Munich, 2017-10-16

OntoBREP: An Ontology for CAD Data and Geometric Constraints

A Link Between Product Models and Semantic Robot Task Descriptions

W3C LBD Community Group Meeting

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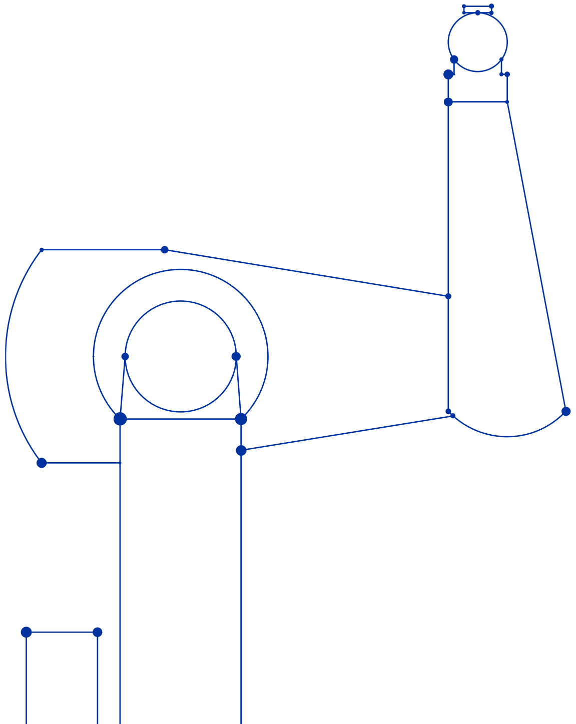

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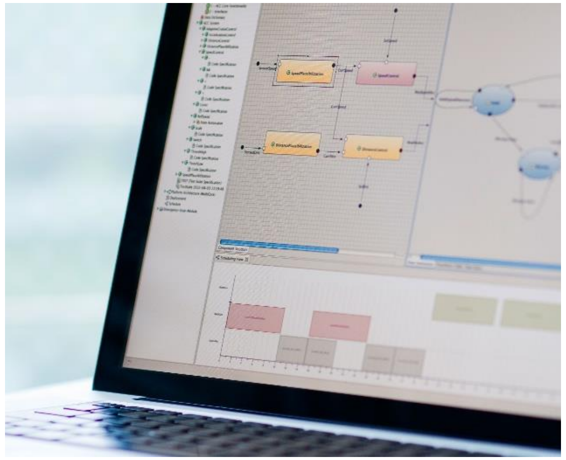
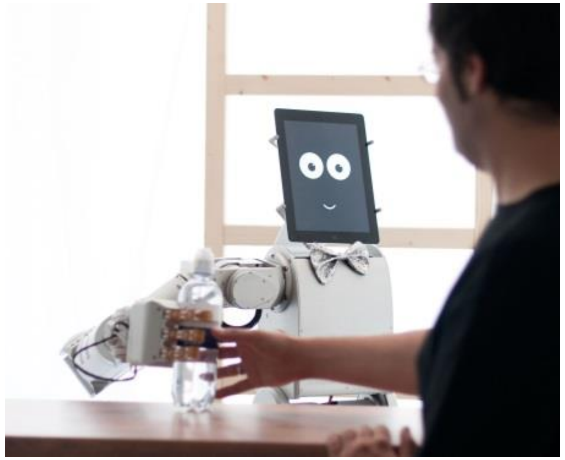
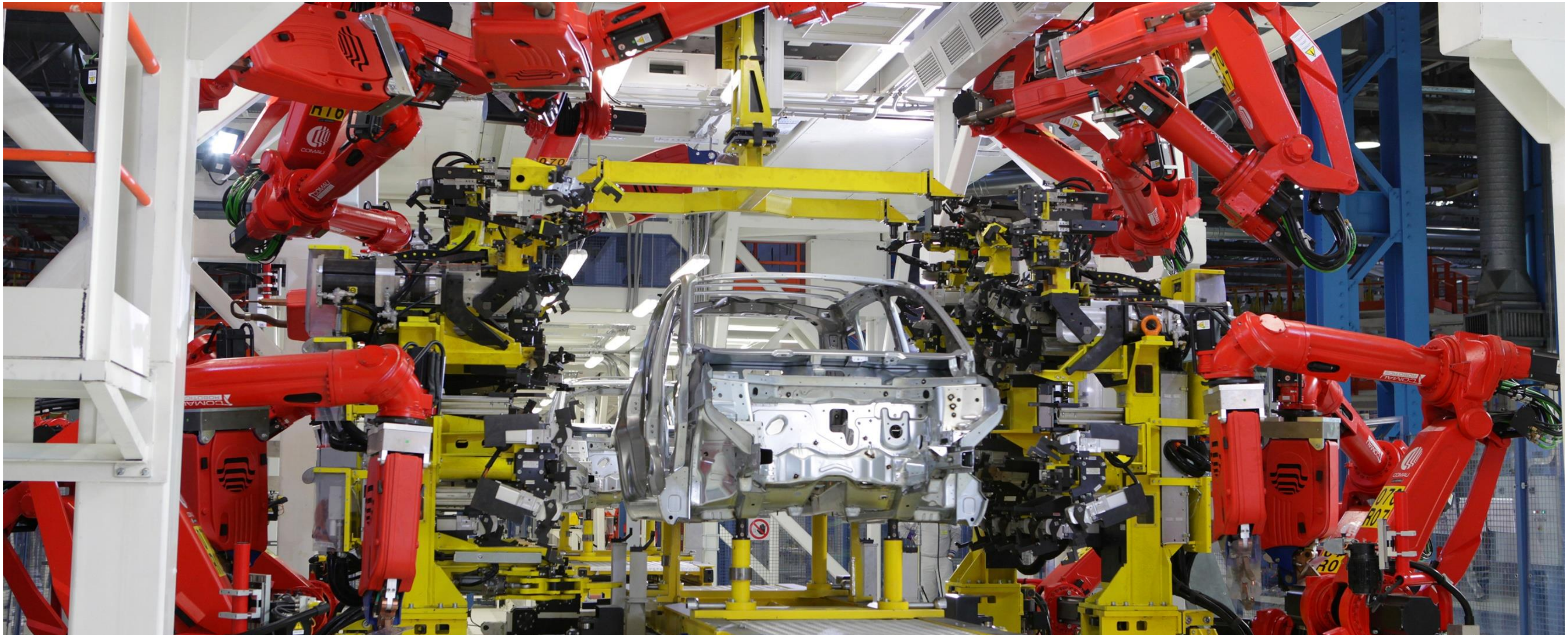




Motivation and Context

Industrial robots in mass production



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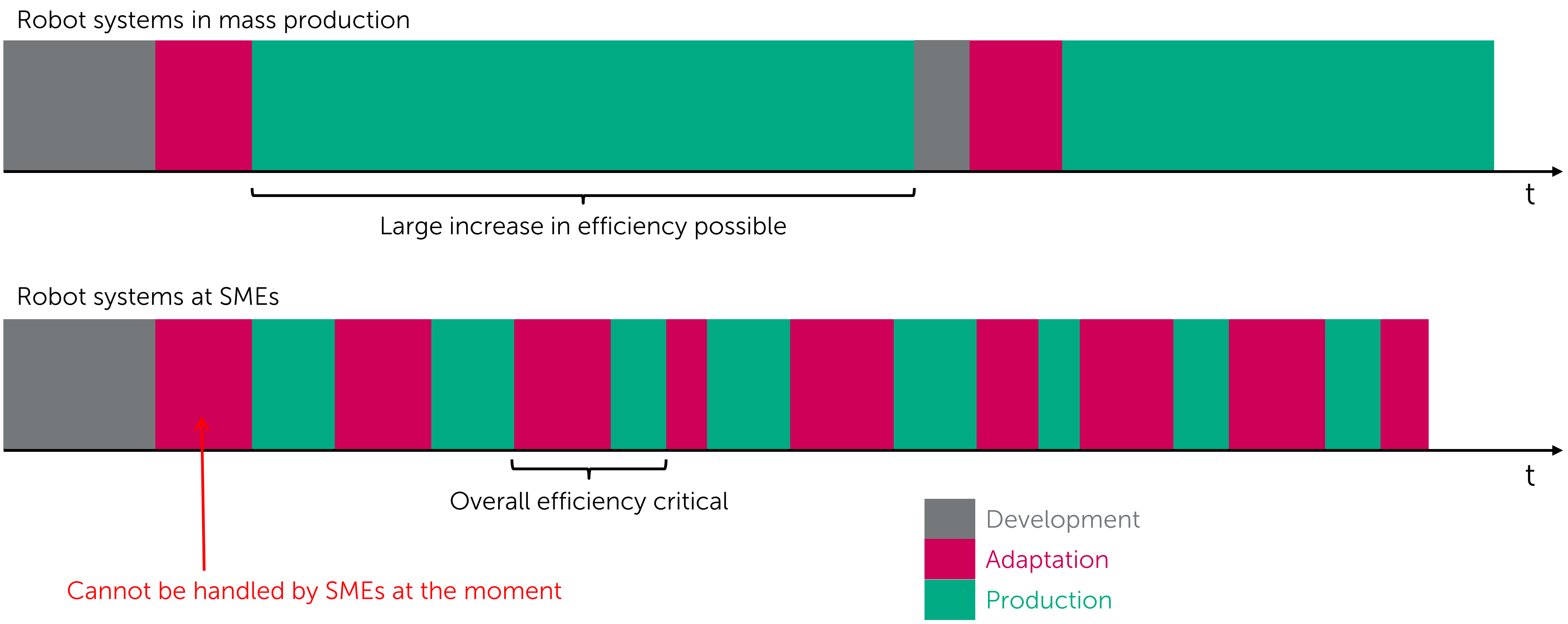
Challenges in automation for SMEs

No robot experts, short production cycles



Robot programming: State-of-the-art

High complexity for non-experts and no connection to process

```
FOR i = 1 TO 6 STEP 1
  DECL POS P1 = {X 900, Y 0, Z 800,
    A 0, B 0, C 0, S 6, T 19}
  PTP P1 CONT Vel= 100 % PDAT1
  LIN P2 CONT Vel= 2 m/s CPDAT1
  CIRC P3, P4, CA 260 C_ORI
ENDFOR
```

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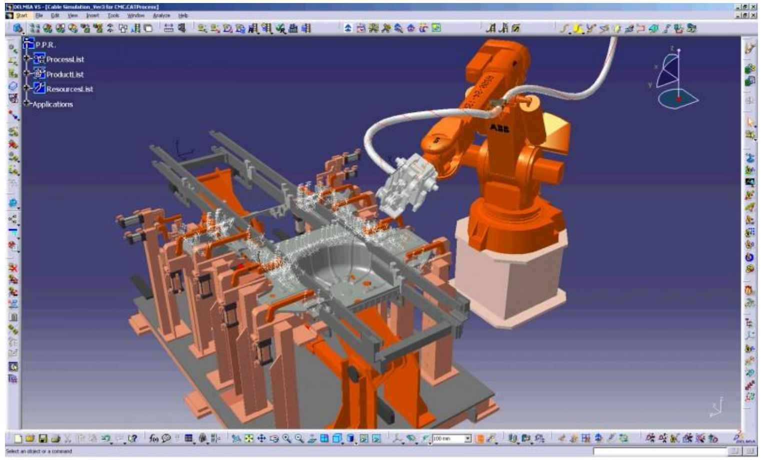

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```
FOR i := 1 TO 6 DO
  P1 := POS(294, 507, 1492, 13, 29, 16)
  MOVE ARM[1] TO P1
