Why is Building Robust and Reliable Robotics Software So Hard?

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CANARIE Research Software Conference Talk

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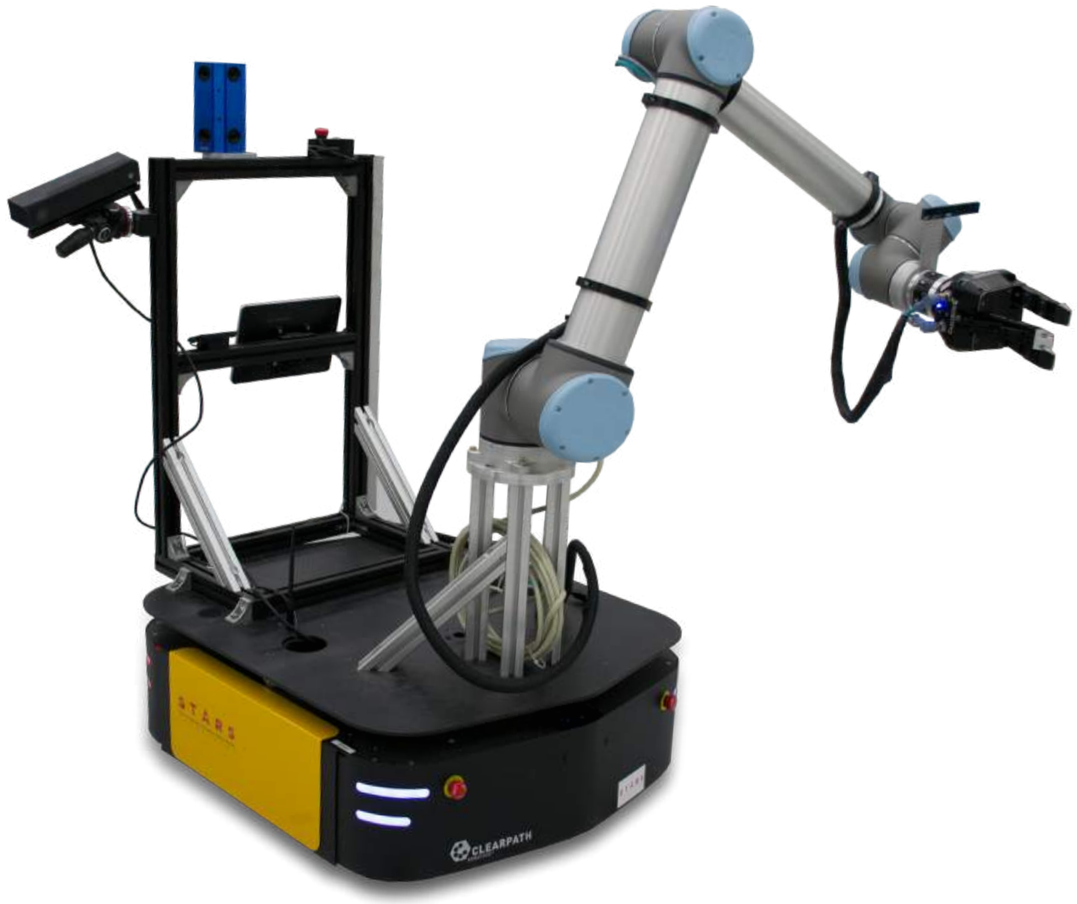
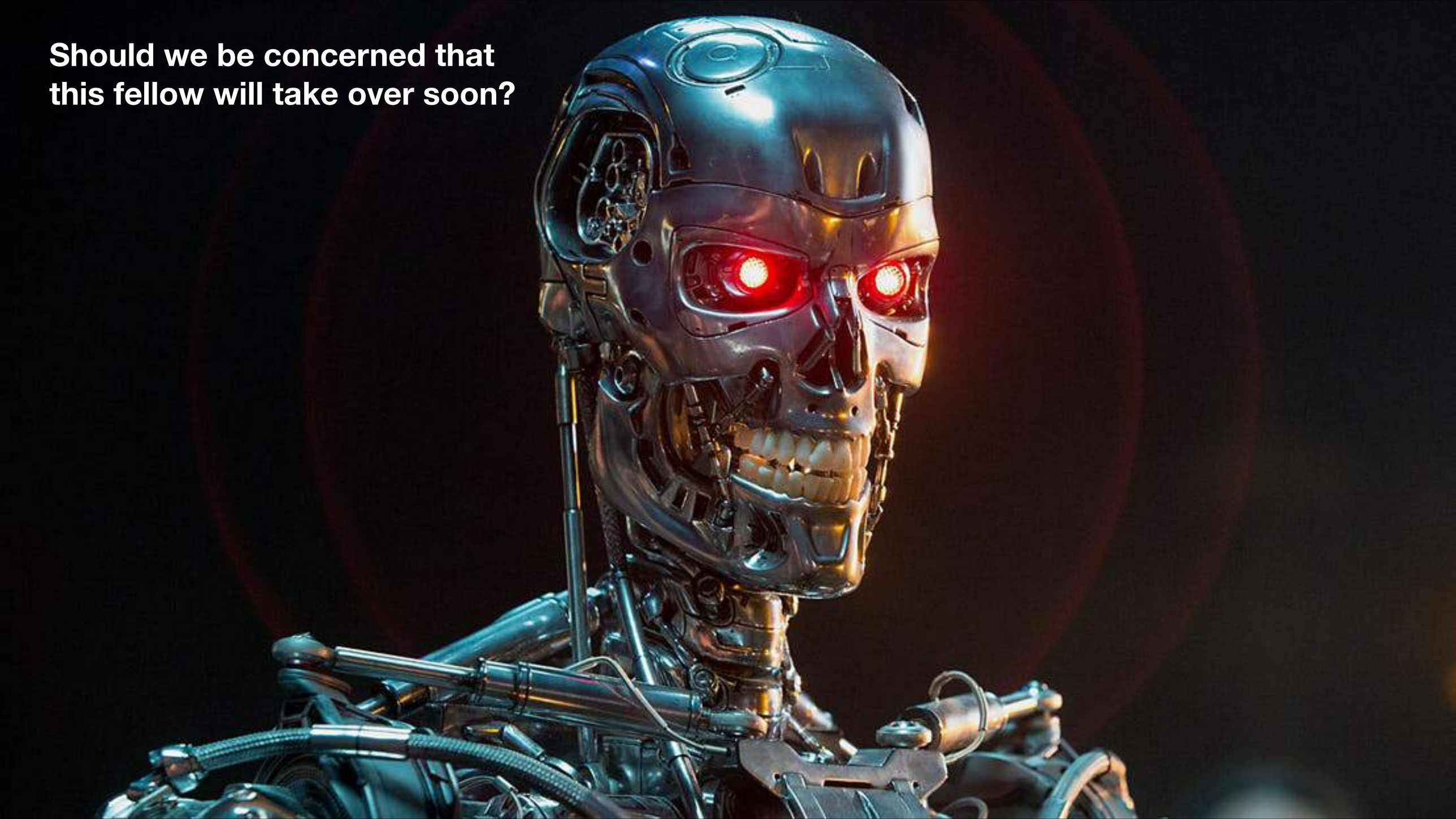
My Background and Research Areas

- My degrees are all in Computer Engineering or Computer Science
  - Began in Canada, rotated through the US, back to Canada
- Direct the Space & Terrestrial Autonomous Robotic Systems Laboratory at U of T
- Research focus is on sensing, perception, navigation, mapping, and manipulation
  - Spend a lot of time working on **collaborative robots**, or '**cobots**'



Should we be concerned that this fellow will take over soon?



