Multi-Fidelity Testing and Evaluation of AI-Enabled Systems

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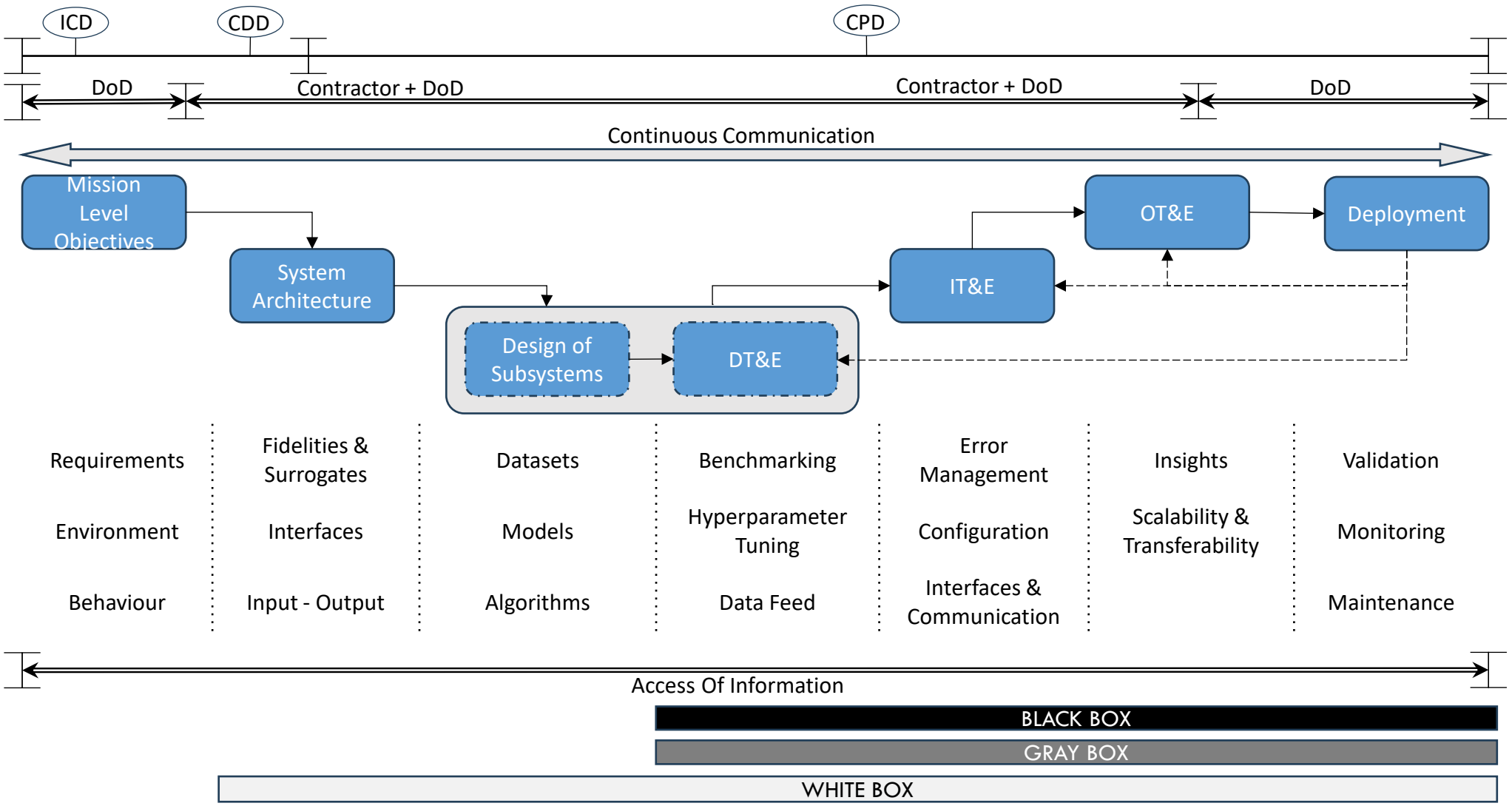
Motivation: Levels of Access of Information



Driving Questions Pertaining to T&E

- **Efficiency of T&E:** How to reduce the cost and time for T&E using evidence generated throughout the systems engineering process?

- **Access:** To what extent does the government need access to training data, algorithms, hardware, and software?
  - Reduced the need for testing (and increase in confidence assurance) resulting from an increase in data/model rights.

- **Cost of IP:** How much to pay for information (data, model parameters, etc.)?