  MOVE ARM[1] LINEAR TO P2
  MOVE ARM[1] CIRCULAR TO P4 VIA P3
ENDFOR
```

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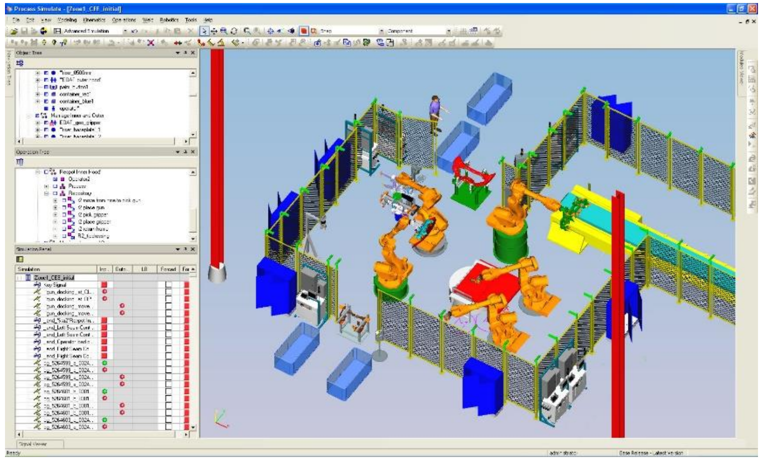

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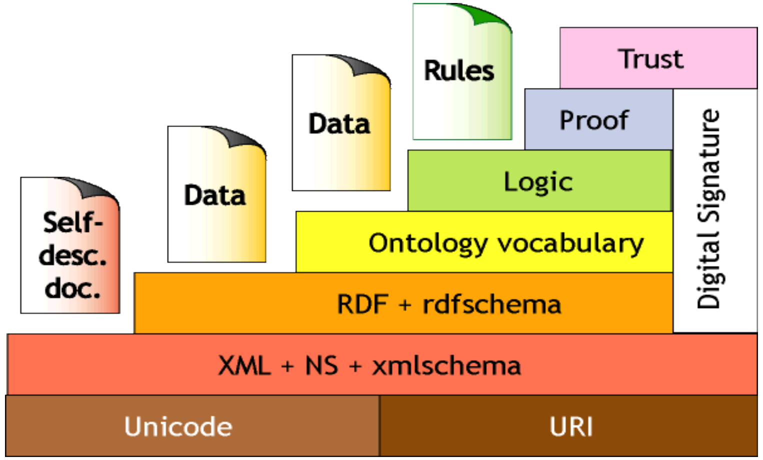
Representation and query of knowledge

Semantic web and ontologies



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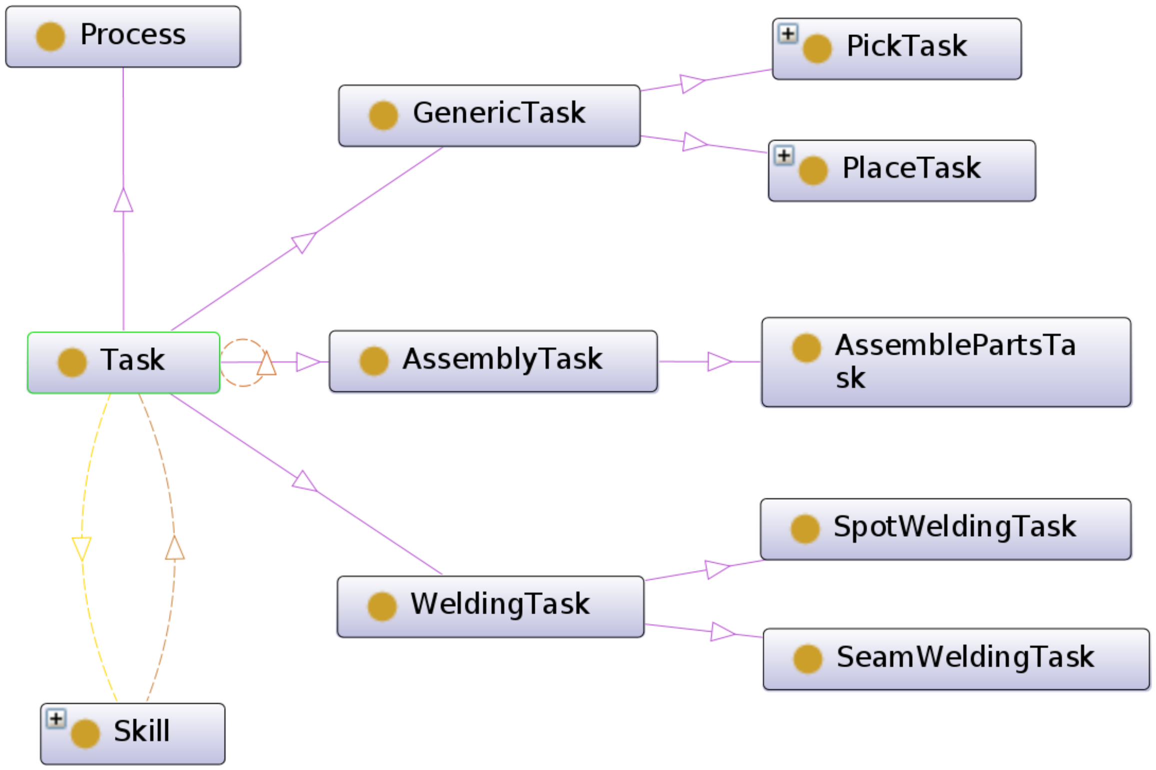
Humans with very efficient task descriptions for complex problems	Service robotics with goal specifications but no explicit step-by-step programming	Semantic web with structured modelling of knowledge
Underspecified commands through natural language	Understanding of capabilities of hardware and software components required	Access to basic knowledge such as colors, sizes, etc.
Understanding requires common and domain-specific knowledge	Logical reasoning and inference	Explicit process description instead of function calls

Semantic process description

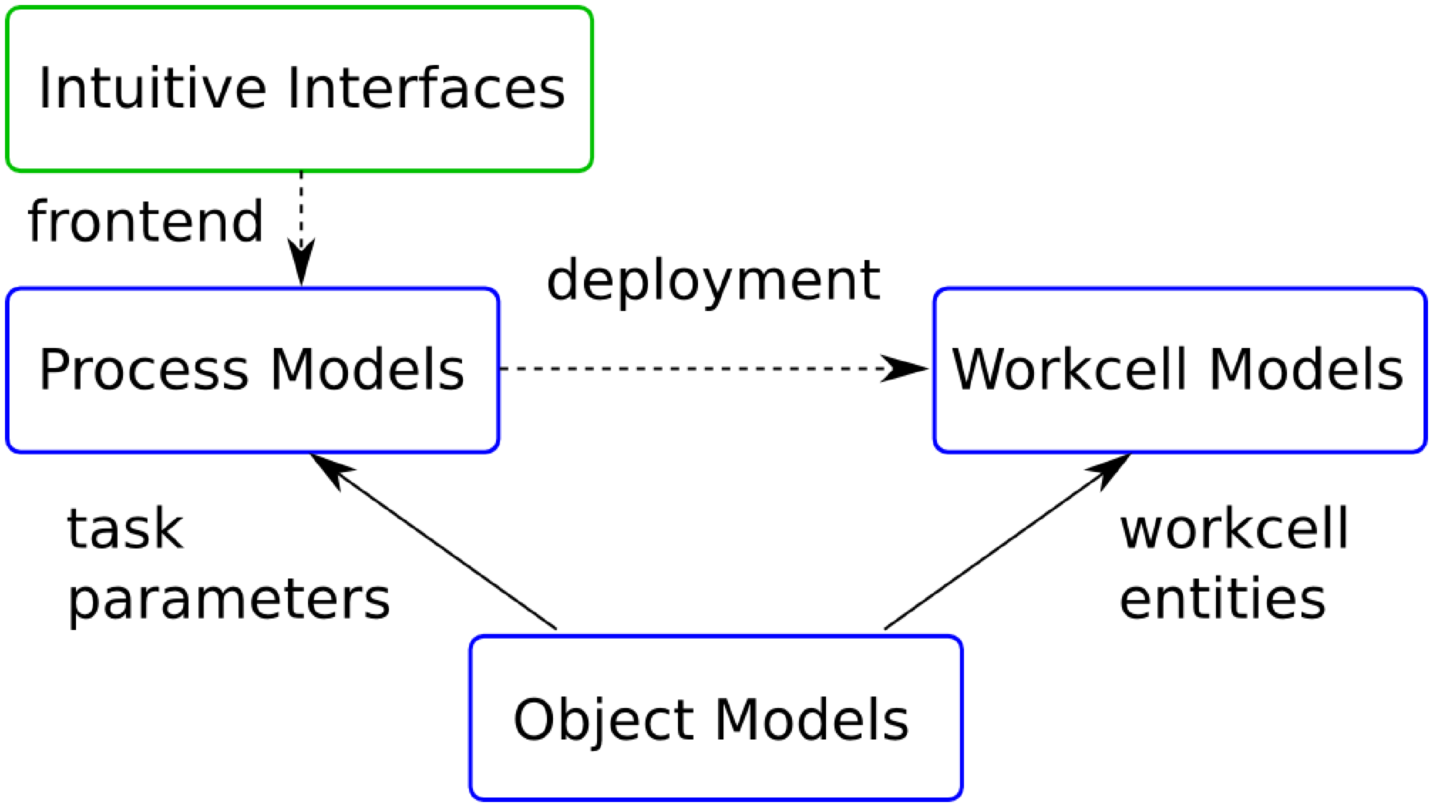
Processes, tasks, and robot skills

P1 := **POS**(1100, -200, 800, 180, 0, 90)
MOVE ARM[1] **TO** P1
$DOUT[602] := FALSE
$DOUT[601] := TRUE
WAIT FOR $DIN[602] = FALSE
WAIT FOR $DIN[601] = TRUE
