Building digital twins for granular materials using EDEM and Omniverse

ASTEC

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Director of Advanced Technologies
Astec Digital

Agenda

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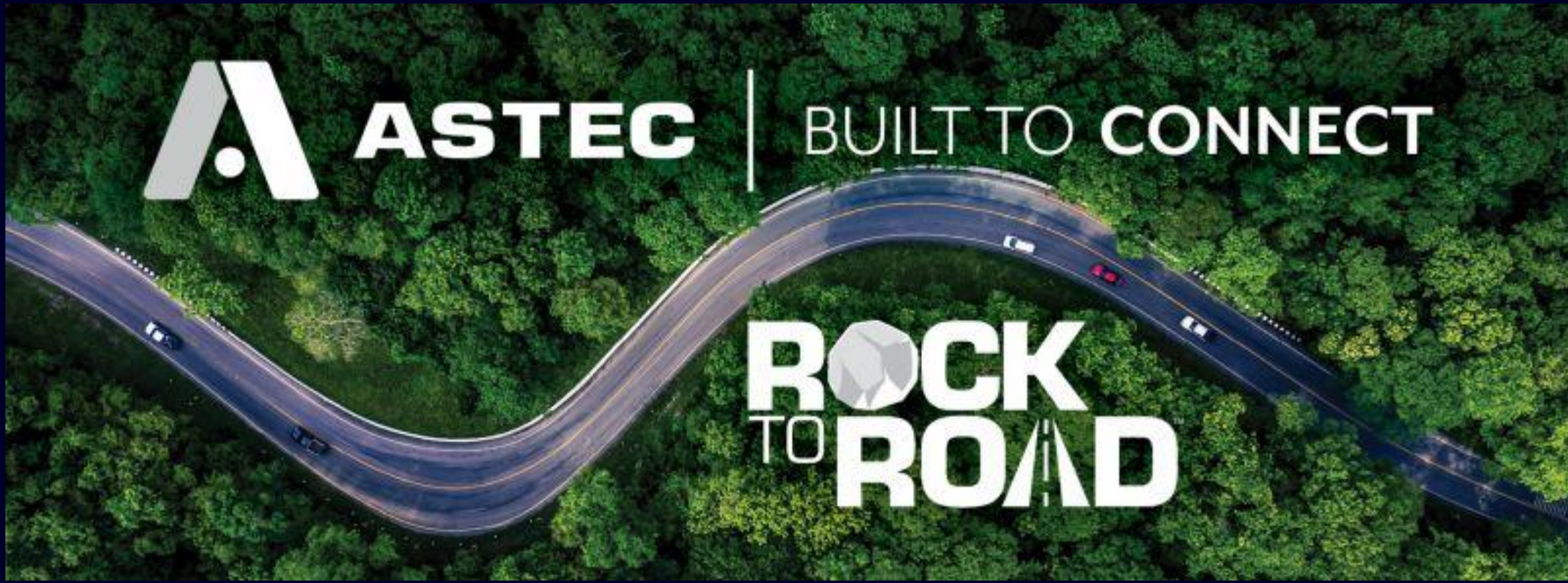
- Introduction and motivation
- The path to Physical AI
- Simulation: CAE vs Robotics
- Challenges of granular material simulation
- Omniverse and EDEM examples
- **Live DEMO**

Introduction to ASTEC



NASDAQ (ASTE) www.astecindustries.com

Physical AI for infrastructure industries

Next generation asphalt plants will be autonomous and fleet connected enabling:

- Reduced Labour Cost
- Improved Quality
- Improved Safety
- Increased Sustainability

Physical AI vs Physics AI

Physical AI

Embodied artificial intelligence that is embedded into physical systems to interact directly with the material world. It relies heavily on the loop of **sensing** (cameras, LiDAR), **thinking** (processing data), and **acting** (moving motors, actuators).

Examples:

- Autonomous Vehicles
- Robots
- Smart Manufacturing

Physics AI

Machine learning and neural networks that have been trained to understand and are constrained by the laws of physics.

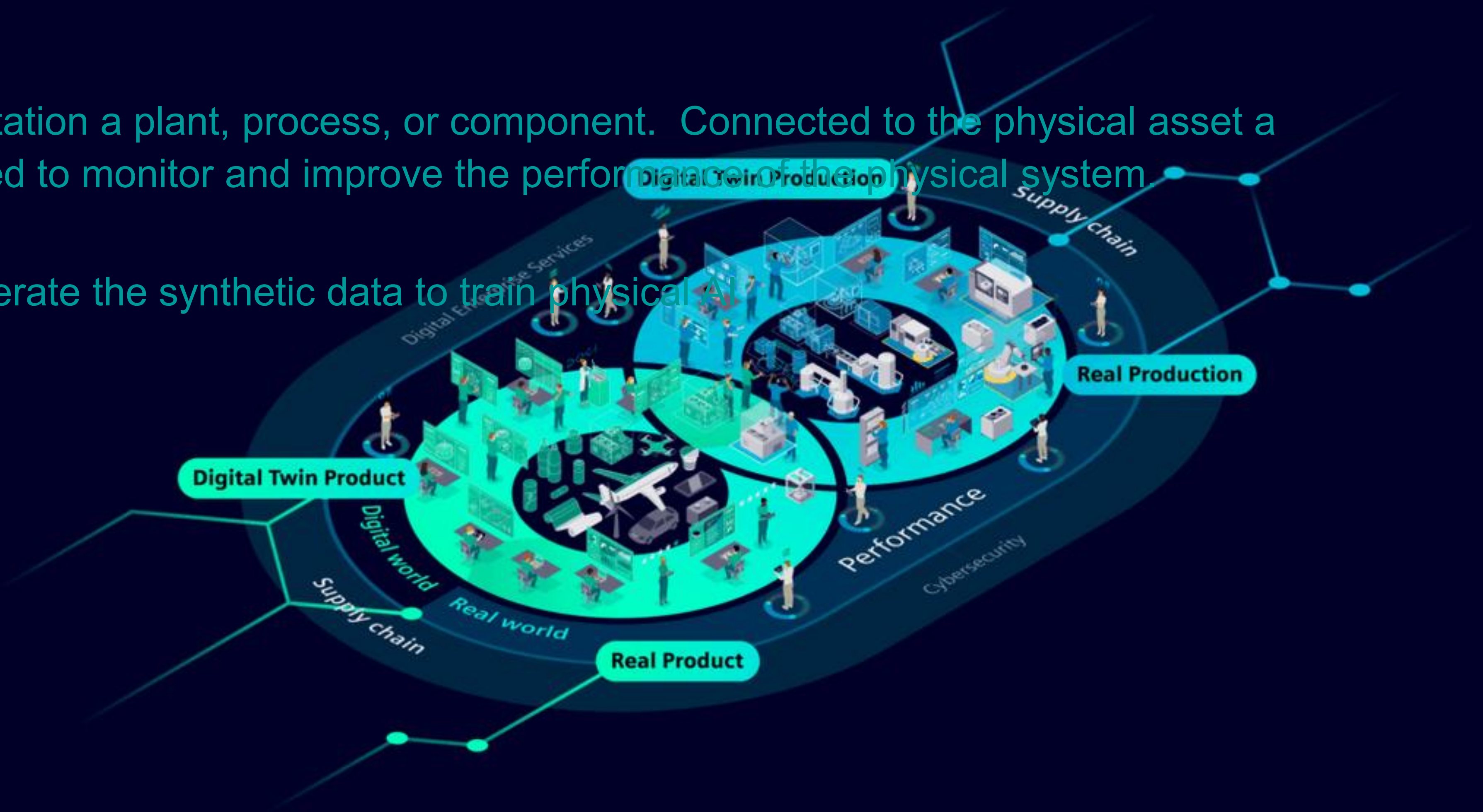
Examples:

- Reduced order modeling (ROM's)
- Physics informed neural networks (PINN's)
- Emerging deep learning architectures
  - DoMino
  - Transolvers/GeoTransolvers
  - AB-UPT

