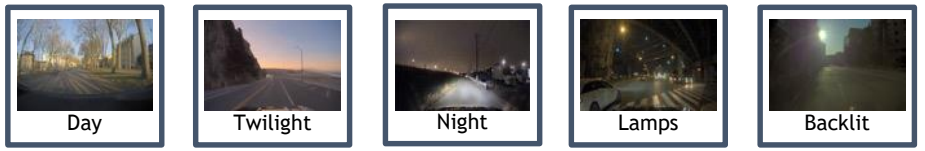
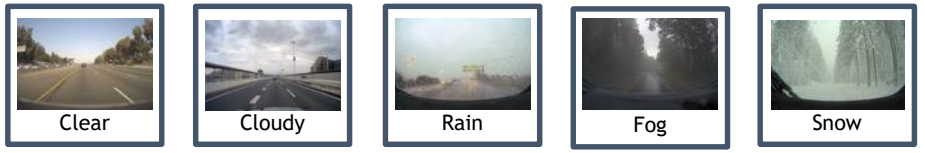
NVIDIA'S AI INFRASTRUCTURE FOR CREATING SELF-DRIVING VEHICLES

CLEMENT FARABET | NVIDIA | GTC 2020

BUILDING AI FOR AV IS HARD

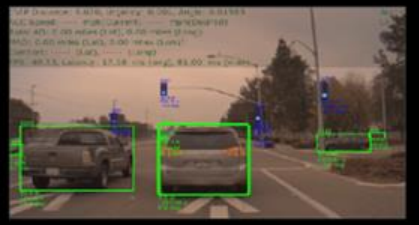
Every neural net in our DRIVE Software stack needs to handle 1000s of conditions and geolocations



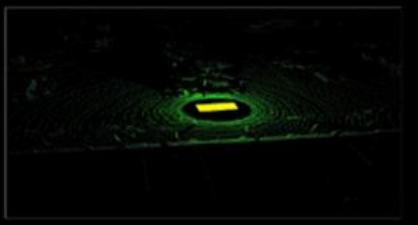



Perception

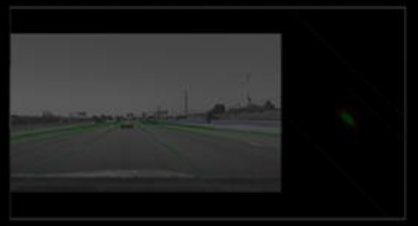

Free Space Perception


Distance Perception


Weather


LIDAR Perception


Camera-based Mapping

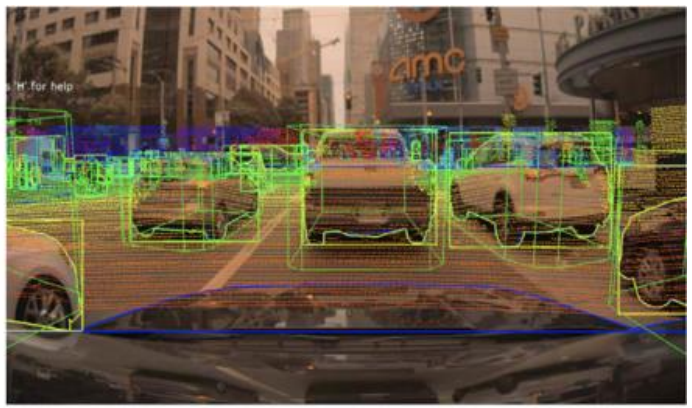

Camera Localization to HD Map

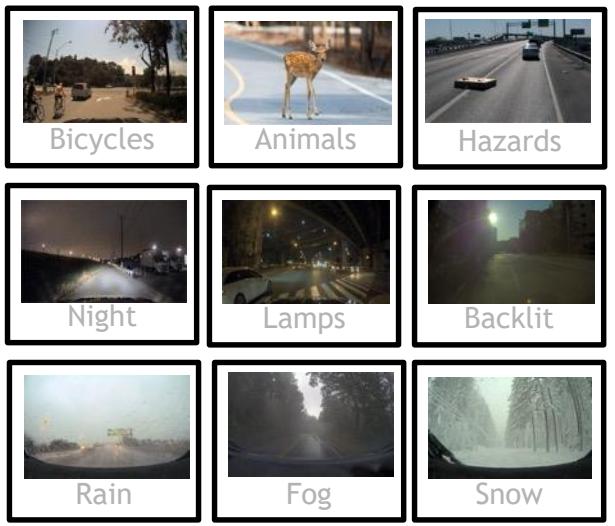

LIDAR Localization to HD Map

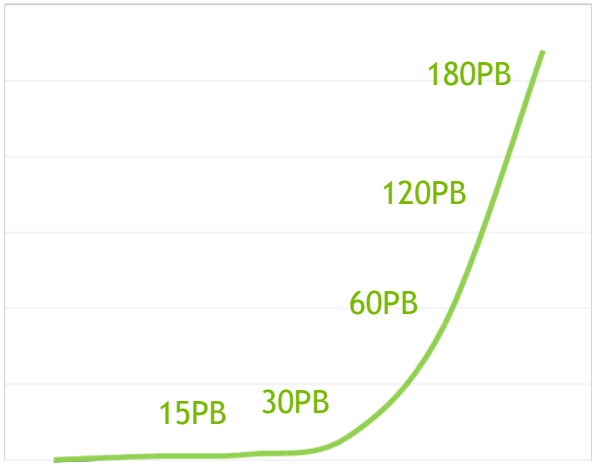

Path Perception


Scene Perception

More Functionality × More Conditions = MASSIVE Data







New features (i.e. lane keeping) require new data…

…and require more real examples to meet safety targets…

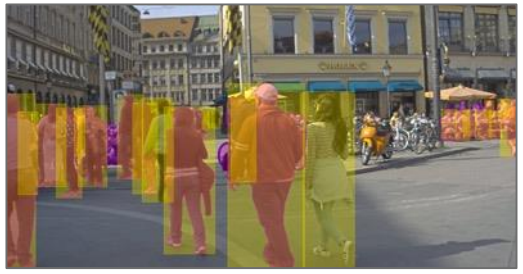
…resulting in exponential data and compute needs

THE CHALLENGE IN NUMBERS

50 Car Fleet, Driving 6 Hours/Day, Generates 1.6PB Each Day

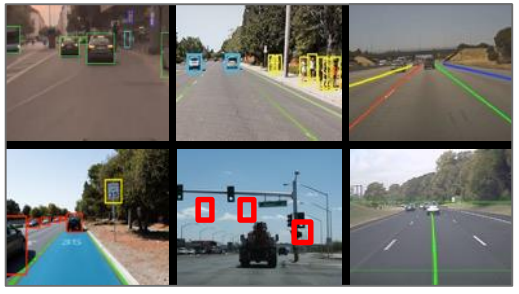
INGESTION
1.6PB/day needs to be transported,
encoded, stored

CURATION
Billions of frames.
Find the 10-14% that are useful



LABELING
Manage 1000+ workers with 50+
projects. Ensure quality every frame.

TRAINING
1,000s GPUs. 20+ models. 100s Engineers,
Optimize each model w/ 50+ parallel experiments.

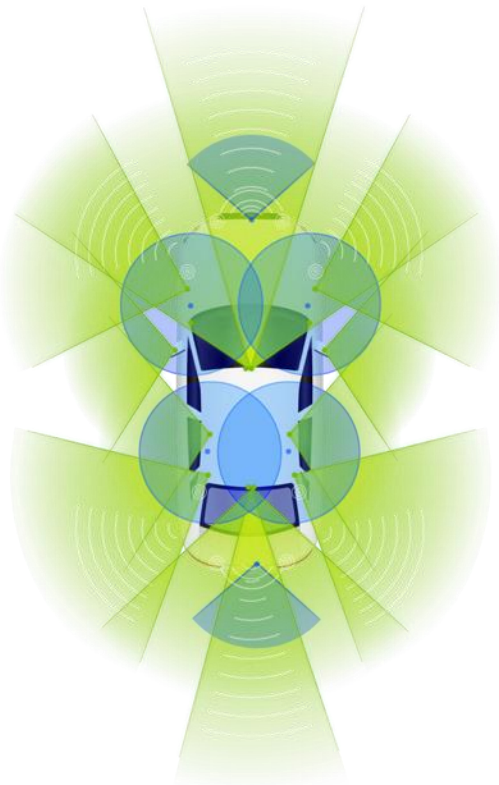


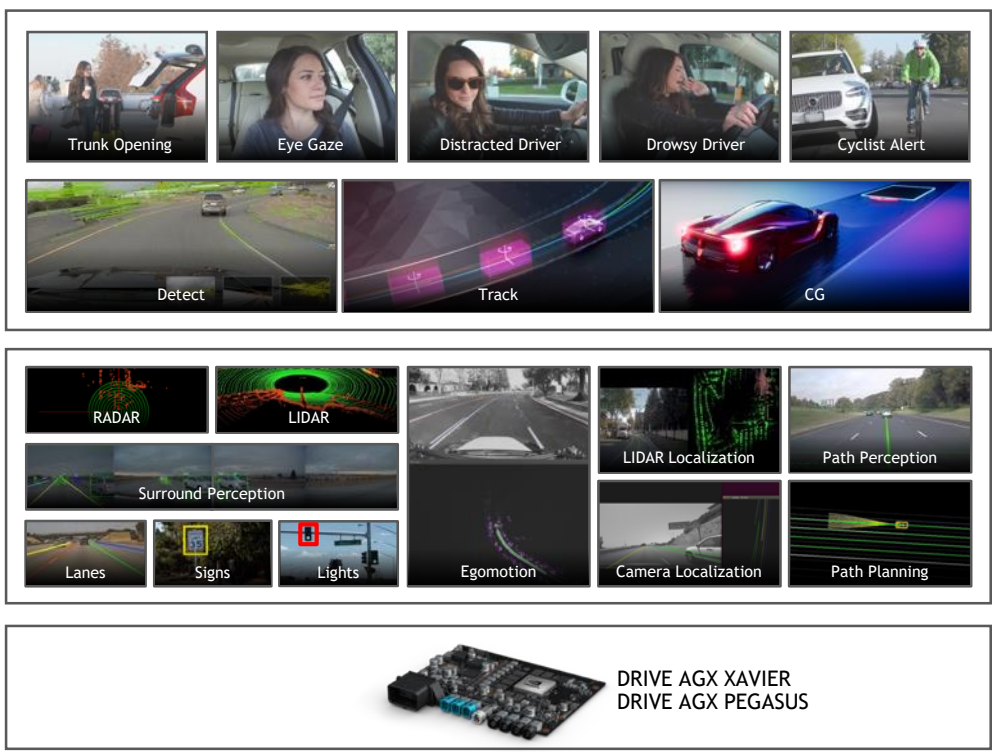
REPLAY
Test against 1,000s hours of sensor data.
Repeat Daily

SIMULATION
Drive millions of miles.
Find the most critical scenarios to test.

