Data Science, AI, and ML in Systems Engineering

From Classical Control to Intelligent Systems

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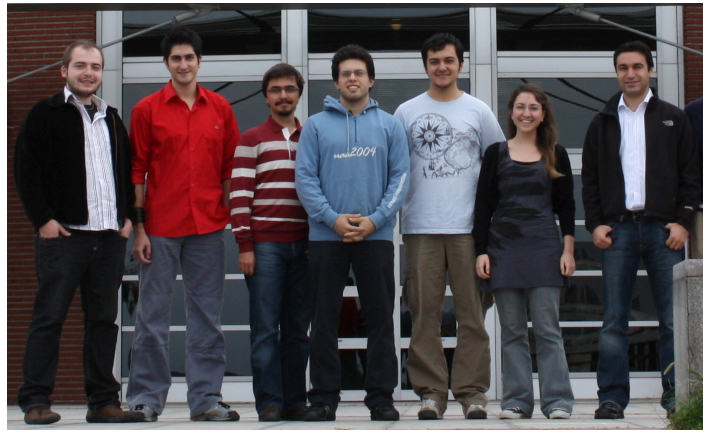
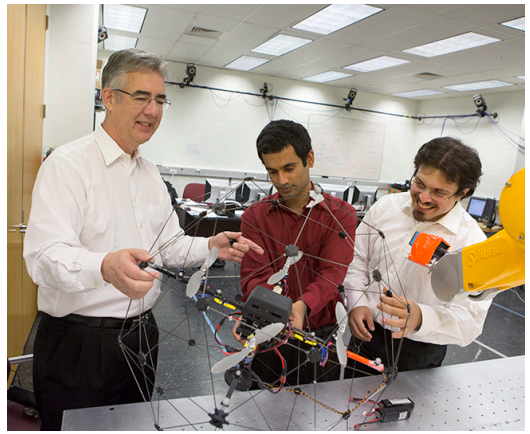
Who am I?

My Journey

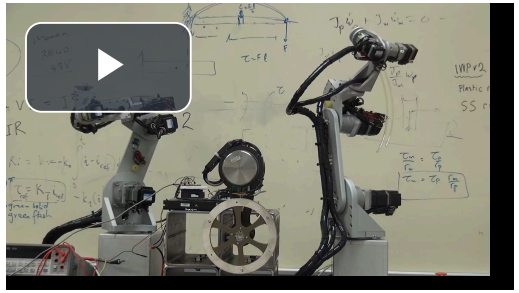
- **Education**: BS/MS in Mechatronics (Turkey), PhD in EE & MS in Math (UTD).
- **Research Training**: Postdoc at U. Naples (Italy) & MIT (USA).
- **Professorate**: Assistant & Associate Professor at **Boise State University** (2017-2025).
- **Currently**: Back home at **UT Dallas** as Associate Professor of Systems Engineering.

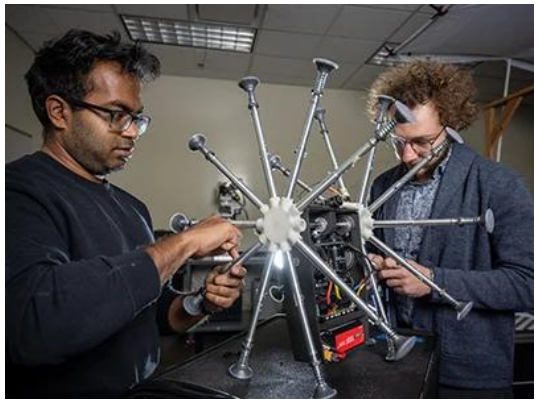




BSU: Locomotion & Contact

- **The Problem**: Robots struggle with uneven terrain and physical collisions.
- **The Solutions**:
  - **Rimless Wheel**: Stability of passive walking.
  - **Astria**: Drone/power-line interaction.
  - **IWP**: Energy-shaping control for acrobatics.