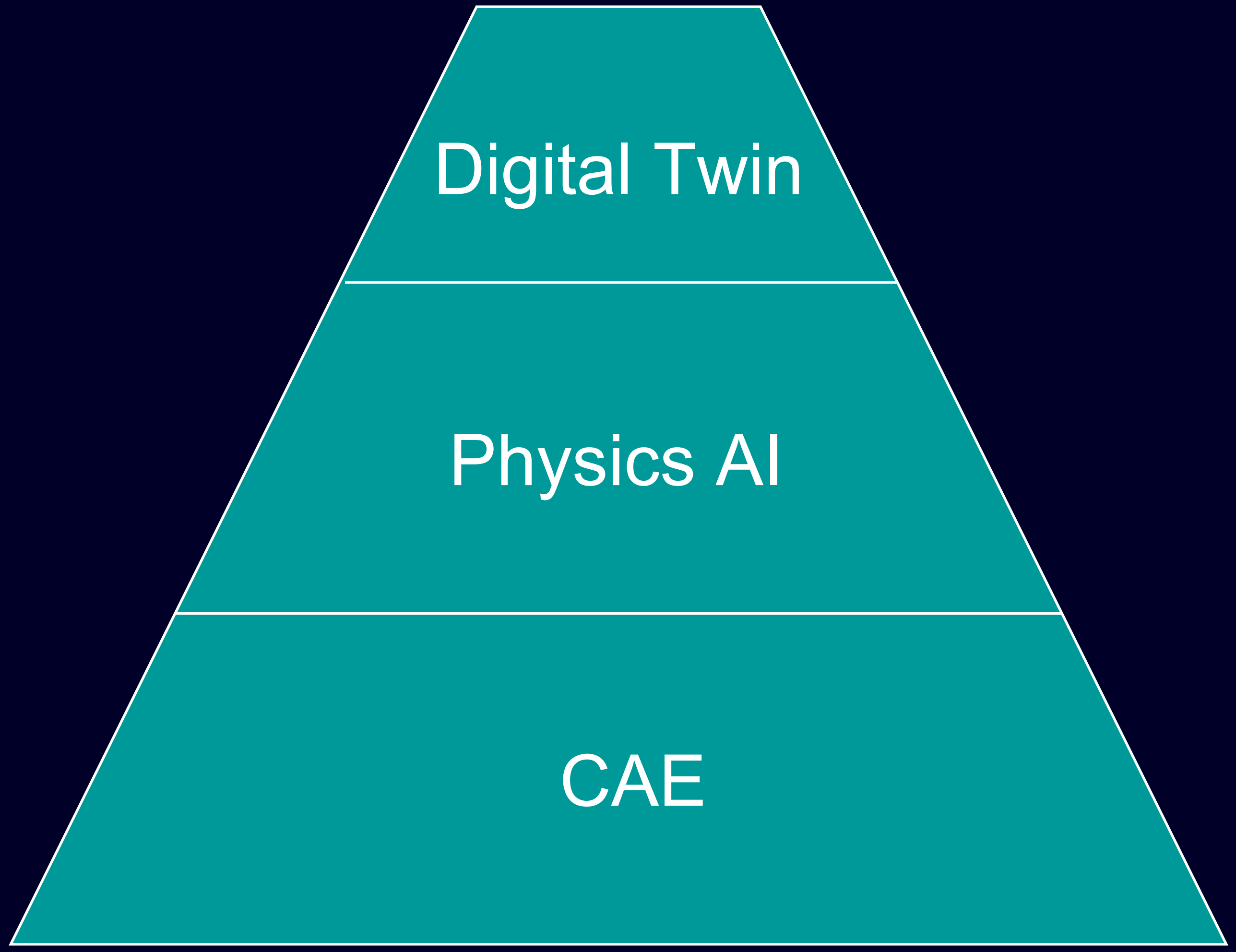
Digital Twin

Digital Twin is a virtual representation a plant, process, or component. Connected to the physical asset a predictive digital twin can be used to monitor and improve the performance of the physical system.

A digital twin is how we can generate the synthetic data to train physical AI



Road to Physical AI



Generate synthetic data to train physics aware DL models and connect these to the physical system

Ability to run physics models faster than real-time to inform machine controls or train policies

Models that accurately represent the physics of the system and environment

Physics Simulation: CAE and Robotics

CAE vs Robotics Simulation

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CAE PARADIGM

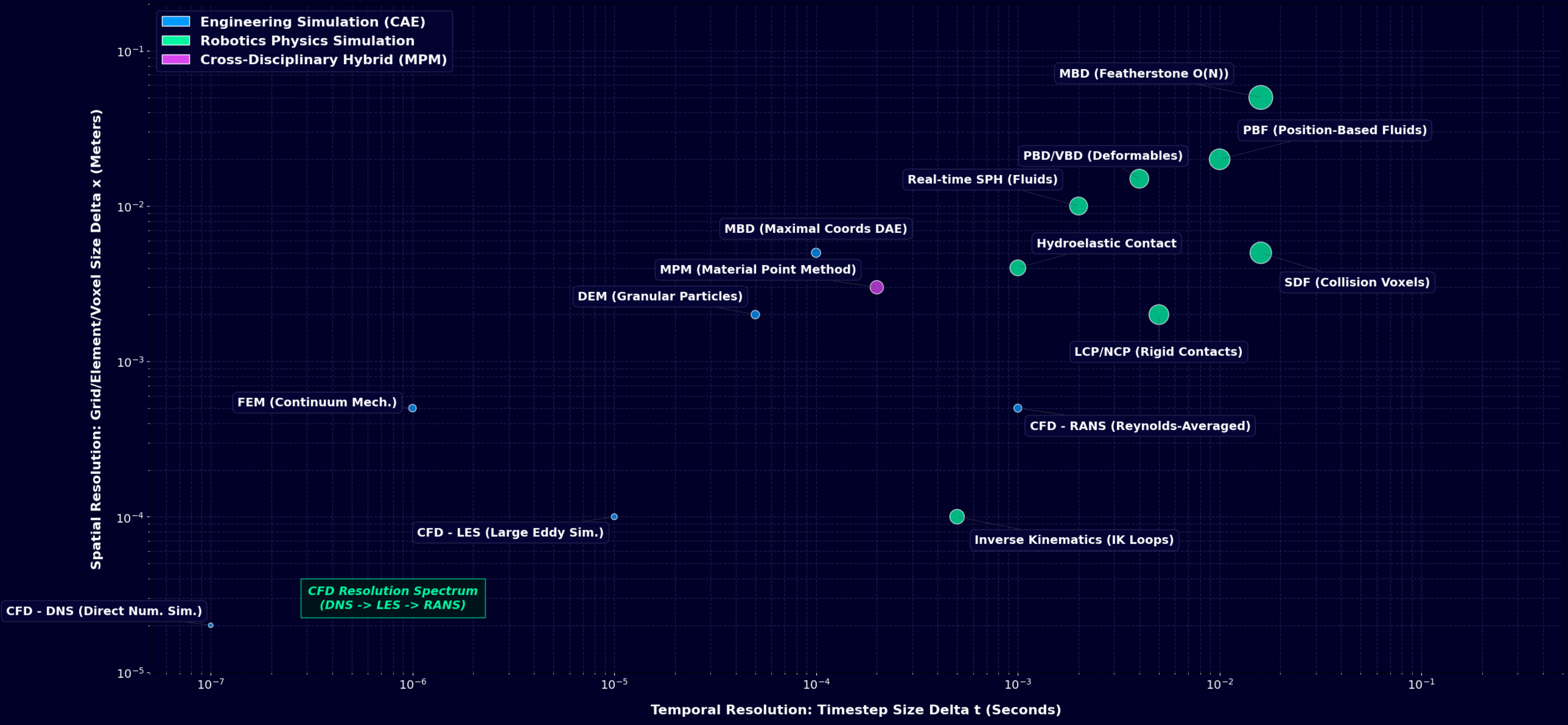
High-Fidelity: Focused on sub-millimeter continuum accuracy to eliminate physical prototyping risks.

ROBOTICS PARADIGM

High-Throughput: Scaled to execute millions of quick physical interactions for continuous RL loops.

Core Task	Engineering Simulation (CAE)	Robotics Physics Simulation
Motion Mapping	Maximal coordinates tracking 6-DOF per link. Unconstrained, slow matrix processing. DAE Solver | $O(N^3)$ Scale	Reduced joint coordinates via Featherstone's recursive dynamics; integrated Inverse Kinematics. Featherstone | $O(N)$ Scale
Collision Detection	Direct mesh-to-mesh geometric intersection checking. Highly detailed boundary searches. FEM Topologies	Simplified primitive shapes and Signed Distance Fields (SDF) allowing fast distance calculation. Volumetric SDF | $O(1)$ Check
Contact Dynamics	Microscopic penalty spring-dampers modeling physical compliance. Requires tiny timesteps. Stiff Non-Linear Springs	Rigid body non-penetration loops solved using Linear & Nonlinear Complementarity Problems. Hard LCP / NCP Solvers
Stress and Deformation	Full continuous volumetric meshes mapped to non-linear physical stress-strain equations. Continuum Mechanics (FEM)	Assumed rigid solids; dynamic meshes approximated via Position-Based Dynamics or soft-patches. Position-Based Dynamics (PBD)
Fluid Dynamics	Exact finite volume Navier-Stokes solvers Computational Fluid Dynamics (CFD)	Liquid simulation via particle positions to satisfy geometric incompressibility constraints Position-Based Fluids (PBF)
Particle Dynamics	Explicit calculation of particle-particle and particle-wall contacts and trajectories Discrete Element Method (DEM)	Tracks moving particles and solves equations of motion on a stationary background grid Material Point Method (MPM)

Simulation Fidelity



When is high fidelity physics required in robotics simulation?

Challenges – Granular Materials

Many industries process granular materials:

- Pharmaceuticals
- FMCG
- Steel manufacturing
- Chemicals
- Mining
- Construction
- Agriculture

Training autonomous systems to operate in these industries requires the ability to accurately simulate the complex behavior of granular materials

Build-up

Blockage

Spillage

Wear

Segregation

Poor compaction

Examples:

- Digital twin for visualization
- Digital twin for robotics co-simulation

What is Omniverse?

NVIDIA Omniverse™ is a collection of accelerated libraries and microservices for developing physical AI simulation applications

OMNIVERSE

- OpenUSD
- Physics and Motion
- Rendering and Simulation
- Runtime and Deployment

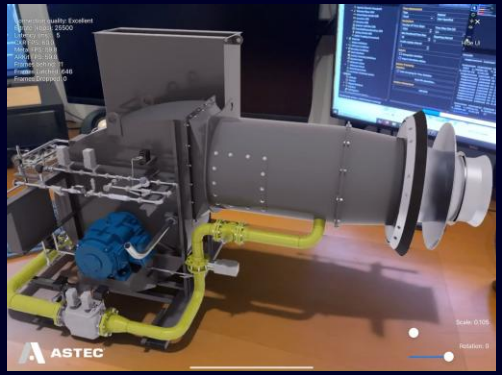
OpenUSD

- A file-format agnostic scene description
- Non-destructive composition
- Addressable data model
- Scalable
- Ecosystem and standardization

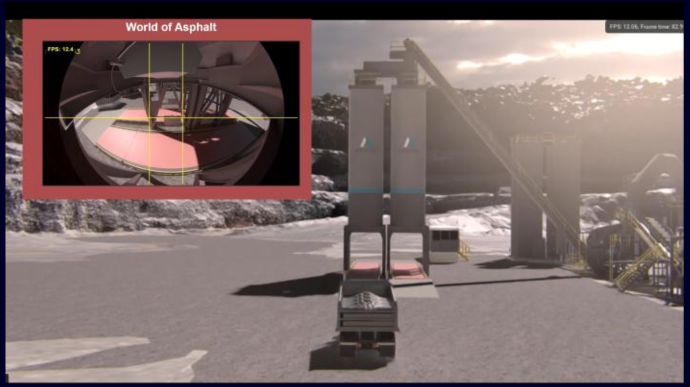
PIXAR

ASTEC Omniverse use cases:

CAE Visualization



XR



Computer Vision

Digital Twins

Digital twin for visualization: aggregate dryer

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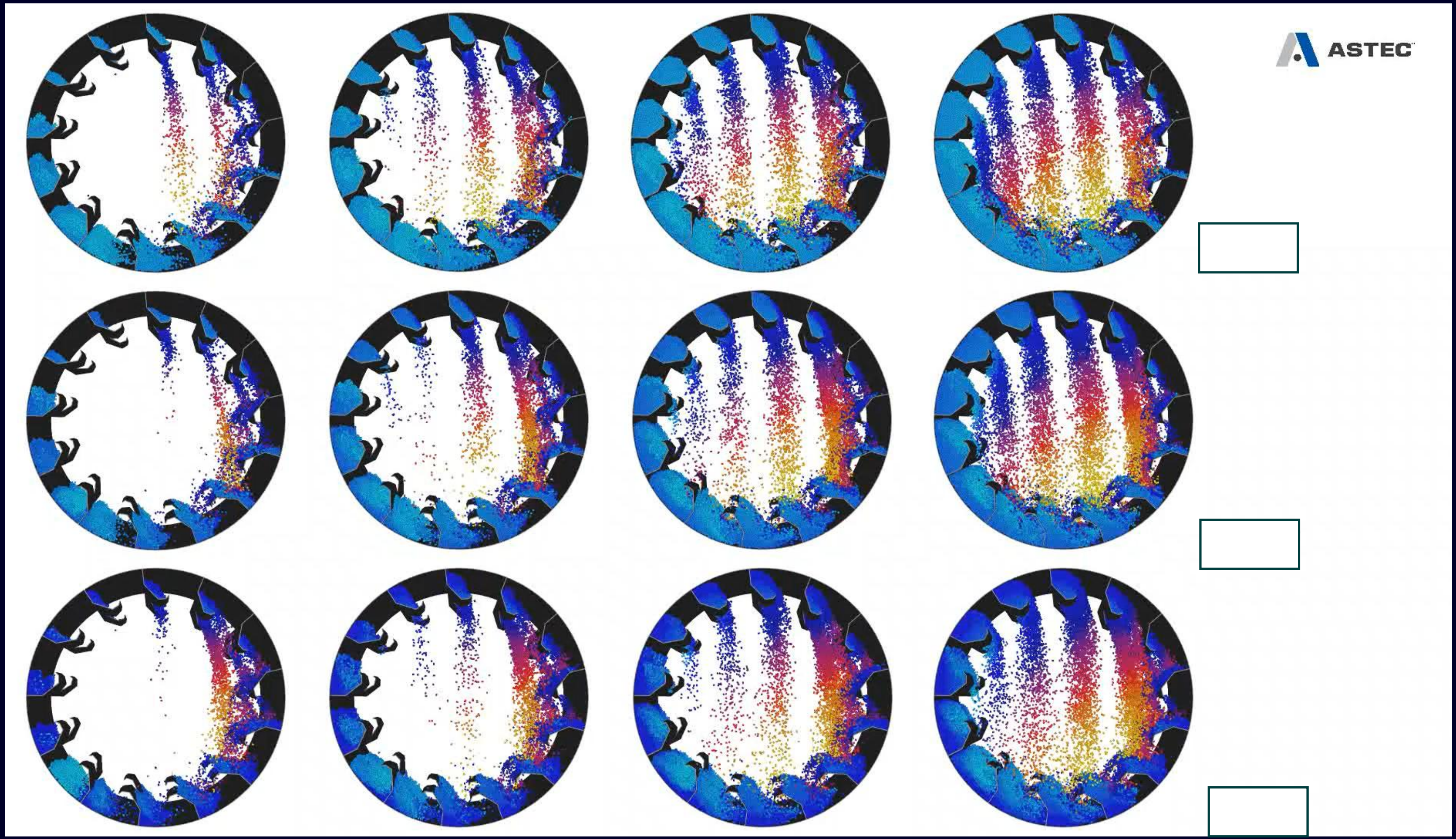

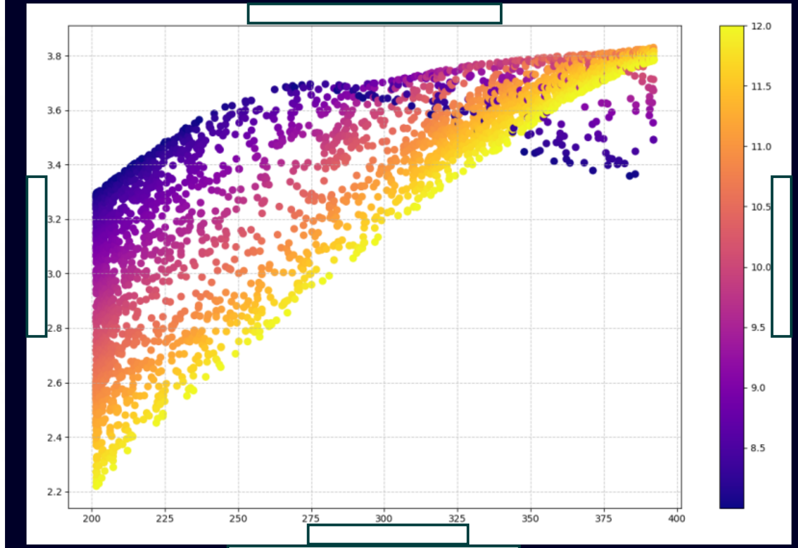

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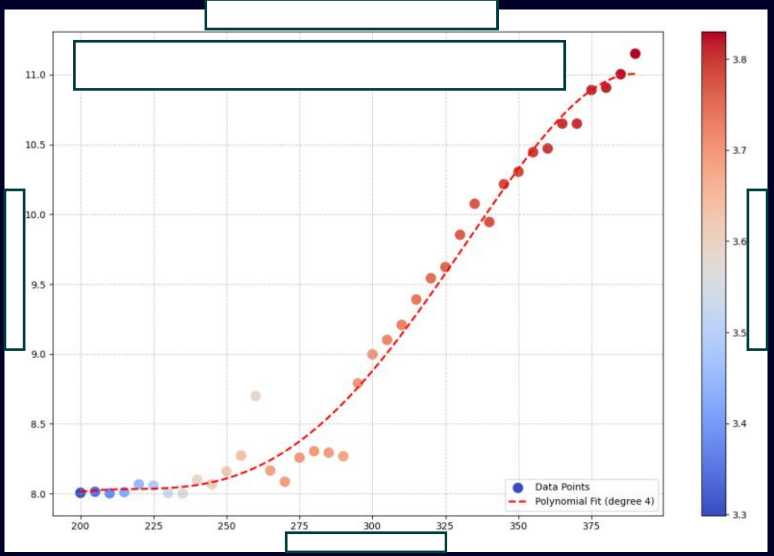

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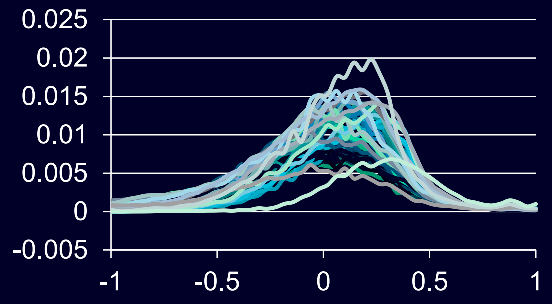

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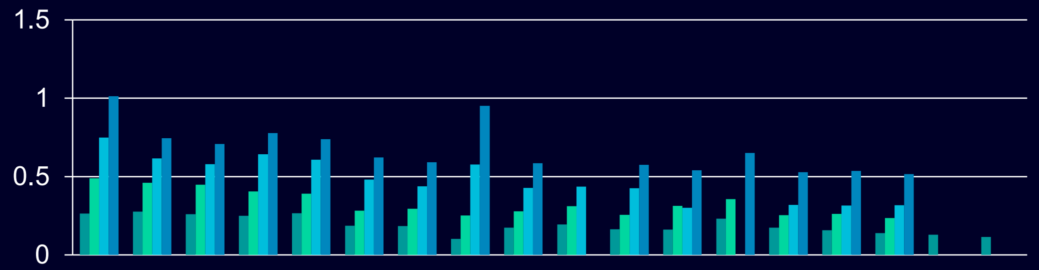

