SynChrono: An MPI-Based, Scalable Physics-Based Simulation Framework for Autonomous Vehicles Operating in Off-Road Conditions

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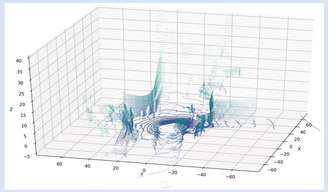
Project Chrono

Chrono is an **open-source** multi-physics engine for simulation of domains from granular flows and fluid-solid interaction to vehicle dynamics and sensing. Chrono is **physics-based** to provide accurate physics simulation in a wide range of domains. Chrono provides many different modules, encompassing different domains and solution methods, two of which; **Chrono::Vehicle** and **Chrono::Sensor** form the basis for **SynChrono**.

Chrono::Sensor

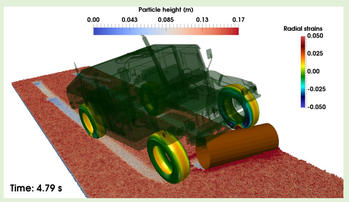
Sedan equipped with camera and lidar navigates the streets of Madison.

Chrono::Sensor seeks to enable realistic data generation from user-defined sensor characteristics such as noise, distortion and lag.
Camera, lidar, GPS and IMU sensors generate synthetic data for software-in-the-loop testing of control algorithms.



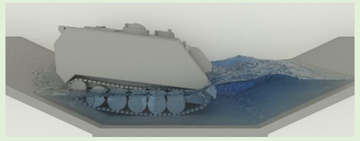
Isometric view of lidar data from an autonomous vehicle.

Chrono::Vehicle



Chrono::Vehicle HMMWV with flexible tires navigating granular terrain.

Chrono::Vehicle provides a set of subsystem templates that enable the modeling and simulation of wheeled and tracked vehicles on rigid, granular and deformable terrain.



A tracked M113 navigates a ditch in a fording operation.

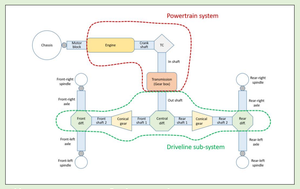
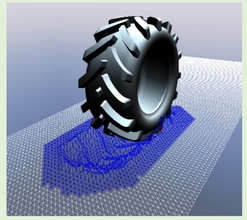


Illustration of the subsystem components that make up a Chrono::Vehicle model.

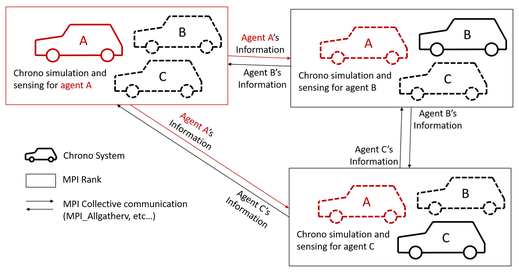
View Chrono on GitHub

View Videos on YouTube



Chrono::Vehicle supports modeling of deformable Soil Contact Model (SCM) terrain, based on semi-empirical Bekker-Wong theory.

SynChrono – Scalability Through MPI



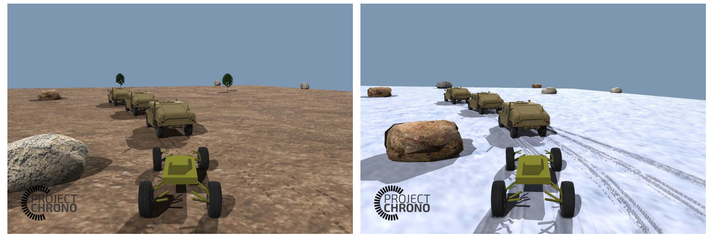
SynChrono improves the scaling performance of Chrono, with respect to adding more agents, in situations where contact between agents is not of interest. Each agent exists in an independent Chrono simulation, so physics computation is limited to a single agent for each system.

- Each ego agent is simulated in its own Chrono system
- All non-ego agents exist as visualization assets only for the purpose of sensing
- Agents exchange state data through MPI
- A vehicle's state data consists of a pose for the chassis and each wheel

End-to-end Learning for Off-Road Mobility

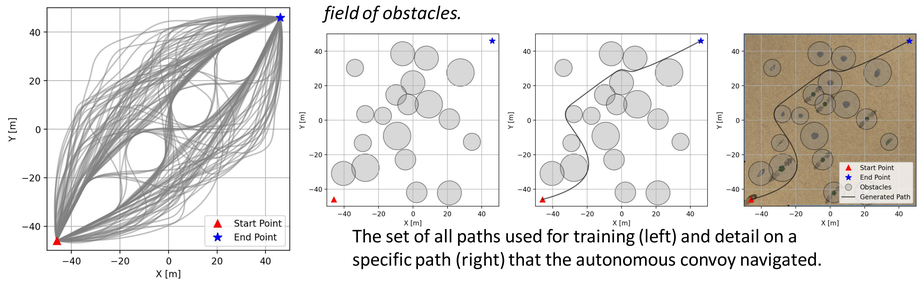
SynChrono, together with **GymChrono**– a platform built on OpenAI Gym for Chrono-based reinforcement learning– can be used together as a simulation environment for autonomous mobility tasks. Their support for deformable terrain enables off-road studies such as convoy navigation.

GymChrono on GitHub



A convoy of autonomous vehicles on silt-like (left) and snow-like (right) deformable (SCM) terrain.

