Model-based Visualization for Resistance Spot Welded Assembly Design

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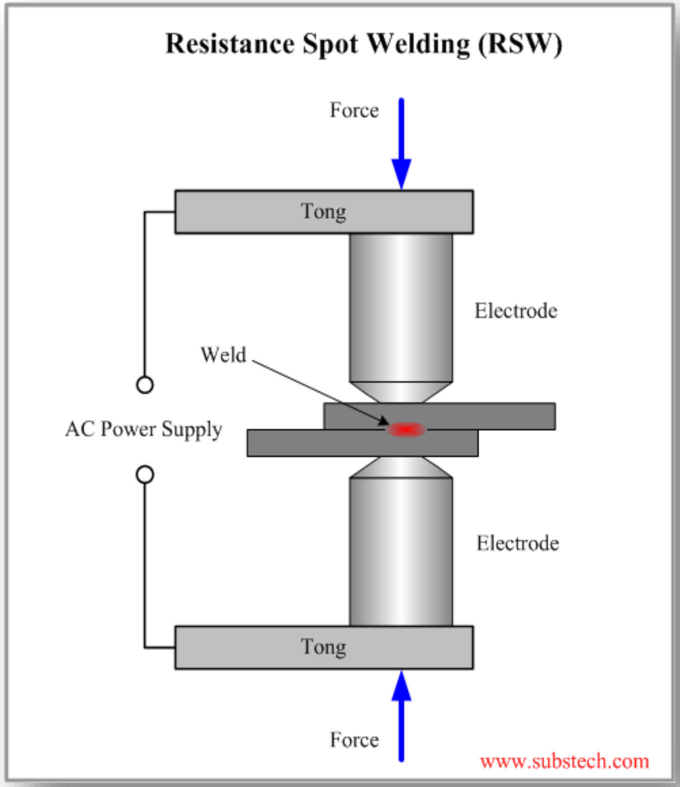
Design + Process = Model-based visualization

Resistance Spot Welding (RSW)

- Resistance spot welding (RSW)
  - Contacting metal surfaces joined by the heat obtained from resistance to electric current (Jeffus, 2002).

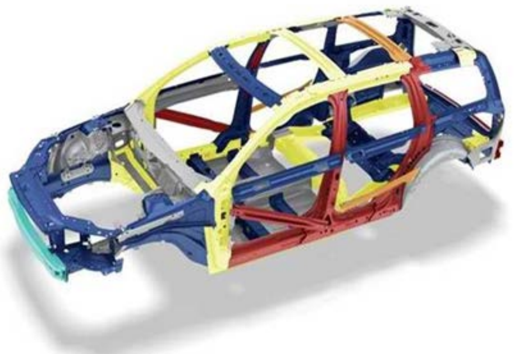
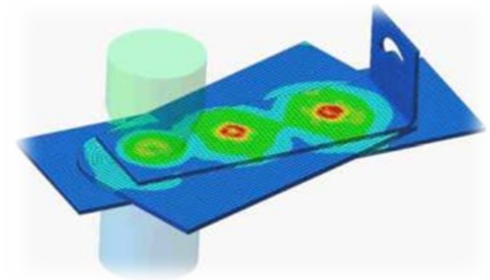
- Contacting point of two metal pieces create weld pool, which is called the spot or nugget.



Source: http://www.substech.com/dokuwiki/doku.php?id=resistance_welding_rw

RSW Impacts

- Design parameters of the work pieces along with RSW process parameters → influences over the shape of the nugget width.
- Process parameters (e.g., electric current, welding time, welding force, etc.) → cause the variation of nugget width.
- Original equipment manufacturers (OEM) carries out numerous tests to design a new weldment (assembly design) → these tests are costly and time consuming.
- Various efforts are made to simulate and predict the nugget width.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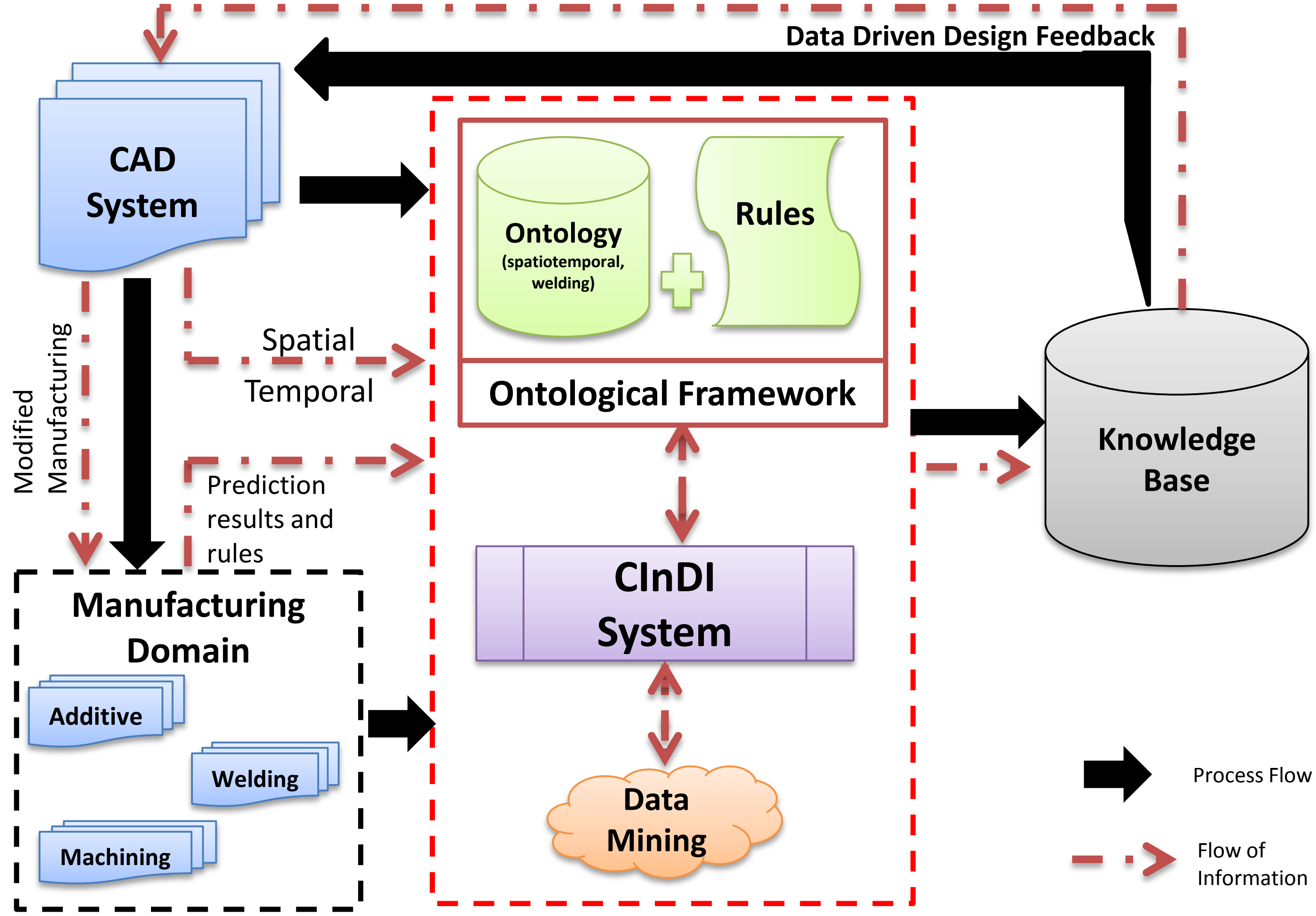
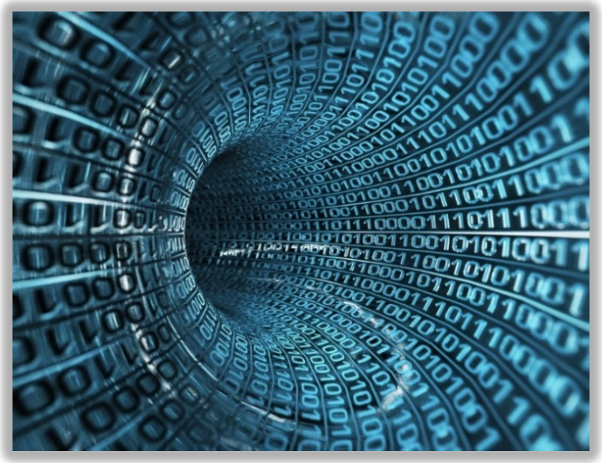
Concept of Data-driven Design



