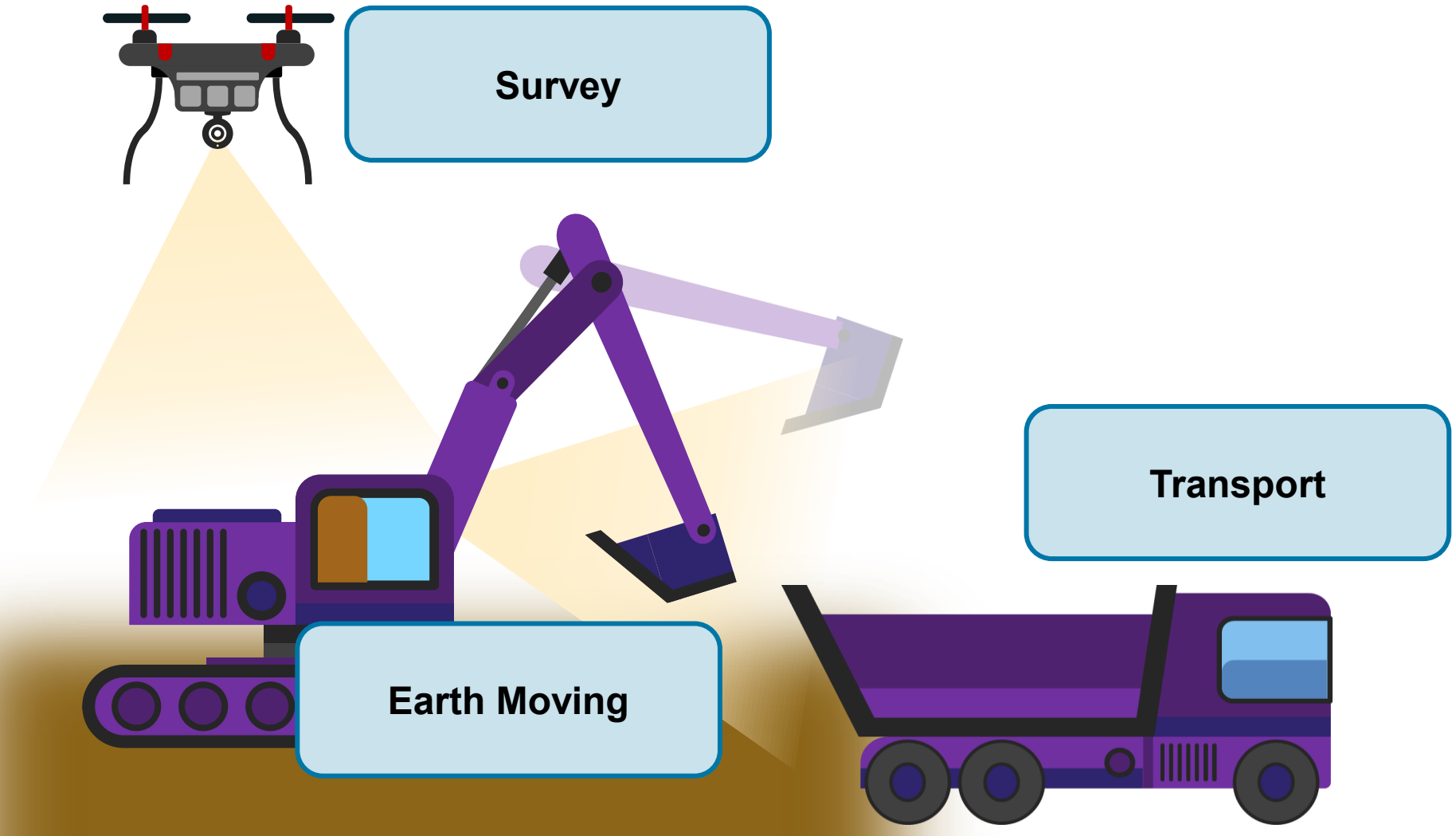
Shaping a Path to Offroad Autonomy Using MATLAB

Ronal George
Senior Application Engineer

Automation & Autonomy in Offroad Vehicle Activities

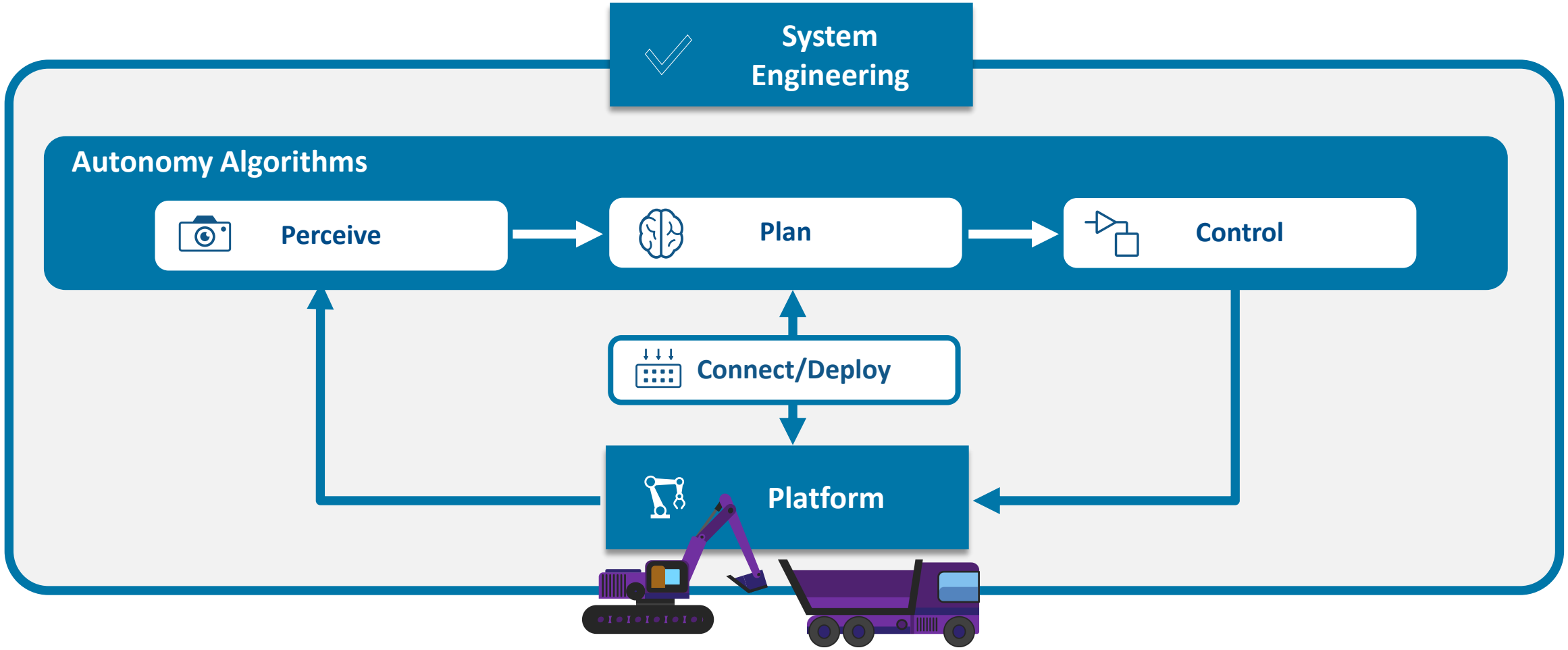


Technologies

- Detection / Identification
- Motion Planning
- Motion Controls

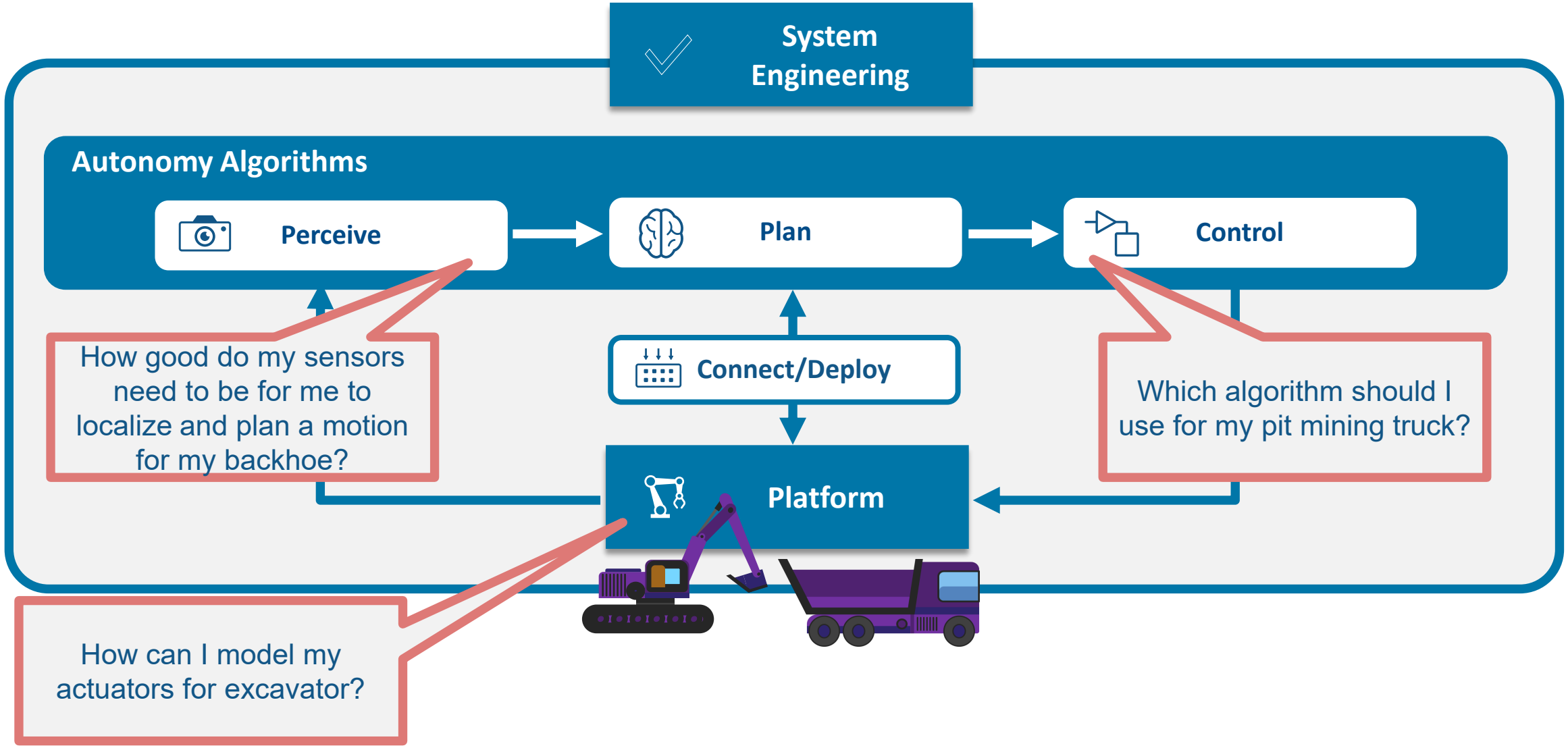
Autonomous Offroad System Development

Technology building blocks



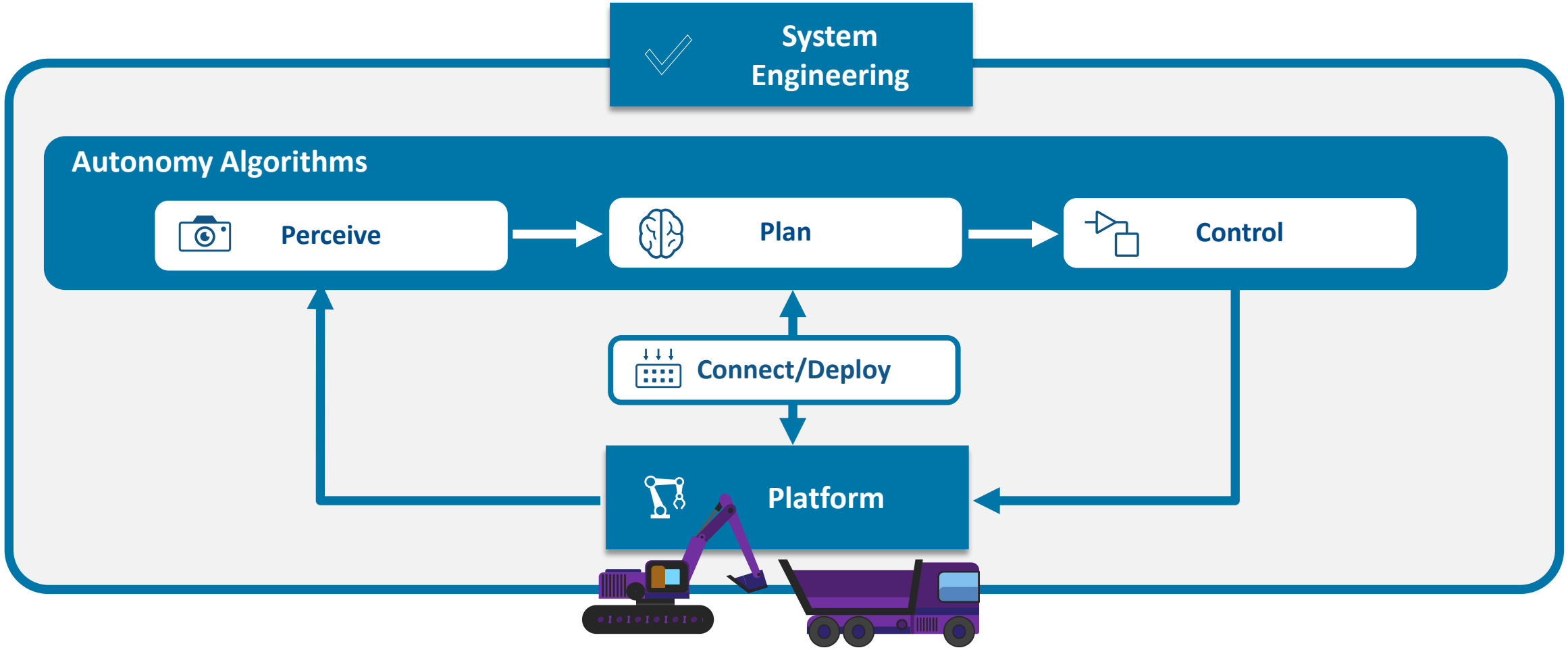
Autonomous Offroad System Development

Technology challenges



Autonomous Offroad System Development

Technology challenges



***Simulation** is essential for all stages of development process and entire product lifecycle*

Offroad vehicle industries are adopting autonomy and intelligence for process optimization, safety, and sustainability

- Although the case study is in agriculture, MathWorks collaborates with many companies in autonomous mining, construction, and defense with similar requirements