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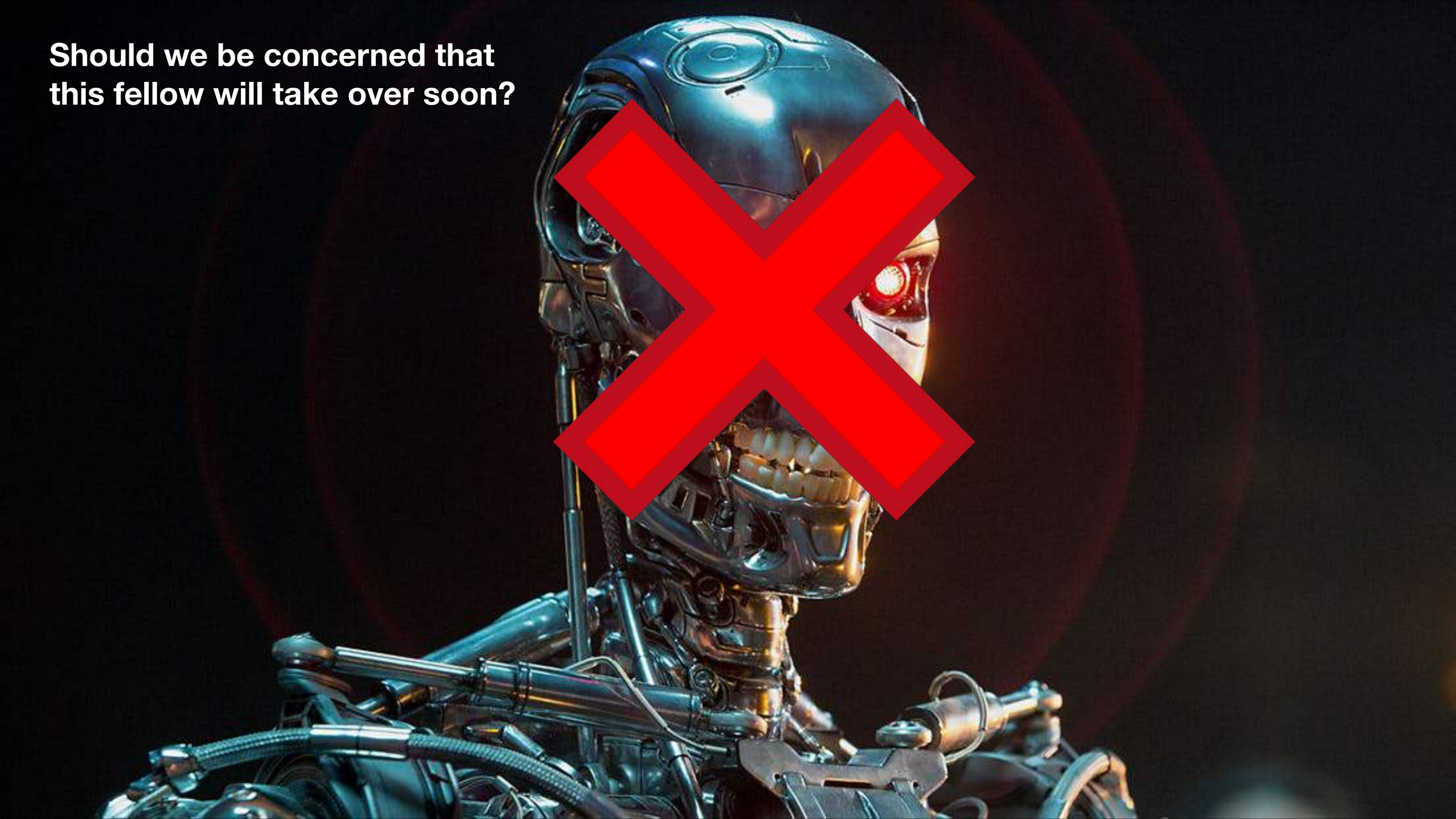
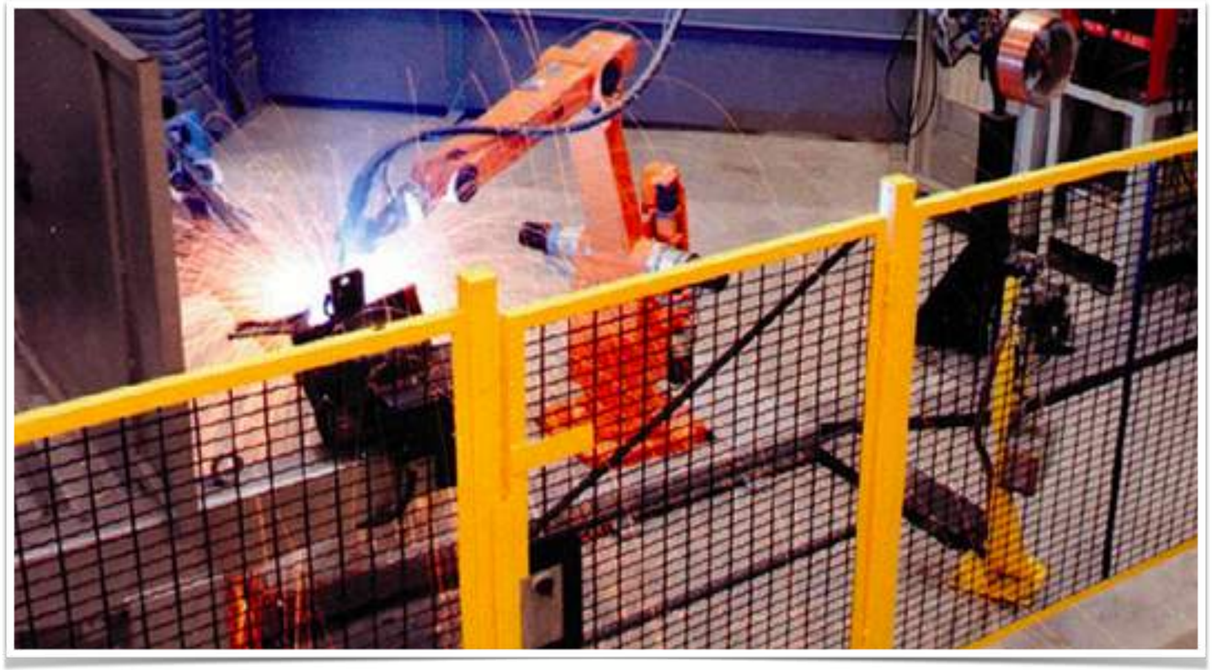