NVIDIA DRIVE: SOFTWARE-DEFINED CAR

Powerful and Efficient AI, CV, AR, HPC | Rich Software Development Platform
Functional Safety | Open Platform | Hundreds of Partners Developing on DRIVE





NVIDIA DRIVE DEVELOPMENT PLATFORM

A complete platform to enable rapid & lifelong AV innovation

Building Autonomous Vehicles (AV) requires a tremendous investment:

Continuous Engineering – For data collection, training, simulation, validation, testing, and deployment

Strong Infrastructure, Tools and Methodology – Comprehensive platform not commercially available today

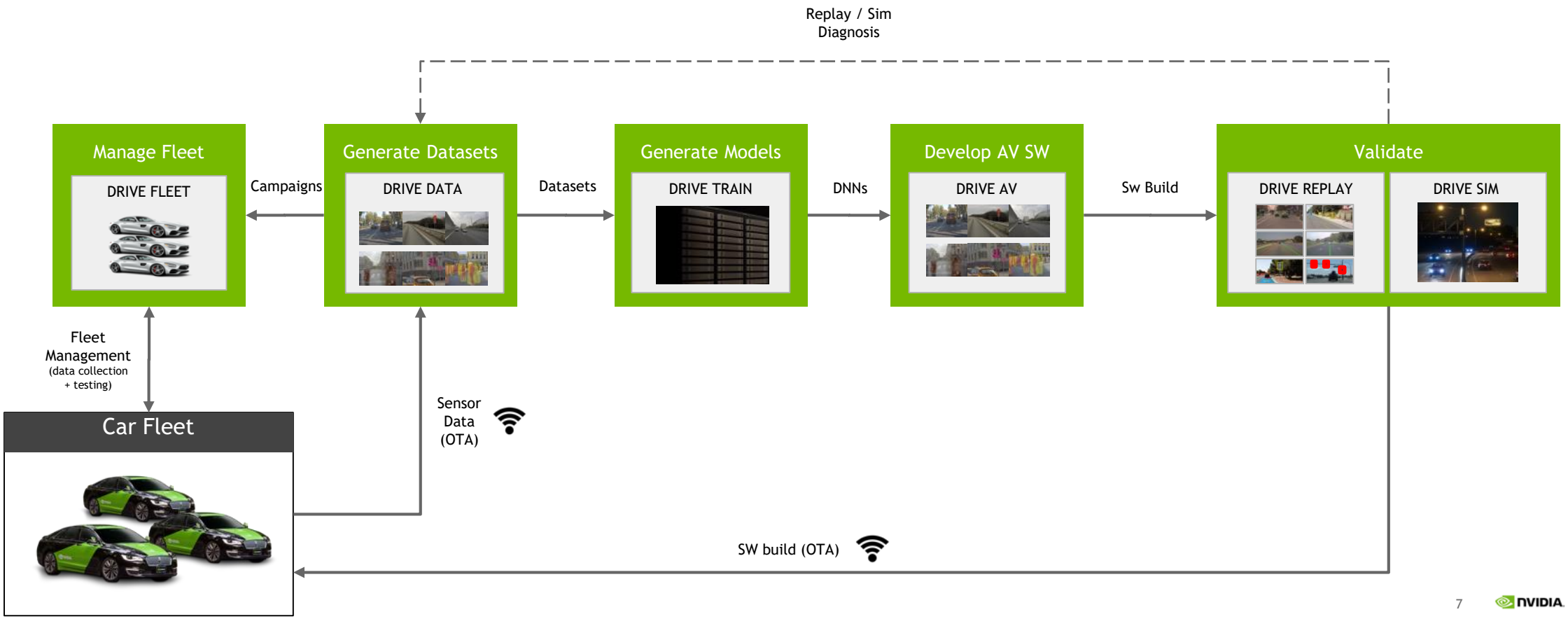
New Algorithms & SW – Target computer needs to be SW defined and programmable

Unified Fleet Management – One base architecture to enable agility of development, bug fixing

NVIDIA's open platform, DRIVE, enables to iterate faster and for the entire product lifecycle

BUILDING A SDC REQUIRES A PROCESS

It requires a data driven approach, rich tools to develop and validate (simulation), Hybrid Cloud + Target Hardware – and a strong methodology!



NVIDIA

NVIDIA DRIVE DEVELOPMENT PLATFORM

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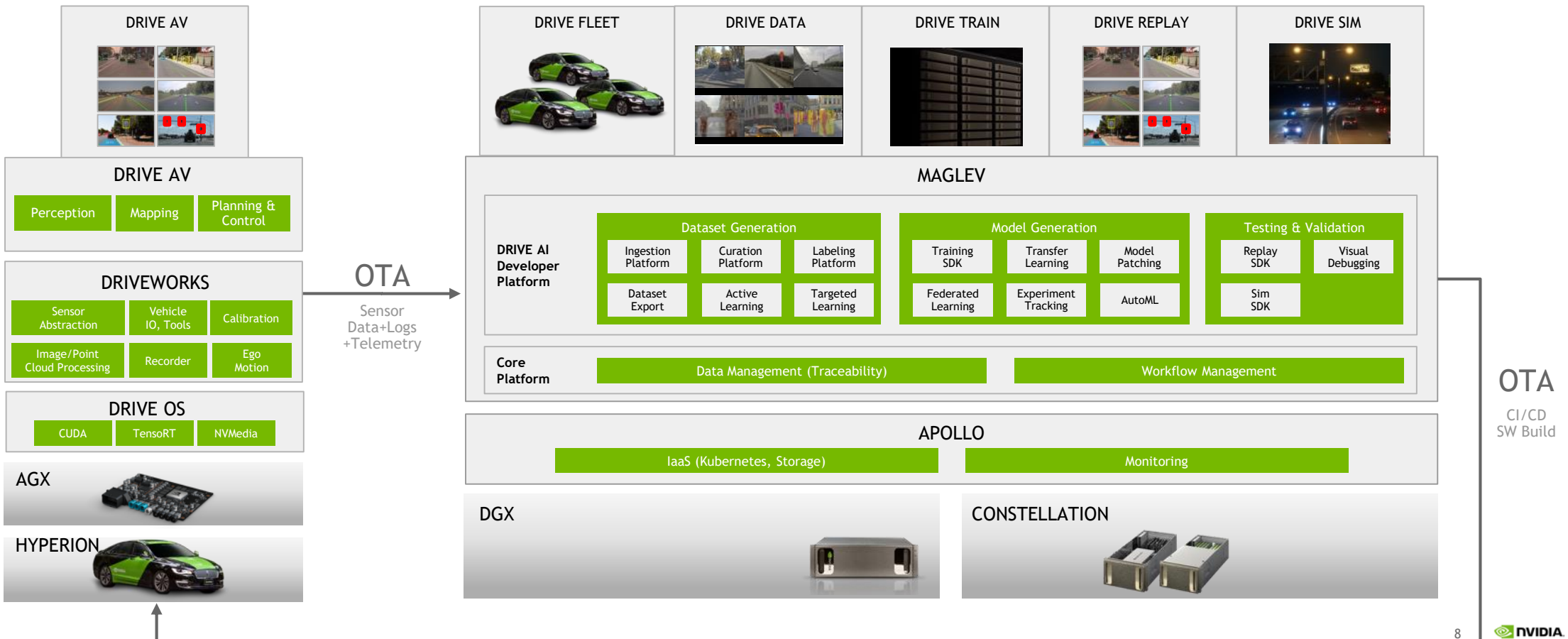
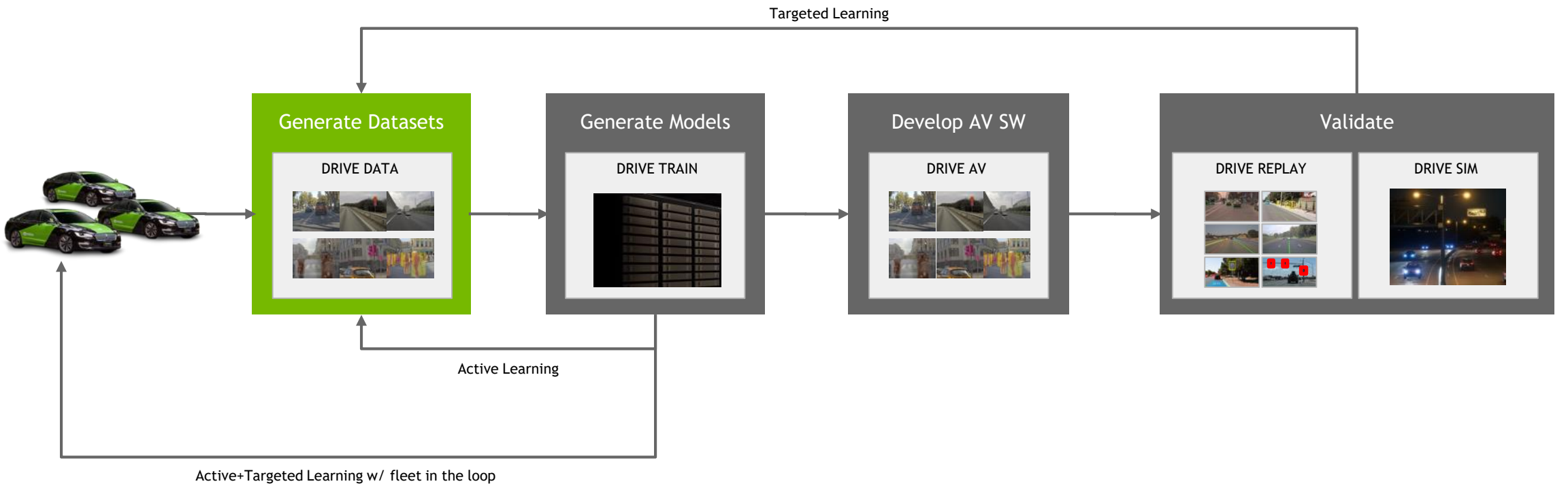


