Qualitative behavioral reasoning from components' interfaces to components' functions for DMU adaption to FE analyses

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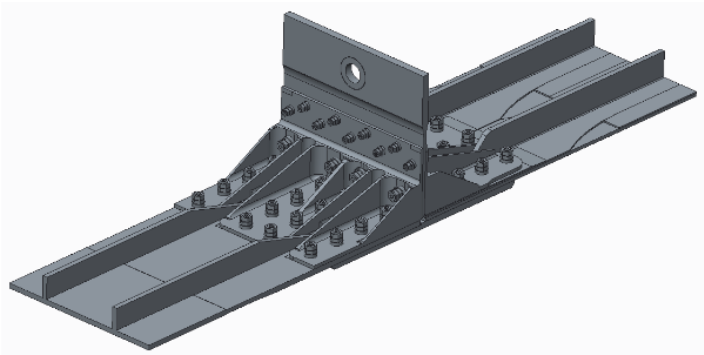
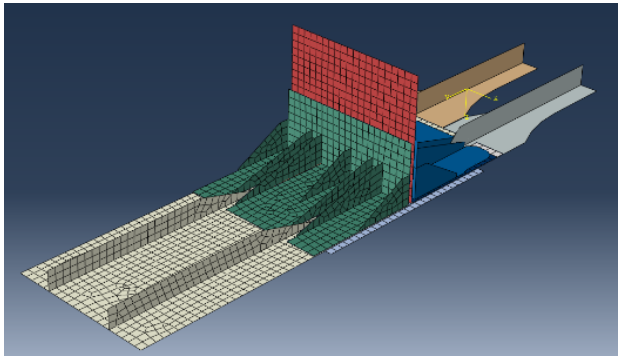
Overview

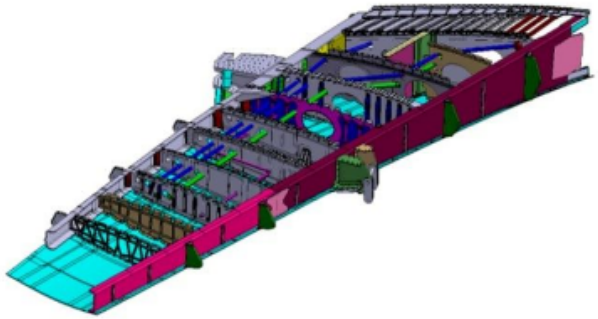
From a Digital Mock-up (DMU) to an FE Model



A DMU of a simple model - courtesy EADS



Simplified, idealized and partially meshed model



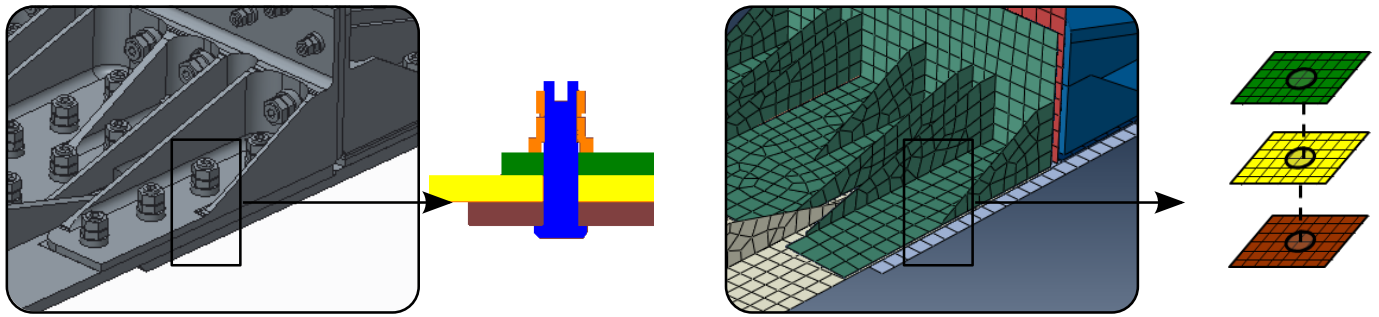
Aircraft wing structure - courtesy EADS

Not workable

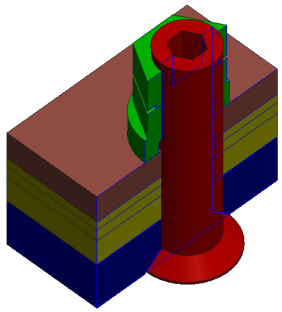
- Starting point: a DMU
  - → a set of objects in 3D space without geometric connexions.
- Too many interactive transformations: not applicable.

