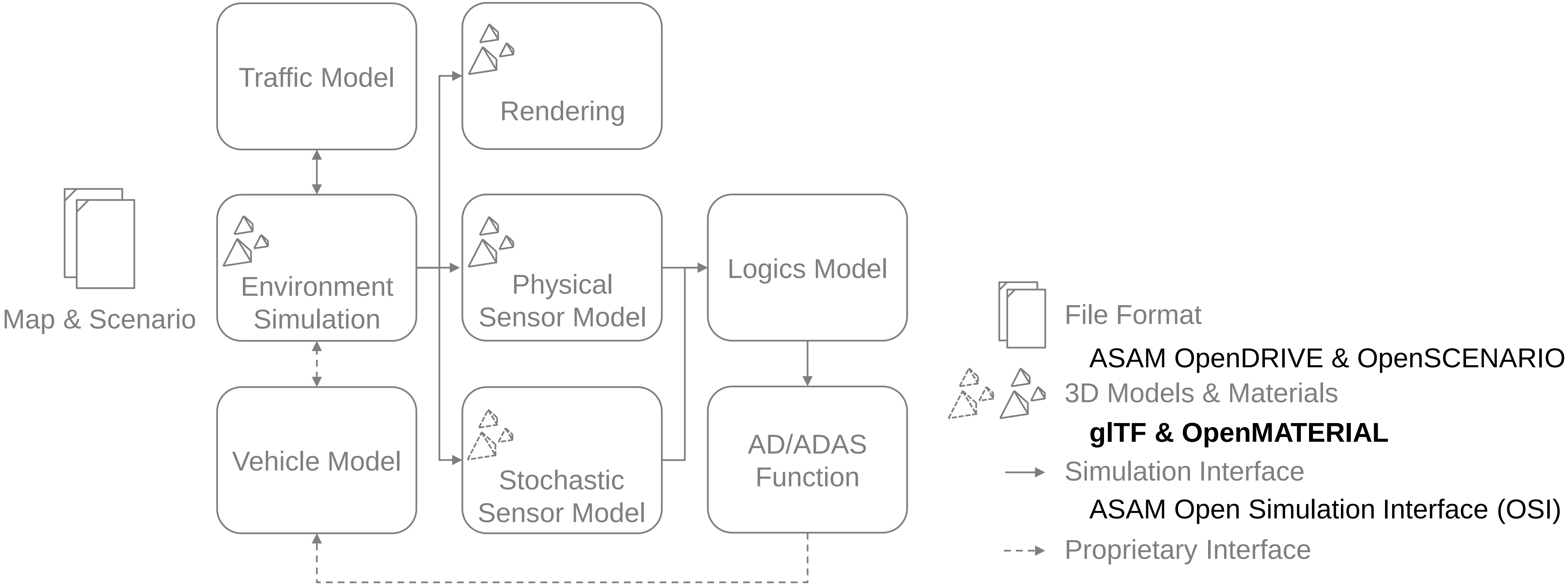
BMW GROUP

OPENMATERIAL

CURRENT STATE