DATA-DRIVEN AI DEVELOPMENT

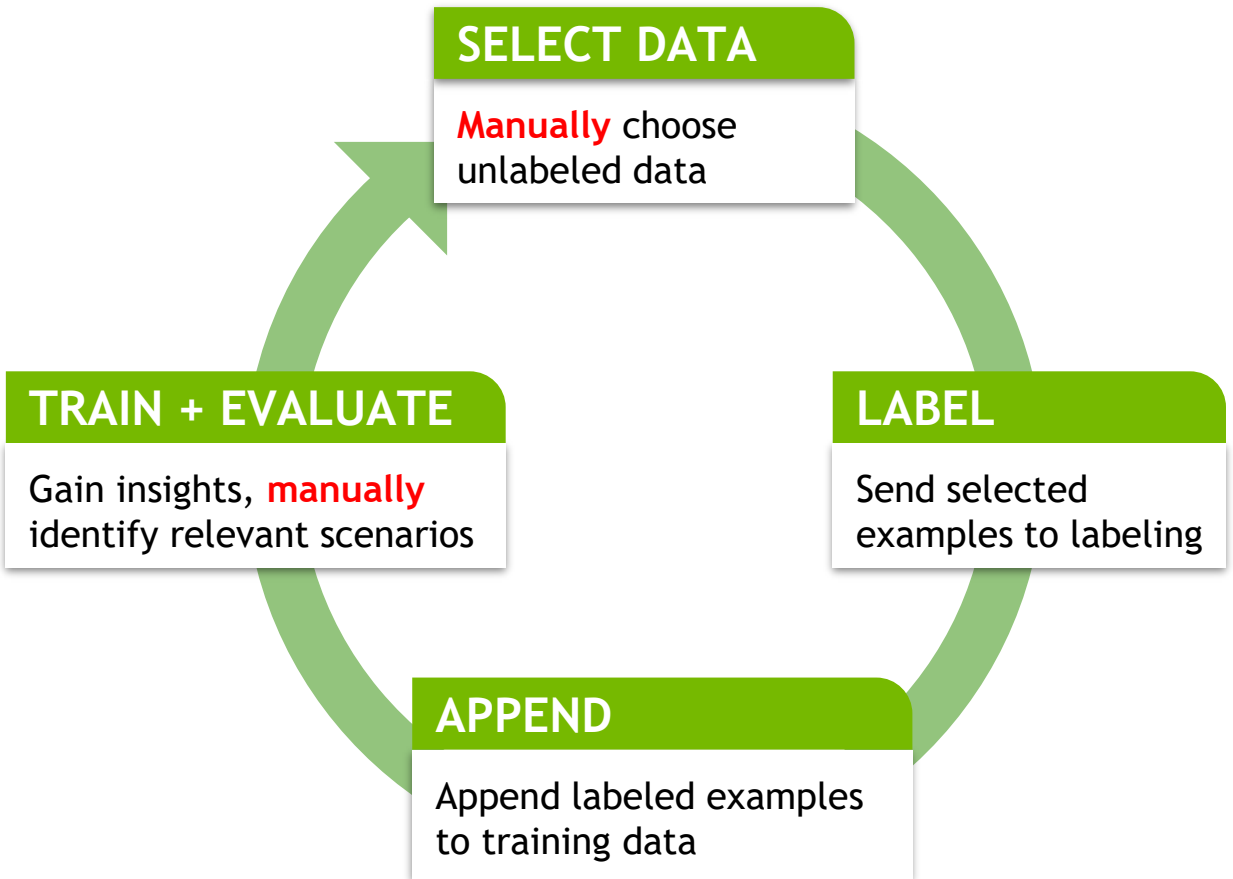
DATA DRIVEN AI DEVELOPMENT

One of the biggest challenges to develop AI is to build the right datasets



TYPICAL DNN ITERATION CYCLE

MANUAL STEPS



Involves a lot of human labor

Doesn't scale

As unlabeled data grows it becomes more and more difficult to drill down to relevant data (already billions of frames today)

Sub-optimal

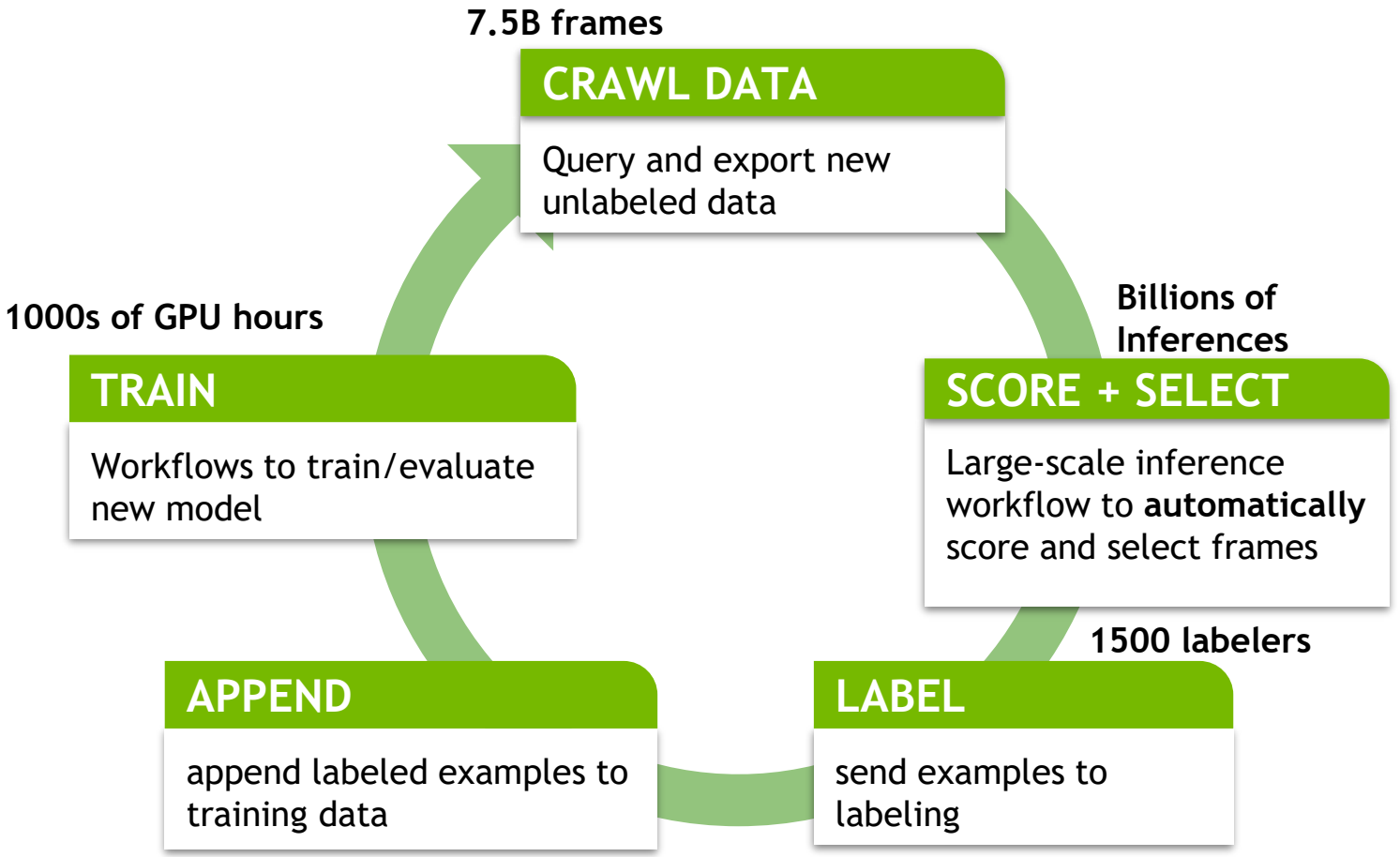
Often unclear what data is actually relevant to improve a model; what is relevant to a model may seem boring to a human (and vice versa)

Error-prone

Humans make mistakes; you may not end up with the training data you wanted/requested

ACTIVE LEARNING AUTOMATED LOOP

Support complete Active Learning cycle at AV scale



Can be completely automated

High level of integration between data lake, compute- and labeling-platform required

Can run workflows with large-scale compute and storage requirements

ACTIVE LEARNING

Core Idea:

- Optimize data selection by having the models tell us what they need.
- Automate the model delivery loop by providing the infrastructure to reduce human intervention to its bare minimum: labeling.