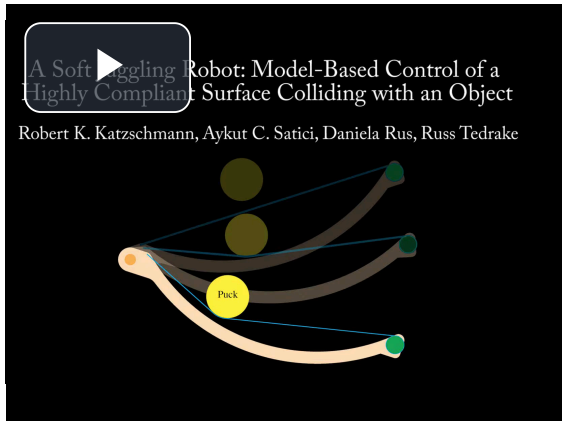




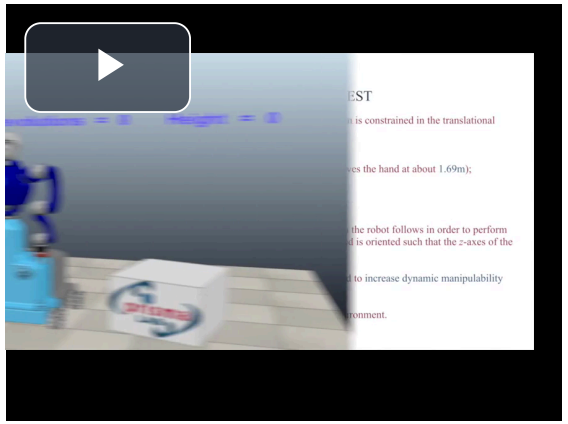
Systems Engineering in Action

Drones

Soft Juggling



Manipulation



> **Note**
>
> Systems Engineering connects **Control Theory**, **Embedded Systems**, and **Mechanical Design** to make these robots work in the real world.

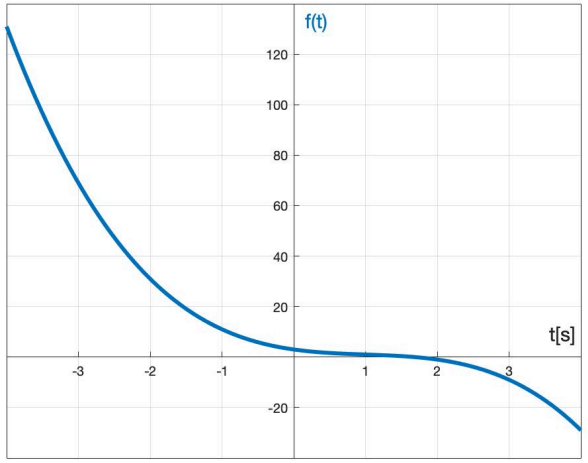
Agenda

1. **The Evolution**
    - From Clockwork to Neural Nets.
2. **The Concepts**
    - DS vs. AI vs. ML.
3. **The Lifecycle**
    - Where AI fits in the V-Model.
4. **Live Case Study**
    - The Furuta Pendulum.
5. **The Future**
    - Black boxes & Ethics.