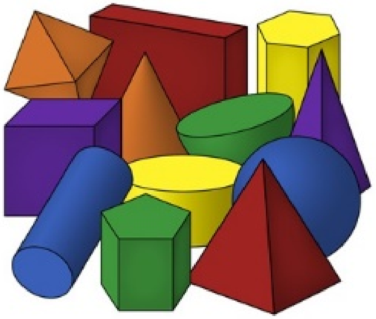
Model Based Engineering and Assembly Design

- MBE to utilize the data model (e.g. CAD data) and to enhance the machine interpretability
  - Reduce the human intervention and enhance the accuracies.
- In manufacturing, CAD used for human understanding only.
  - Not only do humans to understand the model, but software applications have to “understand” the model as well.
- Machine needs to understand the product’s assembly/mating/joining information properly to enhance the machine readability, to reduce the human effort, and to enhance the efficiency.



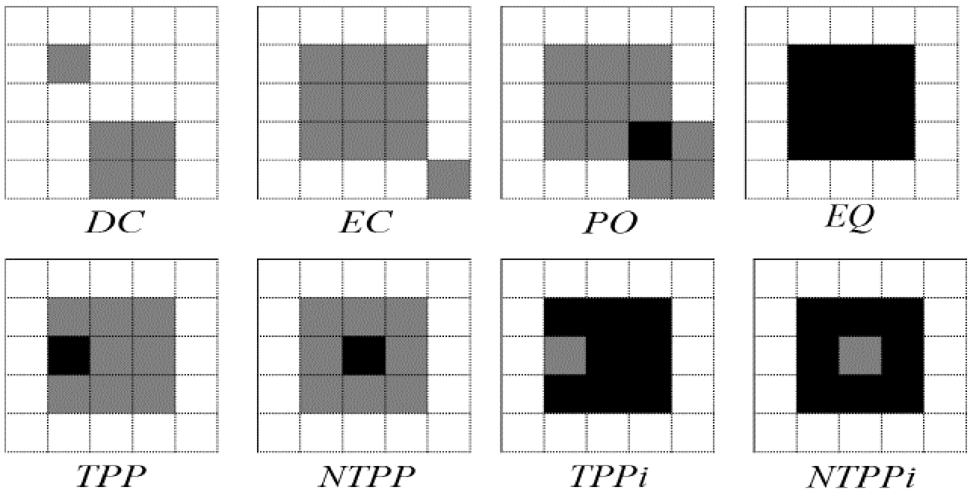
Design and Visualization

- Effective visualization - a powerful way to convey a concept, design intent, or idea in a globally distributed environment
- 3D visualization - a way to represent the concepts in a more understandable manner.
  - X3DOM - 3D visualization in a globally distributed environment.
- *Effective visualization for RSW weldability analysis with the welded assembly design is very limited.*
- Focuses incorporating the 3D design data with the welding process data to represent the process data in a more intuitive way.



Formal Assembly Design Model

- Mereotopology to express the product's part to part assembly relationships.
- Discrete mereotopology (DM) (Randell et al. 2013) utilized to formally represent the product's assembly relationships and static and dynamic behaviors.

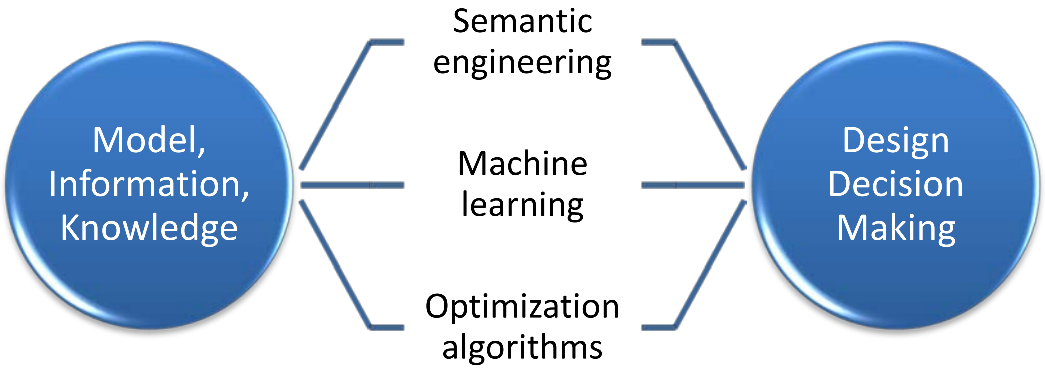


DC := Disconnected
EC := Externally Connected
PO := Partially Overlapped
EQ := Equal
TPP := Tangential proper part
$NTPP$:= Non-tangential proper part
$TPPi$:= Tangential proper part inverse
$NTPPi$:= Non-tangential proper part inverse