A (Very) Brief History of (Bad) Robots

- The first industrial robot, the **Unimate**, created by American inventor George Devol, was deployed at a GM automative assembly plant in New Jersey in 1961
  - This (4,000 lb) machine operated behind a safety cage, far away from workers, just as most factory robots do today
- Despite the cages, and sophisticated (relatively) safety systems, accidents still happen…
  - At least 7 factory deaths have been attributed to robots since 1979
  - In all cases, the cause was *not* failure of the mechanical system



Hardware and Mechanism Design | Robust and Reliable

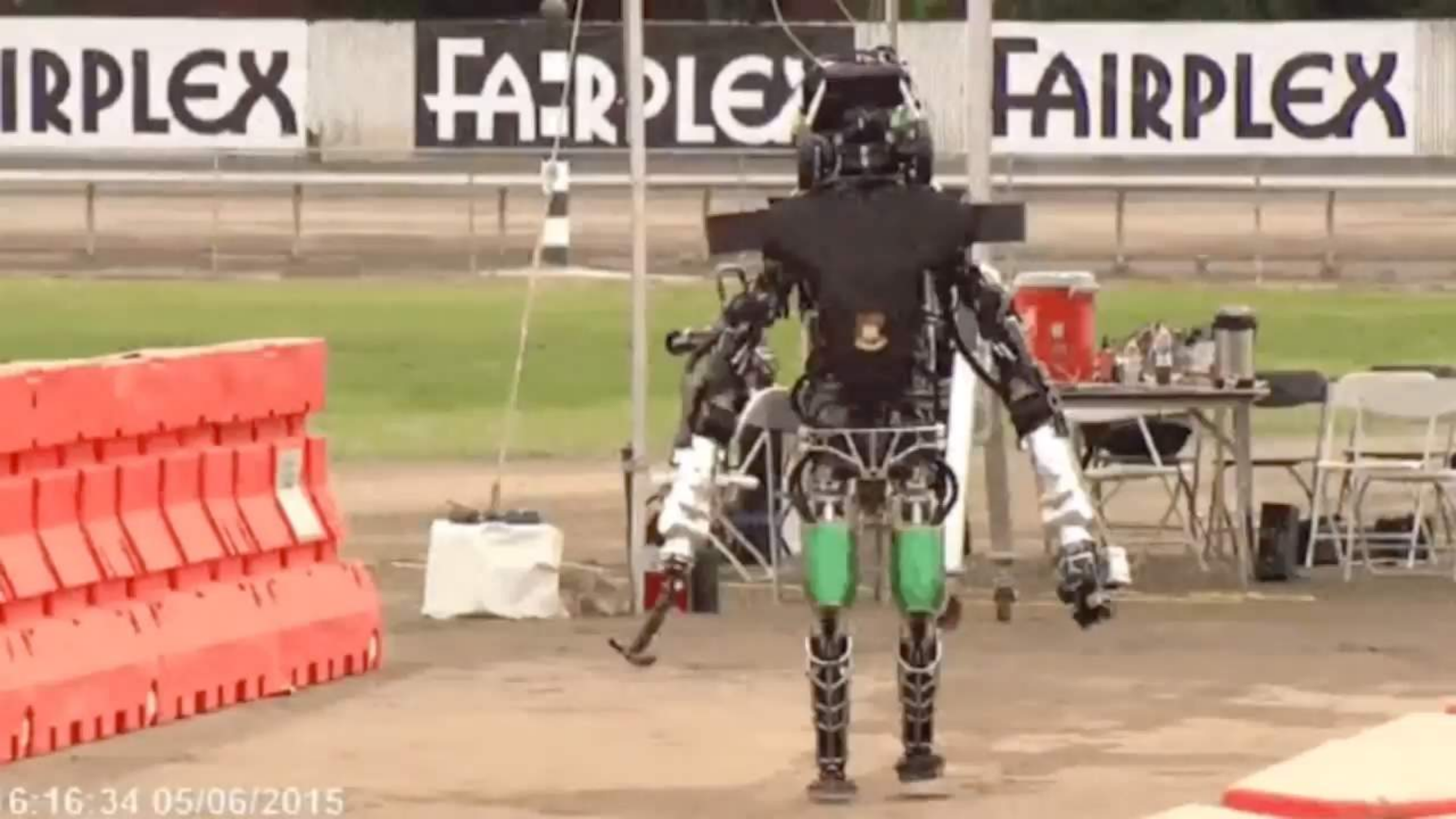
- Gears are one of the oldest inventions, going back 2,000+ years in various forms…
- The harmonic drive (strain wave gearing), which eliminates backlash, was developed in the 1950s…
- We have excellent models of mechanisms, including failure modes and statistics (e.g., MTBF)…
- The electric motor was introduced in the 1830s, and was in practical use by the 1860s…
- Series elastic actuators, which incorporate compliance (via a flexure), are now very popular…
- *These components and their interactions are well understood*

Image: Hebi Robotics

So Where is the Problem? The Devil's in the Software

- The design, development, and test of robotics software is inherently *very* difficult
  - Robotics software tends to be **1) concurrent, 2) distributed, 3) embedded, 4) real time,** and **5) data intensive**
    - These are all *scary* things when robustness, reliability, and safety are required…
- Article from 10 years ago noted "there is a pressing need to engineer the software development process to reduce the cost and time-to-market," while ensuring above requirements are met
- Testing, in particular, is non-trivial because robots are physical (interactive) systems and hence must be deployed in the world

Image: Boston Dynamics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NOT AN EXIT
CAUTION
Boston Dynamics

