Towards a Domain Specific Language for a Scene Graph based Robotic World Model

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Outline

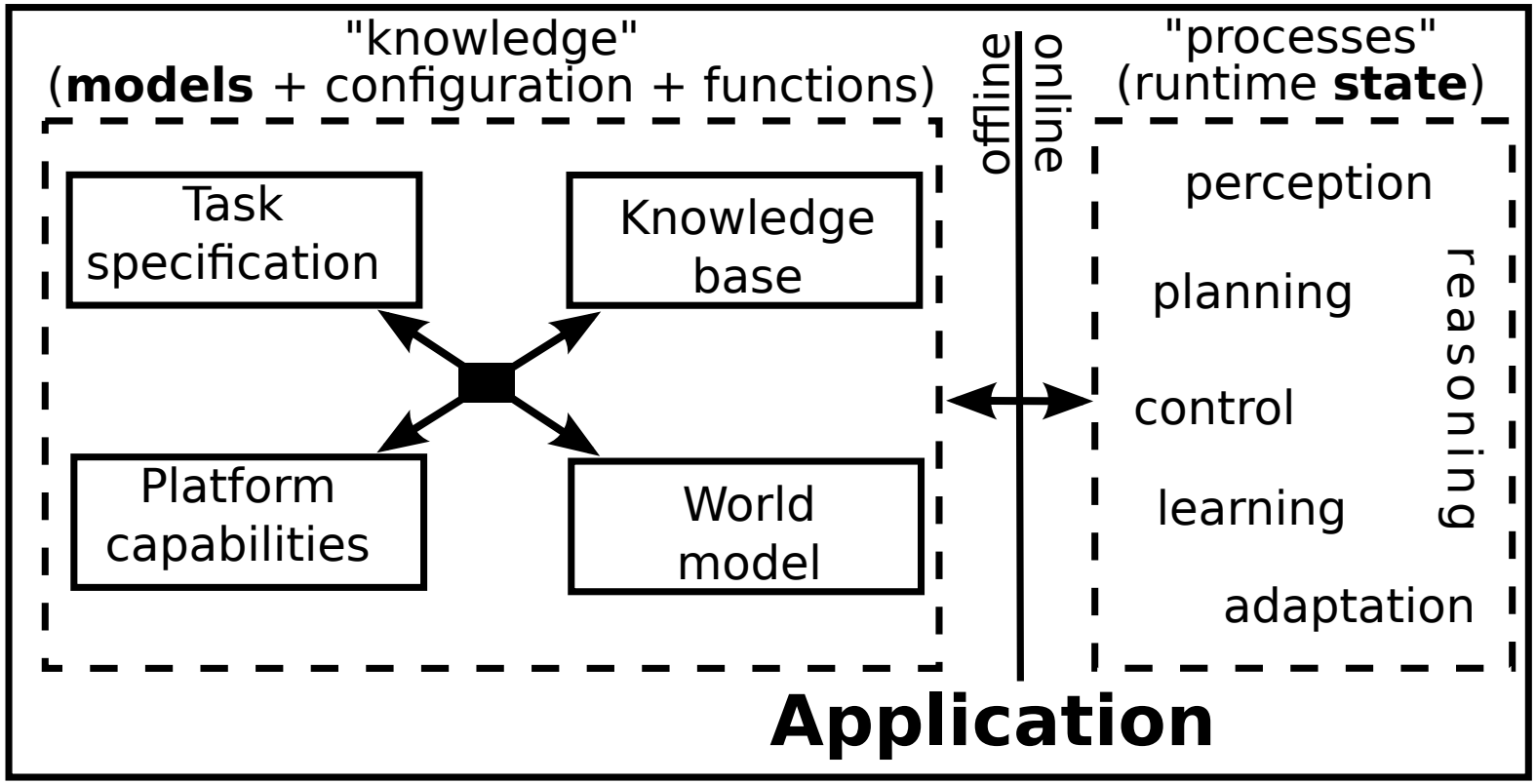
Introduction

The Robot Scene Graph: RSG

The RSG-DSL

Conclusion

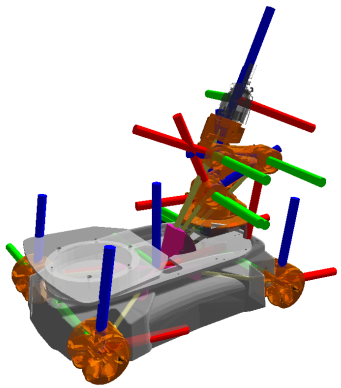
DSLs for robotic applications

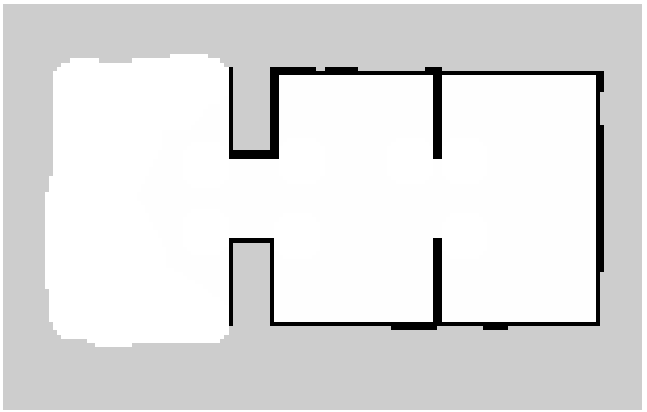


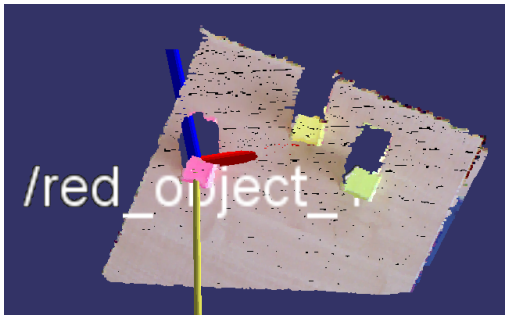
- (Prior) Knowledge
  - Robot, Task, ... **World Model**
- Algorithms
  - For various domains: planning, perception, control, ...
- Framework for execution and communication

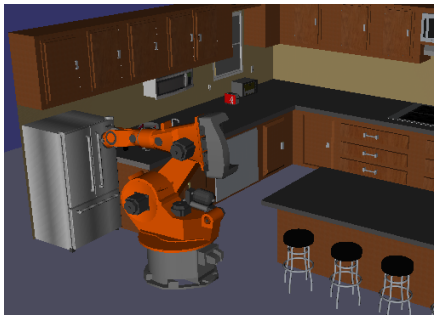
Existing World Models

- Control
  - Kinematic chains
  - Geometry
- Navigation
  - Grids
- Perception
  - 2D/3D images
  - Features
  - Poses
- Planning
  - (Triangle) Meshes