Part 1: The Evolution

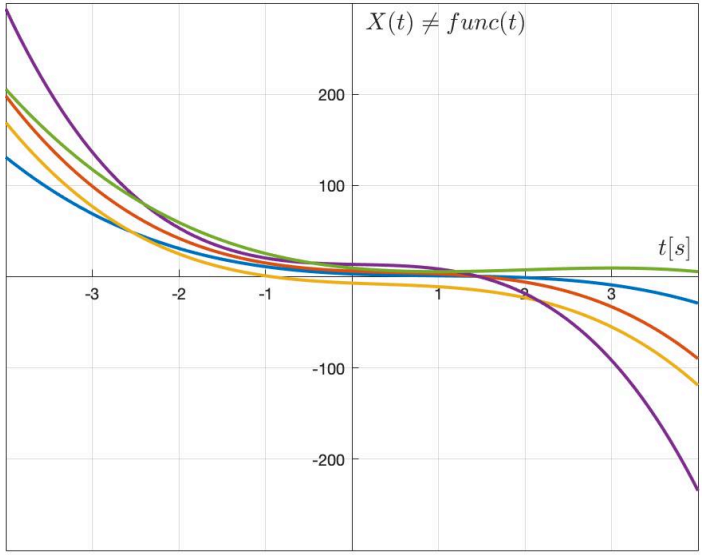
Classical vs. Intelligent Systems

Deterministic



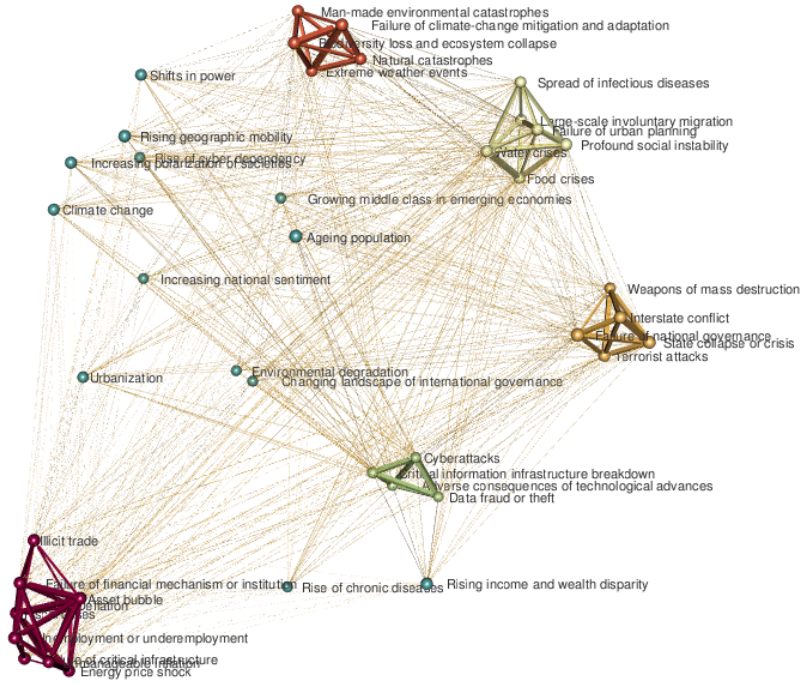
Predictable. Static.

Stochastic



Adaptive. Learning.

Why We Need AI

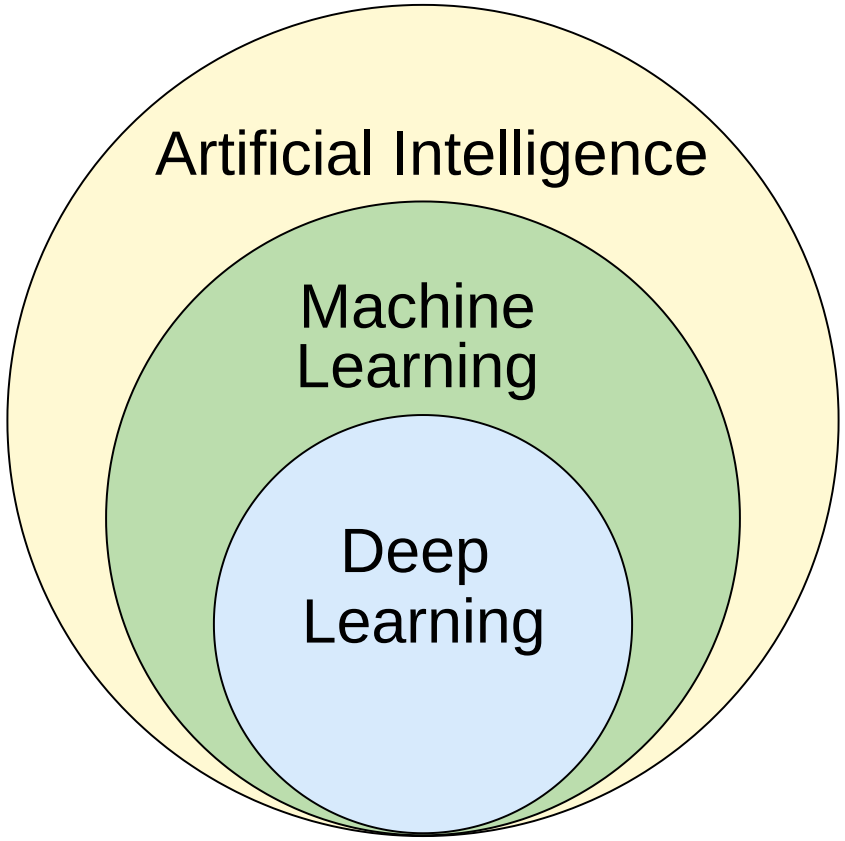


The Complexity Gap

- **Data Volume**: Terabytes/hour.
- **Dimensionality**: Systems with 1000+ variables.
- **Human Limits**: We cannot manually optimize these anymore.