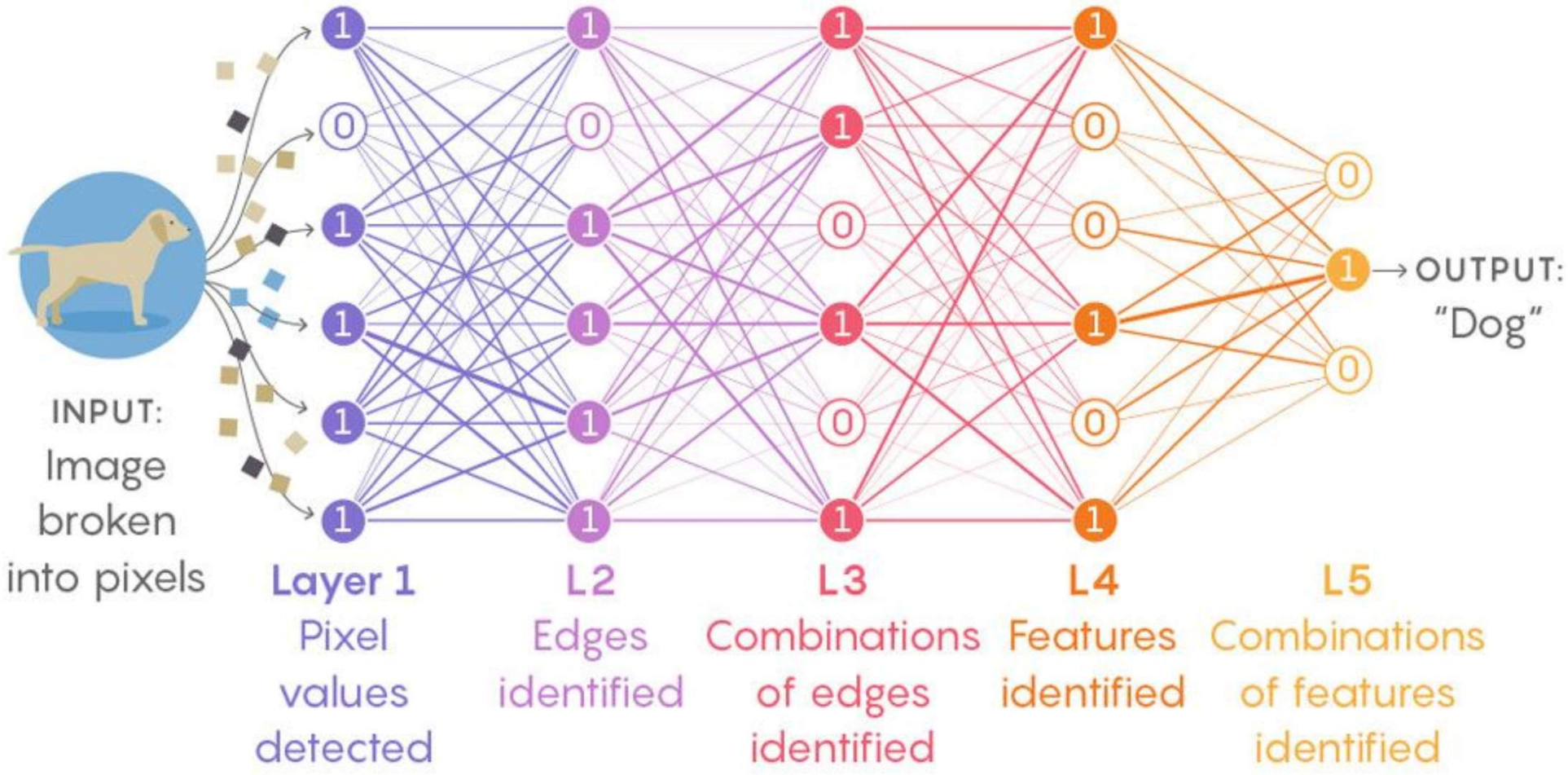
What Happens When Robots Leave Their Cages?

- We are entering an era in which robots are not, or will not in the near future, be behind safety cages
  - ‘Cobots’ are appearing alongside workers in manufacturing, logistics, picking, etc.
  - Self-driving cars have been tested over millions of kilometres on public roads (less in Canada…)
  - Aerial drones are now in regular use in many industries (film/TV, surveying) and might soon deliver packages to your door
- *Robots are (incrementally) becoming parts of our daily lives, and so are interacting with people much more regularly*

Challenges | Software Complexity

- The software that runs modern robotic systems can be incredibly complex, and huge
  - Consider the F-35 codebase: **8 million lines**
  - Statistics on the size of the codebase for, e.g., a Waymo vehicle are hard to come by…
- Estimates of the number of bugs per line of code (or defects per KLOC) vary…
  - *Code Complete* estimated 15—50 / 1000 lines
  - Microsoft claims 0.5 / 1000 lines in production
  - NASA achieved zero for the space shuttle, but at a cost of $1,000's of dollars **per line**

