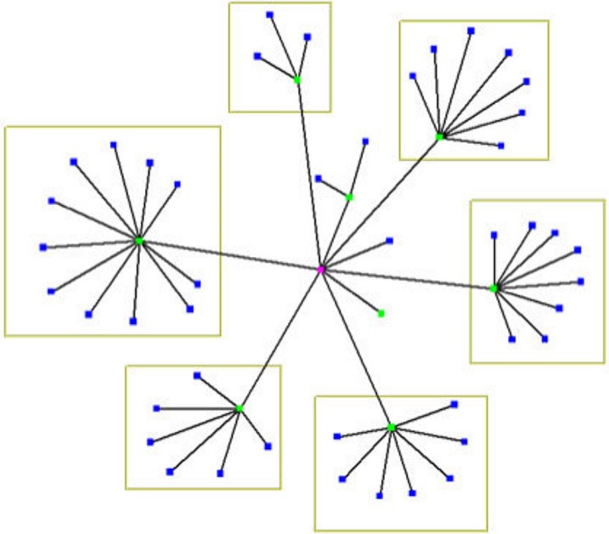


The Industrial Ontologies Foundry

Part of the Open Applications Group

Summary of the IOF PPS WG Ontologies Work

IOF Production Planning and Scheduling Working Group

Prepared by Dusan Sormaz

https://www.industrialontologies.org/

Agenda

- Introduction
- Interoperability
- Areas of work
  - Capability
  - Future and Digital artifacts
  - ISA95 (ISA88)
- Roadmap
- Working Session Agenda

Production Planning and Scheduling WG

Introduction

- Mission
  - ▷ To develop semantic definitions for terms and relations used in product design and manufacturing, production planning, scheduling, and manufacturing execution
- Chairs
  - ▷ Dušan Šormaz, Professor, Ohio University
- Membership and Attendance
  - ▷ IOF members from North America, South America, Europe
  - ▷ 3-10 attendees per meeting
  - ▷ 8-10 regular members

Production Planning and Scheduling WG Members

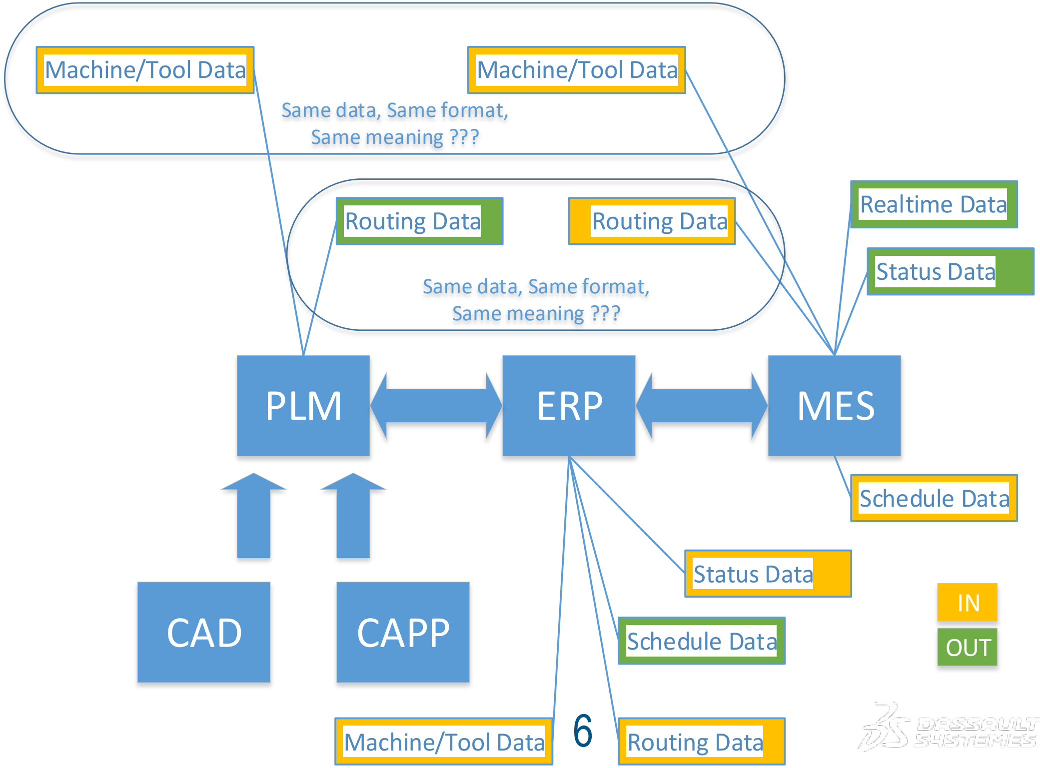
Introduction

Production Planning & Scheduling (PPS) WG
Organization
Airbus SAS
Engineering Semantics
ENIT
ENIT
NIST
Ohio University
Texas State University
The Open University
Universidad Politecnica de Madrid
William & Valerie Sobel LLC