Part 2: The Engineer's Definition

Disentangling the Buzzwords



The Engineering View

Classical

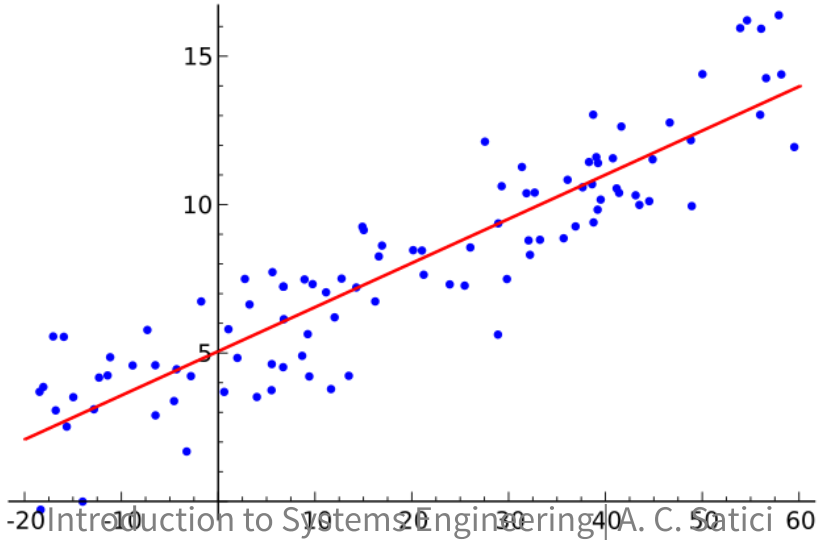
$$y = f(x)$$

We know the physics (F=ma). We write the equation.

Machine Learning

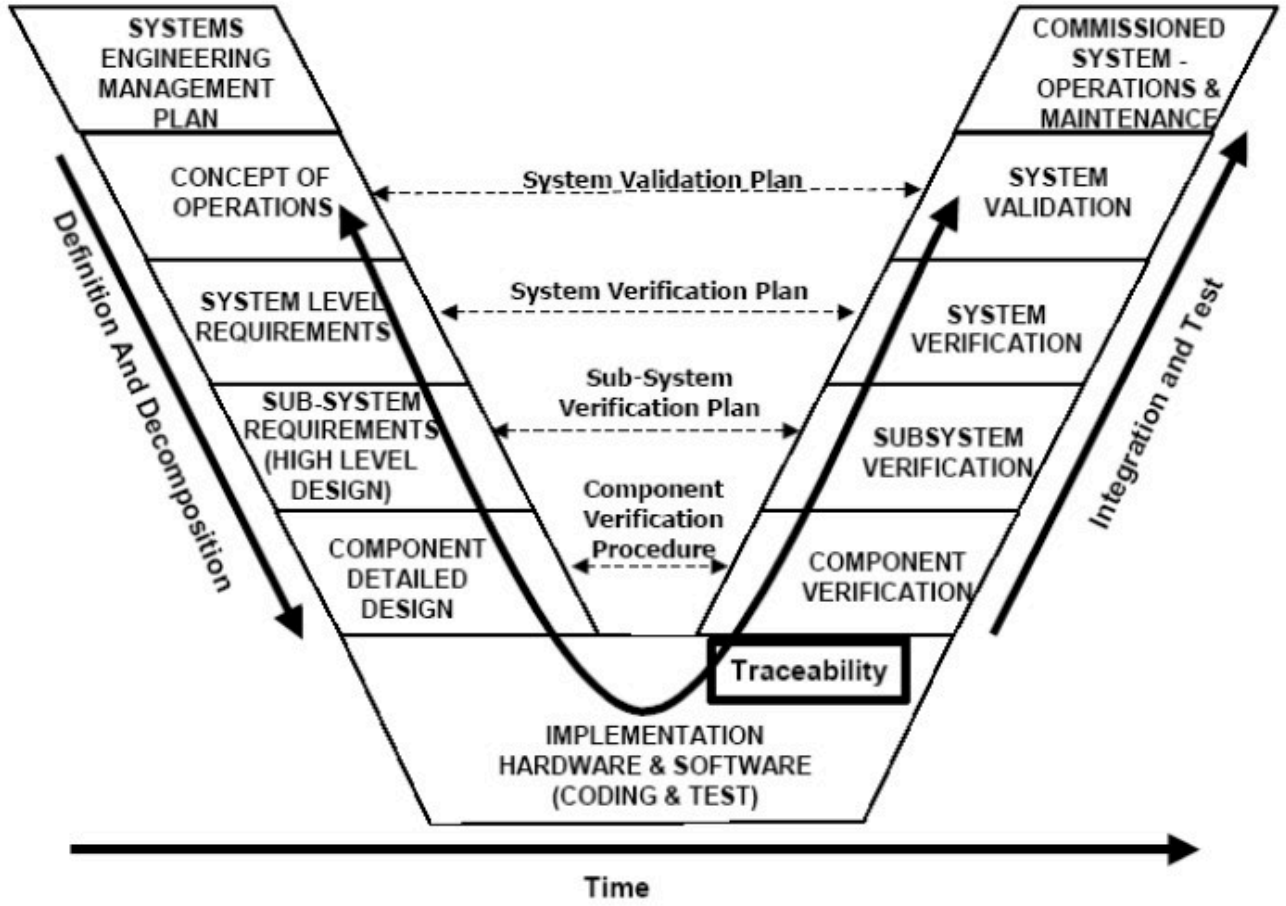
$$y \approx \hat{f}(x)$$

We have the data points. The computer finds the curve.