Challenges | Machine Learning and Interpretable AI



Challenges | Machine Learning and Interpretable AI

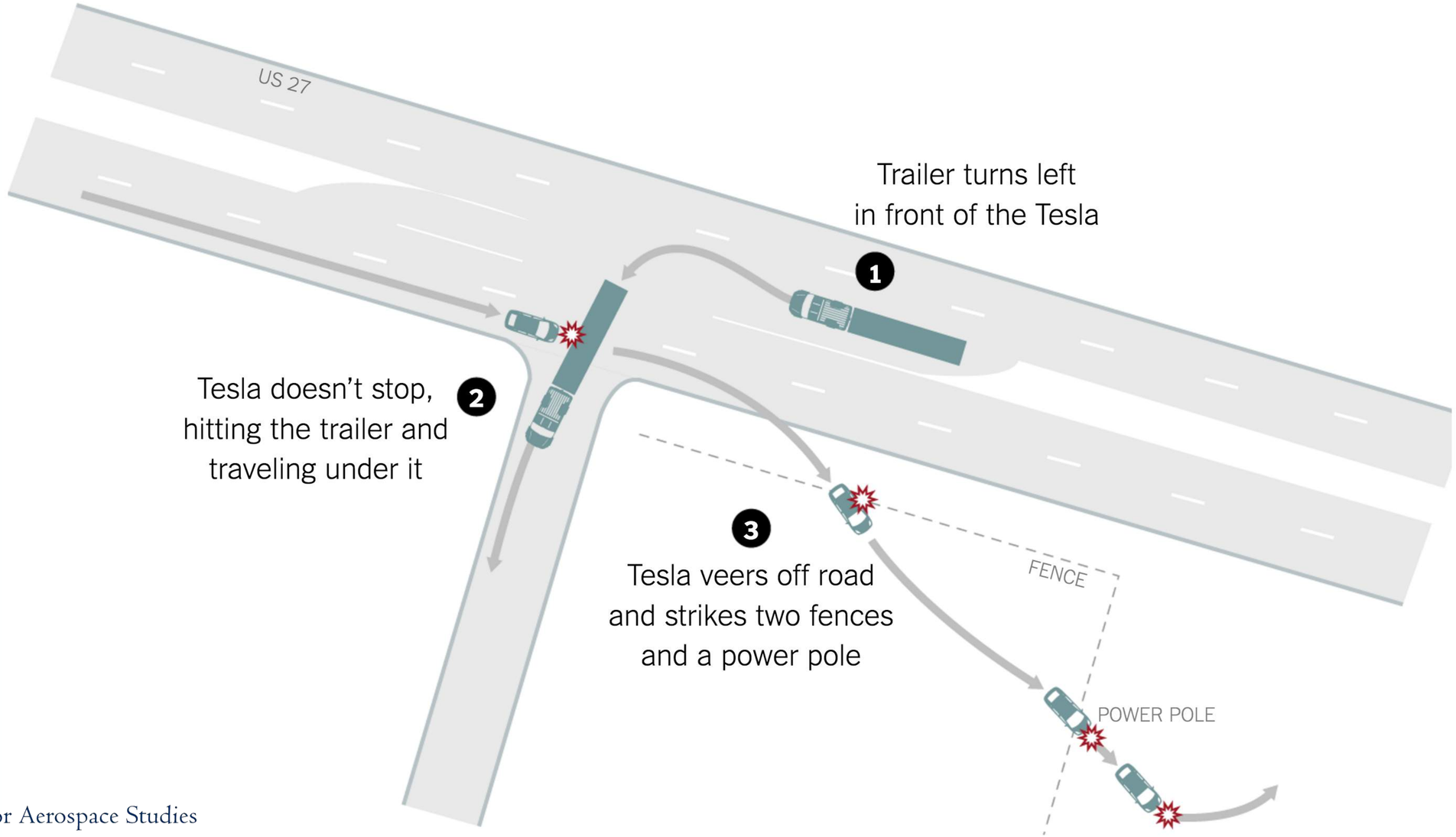
Challenges | The Human Element

- *Most* of the time, human beings do things that are *mostly* predictable (following traffic signals, pedestrian indicators, instructions, etc.)
- *Sometimes*, human beings do irrational and largely *unpredictable* things
  - Driving on the wrong side…
  - Swerving into traffic on a bicycle…
  - Jumping over a safety barrier…
- These events are very difficult for robots to handle! E.g., there may be little or no training data (for learning)

Failures in Edge Cases | Sensor Fusion Gone Wrong

- **Example:** Tesla Model S owner (and fan) Joshua Brown killed May 7, 2016 in Williston, Florida, with Tesla Autopilot system engaged and driving
  - Large 18-wheeler turned left in front of Tesla on divided highway
  - Neither Autopilot nor Brown applied brakes or steering, car drove full speed under trailer “with the bottom of the trailer impacting the windshield of the Model S”
- Tesla’s explanation: “Against bright spring sky background, vision system failed to distinguish white trailer cross-section, while radar mistook trailer for overhead road signage…”
  - Note that Elon Musk has said “LIDAR is a fool’s errand”

Failures in Edge Cases | Sensor Fusion Gone Wrong



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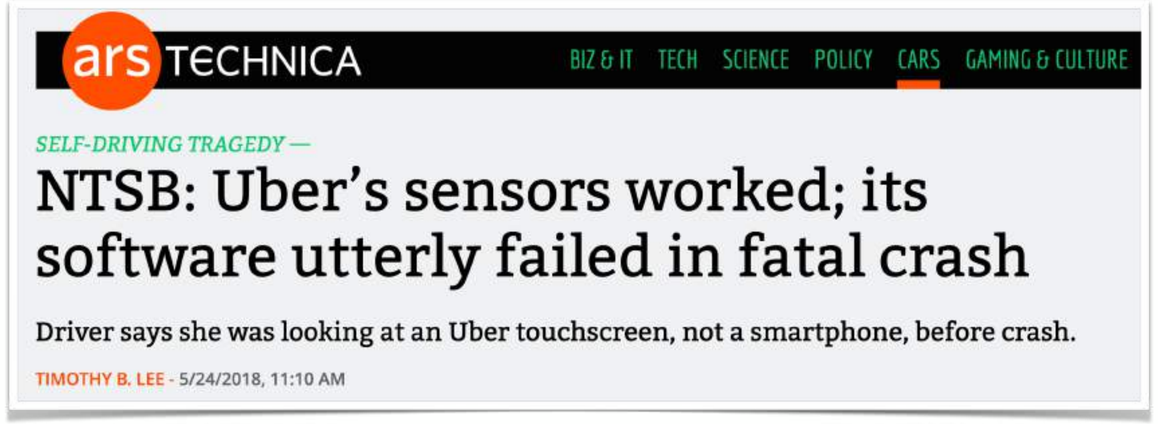
And in March 2019, it happened again…