P2 := **POS**(1100, -200, 650, 180, 0, 90)
MOVE ARM[1] **LINEAR TO** P2
$DOUT[601] := FALSE
$DOUT[602] := TRUE
WAIT FOR $DIN[601] = FALSE
WAIT FOR $DIN[602] = TRUE
MOVE ARM[1] **LINEAR TO** P1



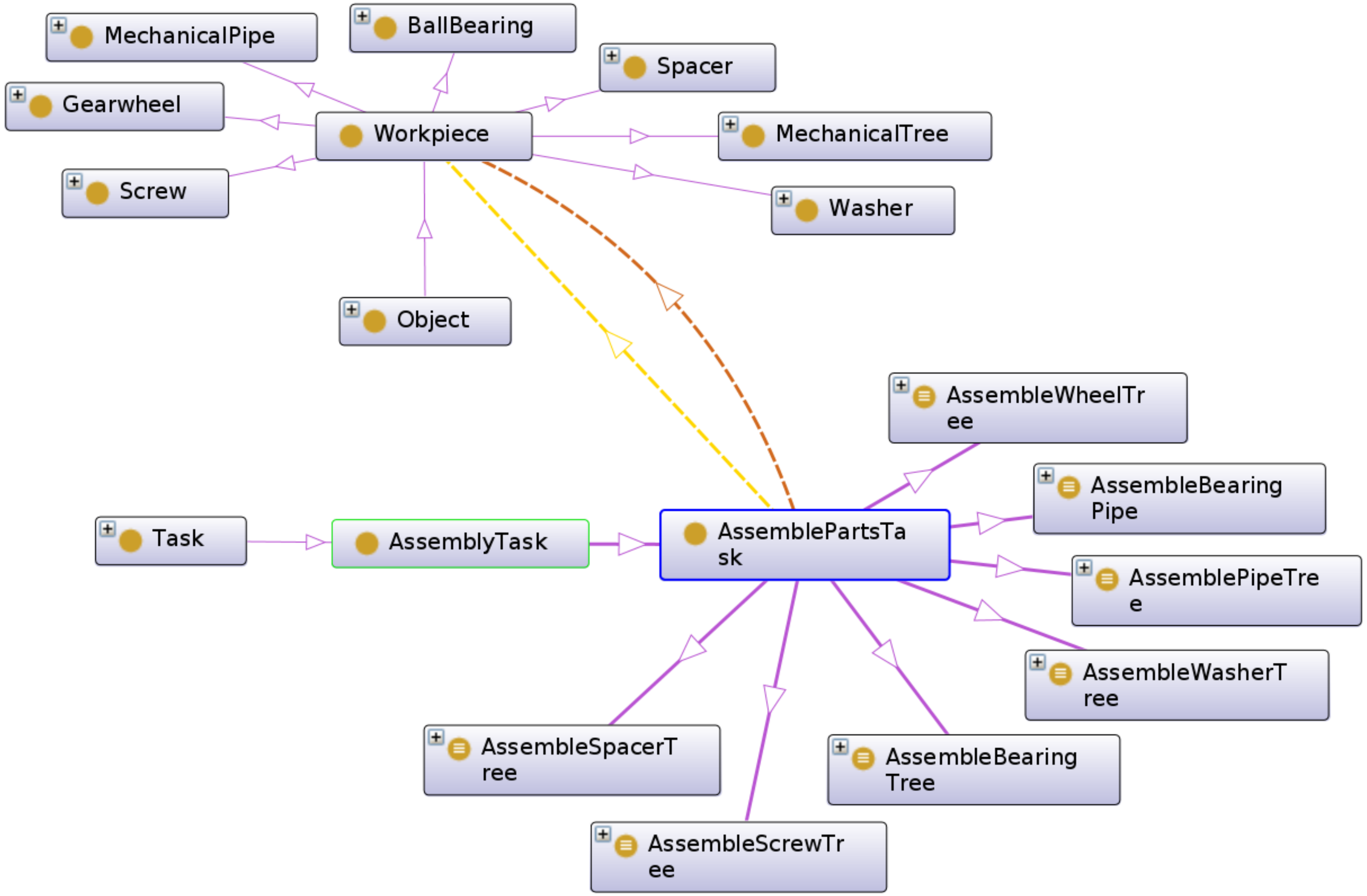
Semantic descriptions as backbone

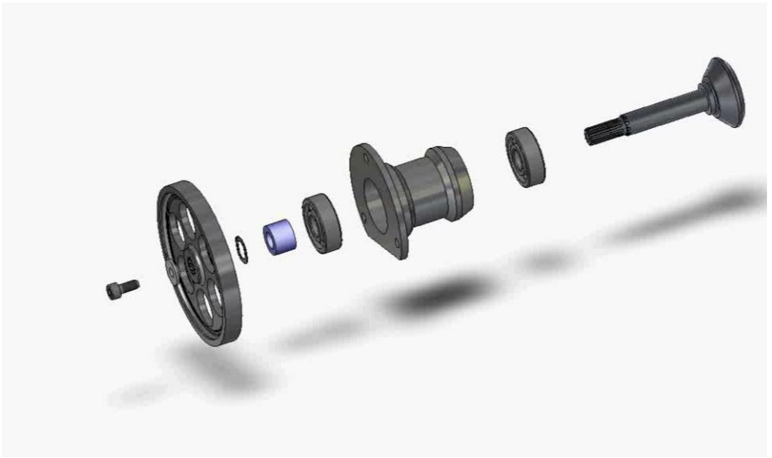
Intuitive interfaces at the front



Semantic description of processes

Connection of parts and assembly tasks





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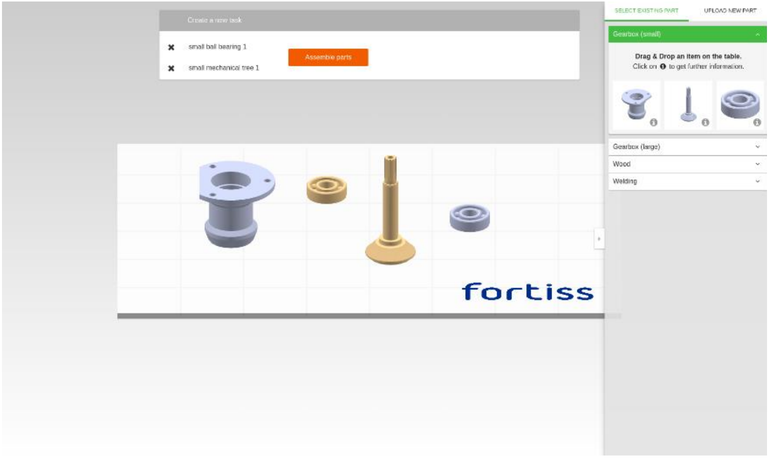


Semantic description of objects

Geometry, mass, material, …

Bounding box

Width/height/depth

Origin

X/Y/Z axis

Weight

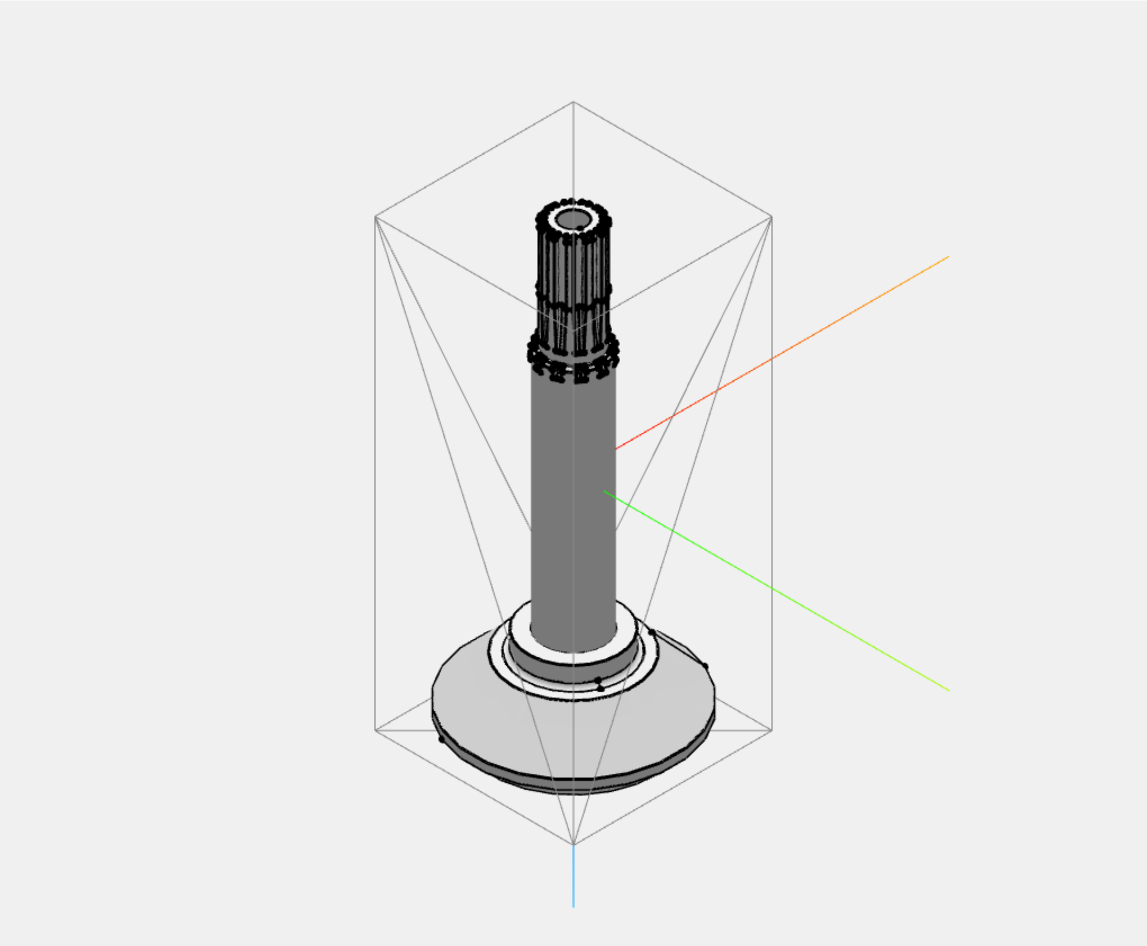
Material properties

Grasp poses

BREP (CAD)

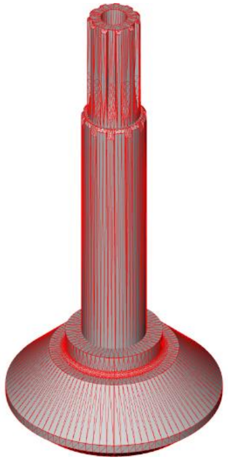
Polygon triangulation

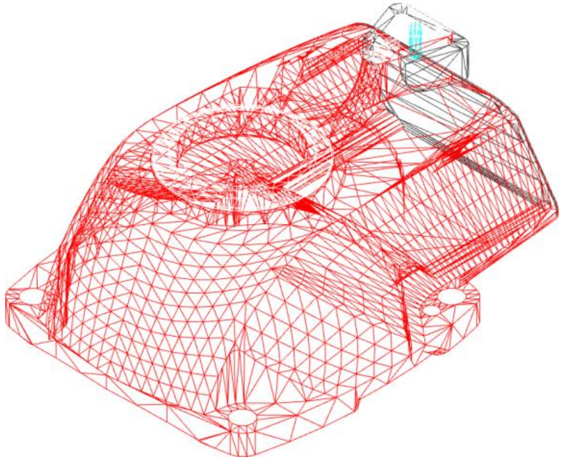
…

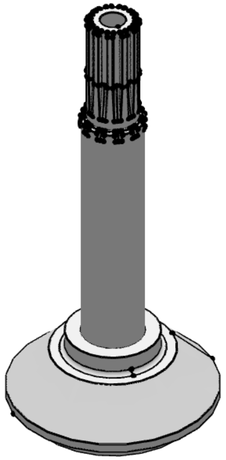


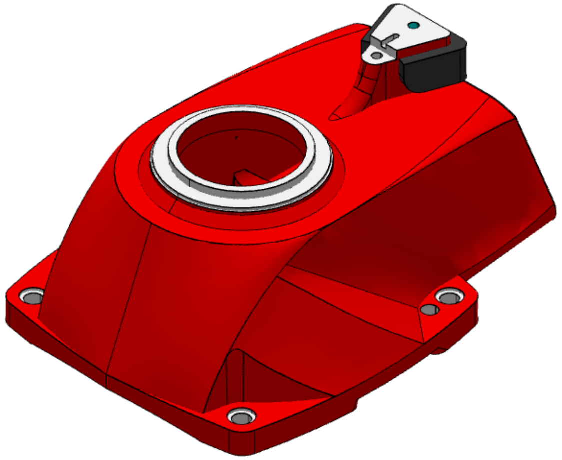
Geometry models of solid objects

Different approaches









Approximation

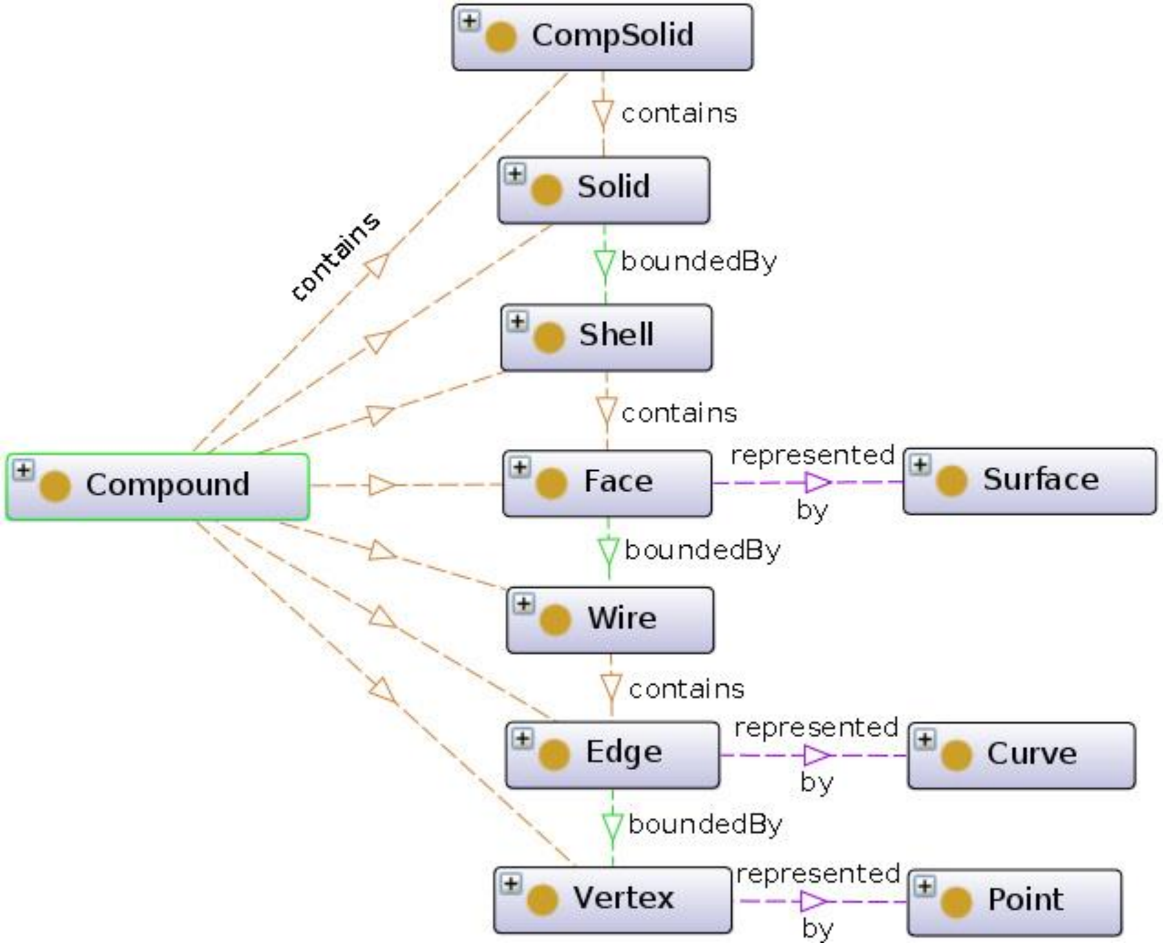
- Polygons (curves are represented by a chain of straight line segments, required for 3D rendering on graphics cards)
- Voxels (regular grid in 3D space)
- Fixed level of detail