Construction

Agriculture

Mining

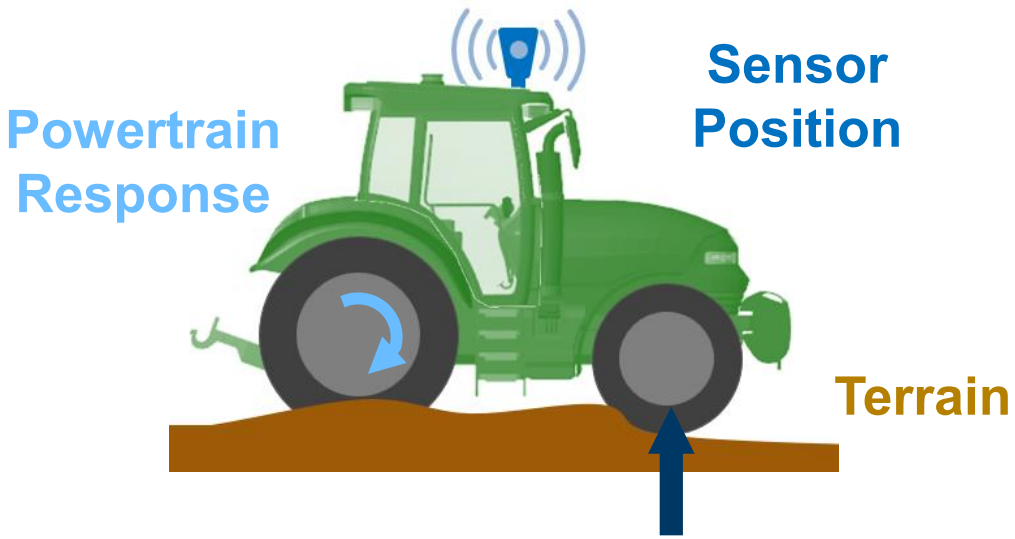
Defense

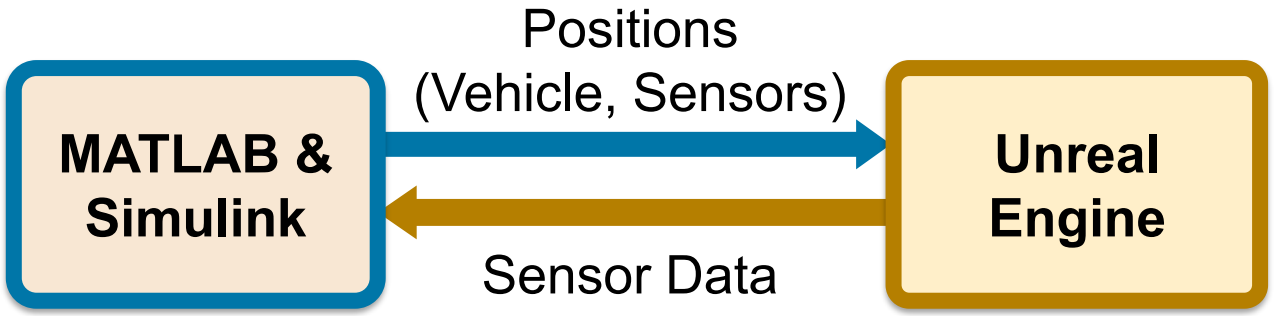
Case Study: Autonomous Emergency Braking for Tractor

- Developing Autonomous Emergency Braking (AEB) controller for a tractor
- Need to decide what sensors, placement and accuracy needed for perception module
- Field testing time is limited, so need to test and validate software modules before then
- **Simulation and Virtual Testing** are key technologies to reduce cost and mitigate risk

Key Takeaways

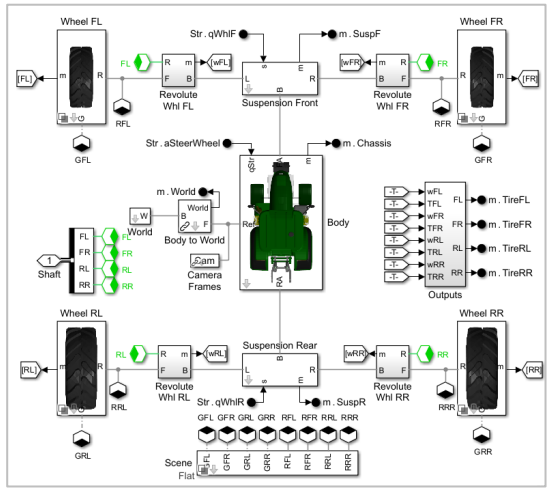
- Capturing physical behavior at the right level of detail enables effective virtual testing
- Connecting with game engine enables sensor data collection and world interactions
- System-level integration enables testing and validation of autonomous systems

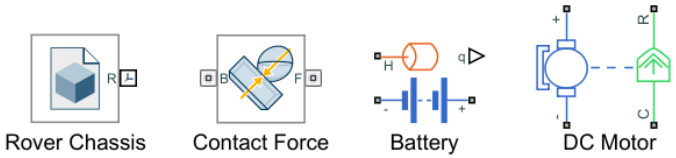




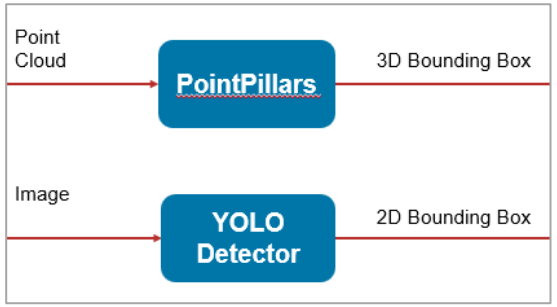
Design, Simulate, and Test Offroad Autonomy

