Carnegie Mellon University
Silicon Valley

Electrical & Computer ENGINEERING

# How to Teach a Drone New Tricks

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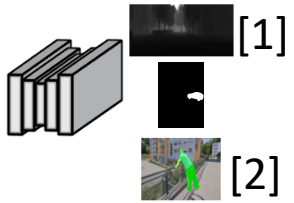
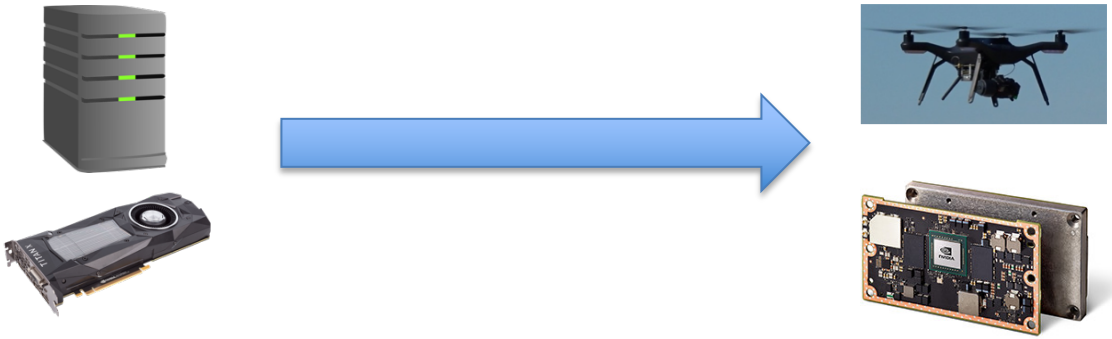
GTC ’18, Santa Clara, CA

# Deep Learning for Intelligence at the Edge

- Drones as tools
  - Direct human control – ”eye in the sky”
  - Unsuited for large fleets or beyond-line-of-sight operation
- Deep learning for intelligence




- Hardware capabilities for deep learning

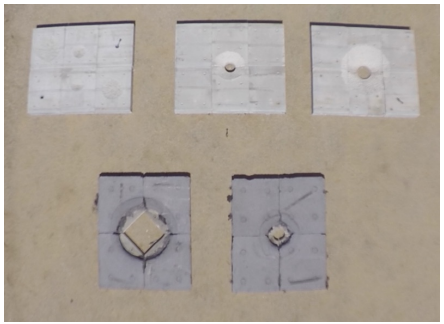


# When Reality Doesn't Meet Expectation

- Gather -> Train -> Deploy
- Example: Train a model to detect potholes in a runway

What we trained for

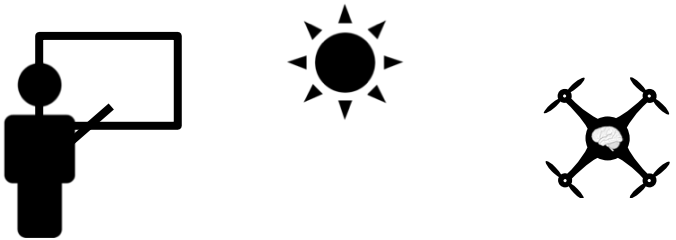
What we found



Source: Wikipedia.org

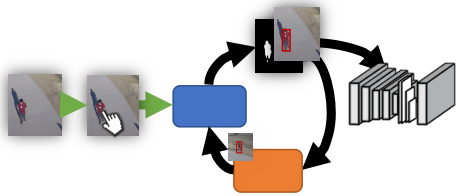
# Teaching a Drone in the Field

- What if the static model isn't good enough?
  - Real scenario may not meet expectations
  - Physical world is constantly changing
- Keep training and learning *in the field*
  - *with human guidance*
  - Learning onboard is now computationally feasible



# Today's Agenda

- A method for quickly train models in-the-field in real-time



- A virtual environment to augment in-the-field online learning

ClickBAIT – Click-based Accelerated Incremental Training

# ONLINE TRAINING IN THE FIELD

# Problem

- Limited availability of human effort will limit the ability to quickly train models

# Research Question

In the context of real-time training of an object detector on a video feed, how do we maximize the **benefit** of every human-provided training event?

# Training Benefit

- How do you quantify the value of a training event?
  - Fixed cost – one click from the user
  - *Training benefit* – Increase in model performance due to that click

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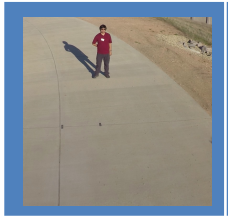
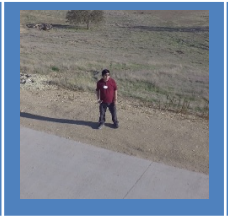
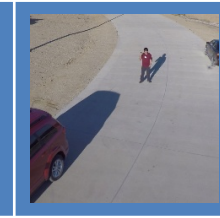
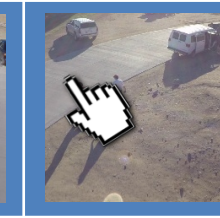
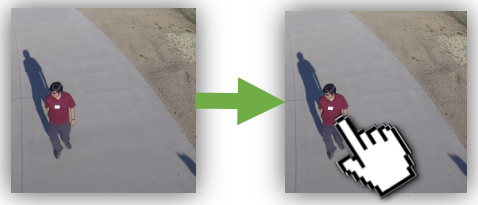
| $\boldsymbol{V}$ |  | |  |  |  |
| $\boldsymbol{U}$ | $\boldsymbol{u_1 = 0}$ | $\boldsymbol{u_2 = 1}$ | $\boldsymbol{u_3 = 0}$ | $\boldsymbol{u_4 = 0}$ | $\boldsymbol{u_5 = 1}$ |
| $P_0 = 0.44$ | $P_1 = 0.44$ | $P_2 = 0.54$ | $P_3 = 0.54$ | $P_4 = 0.54$ | $P_5 = 0.62$ |