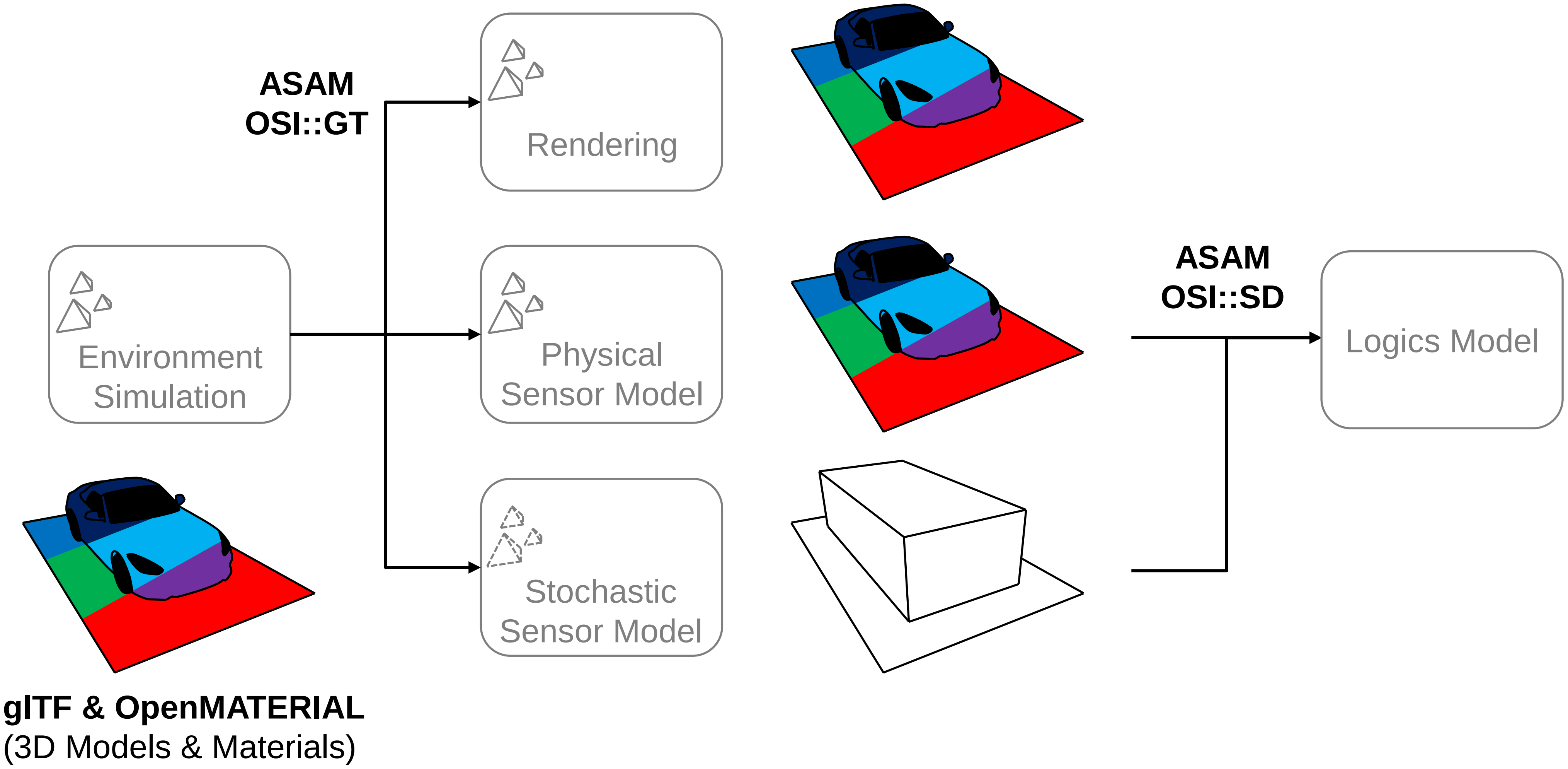
Nov 20th, 2023 | Dr.-Ing. Ludwig Friedmann, BMW AG