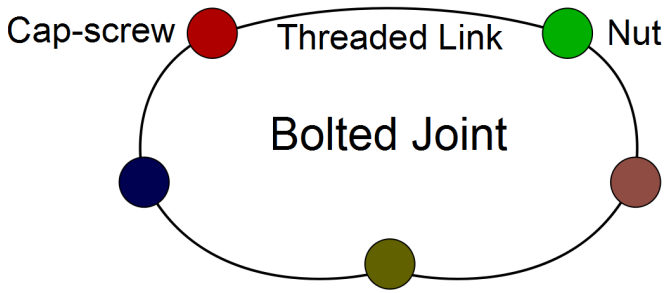
Need for Component's Function and Structure

- Manufacturing (detailed) v.s. simulation (simplified) models.



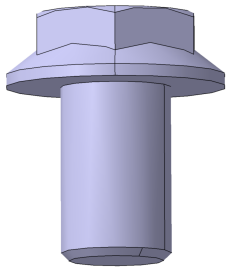
- Shape transformations:
  - Simplifications and idealizations.
- Require geometric interfaces and functions of components.

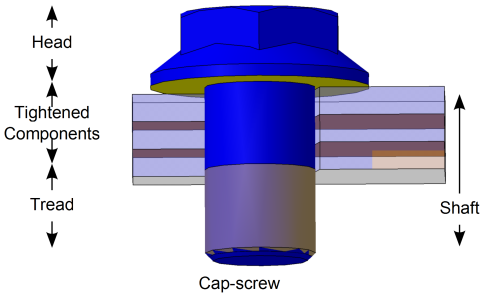




Structuring the Shape of a Component

- What do we have?
  - Component shape as B-Rep model.
  - Unreliable and non-standardized textual data, if any.
- What do we need?
  - Explicit component designation expressing its function.
  - Areas of interaction with other components.
  - Boundary decomposition according to elementary functions, i.e. a structure.

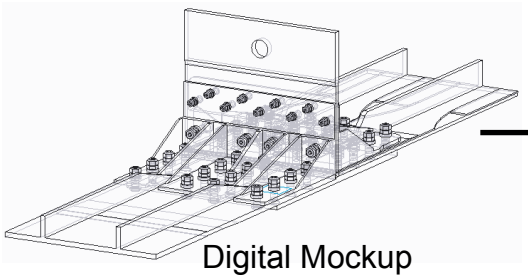




Related Work

- Design methodologies characterize some shape / function / behavior relationships [Gero et al '04, Albers et al '06],
- Shape/function relationships during assembly design & collaborative product development [Roy et al '01, Rahmani et al '12].
  - Too many user's interactions to attach functional information for each component.
- Top-down product behavior models to set up functions during design: Requires interactive connections between component boundary and functions [Roy et al. '02, Kim et al '04].
  - Component structure set up interactively: tedious, error prone.
- Ontology based approaches [Kitamura et al '04, Rachuri et al. '07, Barbau et al. '12].
  - No new functional information is derived.
- Processing components' interfaces [Chouadria et al '06, Clark et al. '08].
  - Reduce user's interactions but far from functional properties.

