UMassAmherst

DESIGN DECISION SUPPORT FOR MBE WITH INFORMATION MODELING

Proceedings of the NIST Model-Based Enterprise Summit 2017

MBE17-024

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eDesign

Overview

- MBE considerations of: 1) semantics and 2) Additive Manufacturing (AM) capabilities
- Toward semantic knowledge management for design/manufacturing
- Method to use information for design/manufacturing decisions
- How we can integrate knowledge domains
- A way to apply this approach for industry

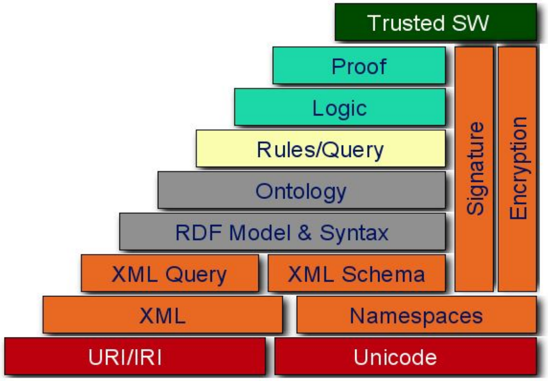
Semantic knowledge management for design / manufacturing

- Motivation
  - Capturing an using AM information in early design
  - Compare AM alternative to other processes early
  - Choose the best process combination early
- Prior approaches for conventional manufacturing
  - Work by Dr. Ameri at Texas State and others
- Approach to integrate AM information
- Process to execute decision rules
- Case study: => Should we AM this part or not?

- Discussion – recent breakthrough

Background

- Why ontologies?



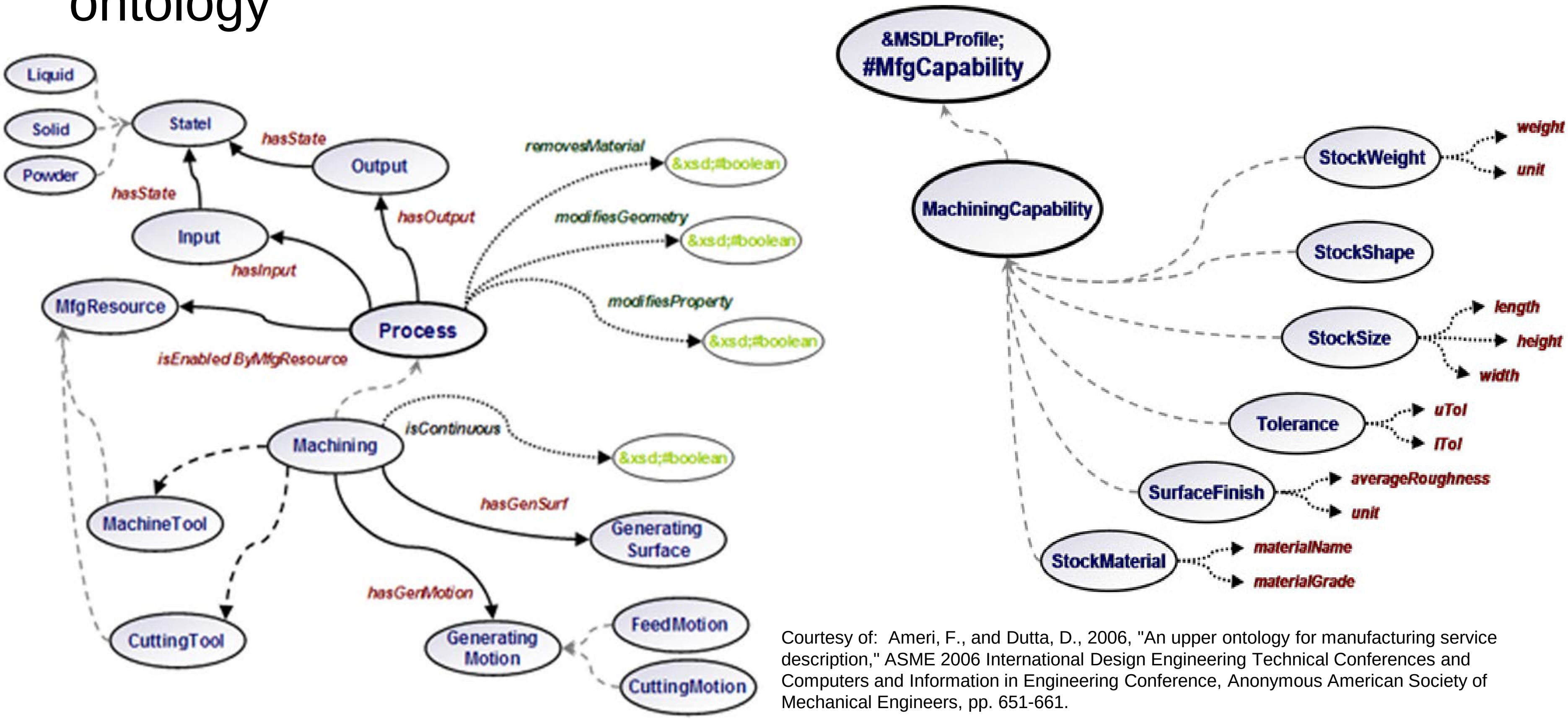
Semantic Web is ...
- a metadata based infrastructure for *reasoning* on the Web
- an *extension*, not a replacement of the current web

Courtesy of: http://www.w3c.it/talks/2005/openCulture/slide7-0.html

- Engineering examples:
  - E-Design framework at UMass
  - Works at:
    - Georgia Tech
    - Clemson
    - Virginia Tech
    - Purdue
    - Wayne State

Prior work at Texas State

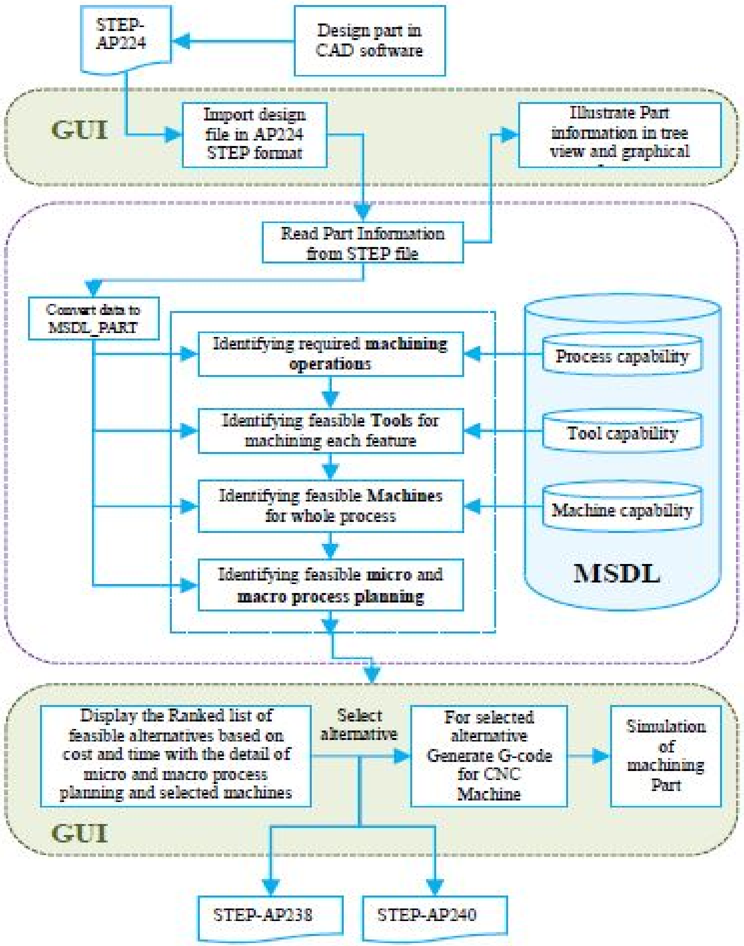
- Manufacturing Service Description Language (MSDL) ontology



Courtesy of: Ameri, F., and Dutta, D., 2006, "An upper ontology for manufacturing service description," ASME 2006 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, Anonymous American Society of Mechanical Engineers, pp. 651-661.

Prior work at Texas State

- Computer Aided Process Planning (CAPP) with MSDL
- Executed for machined part based on its STEP information



Courtesy of: Sadeghi, S., Ameri, F., Negrichi, K., 2013, "An Intelligent Process Planning System Based on Formal Manufacturing Capability Models," Proceedings of the ASME 2013 International Design Engineering Technical Conferences & Computers and Information in Engineering Conference IDETC/CIE 2013, Anonymous pp. 1-10.

Taxonomy development

Designation: F2792 – 12a

Standard Terminology for Additive Manufacturing Technologies[1,2]

This standard is issued under the fixed designation F2792; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This terminology includes terms, definitions of terms, descriptions of terms, nomenclature, and acronyms associated with additive-manufacturing (AM) technologies in an effort to standardize terminology used by AM users, producers, researchers, educators, press/media and others.

NOTE 1—The subcommittee responsible for this standard will review definitions on a three-year basis to determine if the definition is still accurate as stated. Revisions will be made when determined to be necessary.

2. Referenced Documents

2.1 *ISO Standard:*[3]

ISO 10303 -1:1994 Industrial automation systems and integration -- Product data representation and exchange -- Part 1: Overview and fundamental principles

3. Significance and Use

3.1 The definitions of the terms presented in this standard were created by this subcommittee. This standard does not purport to address safety concerns associated with the use of AM technologies. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use of additive manufacturing.

4. Additive Manufacturing Process Categories

4.1 The following terms provide a structure for grouping current and future AM machine technologies. These terms are useful for educational and standards-development purposes and are intended to clarify which machine types share processing similarities. For many years, the additive manufacturing industry lacked categories for grouping AM technologies, which made it challenging educationally and when communicating information in both technical and non-technical settings. These process categories enable one to discuss a category of machines, rather than needing to explain an extensive list of commercial variations of a process methodology.

binder jetting, *n*—an additive manufacturing process in which a liquid bonding agent is selectively deposited to join powder materials.

directed energy deposition, *n*—an additive manufacturing process in which focused thermal energy is used to fuse materials by melting as they are being deposited.

DISCUSSION—"Focused thermal energy" means that an energy source (e.g., laser, electron beam, or plasma arc) is focused to melt the materials being deposited.

material extrusion, *n*—an additive manufacturing process in which material is selectively dispensed through a nozzle or orifice.

material jetting, *n*—an additive manufacturing process in which droplets of build material are selectively deposited.