Interoperability Problem

Interoperability Problem

- Software Tools and Data



Sub-domains in PPS-WG

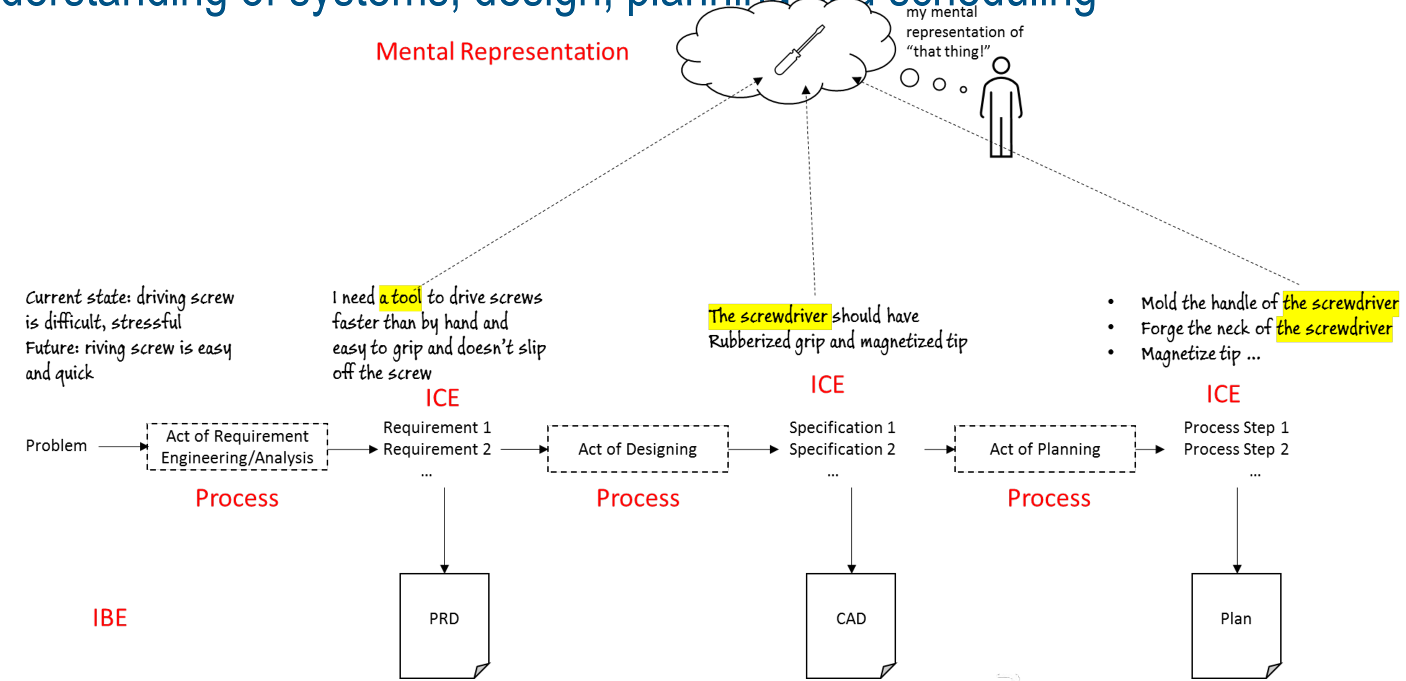
Approach

- Process Planning use case
- Product representation use case
- Manufacturing System design use case
- Scheduling use case
- Assembly planning use case

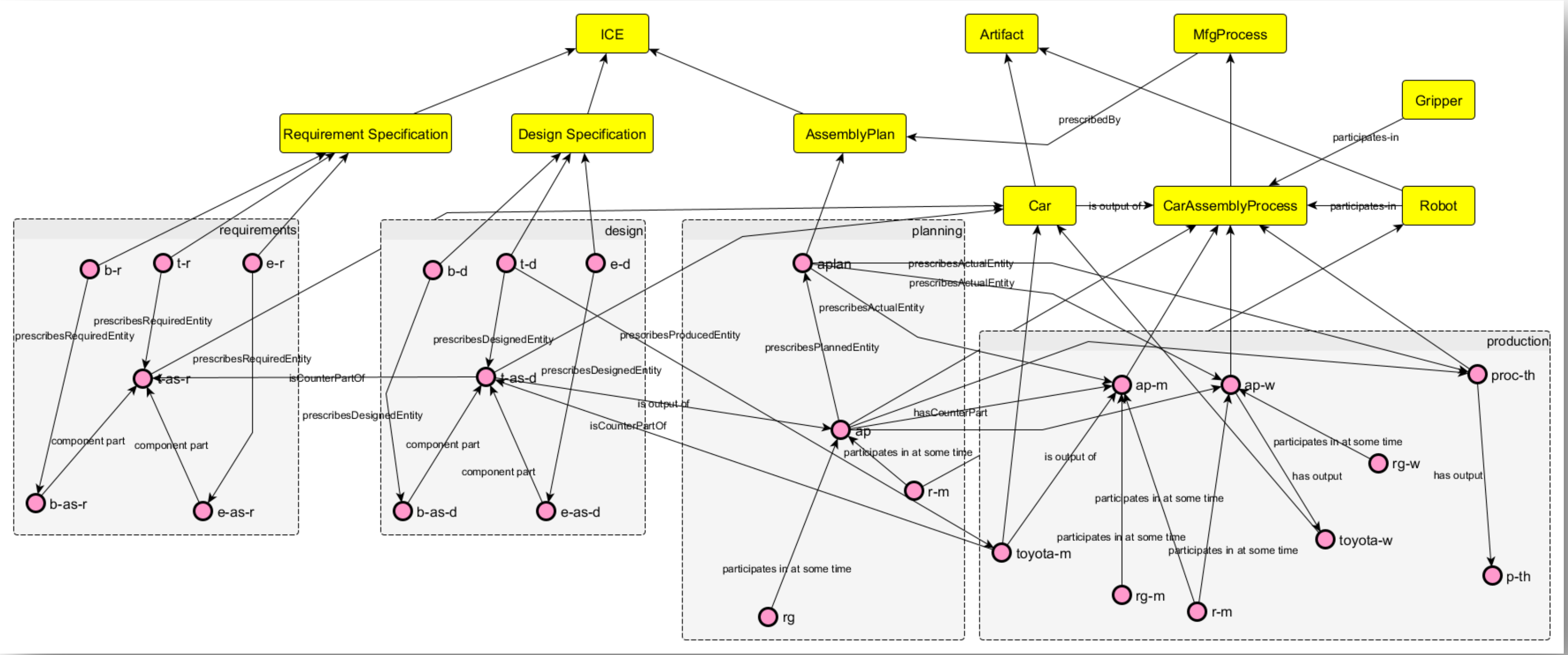
Requirements, Design and Planning

Approach

- Understanding of systems, design, planning and scheduling



Product Life Cycle



Areas of research

- Capabilities of resources and their realization in processes
- Future and Digital Artifacts
- Theory of Planning
- ISA95 (ISA88)