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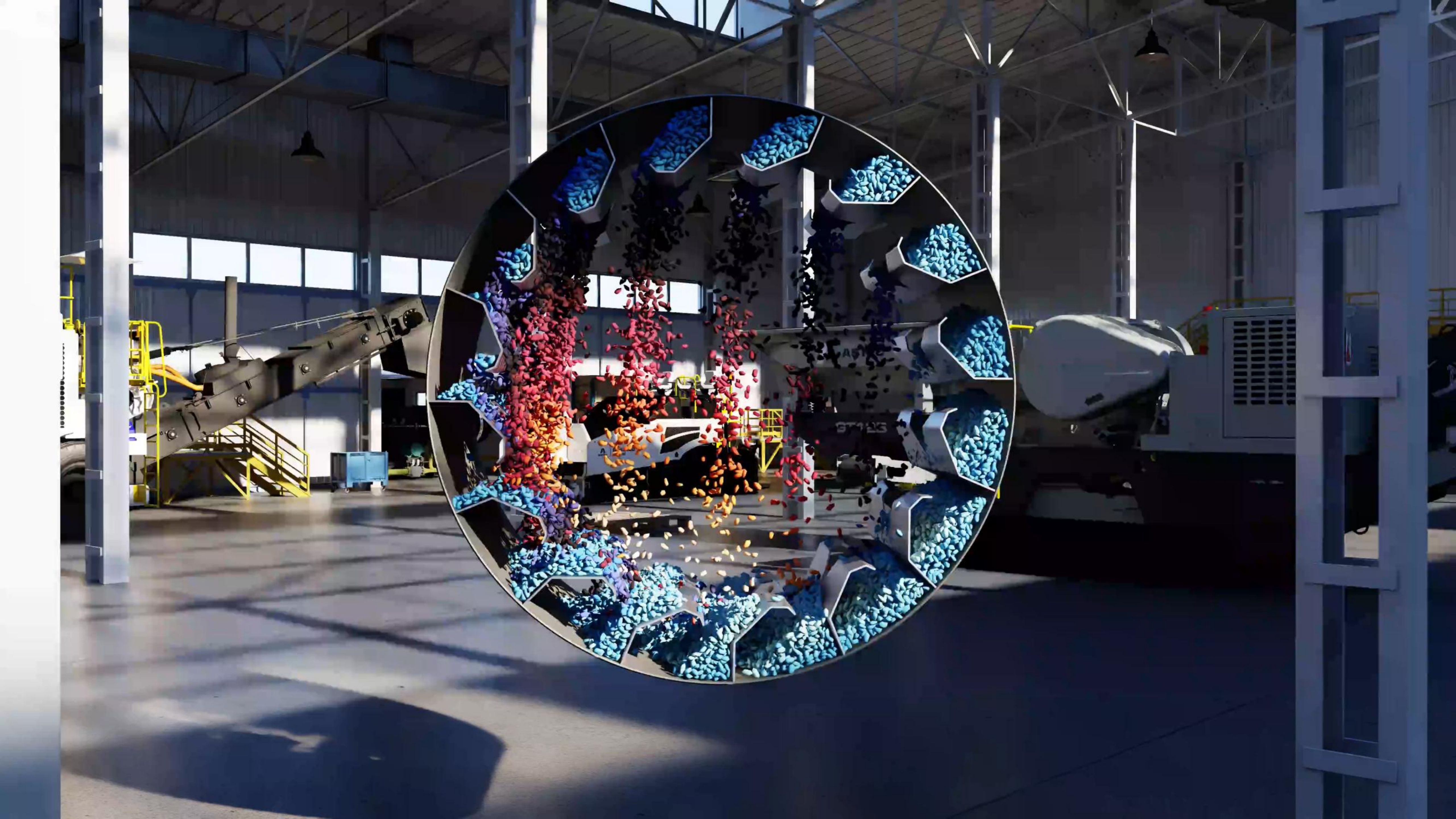

DEM Visualization Using Omniverse

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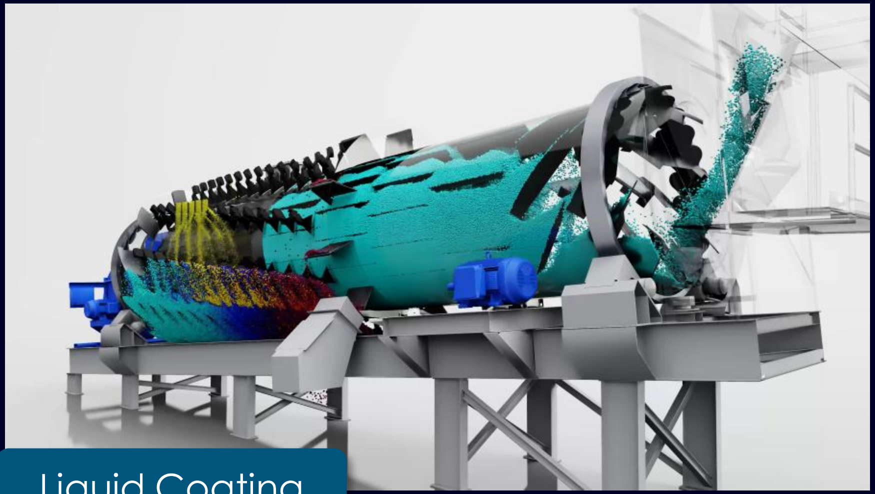
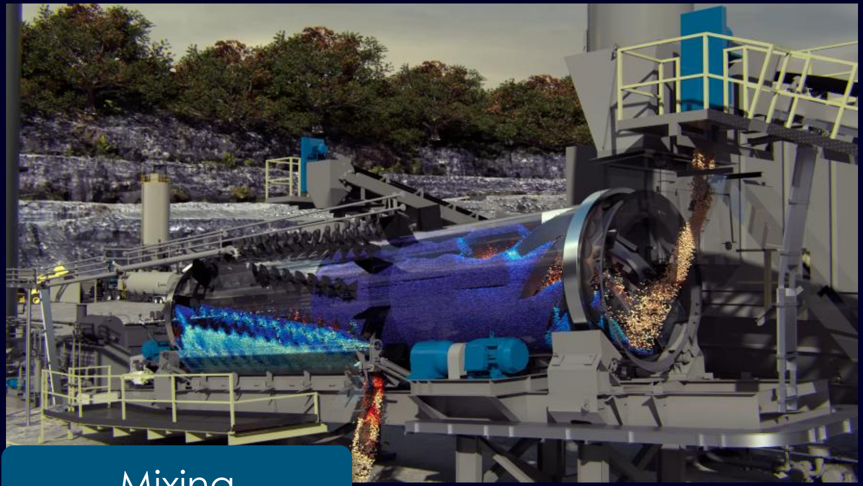
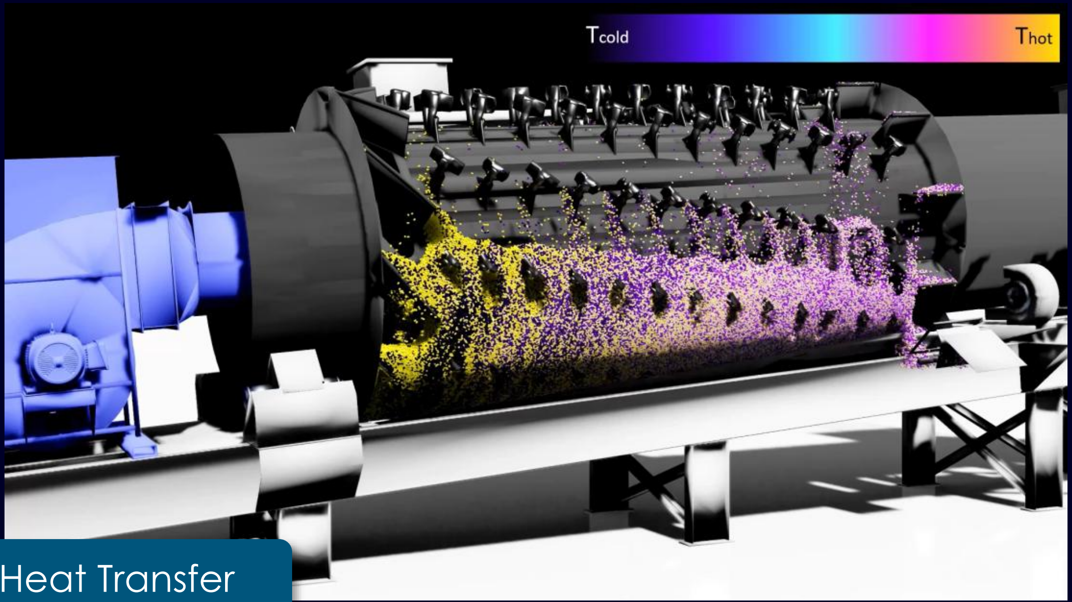