Multibody Dynamics → Control and Perception → High-level Task Scenario

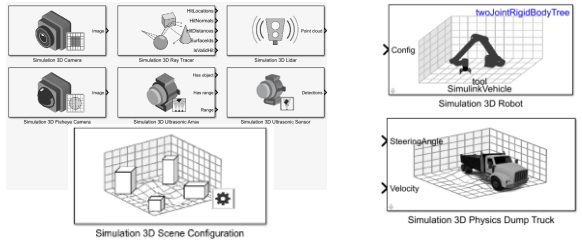




Dynamic Models



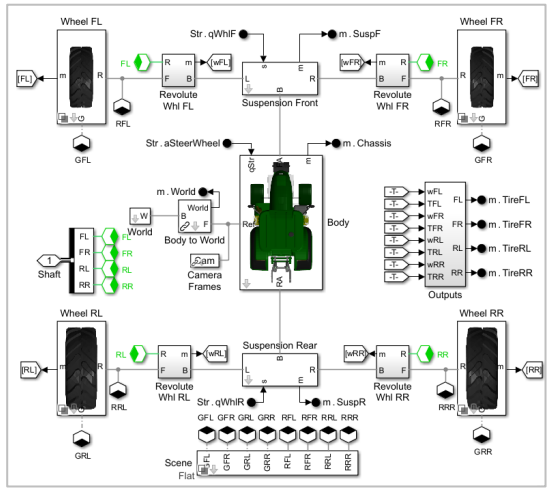
Autonomy Models

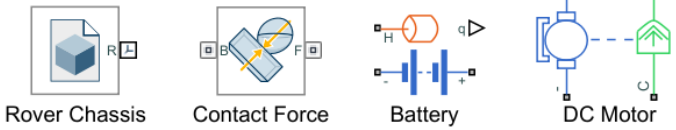


Scene and Agent Models

Design, Simulate, and Test Offroad Autonomy

Multibody Dynamics





Dynamic Models

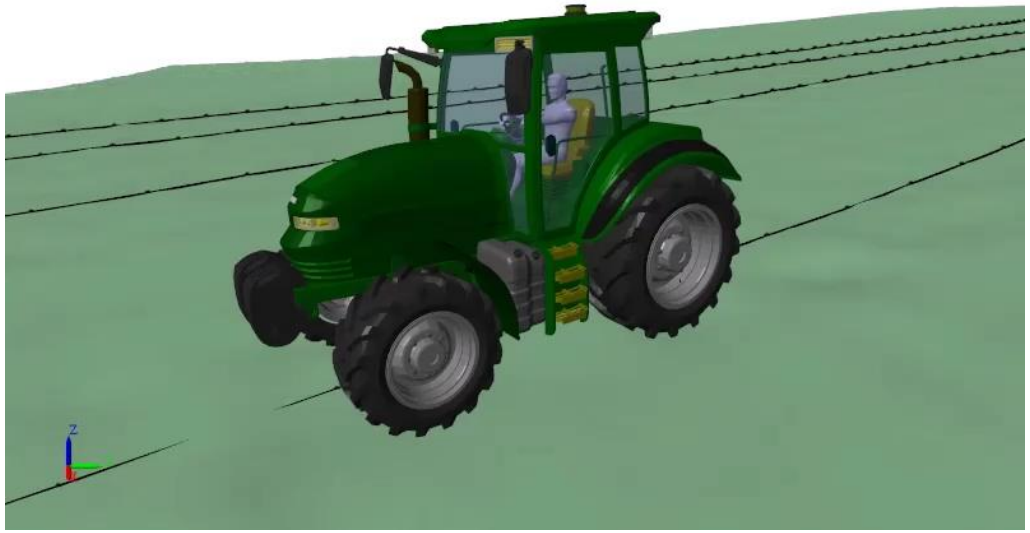
Control and Perception

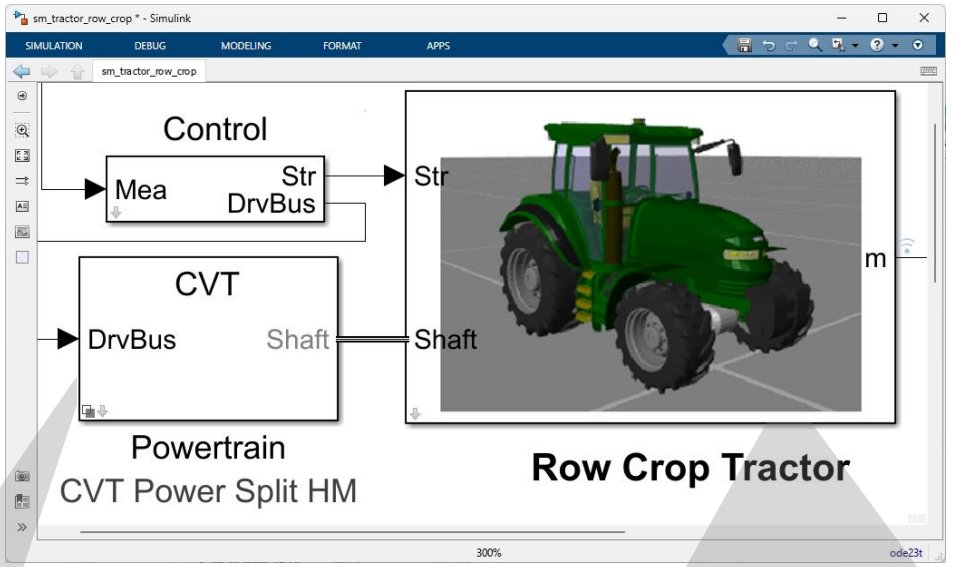
Autonomy Models

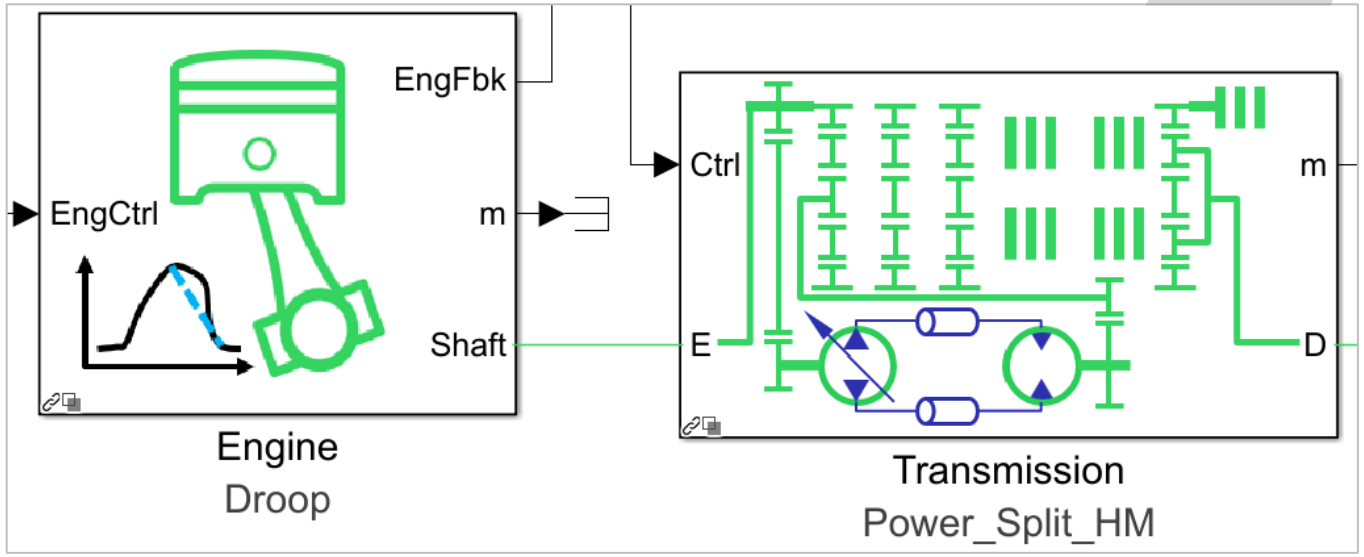
High-level Task Scenario

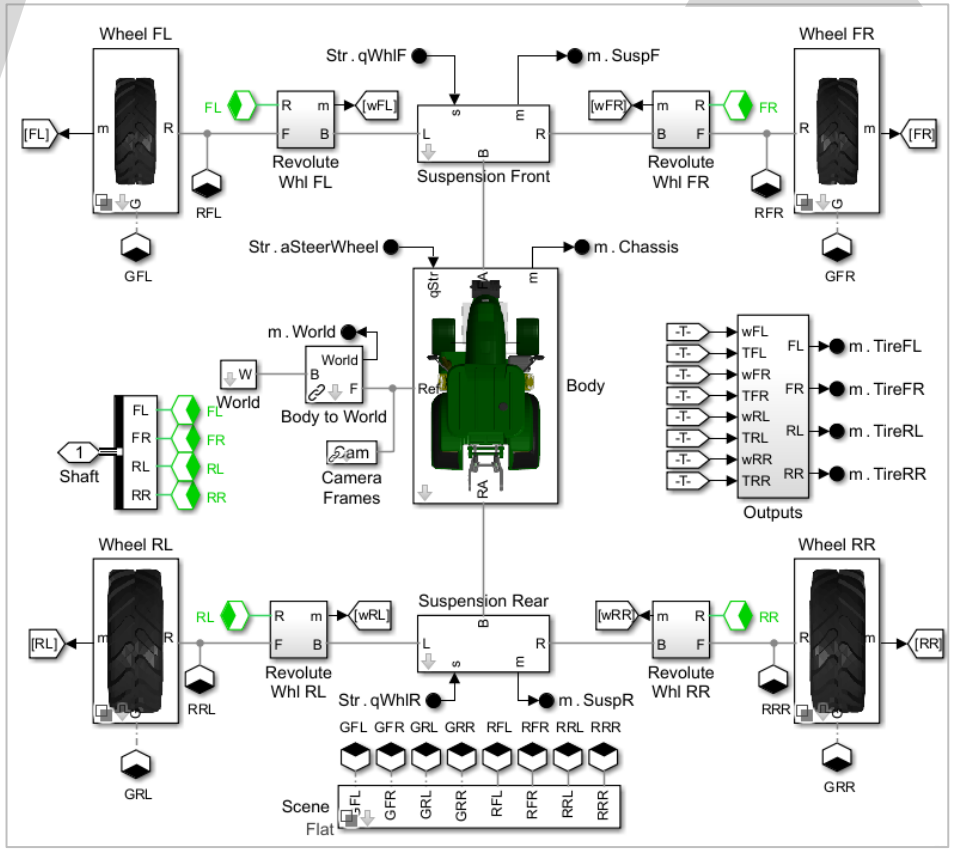
Scene and Agent Models

Tractor Model With Essential Physics



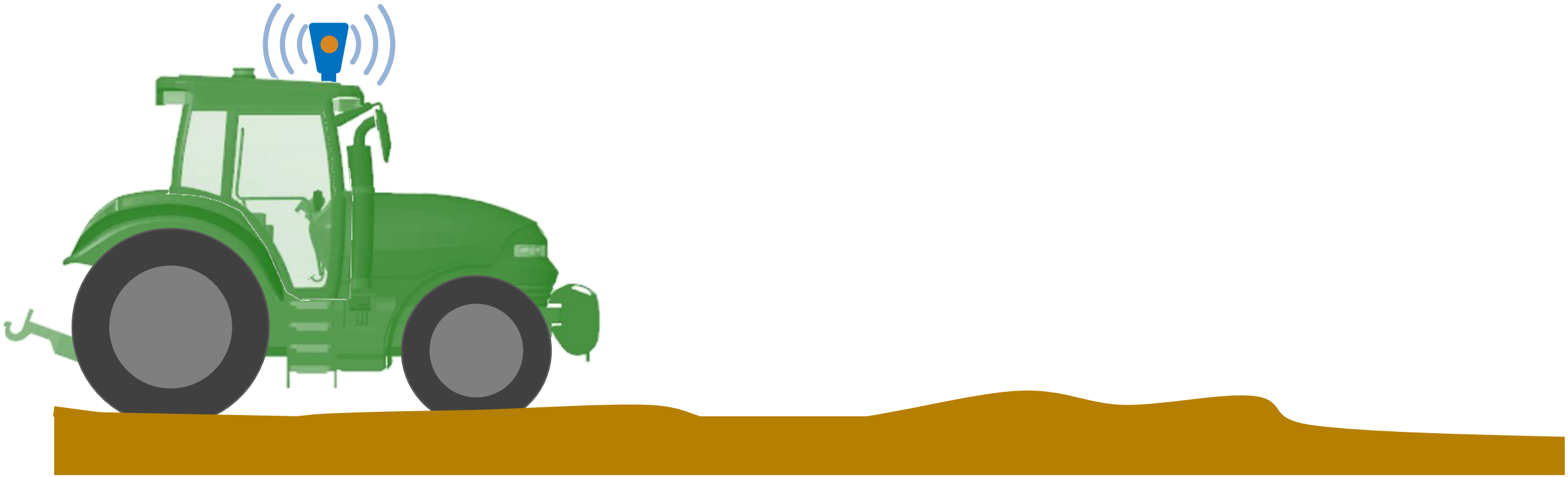






Accurate Sensor Position with Vehicle Suspension Model

- Suspension model affects sensor position
  - Model must capture chassis movement



Accurate Sensor Position with Vehicle Suspension Model

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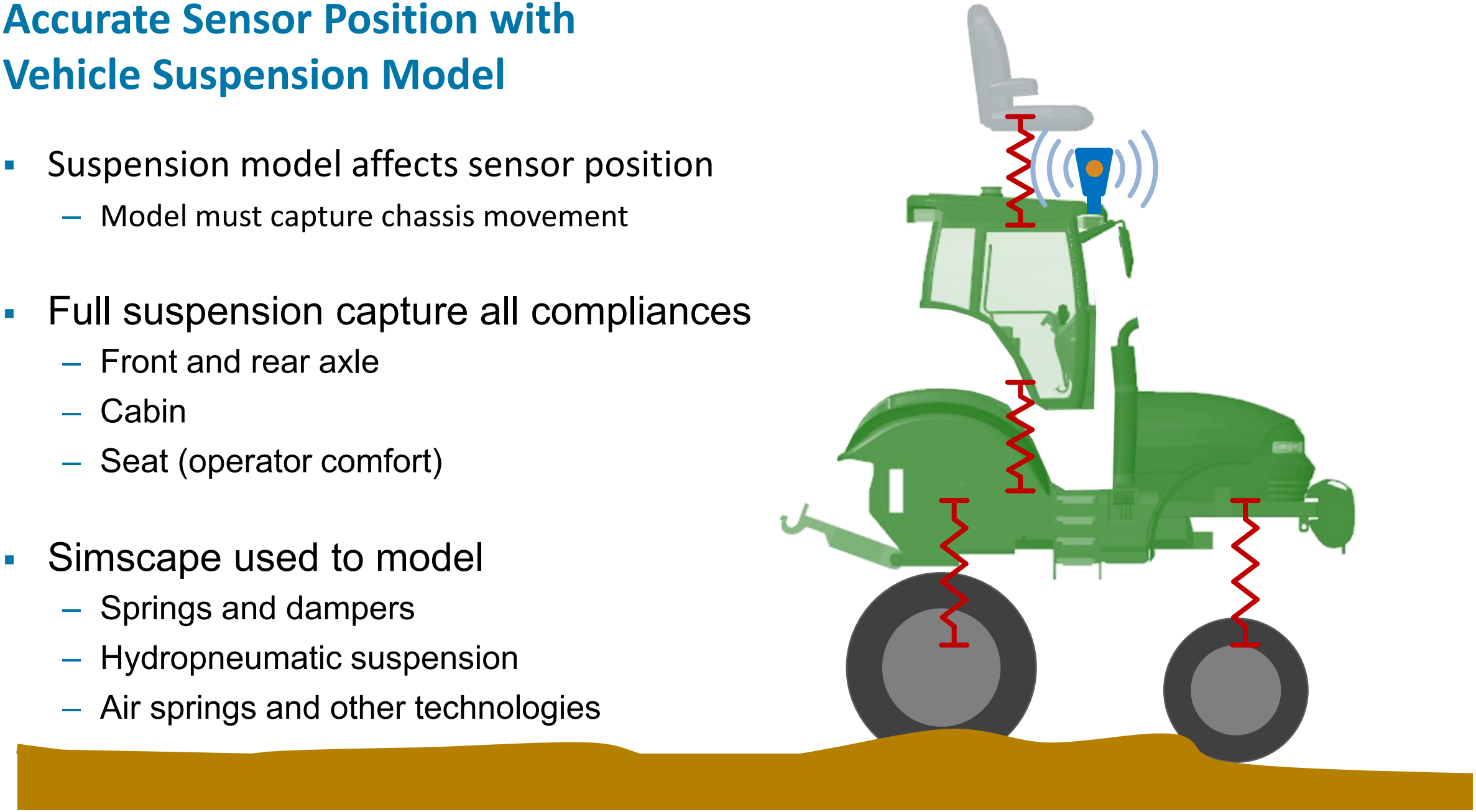
Accurate Sensor Position with Vehicle Suspension Model

- Suspension model affects sensor position
  - Model must capture chassis movement
- Full suspension capture all compliances
  - Front and rear axle
  - Cabin
  - Seat (operator comfort)
- Simscape used to model
  - Springs and dampers
  - Hydropneumatic suspension
  - Air springs and other technologies



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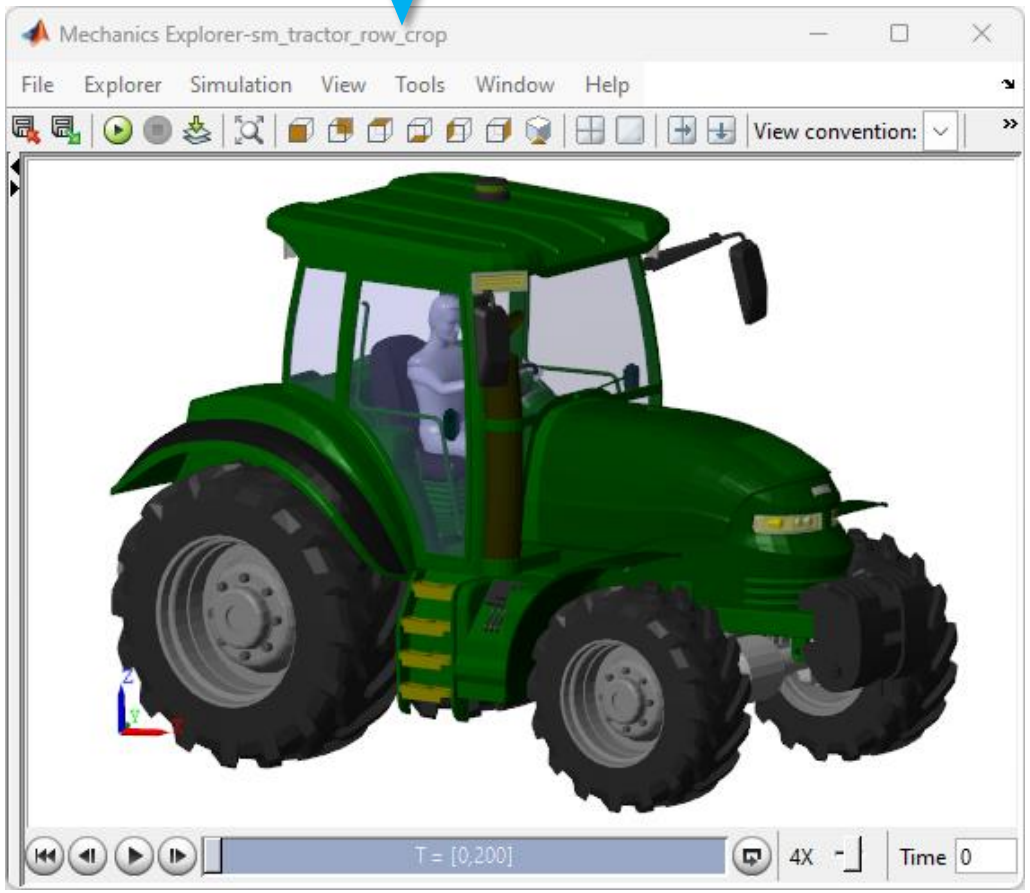
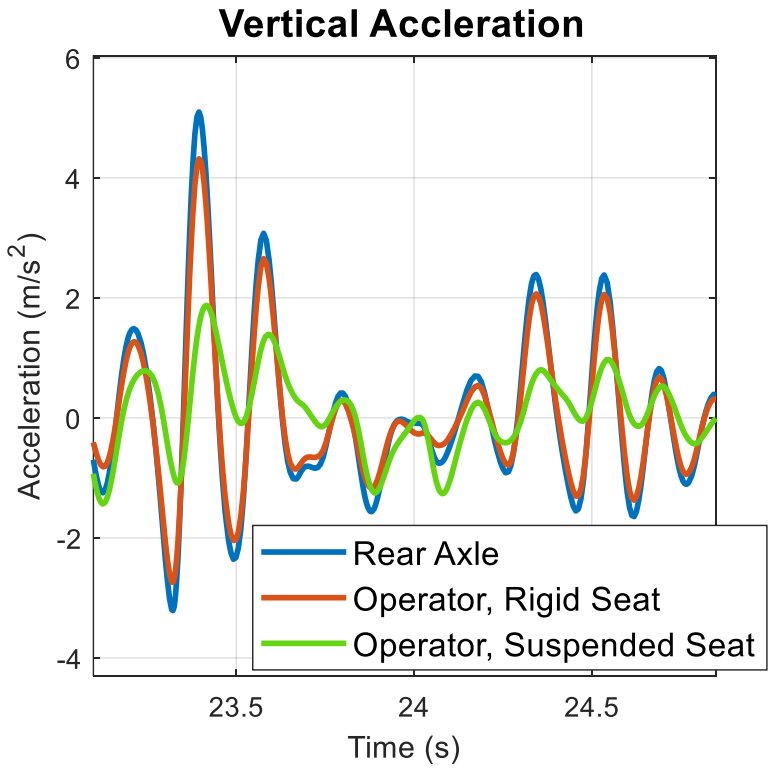
CAD Models

