OPEN SIMULATION INTERFACE.
INTRODUCTION AND OVERVIEW.
DIFFERENTIATION OF SIMULATION DATA INTERFACES.

**Data Update rate**

<table>
<thead>
<tr>
<th>Data</th>
<th>Update rate</th>
<th>Use case</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ego vehicle data</td>
<td>Very high (~1ms)</td>
<td>Ego dynamics simulation.</td>
</tr>
<tr>
<td>Object / road data</td>
<td>Medium (~25 Hz / 40ms)</td>
<td>Sensor simulation.</td>
</tr>
<tr>
<td>Map &amp; backend data</td>
<td>Very low (~sec / min)</td>
<td>Localization on virtual map.</td>
</tr>
</tbody>
</table>
Open Simulation Interface

- Consists of two individual interfaces (entry points) for object data.
- Implementation based on protocol buffers library.

osi::GroundTruth
- Generic object output of the simulation framework.
- World / global reference frame.
- Comprehensive description of the virtual environment including all relevant object data required by statistical sensor models.

osi::SensorData
- Direct input and output of statistical sensor model(s).
- Input for the environment model.
- Sensor reference frame.
- Description of the sensor output including uncertainties.
DATA FLOW USING THE OPEN SIMULATION INTERFACE.

Simulation Framework

OSI Exporter

osi::GroundTruth

Converter
GroundTruth → SensorData

osi::SensorData

Sensor Model

osi::SensorData

Sensor Simulation

OSI Importer

Function Framework

Function

osi::SensorData

osi::SensorData
DATA FLOW USING THE OPEN SIMULATION INTERFACE WITH MULTIPLE SENSOR MODELS.
DATA FLOW USING THE OPEN SIMULATION INTERFACE WITH A SEQUENCE OF (PARTIAL) MODELS.
DATA FLOW IN SIMULATION FOR STATISTICAL AND PHYSICAL SENSOR MODELS.

Simulation Framework → OSI Exporter → osi::SensorData → Sensor Model (phenomenological) → OSI Importer

osi::GroundTruth → Converter

Statistical Model for low level data generation (optional) → OSI low level data Importer

Physical Measurement Model (e.g. Raytracing) → osi::LowLevelData

Tracking (production code or hardware) → Function Framework
SIMULATION OF SPECIFIC ERROR PATTERNS USING FAULT INJECTION (OPTIONAL).
Sensor Model Processing Chain:

1. **osi::GroundTruth**
   - Object-level description of all relevant input data required for the phenomenological / statistical simulation of sensor behavior.

2. **Converter**
   - GroundTruth → SensorData
   - Converter additionally requires knowledge of sensor configurations, produces one specific copy of SensorData for each sensor with data transformed into the sensor’s reference frame. No modification of data takes place.

3. **osi::SensorData**
   - Initial input for the sensor model; contains unmodified data in the representation of the sensor output and a reference to the original GroundTruth.

4. **Sensor Model**
   - The sensor model modifies the data of the input SensorData interface to statistically replicate the sensor behavior; output is the modified data using the same SensorData data structure.

5. **osi::SensorData**
   - Output of the sensor model; contains modified object data that should closely resemble the output of a real sensor including perception function (tracking).
EXEMPLARY INTERNAL ARCHITECTURE FOR STATISTICAL SENSOR MODELS.

Input data: unmodified data if directly from ground truth, modified data if chained to previous sensor model.

Module(s) handling detection of objects including geometric field of view, occlusion, ghost objects / false positives, and false negatives.

Module(s) handling measurement output and uncertainties for directly observable data, e.g. dynamic state variables (position, etc.), bounding box, etc.

Module(s) handling additional object properties derived from tracking, e.g. object classification.

Module(s) handling sensor specific packaging of the data content, e.g. determining most relevant objects for a limited size object list.

Output data: modified data after processing by the sensor model.
**OSI::GROUNDTRUTH DESCRIPTION.**

GroundTruth contains unmodified object data describing the environment of the ego vehicle as required for phenomenological / statistical sensor models in world coordinates.

- **osi::GroundTruth**
  - Vehicle
    - Dynamic objects (wheeled and usually motorized)
  - Object
    - Static obstacles and slow moving road users (pedestrians)
    - Traffic signs
  - TrafficSign
    - Traffic lights
  - TrafficLight
    - Road, lane, and lane marking description
  - Road
    - General environmental conditions
  - Environmental Conditions

---

**Protos:**
- osi_object.proto
- osi_road.proto
- osi_environment.proto
SensorData describes the object data in the environment relative to one specific sensor.

- **osi::SensorData**
  - **SensorDataGroundTruth**: Link to original ground truth data (for reference and validation)
  - **MountingPosition**: Sensor position relative to the ego vehicle reference frame, simplifies transformation
  - **SensorDataObject**: Description of objects in the environment as seen by the sensor, incl. uncertainties
  - **ModellInternal**: Additional data for internal use by the sensor model only

- **osi::GroundTruth**
- **osi_common.proto**
- **osi_sensordata.proto**
- **osi_modelinternal.proto**
LowLevelData describes the output of a (physical) model of the measurement process before tracking and object hypothesis. Only this message does not deal with object data.

- **osi::LowLevelData**
  - **MountingPosition**: Sensor position relative to the ego vehicle reference frame, simplifies transformation
  - **LidarPointCloud**: Generic point cloud as typically output by a lidar sensor.
  - **RadarReflectionList**: List of reflections as seen by a radar sensor including Doppler

osi_lowleveldata.proto