Liquid Coating


Mixing

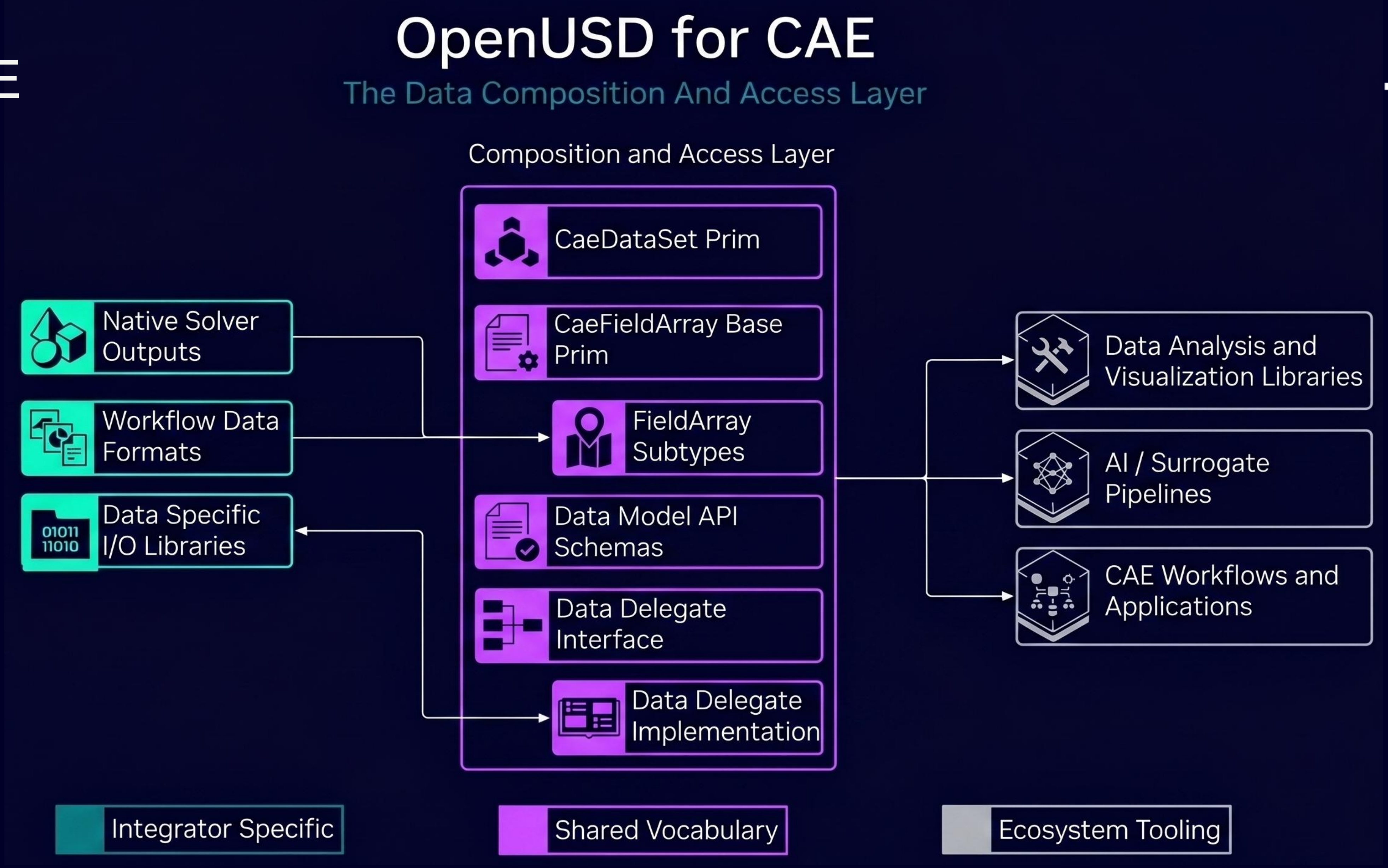

Crushing



Heat Transfer


Drying

Kit-CAE



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https://github.com/NVIDIA-Omniverse/kit-cae

Image courtesy NVIDIA

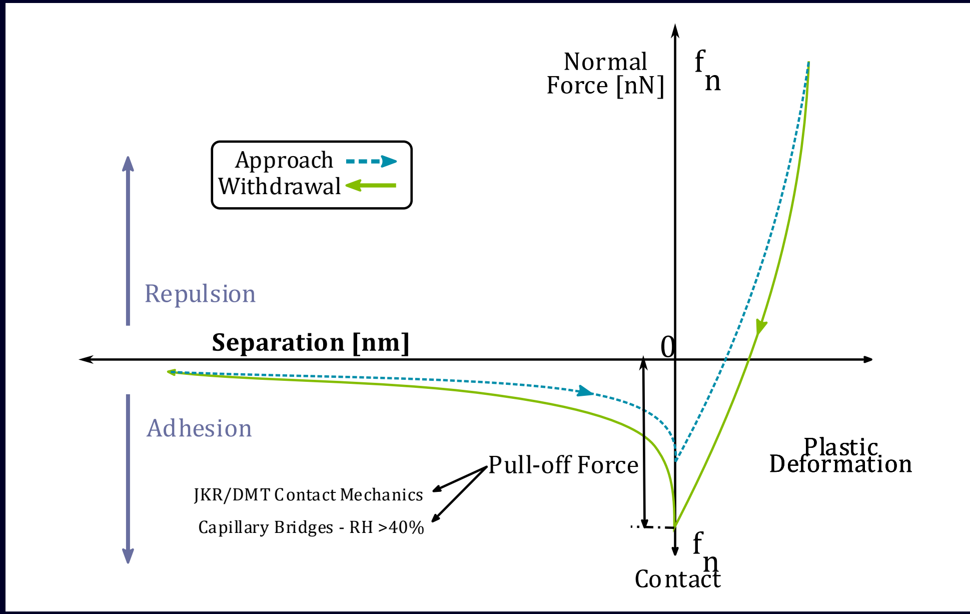
Kit-CAE 3.0 File Importers

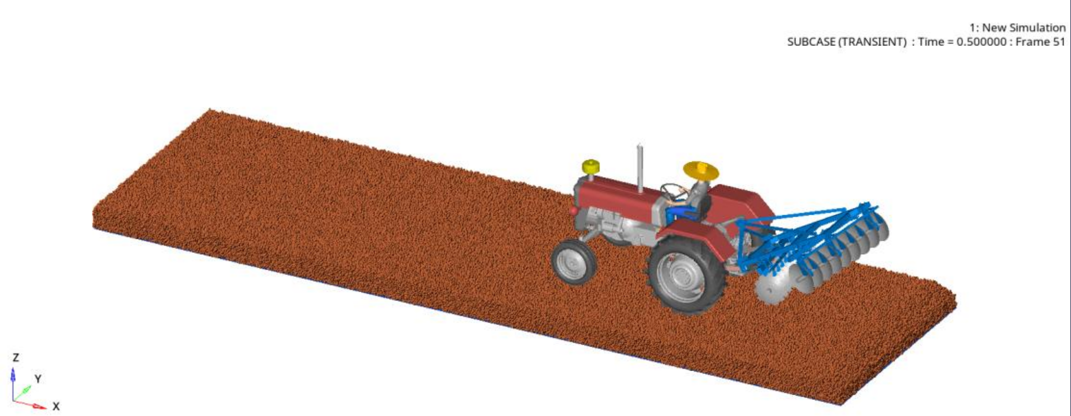
CGNS (.cgns): Structured and unstructured meshes with their field data.
EDEM (.dem): Particle simulation data.
EnSight Gold (.case, .encas): Mesh and field data, including time-varying and polyhedral results.
Eclipse reservoir (.egrid, .grdecl, .data, .init, .unrst): Reservoir grids and result properties.
NanoVDB (.nvdb): Sparse volume data.
NumPy (.npz, .npy): Point clouds and arrays from Python or AI workflows.
OpenFOAM (.foam): OpenFOAM cases without an intermediate conversion.
VTK (.vtk, .vti, .vtr, .vts, .vtp, .vtu): Structured and unstructured VTK datasets.

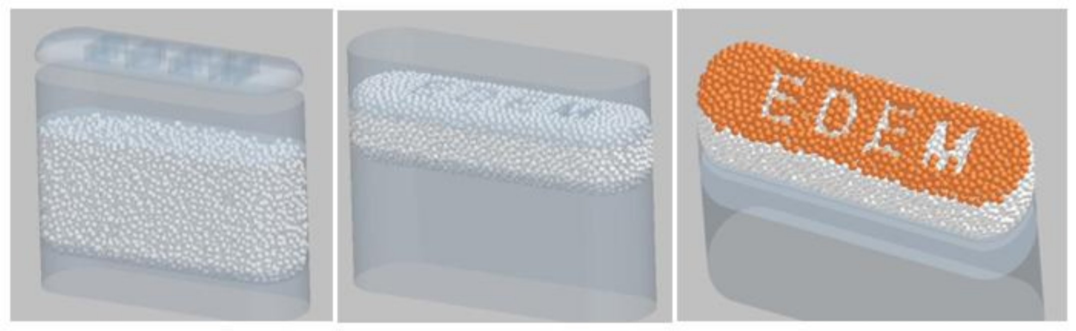
Digital twin for robotics co-simulation

Complex Particle Dynamics: Cohesive and Compressible Materials

The Edinburgh Elasto-Plastic Adhesion (EEPA) model comprises a nonlinear hysteretic spring model to account for the elastic-plastic contact deformation and an adhesive force component that is a function of the plastic contact deformation. When two particles or agglomerates are pressed together, they undergo elastic and plastic deformations. It is assumed that the pull-off strength (adhesion) increases with an increase of the plastic contact area.