Notes:

- We follow research in the area of ***pool-based active learning***:

  Given large pool of unlabeled data ***U*** and small set of labeled data ***L***

  Allow model trained on ***L*** to select examples from ***U*** and send to labelers ("oracle")

- While the optimization philosophy requires minimal infrastructure, full automation has dependencies on a large part of AI Infrastructure.

[1] Active Learning Literature Survey, Burr Settles, Technical Report, 2010

WHY IS ACTIVE LEARNING SENSIBLE?
NOT ALL DATA CREATED EQUALLY!

vs

Some Samples Are Much More Informative Than Others

DRIVENET ACTIVE LEARNING

A/B TEST

Test with **real data** on DriveNet for **object detection**

Goal: improve **detection of Vulnerable Road Users (VRUs) during night**

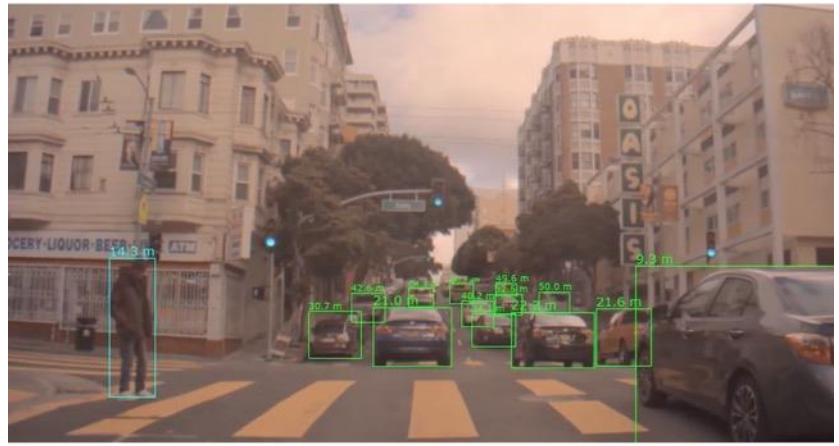
A) curation team manually selected **19k night frames** for VRUs

B) automatically selected **19k frames** with active learning (AL):

train **ensemble of eight DriveNet models** with current data

use metadata in data lake to **filter for dark/artificial** frames

use ensemble to compute **person and bicycle uncertainty to rank frames** and select top 19k (akin Bayesian Active Learning by Disagreement, Houlsby et al.)

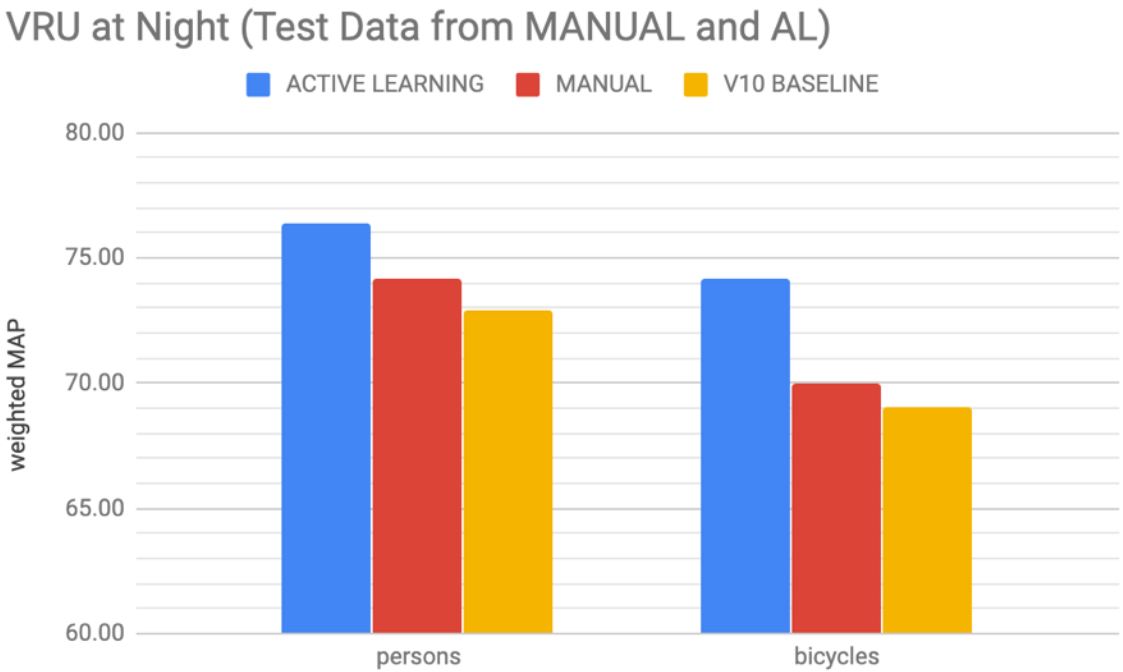


DRIVENET ACTIVE LEARNING

EXAMPLES OF AL-SELECTED FRAMES

DRIVENET ACTIVE LEARNING

A/B TEST RESULTS

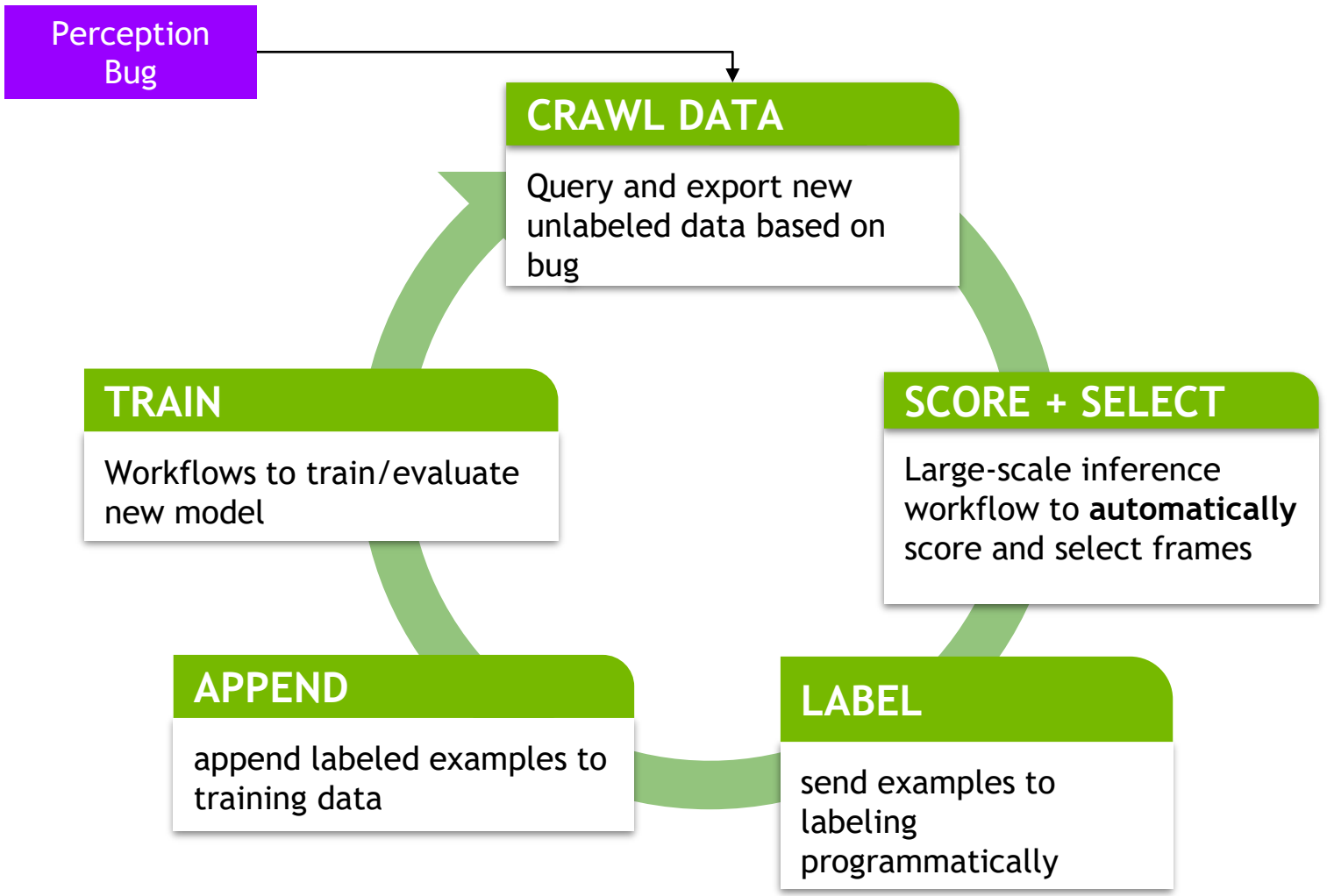


- Improvement of bicycle performance from AL~**5x** compared to improvement by manual selection (5.2% vs 1%)
- Improvement of person performance from AL ~**2.7x** compared to improvement by manual selection (3.5% vs 1.3%)

→ Higher improvements from AL data compared to manually selected data

TARGETED LEARNING

Similar cycle as active learning, but mine data based on “seed” (=bug)