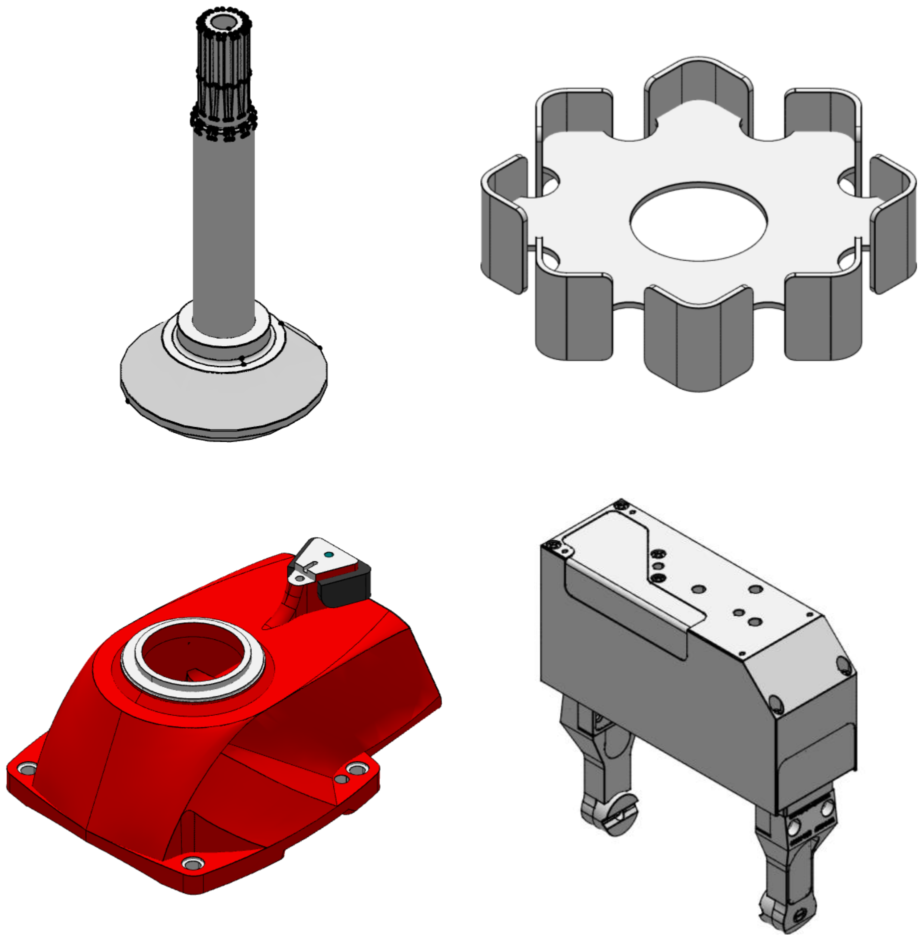
Exact representation

- Constructive solid geometry (CSG): Boolean composition of primitives
- Boundary representation (BREP) used by CAD model standards (STEP, IGES)
- Mathematical models are known
- Triangulated data generated on-the-fly for different applications

Boundary Representation (BREP)

Overview

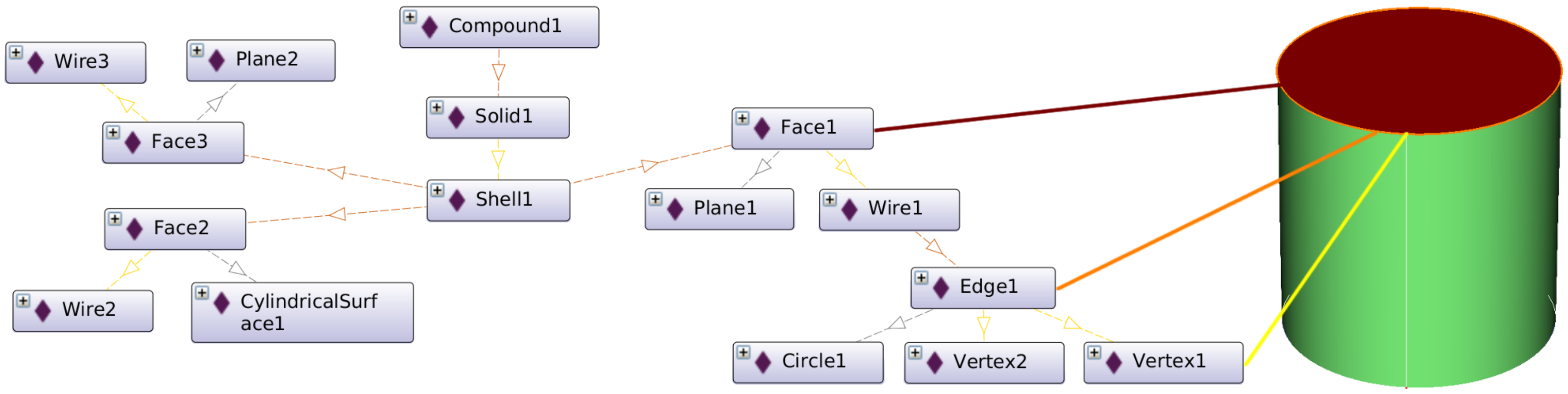




OntoBREP

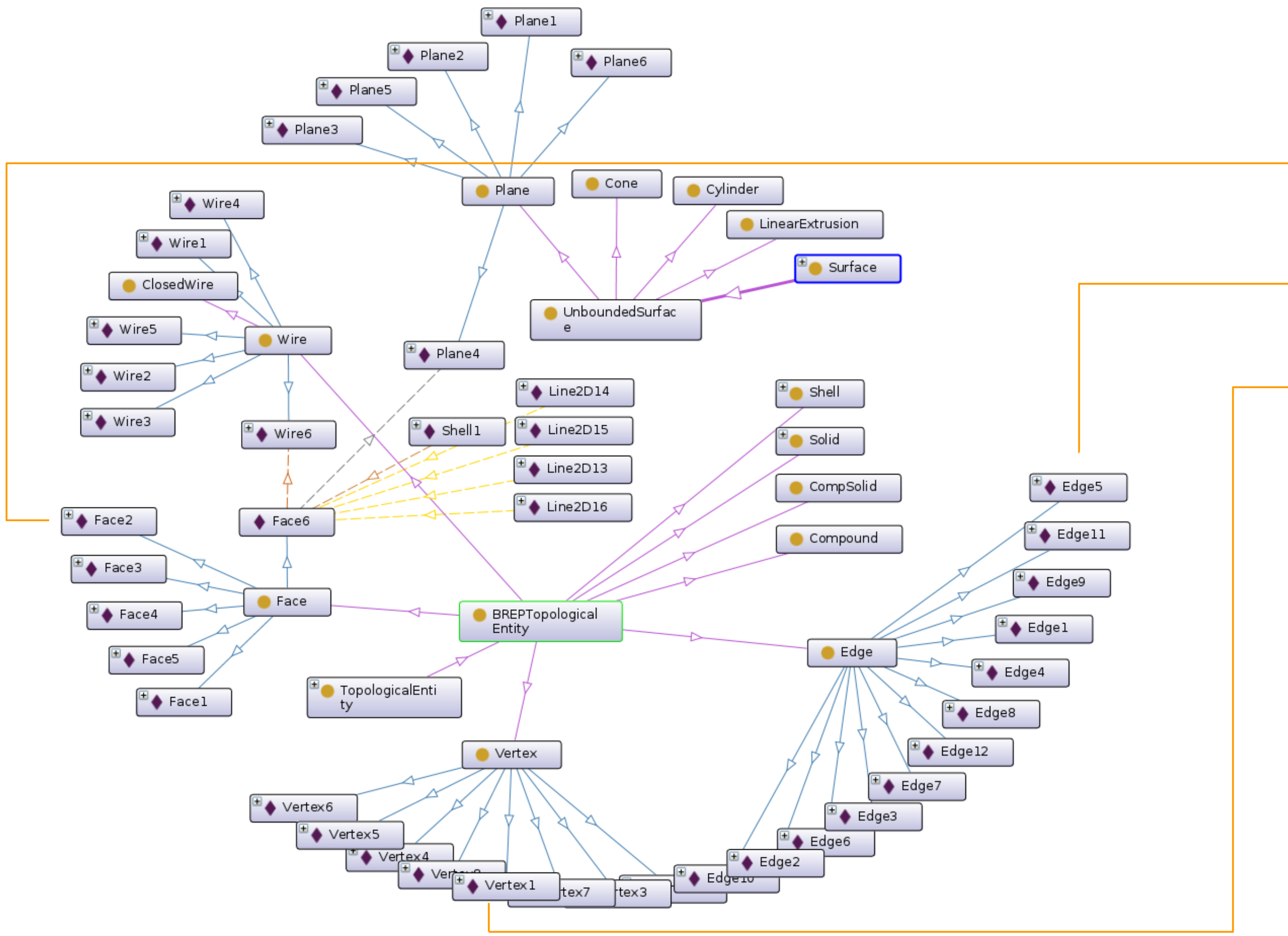
Semantic description language for CAD data

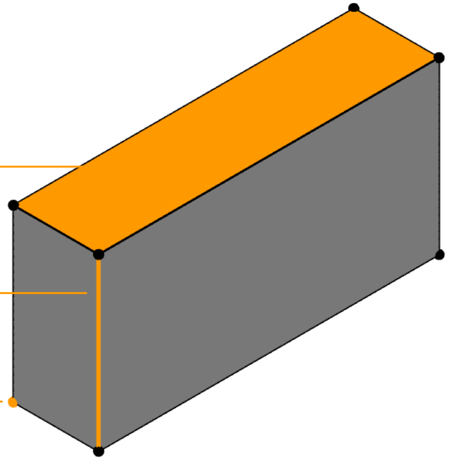
- Using the Web Ontology Language (OWL)
- Taxonomy of topological and geometric entities
- Properties, i.e., topological relations and geometric parameters



Complete example: Cuboid

Representation of geometry information



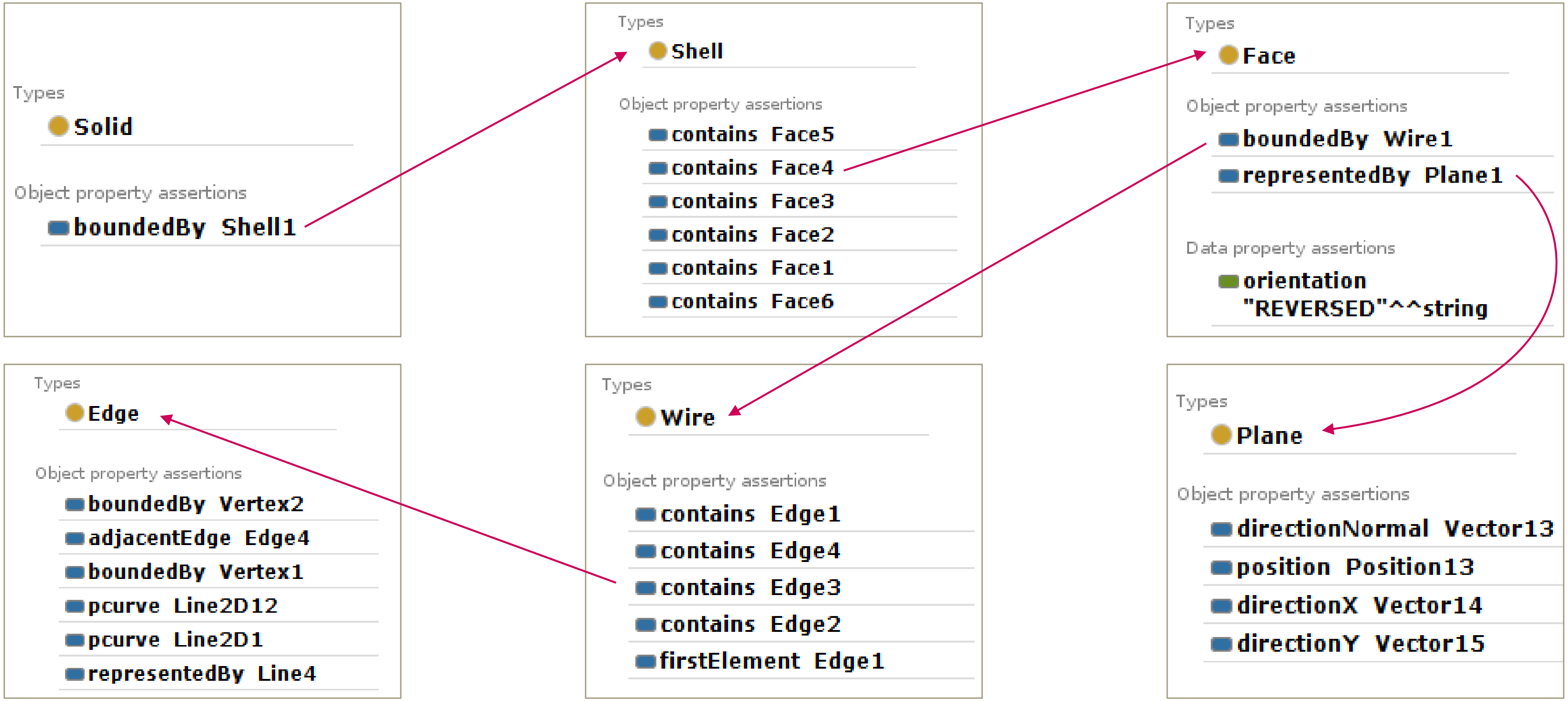


BREP representation of an object with surfaces, edges, points (with unique IDs)

Access to mathematical elements (e.g., axis, radius) of circles, cylinders etc. for linking

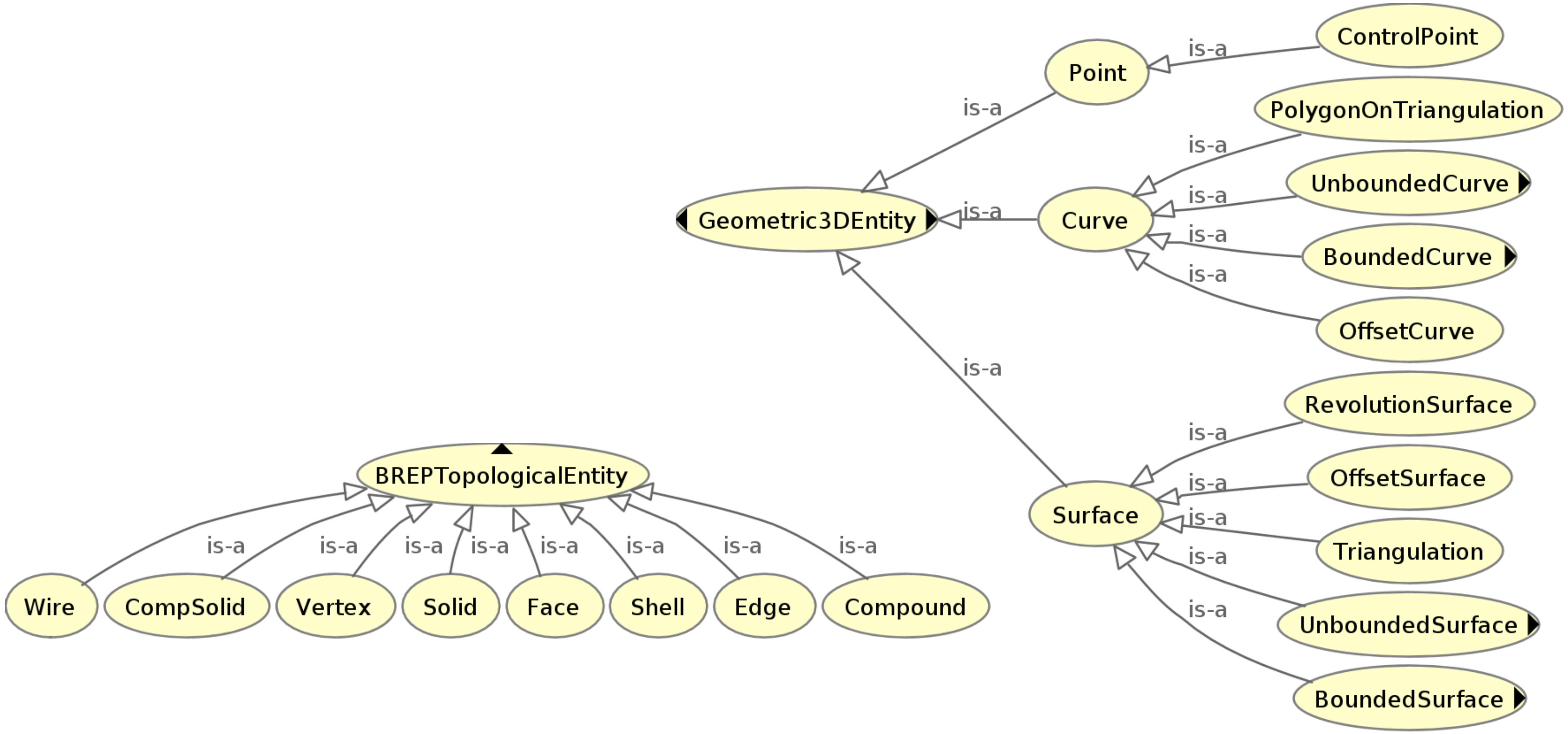
Semantic description of CAD data

The cuboid step-by-step



Description language for BREP

Taxonomies for topological and geometric entities



Annotate geometry data with functional properties

