In the ever-evolving field of automation, the need for sophisticated models to efficiently describe and manage complex tasks has never been greater. The PPR (Product, Process, Resources) modeling paradigm offers a robust framework to address this need, leveraging ontology-based semantic description languages to encode knowledge across various aspects of automation tasks[1].

This blog post delves into the PPR modeling paradigm, highlighting its significance and application in robot-based automation.

What is the PPR Modeling Paradigm?

The PPR modeling paradigm structures automation knowledge into three interconnected categories:

- **Product**: Details about the physical characteristics, configurations, and specifications of the item being manufactured or assembled.
- **Process:** Information on the sequence of operations or steps required to produce or assemble the product.
- **Resources**: Specifications of the tools, equipment, software components, and potentially even human resources that are necessary to carry out the processes.

By organizing information into these three categories, the PPR paradigm enables a comprehensive and systematic approach to automation task modeling and execution.

Ontology-Based Semantic Description Languages

At the core of PPR modeling is the use of ontology-based semantic description languages. Ontologies are formal representations of knowledge within a domain, using concepts and relationships to describe entities and their interactions. In the context of PPR modeling, ontologies provide a shared and reusable framework for encoding information about products and their geometry model, associated manufacturing processes and their subtasks, and involved manufacturing resources, which include hardware and software components that are available in a production environment.

- **Consistency**: Ensuring uniform understanding and interpretation of data across

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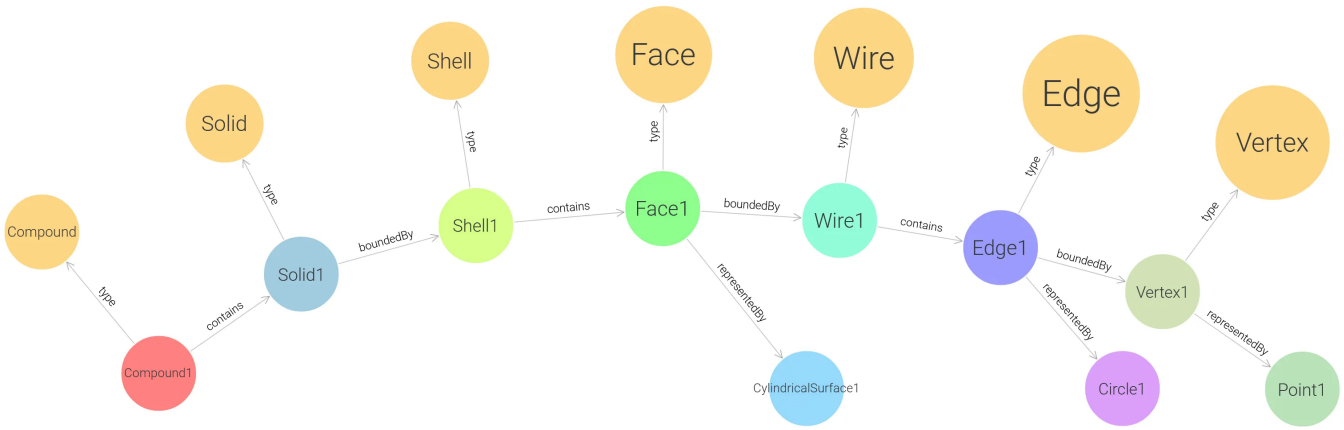
different systems and stakeholders.

- **Interoperability**: Facilitating seamless integration and communication between diverse software tools and platforms.
- **Scalability**: Supporting the expansion of knowledge bases as new products, processes, and resources are introduced.

Product Ontology

In robot-based assembly, the product ontology provides the specifications of each mechanical part. This may include dimensions, mass, materials, and tolerances. For instance, if assembling a gearbox, the ontology would define the types and characteristics of gears, shafts, and housings, ensuring that each component is correctly identified and matched during assembly. We further augment product models with a semantic description of the products' geometry using our OntoBREP ontology.

OntoBREP is an ontology designed to represent the geometric and topological information of three-dimensional (3D) objects[2]. It captures the boundary representation, which includes vertices, edges, faces, and their relationships, forming a comprehensive model of the object's shape and structure. We further develop software tools to automatically convert industry standard formats into the OntoBREP representation, either directly from CAD tools, such as SolidWorks, or via command line tools.



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Process Ontology

The process ontology outlines the operations required to assemble the gearbox. This includes aligning and positioning involved parts and inserting shafts through bearings. Each step is described in terms of the type of action performed, the parameters involved, and the expected outcomes. In a process model, an order of such tasks is defined, which ensures that the robot follows a precise and efficient assembly sequence, minimizing errors and rework.

The creation of specific process models based on the process ontology can be achieved in various ways: If relevant information is already available through other company resources, e.g., relational data bases, the semantic process model can be automatically generated[3]. Another approach is to hide the complexity of manually editing knowledge models behind intuitive graphical user interfaces. This allows domain experts without expertise in knowledge engineering to specify assembly processes in an efficient manner[4].