DISCUSSION—Example materials include photopolymer and wax.

powder bed fusion, *n*—an additive manufacturing process in which thermal energy selectively fuses regions of a powder bed.

sheet lamination, *n*—an additive manufacturing process in which sheets of material are bonded to form an object.

vat photopolymerization, *n*—an additive manufacturing process in which liquid photopolymer in a vat is selectively cured by light-activated polymerization.

5. Terminology

5.1 *Definitions:*

3D printer, *n*—a machine used for 3D printing.

3D printing, *n*—the fabrication of objects through the deposition of a material using a print head, nozzle, or another printer technology.

DISCUSSION—Term often used synonymously with additive manufacturing; in particular associated with machines that are low end in price and/or overall capability.

[1] This terminology is under the jurisdiction of Committee F42 on Additive Manufacturing Technologies and is the direct responsibility of Subcommittee F42.91 on Terminology.

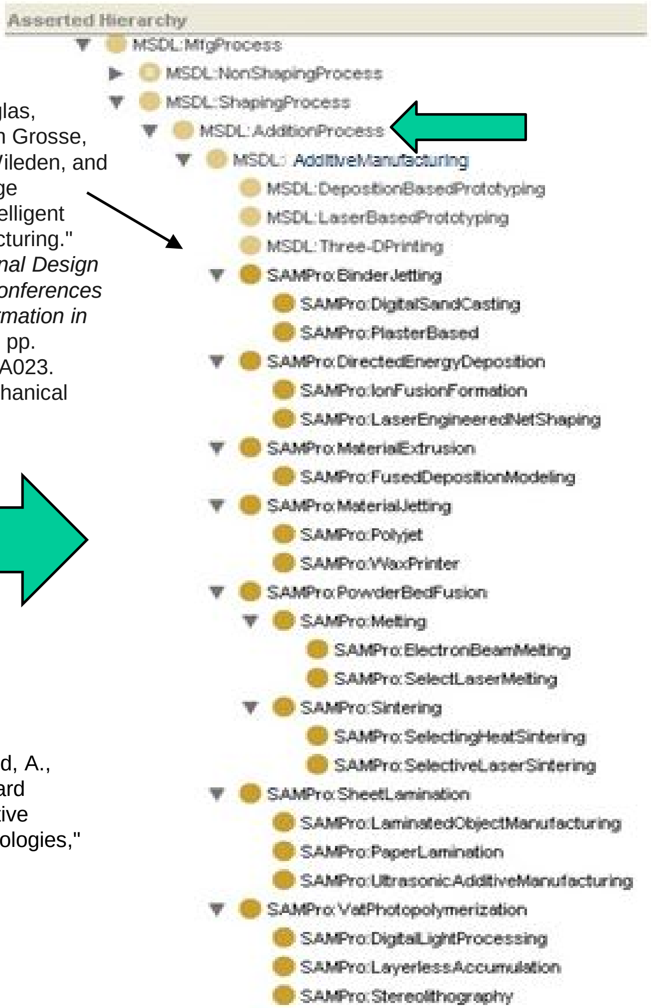
Current edition approved March 1, 2012. Published March 2012. Originally approved in 2009. Last previous edition approved in 2012 as F2792–12. DOI: 10.1520/F2792-12A.

[2] Through a mutual agreement with ASTM International (ASTM), the Society of Manufacturing Engineers (SME) contributed the technical expertise of its RTAM Community members to ASTM to be used as the technical foundation for this ASTM standard. SME and its membership continue to play an active role in providing technical guidance to the ASTM standards development process.

[3] Available from International Organization for Standardization (ISO), 1, ch. de la Voie-Creuse, Case postale 56, CH-1211, Geneva 20, Switzerland, http://www.iso.org/iso/iso_catalogue/catalogue_tc/catalogue_detail.htm?csnumber=20579

Courtesy of: Standard, A., "F2792. 2012. Standard Terminology for Additive Manufacturing Technologies," ASTM F2792-10e1.

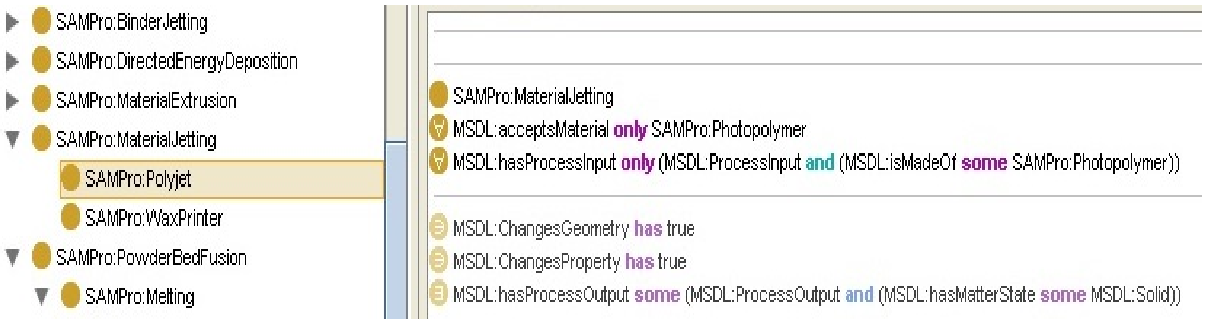
Courtesy of: Eddy, Douglas, Sundar Krishnamurty, Ian Grosse, Maxwell Perham, Jack Wileden, and Farhad Ameri. "Knowledge Management With an Intelligent Tool for Additive Manufacturing." In *ASME 2015 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference*, pp. V01AT02A023-V01AT02A023. American Society of Mechanical Engineers, 2015.



Process capability definition

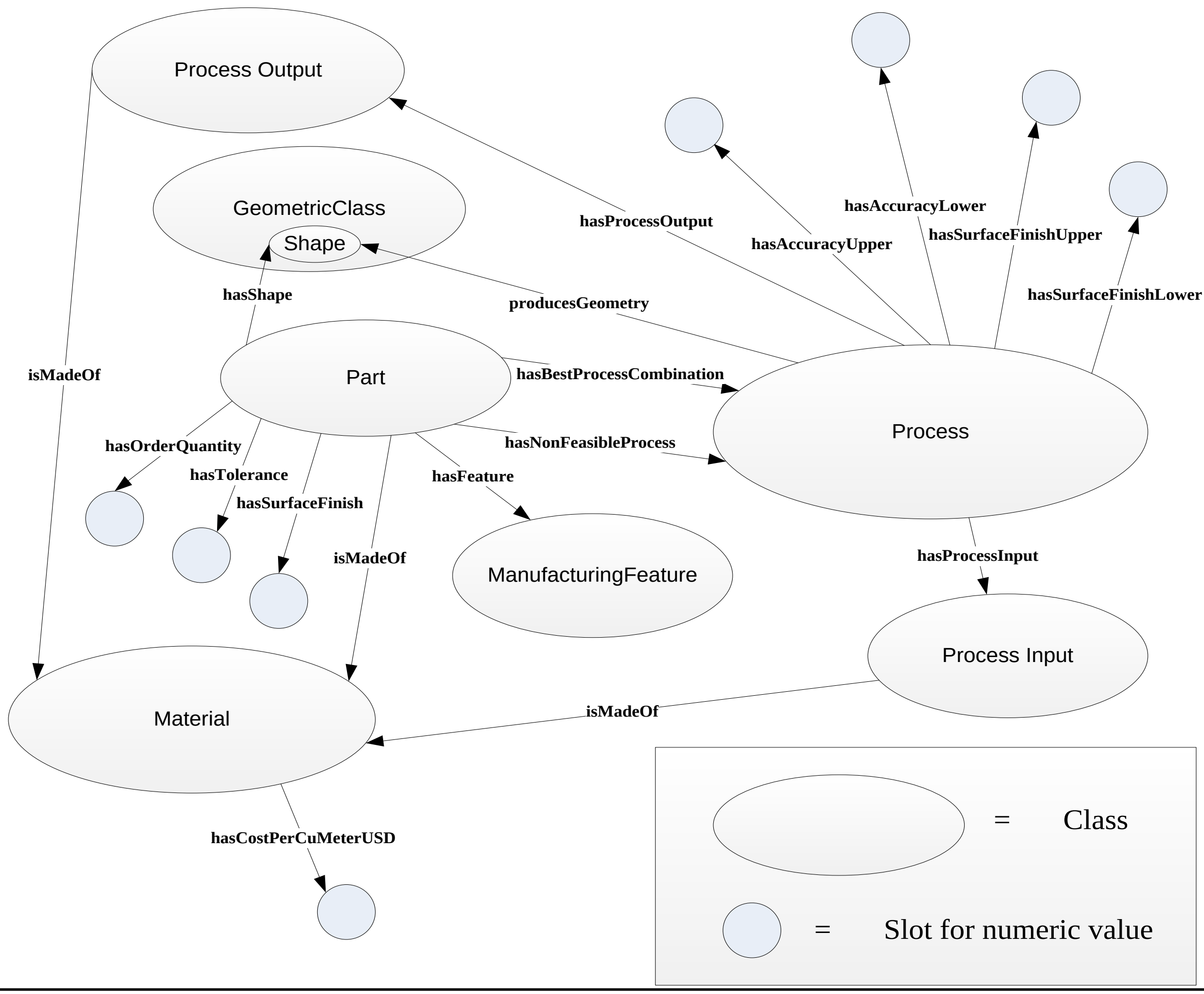
- Using Protégé v. 3.4.8
- Defined by property restrictions
  - Some inherited from conventional process definitions:

  - Others unique to a specific AM process:



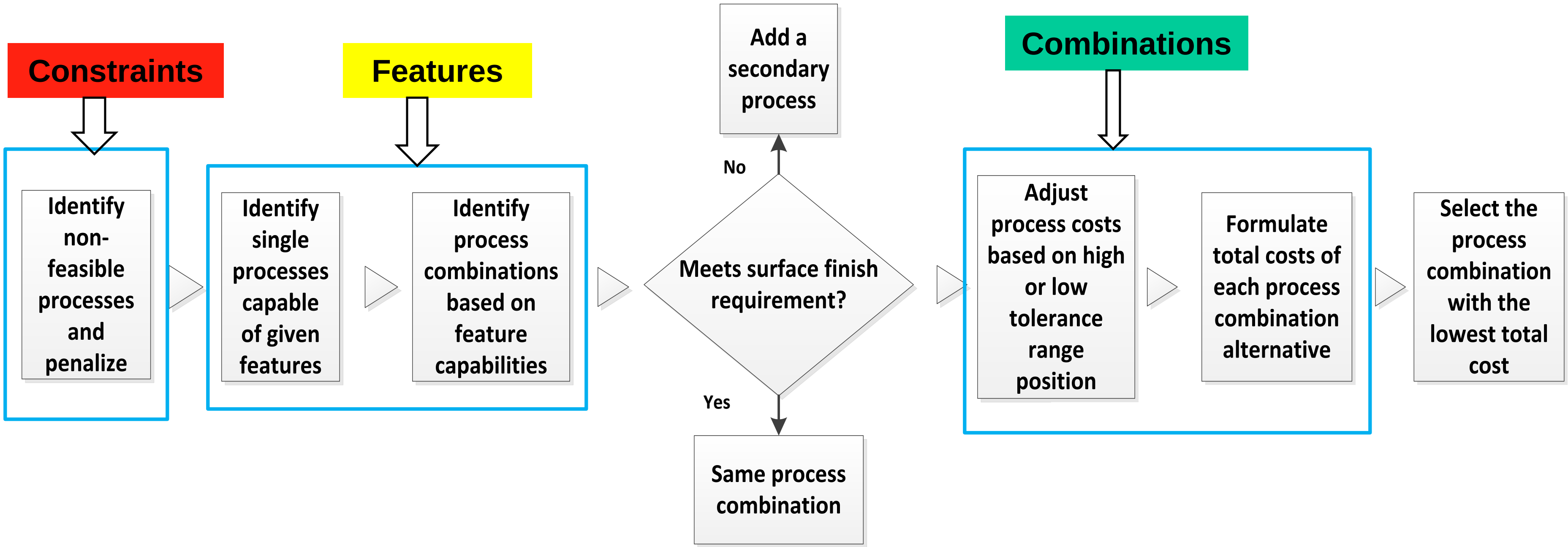
Knowledge management framework

- AM information fits into prior structural framework
- This way, AM processes can be compared to the others.
- Enables Semantic Additive Manufacturing PROcess Planning (SAMPro)



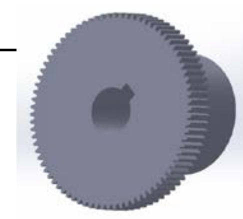
Decision rule process of SAMPro

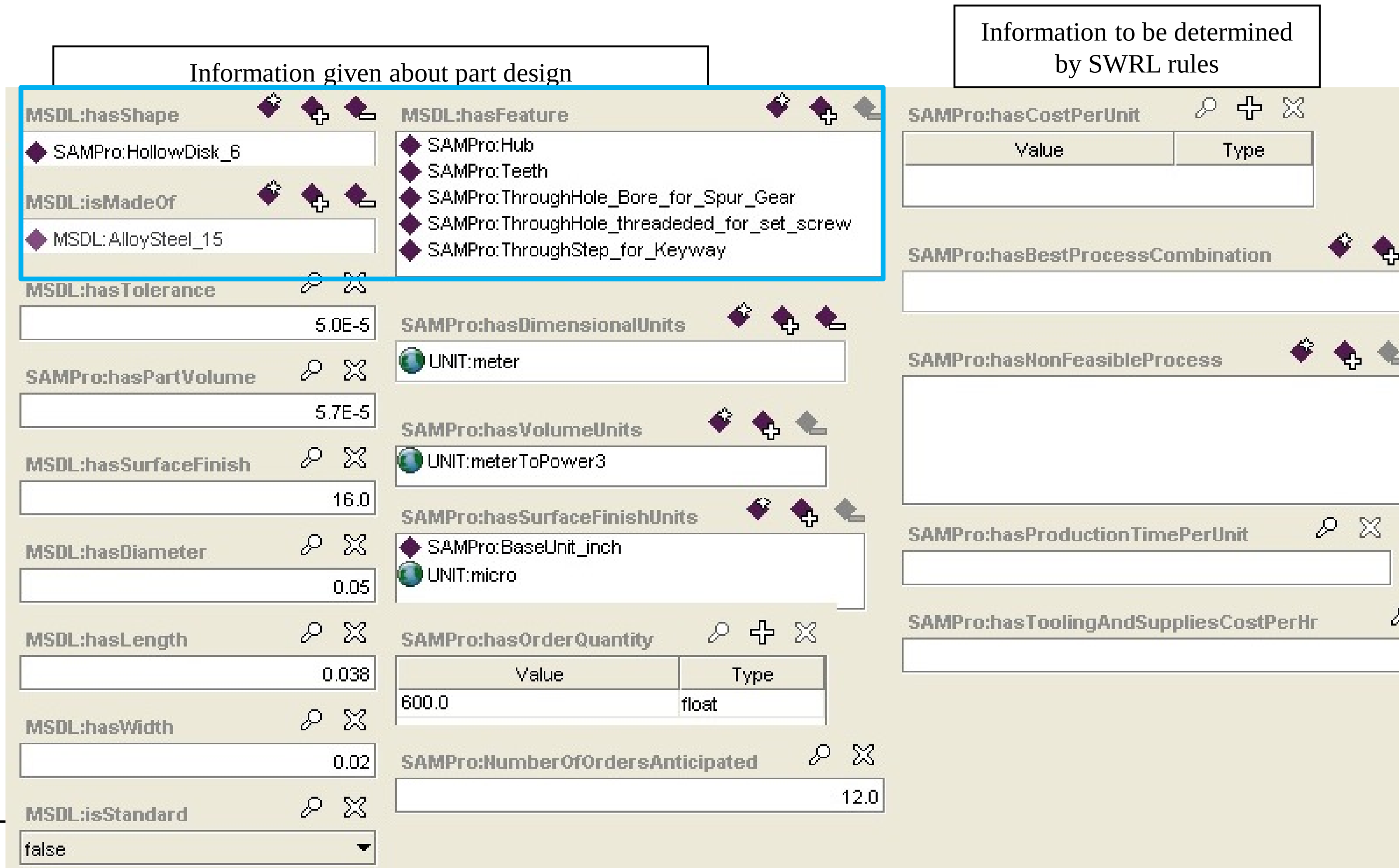
- Aligned with traditional DFM principles
- Executes on information – prior to any CAD
- Early high level comparison => best path to proceed



Case study – steel spur gear

- How should we make it? =>
- Part information



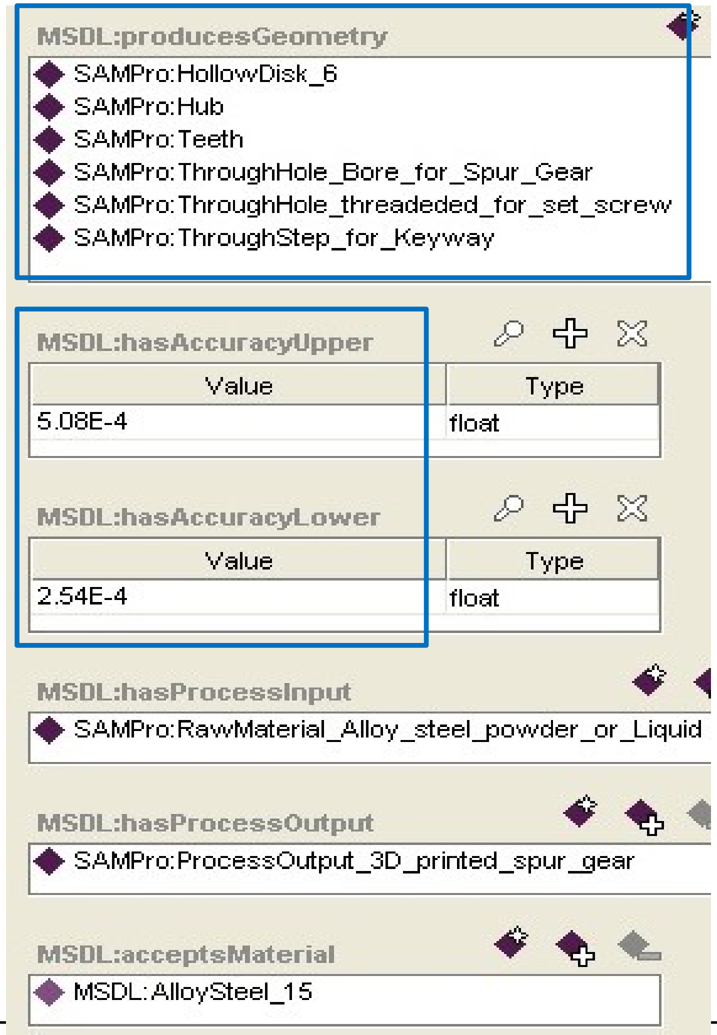


Modeling the information about processes

- Compared to information about the part's requirements

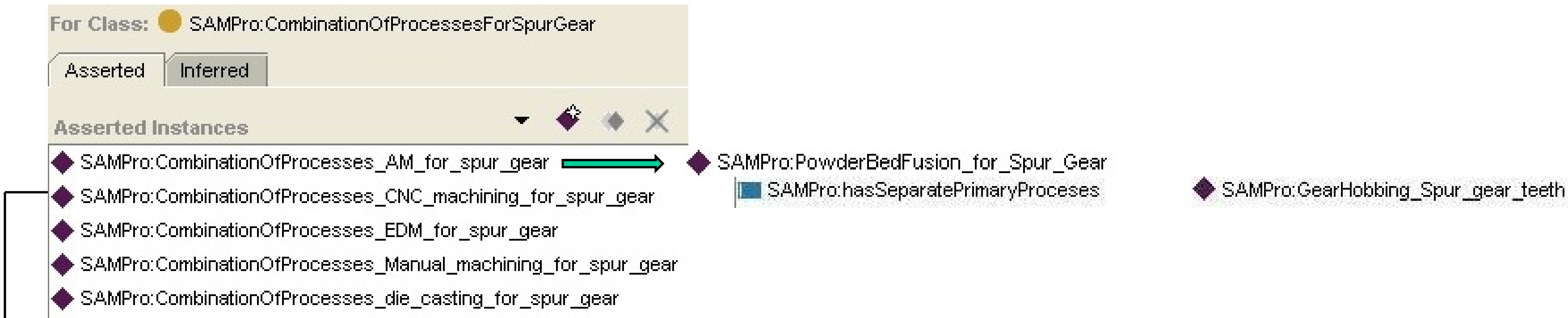
- Utilizes the same framework for AM and conventional manufacturing
  - Note that slots are labeled as MSDL here.
  - Common slots for all processes