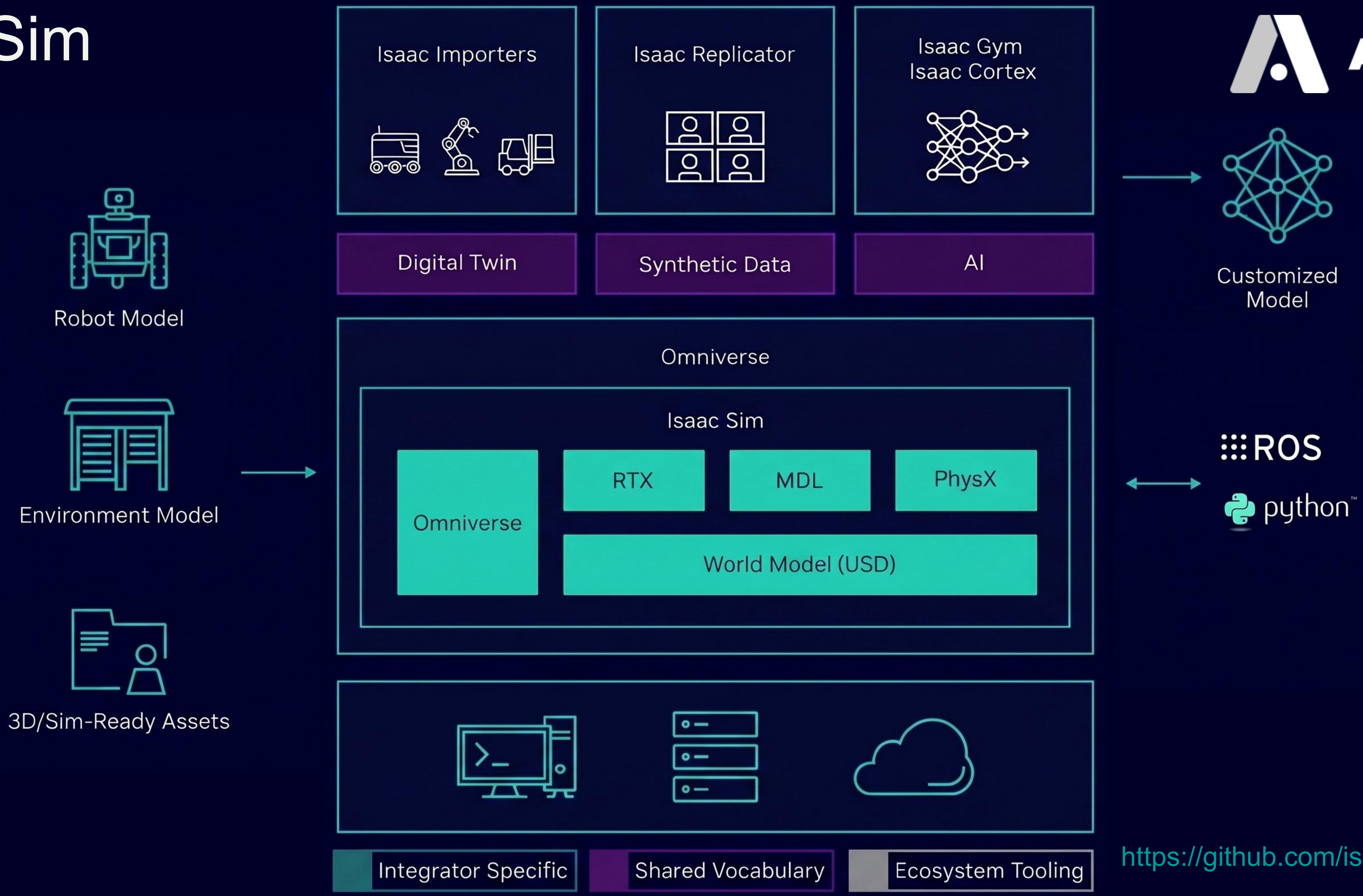






1.Morrissey, J.P., *Discrete Element Modelling of Iron Ore Fines to Include the Effects of Moisture and Fines*, University of Edinburgh, 2013. https://www.era.lib.ed.ac.uk/handle/1842/8270. ↩
2.Thakur, S.C., Morrissey, J.P., Sun, J., Chen, J.F., & Ooi, J.Y. (2014). *Micromechanical analysis of cohesive granular materials using discrete element method with an adhesive elasto-plastic contact model.* Granular Matter, 16(3), 383–400. doi:10.1007/s10035-014-0506-4 ↩
3.Morrissey, J.P., Thakur, S., & Ooi, J.Y. (2014a). *EDEM Contact Model: Adhesive Elasto-Plastic Model. University of Edinburgh.* doi:10.13140/RG.2.2.10139.18724 ↩
4.Morrissey, J.P., Thakur, S., & Ooi, J.Y. (2014b). *Using the Elasto-plastic Adhesion Model: Example Problem. University of Edinburgh.* doi:10.13140/RG.2.2.10978.04809 ↩
5 S. C. Thakur, John P. Morrissey, Jin Sun, Jian-Fei Chen, Jin Y. Ooi, 2014. Micromechanical analysis of cohesive granular materials using discrete element method with an adhesive elasto-plastic contact model. *Granular Matter* , vol.16, pp.383-400.

IsaacSim



https://github.com/isaac-sim/IsaacSim

Image courtesy NVIDIA

Omniverse-EDEM Coupling

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Omniverse/IsaacSim

Simulate rigid bodies
& robotic kinematics
Large timesteps

GEOMETRY MOTION

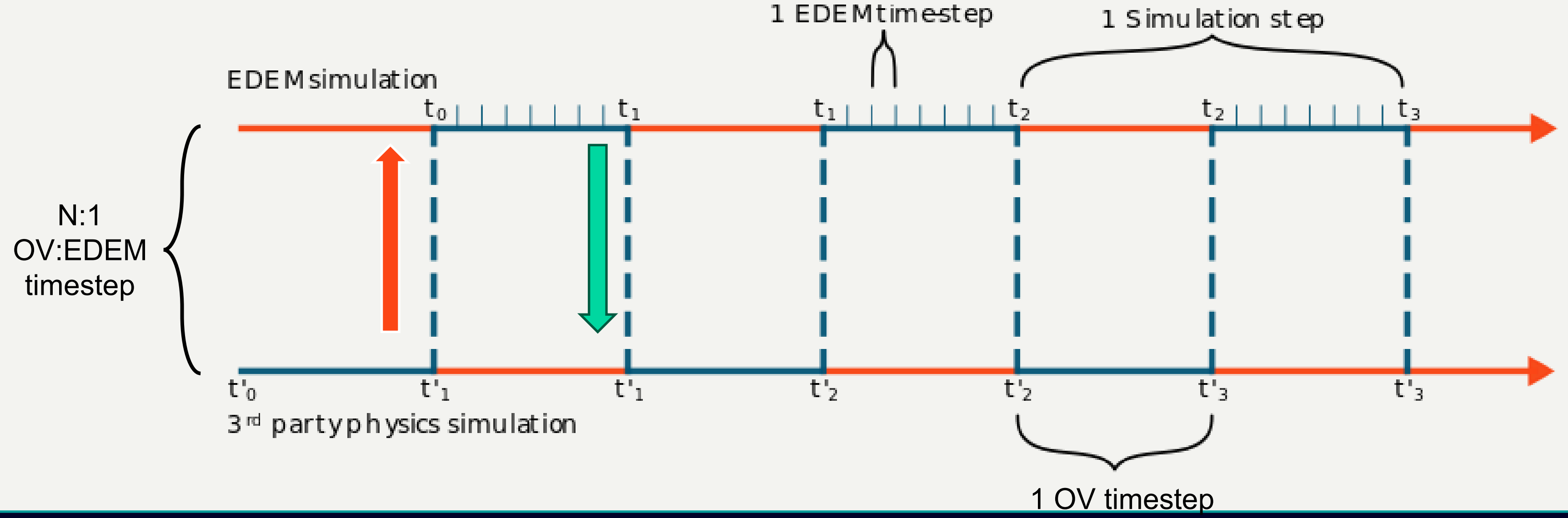
Rigid body position – orientation – velocity

PARTICLE BEHAVIOUR

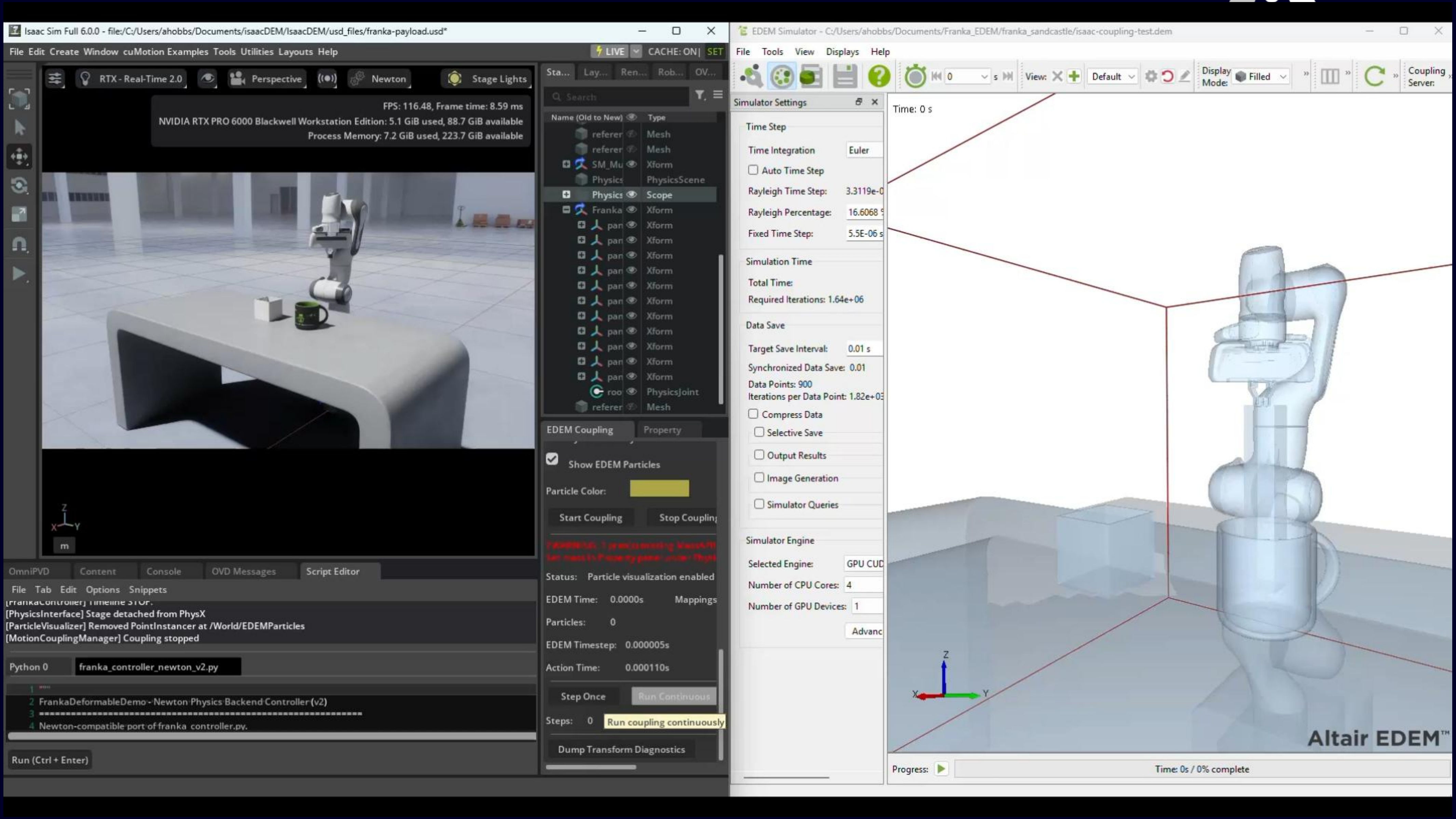
Resulting forces - torques on rigid bodies