Existing World Models

- Control
  - Kinematic chains
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- Perception
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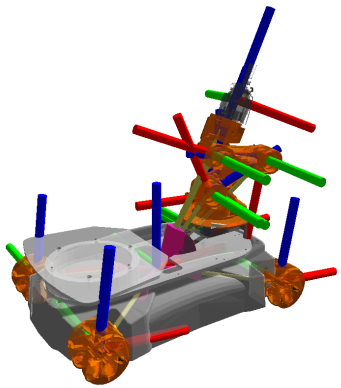
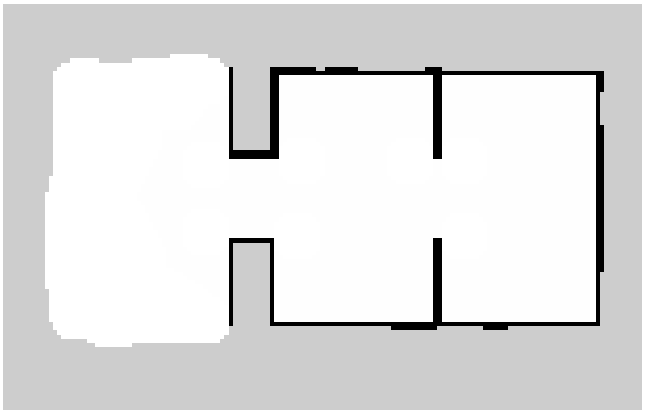
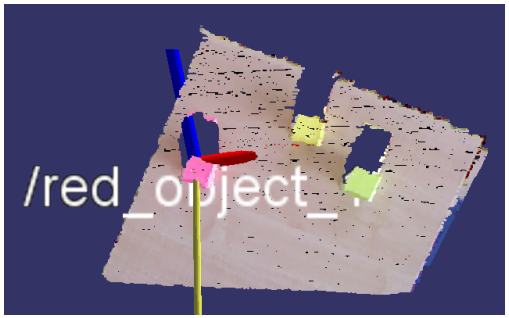
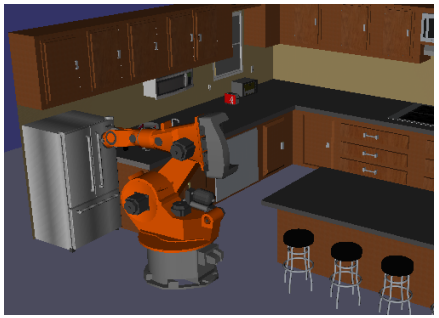
  - Features
  - Poses
- Planning
  - (Triangle) Meshes
- Not well connected yet!

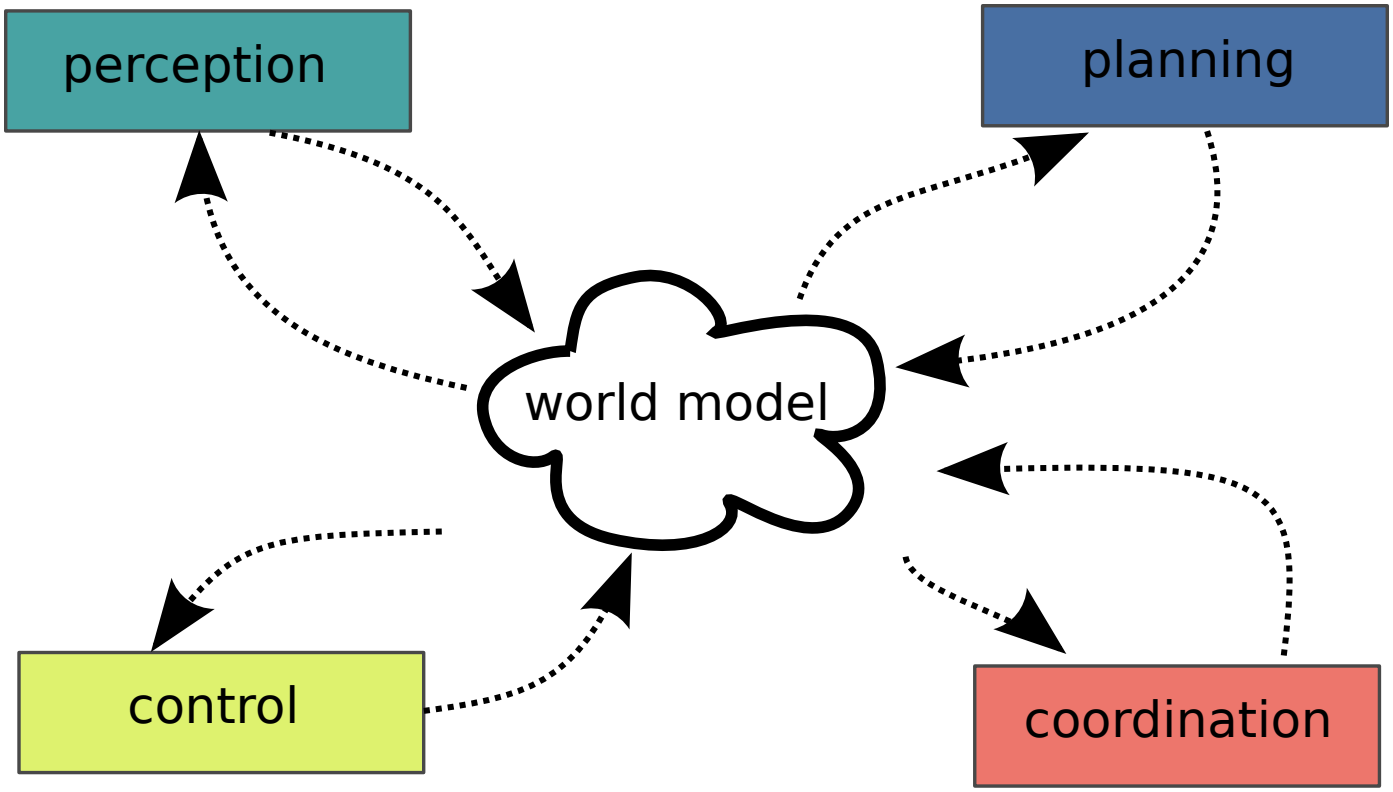






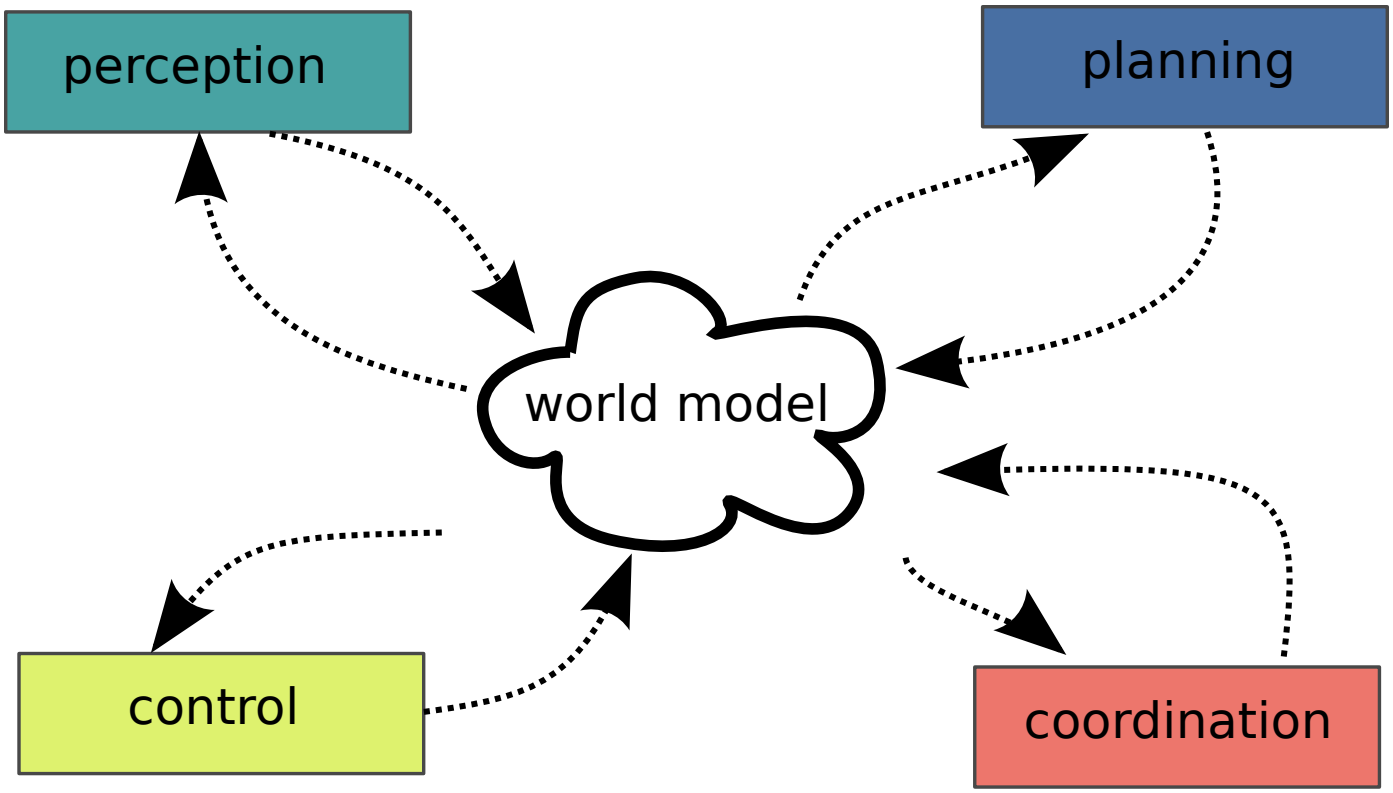


Shared world model for robot applications



- **World Model**: as shared (distributed) resource with dynamic scene, multi-resolution and uncertainty support