Benefit of $u_2 = 0.1$

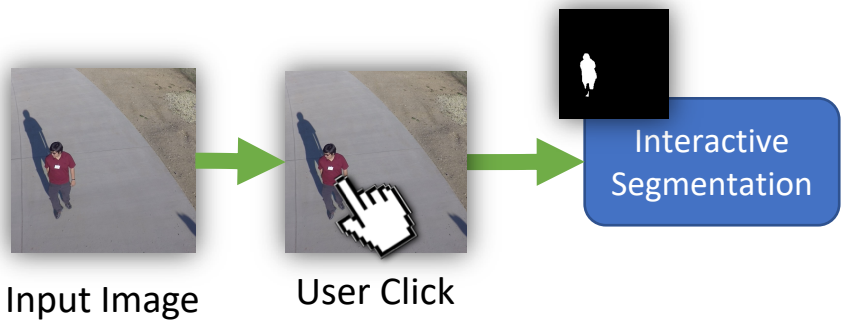
# Assisted Training System - ClickBAIT



Input Image

User Click

# Assisted Training System - ClickBAIT



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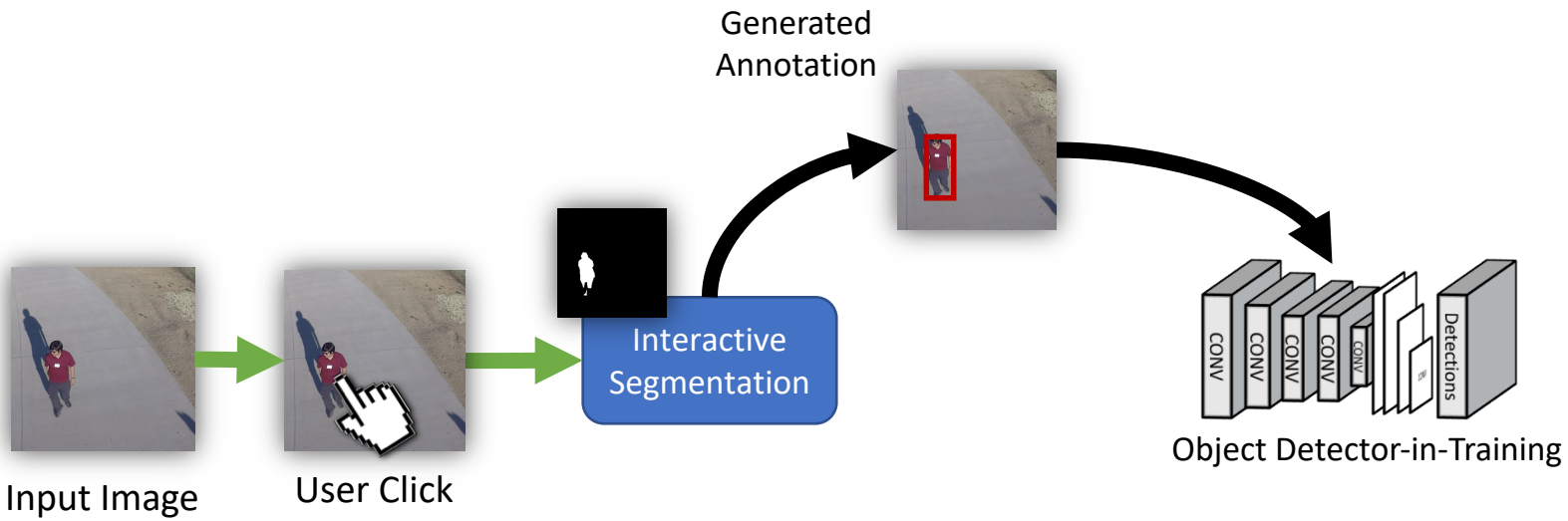