3D MODELS AND MATERIALS IN ADAS/AD SIMULATION



https://github.com/LudwigFriedmann/OpenMATERIAL

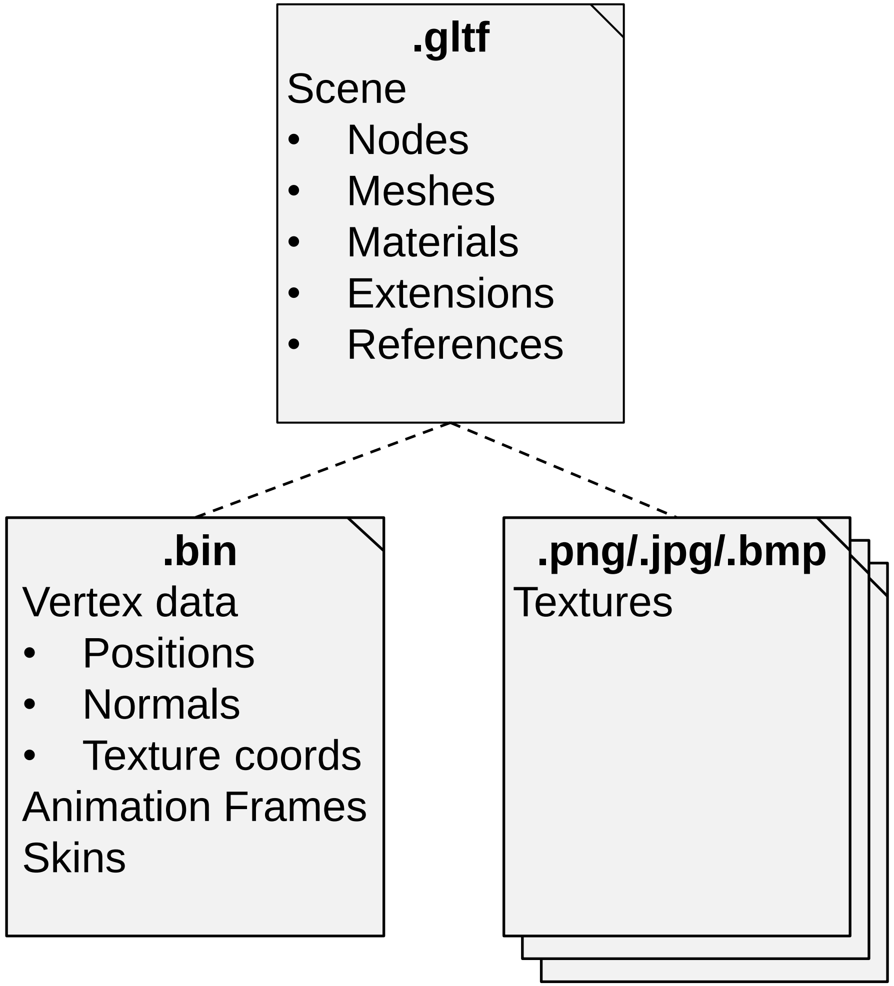
STANDARDIZED INTEGRATION OF 3D MODELS AND MATERIALS



https://github.com/OpenSimulationInterface/open-simulation-interface

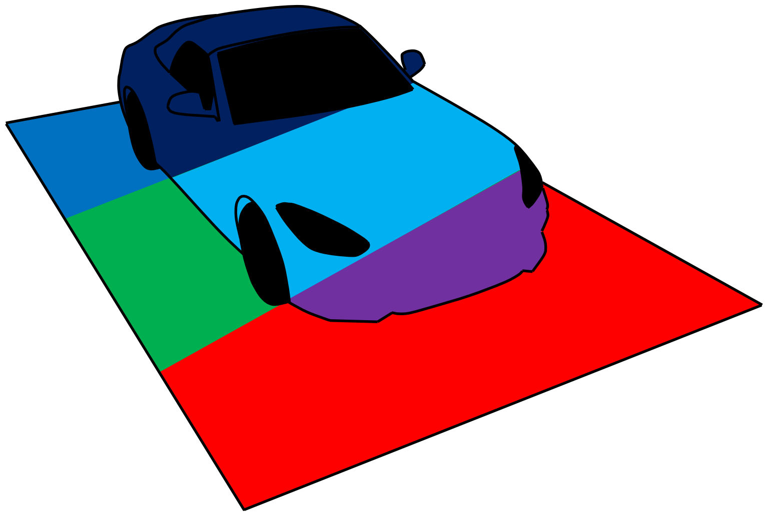
KHRONOS GRAPHICS LAYER TRANSPORT FORMAT (GLTF) 2.0

- Open-source, royalty-free, maintained by Khronos Group
- Optimized for efficient transmission and loading of 3D scenes and models
- Intended as industry standard for 3D model exchange
- Wide support in computer graphics, modelling software, game engines
- Support for extensions, e.g. PBR workflows

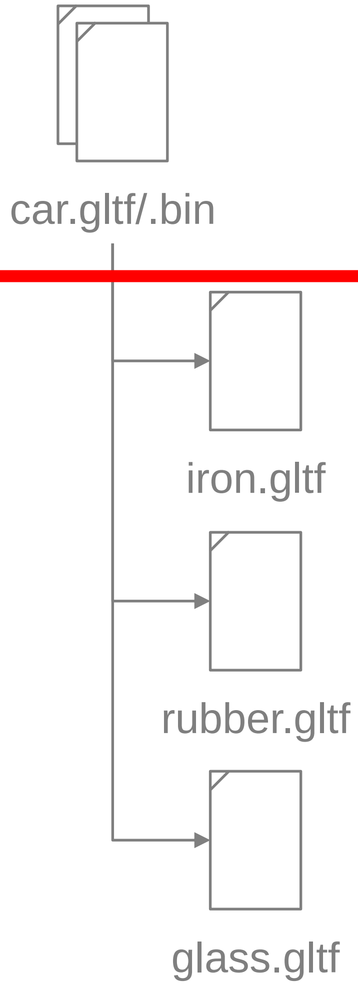


https://github.com/KhronosGroup/glTF

OPENMATERIAL: SCOPE



glTF: 3D Geometry, Rendering
PBR (Metallic-Roughness)