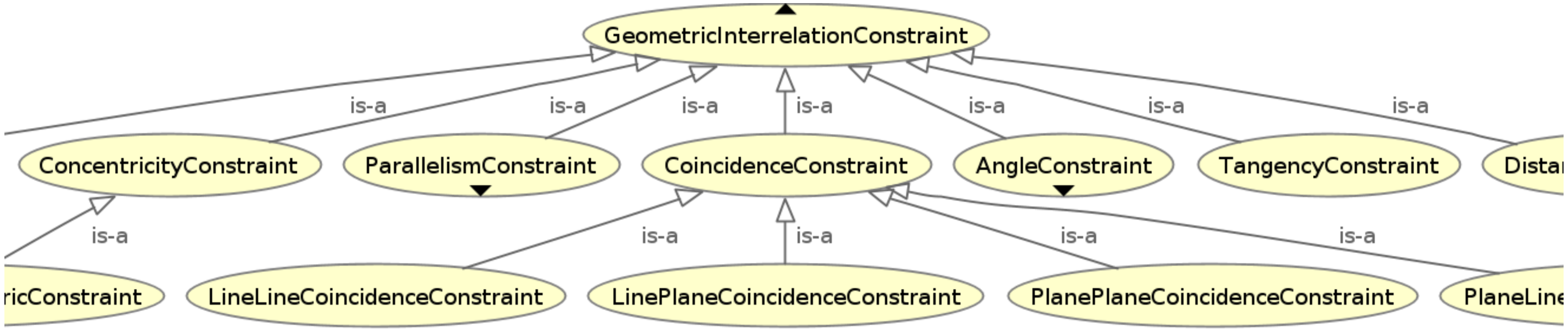
Example application

Find all faces in the environment which are storage surfaces

Geometric interrelation constraints

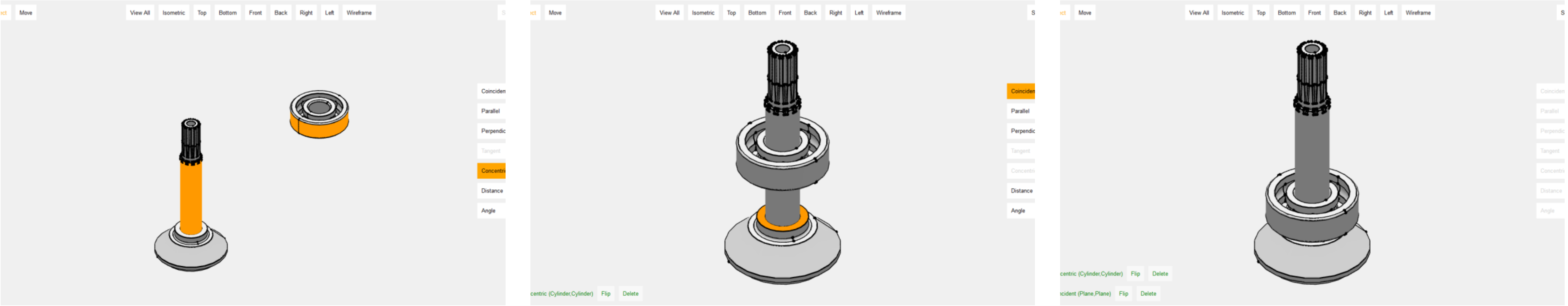
Example application

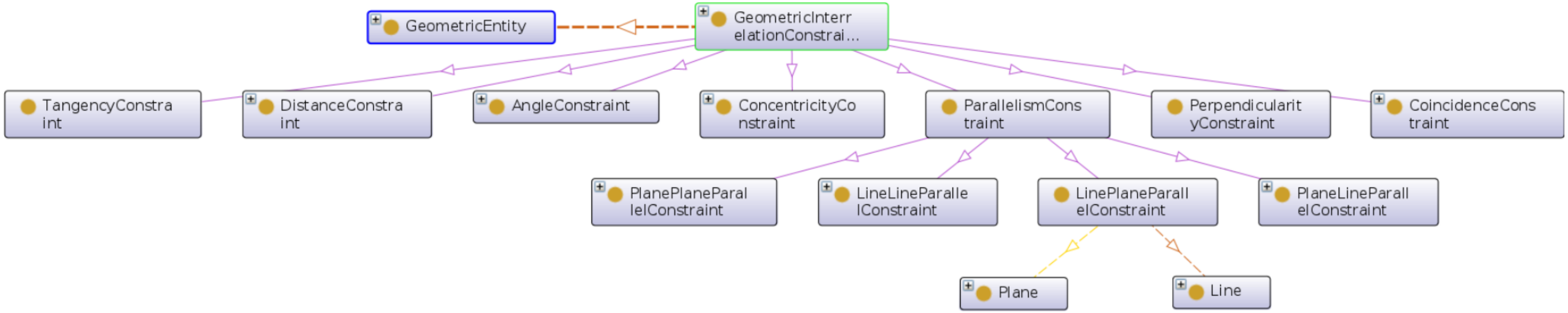
- Defined between topological entities, e.g. edges or faces
  - Fixed geometry and constrained geometry
- Describes (potentially underspecified) relative poses
- Used in task parameterization, e.g.
  - assembly poses,
  - grasp poses,
  - approach poses



Description of geometric constraints

Example: Assembly of parts





Automatic conversion to OntoBREP formalism

Import of STEP and IGES models

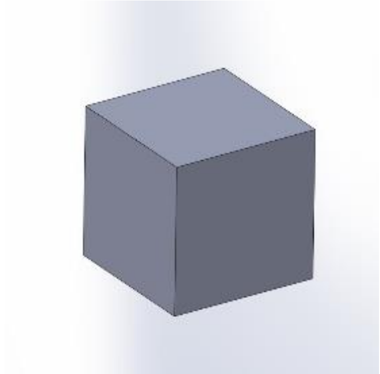
Conversion tool utilizing

- OpenCascade (OCC) CAD kernel
- JNI-based Java wrapper for OCC
- OWL API

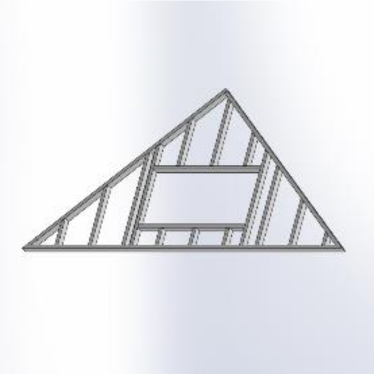
Quantitative Evaluation

- Conversion time
- Load time in Sesame triple store (OWLIM)

Model	*Converting STEP*	*Loading OWL in Sesame*	
	time in ms	*time in ms*	*axioms per ms*
CUBE	365	25	57.2
FRAME	805	343	77.0
ROTOR	1018	704	60.9



cube



frame

rotor

Quantitative evaluation (1)

OWL model related metrics

Comparison of file sizes of

- Standard CAD formats and OWL representations