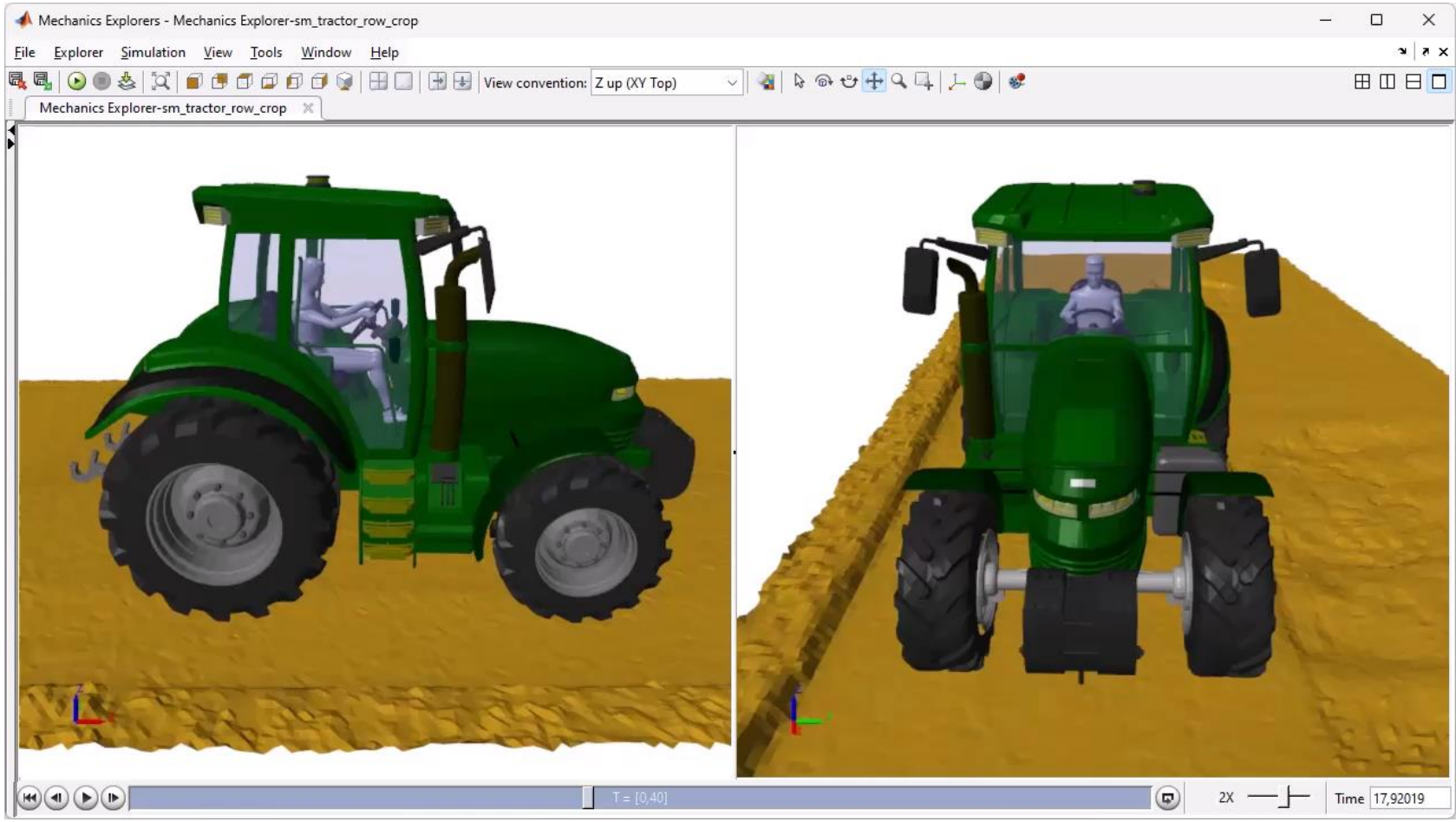
Import Parts and Assemblies



Import Terrain to Test System Under Any Conditions

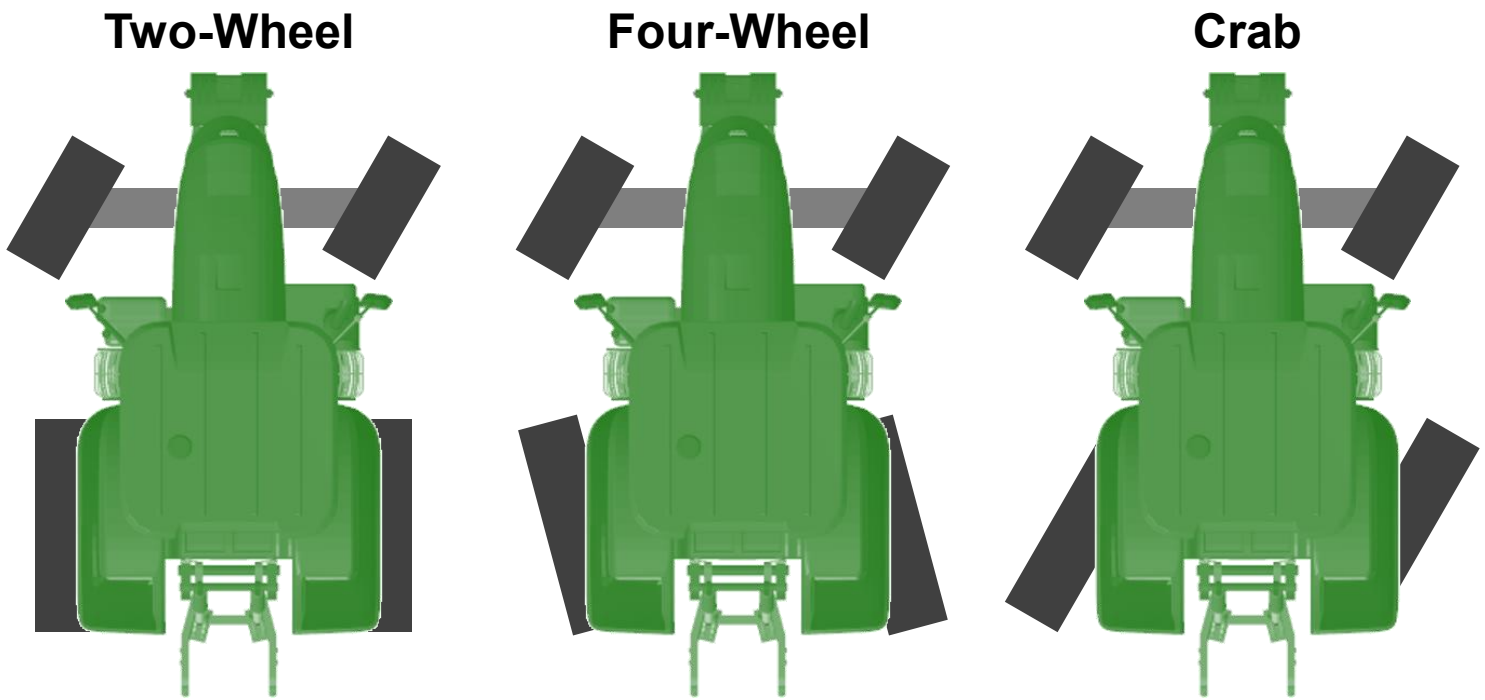
- Import scanned data to model terrain

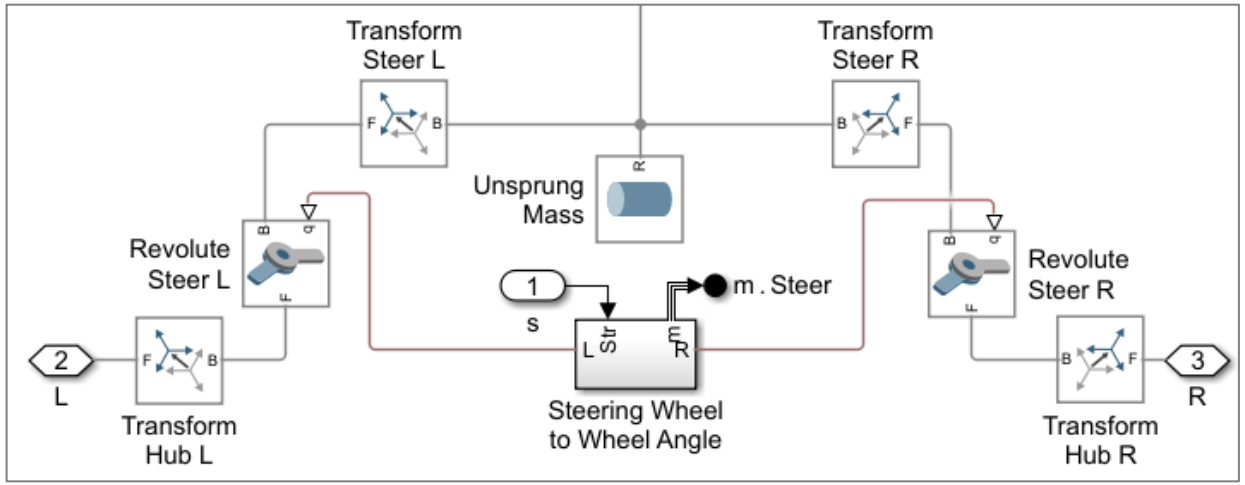




Accurate Path Following with Steering Model

- Many steer modes offered
  - Front wheels only
  - 4 Wheel, proportional
  - 4 Wheel, crab
- All possible with Simscape
- Steering modeled abstractly
  - Faster simulation
  - Fewer parameters
  - More complex linkages possible

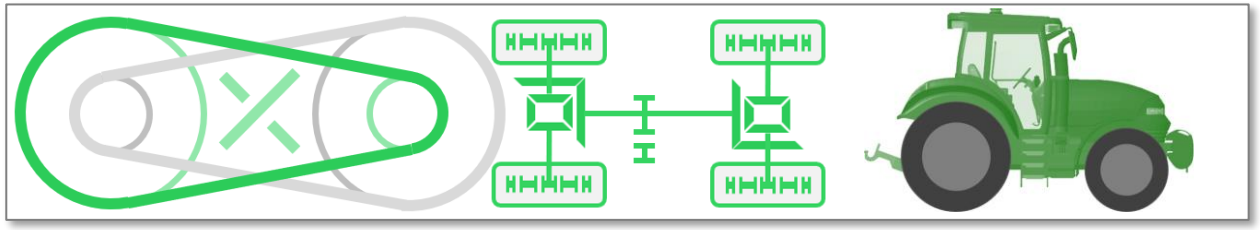




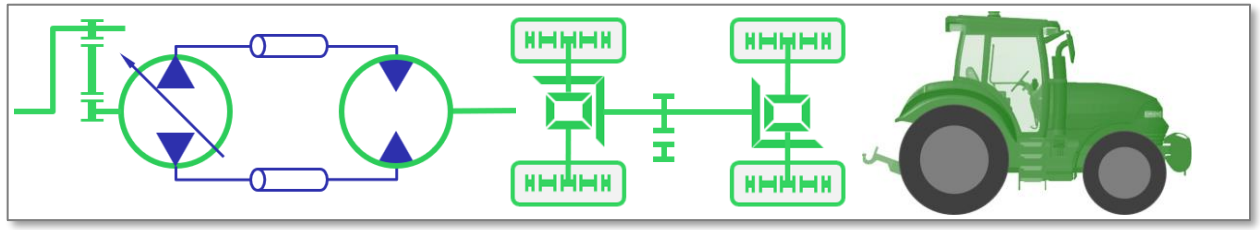
Tailor Model to Match Requirements of Virtual Test

- Use abstract CVT model to capture behaviour
- Swap in CVT designs to interface directly with control algorithms
- Explore other aspects of performance including component choice, efficiency, and electrical technology