EDEM

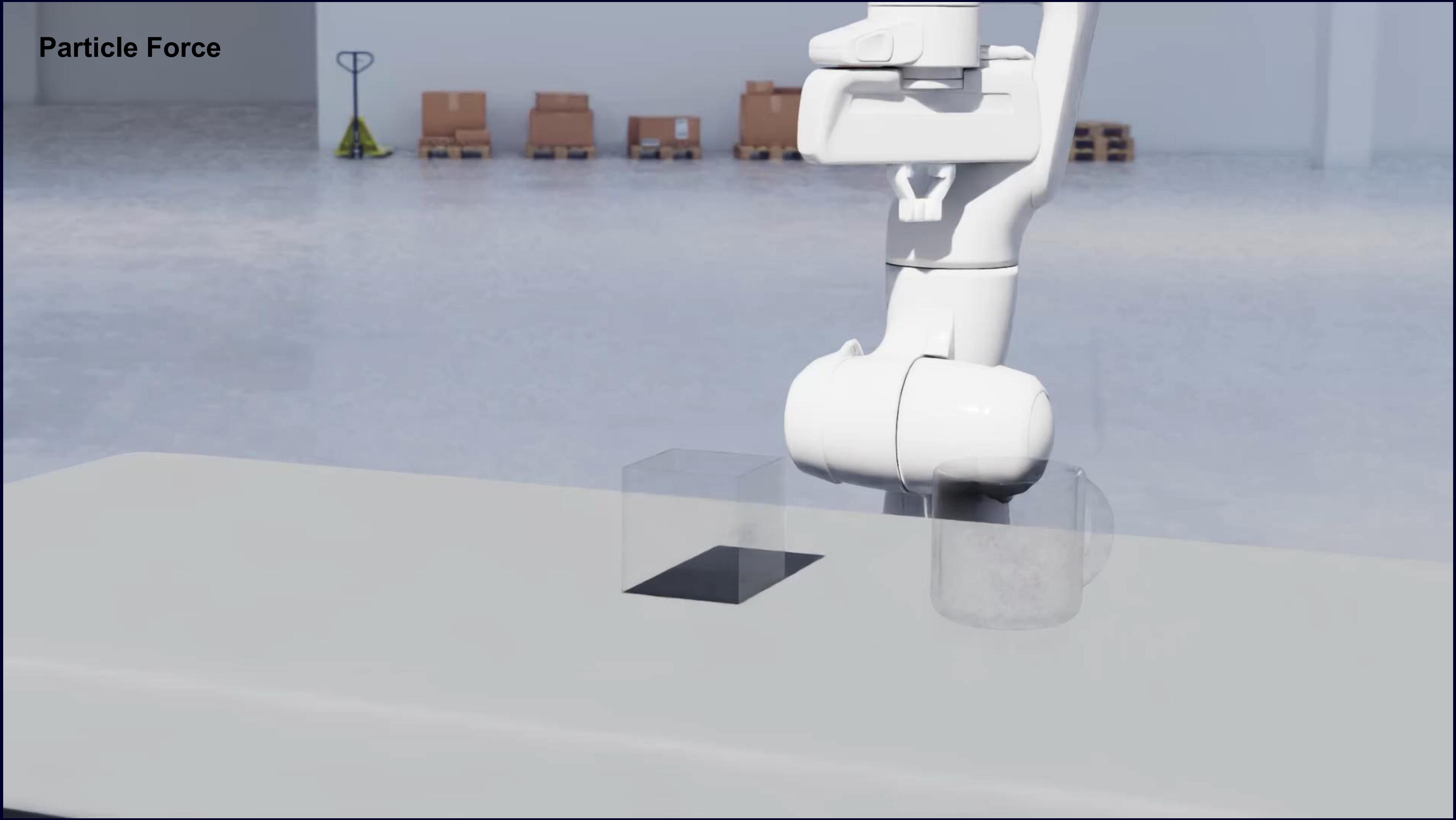
Interpolate
geometry kinematic
Multiple small
timesteps



EDEM – Omniverse Coupling

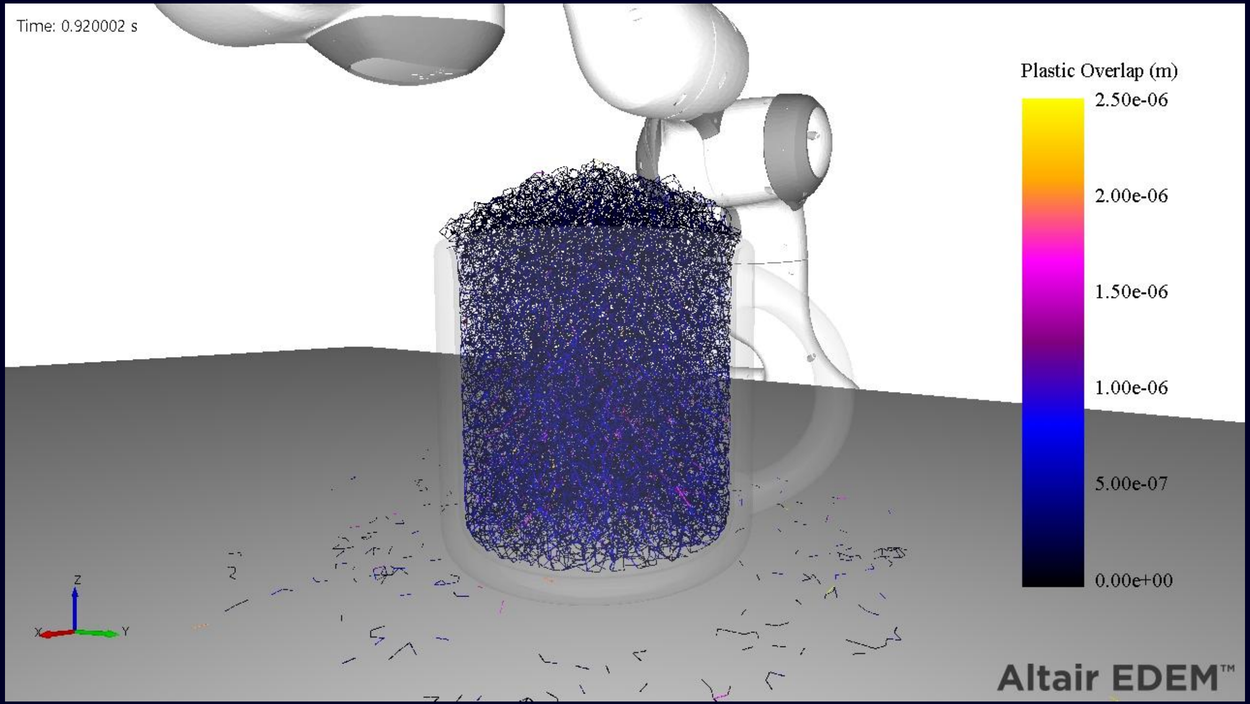


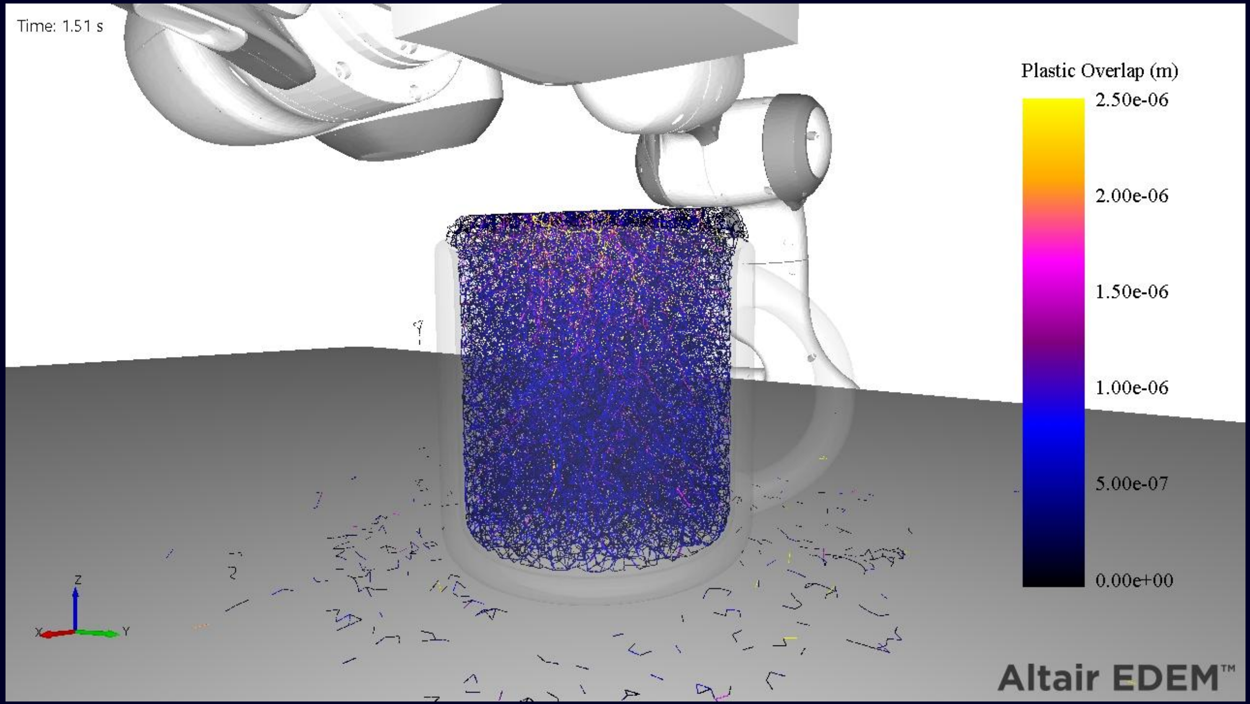
Particle Force



Particle Z Position

Compaction





Pre-compaction minimal plastic overlap

Post-compaction plastic overlap and permanent deformation

Conclusions

Present a path towards physical AI by demonstrating a coupling between Nvidia Omnivserse/IsaacSim and Siemens Simcenter EDEM