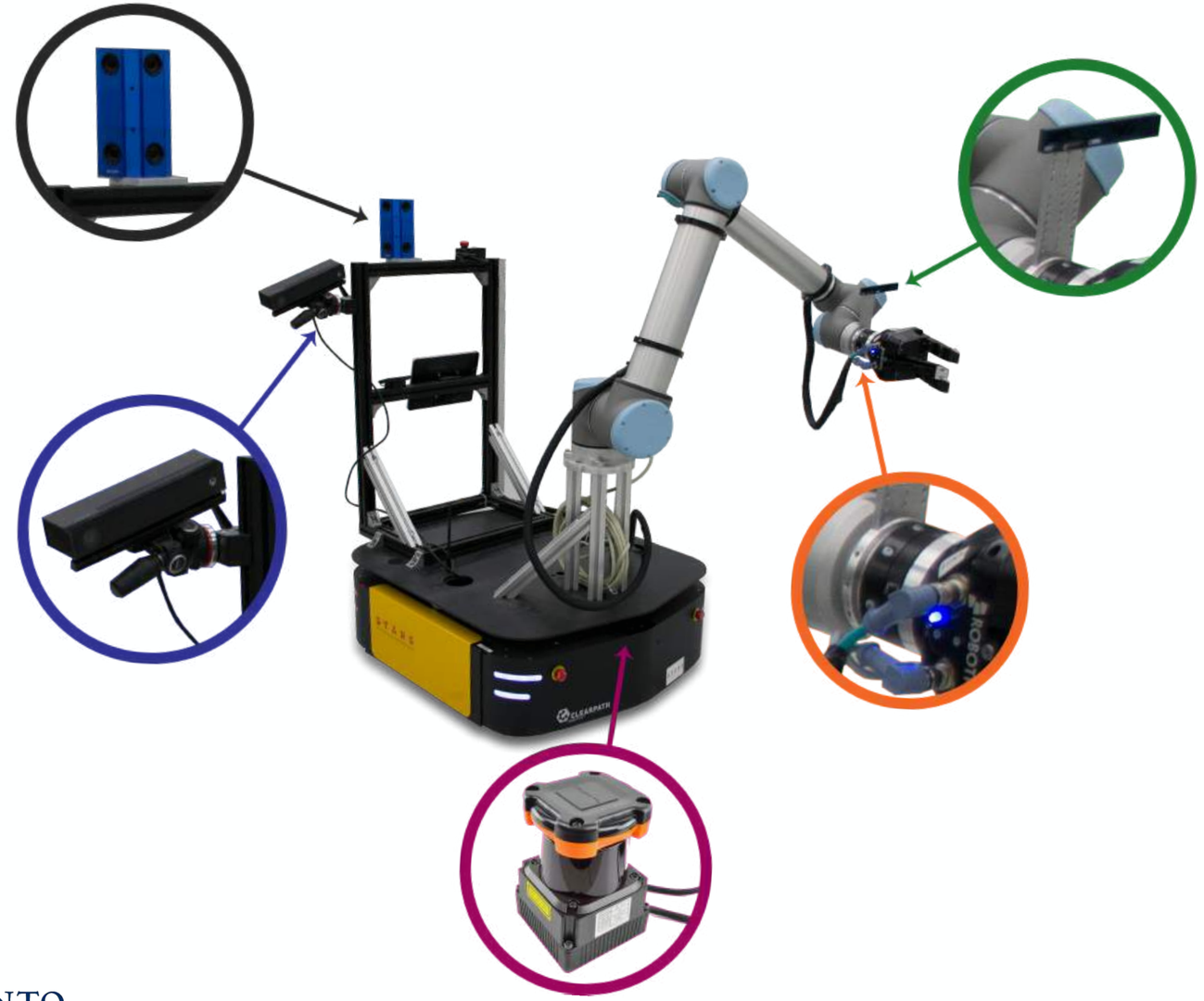
Failures in Edge Cases | Interactions Gone Wrong

- **Example:** Fatal crash involving an Uber self-driving SUV in Tempe, Arizona, March 2018, while in autonomous mode, with safety driver on board…
  - Elain Herzberg, 49, was killed while walking across a highway at night with her bicycle by her side
- Sensors on the car (LIDAR and radar, but not the cameras) did detect the woman, but did not correctly identify her (*unknown object* → *car* → *bike*)
- At 1.3 seconds before impact, software determined an emergency maneuver was needed—*disabled* on Uber cars
  - And the safety driver was *not* alerted; driver was watching her phone…




NTSB

Towards Robustness, Reliability, and Safety | Rich Sensory Systems



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Towards Robustness, Reliability, and Safety | Formal Verification

- Formal verification involves proving the correctness of a piece of code
  - Answers the question: “Have we made what we were trying to make?”
  - Tractable for some algorithms, but remains very difficult for robotics software due to: *concurrency*, *distributed processing*, *embedded nature of code*, *real time requirements*, and *heavy data processing needs*
- This is an active area of robotics research, and new methods are certainly needed
  - Learning systems, in particular, are very difficult to verify (as discussed previously)
  - Predicted to be a hot topic going forward

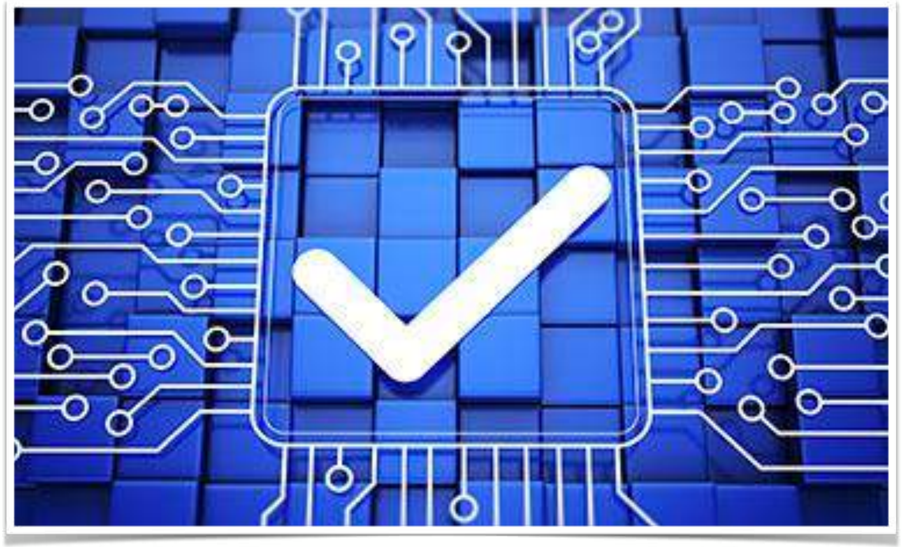
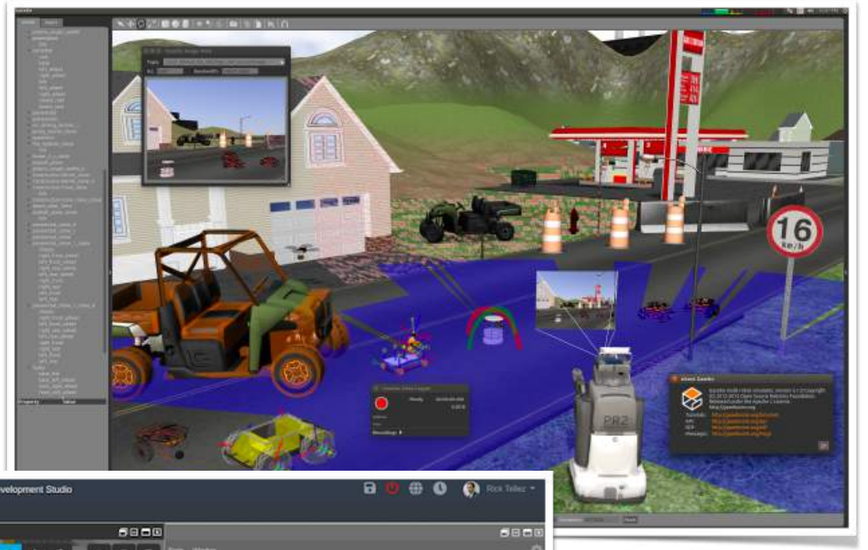
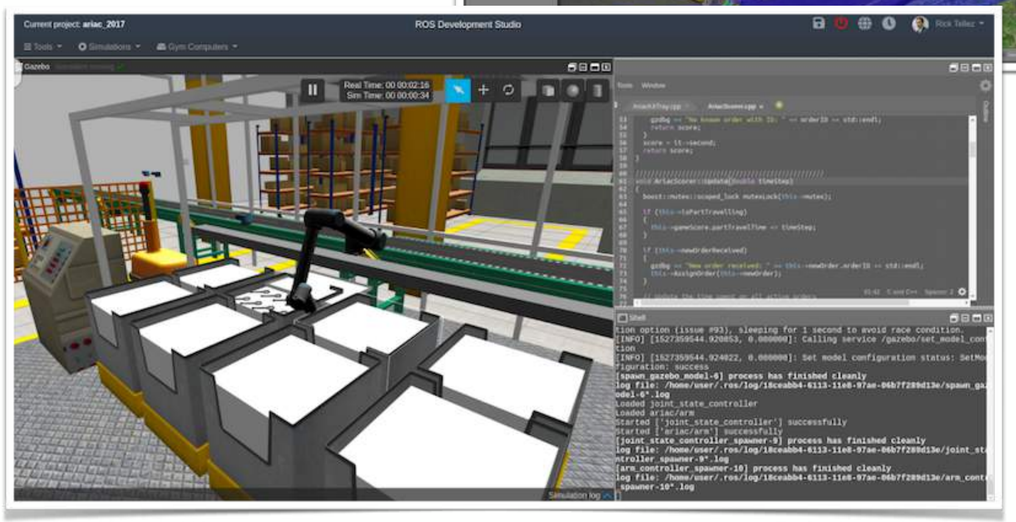