OpenMATERIAL: Material Models
Frequency-specific sensor material properties

OpenMATERIAL:
Asset Info & Model Specs

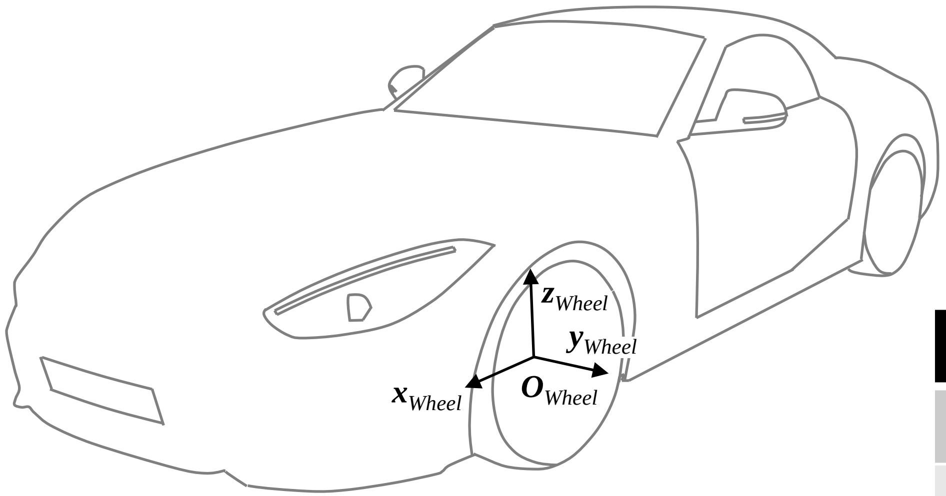
- Semantic Information
- Coordinate Frames
- Node Hierarchy
- Animation
- Quality Requirements
- …

OpenMATERIAL: Validation Tools for 3D Models & Materials

OPENMATERIAL: SPECIFICATIONS AND ASSET INFORMATION FOR 3D MODELS

Coordinate frames

- Reference
- Wheels
- Doors
- Trunk lid
- Lights
- Indicators
- Number plates
- Sensors
- Steering wheel
- Driver's view



Wheel Coordinate Frame	
Origin (O_{Wheel})	Geometric center of the wheel
x-axis (x_{Wheel})	Collinear with the vehicle longitudinal axis, pointing forwards
y-axis (y_{Wheel})	Completes the right-handed coordinate system
y-axis (z_{Wheel})	Perpendicular to the x-axis, pointing upwards

Wheel Neutral Position	
$R_x=0$	Camber at neutral load conditions
$R_y=0$	Rim logos horizontal, readable
$R_z=0$	Straight running
$T_z=0$	Suspension deflection at neutral load conditions

https://github.com/LudwigFriedmann/OpenMATERIAL/tree/master/model_structure

OPENMATERIAL: SPECIFICATIONS AND ASSET INFORMATION FOR 3D MODELS

Model structure

- Semantic structure
- Node naming and hierarchy
- Local transformations
- Animation