- Demand for autonomous systems to improve safety, quality, efficiency, and performance
- Granular materials are common across many industries
- Complex behaviors like cohesion and compaction require advanced contact models
- Bridging the gap between real-time robotics simulation and high-fidelity CAE remains a challenge
- Need for robust physics AI approaches to accelerate simulation of granular systems

Physical AI starts with [fast] accurate physics

Kit-CAE DEMO

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Main Repo: https://github.com/NVIDIA-Omniverse/kit-cae

EDEM glyph coloring fix: https://github.com/andrewinsheffield/kit-cae-3.0

#Clone repo:

gh repo clone andrewinsheffield/kit-cae-3.0

change directory to install folder

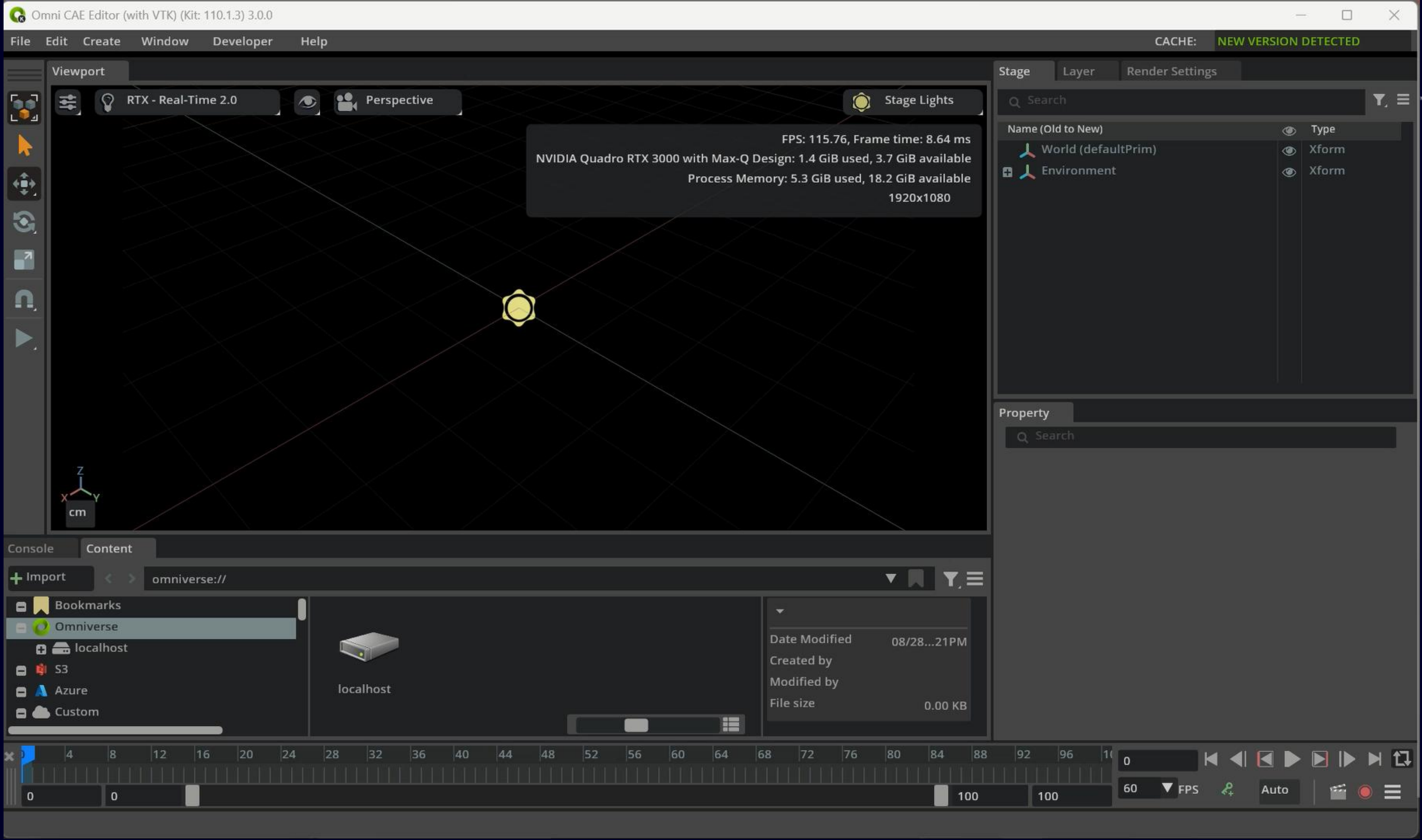
cd kit-cae-3.0

Build application

./repo.bat build –r

Launch application with legacy VTK

./repo.bat launch -n omni.cae_vtk.kit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NEW VERSION DETECTED
Viewport
RTX - Real-Time 2.0
Perspective
Stage Lights
FPS: 115.76, Frame time: 8.64 ms
NVIDIA Quadro RTX 3000 with Max-Q Design: 1.4 GiB used, 3.7 GiB available
Process Memory: 5.3 GiB used, 18.2 GiB available
1920x1080
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Type
World (defaultPrim)
Xform
Environment
Xform
Property
Search
Console
Content
Import
omniverse://
Bookmarks
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S3
Azure
Custom
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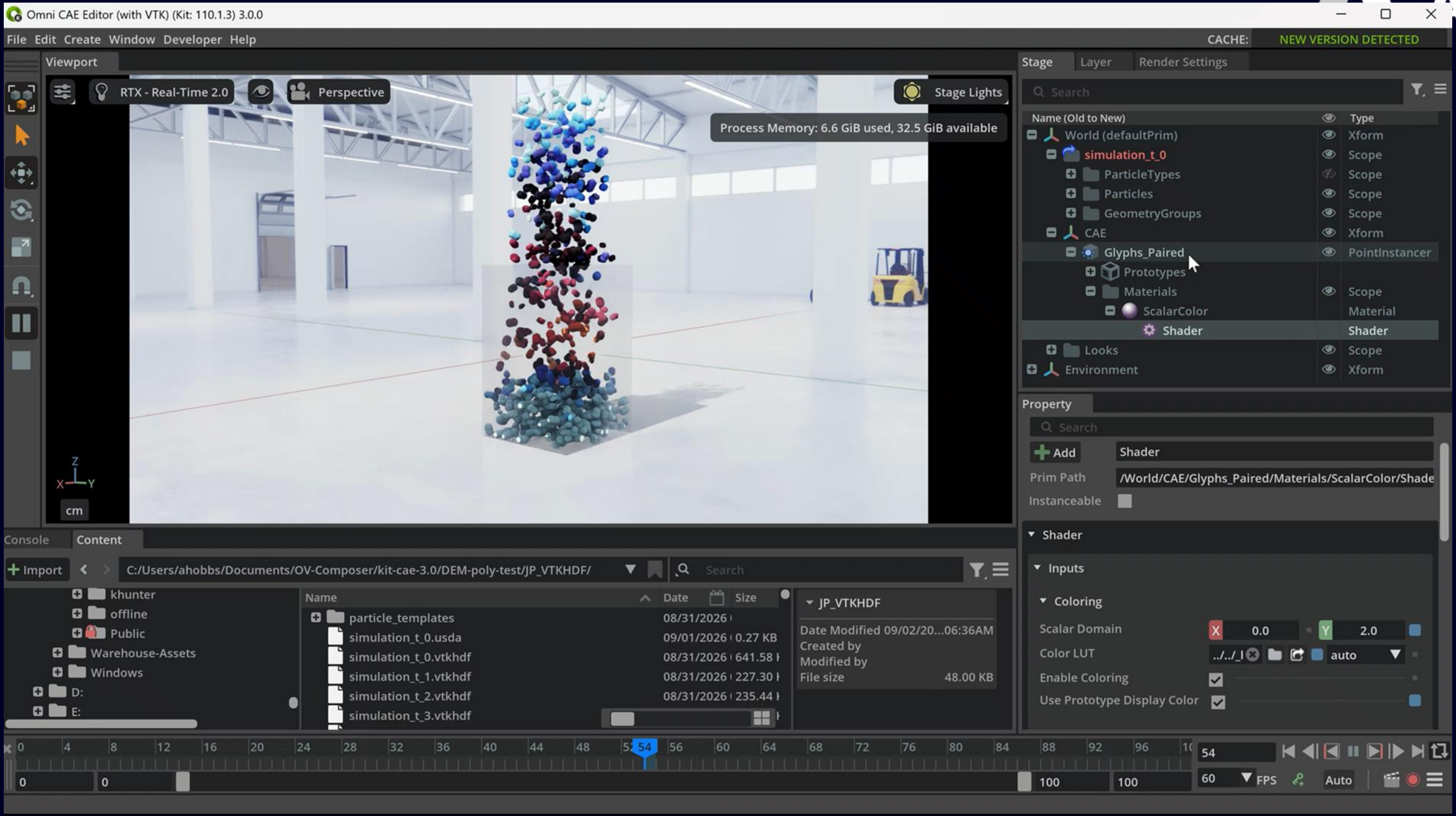
ASTEC™



Omni CAE Editor (with VTK) (Kit: 110.1.3) 3.0.0
File Edit Create Window Developer Help
CACHE: NEW VERSION DETECTED
Viewport
RTX - Real-Time 2.0
Perspective
Stage Lights
Process Memory: 6.6 GiB used, 32.5 GiB available
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Name (Old to New)
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World (defaultPrim) Xform
simulation_t_0 Scope
ParticleTypes Scope
Particles Scope
GeometryGroups Scope
CAE Xform
Glyphs_Paired PointInstancer
Prototypes
Materials Scope
ScalarColor Material
Shader Shader
Looks Scope
Environment Xform
Property
Add
Shader
Prim Path /World/CAE/Glyphs_Paired/Materials/ScalarColor/Shade
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