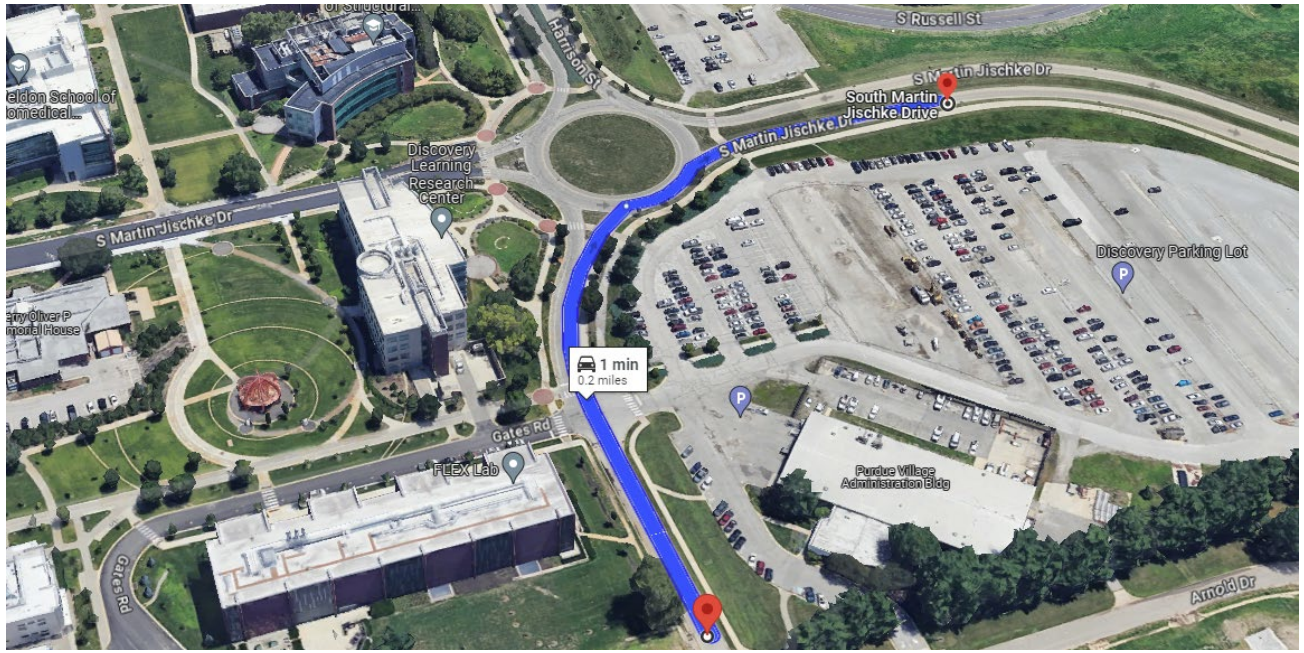
Autonomous Driving Use Case

- AI model: detection system on an autonomous vehicle
- Input: Video file from camera
- Output: Object location in each frame

[6] https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.alten.com%2Fnext-generation-camera-based-adas-development