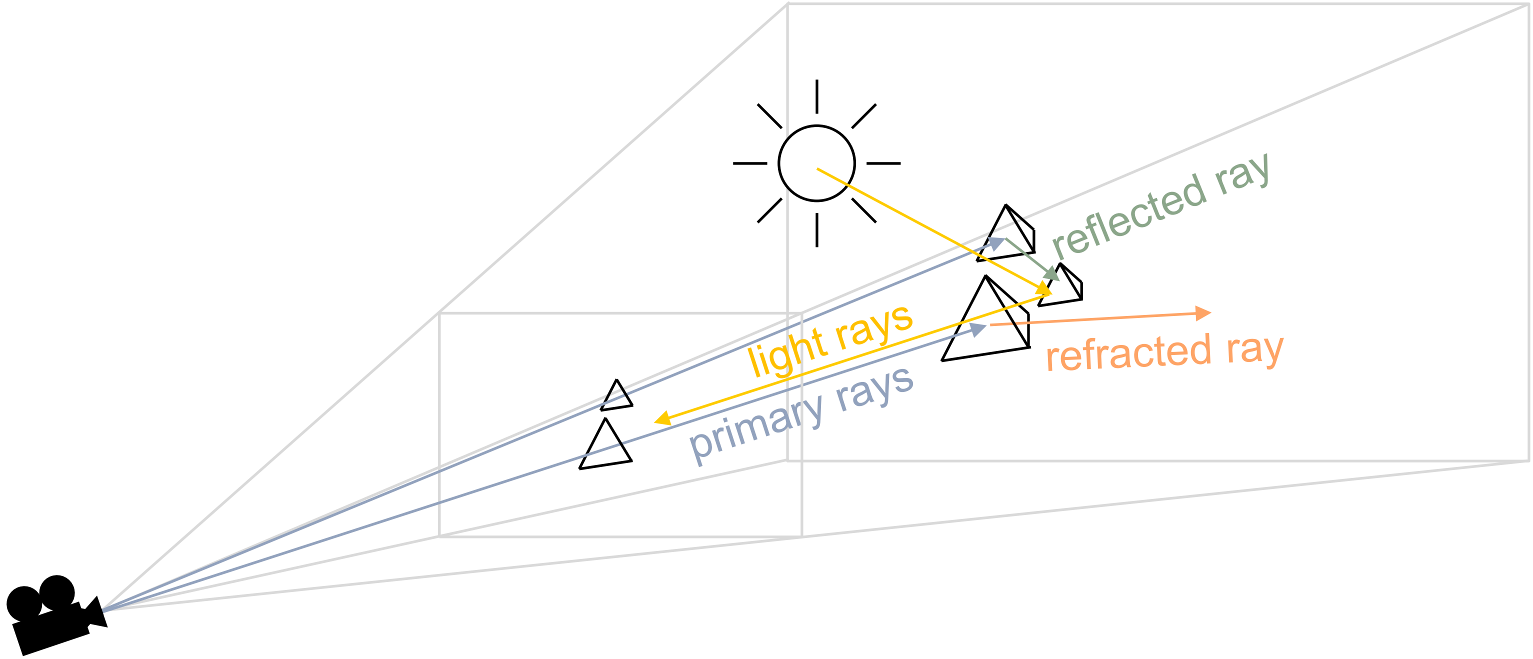
Examples

https://github.com/LudwigFriedmann/OpenMATERIAL/tree/master/model_structure

```
$Type_$Release (T)
|-------Floor
|-------Grp_Exterior
|       |-------Grp_Exterior_Static
|       |-------Grp_Exterior_Dynamic
|               |-------Grp_Wheel_FL (T)
|               |       |-------Grp_Wheel_FL_Steering
|               |       |-------Grp_Wheel_FL_Steering_Rotating (T)
|               |-------Grp_Wheel_FR (T)
|               |       |-------Grp_Wheel_FR_Steering
|               |       |-------Grp_Wheel_FR_Steering_Rotating (T)
|               |-------Grp_Wheel_BL (T)
|               |       |-------Grp_Wheel_BL_Steering
|               |       |-------Grp_Wheel_BL_Steering_Rotating (T)
|               |-------Grp_Wheel_BR (T)
|               |       |-------Grp_Wheel_BR_Steering
|               |       |-------Grp_Wheel_BR_Steering_Rotating (T)
|               |-------Grp_Door_FL (T)
|               |-------Grp_Door_FR (T)
|               |-------Grp_Door_BL (T)
|               |-------Grp_Door_BR (T)
|               |-------Grp_Trunk_Lid (T)
|               |-------Grp_Light_Low_Beam_FL (T)
|               |-------Grp_Light_Low_Beam_FR (T)
|               |-------Grp_Light_High_Beam_FL (T)
|               |-------Grp_Light_High_Beam_FR (T)
|               |-------Grp_Light_Park_FL (T)
|               |-------Grp_Light_Park_FR (T)
|               |-------Grp_Light_Park_BL (T)
|               |-------Grp_Light_Park_BR (T)
|               |-------Grp_Light_Tail_BL (T)
|               |-------Grp_Light_Tail_BR (T)
|               |-------Grp_Light_Brake_BL (T)
|               |-------Grp_Light_Brake_BC (T)
|               |-------Grp_Light_Brake_BR (T)
|               |-------Grp_Light_Reverse_BL (T)
|               |-------Grp_Light_Reverse_BR (T)
|               |-------Grp_Light_Fog_BL (T)
|               |-------Grp_Light_Fog_BR (T)
|               |-------Grp_Indicator_FL (T)
|               |-------Grp_Indicator_FR (T)
|               |-------Grp_Indicator_SL (T)
|               |-------Grp_Indicator_SR (T)
|               |-------Grp_Indicator_BL (T)
|               |-------Grp_Indicator_BR (T)
|               |-------Grp_Number_Plate_F (T)
|               |-------Grp_Number_Plate_B (T)
|               |-------Grp_Convertible_Top
|               |-------Grp_Sensors (T)
|-------Grp_Interior
        |-------Grp_Interior_Static
        |-------Grp_Interior_Dynamic
                |-------Grp_Steering_Wheel (T)
                |-------Grp_Rear_Backrest
                |-------Grp_Eyepoint_Female (T)
                |-------Grp_Eyepoint_Male (T)
```

OPENMATERIAL: MATERIAL MODELS FOR RENDERING AND SENSOR SIMULATION

Technical Basics: Ray Tracing



Visibility
Primary rays (raycasts)