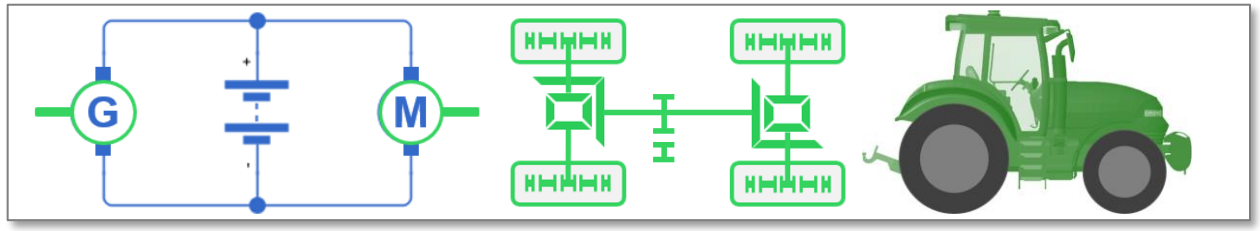
Abstract



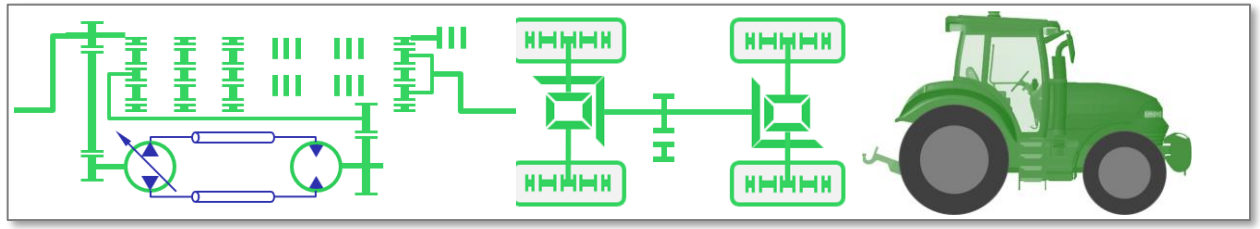
Hydrostatic



Electrical

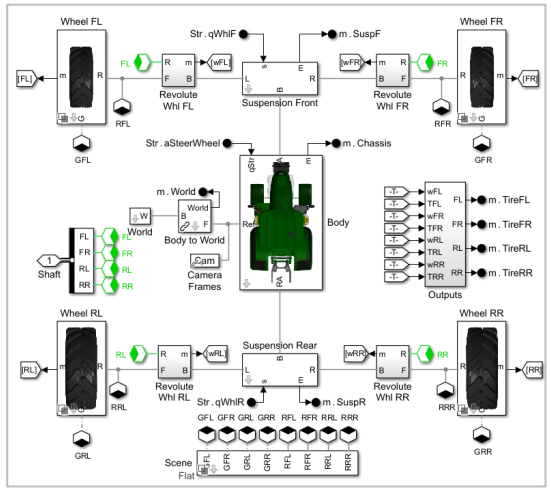


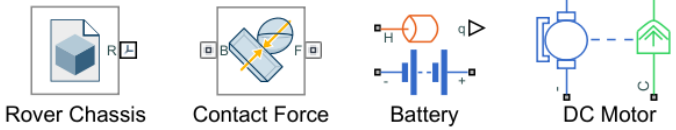
Power Split



Design, Simulate, and Test Offroad Autonomy

Multibody Dynamics





Dynamic Models

Control and Perception

Autonomy Models

High-level Task Scenario

Scene and Agent Models

Design, Simulate, and Test Offroad Autonomy

Multibody Dynamics

Control and Perception

High-level Task Scenario

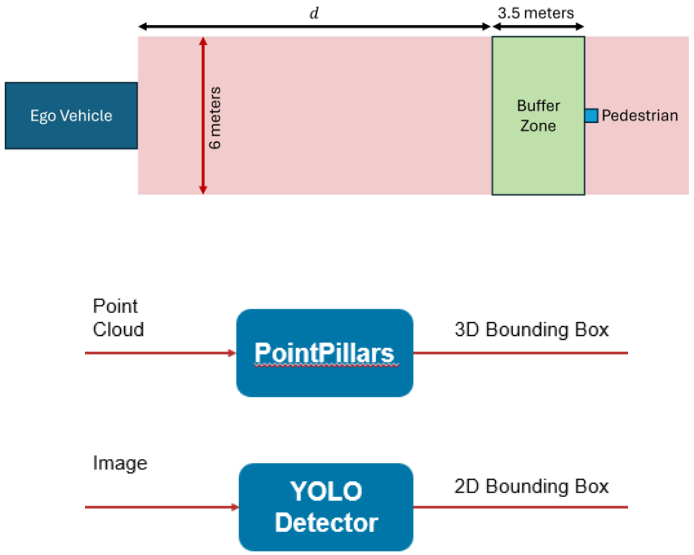
Rover Chassis

Contact Force

Battery

DC Motor

Dynamic Models

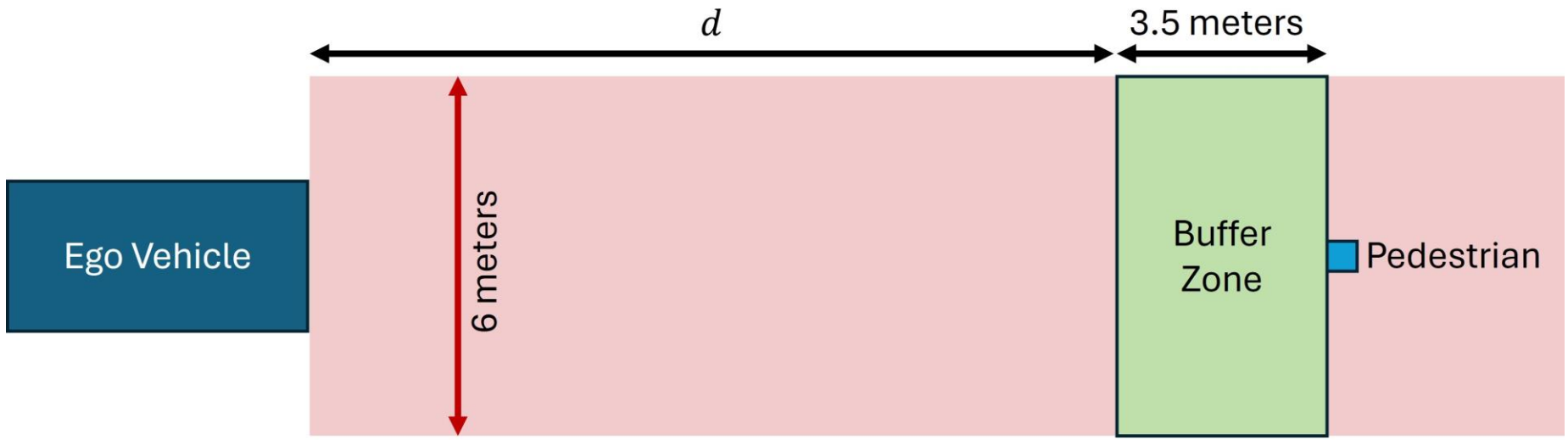


Autonomy Models

Scene and Agent Models

Emergency Braking Logic

Control

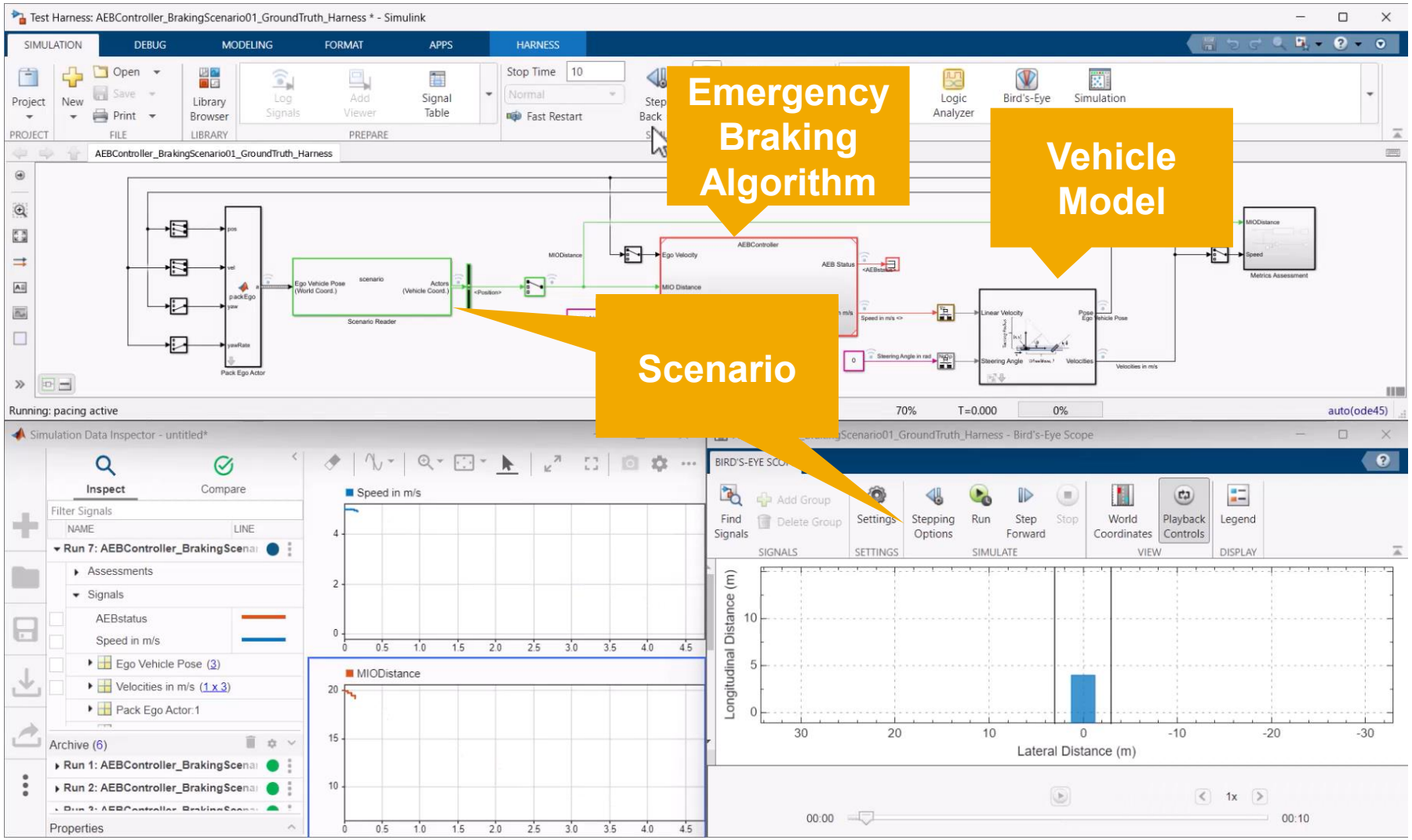


if $d \leq \frac{0.5\, v_{ego}^2}{1}$ then enter braking stage 1 (decelerate at 1 m/s^2)

if $d \leq \frac{0.5\, v_{ego}^2}{2}$ then enter braking stage 2 (decelerate at 2 m/s^2)

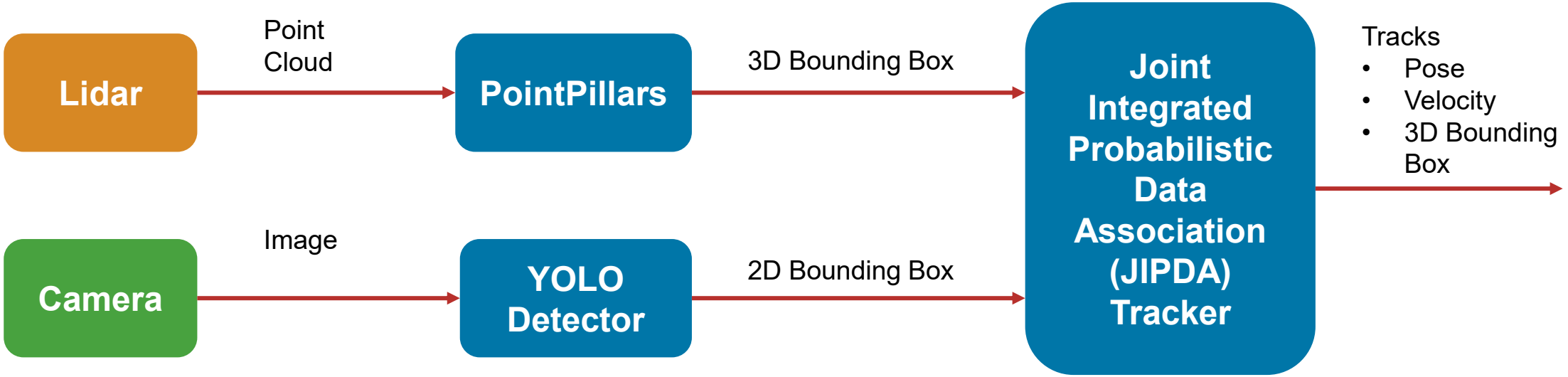
if $d \leq \frac{0.5\, v_{ego}^2}{3}$ then enter braking stage 3 (decelerate at 3 m/s^2)

Testing the Emergency Braking Algorithm



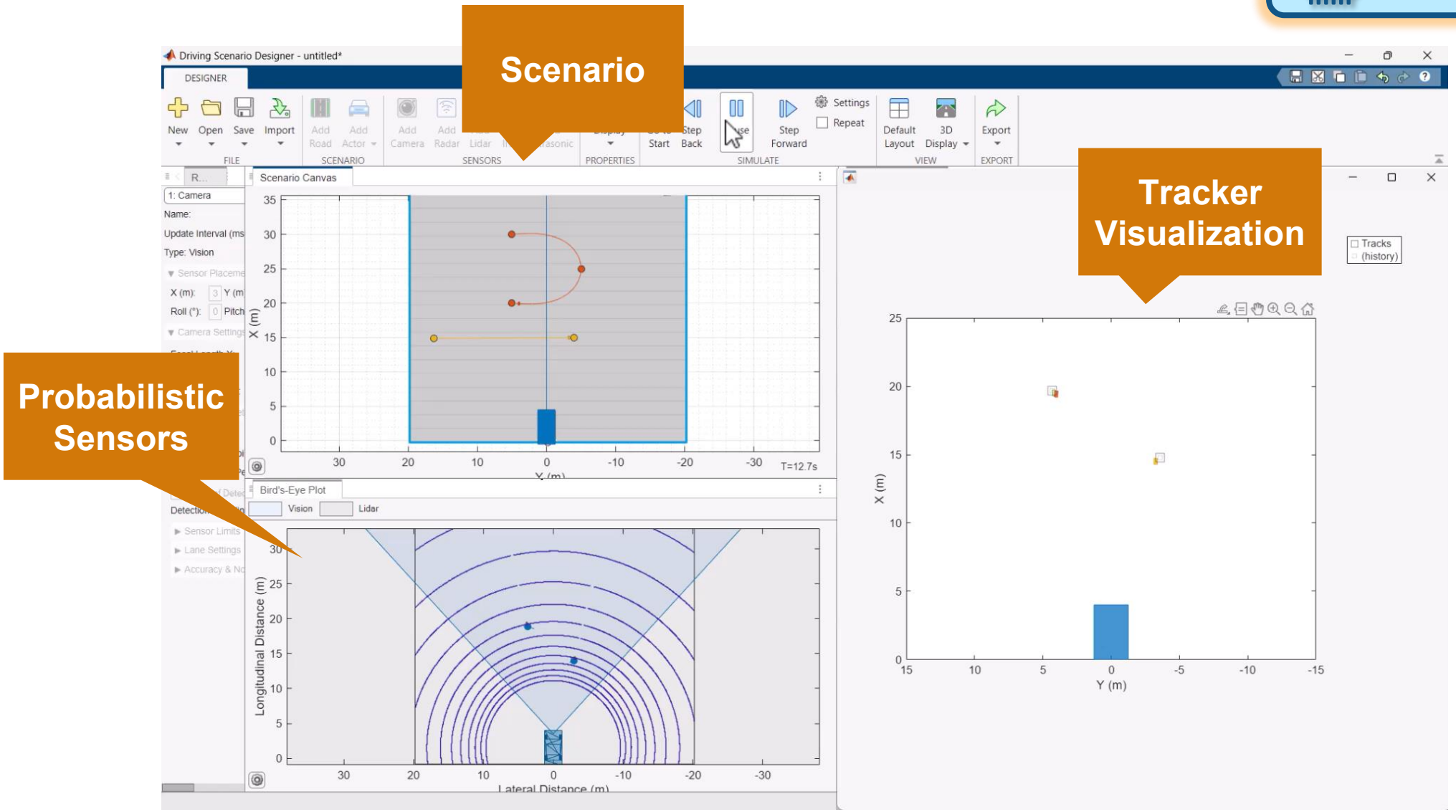
Developing an Object Tracker

Perceive



Testing the Tracker (without detectors)

Perceive



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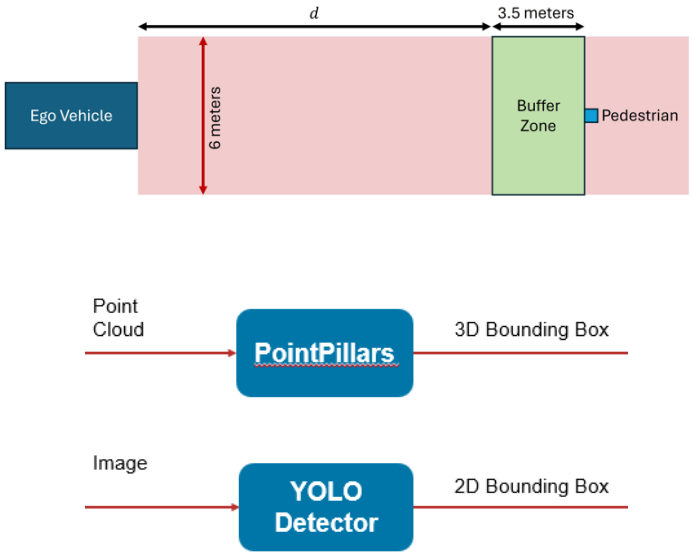

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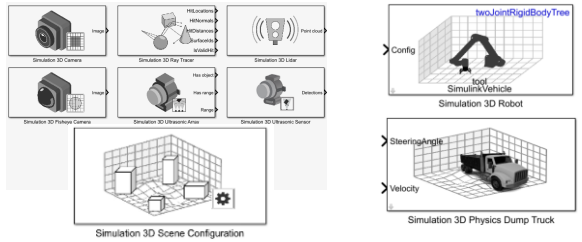
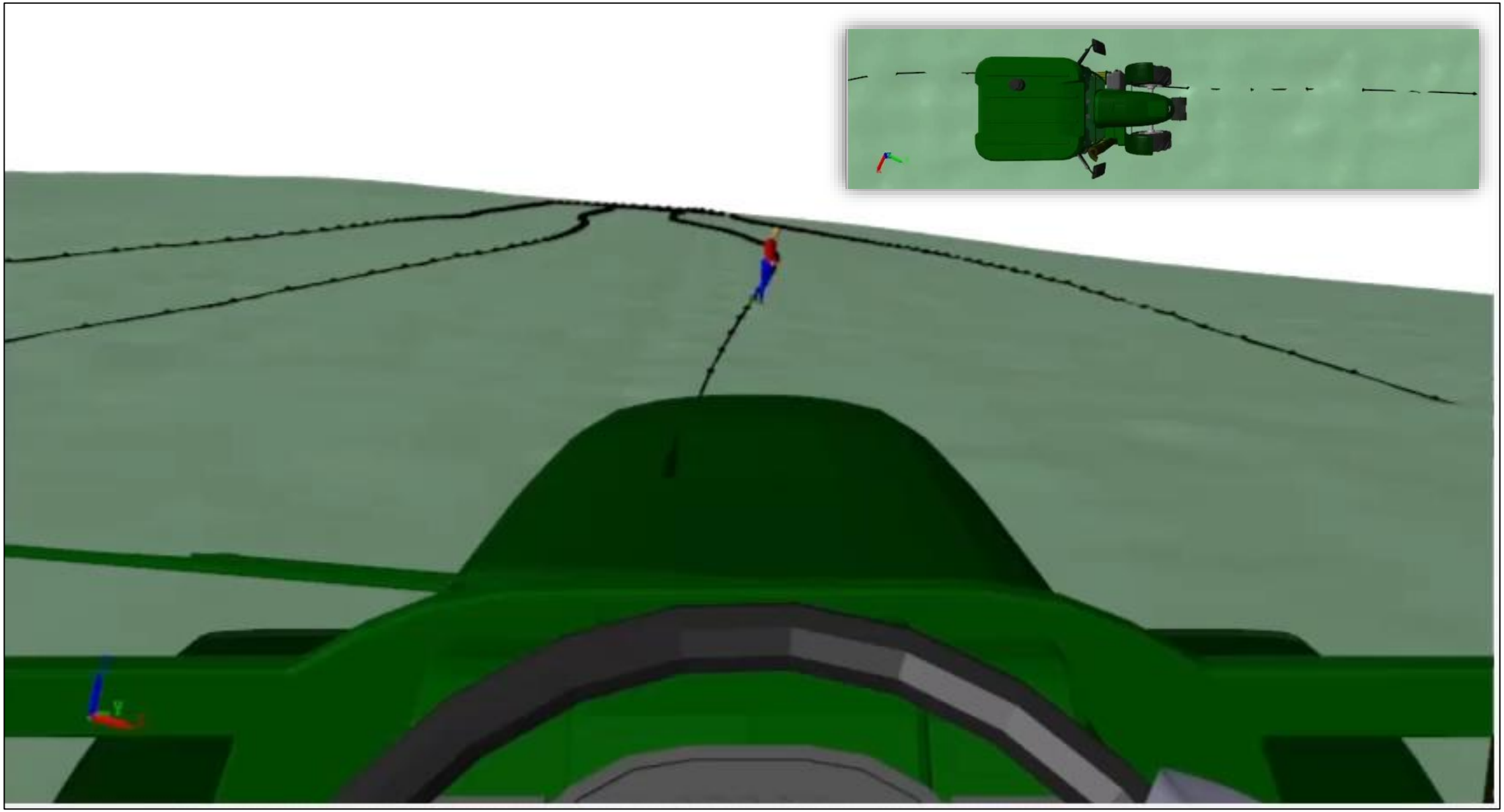