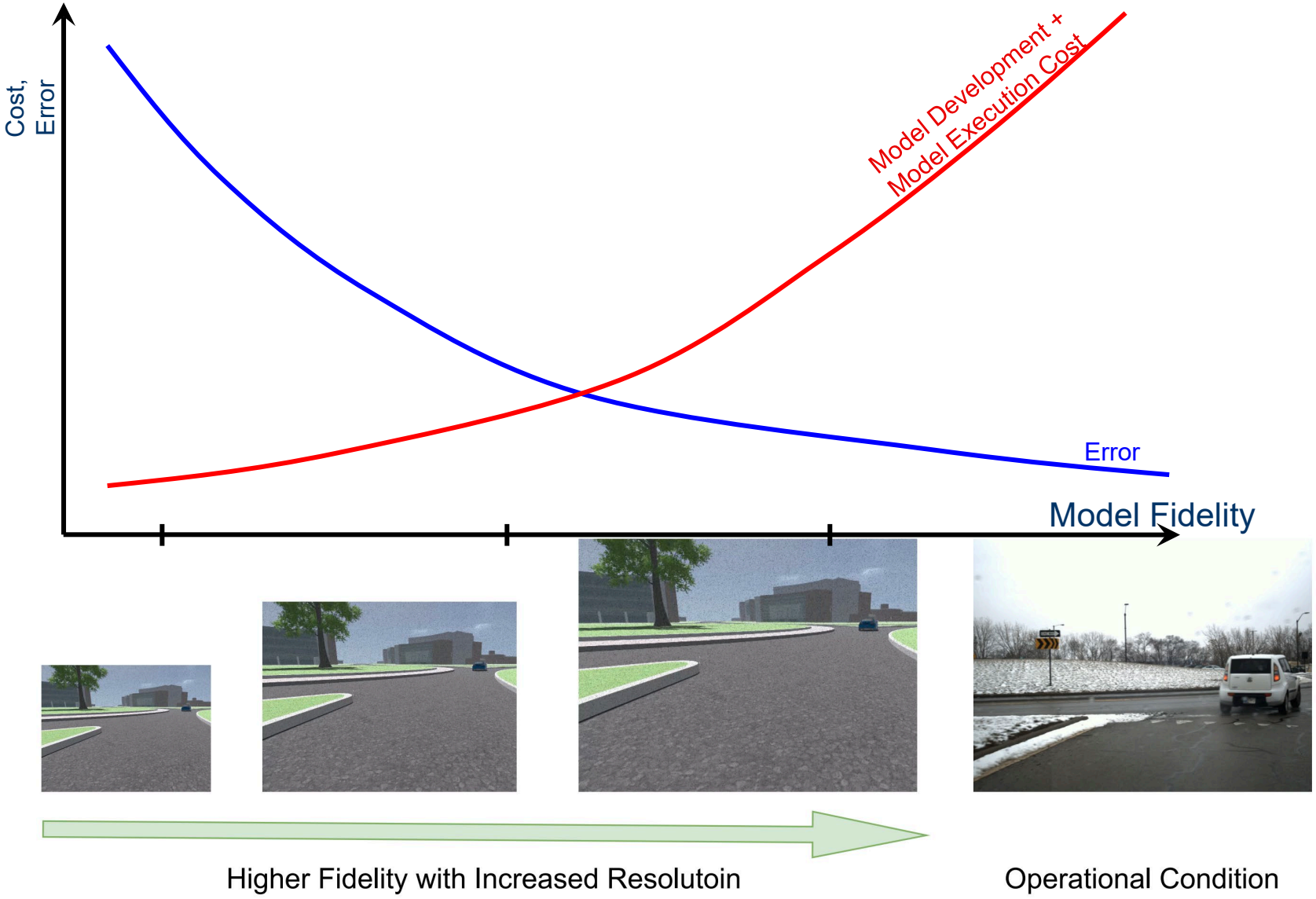
Autonomous Driving Use Case

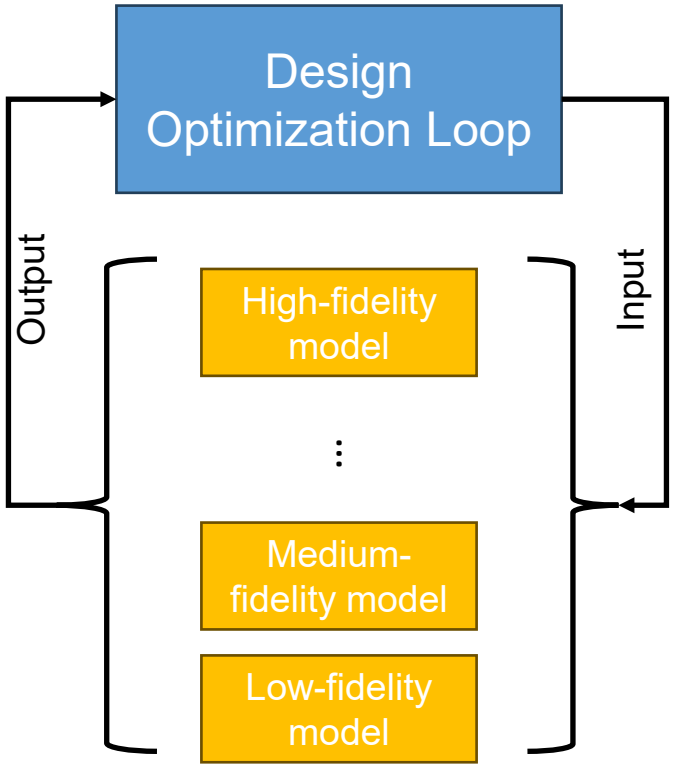
- **System tested:** YOLOv8 (object detection)
- **Setting:** Autonomous Vehicle driving through a roundabout
- **Simulation:** Unity simulation engine and occlusion post-processing



R	Requirements
r_1	System must operate on a 1080p HD video format
r_2	System must operate in direct overhead sunlight
r_3	System must operate in raining weather condition
r_4	System must operate under 25% random occlusion of vision field
r_5	System must operate with a 30 fps operational speed
r_6	System must have average confidence over 80% in vehicle prediction
r_i	…

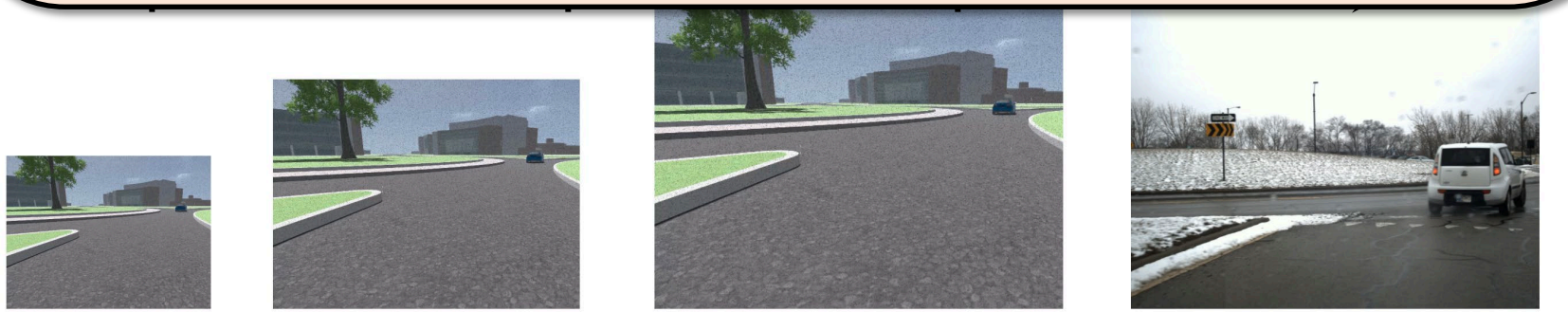
Models at Multiple Fidelities





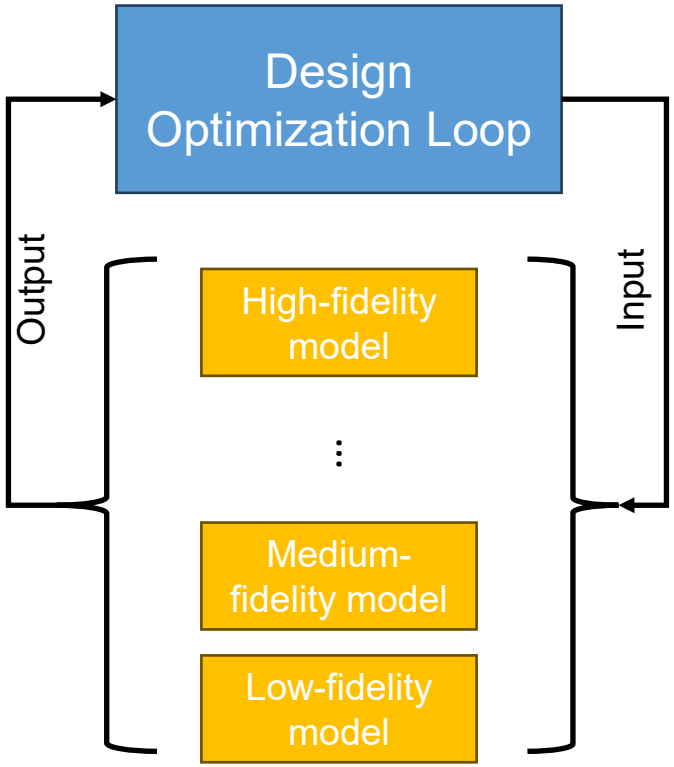
Models at Multiple Fidelities

Need: a method to **design test sequences** to most efficiently reach a **degree of certainty** about how well the system satisfies each requirement in the designated operational environment.