◆ SAMPro:PowderBedFusion_for_Spur_Gear = >



Candidate process combinations

- Examples
  - Several alternatives to compare



Property	Value	Type
rdf:type	SAMPro:CombinationOfProcessesForSpurGear	owl:Class
SAMPro:hasEnvironmentalImpact	MSDL:Medium_5	MSDL:Medium
SAMPro:hasEquipmentOperatorPayrate	165.0	float
SAMPro:hasEquipmentOperatorPayrateUnits	SAMPro:BaseUnit_USD	UNIT:BaseUnit
SAMPro:hasEquipmentOperatorPayrateUnits	UNIT:perHour	UNIT:UnitDerivedByRaisingToPower
SAMPro:hasProductionTimeeUnits	UNIT:hour	UNIT:UnitDerivedByScaling
SAMPro:hasProductionTimePerUnit	0.25	float
SAMPro:hasSeparatePrimaryProceses	SAMPro:GearHobbing_Spur_gear_teeth	MSDL:GearHobbing
SAMPro:hasSetupTime	0.6	float
SAMPro:hasSetupTimeUnits	UNIT:hour	UNIT:UnitDerivedByScaling
SAMPro:hasToolingAndSuppliesCostUSDPerHr	10.0	float
SAMPro:hasVolumeUnits	UNIT:meterToPower3	UNIT:UnitDerivedByRaisingToPower
SAMPro:hasWasteQuantitative	4.0E-5	float

Case specific rules

- Example: What combination of processes are needed to EDM the part?
- SWRL rule to check for tolerance by EDM:

SWRL Rule

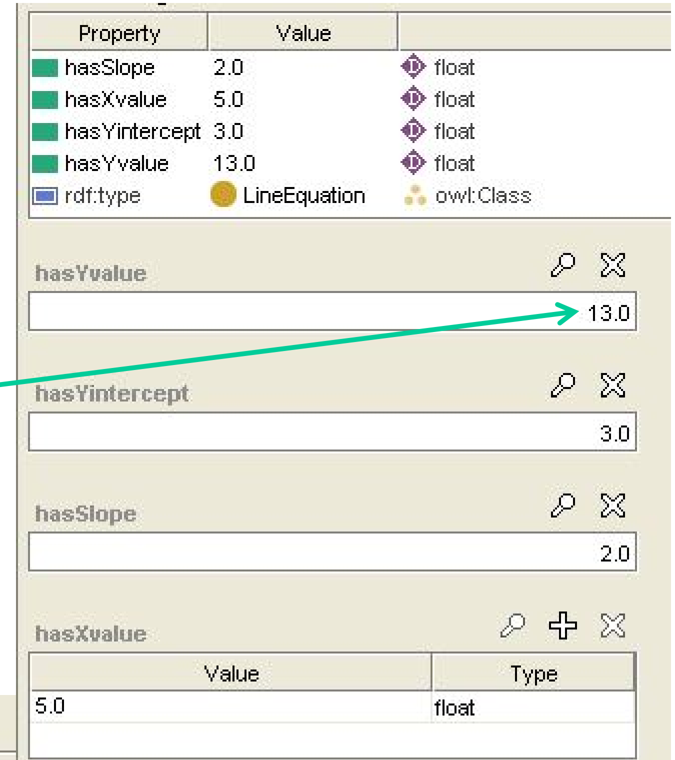
MSDL:Part(SAMPro:SpurGear) ∧ MSDL:WireEDM(SAMPro:WireEDM_Spur_gear) ∧ MSDL:hasTolerance(SAMPro:SpurGear, ?y) ∧
MSDL:hasAccuracyLower(SAMPro:WireEDM_Spur_gear, ?x) ∧ swrlb:greaterThan(?x, ?y) →
SAMPro:hasSeparateSecondayProcess(SAMPro:CombinationOfProcesses_EDM_for_spur_gear, SAMPro:GearHobbing_Spur_gear_teeth)
∧ SAMPro:hasSeparateThirdProcess(SAMPro:CombinationOfProcesses_EDM_for_spur_gear, SAMPro:Reaming_bore_for_spur_gear) ∧
MSDL:hasProcessOutput(SAMPro:CombinationOfProcesses_EDM_for_spur_gear, SAMPro:ProcessOutput_completely_finished_spur_gear)

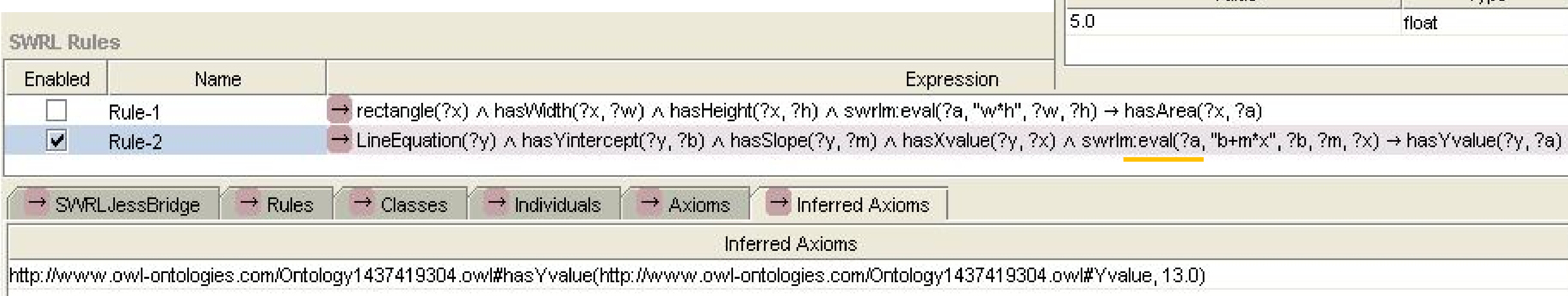
- Inferred information from rule that determined additional processes are necessary:

Property	Value
MSDL:hasProcessOutput	SAMPro:ProcessOutput_completely_finished_spur_gear
rdf:type	SAMPro:CombinationOfProcessesForSpurGear
SAMPro:hasSeparatePrimaryProceses	SAMPro:WireEDM_Spur_gear
SAMPro:hasSeparateSecondayProcess	SAMPro:GearHobbing_Spur_gear_teeth
SAMPro:hasSeparateThirdProcess	SAMPro:Reaming_bore_for_spur_gear

Addressing OWL limitations for calculations

- Import of swrlm built-in
  - Eval function for multiple operations
- Example: y = mx + b
- Execution of the rule below returns the value of





Discussion

Pros

- Consistent with emerging Semantic Web technologies
- Advantage of using prior work to add new concepts
- Shows that AM can fit within conventional manufacturing framework
  - Suitable for consistent logical comparisons => process selection
- Conceptual proof of this concept
  - Potential for early design decisions with transparency
- Extendable to accept constantly expanding knowledge base

Cons

- Time to create rules
- Learning syntax
- Functionality of rules
- User friendliness of the tools needs improvement

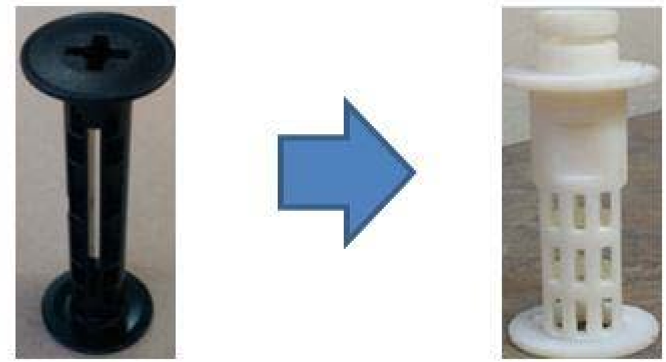
Higher level challenges

- Basic Formal Ontology (BFO) alignment
  - Theory developed by Barry Smith from U at Buffalo and others
  - Can domain concepts be represented consistently and related with other domains?

- Later, how we address these challenges
- Next, methodical prescription for use...

Method to inform design decisions

- Motivation
  - Right decision made early – AM or not AM?
- Decision Support System for Additive Manufacturing (DS-SAM)
  - Usable template
  - Rationale
- Design process
- Case study
- Recent improvements to the method



Which camera spool should we design?

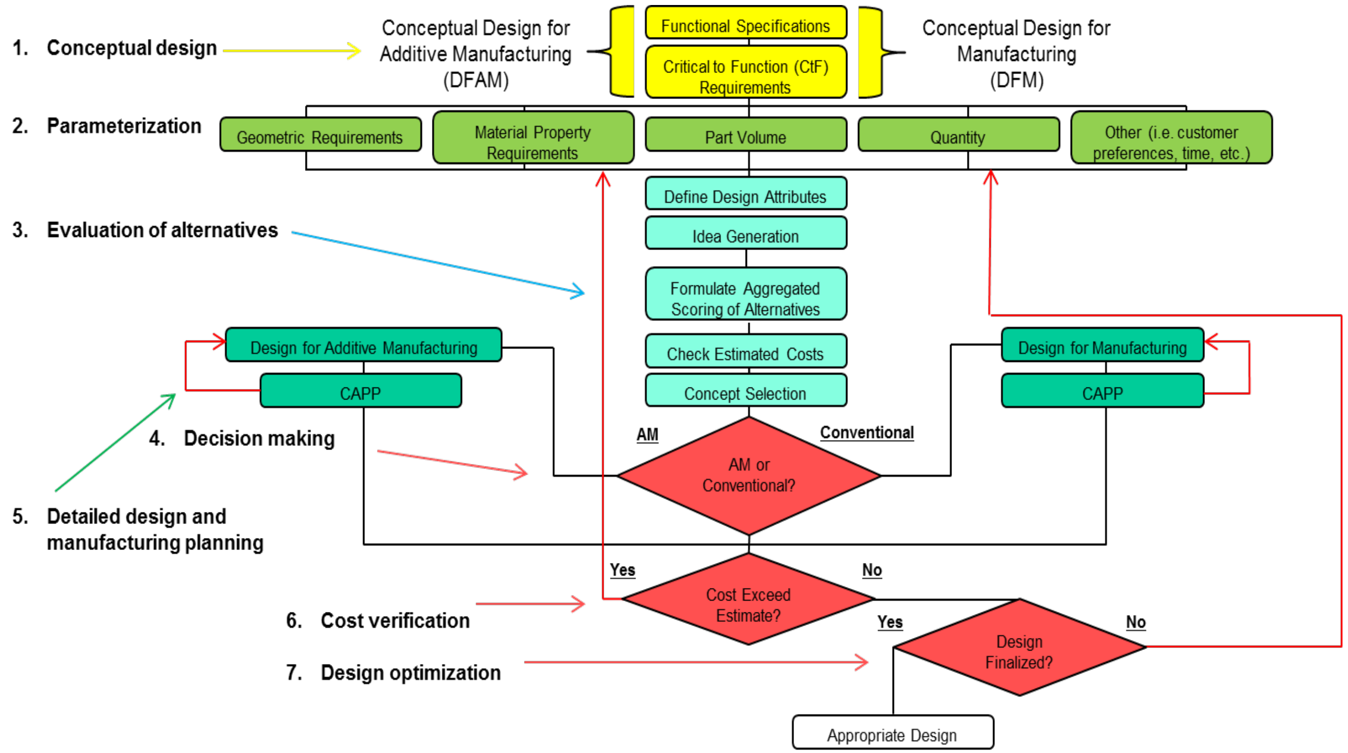
Design courtesy of:
Gibson, Ian, David Rosen, and Brent Stucker. "Design for Additive Manufacturing." - Springer. N.p., 2010. Web. 29 Nov. 2015.