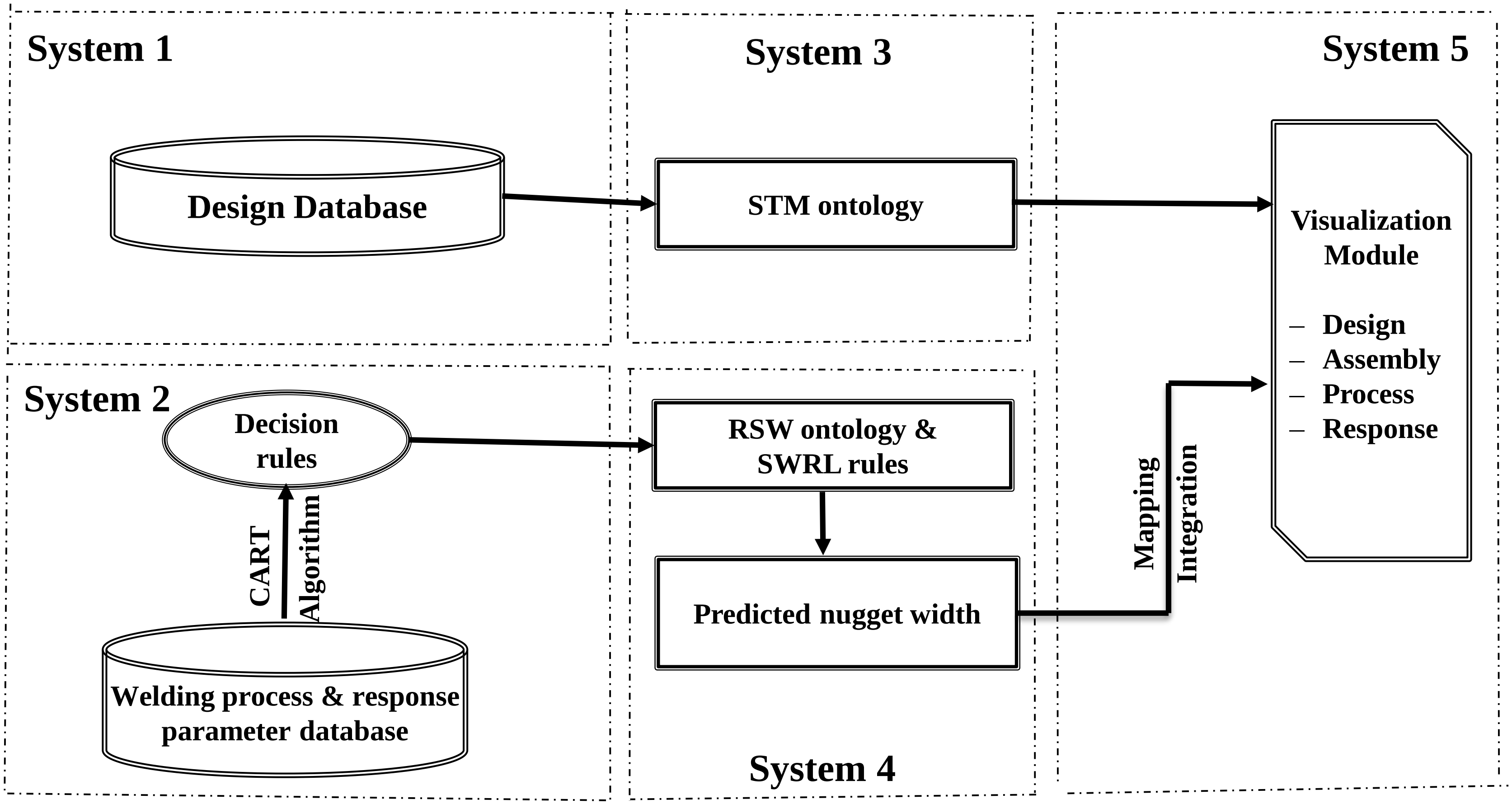
$$xPy := \forall z(zOx \rightarrow zPy)$$

Objectives

- **Model-based visualization framework** to integrate RSW weldability knowledge with assembly models
- **Knowledge-based semantic weldability prediction method** has been developed to effectively predict the weldability of RSW processes, while reducing the data inconsistency effects.