Process Workflow



Digital Mockup

Set of B-Rep models

Extraction of Component´s Interfaces

Geometric representation of components interactions

Assignment of Functional Interpretations

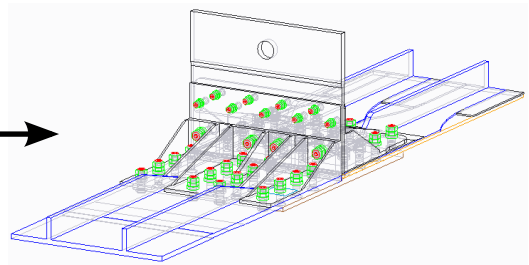
Deriving elemetary functionalities from components interfaces

Qualitative Assessment of Reference States

Symoblic expression of component´s behavior

Assignment of Functional Designations

Matching function patterns to structured components



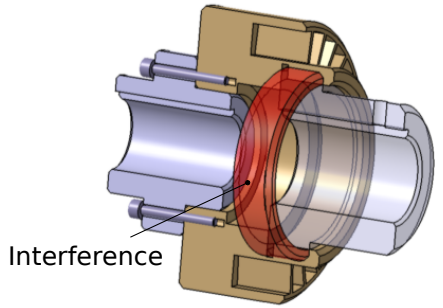
Restructure and Annotated Geometry

Digital Shapes

Extraction CI → FI Assignment → Assesment of RS → FD Assignment

- By convention, digital shapes of components may differ from real ones.

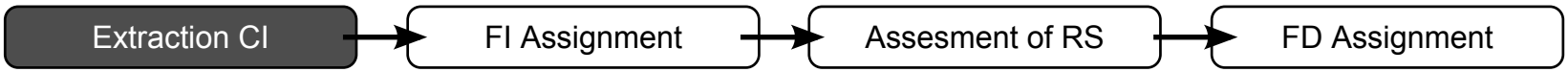
Real spline shaft and bushing



Digital shape of the same components

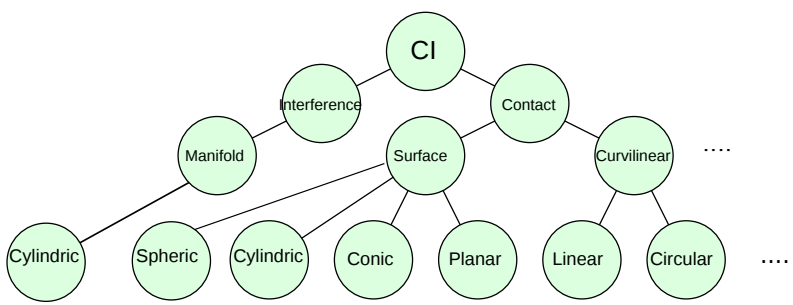
- Interfaces between real components define elementary functions.
  - Contacts and clearences.
- Possible components' geometric interactions in a DMU:
  - Contact
  - Clearance
  - Interference

Taxonomy of Component Interfaces

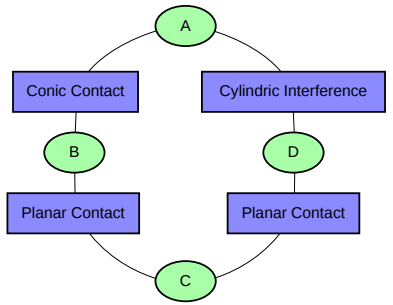


- Interfaces based on functional surfaces: planes, cylinders, cones, spheres.

Component's geometric interaction → *Conventional Interfaces*.



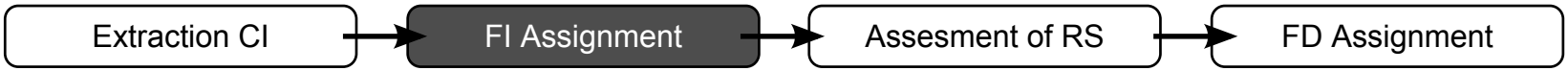
Taxonomy of CI



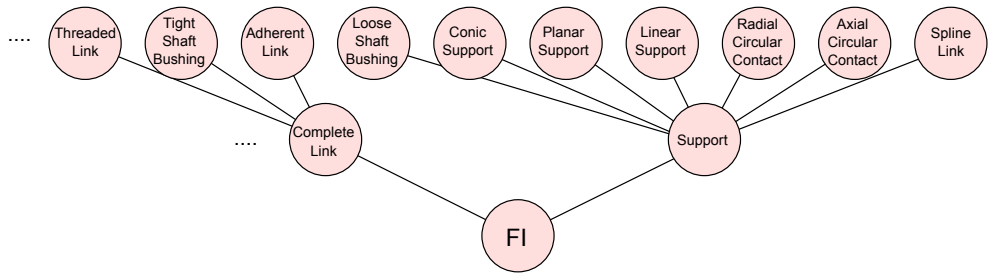
CIG

- Taxonomy of CIs according to functional surfaces & geometric interaction types.
- CIs between DMU components produce a graph (CIG).