Higher Fidelity with Increased Resolutoin

Operational Condition



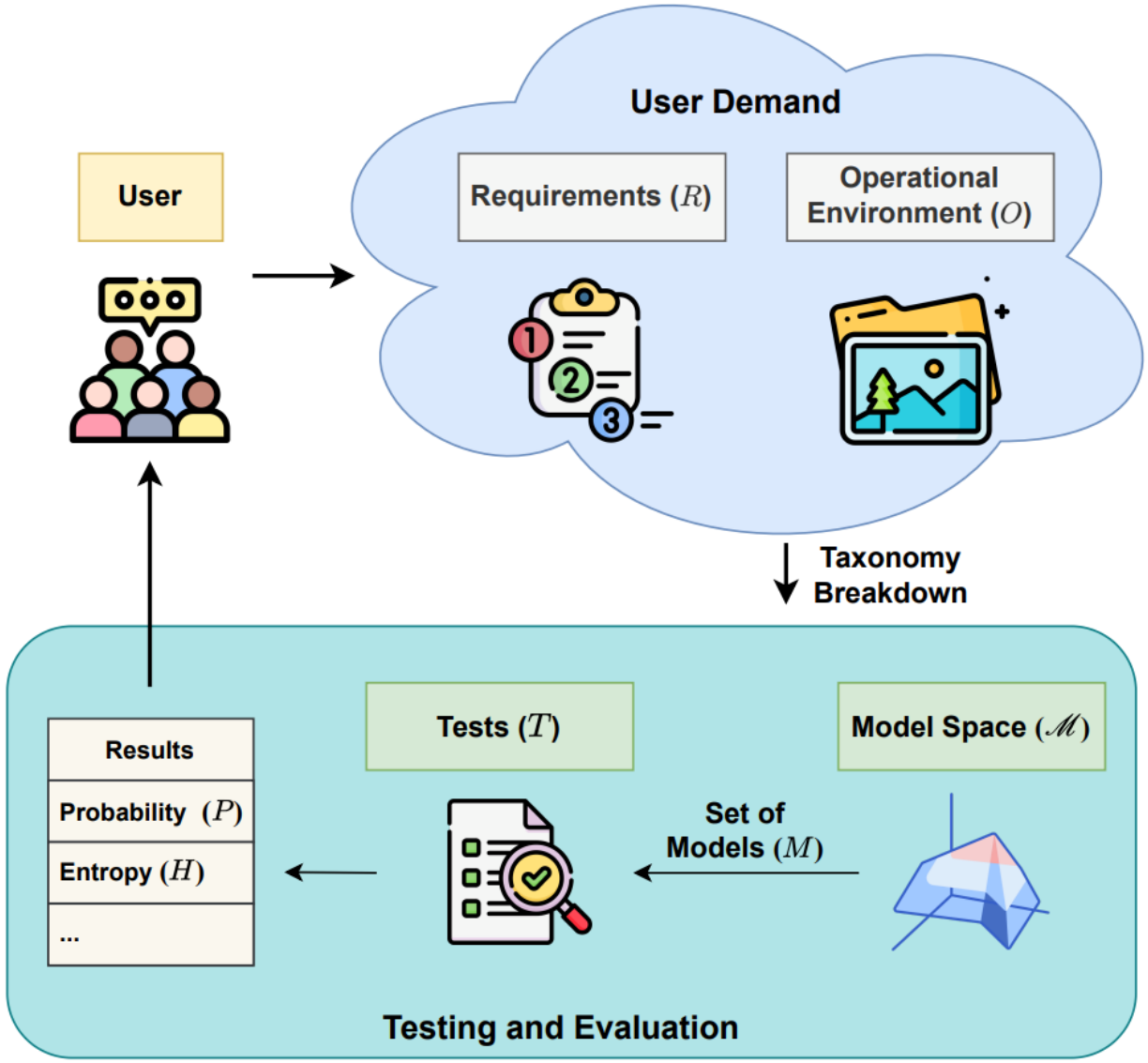
Proposed Approach

Acquisition (User) Side

- Define R & O
- Receive test results

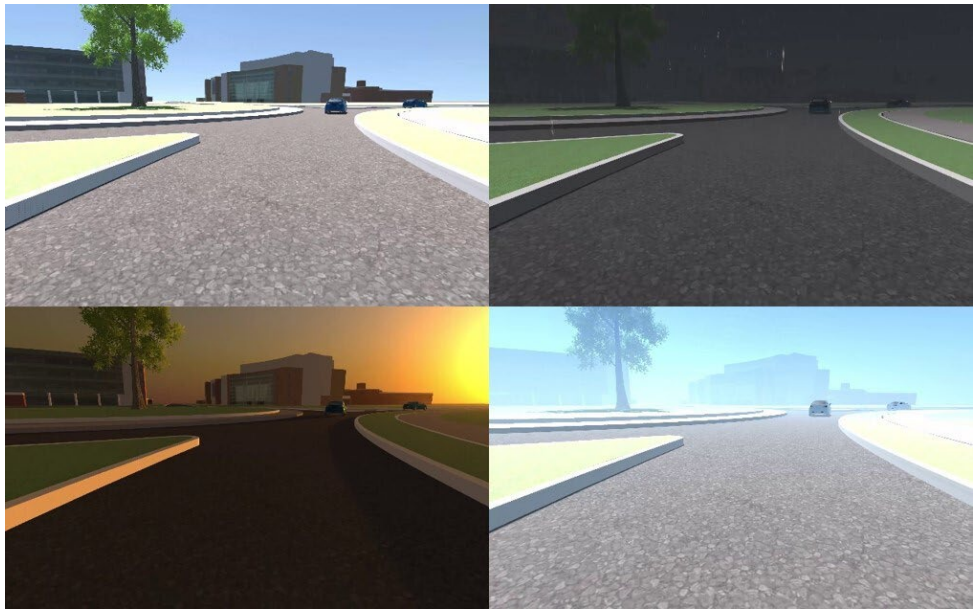
Testing and Evaluation Side

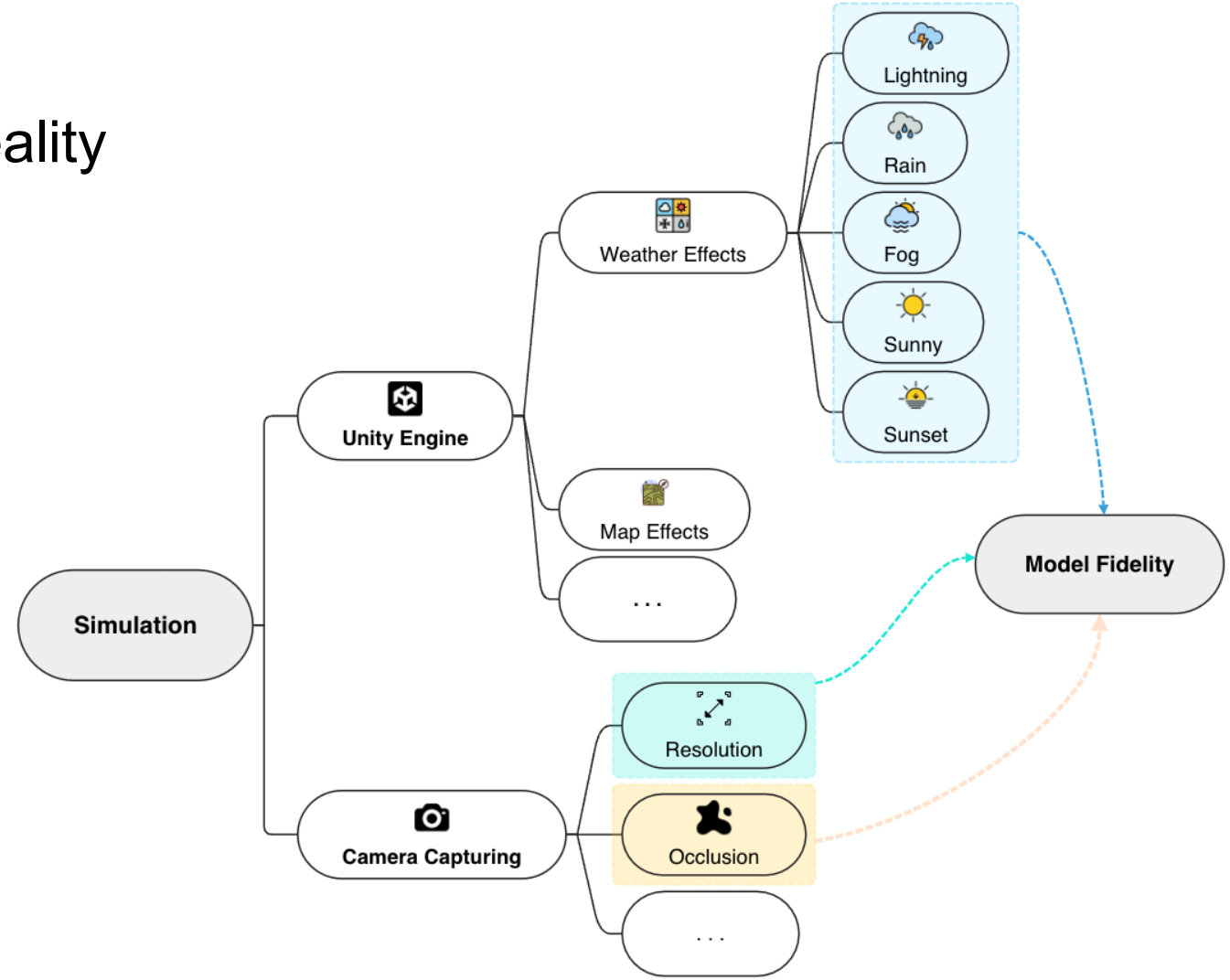
- Model Space Definition
  - Taxonomy Breakdown
- Sequential Test Selection
  - Bayesian Optimization + Entropy
- Updating Belief
  - Bayes' Rule



Constructing the Model Space

- ***Model(m_j):*** instance of simulation
- ***Fidelity:*** accuracy in representing reality
- ***Cost:*** $c = c_p \times c_l \times c_o$