Capabilities of Resources

Capability of manufacturing resource

- State-based definition

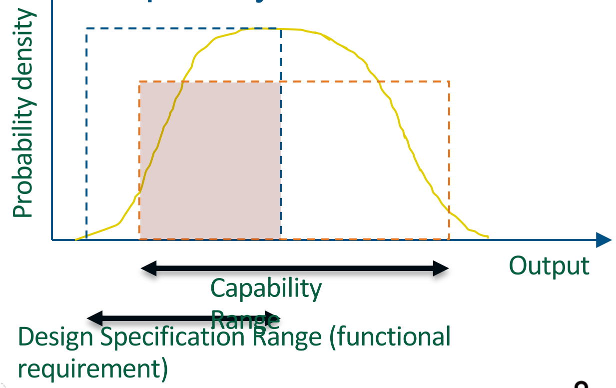
Suitability of a resource for fulfilling a functional requirement (specification).

- **A capability demarcates or predicts the extent by which some function is realized.**
- A resource is suitable for a purpose when the specification (goal in this case) is at least overlapped by the capability range.
- If a resource fulfills the purported requirement (achieves such goal) then the resource must have the related function.

- The change of state in the capability bearing object (or any other co-participant) occurring in the same process should be within the range of the capability.

$$\forall p \exists i\ process(p) \wedge Interval(i) \wedge occurs(p,i) \wedge Function(f) \wedge realizes(p,f) \rightarrow \exists o,q,t_b,t_e\ participates(o,p) \wedge beginAt(i,t_b) \wedge endAt(i,t_e) \wedge \neg holds(o,q,t_b) \wedge holds(o,q,t_e) \wedge (\exists c,f\ Capability(c) \wedge bearerOf(o,f) \wedge bearerOf(o,c) \wedge demarcates(c,f) \wedge (\boldsymbol{max}(\boldsymbol{c}) \geq \boldsymbol{q}) \wedge (\boldsymbol{q} \leq \boldsymbol{min}(\boldsymbol{c}))$$

(from Sarkar and Sormaz, 2019)

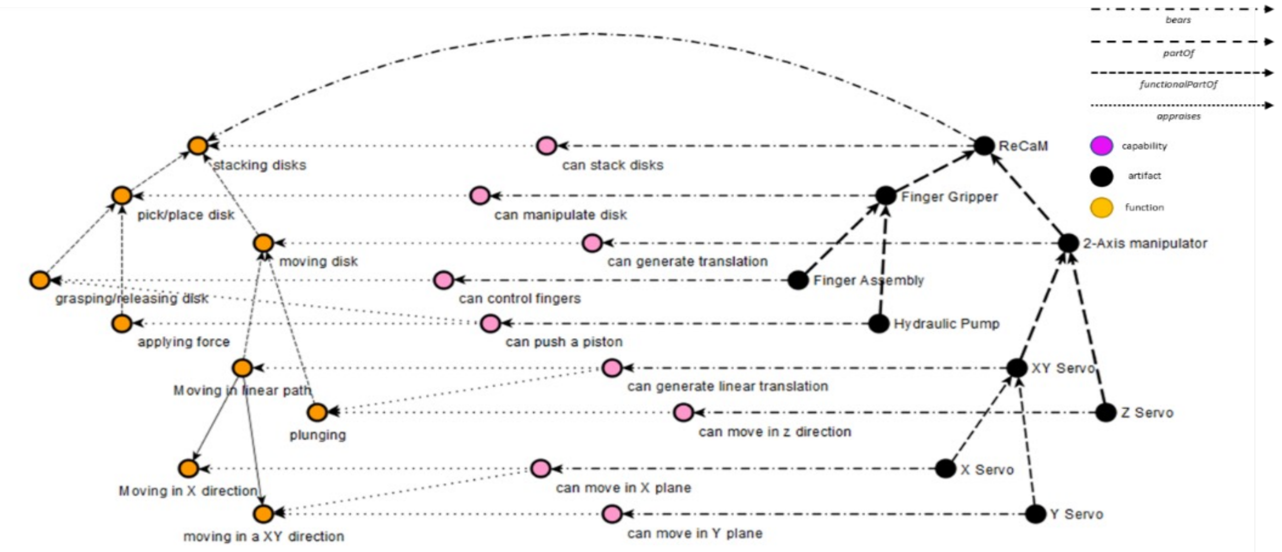


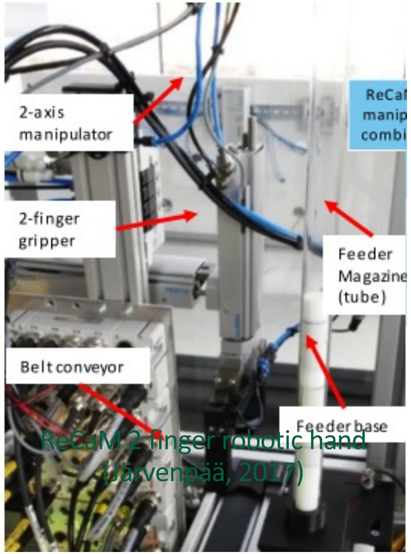
- Naïve substitution

$$\forall p,f\ process(p) \wedge realizes(p,f) \rightarrow \exists g\ associatedGoalOf(g,f) \wedge achieves(p,g)$$

Capability of a complex system

- An example: Axiomatic Design principle applied to derive the structural decomposition of a robotic hand





ReCaM 2 finger robotic hand (Järvenpää, 2017)

Case Study: CNC system (drill)