Shared world model for robot applications



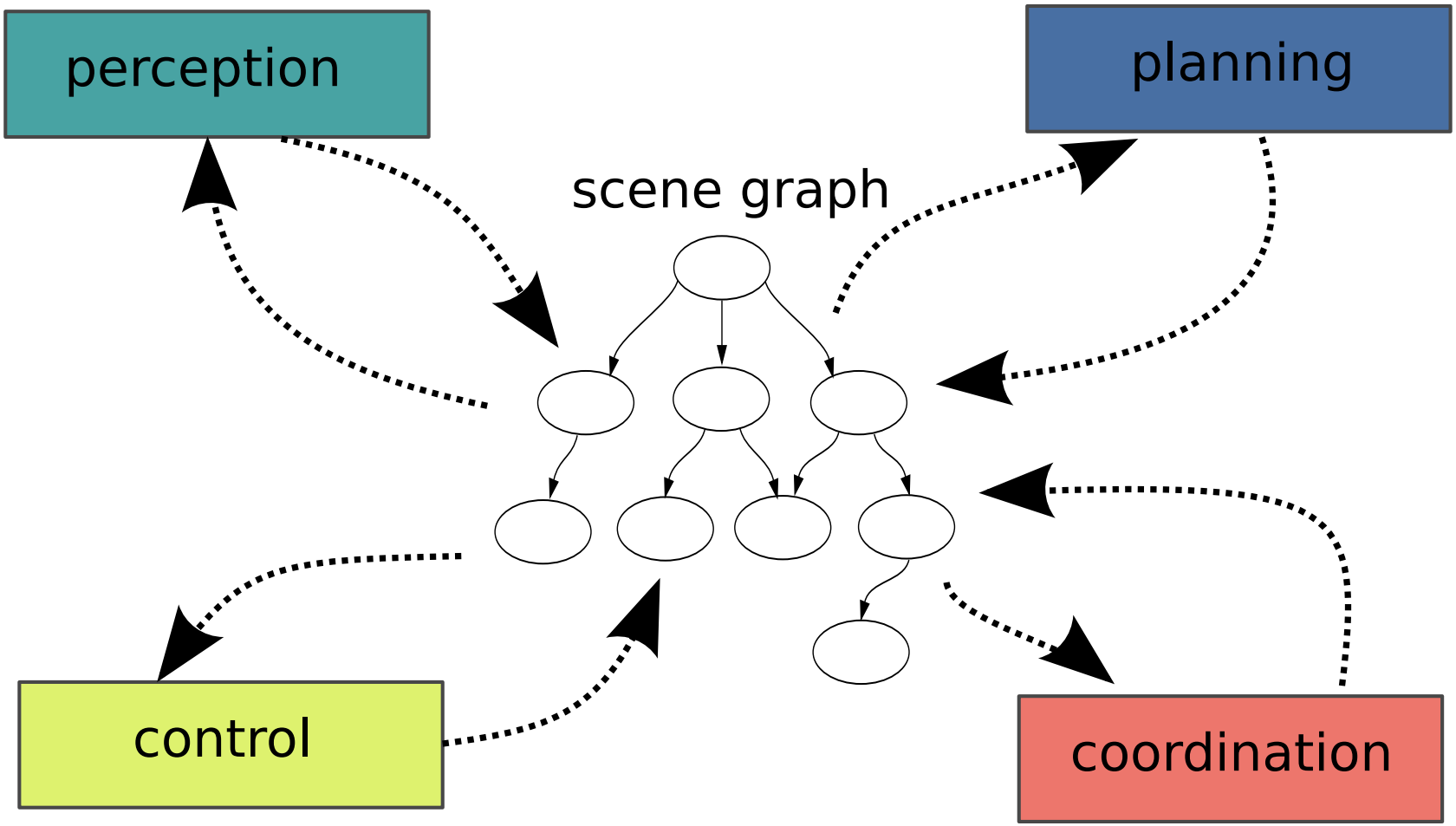
- **World Model**: as shared (distributed) resource with dynamic scene, multi-resolution and uncertainty support
- **Problem**: Does not exist yet!
  - Concept
  - DSL

Contributions

- M3: Ecore framework
- **M2: Xtext based DSL for a world model**
- M1: Editor via Eclipse toolchain
- M0: *Prior work:* C++ implementation (BRICS_3D library), **code generation from M2 level**