Model-Based Visualization and Integration Framework



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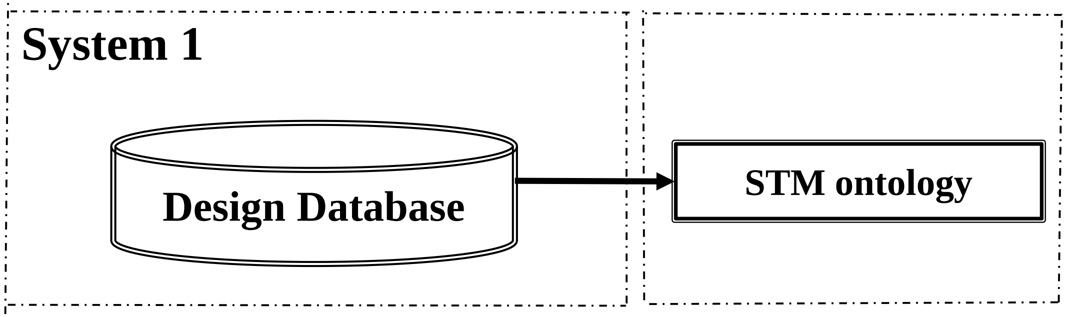
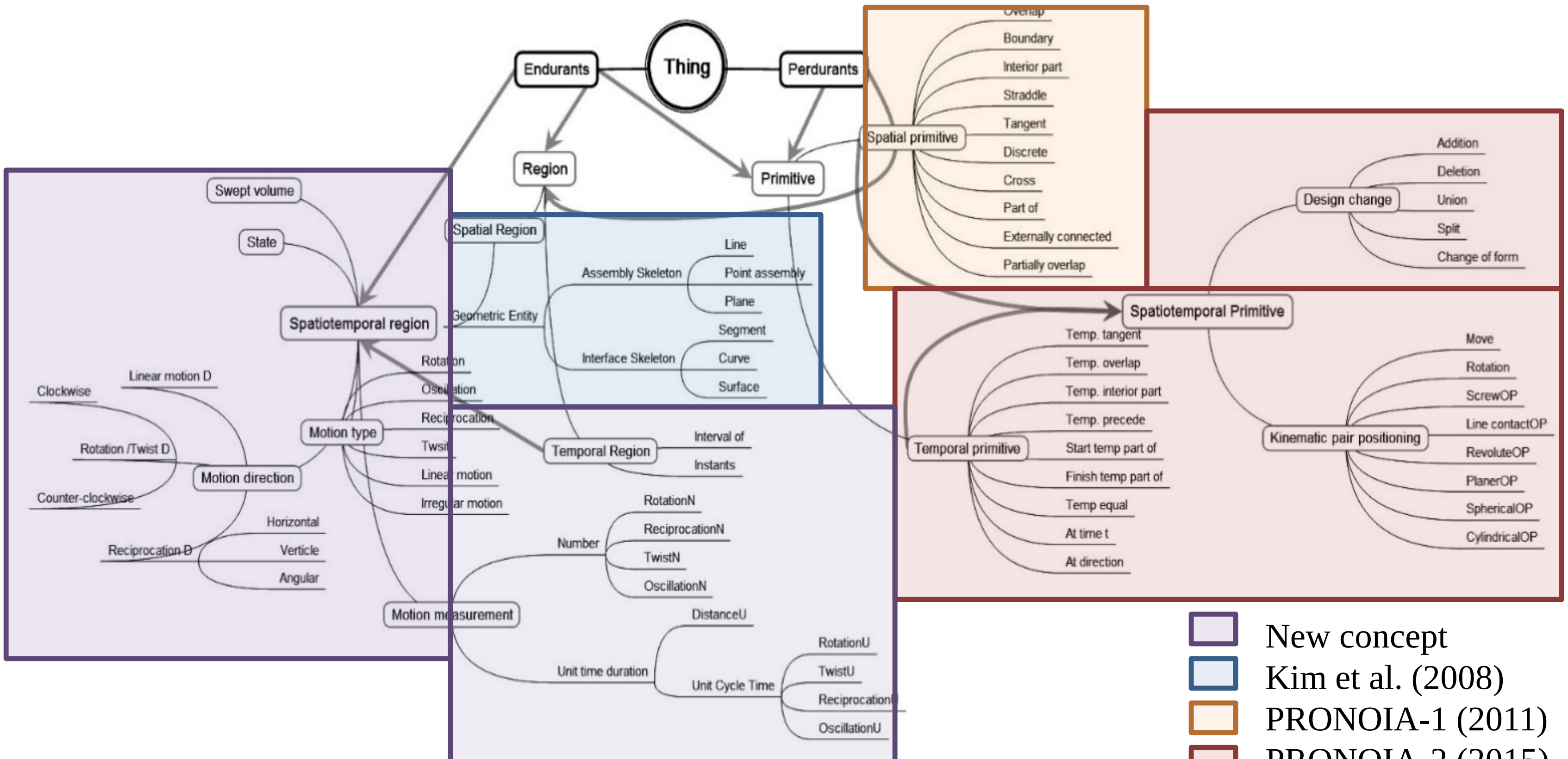
Part 1: Integration of Design Database with STM Ontology

- Design database - the parametric and assembly information
- CAD systems and design database.
- STM (SpatioTemporal Mereotopology) ontology
  - Relevant spatial and temporal design and assembly knowledge.