Background

- Some current **AM research gaps**
  - Design and manufacturing integration
  - Early design stage process planning
  - AM process capabilities vs. conventional manufacturing
  - When and how to best use DFAM
    - When should we not use AM?

- **Objectives:**
  1. Decision making method
     - With early stage information
  2. Usable template to assess and compare alternatives

Decision Support System for Additive Manufacturing (DS-SAM)

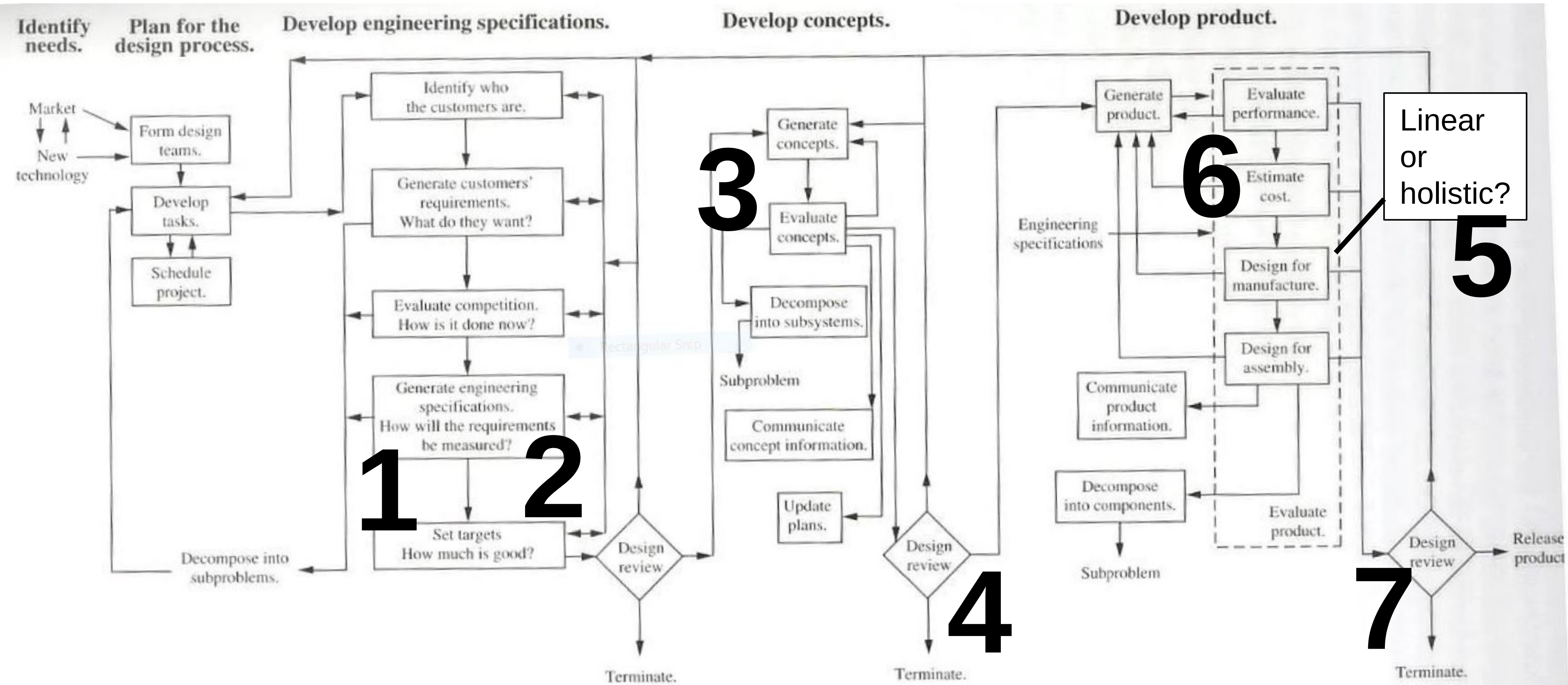


How can we:

1. decide correctly? (effectiveness)
2. decide early? (efficiency)

Courtesy of: Eddy, Douglas, Justin Calderara, Mark Price, Sundar Krishnamurty, and Ian Grosse. "Approach Towards a Decision Support System for Additive Manufacturing." In ASME 2016 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference, pp. V01AT02A047-V01AT02A047. American Society of Mechanical Engineers, 2016.

Where does it fit?



Courtesy of: Ullman, David G. The Mechanical Design Process. New York: McGraw-Hill, 1992.

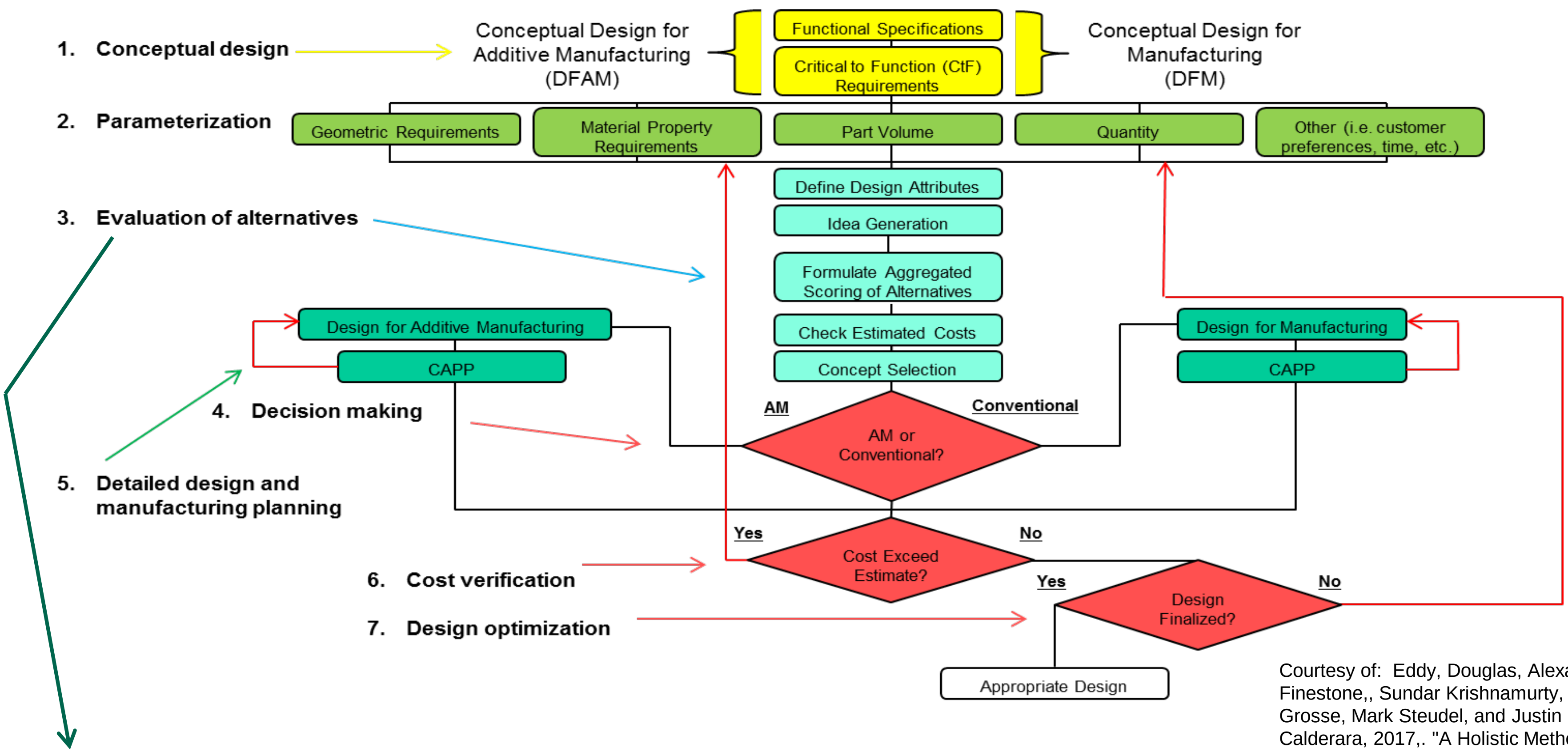
Rationale for approach

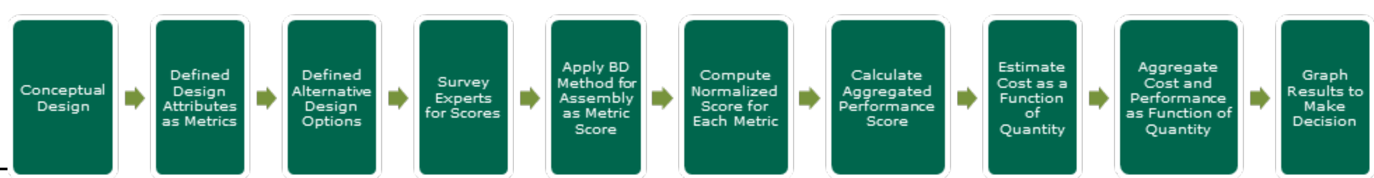
- Manufacturing influence on design
  - Conventional manufacturing => reduce complexity
  - DFAM => increase complexity to improve design