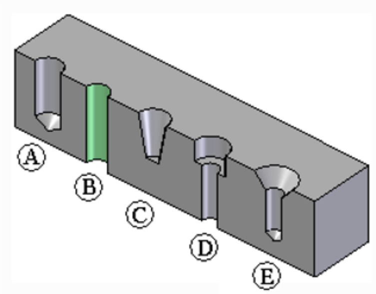
Knowledge acquisition (CNC Machining)

	Feature	Method of Tool Entry	Primary Cutting Motion (feed) of Spindle	The Direction of Cutting
	Closed pocket	Ramping	XY path	Radial Cutting
	Large hole (circular pocket)	Helical interpolation	Circular XY	Radial Cutting
	small hole	Plunging	Rotation	Axial Cutting
	Slot	Ramping	X or Y	Radial Cutting

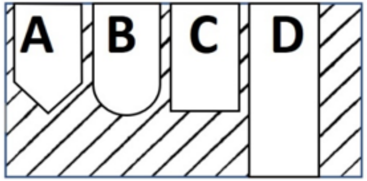
Case Study: CNC system (drill)

Knowledge acquisition (Drill bits)

Side Profile	Type of drill bit	Bottom Profile of hole
Simple Hole-Round Bottom	Conventional/Spur/Spade	B
Simple holes- Flat bottom	Conventional/Spur/Spade	C
Simple holes- V bottom	Conventional/Spur/Spade	A
Counterbore holes- Flat bottom	Counterbore	C
Counterbore holes- Round Bottom	Step Drill	B
Counterbore holes- V bottom	Counterbore	A
Countersink- Flat bottom	Countersink	C
Countersink- Round bottom	Countersink	B
Countersink- V bottom	Countersink	A
Threaded holes- Flat bottom	Tap Drill	C
Threaded holes- Round bottom	Tap Drill	B
Threaded holes- V bottom	Tap Drill	A



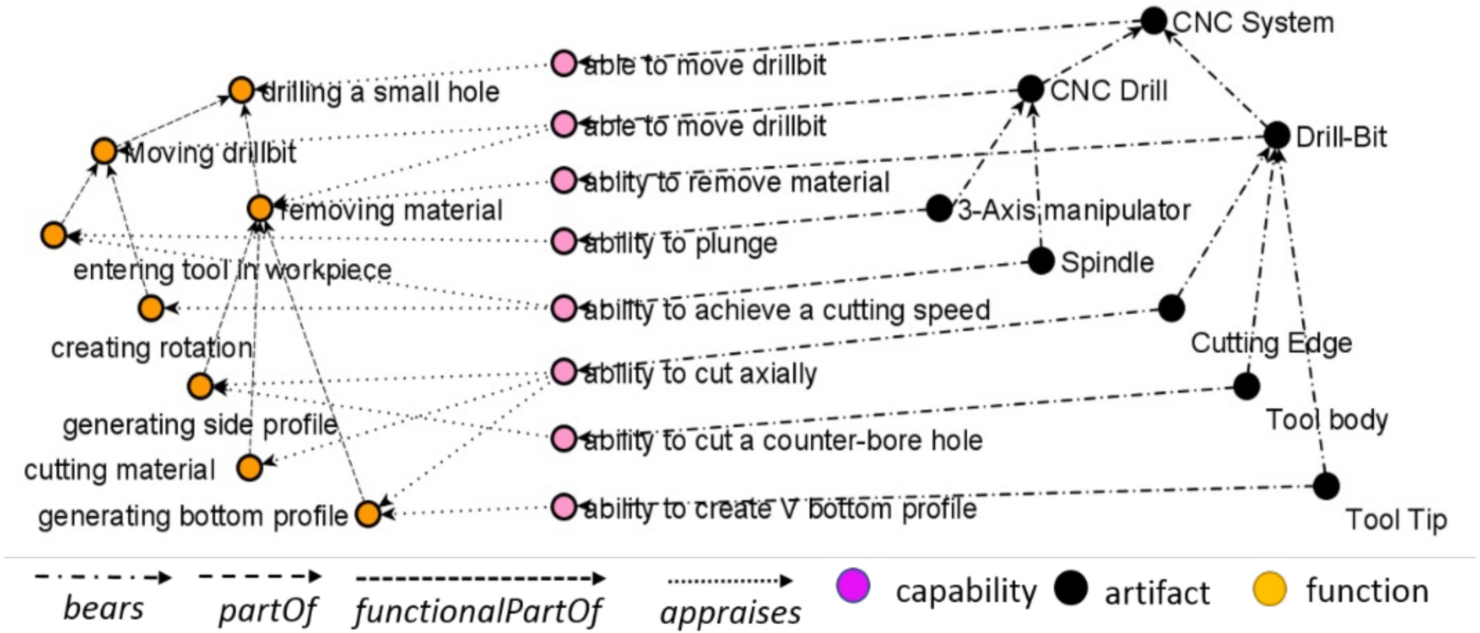
A. Simple hole
B. Threaded hole
C. Tapered hole
D. Counterbore
E. Countersink



Bottom Profile of Hole:
A. V bottom
B. Round Bottom
C. Flat Bottom
D. Through-Hole