Similar cycle as for active learning, but:

Relies on bug to seed search through data lake

MINE FOR DATA SIMILAR TO THE BUG

Using similarity in DNN feature space, retrieve top-N similar images from unlabeled data if they exist

QUERY IMAGE
(Example Drivenet v10 heavy truck FN error in KPI dataset)

RETRIEVE TOP-N SIMILAR IMAGES
(provided such similar images exist in the unlabeled data lake)

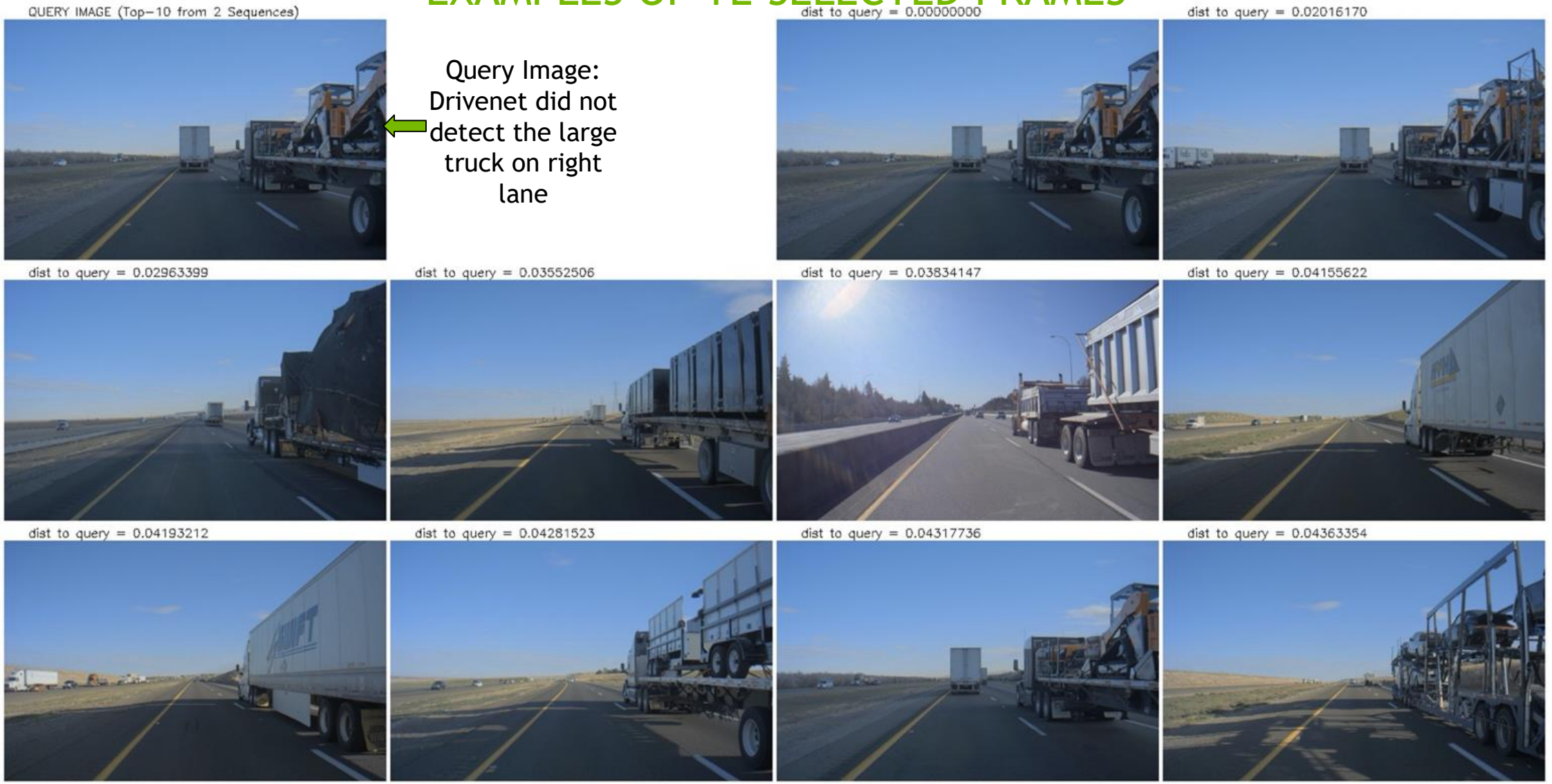
DRIVENET TARGETED LEARNING

EXAMPLES OF TL-SELECTED FRAMES

Query Image: Drivenet did not detect the large truck on right lane

DRIVENET TARGETED LEARNING

EXAMPLES OF TL-SELECTED FRAMES

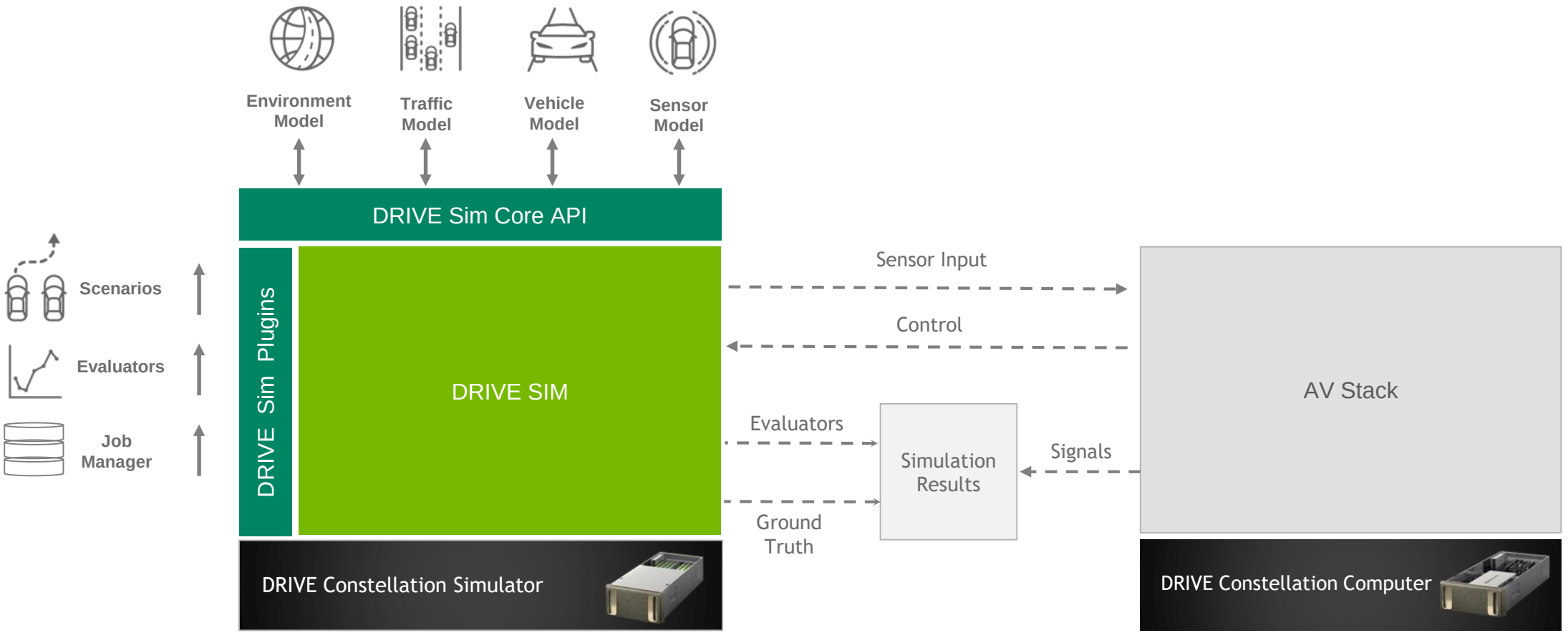


Query Image: Drivenet did not detect the large truck on right lane

POWER OF SIMULATION TO AUGMENT REAL DATA

NVIDIA DRIVE SIM

Hardware-in-the-loop AV Simulator



DRIVE SIM | ENVIRONMENT MODEL

Change Time of Day

DRIVE SIM | ENVIRONMENT MODEL

Add Traffic Scenarios

DRIVE SIM | ENVIRONMENT MODEL

Change Weather

DRIVE SIM | SCENARIO DESCRIPTION LANGUAGE

Python-based Scenario API

Python Scenario API

```
 # create scenario
S = py_drivesim_api.nvsim.Scenario()
S.bindToSimulation(DDS_CONFIG, DDS_DOMAIN)
...
S.spawnEgo(actorName='ego', position=position)
S.setSpeed(actorName='ego', speed=30.0)
S.spawnNonEgo(actorName='actor-1’,
                          position=position,
assetID=1)
...
S.laneChange(actorName='actor-1',toLeft=True,)
...
...
```

DDS Messaging

DRIVE SIM

Scenario Queue

1. Create Ego
2. Set Ego Speed
3. Create Actor
4. …
5. Actor Change Lanes
6. …
7. …

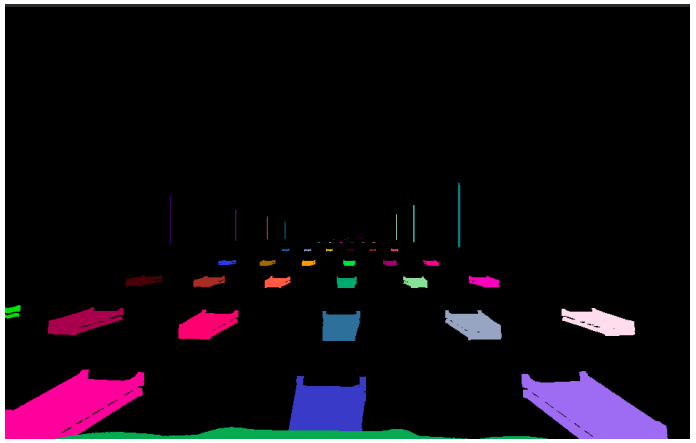
DRIVE SIM | SCENARIO DESCRIPTION LANGUAGE