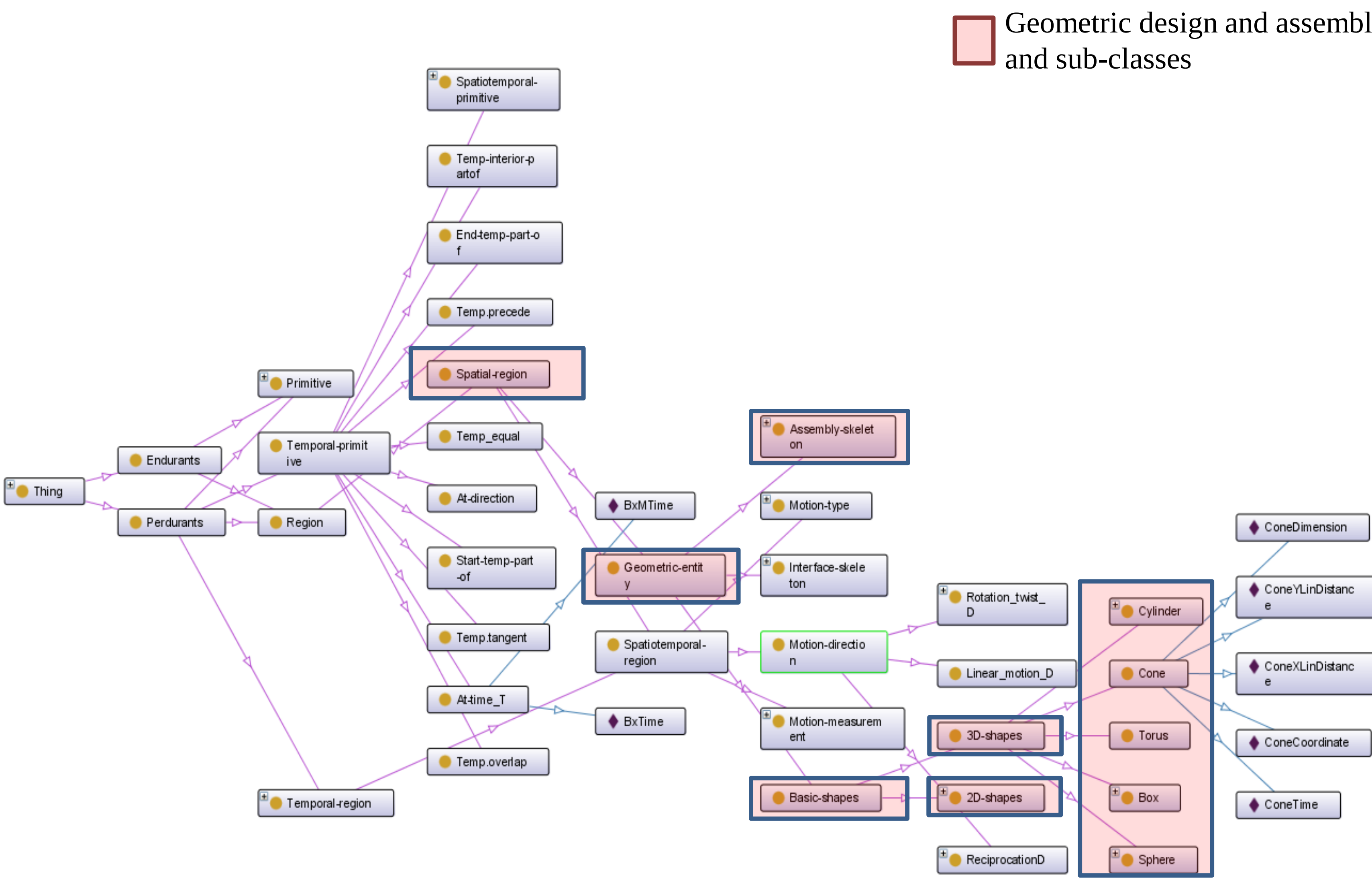


STM Ontology - Concept Map



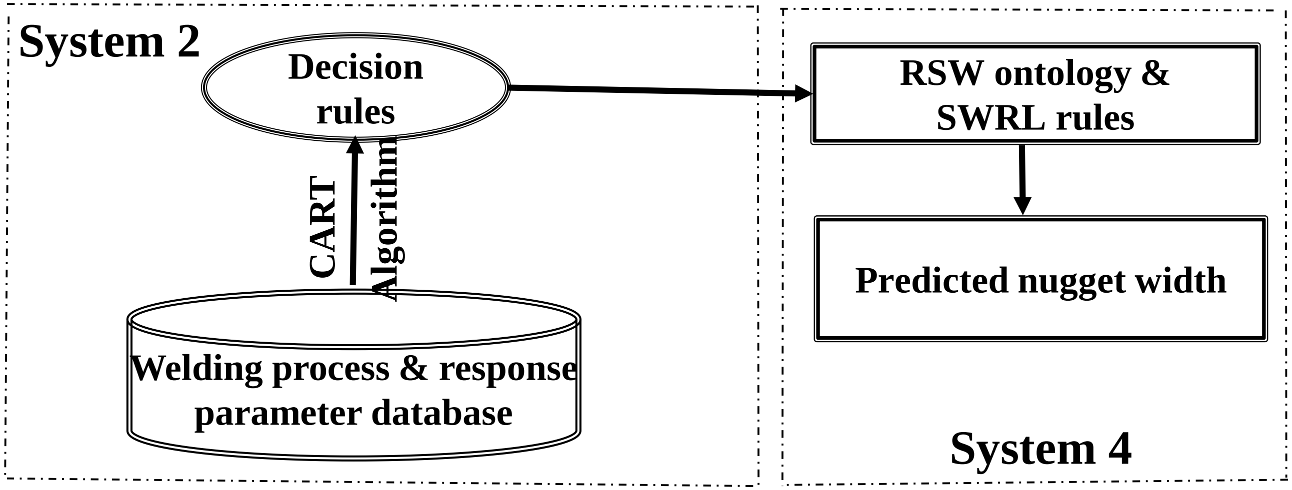
New concept
Kim et al. (2008)
PRONOIA-1 (2011)
PRONOIA-2 (2015)

STM Ontology



Part 2: Rule Extraction and SWRL Generation

- Classification and Regression Tree (CART) algorithm
  - To extract the decision rules and converted them into SWRL rules
- System predicting the response parameter (i.e., nugget width) based on the given design and process parameters



Parameters in RSW Quality Dataset

Feature types			
Geometric Parameters	Design Parameters	Process Parameters	Response Parameters
Length (mm) Thickness (mm) Height (mm) Radius (mm)	Material Thickness (mm) Coating-EG (Electrogalvanized) Coating-HDG Coating weight (gm/m2) Surface class	Weld force (lbs) Minimum button Diameter of stack-up (mm) Weld current (kA) Weld time (ms) Weld time cycle	Nugget width (mm)

Regression Model for Analyzing Welding Dataset

$$\boldsymbol{Y_p} = \bar{\boldsymbol{r}}(\boldsymbol{X_t}) = [\boldsymbol{r}(\boldsymbol{X_t}, \boldsymbol{\lambda}, \boldsymbol{D})]$$

Y_p = Final predicted value.

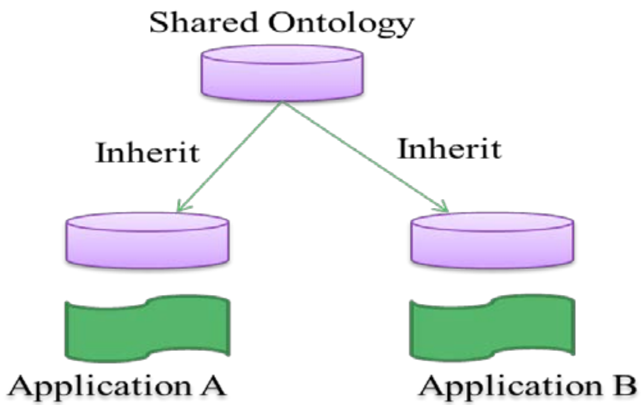
$\bar{r}$ = Average regression function.

X_t = Observation from test set.

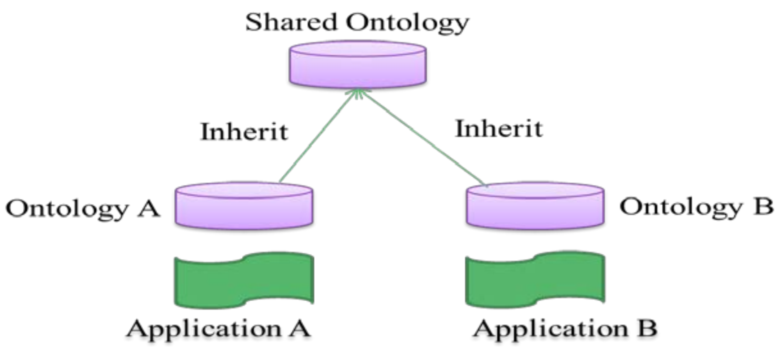
λ = Random parameter of partition.

D = Total data.