Vehicles in the convoy were trained to follow a path through a random field of obstacles.

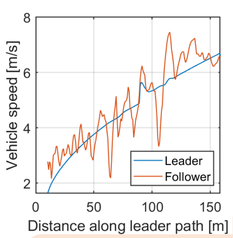


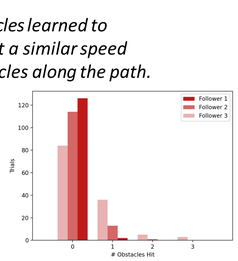
The set of all paths used for training (left) and detail on a specific path (right) that the autonomous convoy navigated.

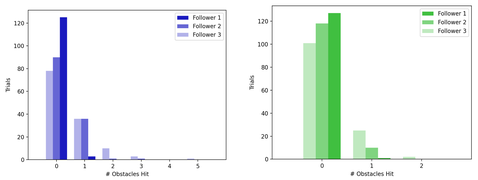
The leader knew the path and used a simple path-following controller to stay on it. The following vehicles learned a policy based on low-resolution imagery of the world ahead of them.

Comparison between a full-resolution camera used for visualization and a low-resolution camera used in training.

The following vehicles learned to follow the leader at a similar speed and to avoid obstacles along the path.

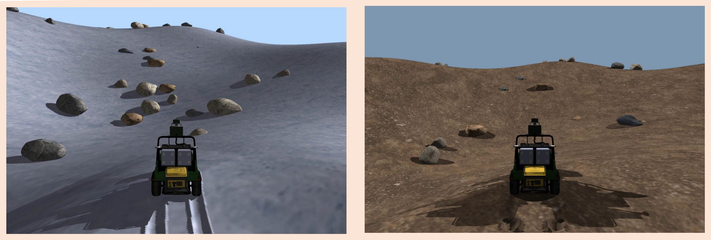






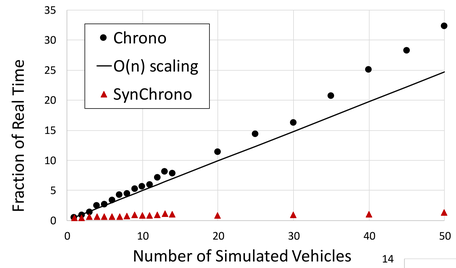
Histograms of obstacles hit for each vehicle in the convoy for rigid, silt-like and snow-like terrain. This histogram data shows the better relative behavior of vehicles on harder terrain and for vehicles closer to the leader

In a separate scenario, an off-road gator was trained to quickly navigate a hilly, obstacle-filled terrain to reach an objective.



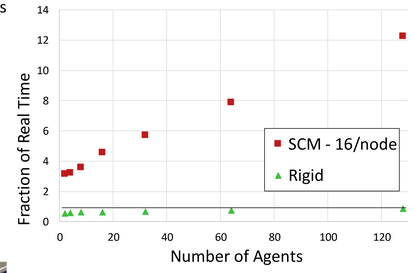
Chrono::Vehicle's deformable terrain model was used for the environment along with reinforcement learning in GymChrono. The terrain on the left is softer, the terrain on the right is harder.

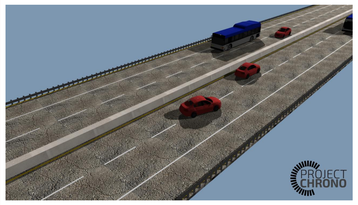
SynChrono Scalability Studies



SynChrono builds on the physics-based modeling capabilities of Chrono to provide a scalable platform for autonomous vehicle mobility studies. SynChrono's MPI framework allows it to scale in close to constant time up to tens of agents, all simulated in a time and space coherent world.

Scaling Results on rigid terrain (above) and on deformable SCM Terrain (right). SynChrono scales in close to constant time and can add additional agents at little cost compared to Chrono.

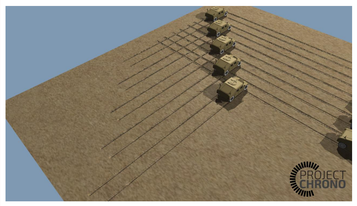




Autonomous vehicles perform a lane change in a highway environment.

The good weak scaling is because each MPI thread handles one autonomous agent (AV, robot, traffic light, etc.) As more agents are added, the simulation time does not go significantly up if MPI-connected hardware resources are adequately provisioned for the simulation.

SynChrono can be used for scenarios ranging from simple highways, to complex urban environments, off-road terrain situations, and more.



HMMWVs cross paths with each other on deformable terrain. Benchmark test used for scalability analysis.

Six vehicles navigate an intersection on the University of Wisconsin–Madison campus.

Future Work

Flexibility in number of SynChrono agents per MPI rank to allow better sharing of expensive computational assets

Streamlined message structures to improve scaling performance of SCM terrain

Tighter integration with platforms like ROS for controller creation and straightforward deployability.

Simple scenario customization through json files.

Integration with hardware for Human-In-The-Loop studies

References & Links

Project Chrono. Chrono: An Open Source Framework for the Physics-Based Simulation of Dynamic Systems. http://projectchrono.org.

R. Serban, M. Taylor, D. Negrut and A. Tasora. Chrono::Vehicle – Template-based Ground Vehicle Modeling and Simulation, International Journal on Vehicle Performance, 5(1), pp. 18-39

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