Case study

A CNC system design for drilling a small hole



Future and Digital Artifacts

Requirements

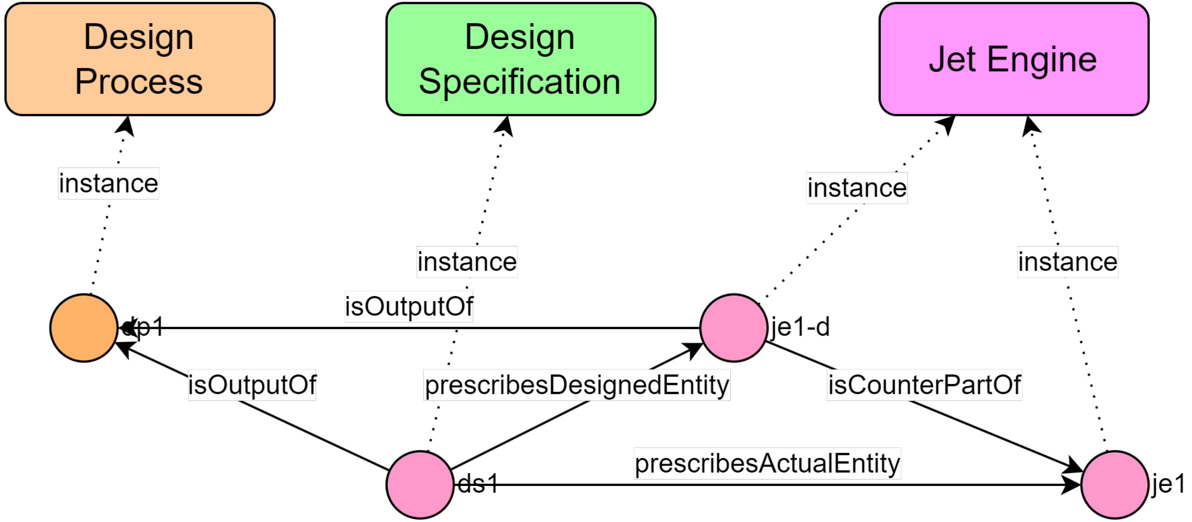
- General Requirements
  - Scalability ex. as-designed and as-manufactured
  - Number of constructs (classes, relations, and individuals) required
  - Information retrieval efficiency
  - IOF/BFO (Basic Formal Ontology) compliance
  - Digital twin modeling for a product/process/system

- Use Case Requirements
  - Structures and components
  - Process Settings
  - Participants
  - Required attributes (equipment capabilities)
  - Changes in designs from each version
  - Process plan (the implementation of optional steps)

Approaches for future artifacts

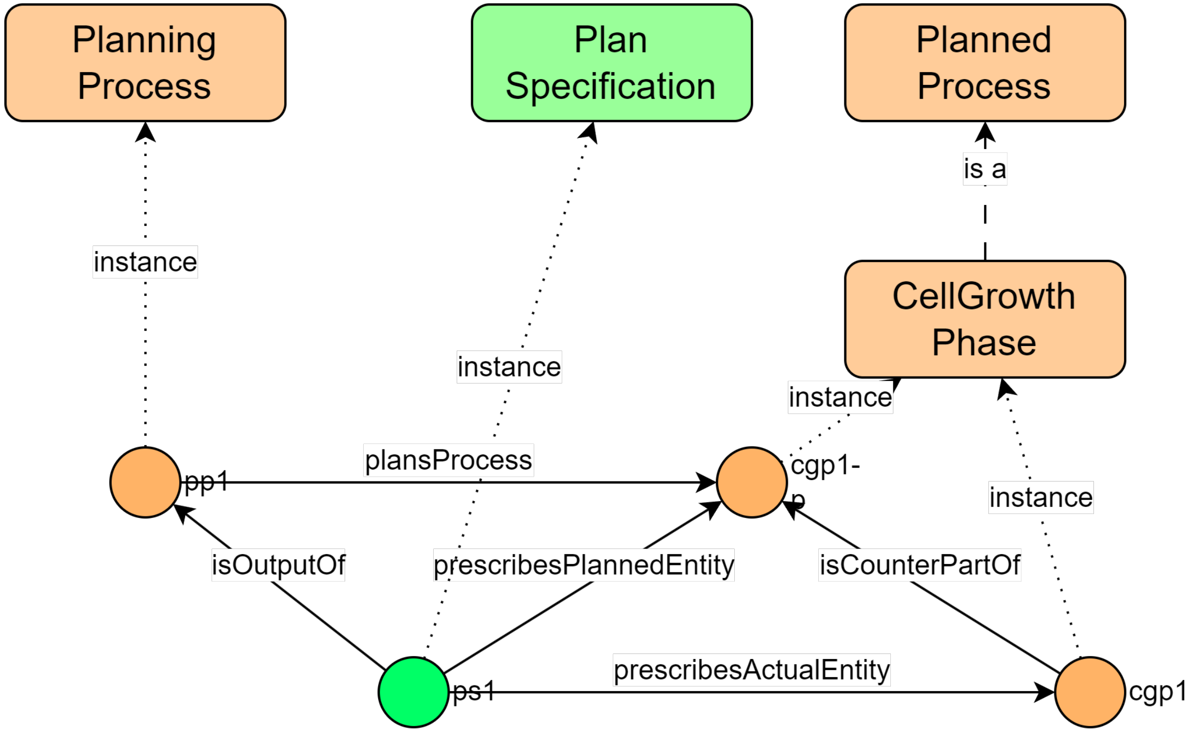
- Use ICE to represent all information (knowledge, decisions) about the future artifacts
- Use MRO approach to represent future artifacts, based on replica of relations (from BFO or any) into modal relation space
- Use R/S approach (given in a paper by Sarkar and Sormaz), specialize ICE to have Representation and Specification as subclasses
- Use CR approach, which is motivated by MRO approach but connects relations and provides for new relations between designed/planned entities and actual entities

Design Artifact and Actual Artifact



There is timeline here:
Design artifact starts its existence before actual artifact