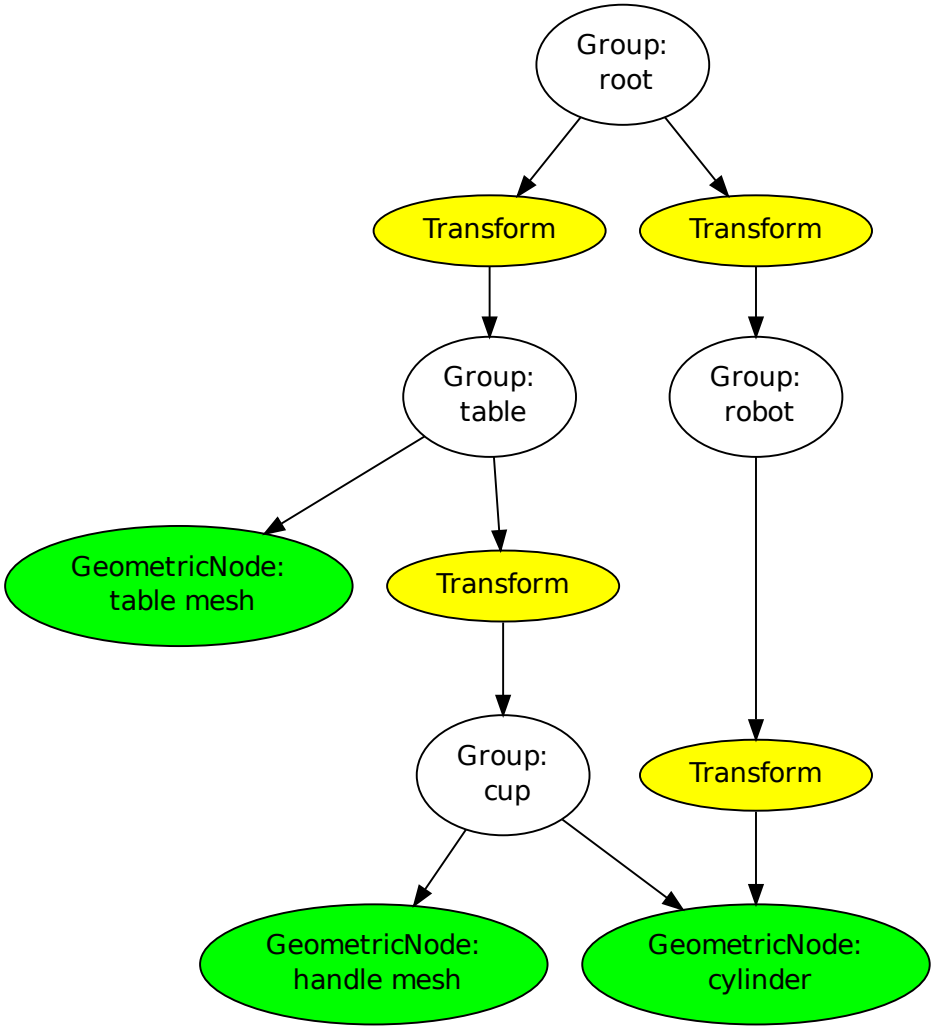
The Robot Scene Graph: RSG

RSG: Robot Scene Graph



RSG: Robot Scene Graph

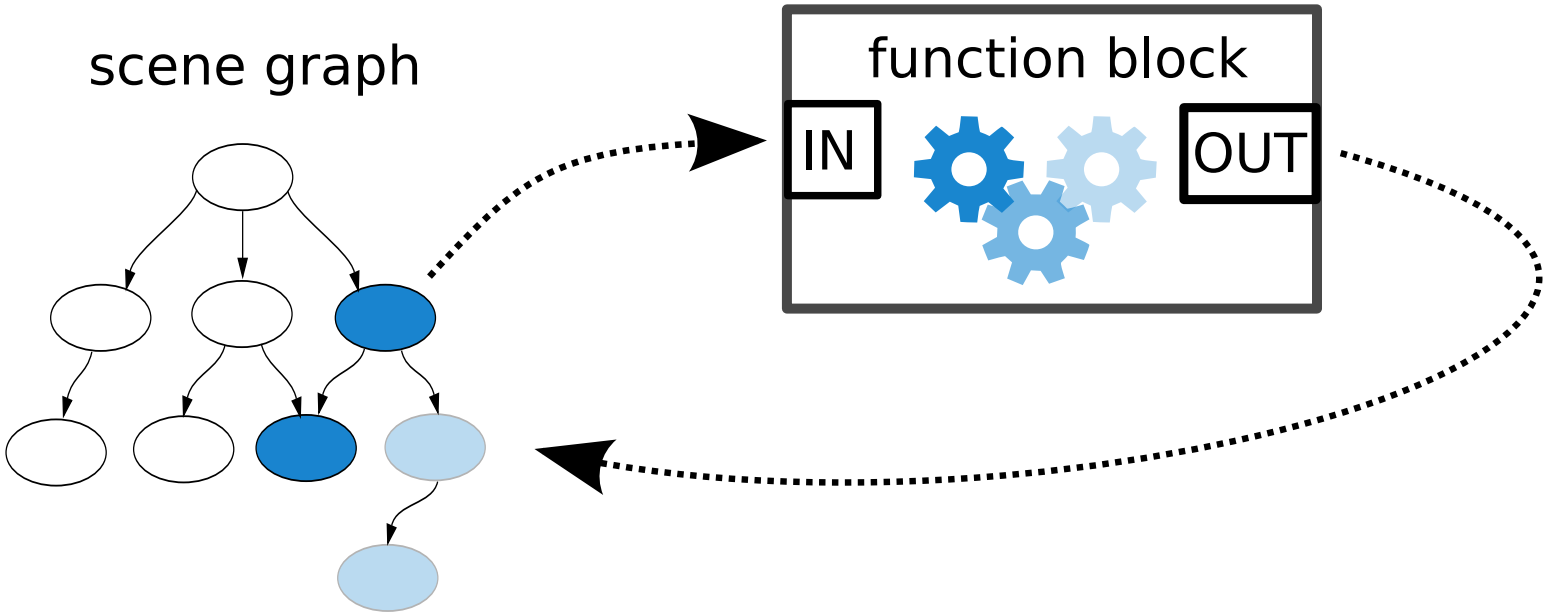
- RSG contains:
  - **Objects**
    - Low level like a point cloud
    - High level *scene objects*
  - **Relations**
  - Both organized in a *Directed Acyclic Graph (DAG)*
- Example graph
  - Scene with table
  - Cup on table
  - Robot observes cup



RSG: Nodes

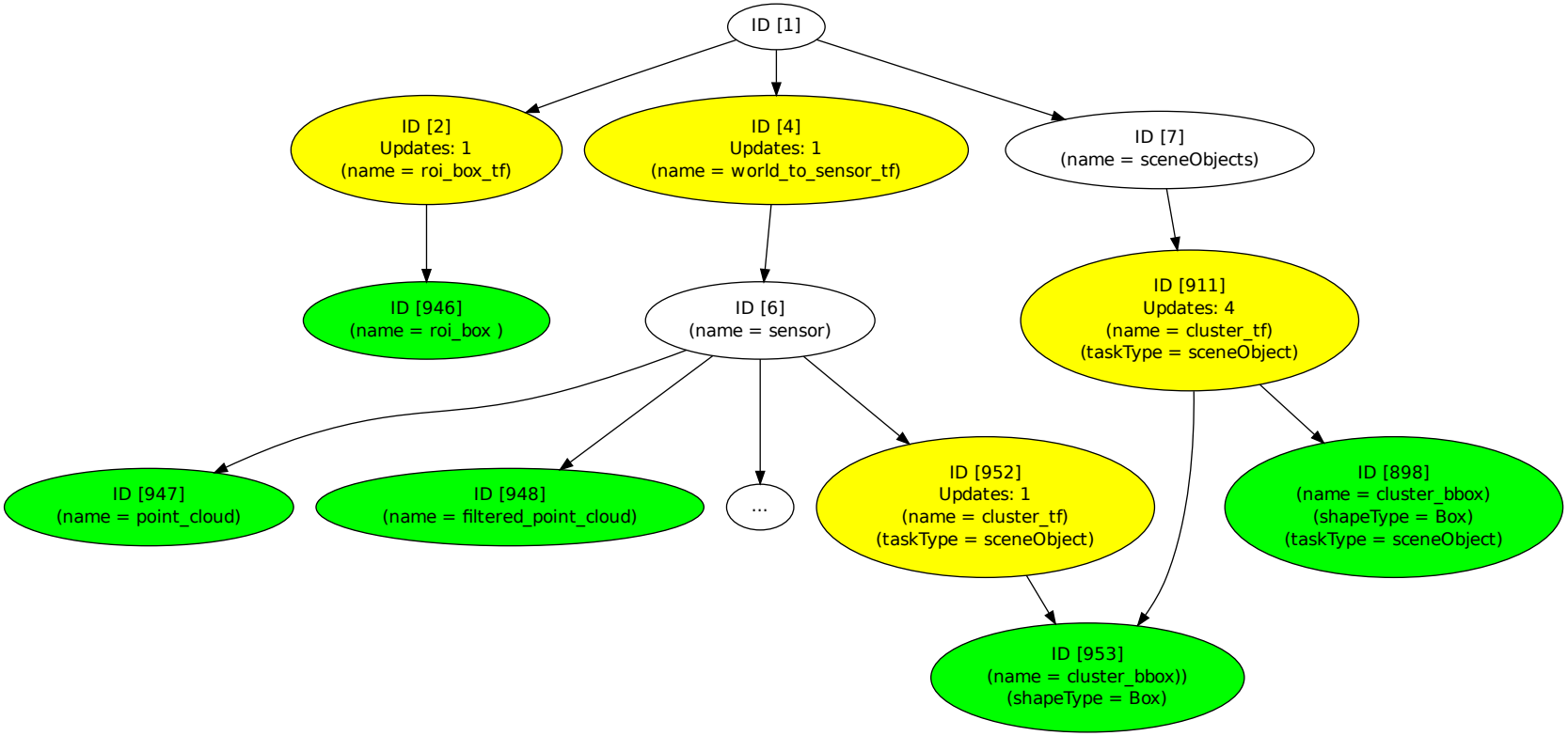
- Nodes
  - Unique IDs
  - Attributes
- GeometricNodes
  - Point Cloud
  - Mesh
  - Box
  - Cylinder
- Groups
- Transforms
  - Cache with time stamps

RSG: Function blocks



- A function block is a generic computation hosted by the world model
- Consumes a part of the world model and might perform updates or add new data
- Inputs and outputs are based on (unique) IDs