Building Ontology

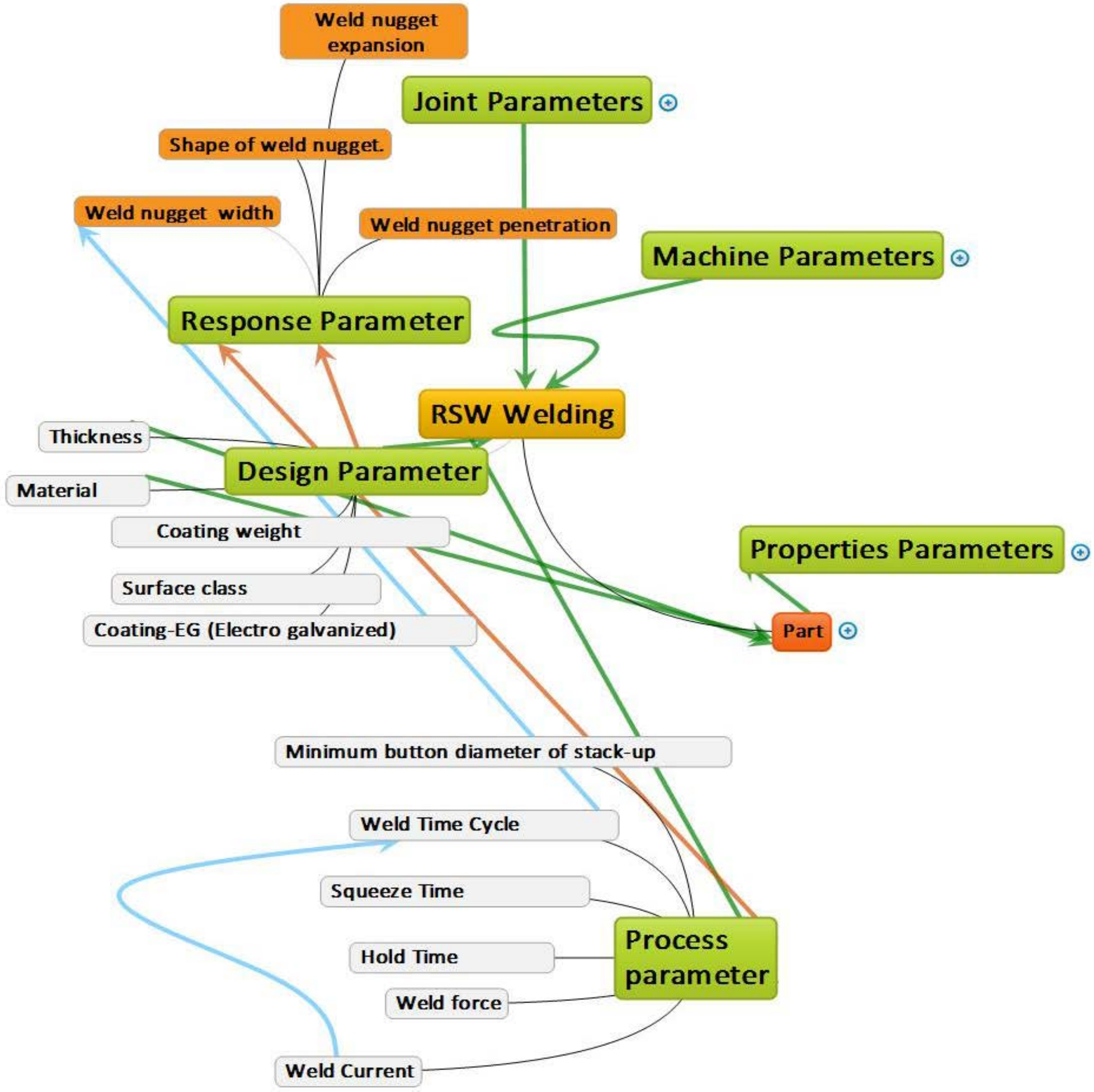


Top – Down Approach

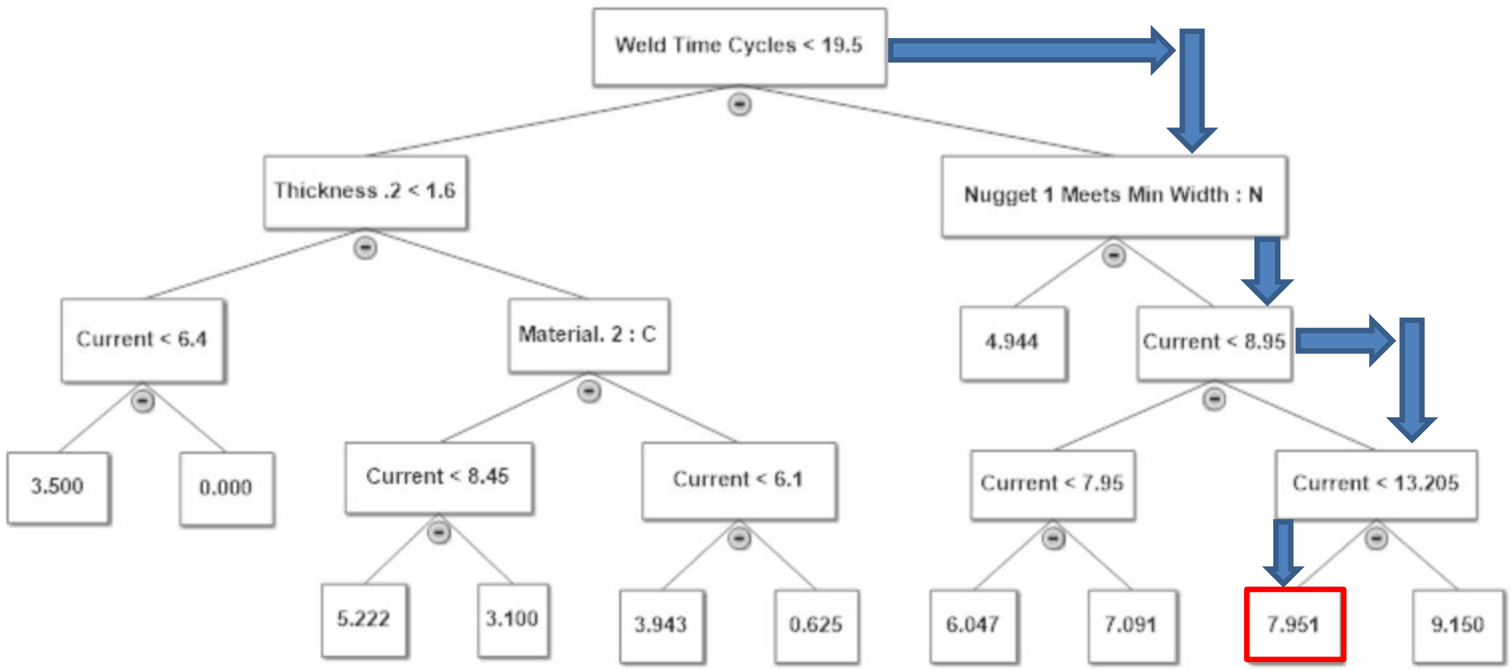


Bottom – Up Approach

RSW Ontology Concept Map



Decision Tree Example



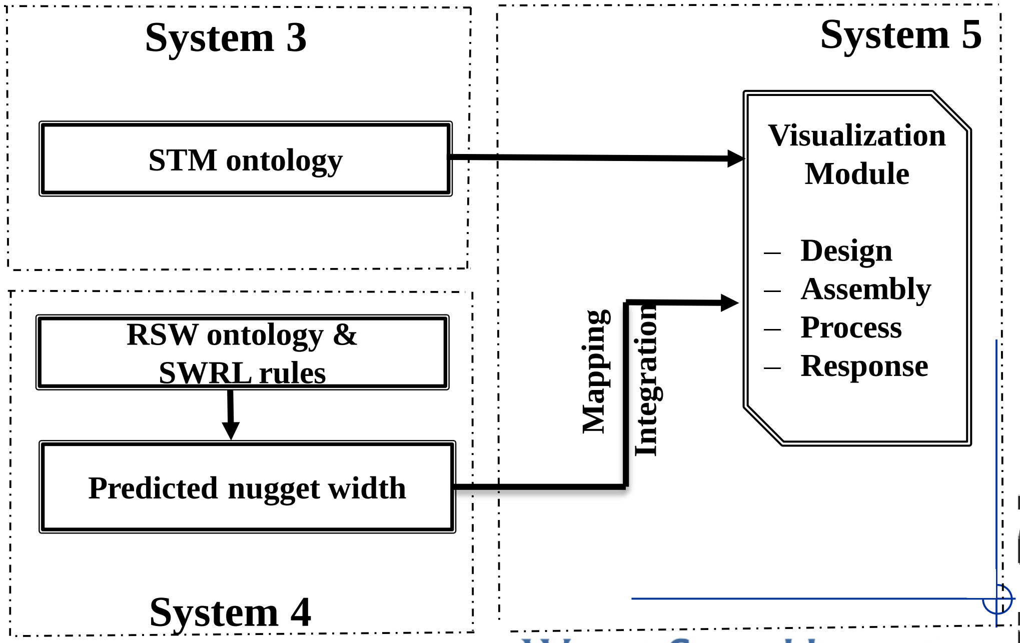
If Weld Time Cycles is greater than 19.5 (unit) (consider right side of the branch)
AND Nugget 1 Meets Min Width is true
AND Current is greater than 8.95 (unit)
AND Current is less than 13.205 (unit)
THEN Nugget Width will be 7.951 (unit)

SWRL Rule Conversion

Rule	Test cases
Decision rule	If Weld Time Cycles is greater than19.5 (unit) (consider right side of the branch) AND Nugget 1 Meets Min Width is true AND Current is greater than 8.95 (unit) AND Current is less than 13.205 (unit) THEN Nugget Width will be 7.951 (unit)