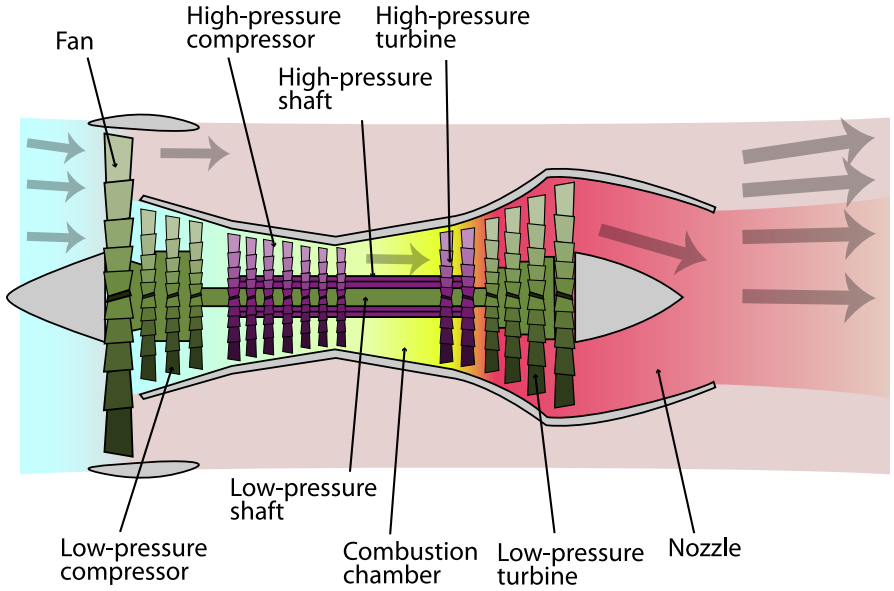
Part 3: The Lifecycle

The V-Model and AI



Operations: The Digital Twin

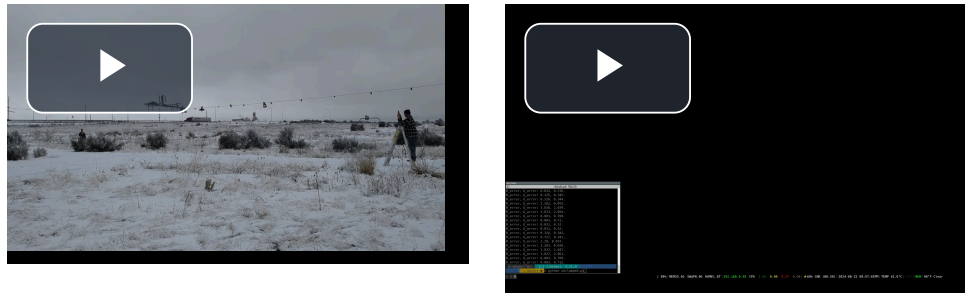
Physical Asset



Digital Replica

Astria: Digital Twin

- **The Physical Asset**: Autonomous drone with a gripper.
- **The Digital Replica**: High-fidelity physics-based simulation.
- **Systems Goal**: Testing contact physics and control logic virtually before risking expensive hardware on power lines.

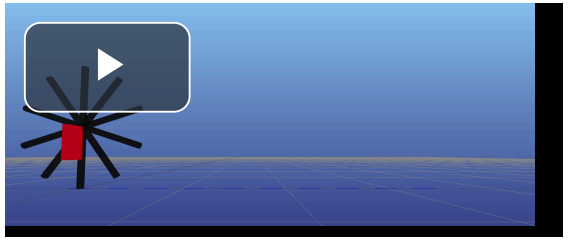


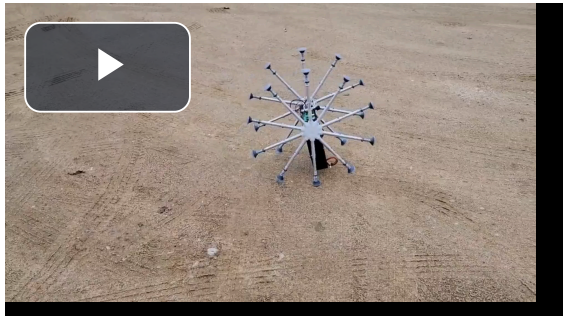
Real-world (Left) vs. Sim2Real Replica (Right)