RSG: Example

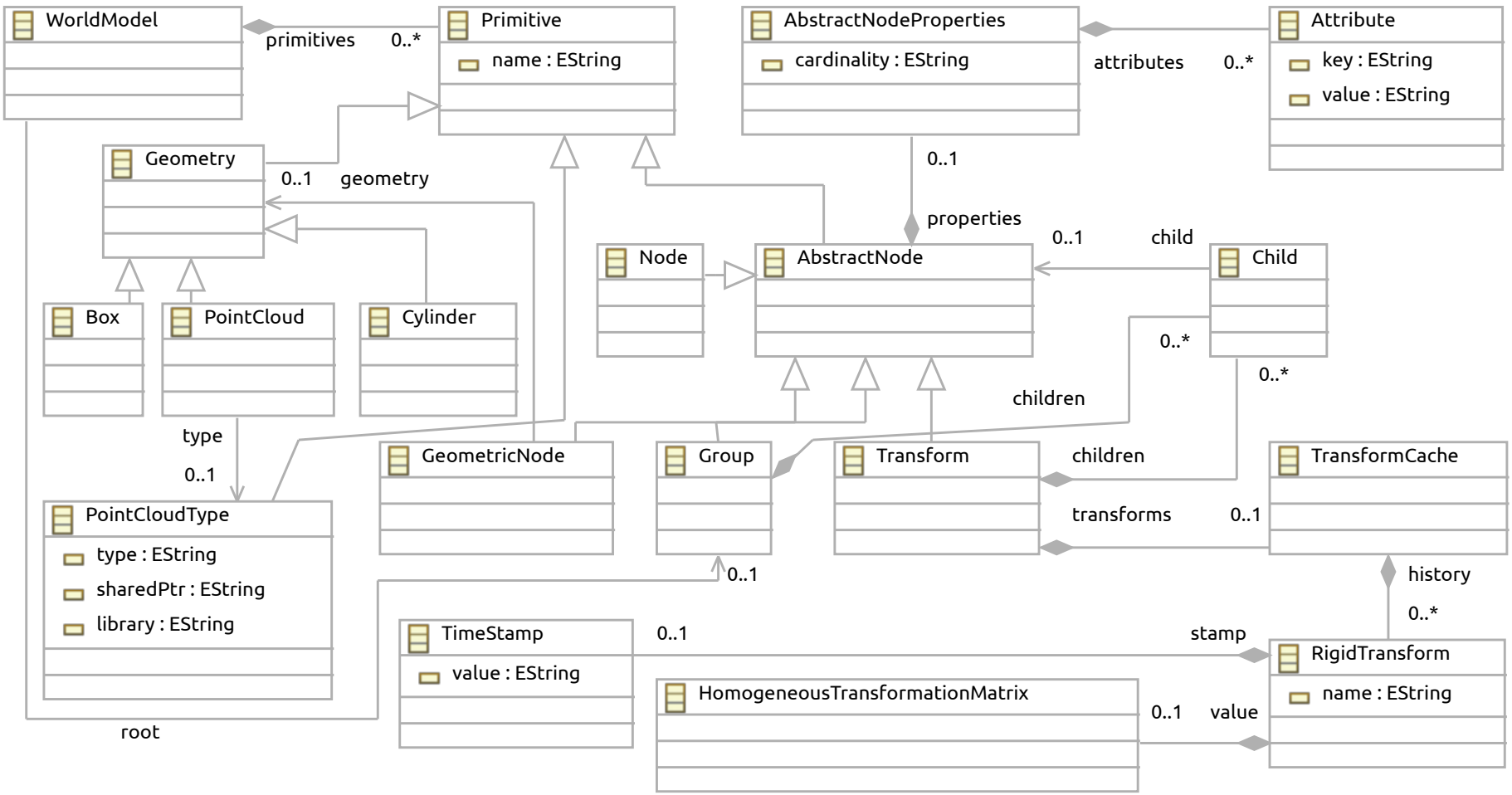

ID [1]
ID [2]
Updates: 1
(name = roi_box_tf)
ID [4]
Updates: 1
(name = world_to_sensor_tf)
ID [7]
(name = sceneObjects)
ID [946]
(name = roi_box)
ID [6]
(name = sensor)
ID [911]
Updates: 4
(name = cluster_tf)
(taskType = sceneObject)
ID [947]
(name = point_cloud)
ID [948]
(name = filtered_point_cloud)
...
ID [952]
Updates: 1
(name = cluster_tf)
(taskType = sceneObject)
ID [898]
(name = cluster_bbox)
(shapeType = Box)
(taskType = sceneObject)
ID [953]
(name = cluster_bbox))
(shapeType = Box)

The RSG-DSL

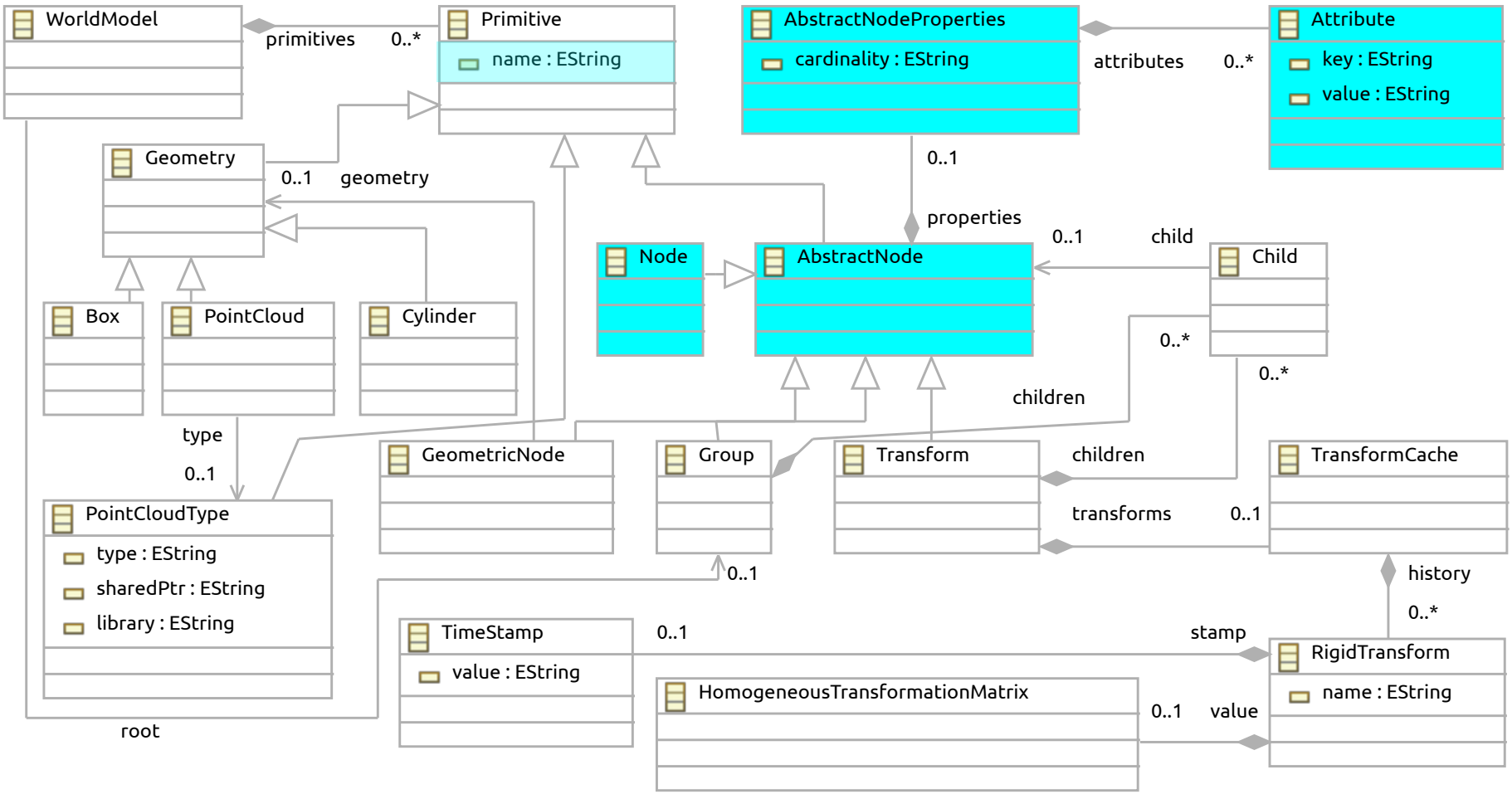
RSG-DSL Overview

- **Primitives**: Node types, function blocks
- **Relationships**: DAG structure
- **Transformations**: Model-to-text (C++)