Scene and Agent Models

Comprehensive Model Enables Complete Virtual Test



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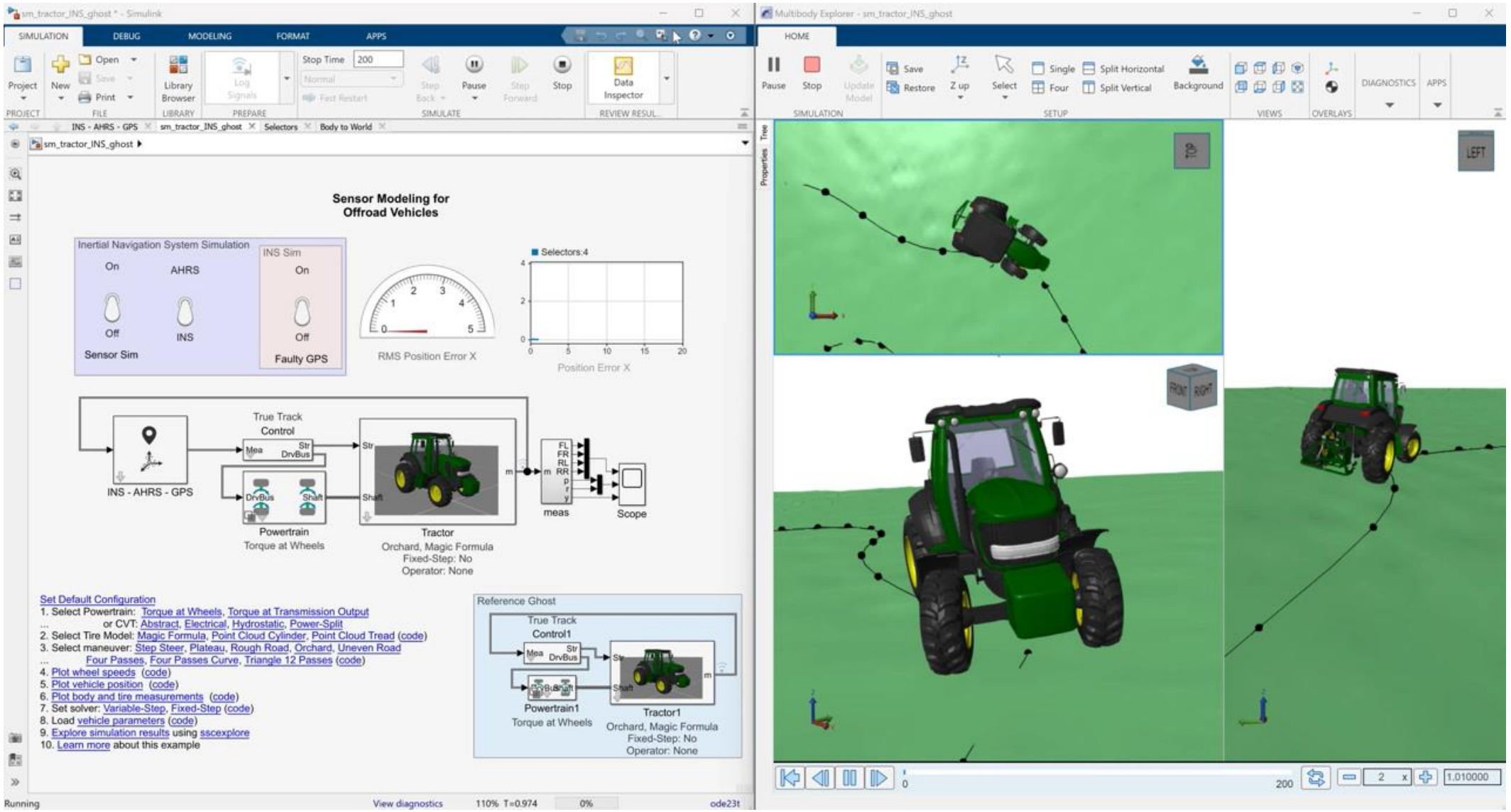

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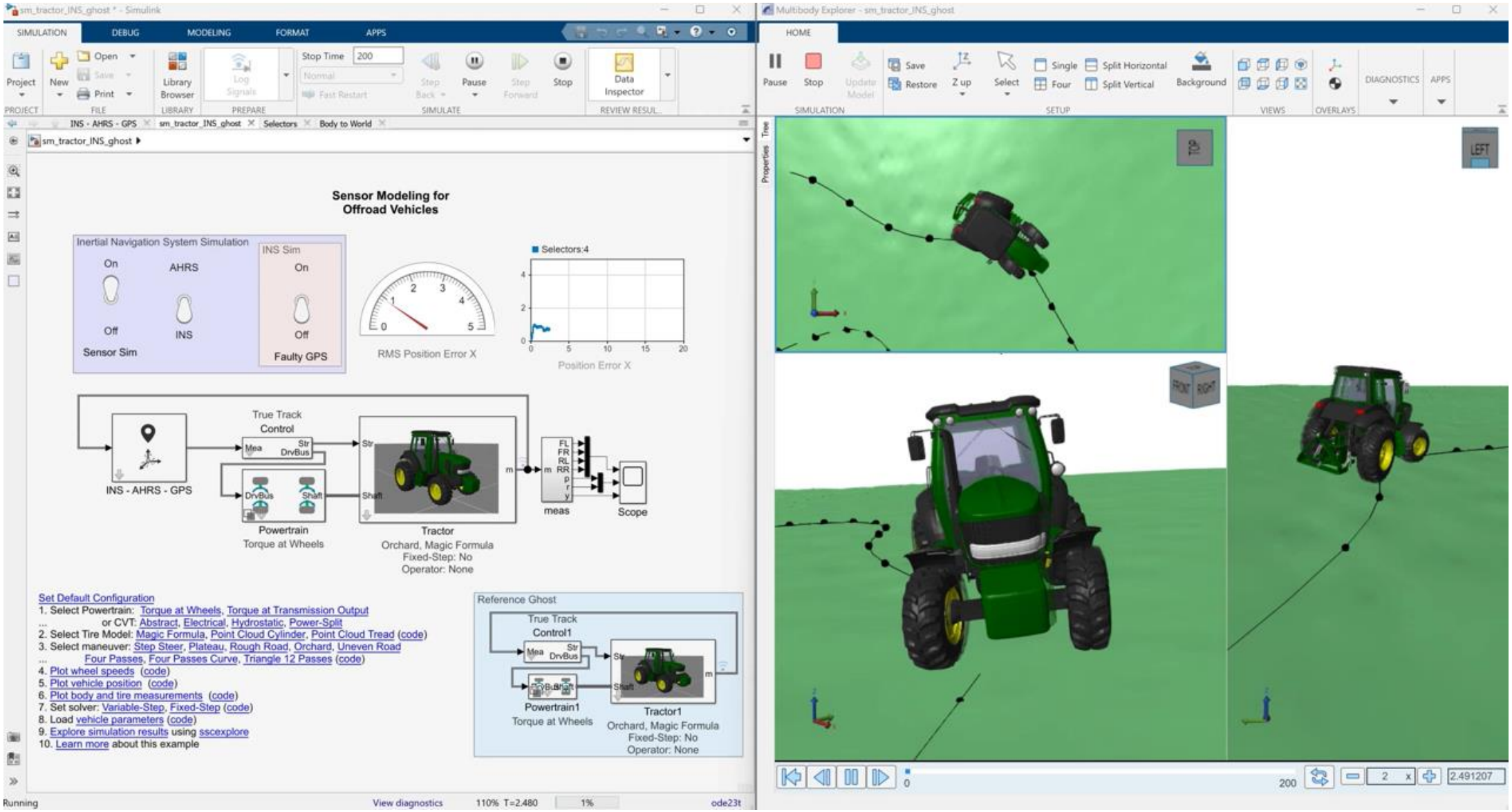
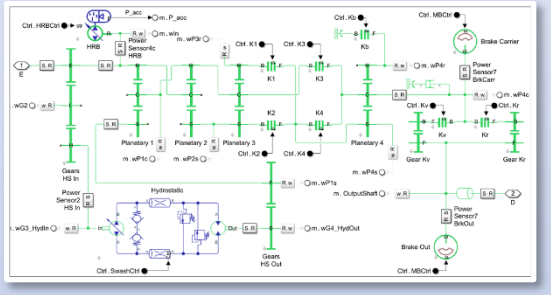


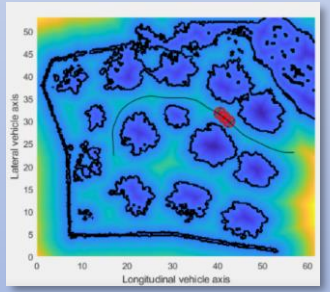
Perform closed-loop, deterministic simulations with Unreal Engine

MATLAB & Simulink

- Physics of main actor(s)



- Perception, Planning, Control Algorithms



actor position

sensor location

Lock-step co-simulation

sensor information

collision information

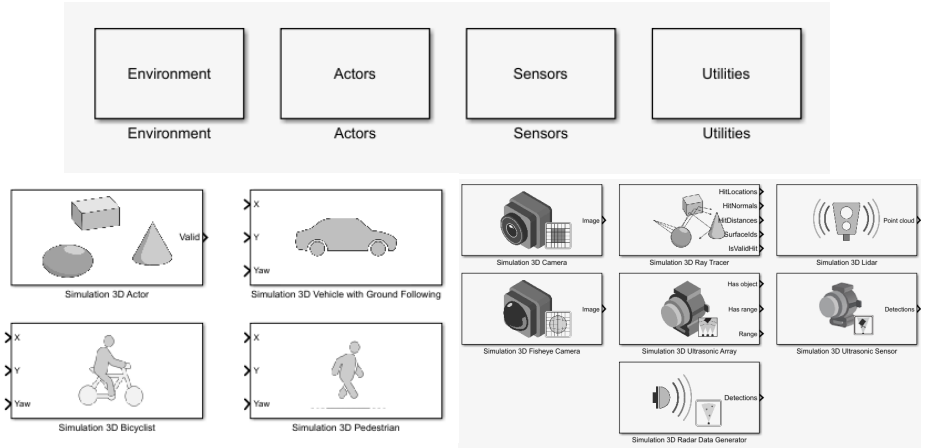
Unreal Engine

- Rendering / lighting
- Physics of non-Simulink actors
- Collision detection

Simulink 3D Animation

copy	Copy all properties from another actor
propagate	Propagate value of selected property to actor and its children
gather	Return values of selected property from all objects in selected branch
findBy	Find all actors that match specified criteria
restoreSnapshot	Restore actor to state of properties saved in specified snapshot
takeSnapshot	Take snapshot of selected properties
createMesh	Create new mesh with specified values
addMesh	Add mesh on top of current mesh
load	Load or import 3D file
save	Save actor and children to a MAT file
createShape	Create geometry for basic primitives

MATLAB API's for run-time and edit-time import of 3D content

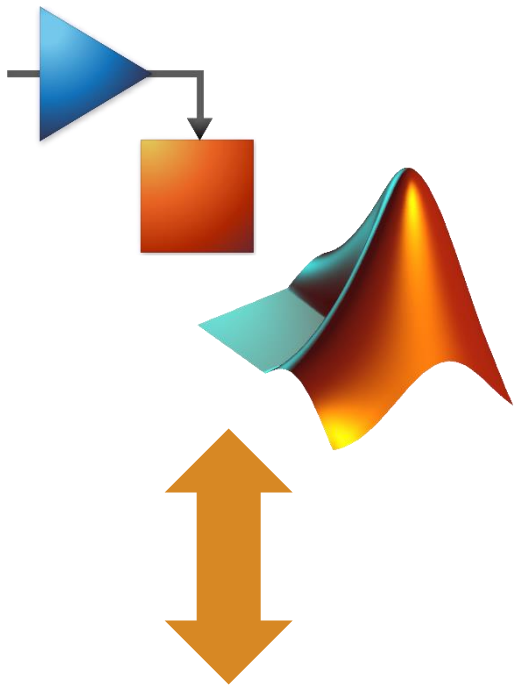


Simulink blocks for connecting to Unreal Engine co-simulation

Foundational features for domain-specific workflows to build on

Basic set of **scenes, actors, and sensor models** for 3D simulation

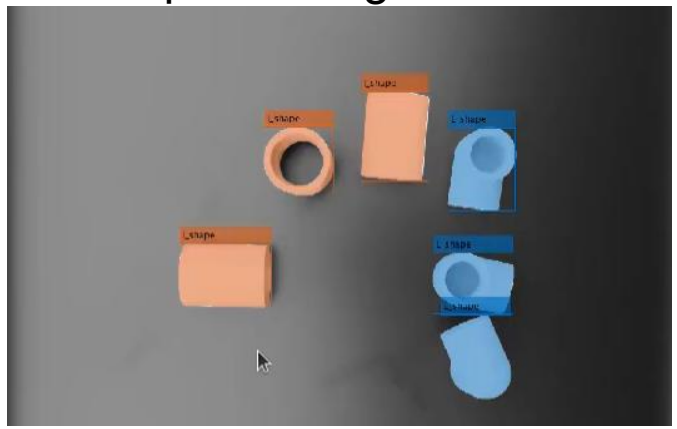
Simulink 3D Animation provides an interface to the Unreal Engine