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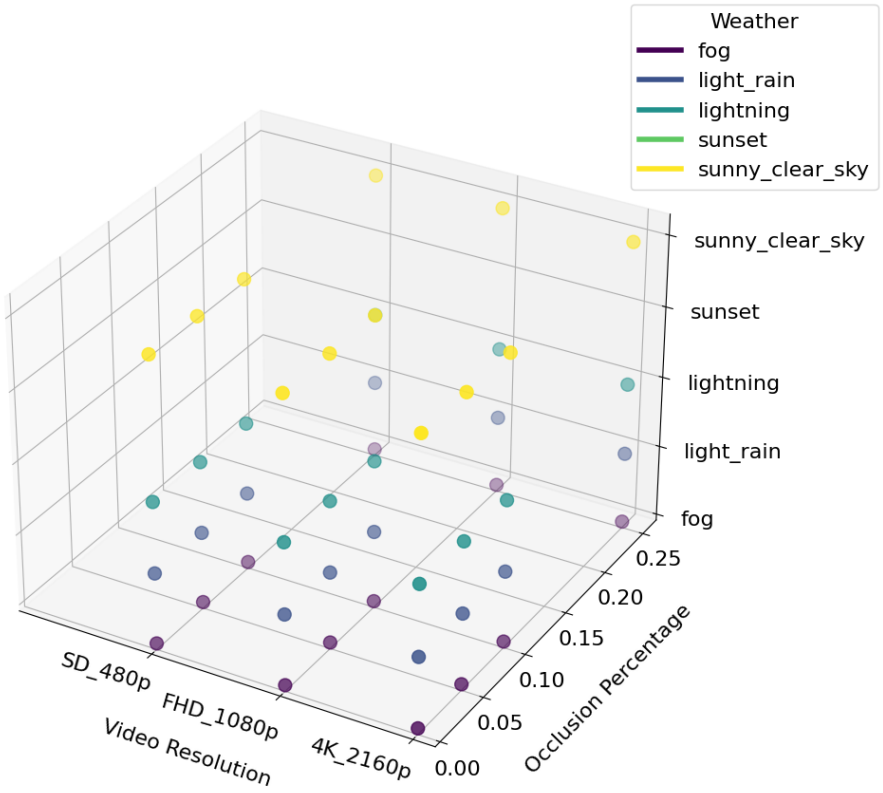
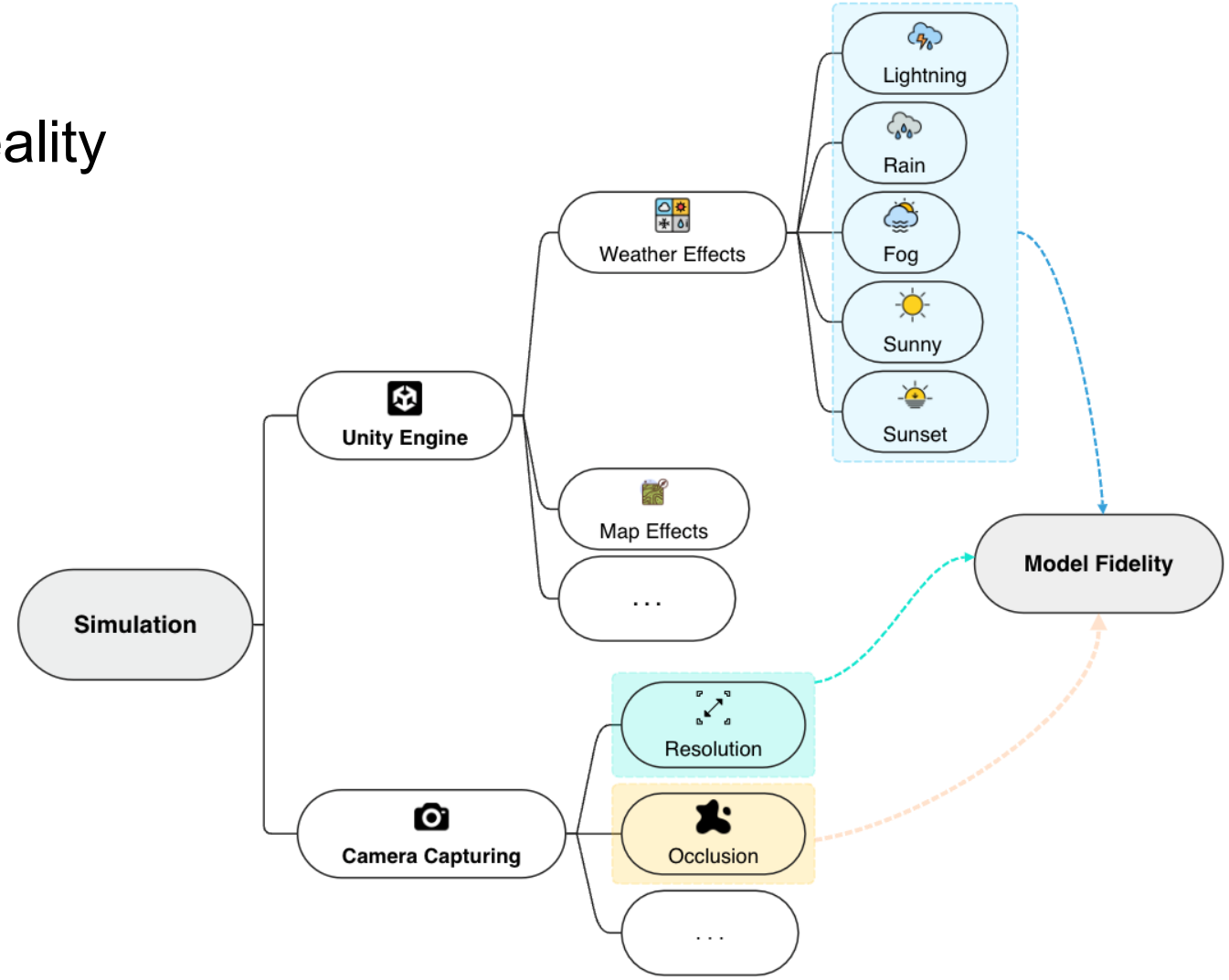
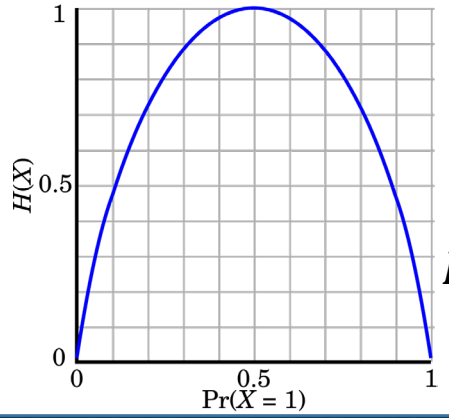