SWRL rule	weld_time_cycles(?x, ?y) ^ swrlb:greaterThanOrEqual(?y, 19.5) ^ Nugget_1_meets_min_width(?x, true) ^ weld_current(?x, ?z) ^ swrlb:lessThan(?z, 13.205) ^ swrlb:greaterThanOrEqual(?z, 8.95) -> nugget_width(?x, 7.951)

Part 3: Mapping, Integration, and Visualization

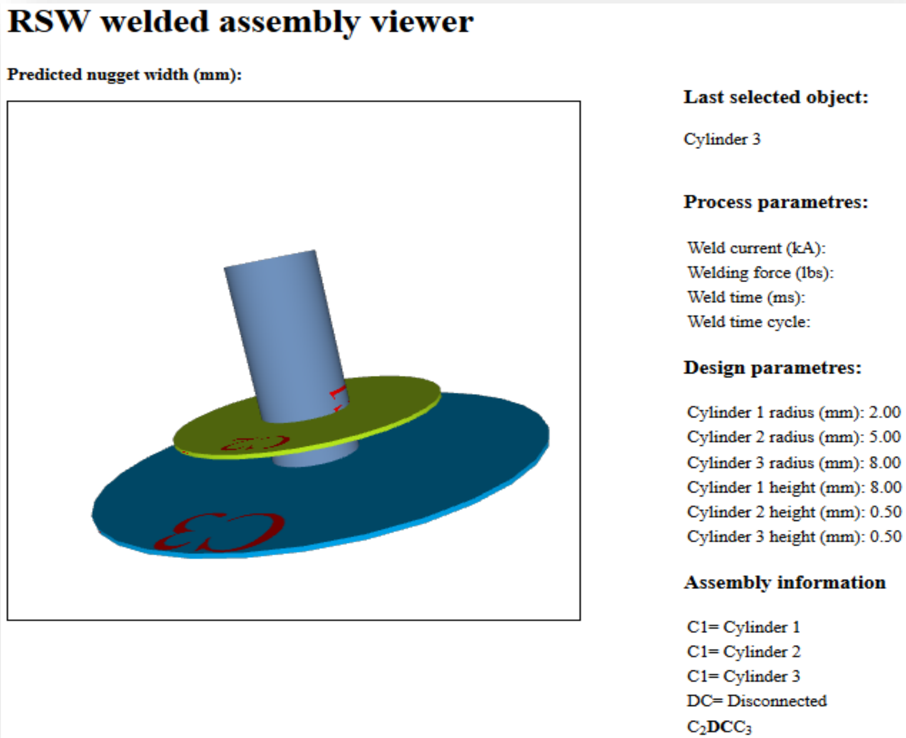
- **X3DOM** visualizes 3D contents along with their relevant information
- **Schema mapping** enables the seamless data transfer among the systems.
- System 3 (STM ontology : geometric and assembly knowledge) and 4 (RSW ontology : welding process and response knowledge) mapped with system 5 (X3DOM).
- MATLAB is utilized to parse the ontologies (STM and RSW) to extract the mapped information for the X3DOM.
- X3DOM can visualize the welding process, response and geometric information.