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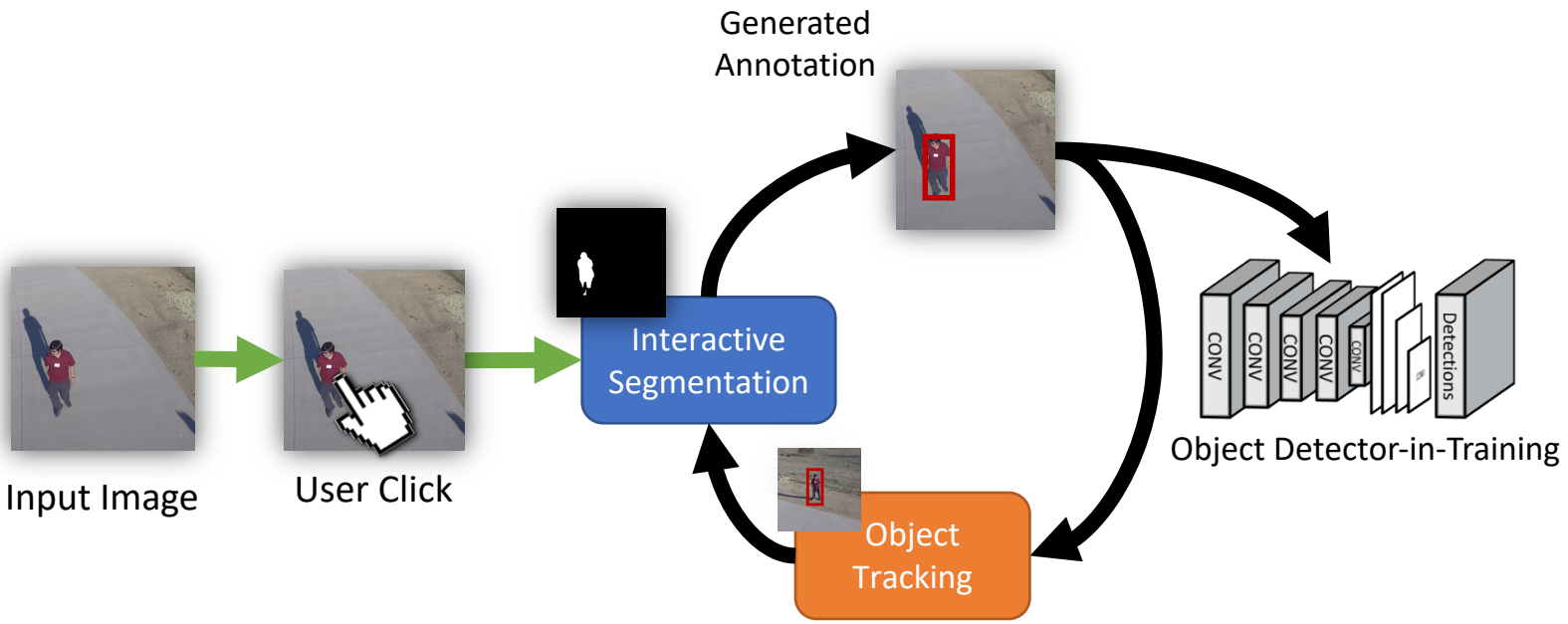
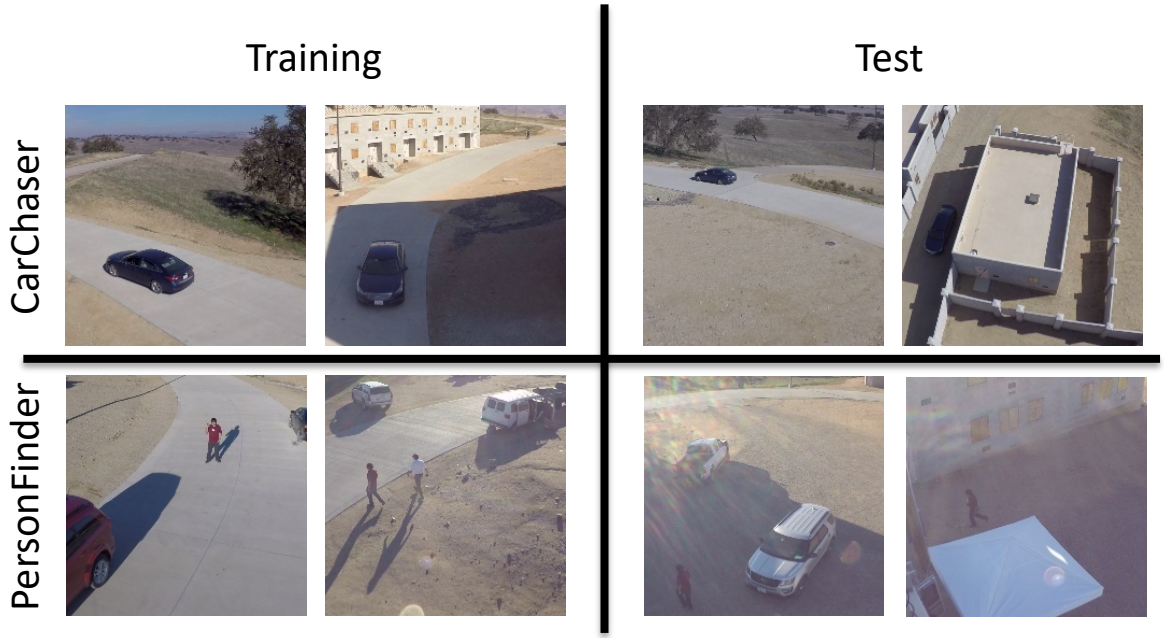
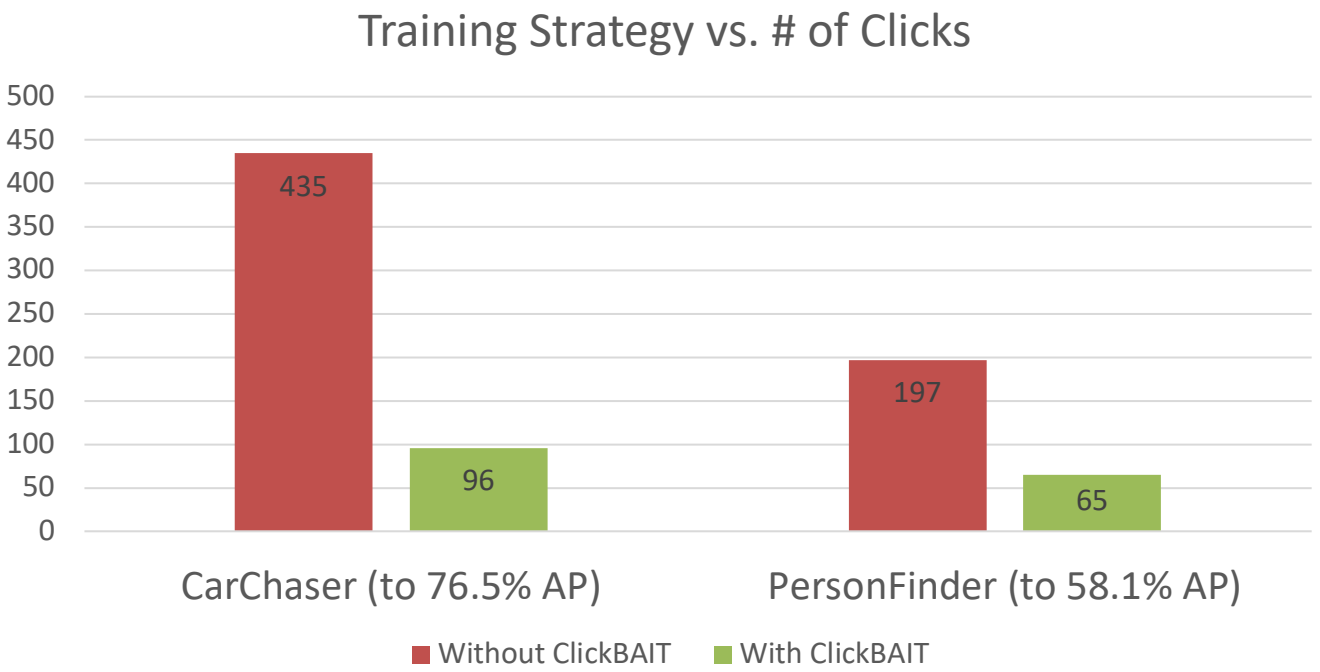