Future Process and Actual Process



Use Case Studies

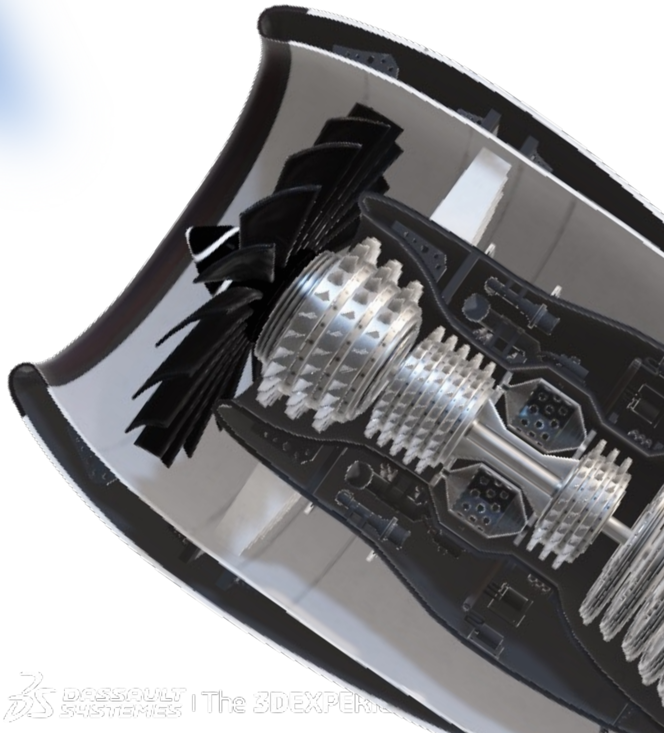
- Jet Engine
  - Requirements, Design, Realization
- Biomanufacturing Process
  - Process Design, Process control, Realization

Jet Engine Design and Requirement Verification

- An engineering task:

"There is a need to design and produce a jet engine that will have a compressor as its part, and it will be able to produce a minimal thrust of 700 kN".

This simple example provides sufficient elements to compare the approaches.



OAGi

Jet Engine Competency Questions

a. What is the thrust of a real engine?

b. Does a real engine have at least the same thrust as its design?

c. Does a ball bearing of a fan assembly in a real engine meets the load requirement?

d. Does a turbine diameter of real engine has value as specified in the design?

e. What are the (real) components and subcomponents of a real jet engine?

f. What is the difference of real engine thrust and designed engine thrust?

g. Does a real engine have all the designed components and subcomponents and nothing extra?

h. Does a real engine have any extra components or subcomponents not in the design?

i. Which engines are built as designed?

j. Which (real) engines failed design specification?

k. Which revisions of the design meet a revision of its requirements

Query b – CR Approach

Does a real engine have at least the same thrust as its design?

```
SELECT ?engine ?thrust ?realthrustValue ?spec ?engdesign ?thrustdesign ?thrustDesignValueExpr ?isSatisfactory
   WHERE {

   ?engine rdf:type jeb:JetEngine.                                          # find engine and its thrust
   ?spec cr:prescribesActualEntity ?engine.
   ?engine core:hasQuality ?thrust
   ?thrust core:hasValueExpressionAtAllTimes ?thrustValueExpr.              # find the thrust value
   ?thrustValueExpr core:hasSimpleExpressionValue ?realthrustValue.
   ?spec cr:prescribesDesignedEntity ?engdesign.                            # find the engine design from associated spec
   ?engdesign core:hasQuality ?thrustdesign.
   ?thrustdesign core:hasValueExpressionAtAllTimes ?thrustDesignValueExpr.  # find design thrust value
   ?thrustDesignValueExpr jeb:hasLowerBoundValue ?designThrustValue.

   BIND((?realthrustValue >= ?designThrustValue) as ?isSatisfactory)        }# compare them
```

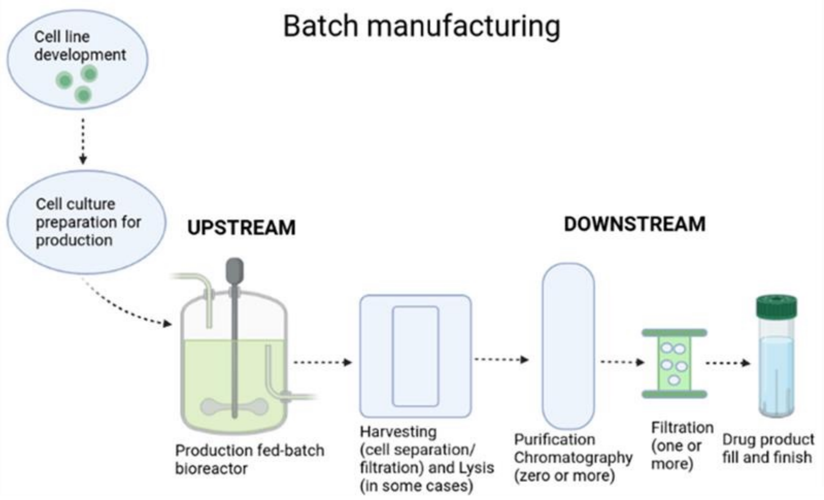
Query b – ICE Approach

Does a real engine have at least the same thrust as its design?

```
SELECT DISTINCT ?jetEngineDesignSpec ?jetEngine ?designedThrustValue ?realThrustValue ?isSatisfactory WHERE
{
?jetEngine rdf:type jet:JetEngine.                                         #retrieve all individuals that are jet engines
?jetEngine core:hasQuality ?thrust.
?thrust core:hasValueExpressionAtAllTimes ?thrustValueExpr.                #retrieve thrust
?thrustValueExpr core:hasSimpleExpressionValue ?realThrustValue.
?jetEngineDesignSpec rdf:type jet-ice:JetEngineSpec.                       #retrieve all designs for the jet engine
?jetEngineDesignSpec core:prescribes ?jetEngine.
?jetEngineDesignSpec core:prescribes ?thrustSpec.
?thrustSpec bfo:BFO_0000110 ?thrustDesignValueExpr.                        #retrieve thrust specificattion value
?thrustDesignValueExpr jet-ice:hasLowerBoundValue ?designedThrustValue.
BIND((?realthrustValue >= ?designedthrustValue) as ?isSatisfactory) #compare them
}
```