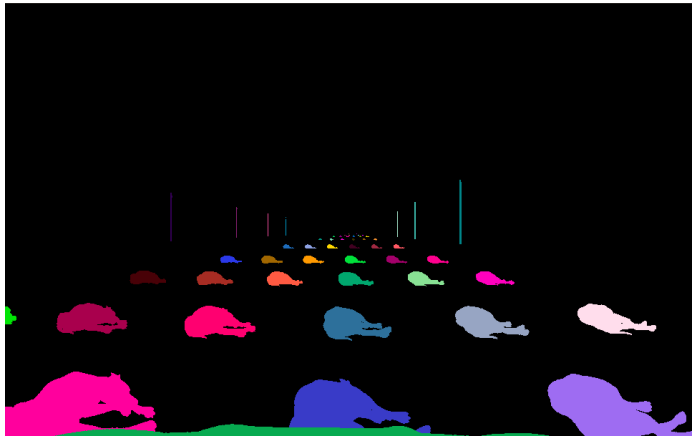
Weather | Time of Day

NVIDIA

SIMULATION USED FOR DATA AUGMENTATION

Here an example of augmenting real data
with sim data for rare events





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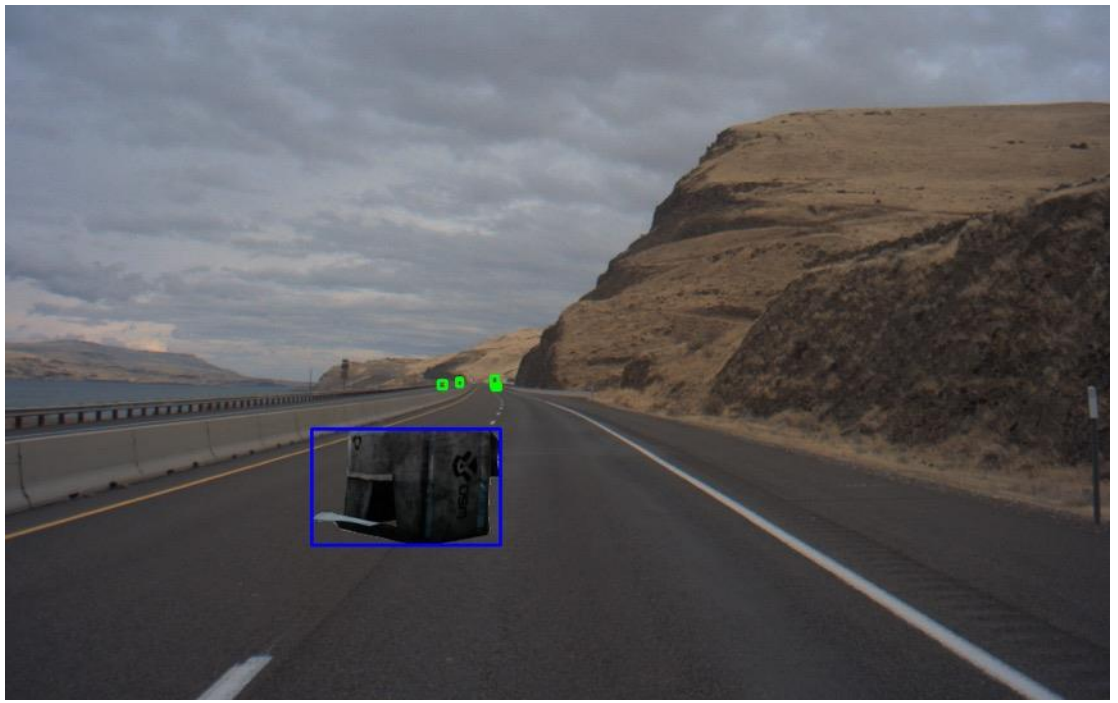
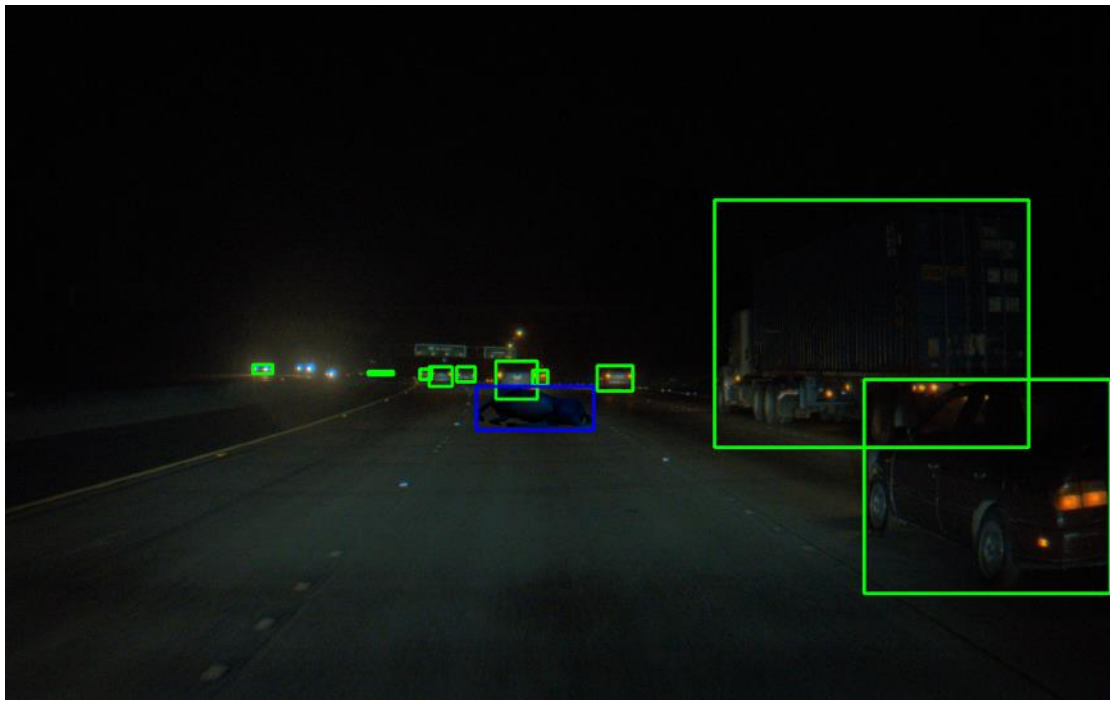




SIMULATION USED FOR DATA AUGMENTATION

Here an example of augmenting real data
with sim data for rare events

SIMULATION USED FOR DATA AUGMENTATION

Results on real data

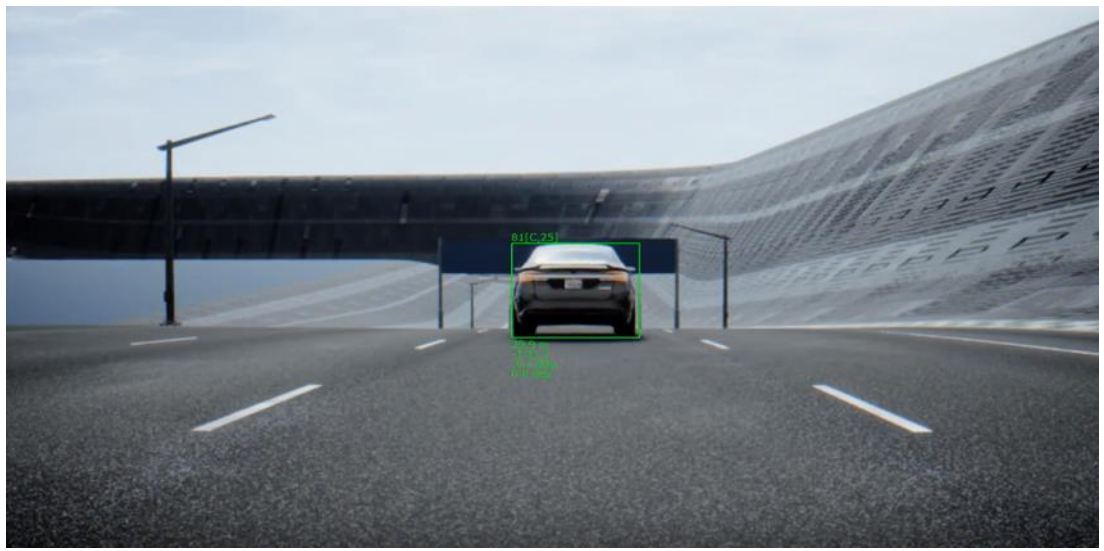
SIMULATION USED FOR DATA AUGMENTATION

Results on real data

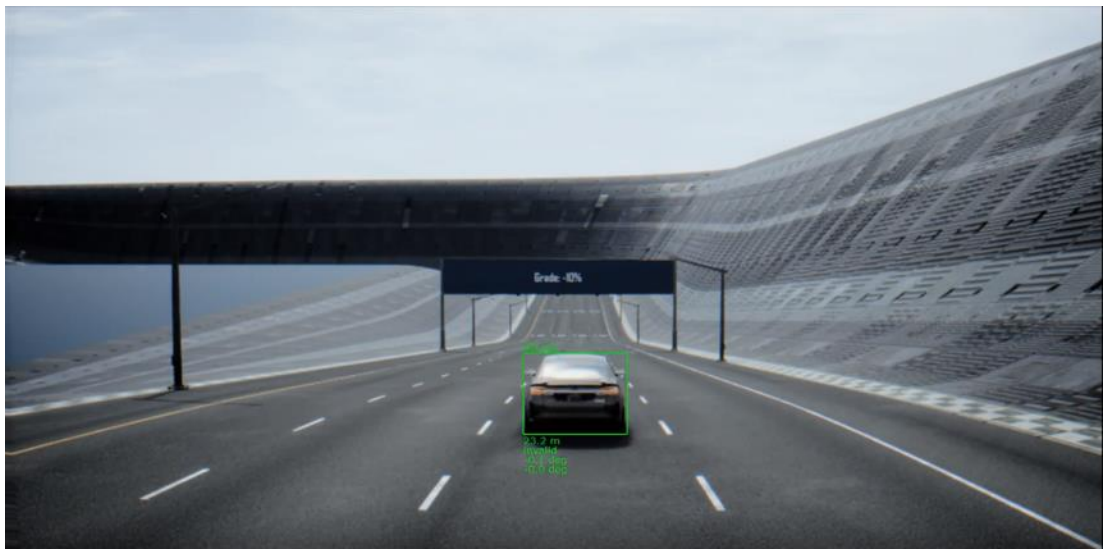
SIMULATION USED FOR VALIDATION

Here an example of defining a scenario to measure impact of sensor placement on perception

