/spez\\_lbr\\_iiwa\\_en.pdf](https://www.kuka.com/-/media/kuka-downloads/imported/48ec812b1b2947898ac2598aff70abc0/spez_lbr_iiwa_en.pdf)
- Right-hand Rule
  - [https://en.wikipedia.org/wiki/Right-hand\\_rule](https://en.wikipedia.org/wiki/Right-hand_rule)
- DH Parameters
  - [https://en.wikipedia.org/wiki/Denavit%E2%80%93Hartenberg\\_parameters](https://en.wikipedia.org/wiki/Denavit%E2%80%93Hartenberg_parameters)