DSL Primitives for RSG node types



DSL Primitives for RSG node types



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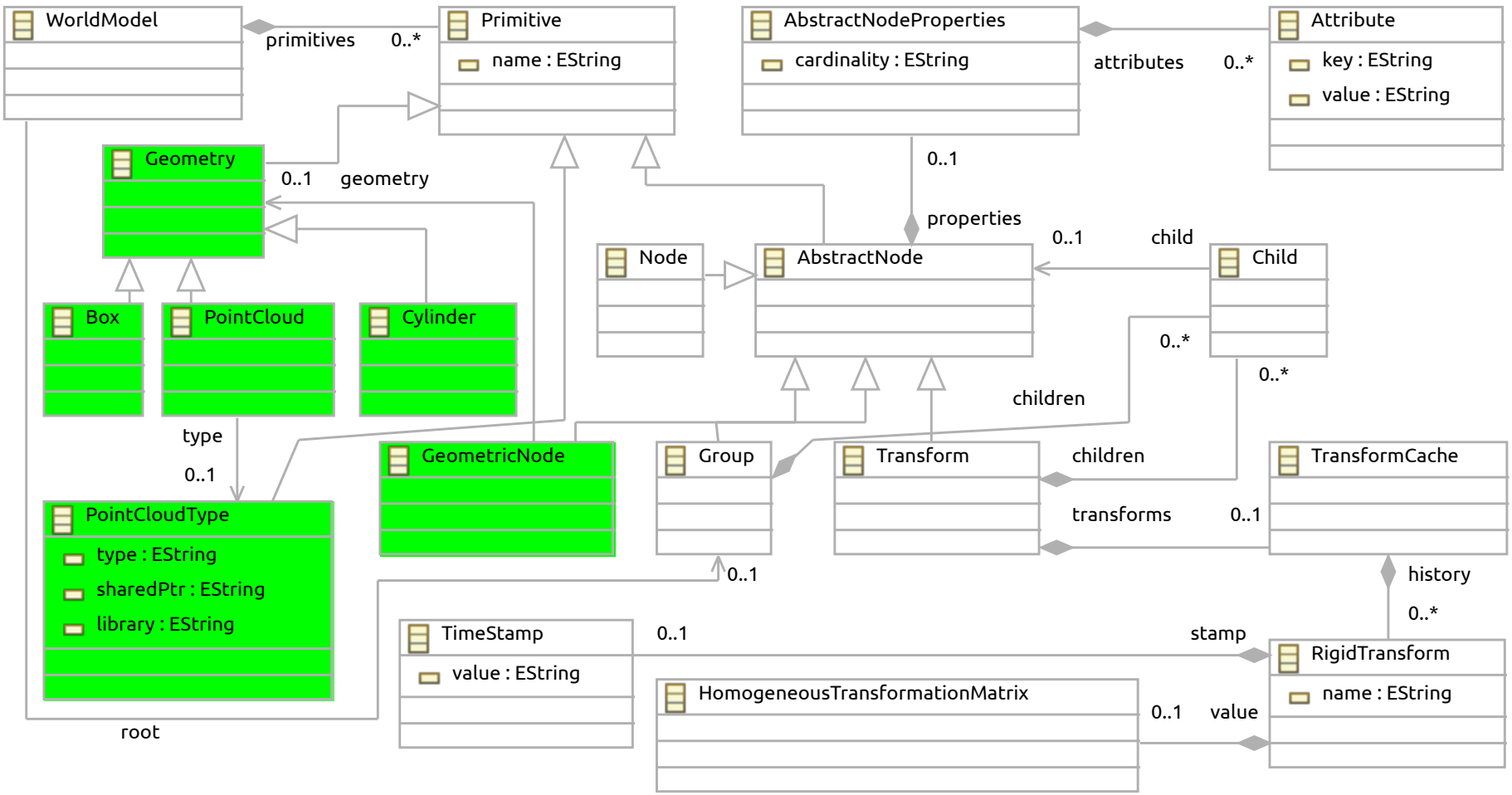