Taxonomy of Functional Interfaces



- Functional behavior derived from CIs
  - → Functional Interfaces (FIs).
- Duality geometry/interaction forces
  - → FI Taxonomy.



- Represented in terms of **screws** $\{\overrightarrow{force}|\overrightarrow{moment}\}$.
- Several FIs for one CI
  - → Need for filtering process.

Qualitative Interface Behavior

Extraction CI → FI Assignment → Assesment of RS → FD Assignment

- No quantitative data
  - Symbolic representation of interaction forces/moments.

`Not Null`	$\neq$	propagates internal forces / moments in either direction.
`Null`	0	doesn't propagate any internal force / moment.
`Strictly Positive`	$>$	propagates internal forces / moments in the positive direction only.
`Strictly Negative`	$<$	propagates internal forces / moments in the negative direction only.
`Arbitrary`	$*$	may propagate internal forces / moments in either direction

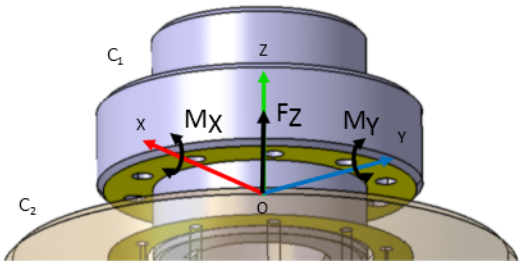
- One qualitative screw per FI.

$$\left\{\begin{array}{c|c} 0 & \mathcal{M}_x \\ 0 & \mathcal{M}_y \\ \mathcal{F}_z & 0 \end{array}\right\}_{O/x,y,z}$$

Quantitave Screw

$$\left\{\begin{array}{c|c} 0 & * \\ 0 & * \\ > & 0 \end{array}\right\}_{O/x,y,z}$$

Qualitative Screw



Filtering out Functional Interfaces

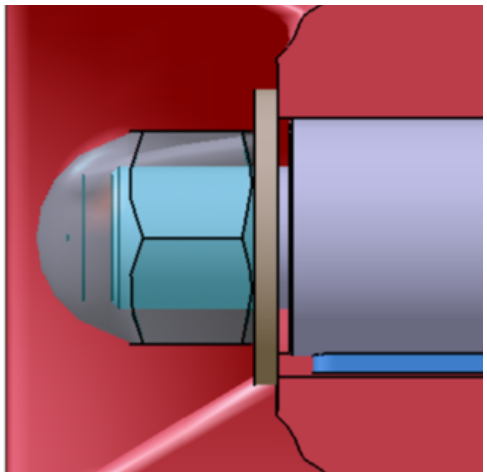
Extraction CI → FI Assignment → Assesment of RS → FD Assignment

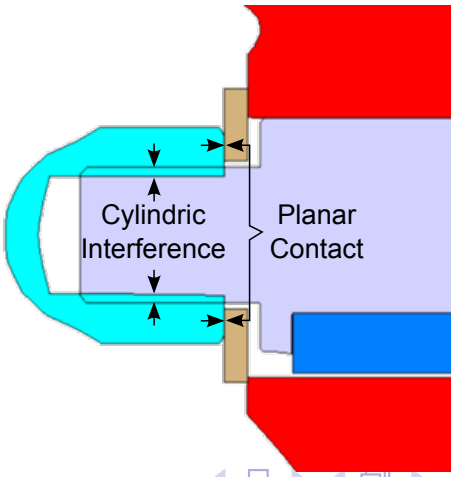
- Shape $\leftrightarrow$ Behavior $\leftrightarrow$ Function
- Setting up a qualitative behavior using independent *states*,

Reference State

Expresses the behavior of either the whole or a part of a product.