Rimless Wheel: Robustness

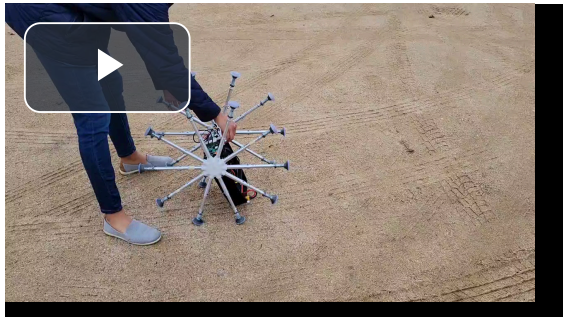
- **Systems Goal**: Walking that doesn't fall when the ground changes.
- **Non-examples**:
  - Falling over (unstable).
  - Tripping on uneven ground (fragile).
- **Examples**:
  - Steady rhythm on flat ground.
  - **Robustness**: Recovering from uneven terrain.

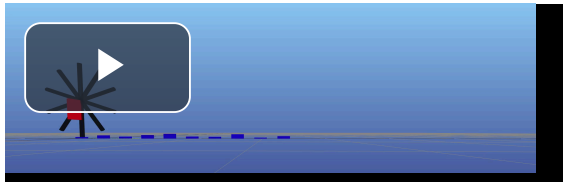
Non-examples (Not Working)





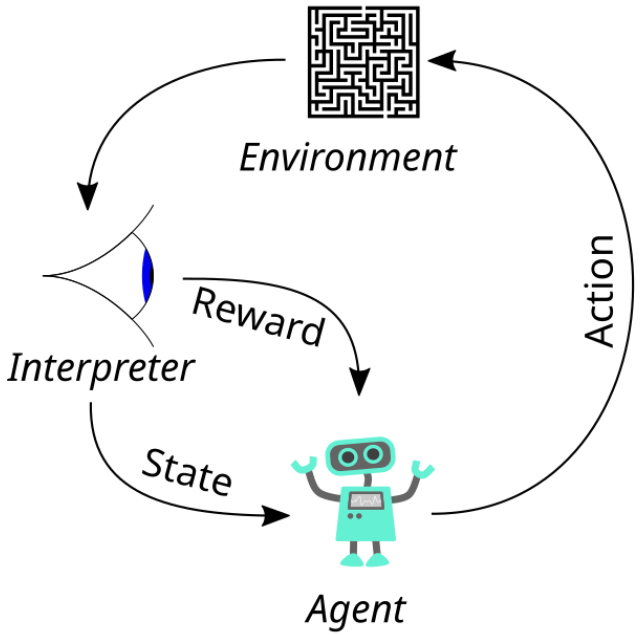
Examples (Working Well)





Part 4: Live Case Study

How AI Learns to Control

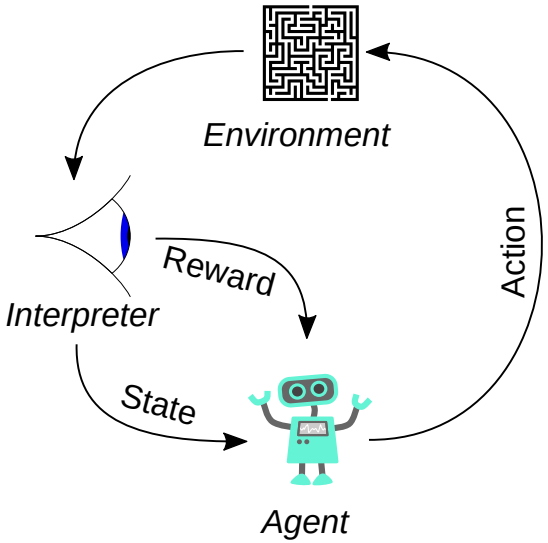


Reinforcement Learning

1. **Observe** state.
2. **Take Action** (Voltage).
3. **Get Reward** (+1 if upright).