Roadster FC height = 1.1m

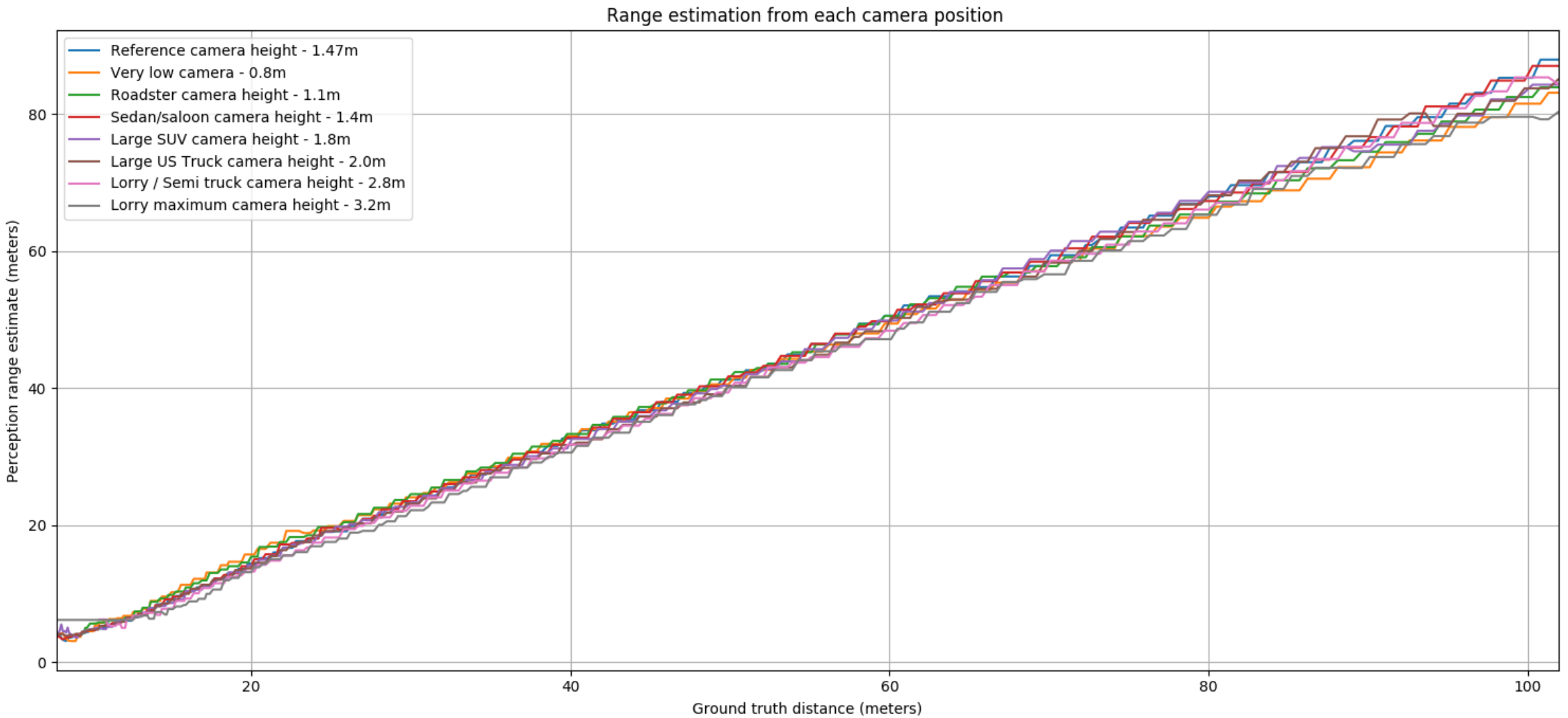


Semi truck FC height = 2.8m



PERCEPTION PREDICTION IN SIM

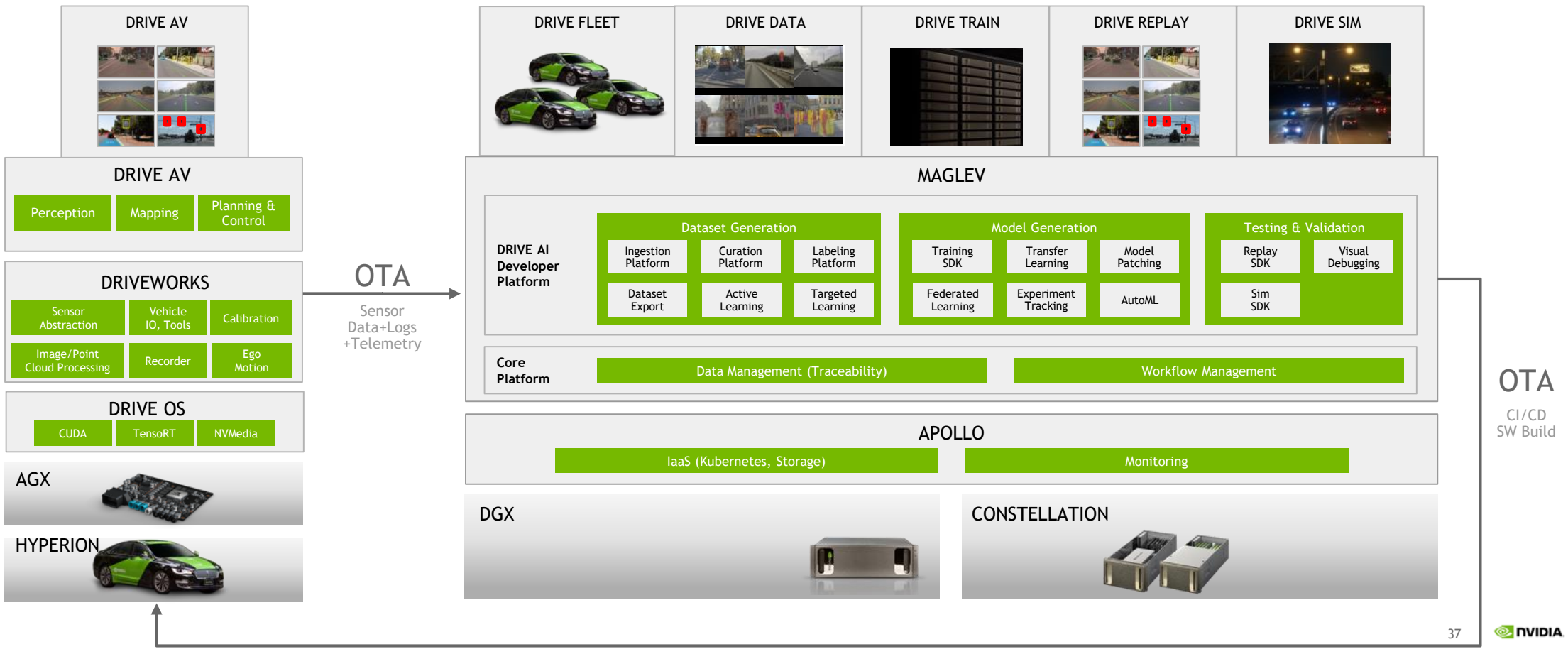
Here looking at a DNN predicting the distance of the vehicle in front