Image: edX

Towards Robustness, Reliability, and Safety | Simulation

- Real-world robot testing is difficult, time consuming, and expensive…
- A promising avenue is to develop better and more realistic simulation software (for learning, etc.)
  - Many robot simulators and physics engines already exist, but there is still a need to better emulate, e.g., grasping and contact
- In addition to various open source efforts, numerous companies have become involved (e.g., NVIDIA) for domains such as autonomous driving





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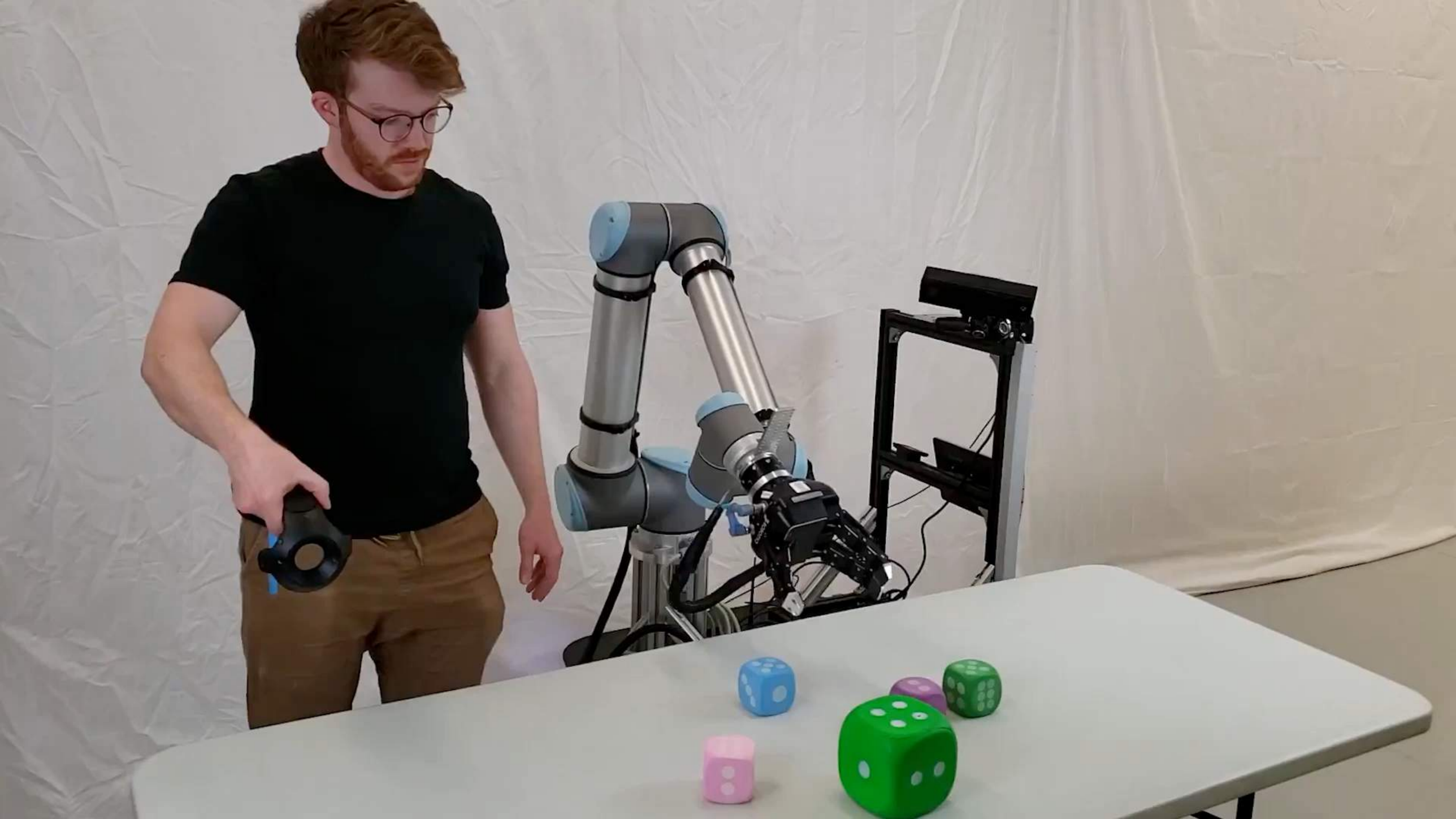
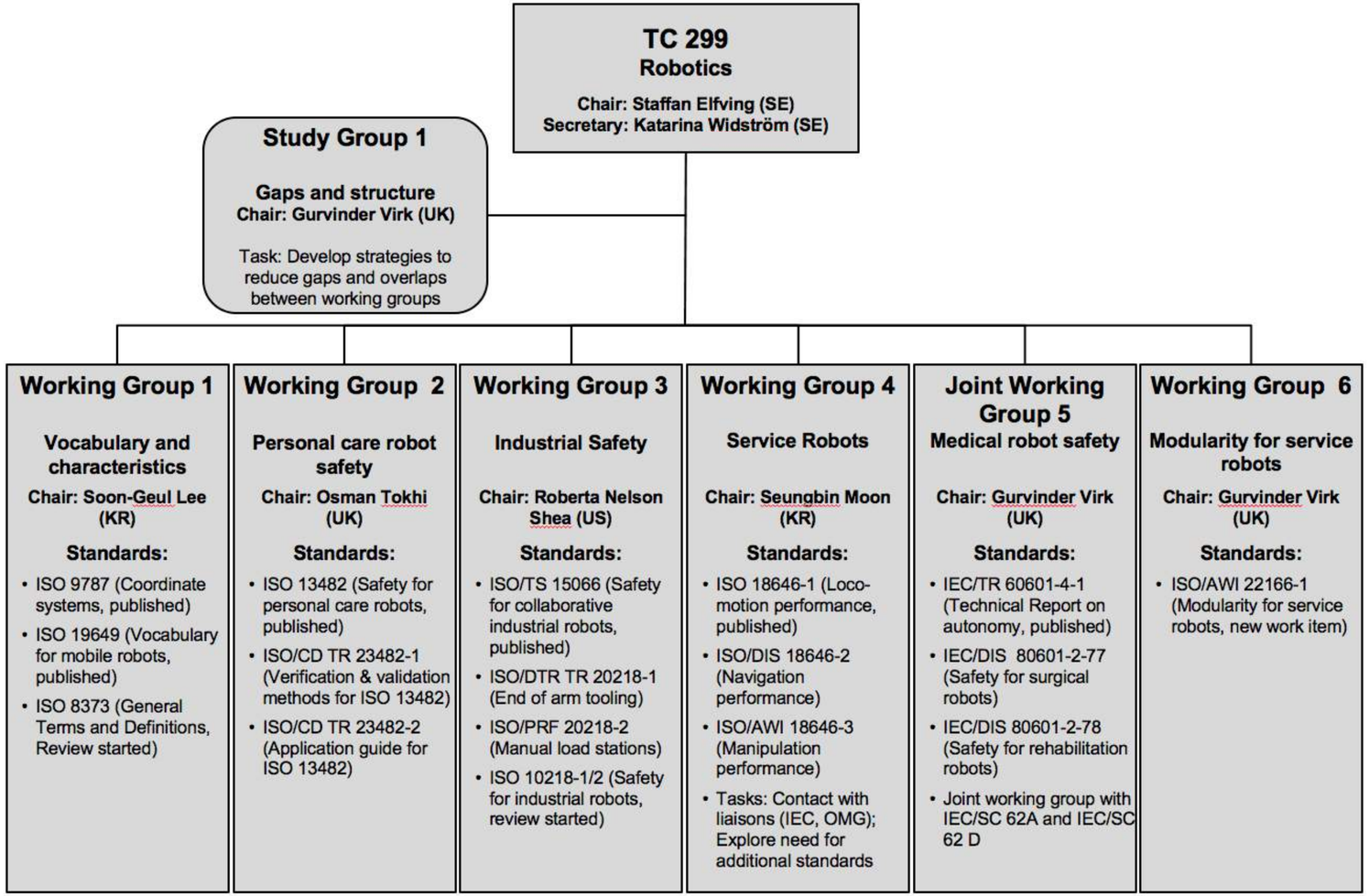