# Online Training Datasets

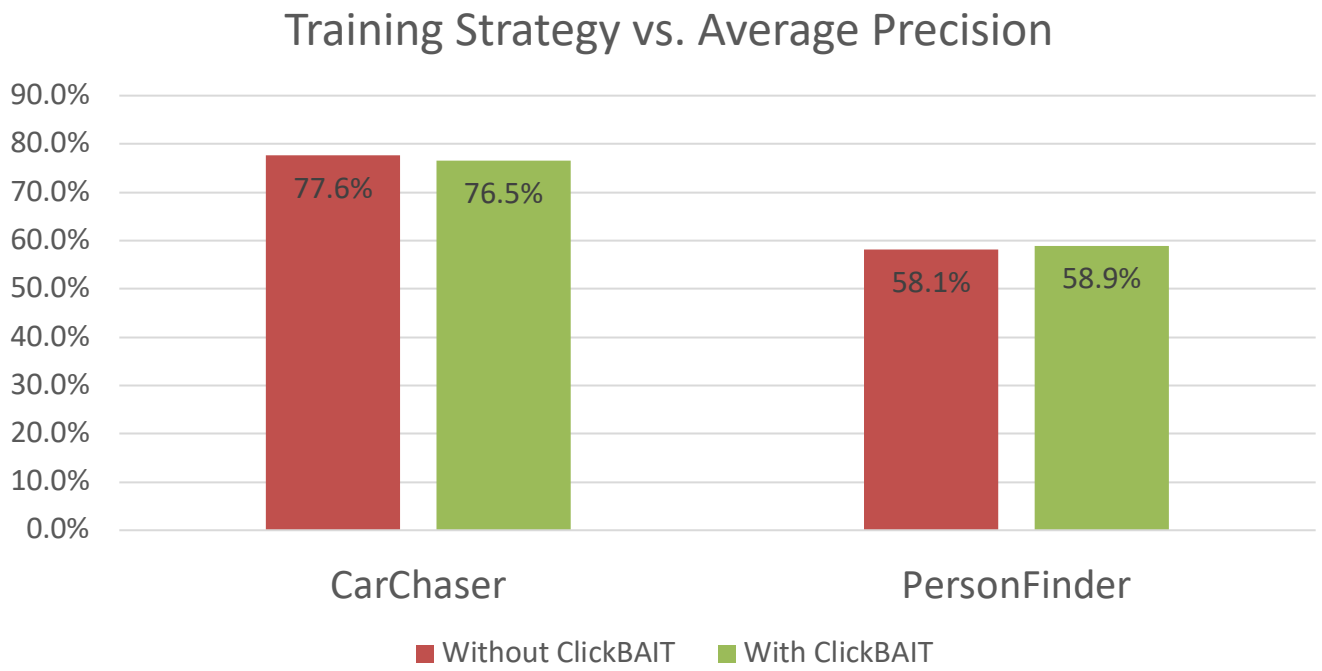
- Two datasets:
  - CarChaser (878 train and 317 test)
  - PersonFinder (422 train and 156 test)



# Results: 1/4 the clicks required…



# … without sacrificing performance.



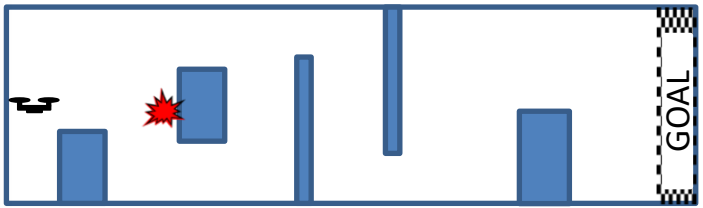
VIPER – Virtual Image Processing Environment for Research

# TRAINING IN THE VIRTUAL FIELD

# The Problem with Training in Reality

- Some problems require lots and lots of (potentially dangerous) experience gathering

- The problem is providing the *real experience*



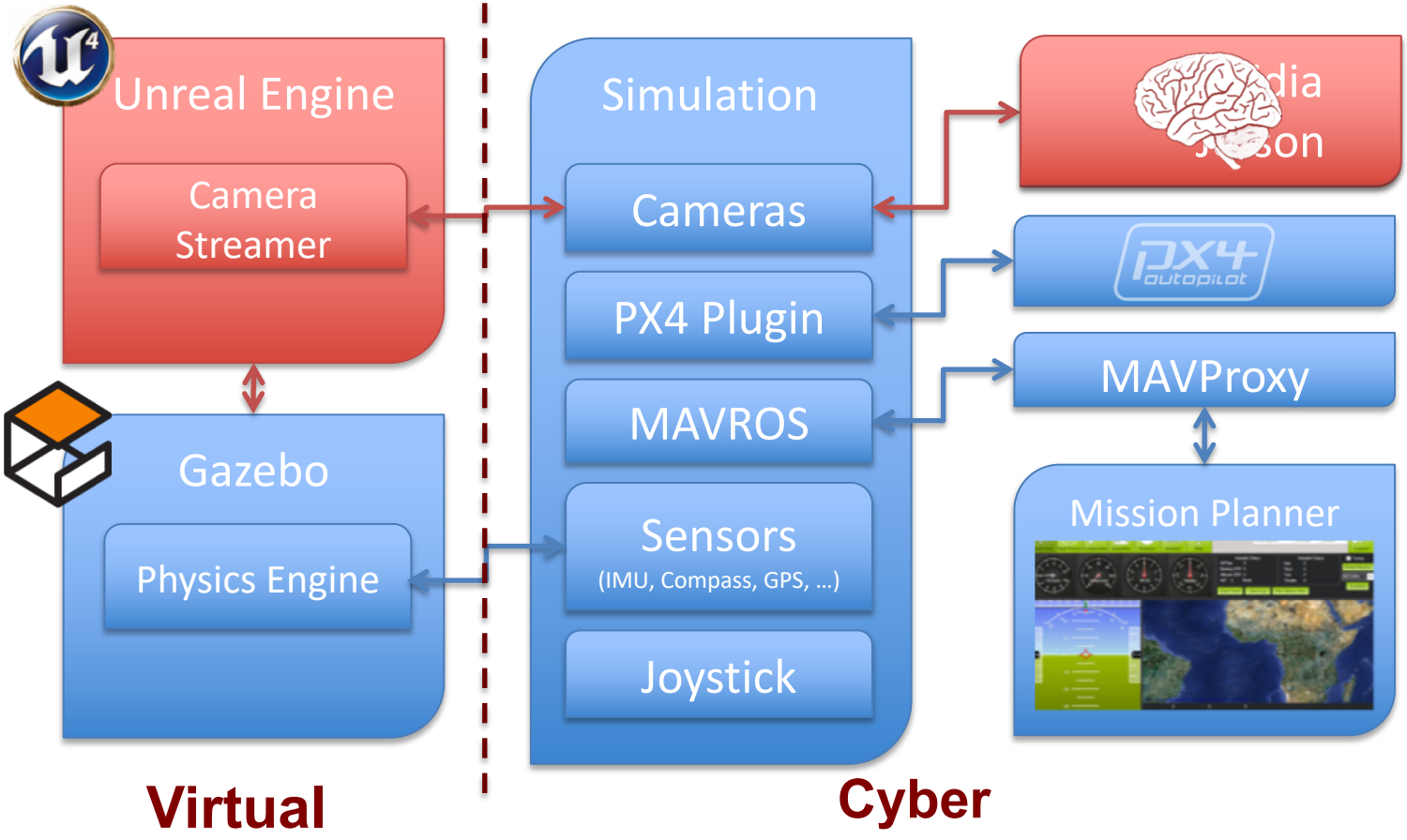
# Solution: A Virtual Classroom

- Experiential learning without *real experience*

- Photo-realistic, faster-than-real-time “safe” classroom to make mistakes, receive score, incrementally improve