Lighting & Shadows (Light Distribution)
Light rays

Reflections
Reflected rays

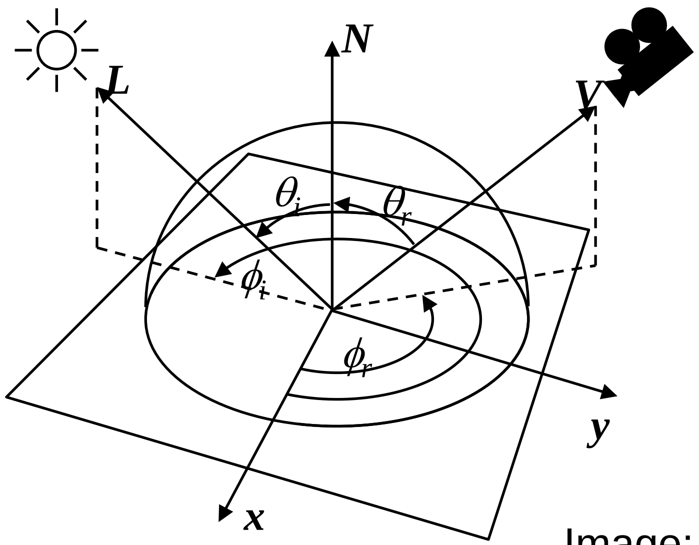
Opacity/Translucent Objects
Refracted rays

single render loop

- Ray tracing forms the basis of modern rendering and sensor simulation
- Key concept: Bidirectional Reflectance Distribution Function (BRDF)
- Physically Based Rendering (PBR) approximates BRDFs

OPENMATERIAL: MATERIAL MODELS FOR RENDERING AND SENSOR SIMULATION

Technical Basics: Bidirectional Reflectance Distribution Functions (BRDF)



$$BRDF = f(\theta_i, \phi_i, \theta_r, \phi_r) = f(\boldsymbol{L}, \boldsymbol{V})$$

$$BRDF = \frac{dL_r(\theta_r, \phi_r)}{dE_i(\theta_i, \phi_i)} = \frac{Radiance\ in\ direction\ \boldsymbol{V}}{Irradiance\ in\ direction\ \boldsymbol{L}}$$

Image: N. Gebhardt. Einige BRDF Modelle.
irrlicht3d.org/papers/BrdfModelle.pdf

- Defined by National Bureau of Standards (USA, 1977)
- Models specular reflection, diffuse diffraction and refraction
- Many different models (from visually plausible to physically accurate)
- Physical modeling requires physical material properties

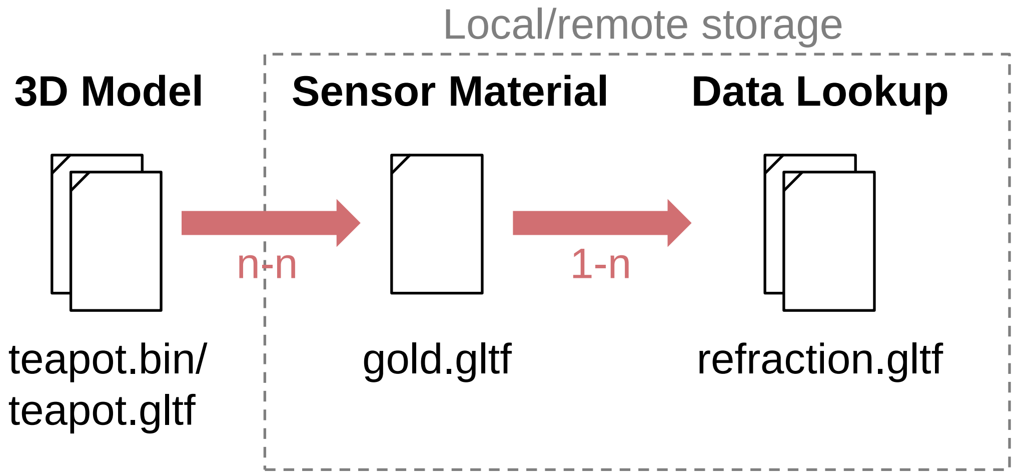
OPENMATERIAL: MATERIAL MODELS FOR RENDERING AND SENSOR SIMULATION

Motivation

- Heterogeneous simulation frameworks require standardized 3D models and materials to achieve scalability
- Khronos glTF and its material models supports common rendering workflows, e.g. metallic-roughness (PBR)
- Sensor simulation requires physics-based material models for accurate modeling of wave-matter interaction
- Specific sensor modalities require individual sets of frequency-specific material parameters

Key concepts

- OpenMATERIAL adds physics-based material models to glTF via glTF extension mechanisms
- OpenMATERIAL materials are referenced from glTF 3D models
- OpenMATERIAL materials reference wavelength-specific lookup-tables



https://github.com/LudwigFriedmann/OpenMATERIAL/tree/master/glTF_extensions/OpenMaterial_reference_link