- Compressed and uncompressed variants

Model	*File Size in kB*									
	BREP		*STEP*		*IGES*		*OWL Manchester*		*OWL RDF/XML*	
	plain	*zipped*	*plain*	*zipped*	*plain*	*zipped*	*plain*	*zipped*	*plain*	*zipped*
CUBE	4.0	0.9	15.9	2.9	21.2	1.6	51.6	3.1	150.0	4.7
FRAME	143.5	15.9	353.7	38.9	444.7	27.4	1010.3	49.6	2764.3	69.6
ROTOR	170.8	20.0	650.8	63.3	896.0	54.6	1636.9	79.6	4455.3	115.8

Quantitative evaluation (2)

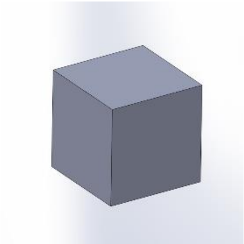
From BREP entities to OWL axioms

Model	*Number of topological BREP entities*								
	Ve [a]	*Ed* [b]	*Fa* [c]	*Wi* [d]	*Sh* [e]	*So* [f]	*CS* [g]	*Co* [h]	*Total*
CUBE	8	12	6	6	1	1	0	1	35
FRAME	152	228	114	114	19	19	0	1	647
ROTOR	270	405	153	155	9	9	0	1	1002

[a]Vertex [b]Edge [c]Face [d]Wire [e]Shell [f]Solid [g]CompSolid [h]Compound

Number of OWL axioms							
C [i]	*OP* [j]	*DP* [k]	*I* [l]	*CA* [m]	*OPA* [n]	*DPA* [o]	*Total*
15	12	17	206	206	281	694	1431
16	12	17	3915	3915	5358	13186	26419
19	12	18	6068	6068	8342	22314	42841

[i]Class [j]Object property [k]Data property [l]Individual [m]Class assertion [n]Object property assertion [o]Data property assertion



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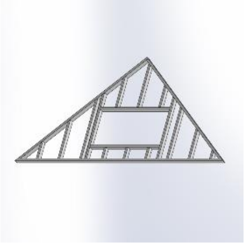