- *Hardware-in-the-loop*

# Architecture Overview



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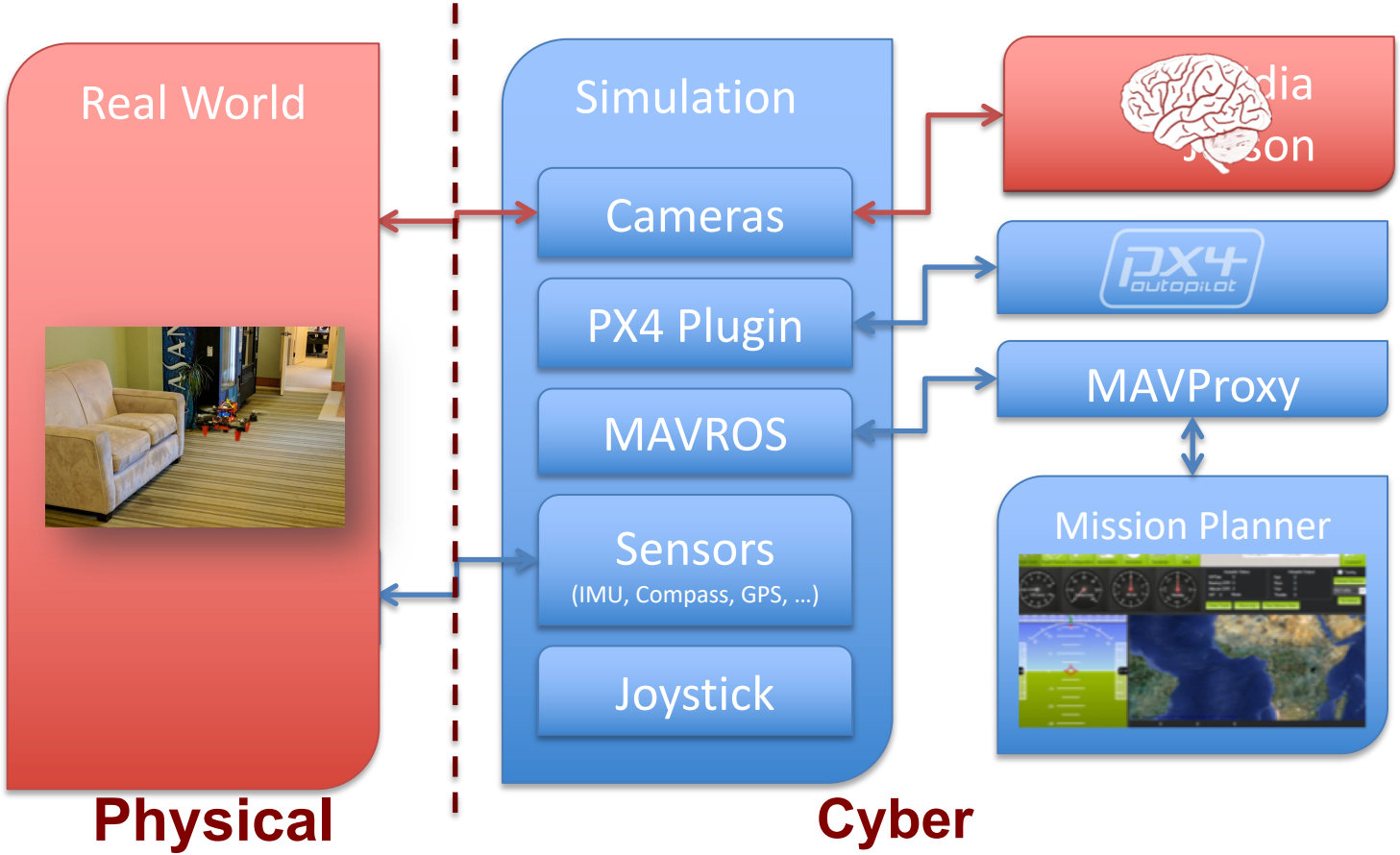
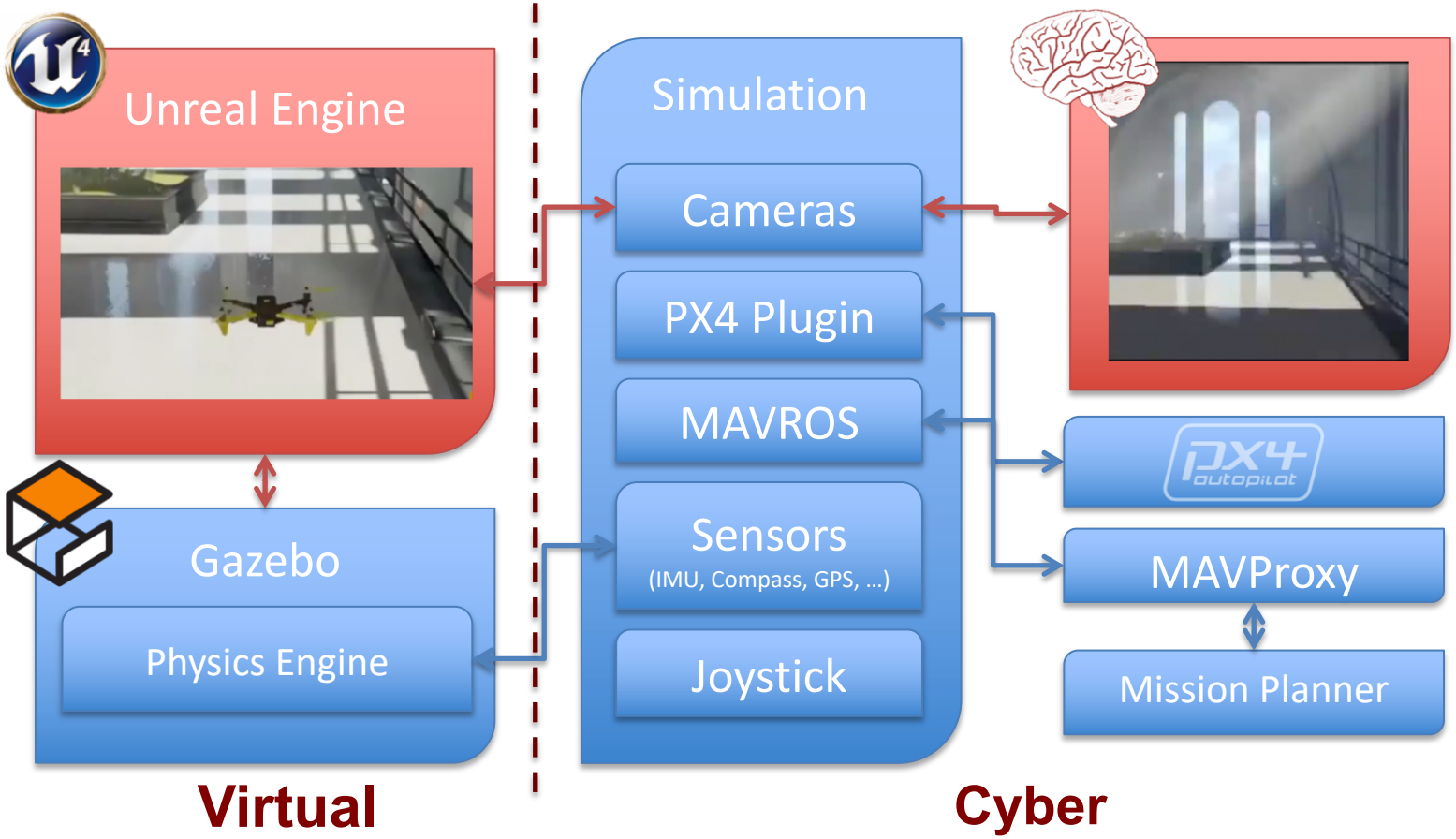
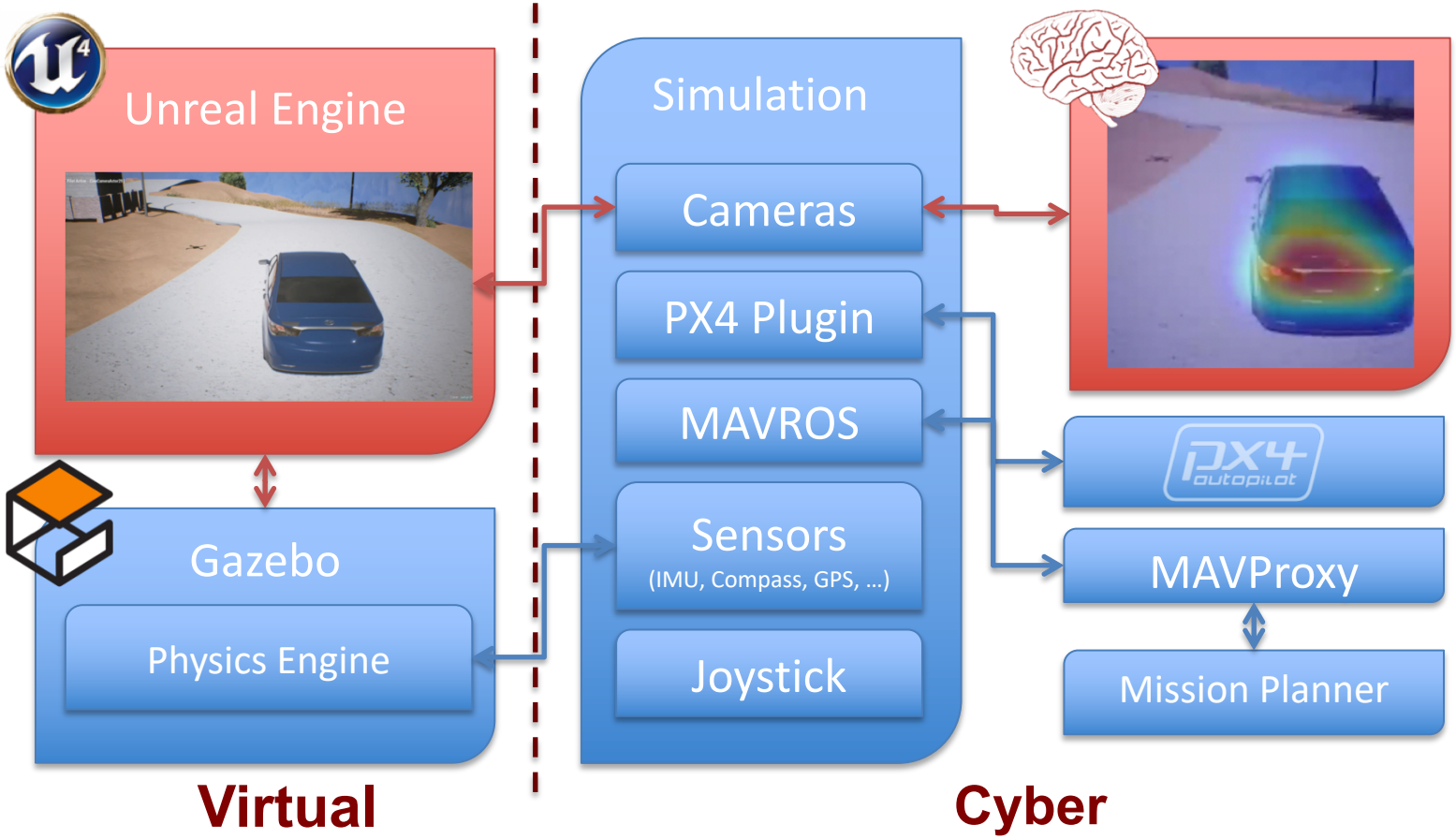