Sim2Real: The Reality Check

Simulation



Perfect Math

Reality

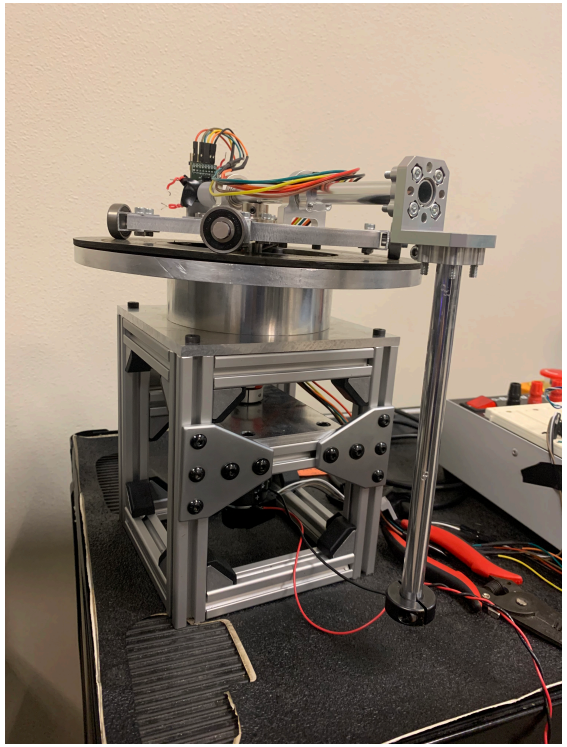
Noise & Friction

Learning to Walk: RL in Action

- **The Goal**: Make the robot walk forward.
- **The Process**:
  - Start with zero knowledge.
  - Try random actions.
  - Get rewarded for forward motion.
  - **Result**: Emergent walking behavior.

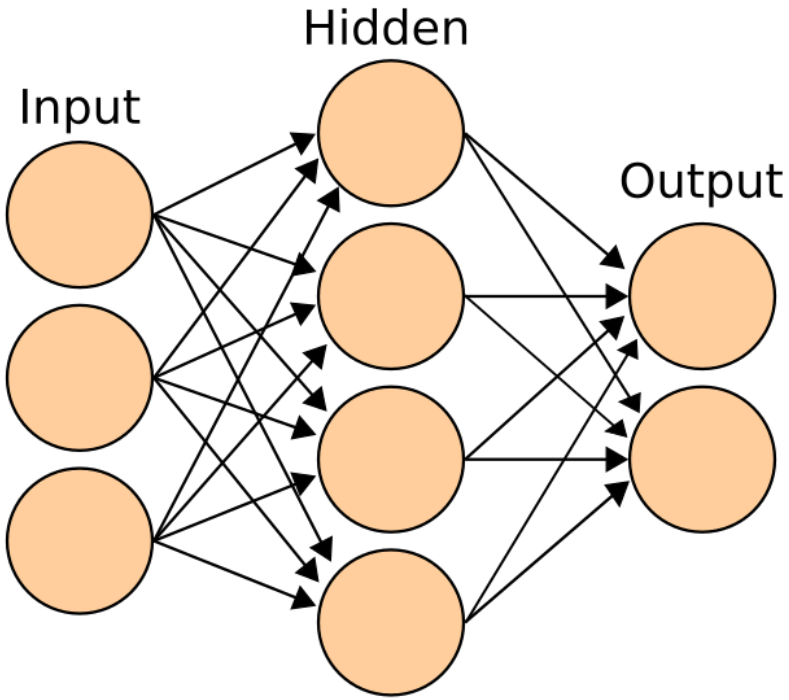
The Furuta Pendulum

- **Goal**: Balance upright.
- **Actuator**: Base Motor.
- **Sensor**: Encoders.

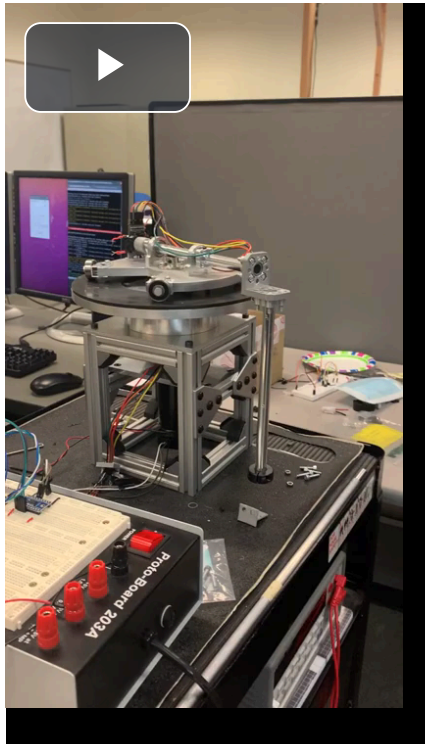


Integration: The Furuta Pendulum

Controller Architecture



Performance (Pre-Move)



- **Hardware**: Assembled (Physical).
- **Controller**: Neural Network (Code).
- **Current Status**: Broken (Moved to Dallas).