Resource Ontology

The resource ontology specifies the robots, tools, and equipment that may be used in the assembly process. It details the types of different robotic arms, grippers, and other end-effectors, and the required sensors for object recognition or quality control. As part of the semantic resource models, invocable skills and their required skill parameters are formally represented[5]. This enables the robot system to automatically analyze the capabilities of a setup and to infer higher level capabilities of the overall system, that arise from the combination of basic skills of individual resources and information about the resources' topological connections.

For instance, the presence of a parallel gripper and a particular robot arm provides information about available basic skills, such as open or closed gripper and different robot movement skills. Through the explicit modeling of the gripper being mounted to the robot flange, the system can infer a pick-and-place capability. By encoding this information, the system can optimize resource allocation, identifying and selecting suitable tools and equipment for each task of an assembly process.

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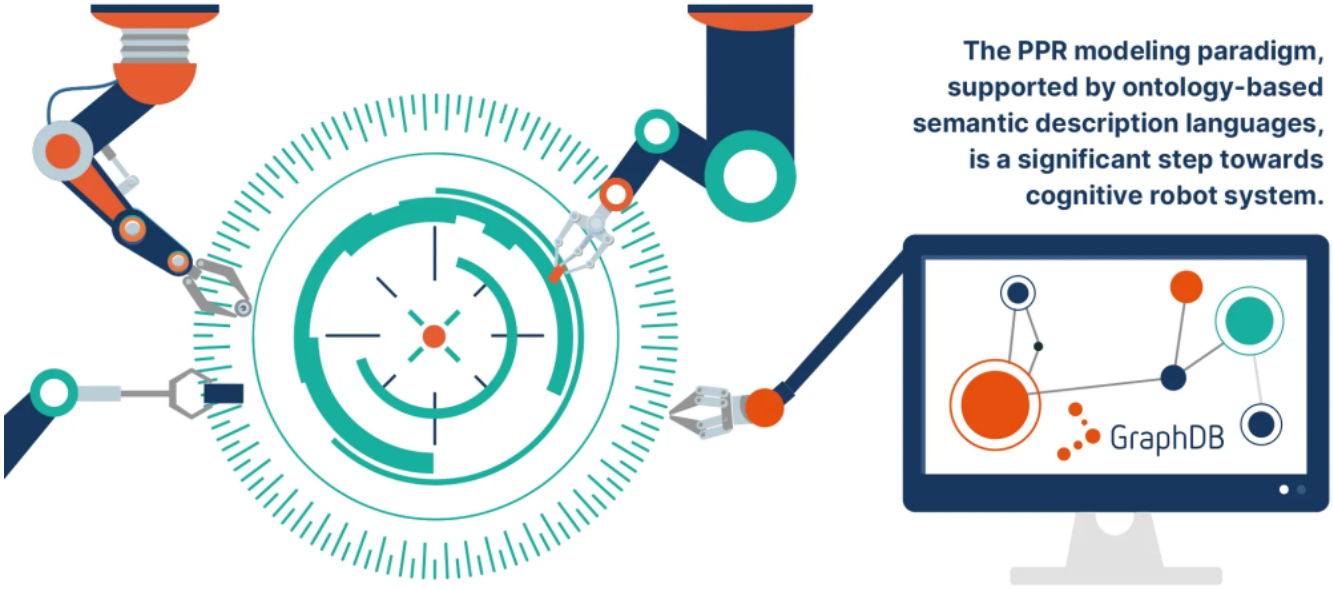
Benefits of PPR Modeling in Automation

Implementing the PPR modeling paradigm offers several key benefits: 1) improved efficiency, 2) enhanced flexibility, and 3) higher quality. By providing a clear and structured framework for managing automation tasks, PPR models reduce the time and effort required for planning and execution. The modular nature of PPR models allows for easy adaptation to changes in products, processes, or resources, facilitating quick reconfiguration of assembly lines. Detailed ontologies ensure precise execution of tasks, reducing the likelihood of errors and enhancing the overall quality of the assembled products.



Conclusion

The PPR modeling paradigm, supported by ontology-based semantic description languages, is a significant step towards a cognitive robot system. Ontotext GraphDB is an appropriate storage layer for those ontologies, which enables knowledge management and reasoning over the created models. By systematically organizing knowledge about products, processes, and resources, it endows robot systems with the required insights into their tasks and

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associated context knowledge to enable efficient and more flexible operation.

As a result, the level of autonomy of these knowledge-augmented systems can be increased, leading to the ability of self-assessment of the feasibility of automation tasks and – to a certain extent – the autonomous handling of errors during runtime. This paves the way for smarter and more adaptive manufacturing systems that will play a crucial role in driving innovation and competitiveness in automation.

For more information about fortiss and their research, you can contact them directly.

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