- Increases array of design concepts

- Holistic comparison of alternatives
  - Parameterized
  - Multiple attributes

DS-SAM approach

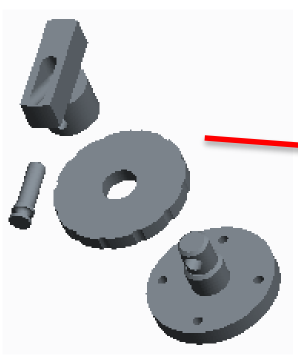




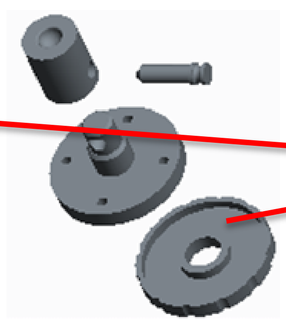
Courtesy of: Eddy, Douglas, Alexander Finestone,, Sundar Krishnamurty, Ian Grosse, Mark Steudel, and Justin Calderara, 2017,. "A Holistic Method toward a Decision Support System for Additive Manufacturing" ASME Journal of Mechanical Design Special Issue: Designing for Additive Manufacturing, **in review.**

Case Study: Animal Subject Test Mechanism

- Parts used in mouse-leg mounting rig for cancer research lab
  - Originally CNC machined of aluminum
- **Goal:** Use DS-SAM to determine whether correct process was used, analyze for various quantities
- Collaboration with Prof. Maureen Lynch at UMass Life Sciences Lab

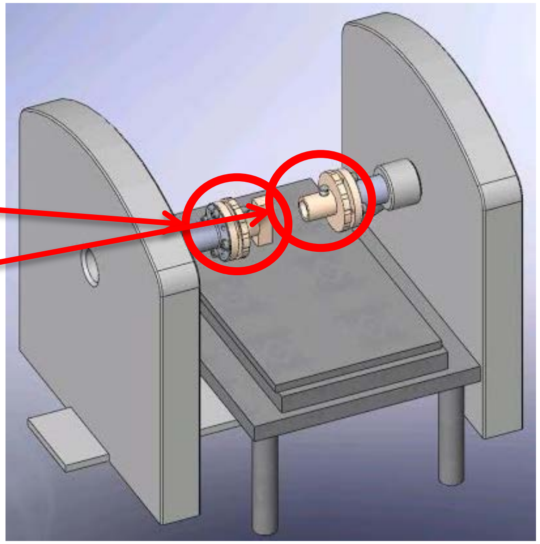


Ankle Fixture



Knee Fixture

Original Configuration

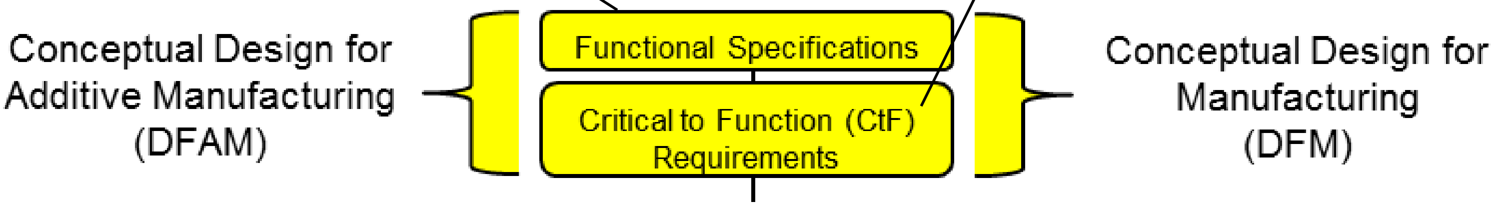


Proposed AM Parts

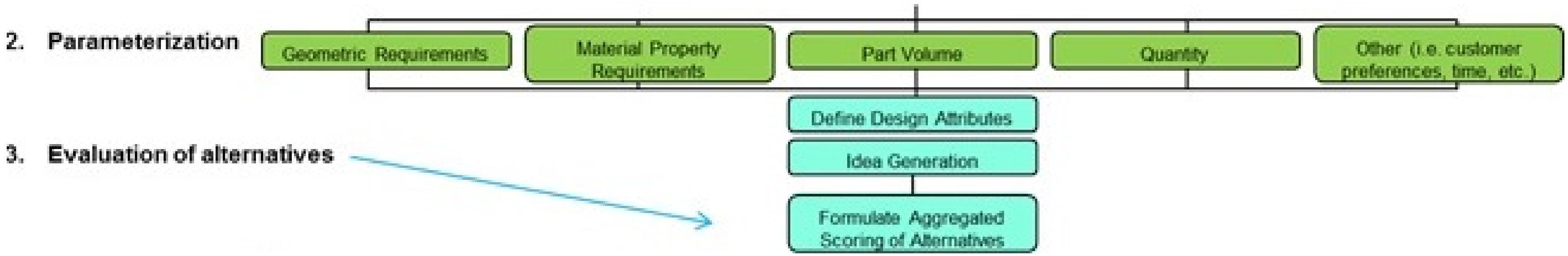
Function specifications and requirements

Functional Specification
Must be attachable and detachable from rig
Must allow mouse to be mounted easily
Must be capable of gripping the mouse securely
Must be able to be cleaned without damaging parts
Must not cause injury or pain to mouse

Critical to Function Requirement (CtF)
Dimensions of knee and ankle slot must be exact
Knee and ankle fixtures must be detachable
Dimension of bore on mounting disk must be snug and parallel to the shaft
Material must be sufficiently strong to withstand cyclic loading



Alternatives identified



	Material	Method of Fabrication
1	Plastic	Injection mold as 8, separate parts
2	Metal	Machine as 8, separate parts
3	Plastic	Injection mold as 2 parts
4	Metal	Machine as 2 parts
5	Plastic	Rapid Injection Mold as 2 parts
6	Plastic	AM as 8, separate parts
7	Metal	AM as 8, separate parts
8	Plastic	AM as 2 parts
9	Metal	AM as 2 parts

Formulate aggregated scoring

- Scoring from expert with AHP
  - Preference
  - Performance
- DFA for "Ease of Assembly"
  - 8 part efficiency = 32%
  - 2 part efficiency = 100%

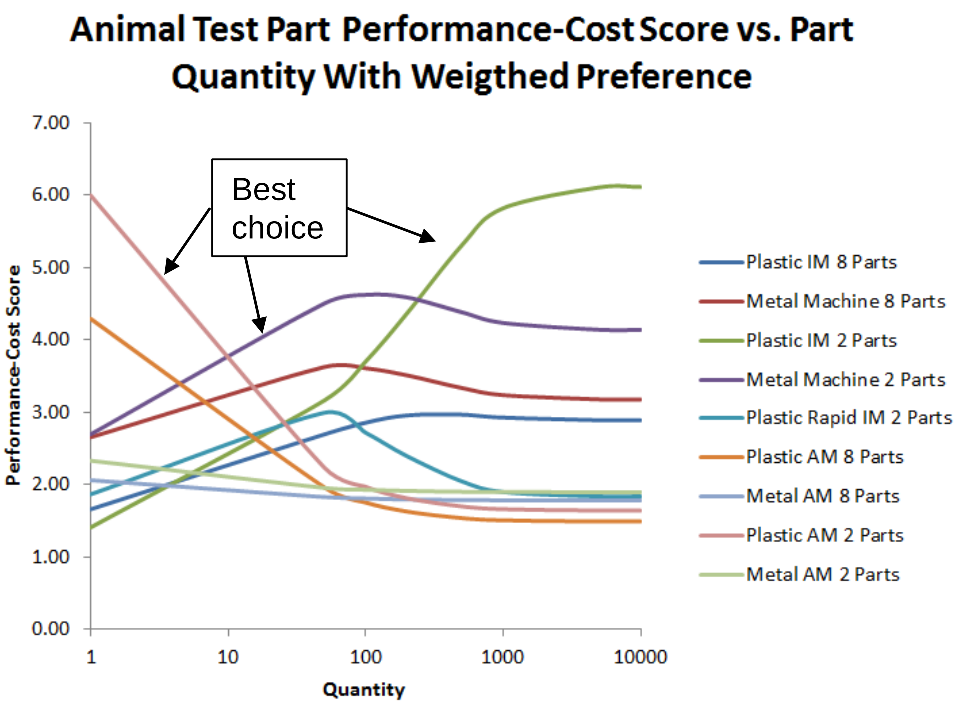
Final Rankings of Alternatives	
1st	Metal Machine 8 Parts (0.1649)
2nd	Metal Machine 2 Parts (0.1519)
3rd	Metal AM 2 Parts (0.1353)
4th	Metal AM 8 Parts (0.1274)
5th	Plastic AM 2 Parts (0.1036)
6th	Plastic IM 8 Parts (0.0984)
7th	Plastic AM 8 Parts (0.0958)
8th	Plastic IM 2 Parts (0.0711)
9th	Plastic Rapid IM 2 Parts (0.0515)

Critical Criteria	Preference Score
Cleaning	3
Withstand Fatigue Load	10
Geometry	8
Mouse Safety/Comfort	7
Ease of Assembly	5

	Cleaning	Withstand Fatigue Load	Geometry	Mouse Safety/Comfort	Ease of Assembly
Plastic IM 8 Parts	7	8	9	9	[redacted]
Metal Machine 8 Parts	10	10	8	8	[redacted]
Plastic IM 2 Parts	7	8	3	6	[redacted]
Metal Machine 2 Parts	10	10	3	6	[redacted]
Plastic Rapid IM 2 Parts	7	7	3	6	[redacted]
Plastic AM 8 Parts	7	6	10	10	[redacted]
Metal AM 8 Parts	8	8	10	10	[redacted]
Plastic AM 2 Parts	7	6	10	10	[redacted]
Metal AM 2 Parts	8	8	10	10	[redacted]

Comparative results

Final formulation: $PerfCost(N) = [(Perf_{Score}) * (Perf_{weight})] + [(Cost_{Norm}(N)) * (Cost_{weight})]$



	Performance Rankings of Alternatives
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Discussion