Part 5: The Future

The Black Box Problem

Classical Code

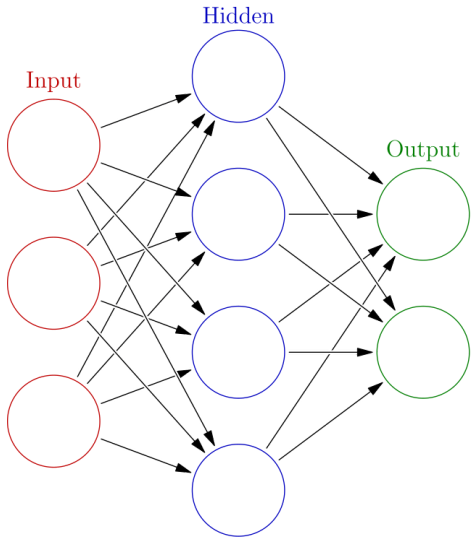
```
IF speed > 50 THEN brake
```

(Traceable)

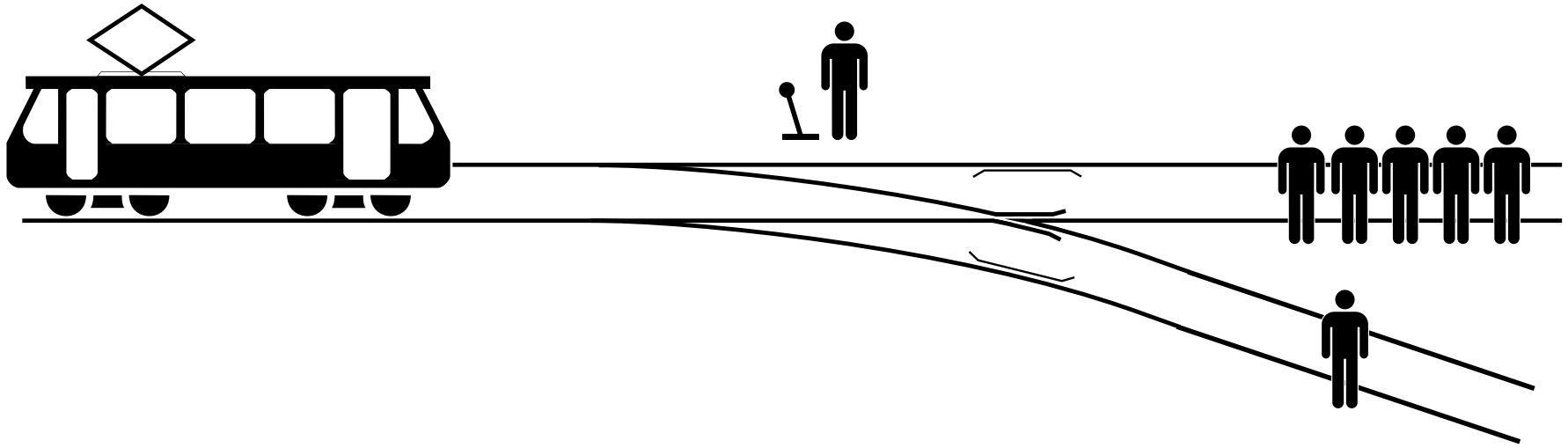
Neural Network

```
0.23 * x1 + 0.99 * x2
...
```

(Opaque)

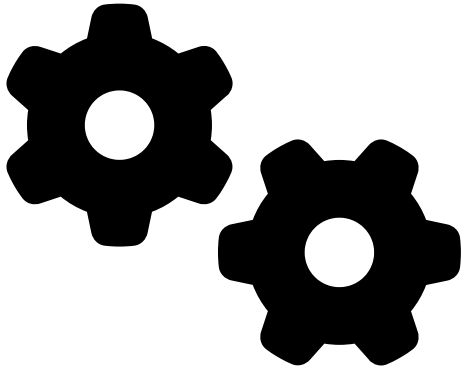


The Ethics of AI



Conclusion

Summary



1. **Systems are changing**: From static to dynamic.
2. **Tools**: Python/MATLAB + Control Theory.
3. **Mindset**: AI is just a subsystem. Integration is key.

Questions?

Thank you!

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Questions?