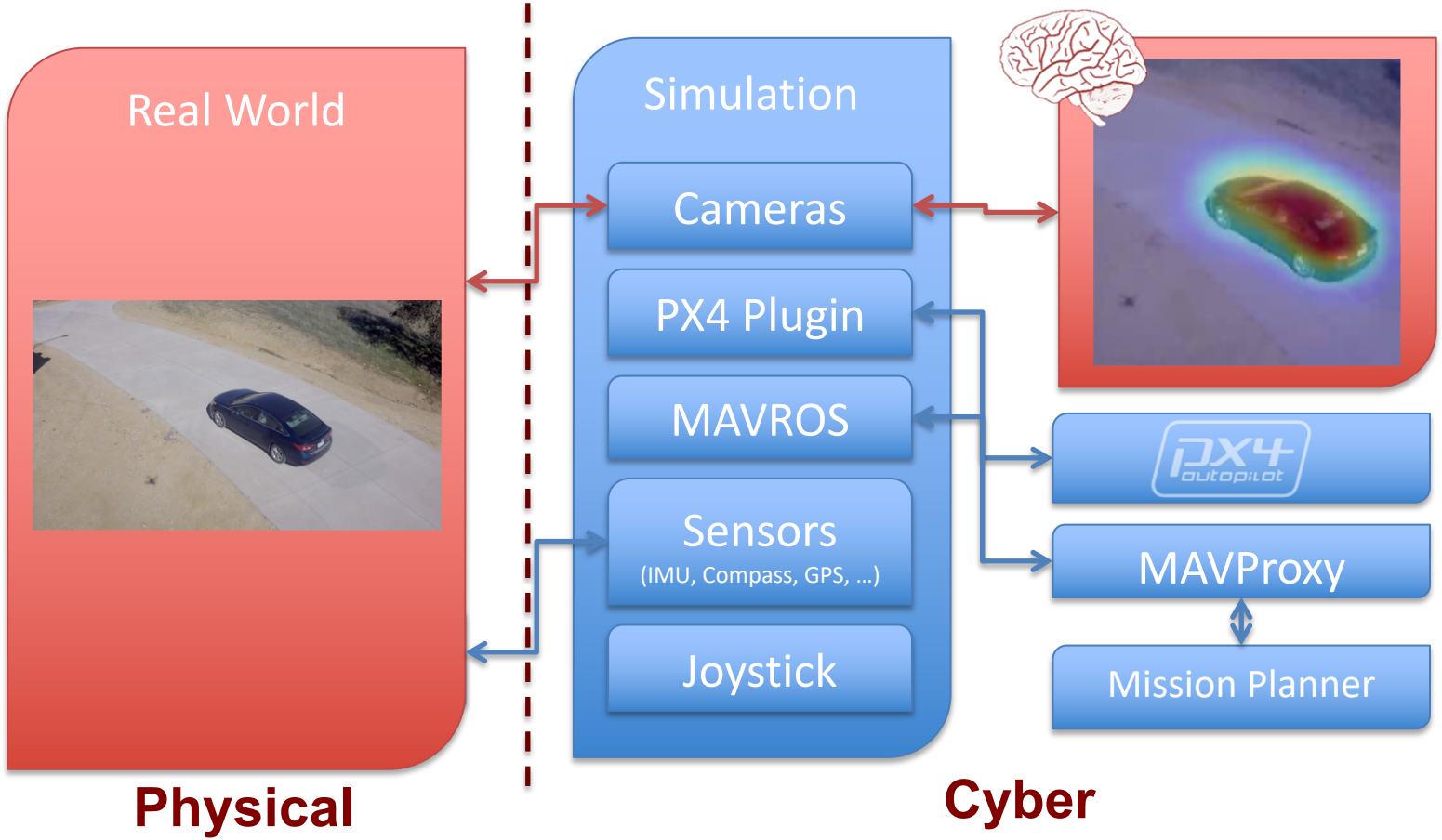
# VIPER in Action



# VIPER in Action – Train in the Virtual…

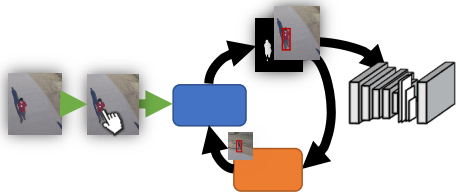


# VIPER in Action – Execute in the real!



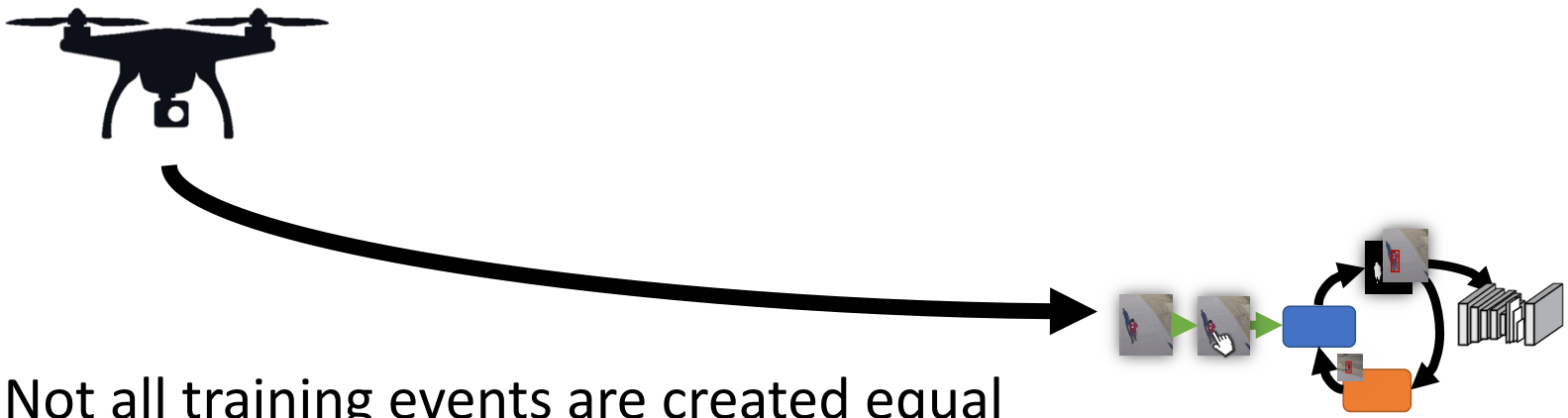
# Conclusion

- We can enable efficient, real-time human-in-the loop training onboard embedded, flying platforms