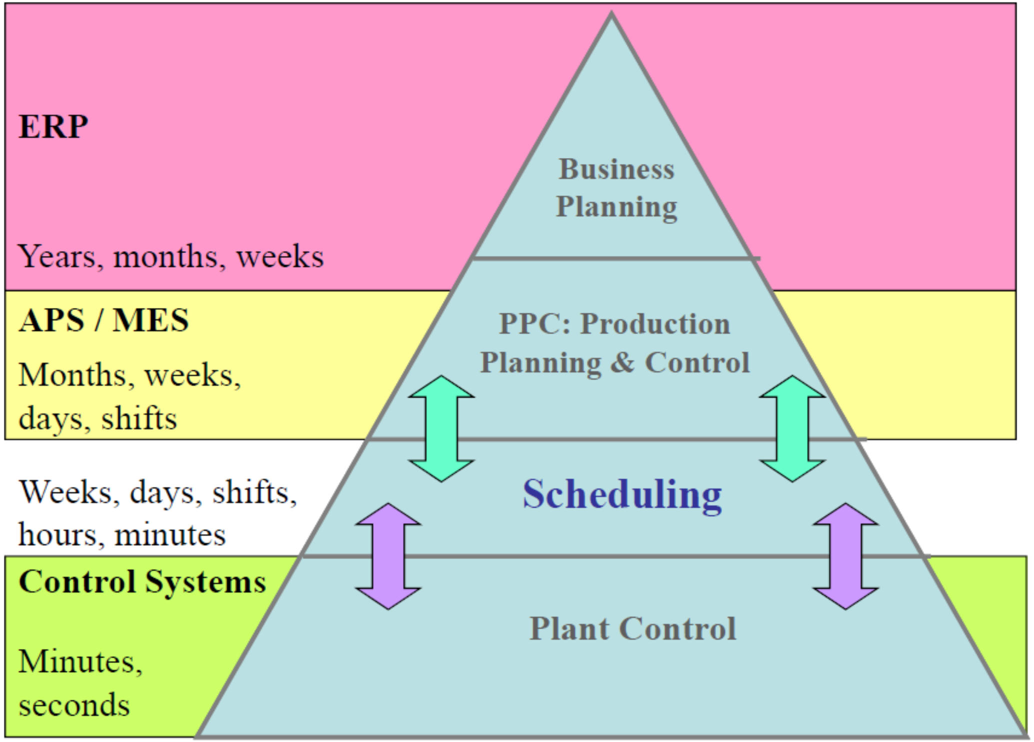
Biomanufacturing Process

- The fed-batch production bioreactor unit operation consists of two phases: growth phase and production phase. The growth phase precedes the production phase. In both phases the pH MUST be kept at 7± 0.1. To achieve this a pH controller is required as a process participant which has the capability to control pH up to a precision of 0.1. The process specification prescribes to use either bioreactor instance1 or instance2. In the run instance 1 was used. Both bioreactors are identical w.r.t. volume which is 3L. The unit operation duration is 21 days. However, due to some in-process complications the run only lasted 18days (we do not have to capture the in-process complications) just the duration difference.

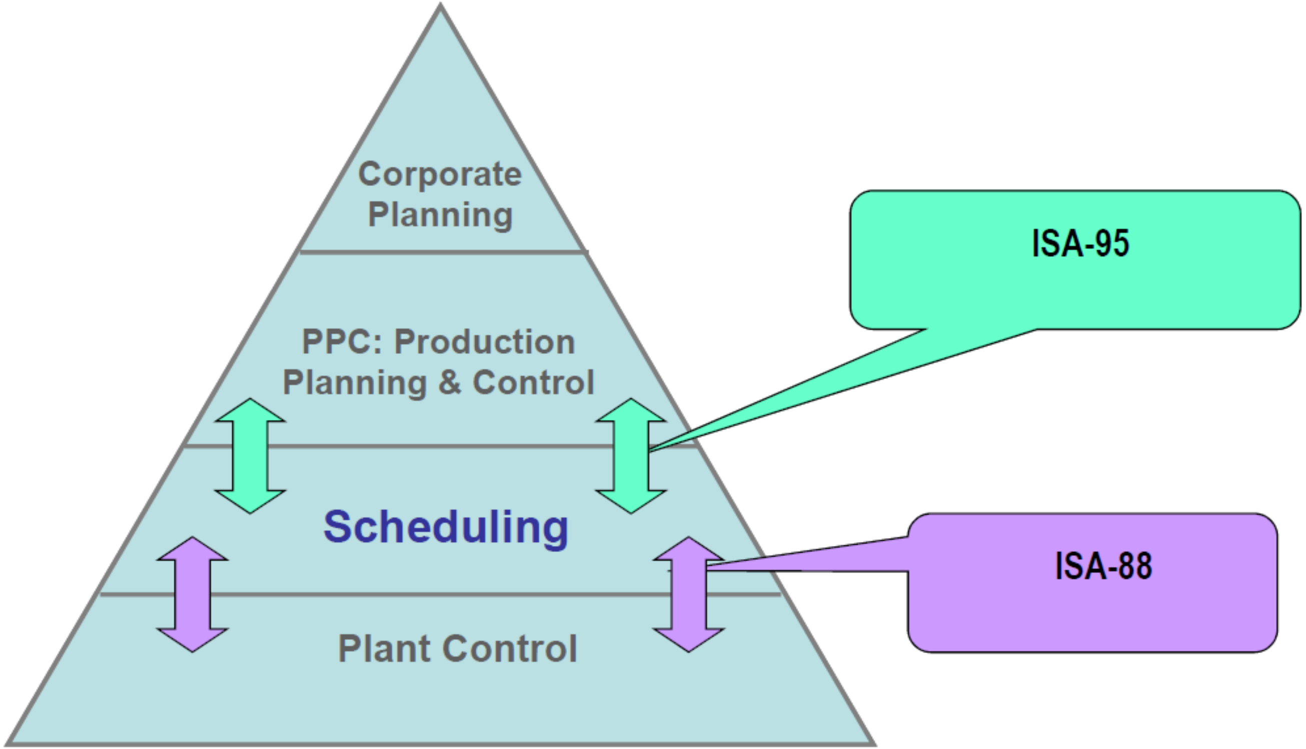


ISA 95 (ISA 88)