OPENMATERIAL: MATERIAL MODELS FOR RENDERING AND SENSOR SIMULATION

Khronos glTF Metallic-Roughness PBR Material Model

Parameters

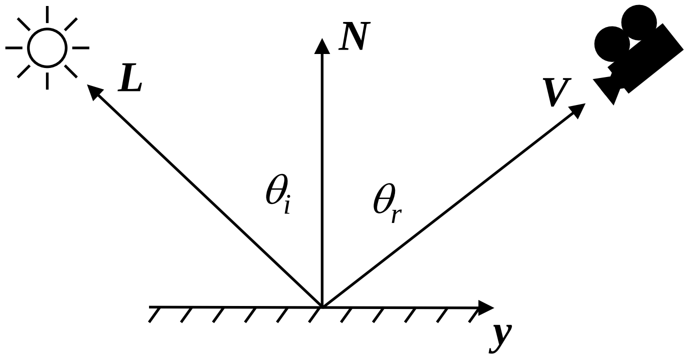
- Base color
- Metallicness
- Roughness
- Emissivity
- Occlusion
- Normals

Rendering materials are typically designed for visual plausibility, not for physical accuracy!

OPENMATERIAL: MATERIAL MODELS FOR RENDERING AND SENSOR SIMULATION

OpenMATERIAL Camera Material Model

Wavelength range: ≈ *390-700 nm*



Parameters

- Index of Refraction N (speed of light in vacuum / phase velocity in medium) [-]

  $N = n + ik$
  N: Complex refraction index
  n: Refraction index
  k: Absorption coefficient

- Lambert Emissive Coefficient C (light emission) [-]

https://github.com/LudwigFriedmann/OpenMATERIAL/tree/master/glTF_extensions/OpenMaterial_material_parameters
https://github.com/LudwigFriedmann/OpenMATERIAL/tree/master/glTF_extensions/OpenMaterial_ior_data
https://github.com/LudwigFriedmann/OpenMATERIAL/tree/master/glTF_extensions/OpenMaterial_emissivity_data

OPENMATERIAL: MATERIAL MODELS FOR RENDERING AND SENSOR SIMULATION

OpenMATERIAL Radar Material Model

Wavelength range: $\approx 3.893\ mm\ (77\ GHz)$ to $1.249\ cm\ (24\ GHz)$

Parameters

- Relative Permittivity ε_r (electric polarizability) $[F/m]$

  $\varepsilon_r = \varepsilon_1 - i\varepsilon_2$ $\quad$ $\tan\delta = (-)\ \varepsilon_2 / \varepsilon_1$

  ε_1: *Real part* $\quad$ δ: *Dissipation factor*

  ε_2 : *Imaginary part*

- Relative Permeability μ_r (magnetizability) $[H/m]$

  $0 \leq \mu_r < 1$ *Diamagnetic materials (vacuum, nitrogen, copper, water)*

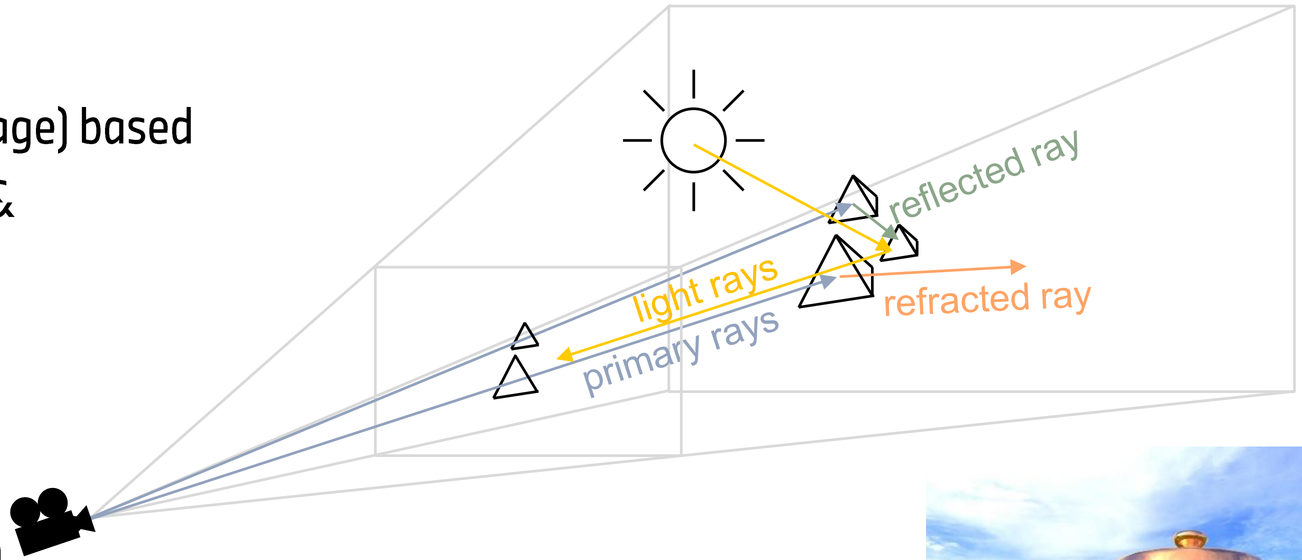
  $\mu_r > 1$ *Paramagnetic materials (oxygen, air)*