- A virtual, *hardware-in-the-loop* environment can augment and accelerate real-world learning

# Closing the Loop: Autonomous Curiosity



- Not all training events are created equal
  - Context should suggest which events are useful and which are not
- Learner's *mobility* introduces degrees of freedom absent in an offline training setting

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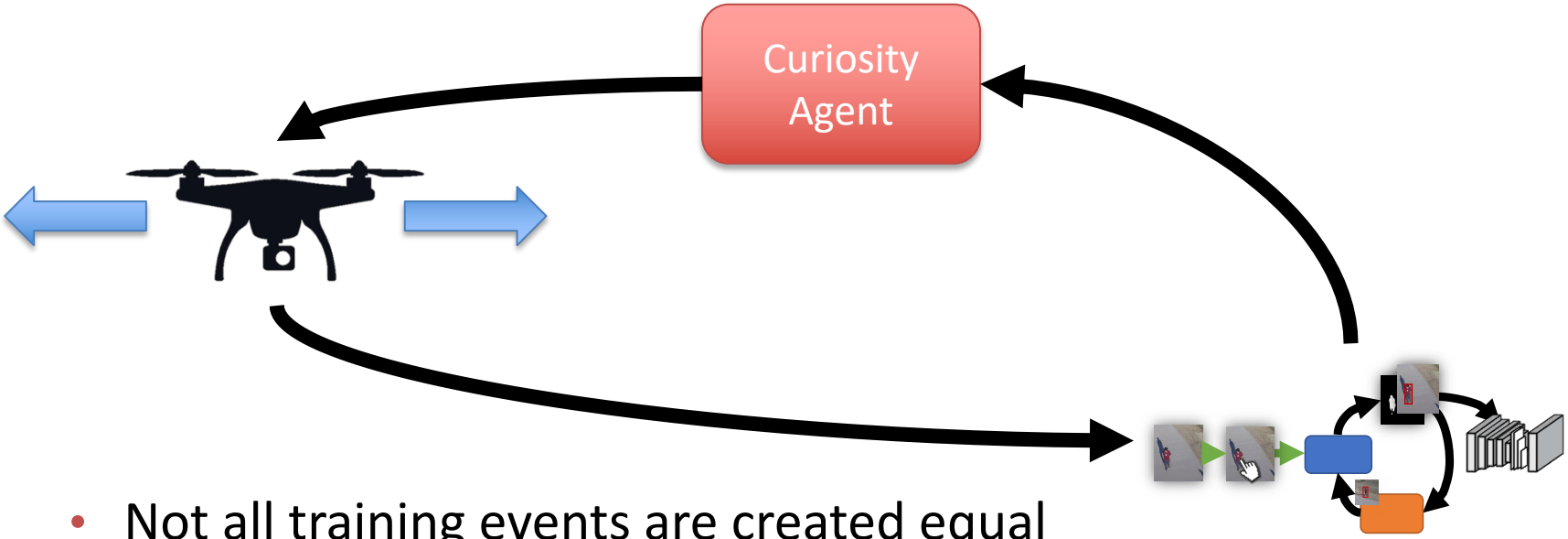


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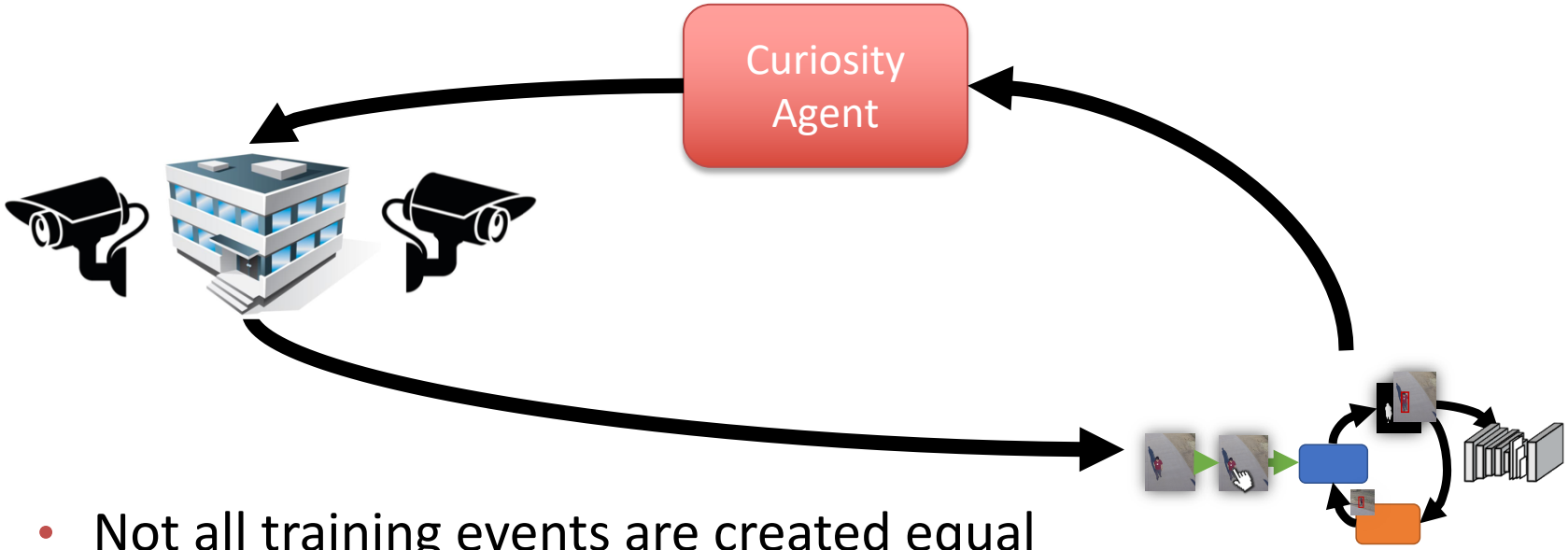


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Thank You!
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