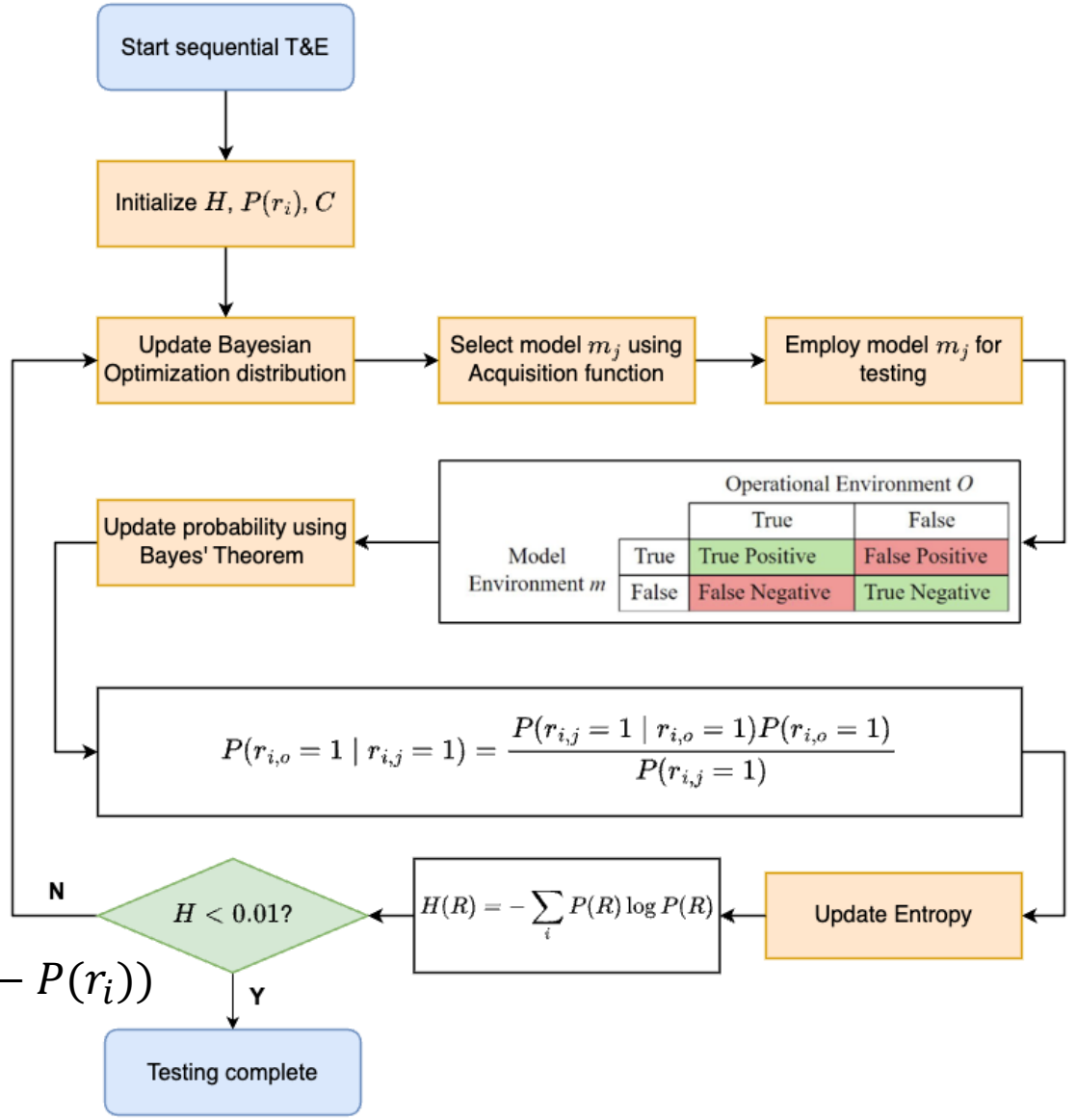
Sequential Model Selection

- **Random variables:** $r_{i,j}$, $r_{i,o}$ (probability of requirement r_i being satisfied)
- **Objectives of the T&E process:**
  - minimize uncertainty about whether the system satisfies the requirements in the operational environment
  - Minimize the cost of T&E
- **Model selection:** Acquisition Function
- **Belief update:** Bayes' Rule



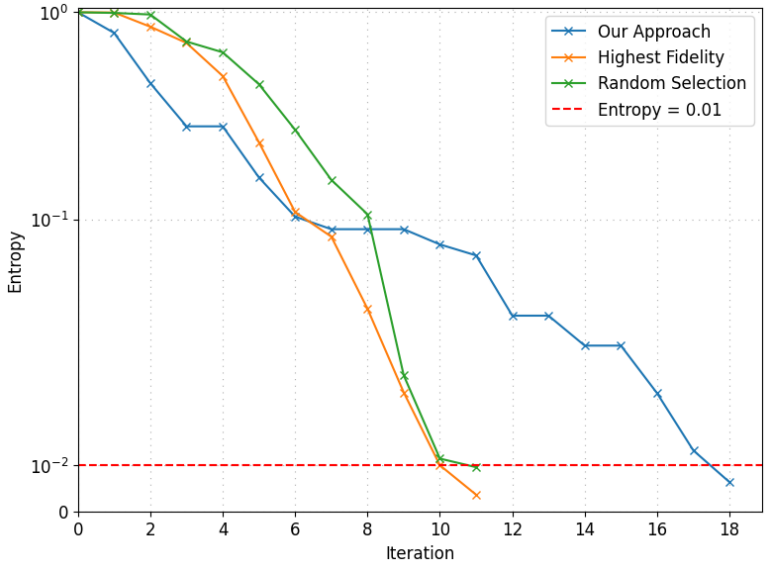
Uncertainty measure: Shannon Entropy

$$H(r_i) = -P(r_i)log_2P(r_i) - (1 - P(r_i))log_2(1 - P(r_i))$$

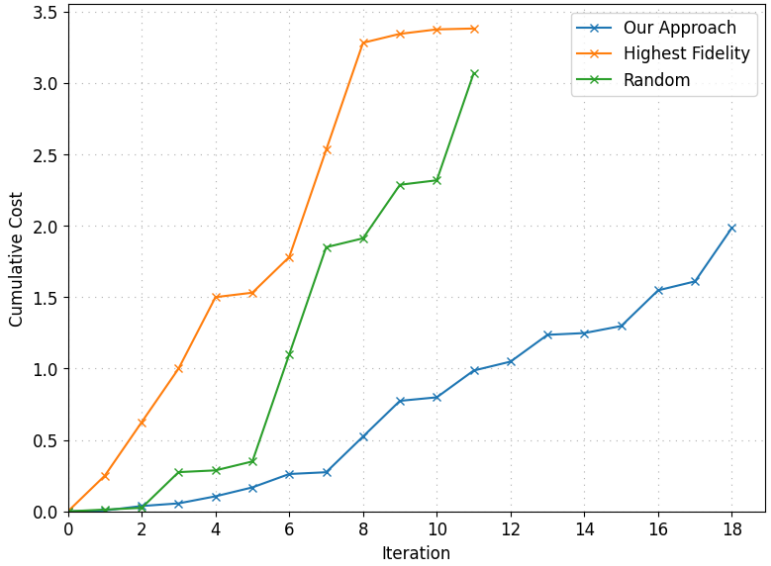


Experiment Results

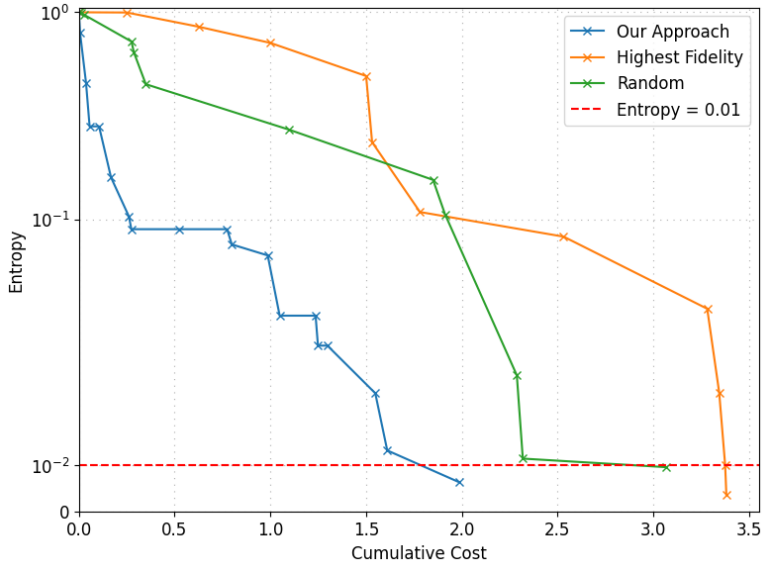
- Stop condition: entropy $H < 0.01$.
- Entropy and accumulated costs are recorded.
- Our approach: **41% reduced cost**, broader exploration of model space