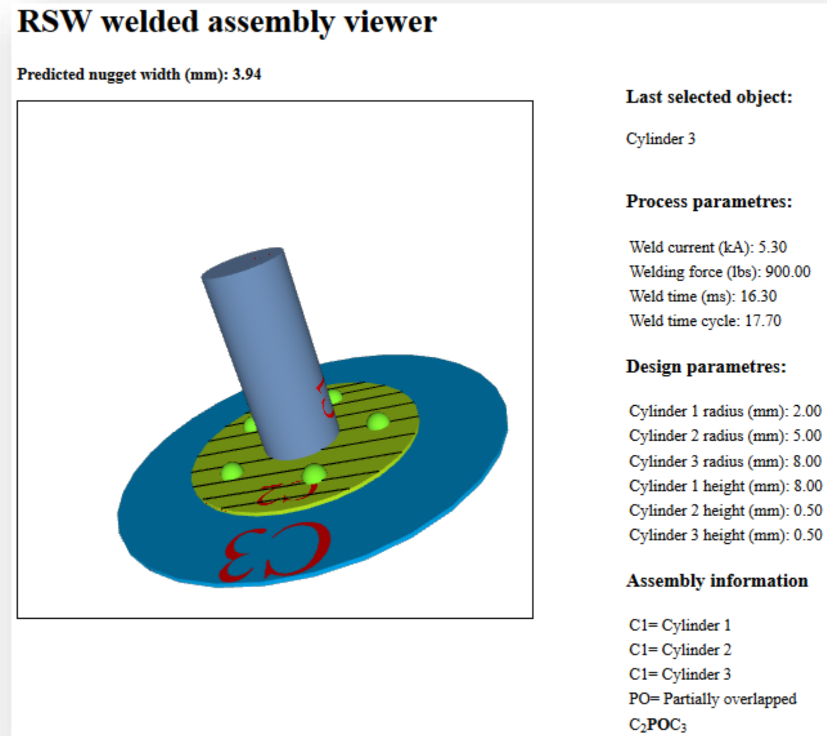
RSW Assembly Design Viewer

- Visualize the welded and non welded assembly.
- Capable of showing the stages of joining and the interrelationships between the mated or unmated parts
- Two basic parts.
  - Visualization interface.
    - X3DOM works as a html based visualization interface; traditional browser is utilized for the visualization.
    - MATLAB is utilized to convey the necessary information from the ontologies to the X3DOM.
    - Protégé to develop the ontologies.
  - Display information of the visualized 3D object.

Demonstration - Case 1



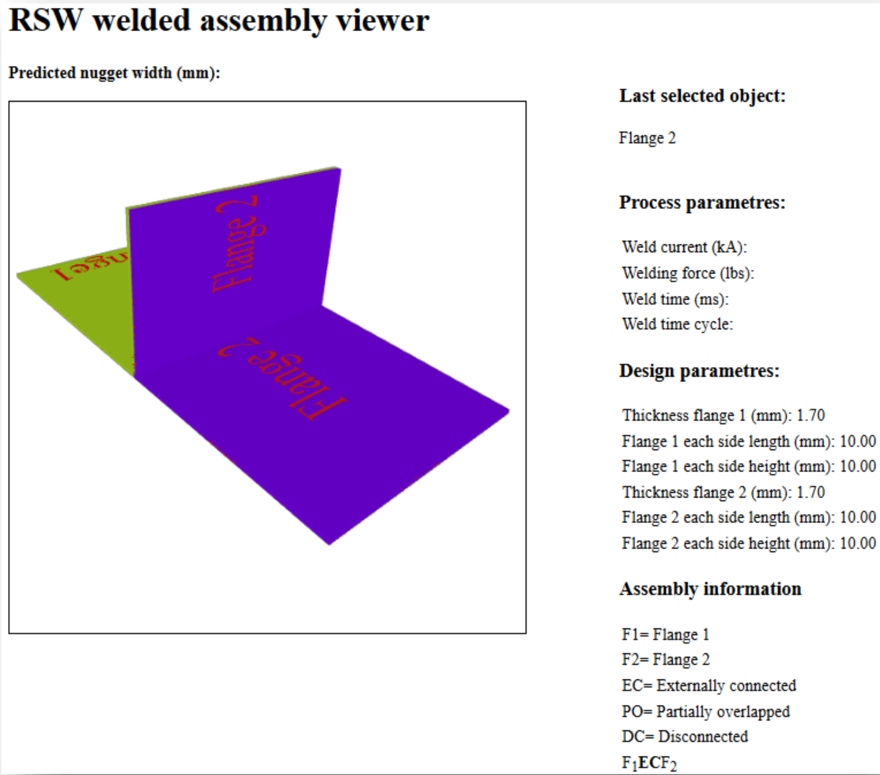
Before Welding



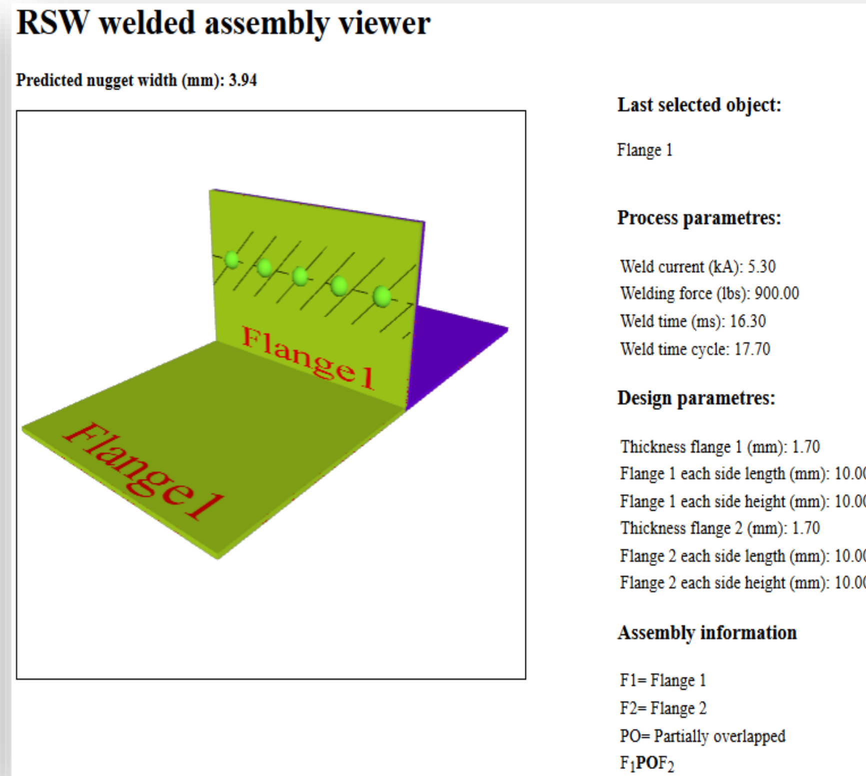
After Welding

- To understand the joining/welding process properly, it is important to visualize the models before/after welding.
- Visualizer can show the interrelationships between mated and unmated parts before/after welding

Demonstration - Case 2



Before Welding



After Welding

- Process, response, design and assembly information visualized before/after welding
- Predicted nugget sizes and displayed.

Summary

- Combines **the geometric design database with the RSW process database** and using the data **predicts and visualizes weld quality**
- **Data-driven and model-driven visualization** for RSW weldability knowledge
- CAD environment used as a design database and then the design database integrated with the STM ontology to extract the design and assembly knowledge
- STM ontology captures the spatial entity of a weldment
- Welded assembly design and process information taken to the RSW ontology from the welding database
- Decision rules extracted from the welding datasets and converted into semantic rules for the machine interpretability and easy information transfer
- **Design, process, and weldability information visualized** for redesign if needed
- Ongoing works
  - Data driven assembly modeler
  - Work on more complex geometry
  - Temporal entities for dynamic welding process

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Thank you