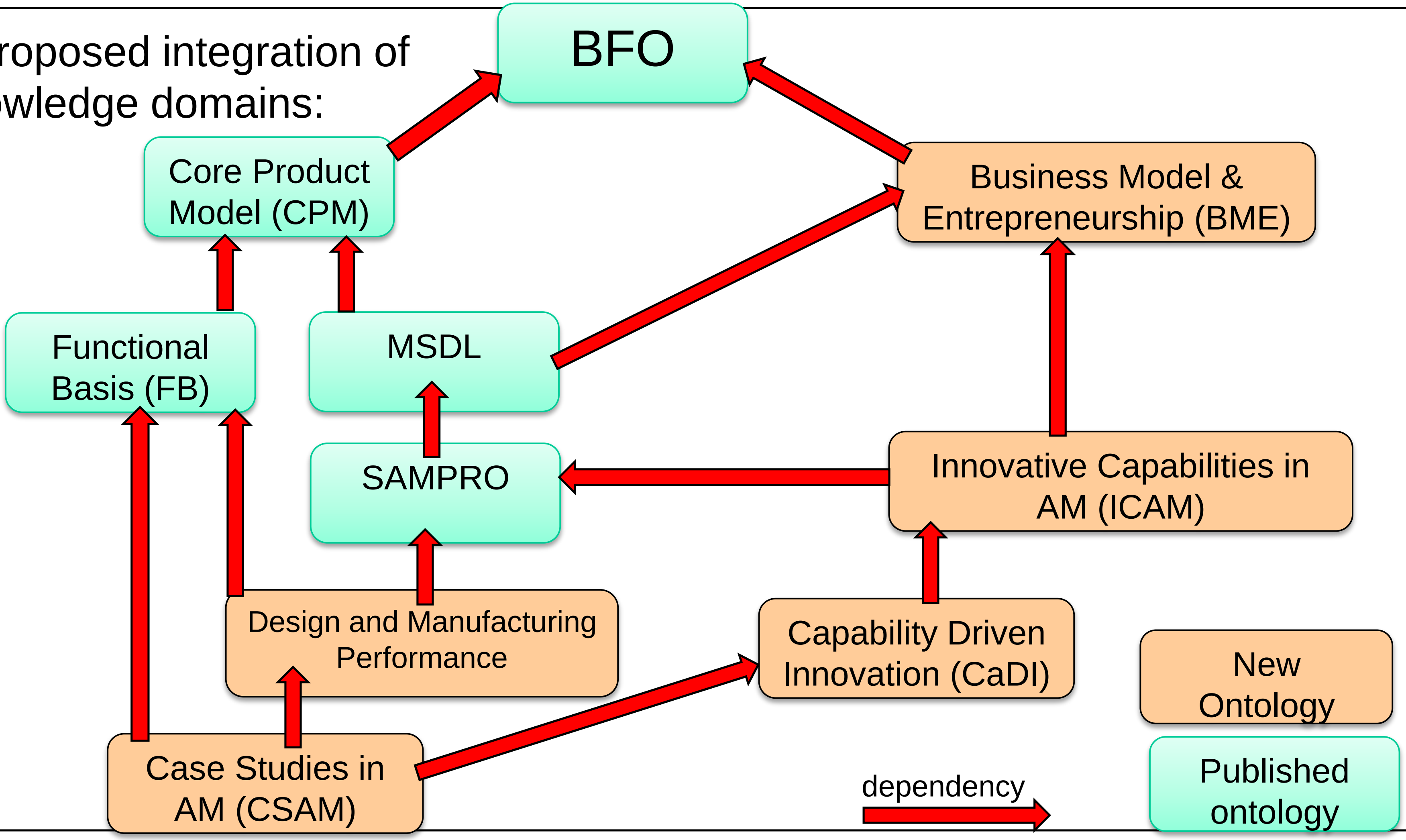
Contributions:

- Practical guidance
- Useful methodology
- Recent improvements

- Important guidelines:
  1. Is it grounded in established principles?
  2. Can we make the best decision as early as possible?
  3. Is it as efficient as possible?
  4. Can we combine for fit with other approaches?
     a) How does it compare with others?
     b) And within high level domain concepts?...

How can we solve the high level information modeling problem?

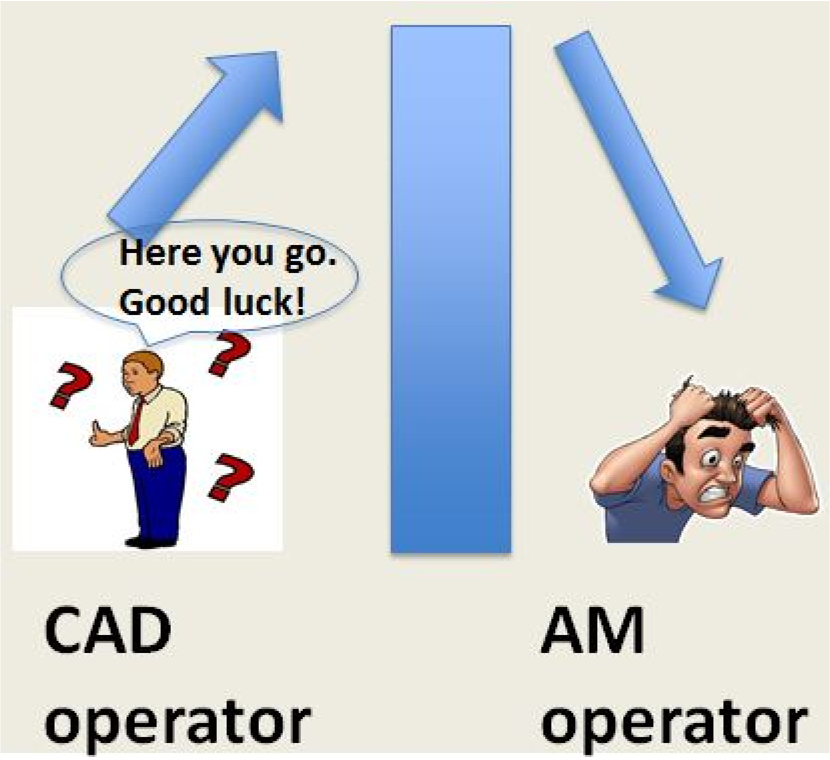
A proposed integration of knowledge domains:



Industry relevance

The disconnect between CAD and metal AM operations gets expensive!

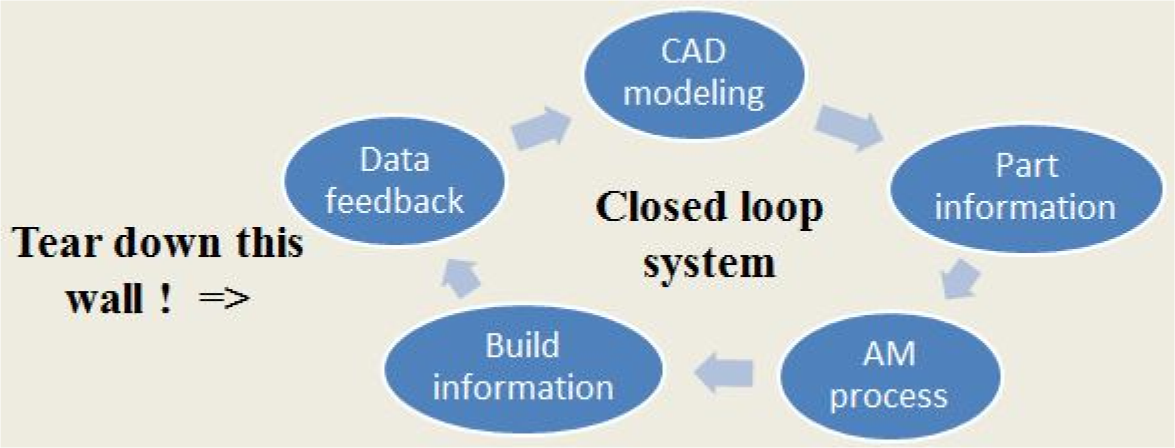
- **Problem:** Nothing tells a CAD operator whether their model will produce a good or bad part until it's too late!
- **Solution:** An effective tool would alert the CAD operator by a green light or red flag

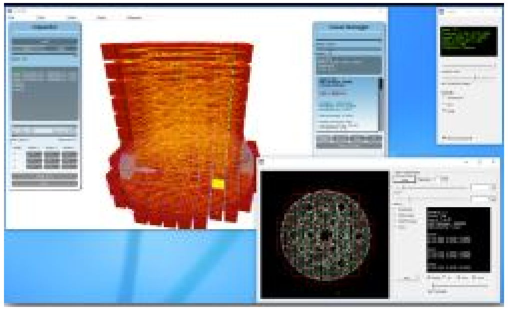


Problem statement

There's a lack of open qualification and certification data tools for metallic AM parts!