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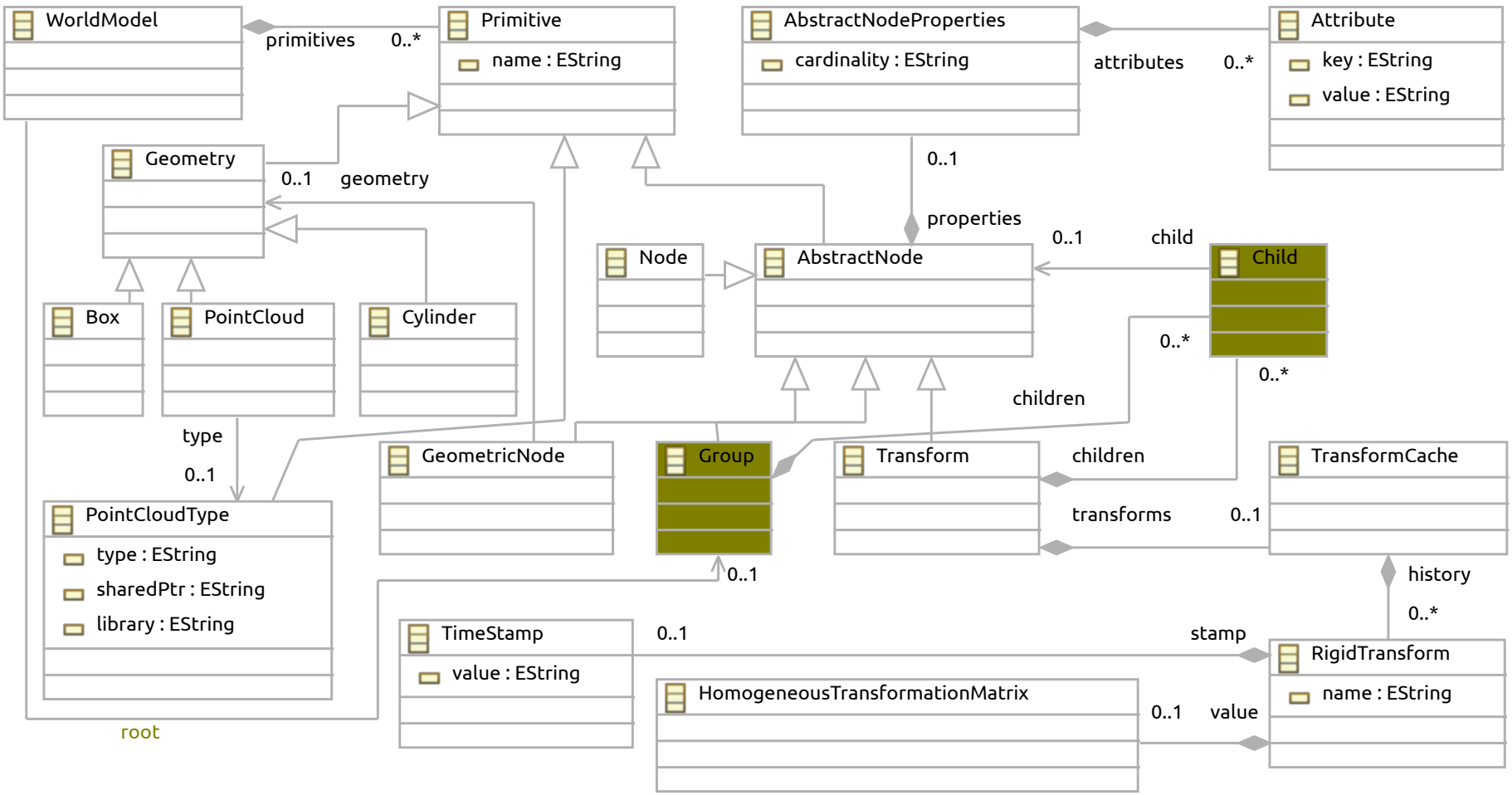
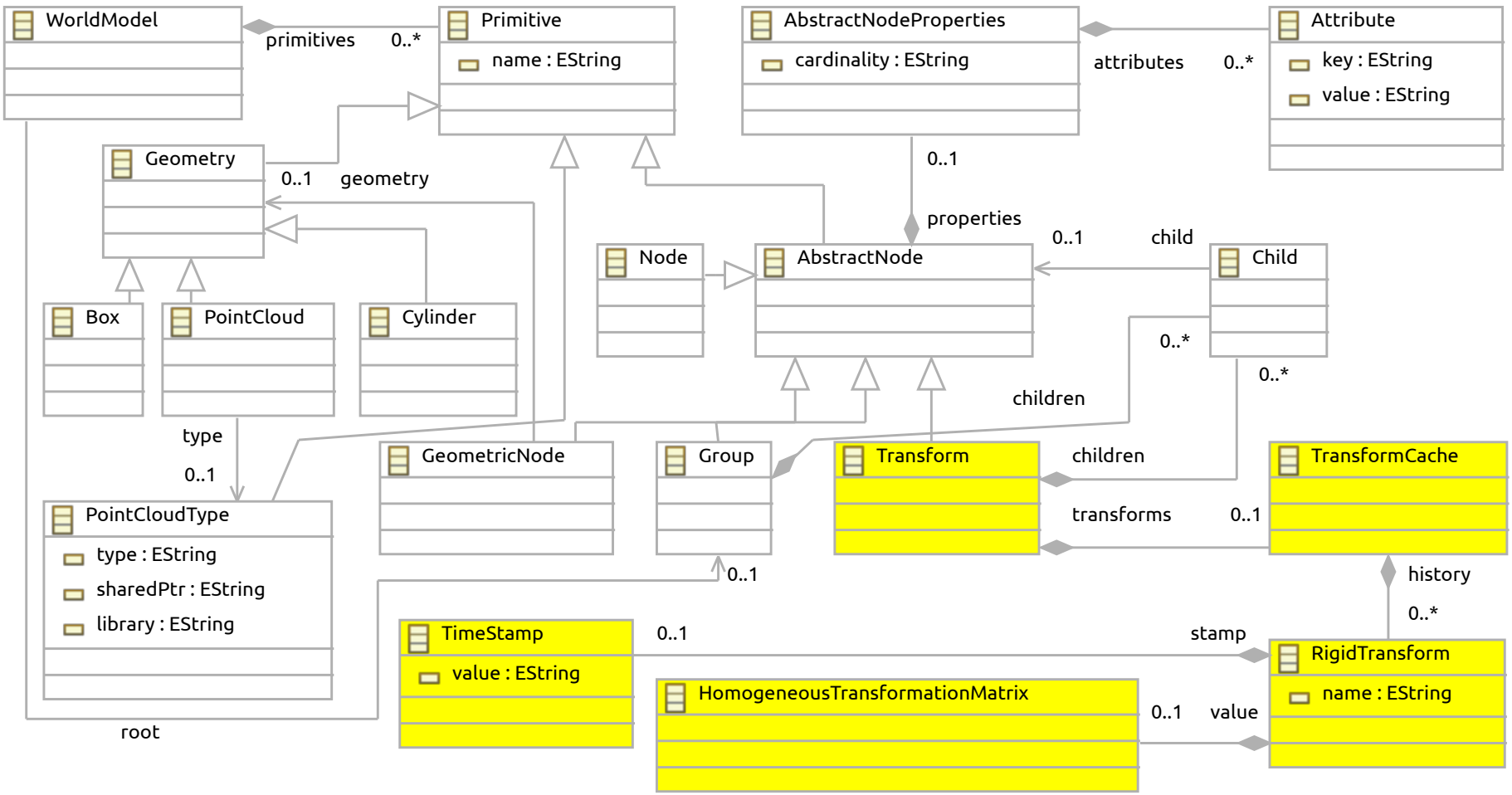


DSL Primitives for RSG node types



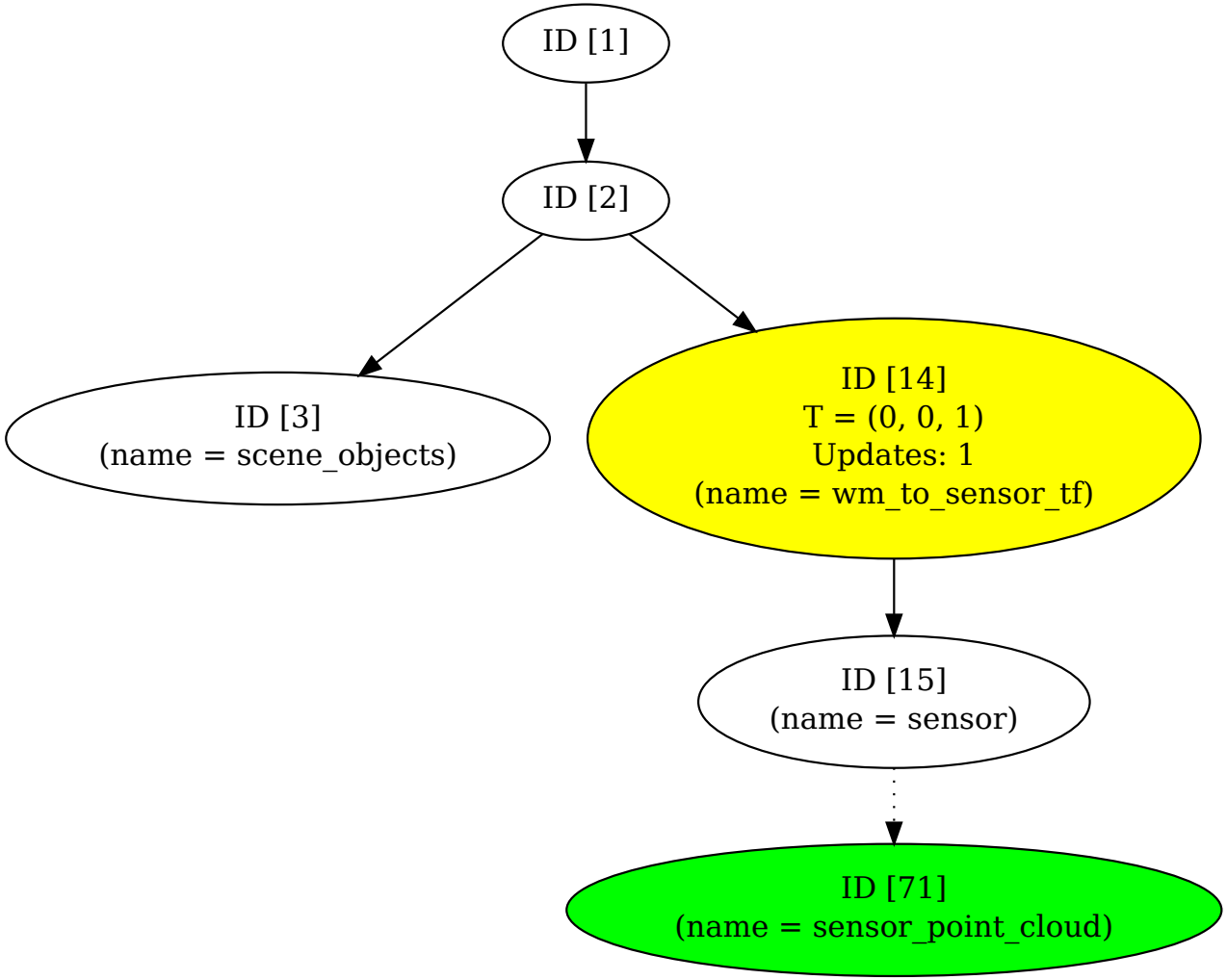
Example scene setup

```
root rootNode // application scene

Group rootNode {
  child group1
  child worldToCamera
}

Group group1 {
  Attribute ("name", "scene_objects")
  child kitchenTable
}

Transform worldToCamera {
  Attribute ("name", "wm_to_sensor_tf")
  child sensor
  transforms {
    RigidTransform t1 {
      stamp TimeStamp ( 0.0 s)
      value HomogeneousTransformationMatrix (
      [1.0, 0.0, 0.0, 0.0 m ],
      [0.0, 1.0, 0.0, 0.0 m ],
      [0.0, 0.0, 1.0, 1.0 m ],
      [0.0, 0.0, 0.0, 0.0   ])
    }
  }
}
Group sensor {
  Attribute ("name", "sensor")
}
```