UNREAL ENGINE

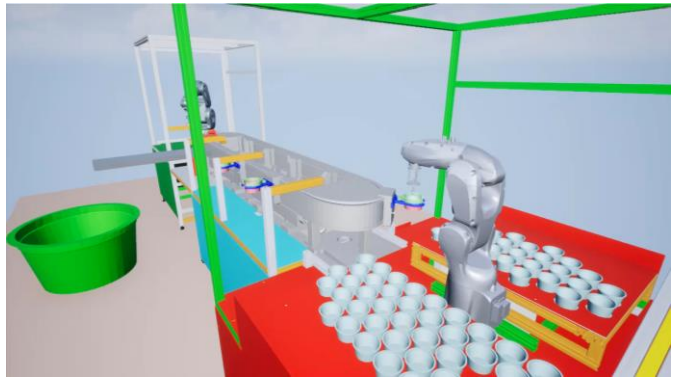
Aerospace: Path Planning, Terrain Visualization

AI: Synthetic Data Generation for Deep Learning workflows



Automotive: Automated Driving or Vehicle Dynamics Simulations

Robotics: Offroad, Manipulators, Manufacturing, Virtual Commissioning

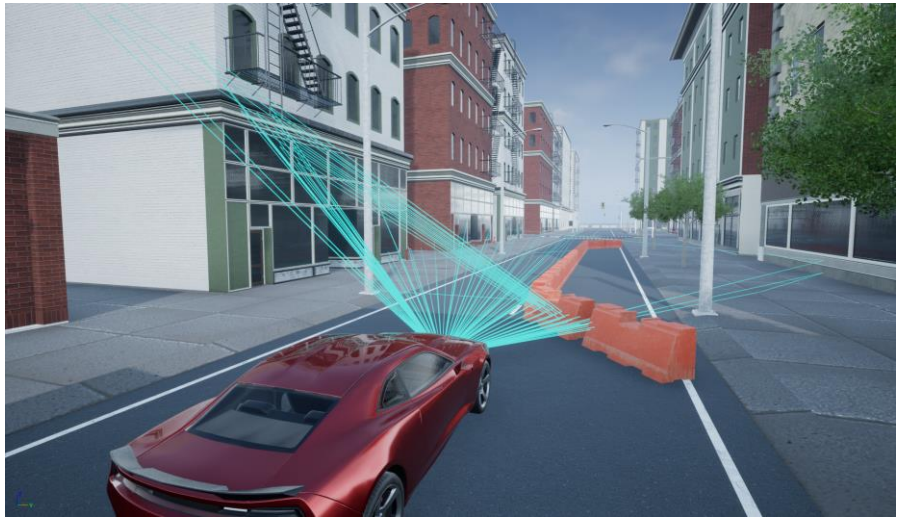


Why 3D Simulation?

- Visuals are universal
  - Easily debug issues
  - Sell your concept or product

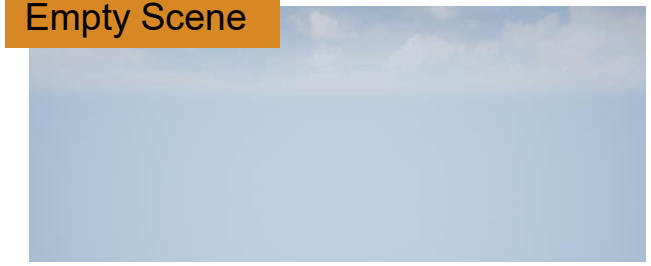
- 3D environments are data-rich
  - Simulate camera, radar, or lidar data
  - Ray tracing enables other sensor simulations

- With Simulink 3D Animation you can:
  - Simulate control algorithms and visualize your UAVs, Robots or Offroad systems in a 3D environment



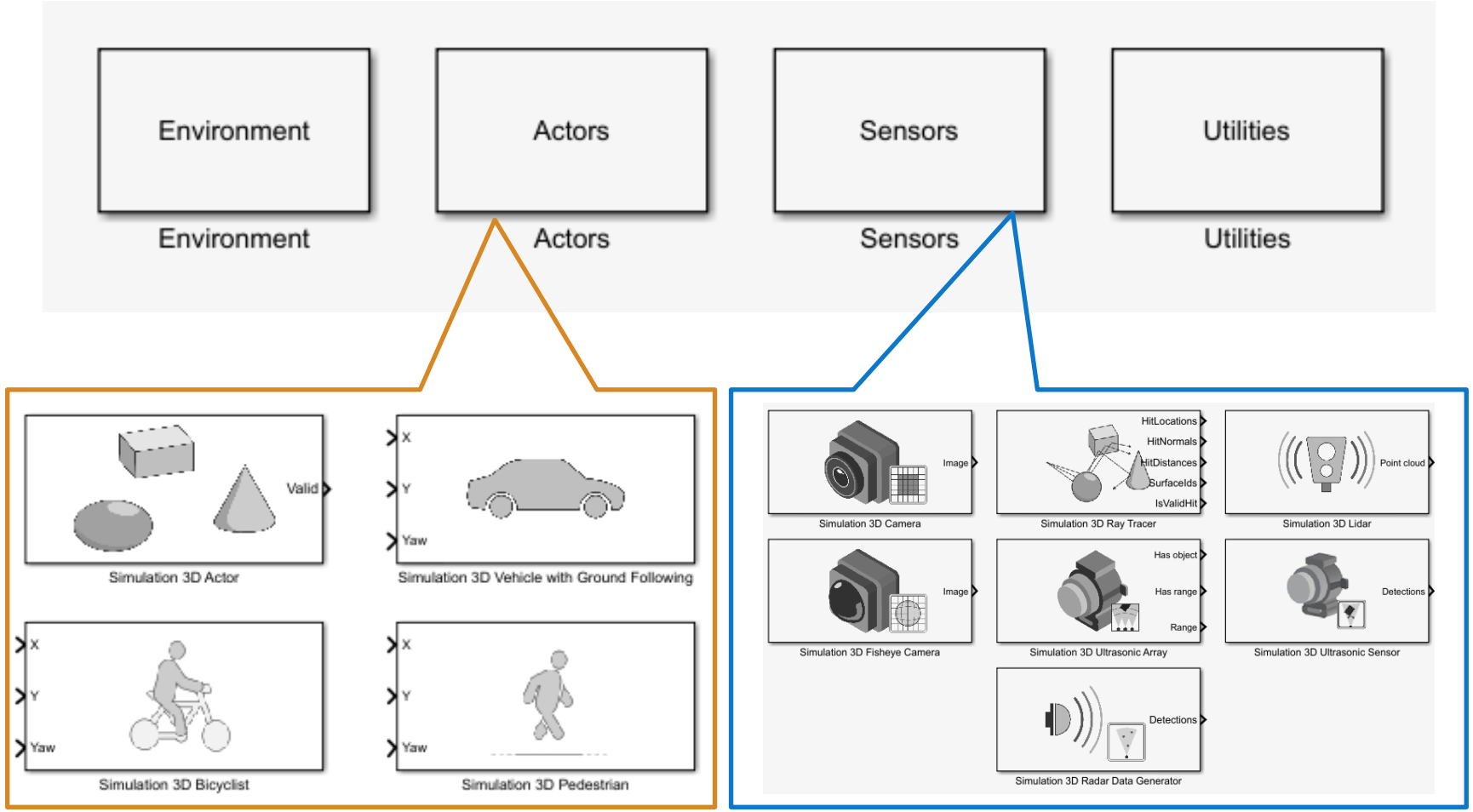
Simulation-based workflows: Library of scenes, actors, and sensors

Empty Scene



Curved Road

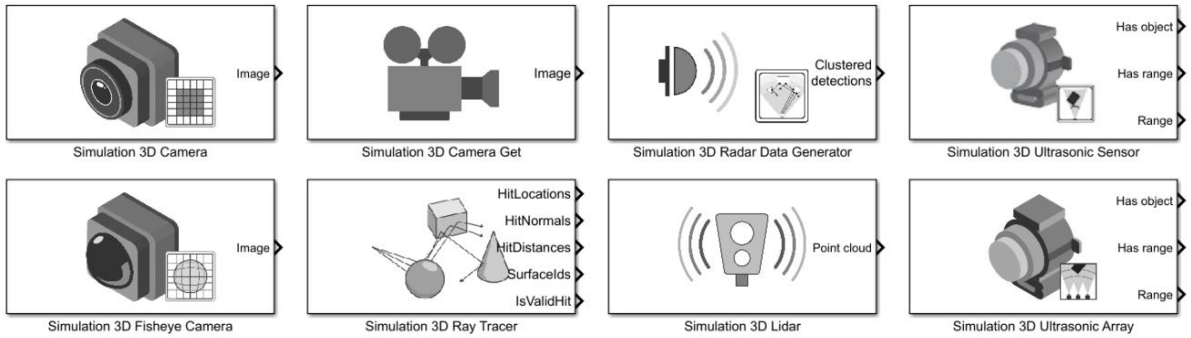
Straight Road

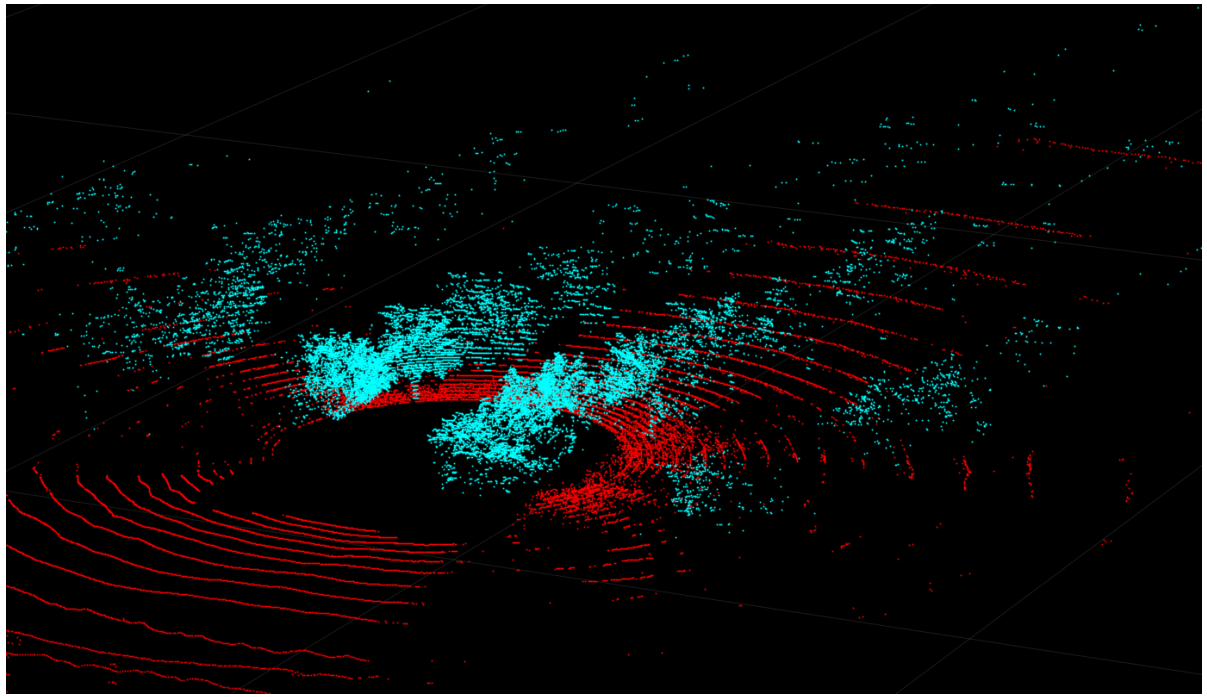


Key benefit: ***Perform 3D simulations out-of-the-box from the Simulink environment***