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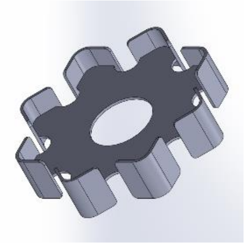
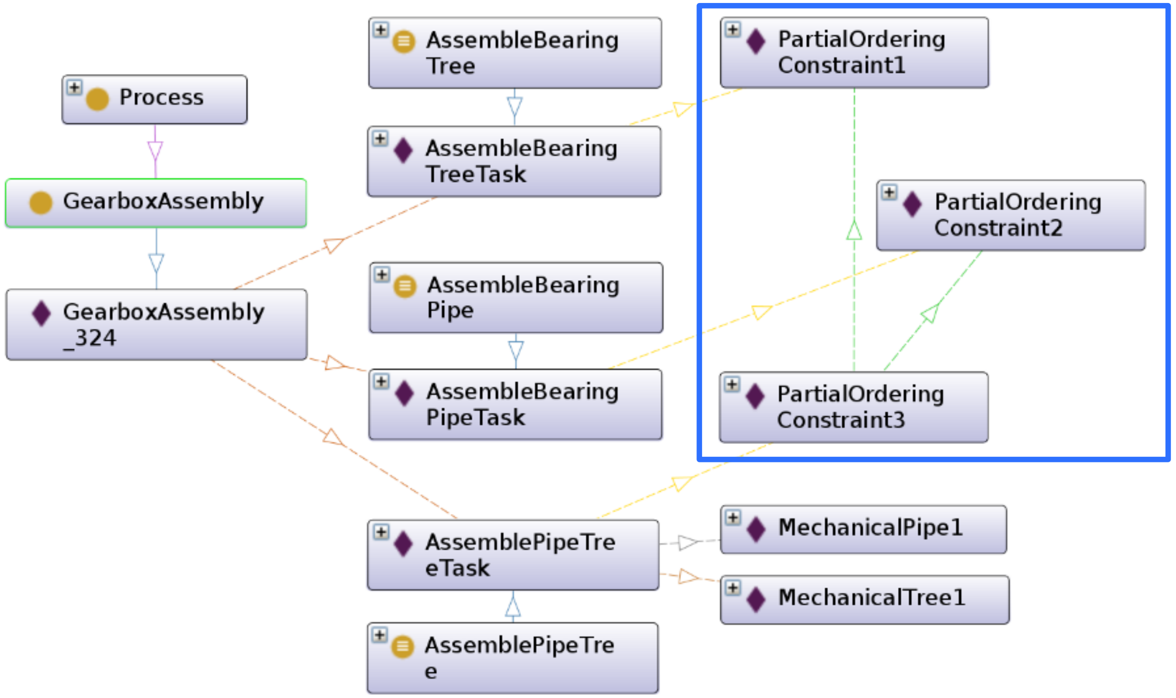
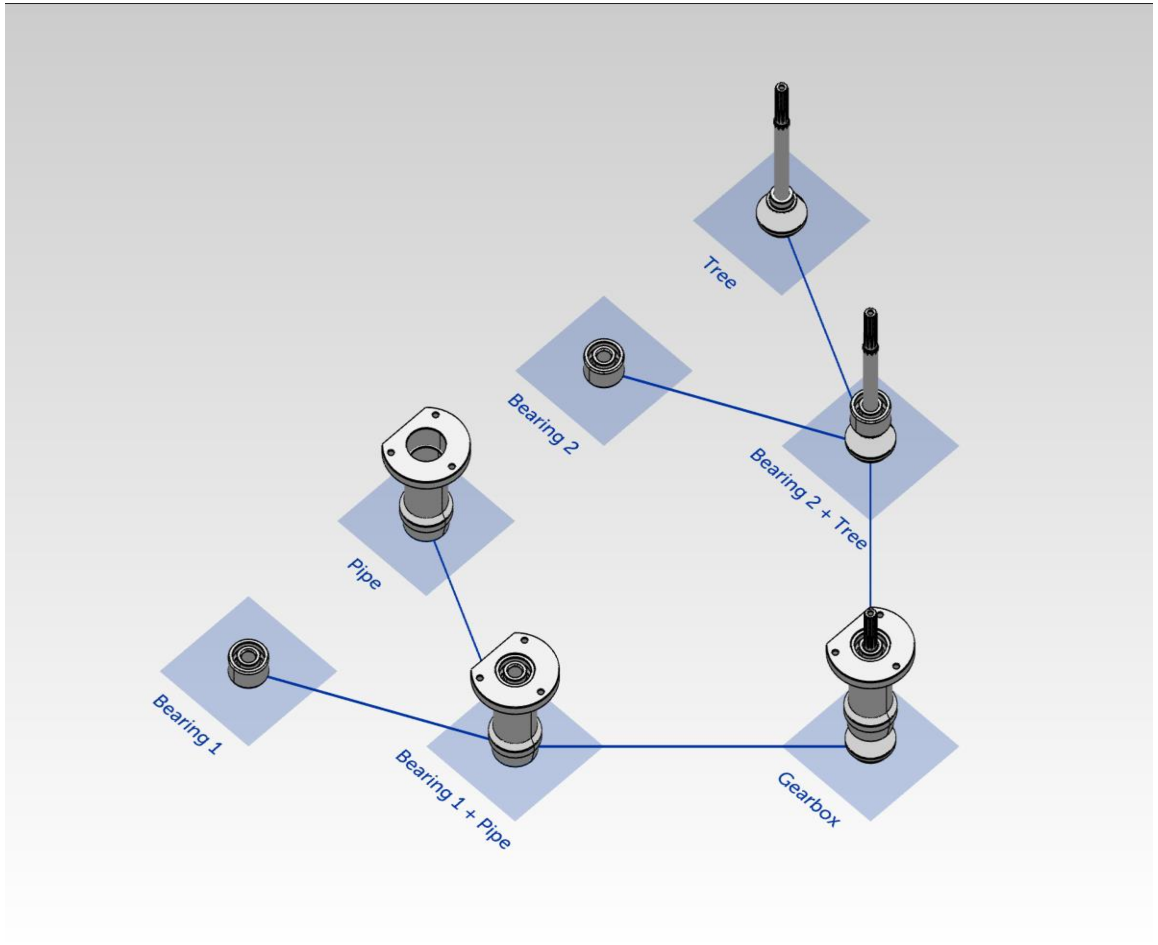


rotor

Semantic description of an assembly task

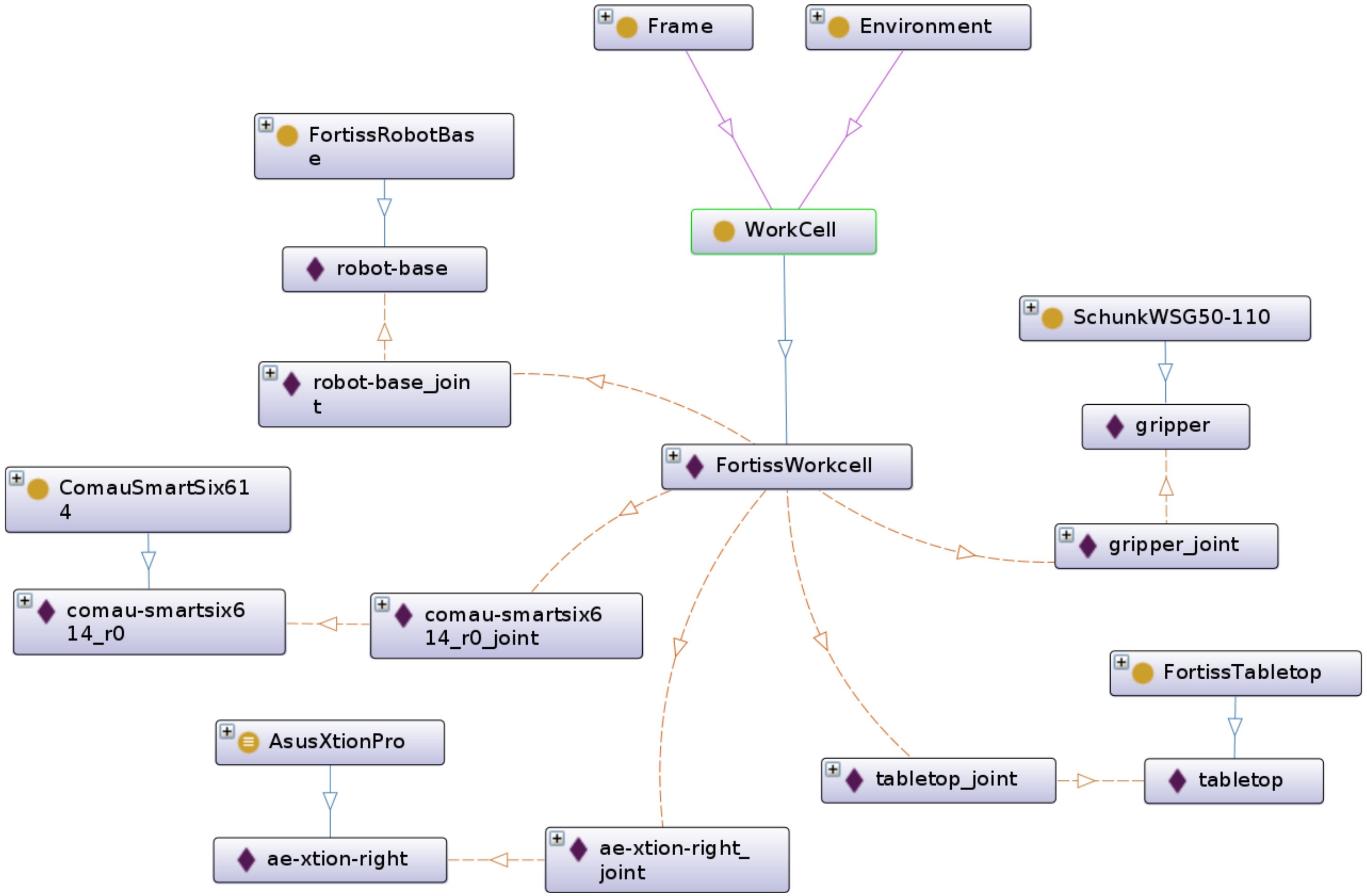
Partial ordering specifies assembly sequence

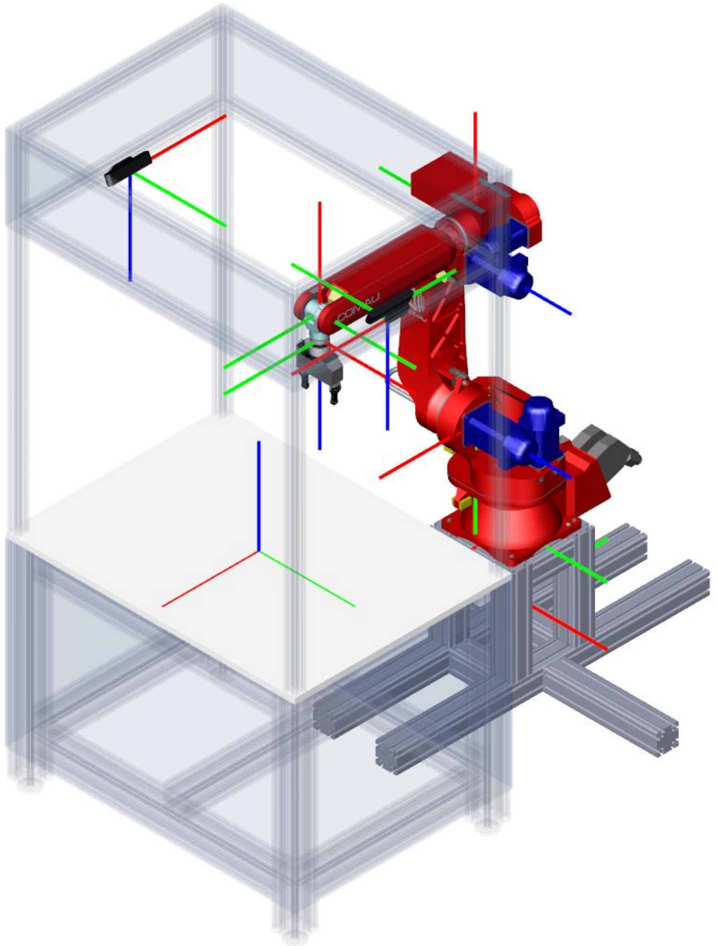




Semantic description of workcell and factory

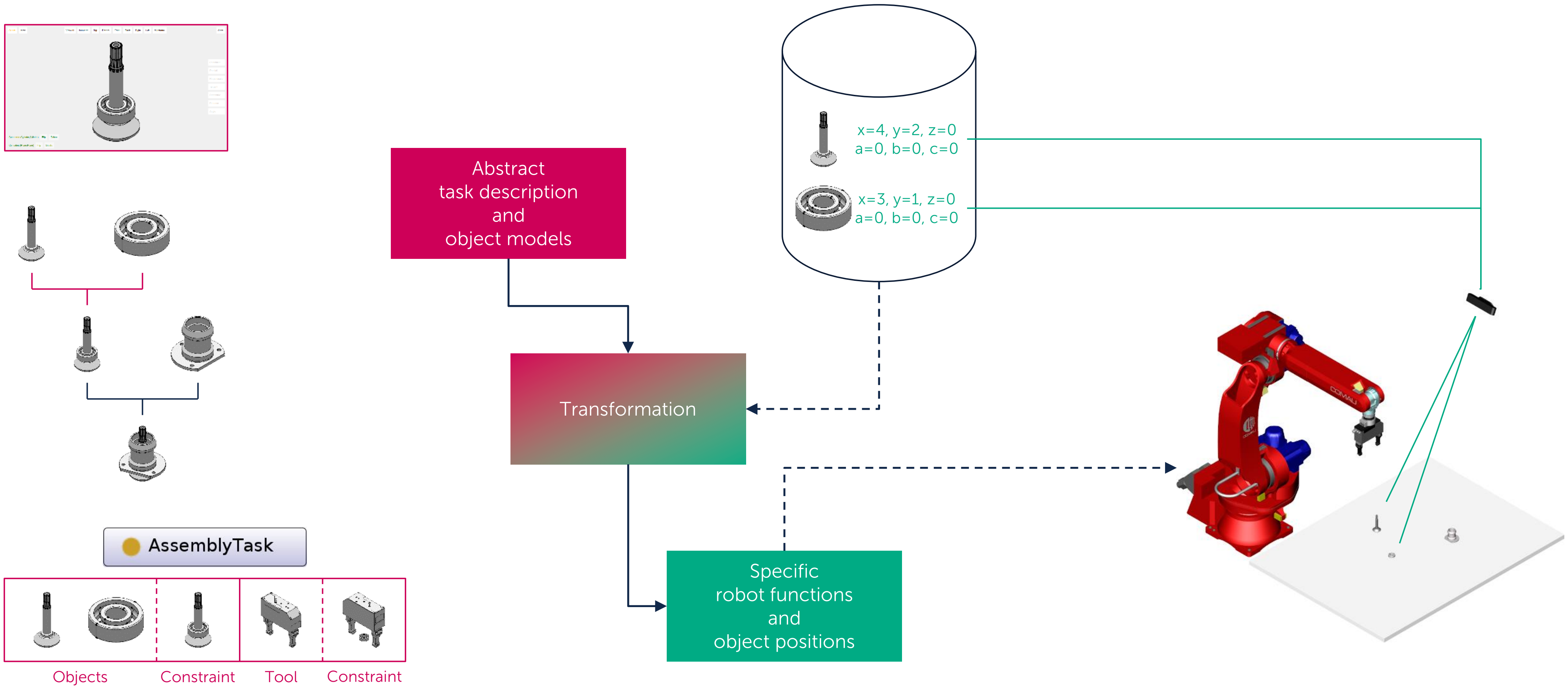
Modeling of sensors, robots, and tools





Semantic process description

From abstract task to concrete execution



HOW TO TEACH YOUR ROBOT IN 5 MINUTES

Andre Gaschler, Ahmed Ghazi, Ingmar Kessler, Alexander Perzylo, Stefan Profanter, Markus Rickert, Nikhil Somani

SMErobotics @ AUTOMATICA 2016

https://www.youtube.com/watch?v=ZxMZrs1nf7Q

Related publications

Nikhil Somani, Markus Rickert, and Alois Knoll. **An exact solver for geometric constraints with inequalities**. *IEEE Robotics and Automation Letters*, 2(2):1148-1155, April 2017. Accepted for presentation at ICRA 2017.

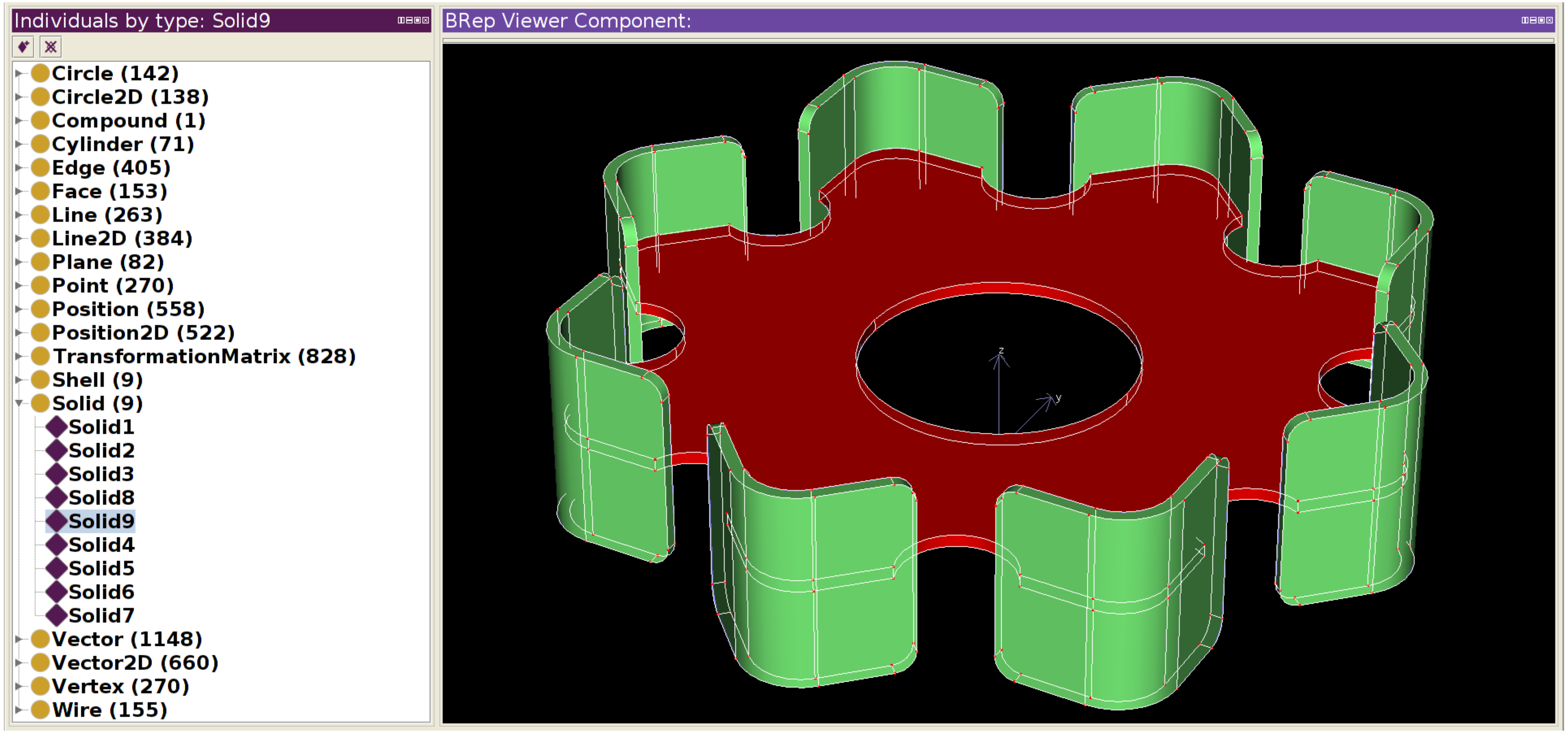