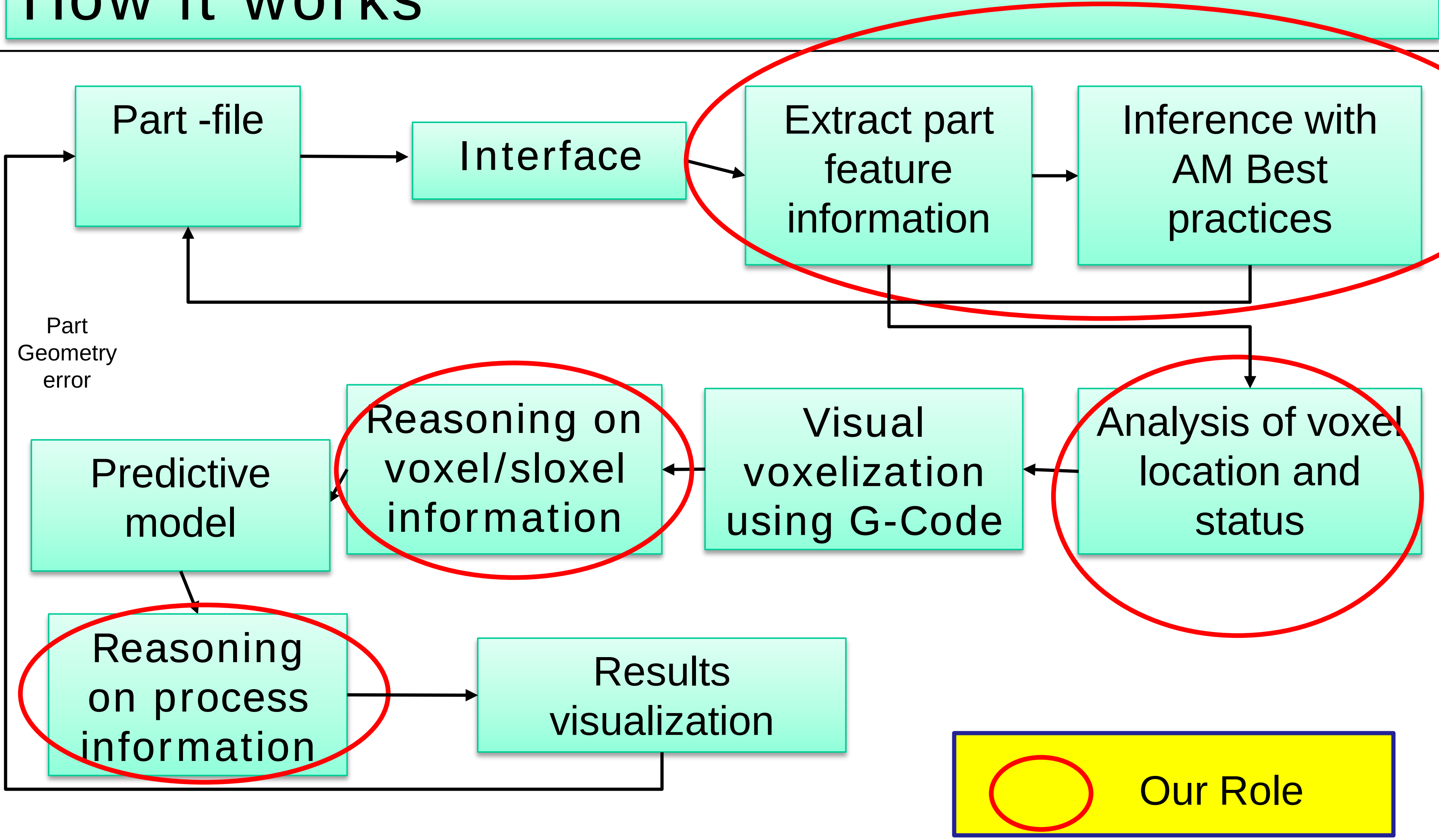
- Potential data includes: tool parameters, result targets, scan paths, process data, and measured results.
- Existing CAD tools can not acquire and manage such data
- Framework required to manage, store, and manipulate data





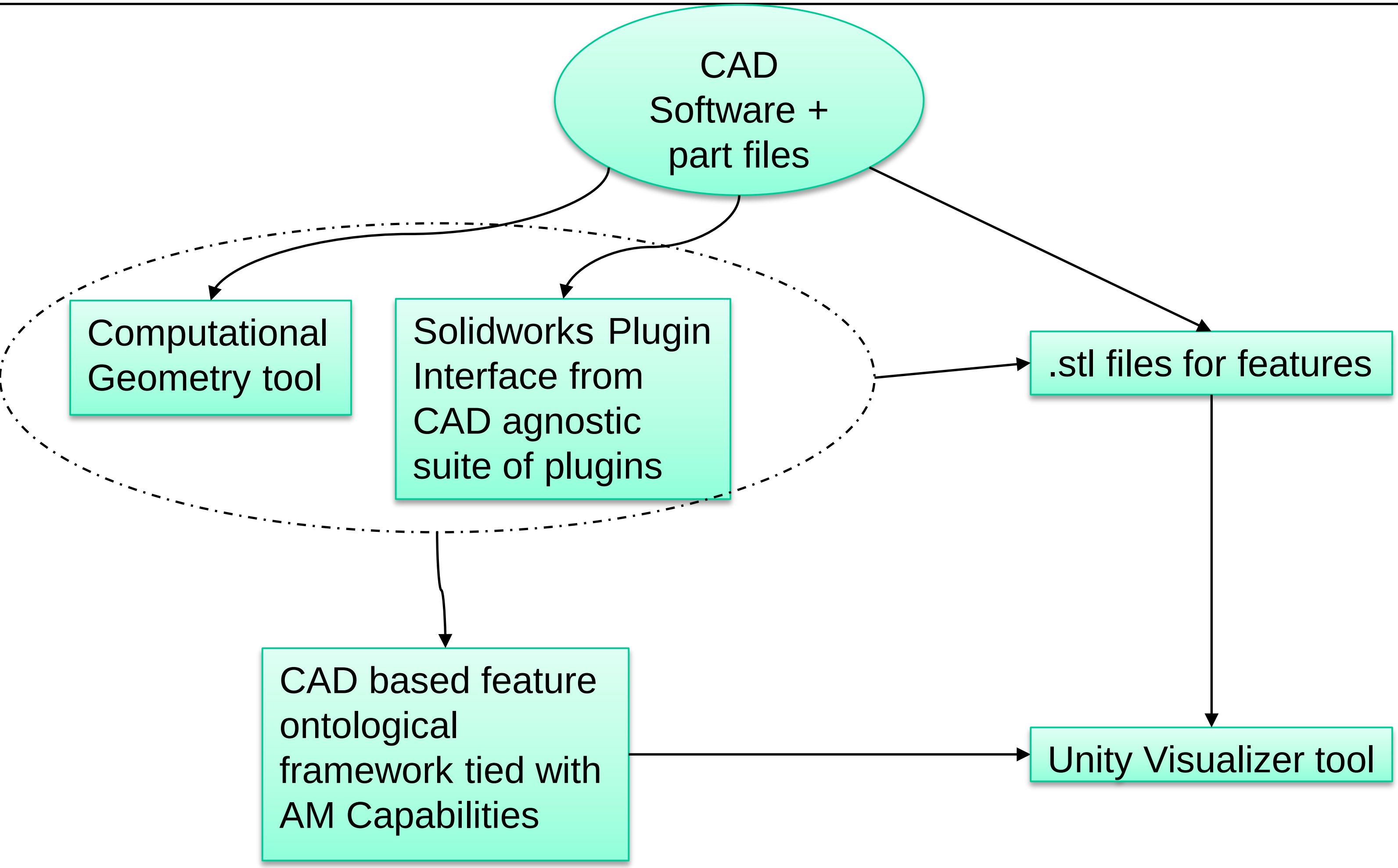
Courtesy of:
http://ftllabscorp.com/

How it works

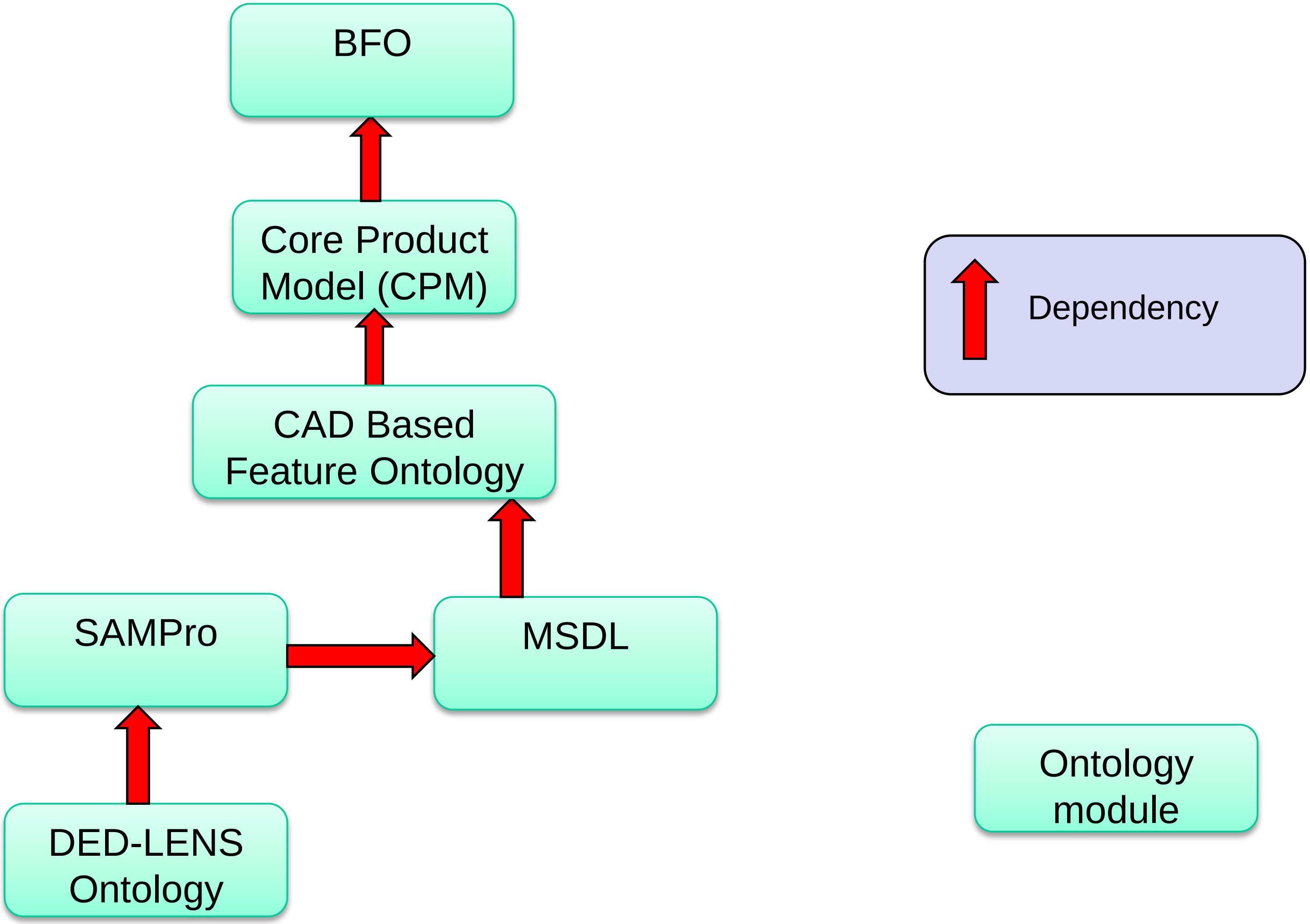


Part -file
Interface
Extract part feature information
Inference with AM Best practices
Part Geometry error
Reasoning on voxel/sloxel information
Visual voxelization using G-Code
Analysis of voxel location and status
Predictive model
Reasoning on process information
Results visualization
Our Role

Visualization tool flow



CAD feature ontology in BFO



Summary

- Represent knowledge for AM with that of other manufacturing semantically (based on context)
- Information can be used in methodical decision making.
- Method addressed early decision making about AM or not AM assessments.
- Future work could link information domains at the highest level of concepts.
- Application can relate part features to AM capabilities to influence design/process decisions.

Questions?