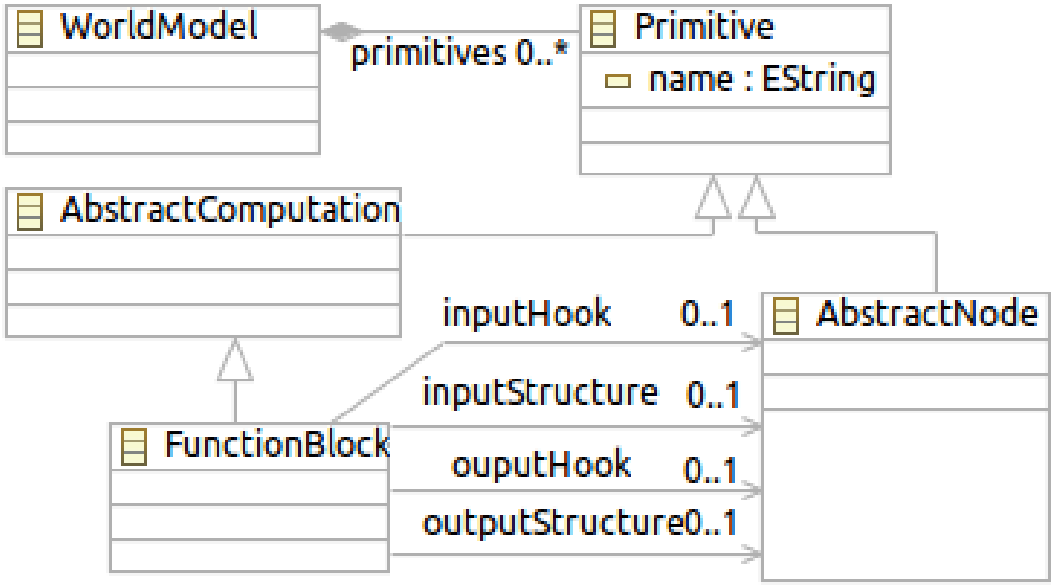

Generated code (excerpt)

```
1  std::vector<rsg::Attribute> attributes; // Instantiation of list of attributes.
2  unsigned int rootNodeId;        // IDs correspond to names in model on M1 level.
3  unsigned int group1Id;
4  unsigned int worldToCameraId;
5  // [...]
6
7  /* Add group1 as a new node to the scene graph */
8  attributes.clear();
9  attributes.push_back(Attribute ("name", "scene_objects"));
10 wm->scene.addGroup(rootNodeId, group1Id, attributes); // group1Id = output
11 // [...]                                              // -> returns a unique ID.
12
13 /* Add worldToCamera as a new node to the scene graph */
14 attributes.clear();
15 attributes.push_back(Attribute ("name", "wm_to_sensor_tf"));
16 brics_3d::IHomogeneousMatrix44::IHomogeneousMatrix44Ptr worldToCameraInitialTf(
17   new brics_3d::HomogeneousMatrix44(
18     1.0, 0.0, 0.0,
19     0.0, 1.0, 0.0,
20     0.0, 0.0, 1.0,
21     0.0 * 1.0, 0.0 * 1.0, 1.0 * 1.0  // Values are scaled to SI unit [m].
22 ));
23
24 wm->scene.addTransformNode(rootNodeId, worldToCameraId, attributes,
25   worldToCameraInitialTf, brics_3d::rsg::TimeStamp(0.0, Units::Second)
26 );       // Value is scaled to SI unit [s].
```


Resulting scene graph



DSL Primitives for RSG function blocks



Example function block

```
PointCloudType PointCloudPCL {
  type "pcl::PointCloud<PointType>"
  sharedPtr "pcl::PointCloud<PointType>::Ptr"
  library "pcl"
}

PointCloud inputCloud type PointCloudPCL
PointCloud planeCloud type PointCloudPCL

GeometricNode pointCloud {
  Attribute ("name", "point_cloud")
  geometry inputCloud
}

Group planes {
  Attribute ("name", "planes")
  child tfToPlaneCentroid
}
```

```
GeometricNode horizontalPlane {
  Attribute ("name", "plane")
  geometry planeCloud
}

FunctionBlock horizontalPlaneSegmentation {
  inputStructure pointCloud
  inputHook sensorPointCloud
  outputStructure planes
  outputHook sensor
}
```


Generated code (excerpt)

```
1  /* Interface stub for HorizontalPlaneSegmentation function block */
2  class HorizontalPlaneSegmentation : public rsg::IFunctionBlock {
3  public:
4
5    /* used input IDs */
6    unsigned int pointCloudId;
7
8    /* used output IDs */
9    unsigned int planesId;
10   unsigned int cloudCenterToPlaneCenterId;
11   unsigned int horizontalPlaneId;
12
13   HorizontalPlaneSegmentation(brics_3d::WorldModel* wmHandle) : IFunctionBlock
         (wmHandle) {};
14   virtual ~HorizontalPlaneSegmentation(){};
15
16   virtual void configure(brics_3d::ParameterSet parameters){}
17   virtual void execute(){}
18
19 protected:
20
21 /* data conventions */
22 const static unsigned int horizontalPlaneSegmentationInputHookId  = 0;
23 const static unsigned int horizontalPlaneSegmentationOutputHookId  = 1;
```


Generated code (excerpt)

```
1   pcl::PointCloud<PointType>::Ptr getInputCloudPointCloud() {
2     pcl::PointCloud<PointType>::Ptr inputCloudData (new pcl::PointCloud<
          PointType>());
3
4     /* Query the world model based on the input id pointCloudId  */
5     brics_3d::rsg::TimeStamp resultTimeStamp;
6     brics_3d::rsg::Shape::ShapePtr shape;
7     wm->scene.getGeometry(pointCloudId, shape, resultTimeStamp);
8
9     /* Resolve (raw) data type known by model */
10    brics_3d::rsg::PointCloud<pcl::PointCloud<PointType> >::PointCloudPtr
          inputCloudContainer(new brics_3d::rsg::PointCloud<pcl::PointCloud<
          PointType> >());
11    inputCloudContainer = boost::dynamic_pointer_cast<brics_3d::rsg::PointCloud<
          pcl::PointCloud<PointType> > >(shape);
12    inputCloudData = inputCloudContainer->data;
13
14    return inputCloudData;
15  }
16
17 };
```


Conclusion

- Robot applications require models for different aspects $\Rightarrow$ the **world model** is one of them
- *Different* existing world models for various domains $\Rightarrow$ RSG is shared world model
- RSG-DSL
  - Primitives: Nodes, function blocks
  - Relations: DAG structure
  - Transforms: Model-to-text (C++)
- Expresses
  - Prior knowledge: *scene setups*, known objects
  - Interfaces for function blocks
- Future works
  - Uncertainty, multi resolution support, triggers
  - Composition with other DSLs