Alexander Perzylo, Nikhil Somani, Stefan Profanter, Ingmar Kessler, Markus Rickert, and Alois Knoll. **Intuitive instruction of industrial robots: Semantic process descriptions for small lot production**. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 2293-2300, Daejeon, Republic of Korea, October 2016.

Nikhil Somani, Alexander Perzylo, Caixia Cai, Markus Rickert, and Alois Knoll. **Object detection using boundary representations of primitive shapes**. In *Proceedings of the IEEE International Conference on Robotics and Biomimetics (ROBIO)*, Zhuhai, China, December 2015.

Alexander Perzylo, Nikhil Somani, Markus Rickert, and Alois Knoll. **An ontology for CAD data and geometric constraints as a link between product models and semantic robot task descriptions**. In *Proceedings of the IEEE/RSJ International Conference on Intelligent Robots and Systems (IROS)*, pages 4197-4203, Hamburg, Germany, September 2015.

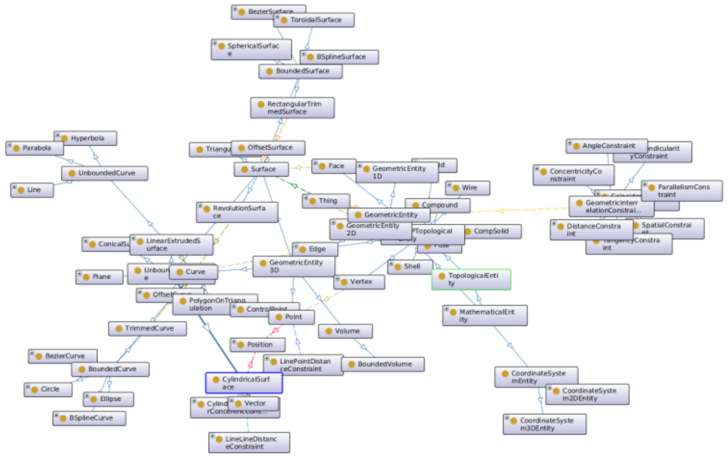
Visualization plugin for OntoBREP models

Integration in Protégé ontology editor (work in progress)



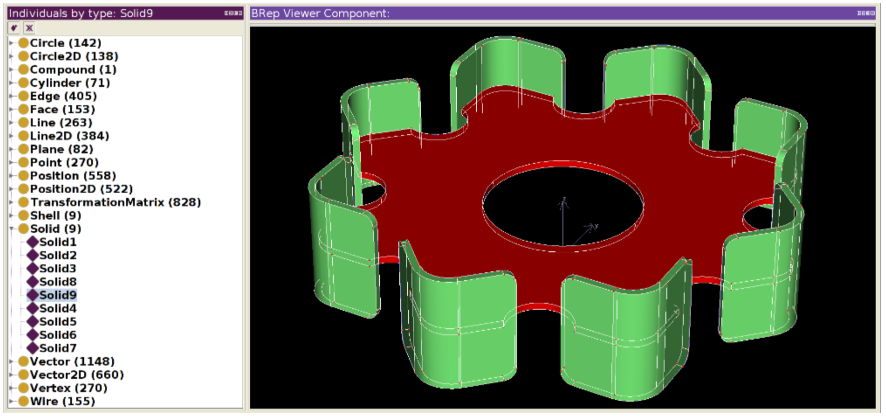
Open source release (partial release)

OntoBREP on GitHub



GitHub repository:
https://github.com/ontobrep

- OWL ontology
- SWIG project for generating Java bindings for OpenCascade library (C++)



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