KEY INGREDIENTS
TO AN EFFECTIVE AV DEV PLATFORM

NVIDIA DRIVE DEVELOPMENT PLATFORM

A complete platform to enable rapid & lifelong AV innovation



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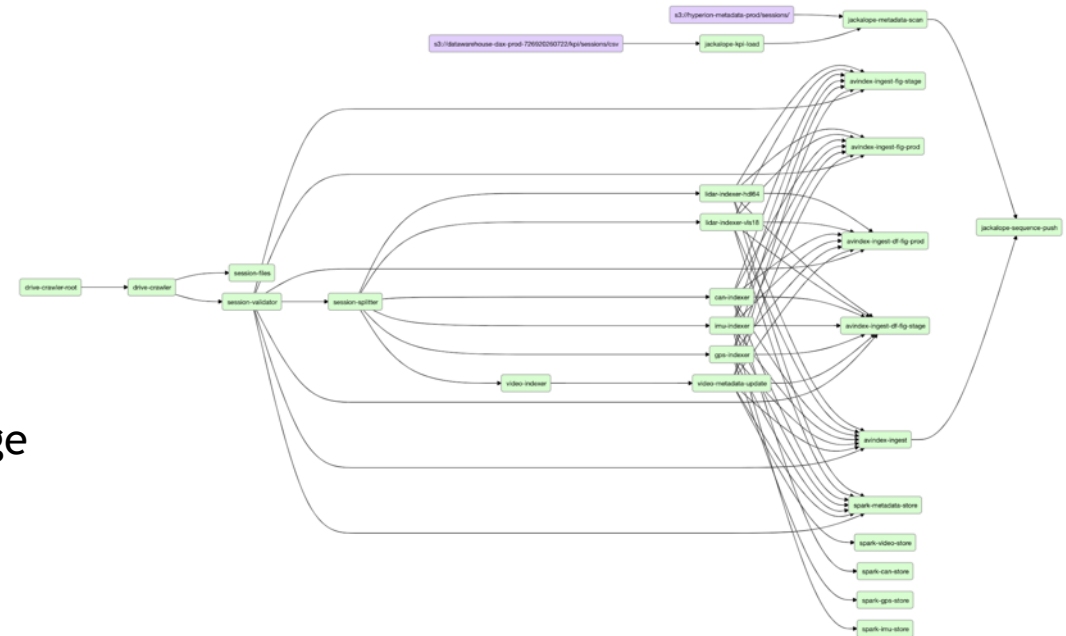
WORKFLOW MANAGEMENT

Core Infra to efficiently, safely run complex tasks

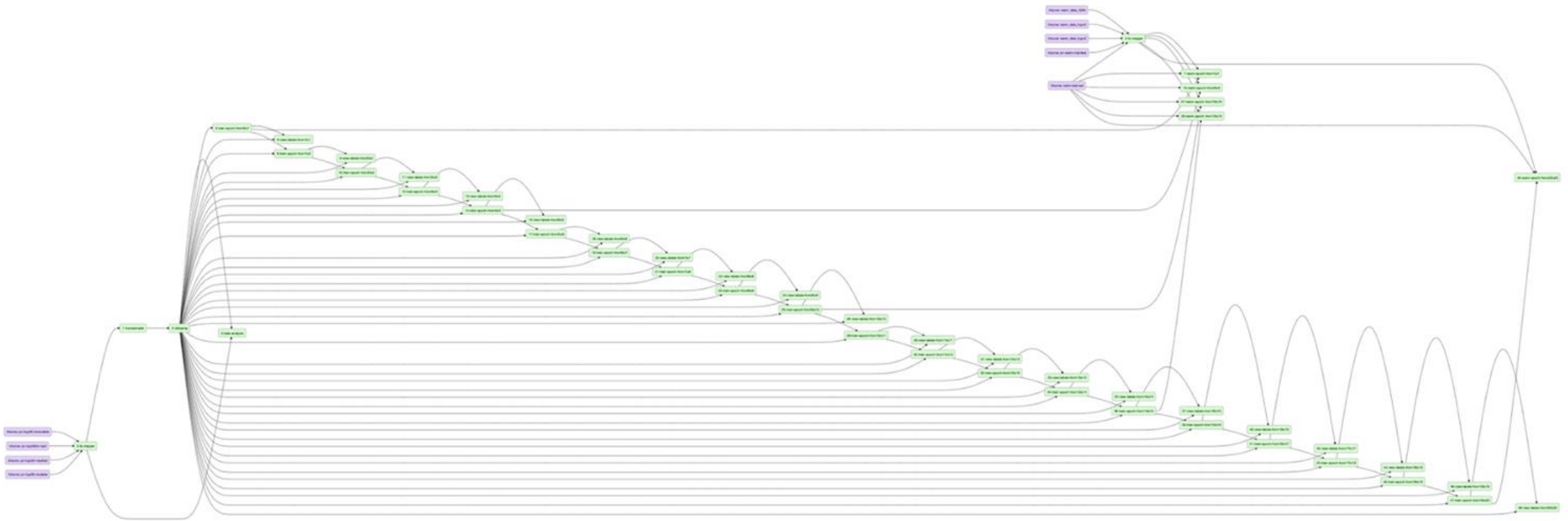


A unified **advanced, flexible workflow system** to run large interdependent tasks.

A **fine-grained access management** system to data and compute.

Efficient scheduling across hundreds of users.

WORKFLOWS TO DEFINE TRAINING PIPELINES

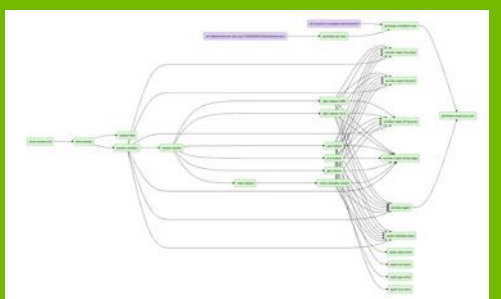


WORKFLOWS TO SUPPORT DATA/ETL PIPELINES

Test Fleet

Data Collection Fleet

DATA INDEXING, INTEGRITY, CATALOGING



HUMAN DATA TAGGING

DATA MANAGEMENT APIs

NVIDIA DGX SATURNV

World's Largest Enterprise AI Infrastructure Buildout

2000 DGX Nodes

16,000 GPUs

1.8 ExaFLOPs

~1000 Unique Users Across NVIDIA

DRIVE CONSTELLATION

Virtual AV Simulator

Hardware in the-Loop System Level Simulator

Timing Accurate | Bit Accurate

Scalable | Data Center Solution

Efficient | Scenarios of Interest

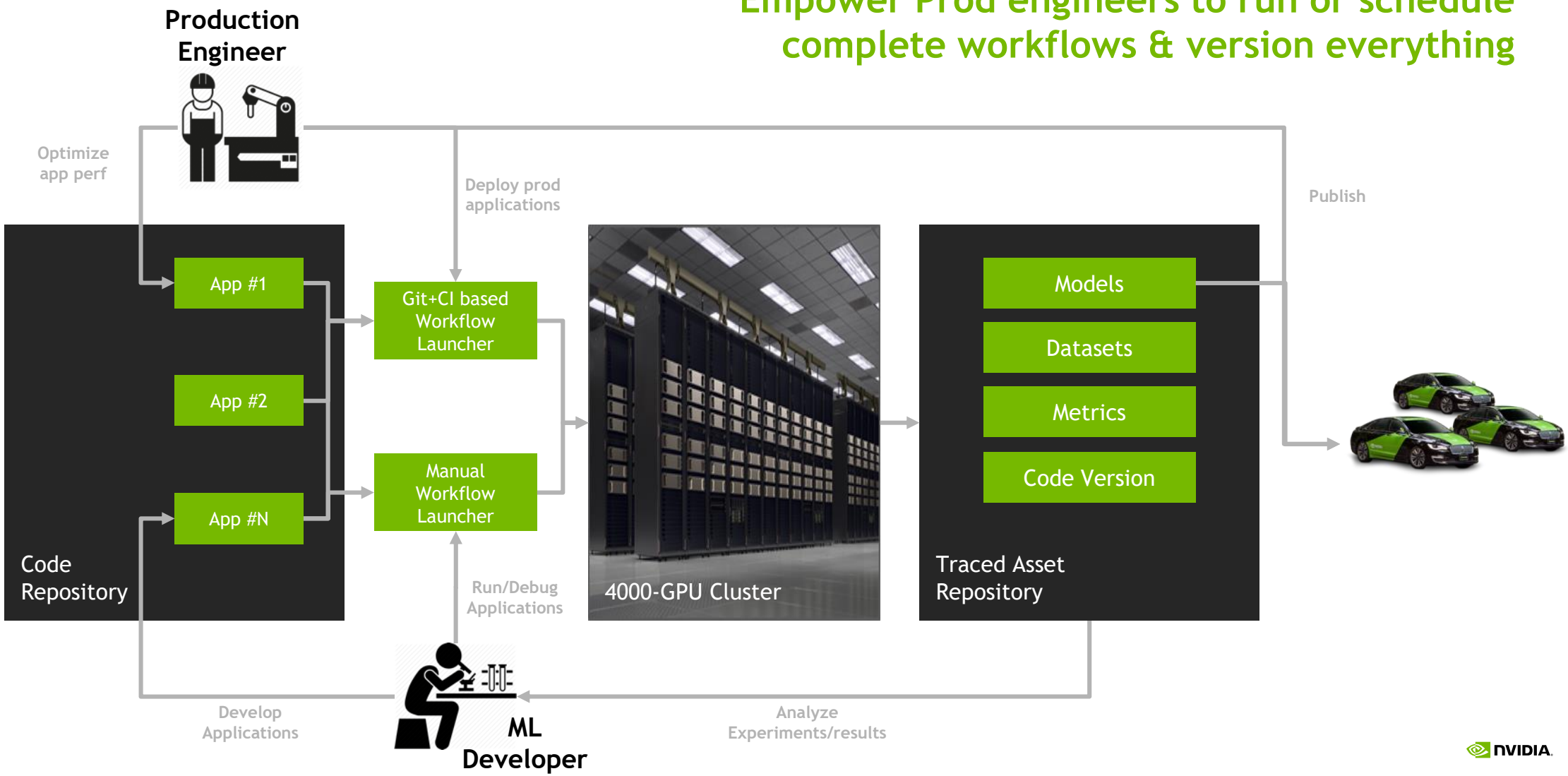
Simulate Rare and Difficult Conditions

CONSTELLATION TEST FLEET IN THE DATA CENTER

Virtual Proving Ground for AVs

AUTOMATION & TRACEABILITY

Empower Prod engineers to run or schedule complete workflows & version everything



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THANK YOU

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