entropy over number of tests



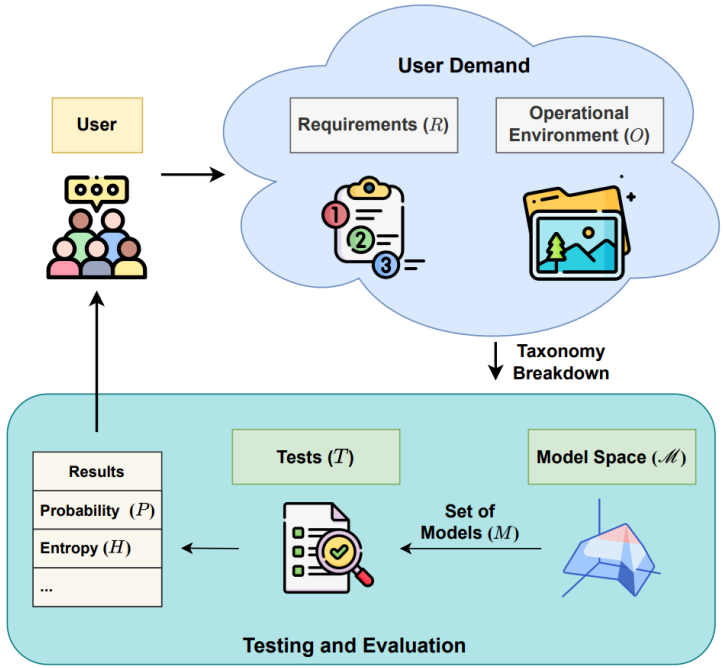
cumulative cost over number of tests

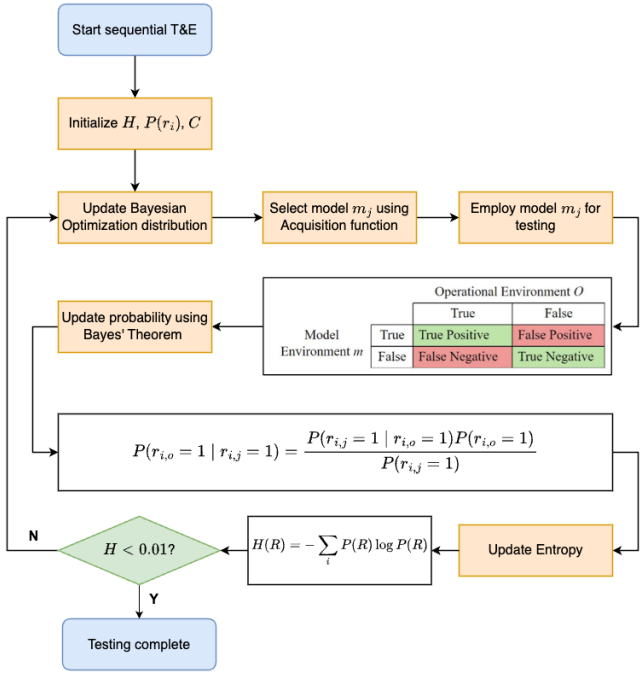


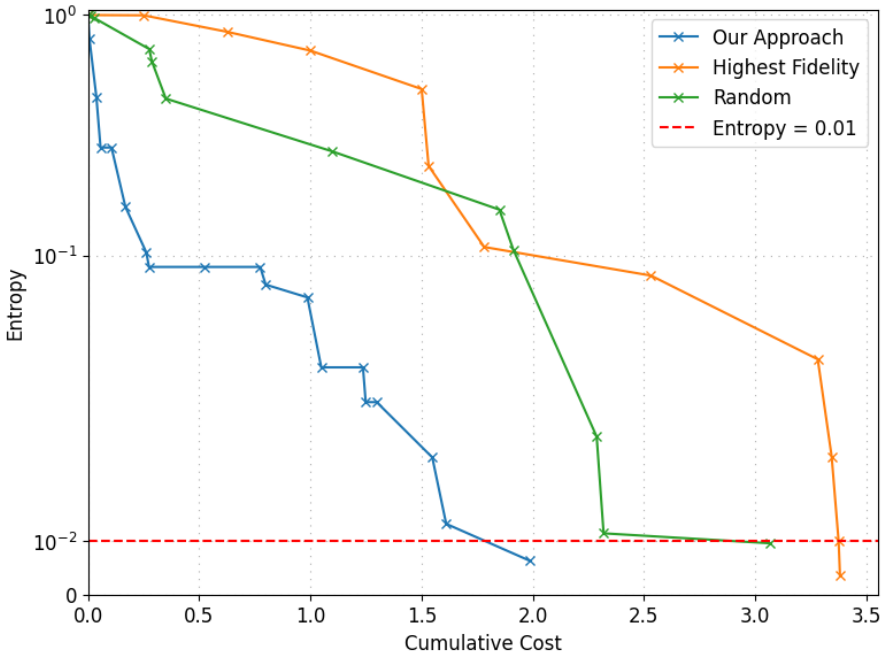
entropy vs. cumulative cost

Conclusions

- ***A method*** for designing a multi-fidelity test plan to verify whether the given AI-enabled system can satisfy the given list of requirements and corresponding failure modes.
- The proposed method can ***find the testing sequence with maximum utility*** by experimenting with testing the perception system of an autonomous vehicle.







Future Work

- Refine the use case to include evolving AI models
- Automation in test generation and model selection.
- Using high and low-fidelity models in parallel.
- Adaptive testing with evolving systems.

Video captured from Carla simulation engine

Thank you

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