Towards Robustness, Reliability, and Safety | Standardization

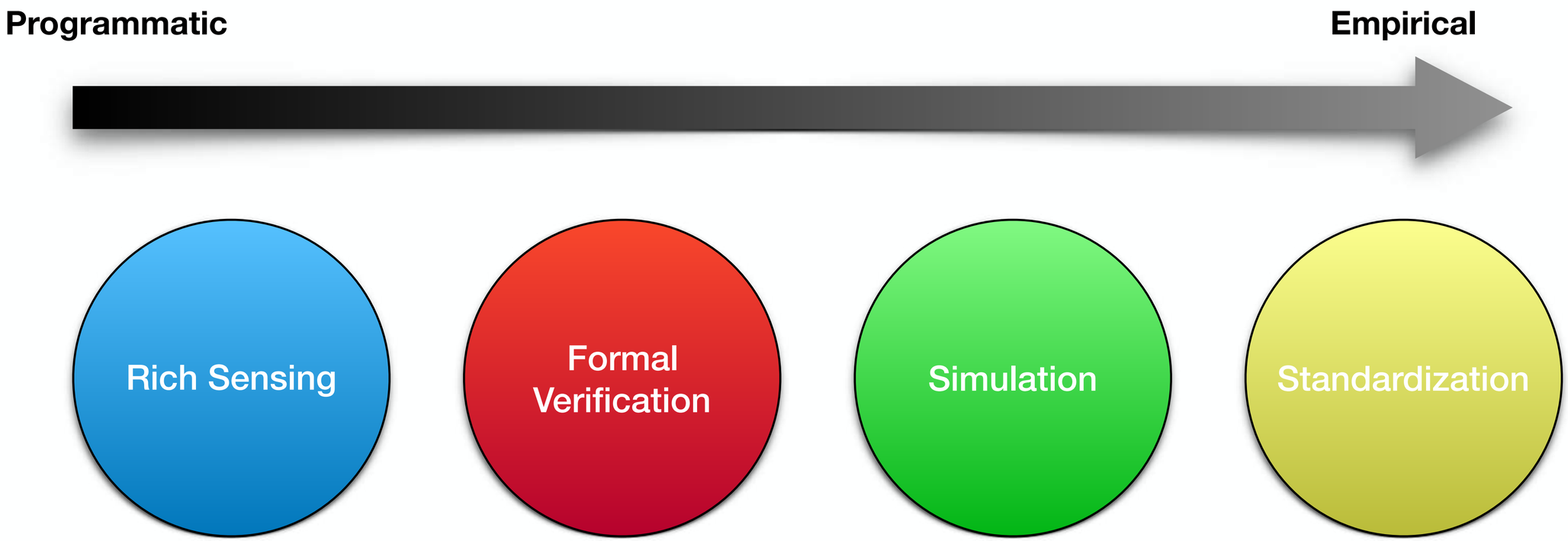


Towards Robustness, Reliability, and Safety | Human Understanding

- To some extent ‘peaceful coexistence’ depends on our own understanding of the capabilities and limitations of robotic systems
- There is a need to educate the general public about robotics
  - Machines will become both smarter and safer over time, but that doesn’t mean we should ignore training
- The field of Human-Robot Interaction has explored, and continues to actively explore, this domain

Image: Hacker Noon

Summary | A Path to Robustness, Reliability, and Safety



Thank You | Questions?

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http://starslab.ca/

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