  $\mu_r \gg 1$ *Ferromagnetic materials (iron, ferrite, cobalt, nickel)*

- Surface Roughness R (Surface height root-mean-square) $[\mu m]$

  https://github.com/LudwigFriedmann/OpenMATERIAL/tree/master/glTF_extensions/OpenMaterial_material_parameters
  https://github.com/LudwigFriedmann/OpenMATERIAL/tree/master/glTF_extensions/OpenMaterial_permeability_data
  https://github.com/LudwigFriedmann/OpenMATERIAL/tree/master/glTF_extensions/OpenMaterial_permittivity_data

OPENMATERIAL: VALIDATION TOOLS FOR 3D MODELS & MATERIALS



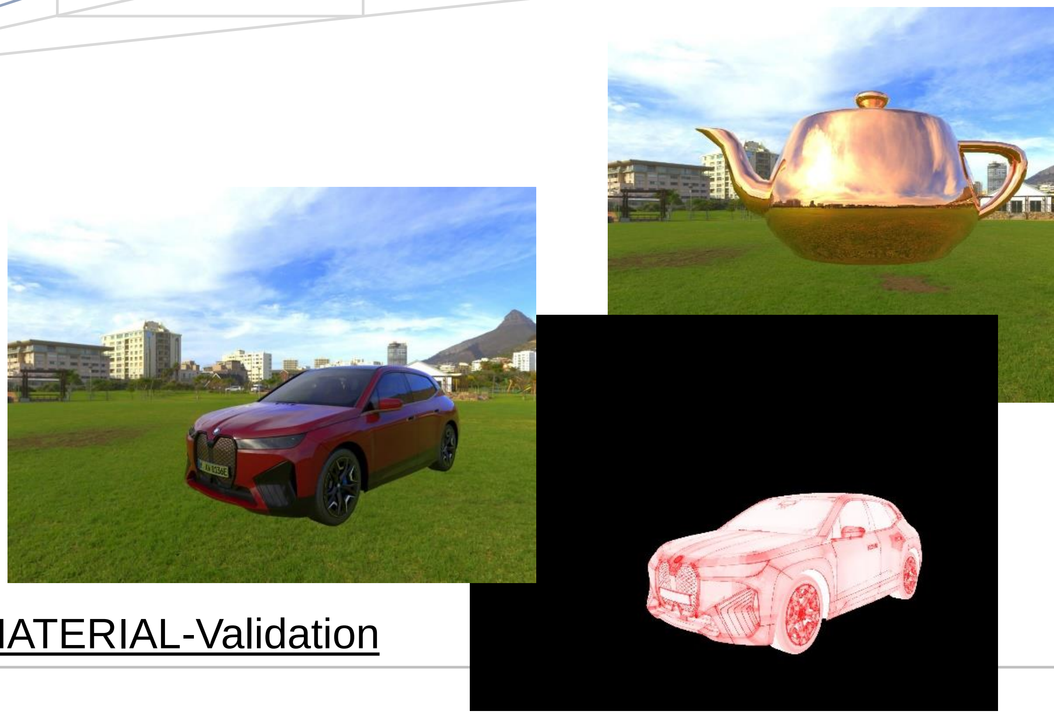
Bi-directional path tracing

- Lighting: Point-source & HDRI (High Dynamic Range Image) based
- Material support: OpenMATERIAL Camera Model (IOR) & glTF Metallic-Roughness Model (PBR)

Validation rendering modes

- Light-box & scene rendering
- Primitive ID, Geometry ID and Material ID visualization
- Roughness map and metallic map visualization
- Mesh density visualization
- Surface gradient visualization
- Inverted normal visualization

- Batch processing (configurable camera and lighting parameters)



https://github.com/LudwigFriedmann/OpenMATERIAL-Validation