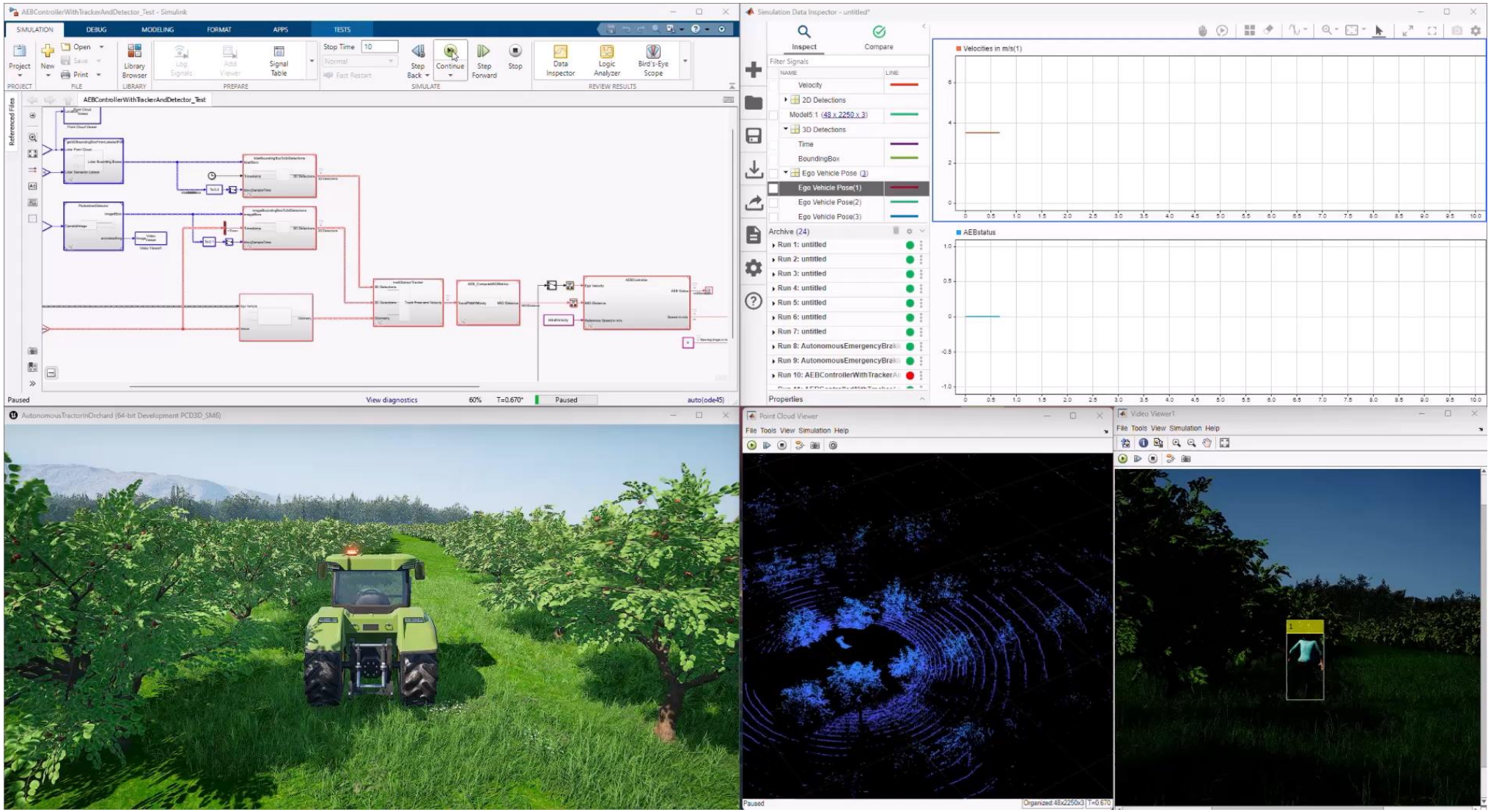
Sensor Models

Camera





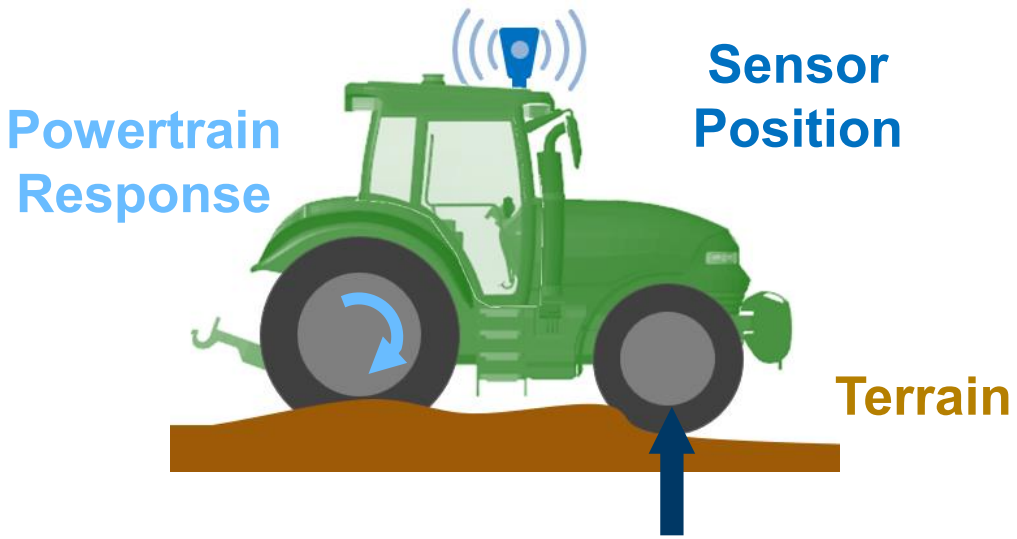
Lidar

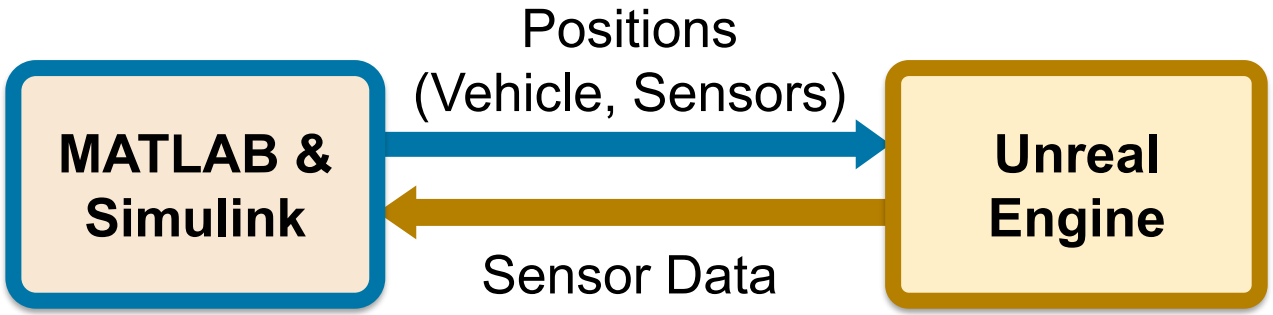

AEBControllerWithTrackerAndDetector_Test - Simulink
SIMULATION
DEBUG
MODELING
FORMAT
APPS
TESTS
Stop Time
Step Back
Continue
Step Forward
Stop
Data Inspector
Logic Analyzer
Bird's-Eye Scope
Simulation Data Inspector - untitled*
Inspect
Compare
Filter Signals
Velocity
2D Detections
Model5:1 (48 x 2250 x 3)
3D Detections
Time
BoundingBox
Ego Vehicle Pose (3)
Ego Vehicle Pose(1)
Ego Vehicle Pose(2)
Ego Vehicle Pose(3)
Archive (24)
Run 1: untitled
Run 2: untitled
Run 3: untitled
Run 4: untitled
Run 5: untitled
Run 6: untitled
Run 7: untitled
Run 8: AutonomousEmergencyBraki
Run 9: AutonomousEmergencyBraki
Run 10: AEBControllerWithTrackerAn
Properties
Velocities in m/s(1)
AEBstatus
AutonomousTractorInOrchard (64-bit Development PCD3D_SM6)
Point Cloud Viewer
File Tools View Simulation Help
Video Viewer1
File Tools View Simulation Help

Scenario-
Based
Testing

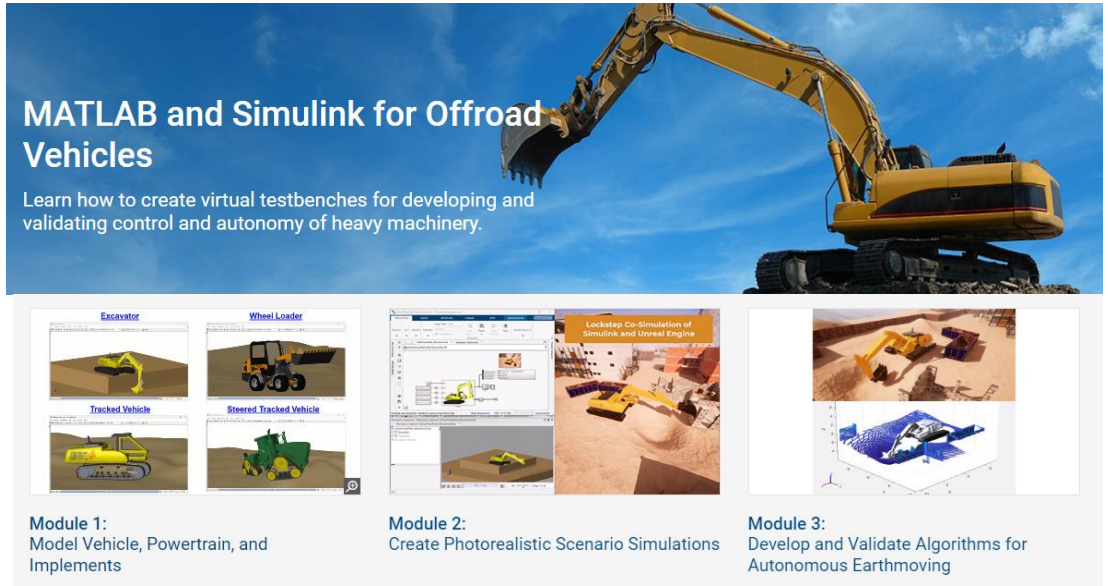
Key Takeaways

- Capturing physical behavior at the right level of detail enables effective virtual testing
- Connecting with game engine enables sensor data collection and world interactions
- System-level integration enables testing and validation of autonomous systems

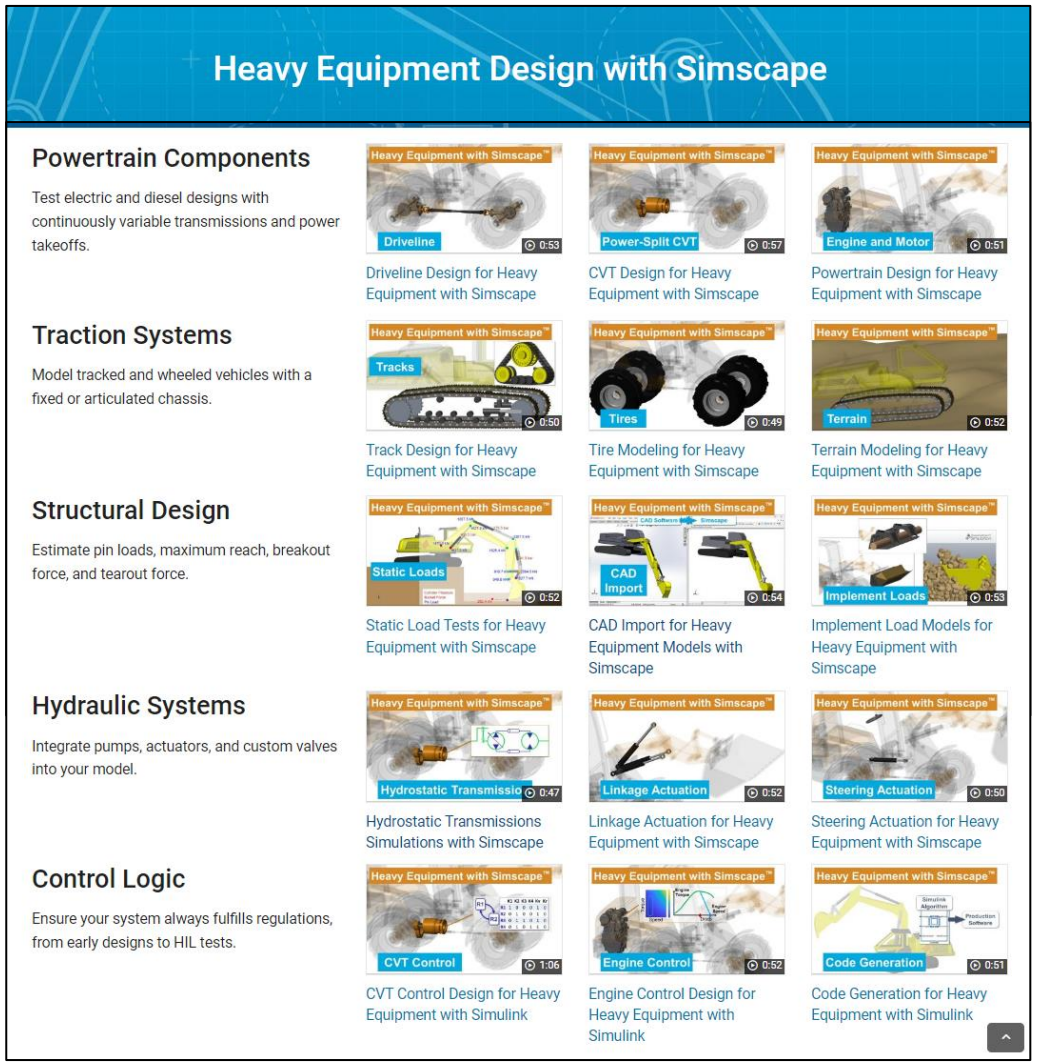




Offroad Vehicle Resources



www.mathworks.com/solutions/robotics/offroad-vehicles.html



www.mathworks.com/solutions/physical-modeling/heavy-equipment.html

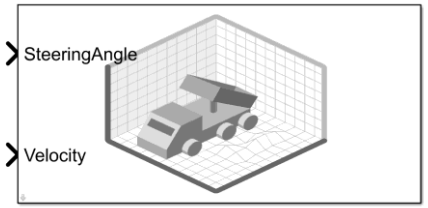
Call to Action:

Try New Offroad Autonomy Library Support Package!

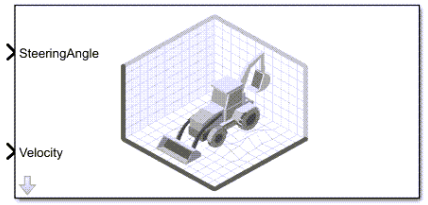
Robotics System Toolbox Offroad Autonomy Library

by MathWorks Robotics and Autonomous Systems Team STAFF

Design, Simulate, and Test Autonomous Offroad Vehicle Applications

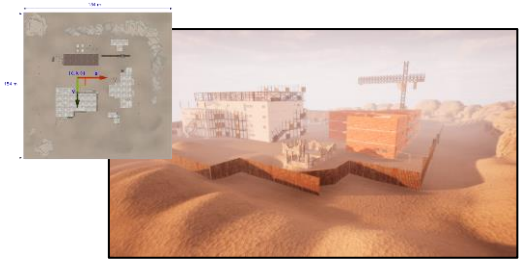


Simulation 3D Physics Dump Truck

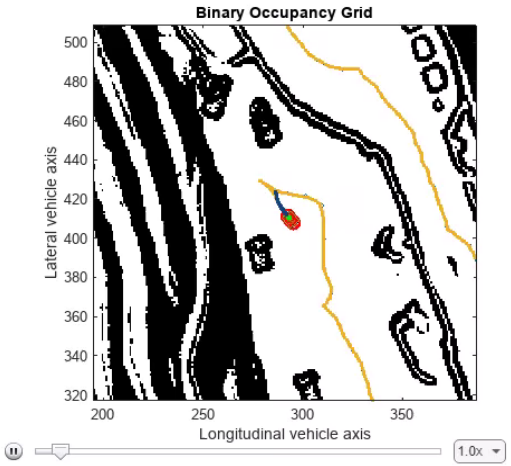


Simulation 3D Physics Backhoe

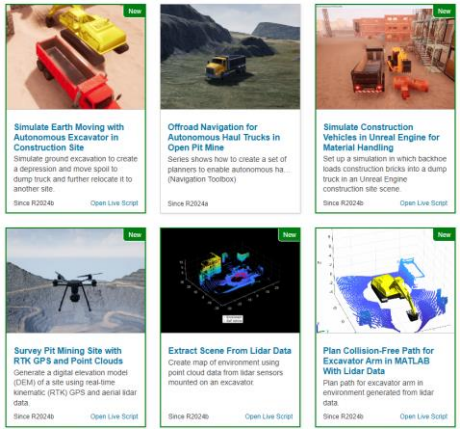
Physics Models



Scenes



Algorithms

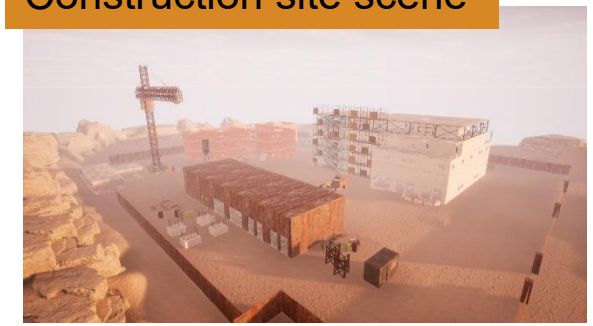


Examples

MathWorks offers domain-specific scenes and assets for Offroad Autonomy applications

Offroad pit mine scene

Construction site scene



Scenes

Simulation 3D Physics Dump Truck

Simulation 3D Physics Backhoe

Assets

Offroad Navigation for Autonomous Haul Trucks in Open Pit Mine

Simulate Earth Moving with Autonomous Excavator

Examples

MathWorks Engineering Support

In-Depth Resources & Office Hours

Training

Onsite/Virtual Workshops

Guided Evaluations

Consulting

Technical Support

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Accelerating the pace of engineering and science