Hierarchical Planning



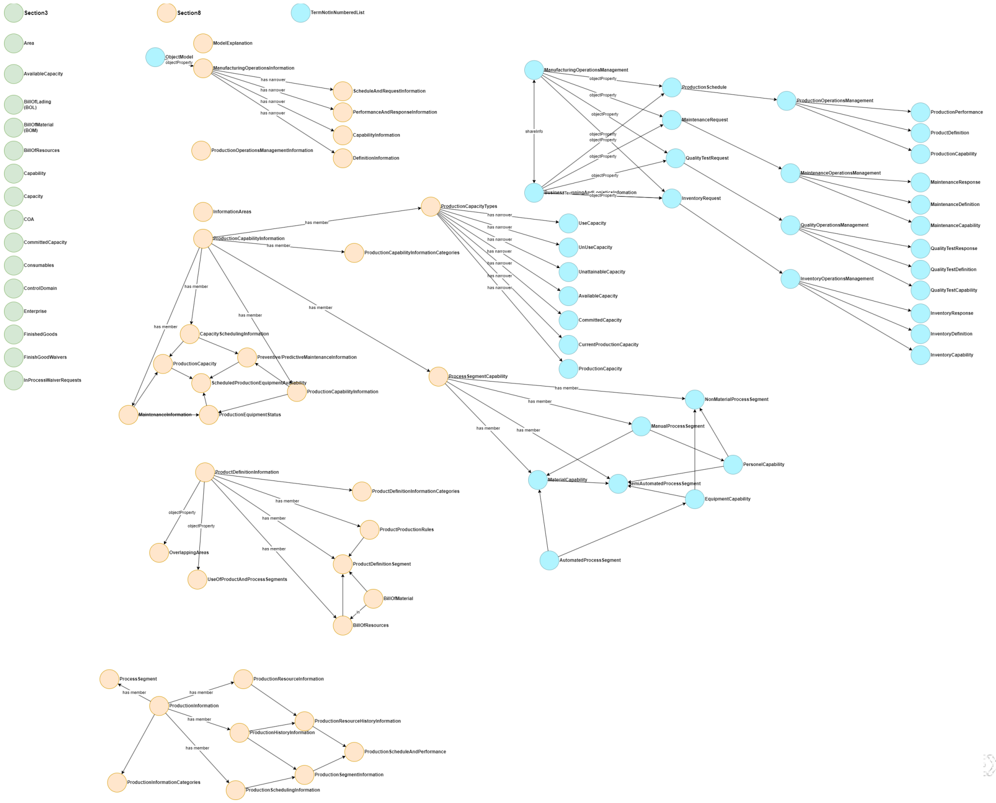
ISA 95 / ISA 88 Pyramid



ISA 95 work

- Presentation by Dennis Brandl
- Presentation/Participation by Gabriela Henning
- Started working on ISA95 concepts
  - Extracted terms from Part 1 Section 3 – definition
  - Extracted terms from Part 1 Section 5.3
  - Extracted terms from Part 1 Section 8

ISA 95 Concept Analysis



Publications

- Dušan Šormaz, Boonserm Kulvatunyou, Miloš Drobnjaković, Saruda Seeharit, Comparative Study of Approaches for an Ontology of Digital Artifacts, Proceedings of the ASME 2023 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, IDETC/CIE2023, August 20-23, 2023, Boston, MA
- Dusan Sormaz, Arkopaul Sarkar, Workshop Semantic data interoperability and integration for resilient manufacturing, 27th International Conference on Production Research, Cluj-Napoca, Romania, 23-28 July 2023.
- Arkopaul Sarkar, Milos Drobnjakovic, Sina Namaki Araghi, Mohamed Hedi Karray and Dusan Sormaz, Ontology Modeling of Plan and their Conformance to Manufacturing Execution, Proceedings of 27th International Conference on Production Research, Cluj-Napoca, Romania, 23-28 July 2023.
- Riad Al Hasan Abir, Mandvi Malik Fuloria, Dusan Sormaz, Peter Adjei, Felix Asare, David Koonce and Saruda Seeharit, Ontology Model for Mapping Terms and Relations in Plastic Manufacturing – A Case Study, Proceedings of 27th International Conference on Production Research, Cluj-Napoca, Romania, 23-28 July 2023.
- Peter Adjei, Felix Asare, Dušan Šormaz, Riad Al Hasan Abir, Mandvi Fuloria, David Koonce, and Saruda Seeharit, Application of Ontology Reasoning in Machining Process Planning – Case Study, Flexible Automation and Intelligent Manufacturing: Establishing Bridges for More Sustainable, Proceeding of FAIM2023, June 18-22, 2023.
- F Ameri, D Sormaz, F Psarommatis, D Kiritsis, Industrial ontologies for interoperability in agile and resilient manufacturing, International Journal of Production Research 60 (2), 420-441, 2022

Roadmap for IOF PPS WG Jan-June 2024

- Finish planning terms
- Digital artifacts
- Synchronize discrete, batch and process manufacturing terms (ISA95)
- Apply more use cases
- Scheduling terms
- Release the first version of planning ontology by June 30, 2024

- We need more participation in IOF PPS WG

Working Session Agenda

Thursday, 2/8, Breakout Room 2

- 16:00-16:30 – Ontology of future entities and digital artifacts – D. Sormaz
- 16:30-17:00 – Theory of Planning – A. Sarkar
- 17:00-17:30 – Production Planning and Scheduling WG Roadmap – D. Sormaz
- 17:30-18:00 - Discussion

Questions