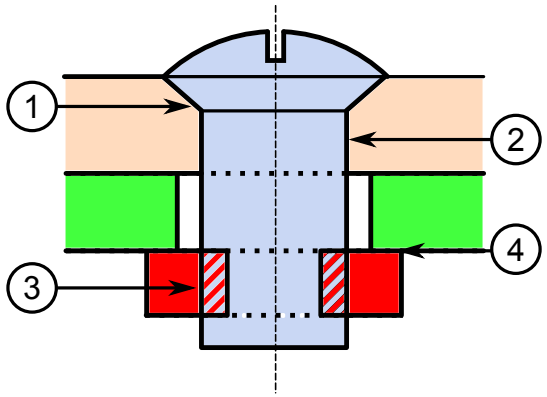
- Relaxed state: components of a DMU must not fall apart.
  $\rightarrow$ Every component is at static equilibrium $\sum \{\vec{F}|\vec{M}\} = \{\vec{0}|\vec{0}\}$.





Filtering out FIs (example)

1. Conic Contact
2. Cylindric Contact
3. Cylindric Interference
4. Planar Contact



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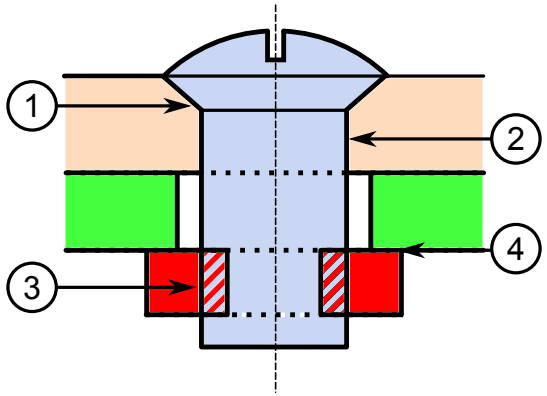

Conic Contact (1)	Conic Support	Conic Support	Conic Support	Conic Support
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$
Cylindric Contact (2)	Loose Fit	Loose Fit	Snug Fit	Snug Fit
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$
Cylindric Interference (3)	Spline Link	Threaded Link	Spline Link	Threaded Link
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$
Sum	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$

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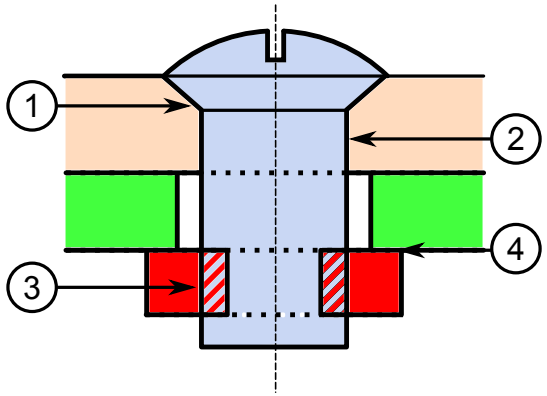
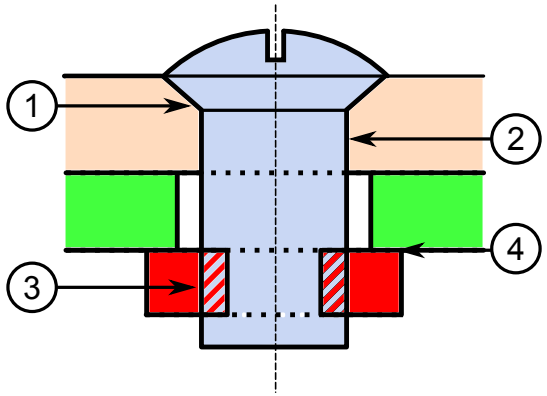


Conic Contact (1)	Conic Support	Conic Support	Conic Support	Conic Support
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$
Cylindric Contact (2)	Loose Fit	Loose Fit	Snug Fit	Snug Fit
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$
Cylindric Interference (3)	Spline Link	Threaded Link	Spline Link	Threaded Link
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$
Sum	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$

Planar Contact (4)	Planar Support	Planar Support
	$\left\{\begin{array}{c\|c} 0 & * \\ 0 & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} 0 & * \\ 0 & * \\ < & 0 \end{array}\right\}$
Cylindric Interference (3)	Spline Link	Threaded Link
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$
Sum	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$

Filtering out FIs (example)

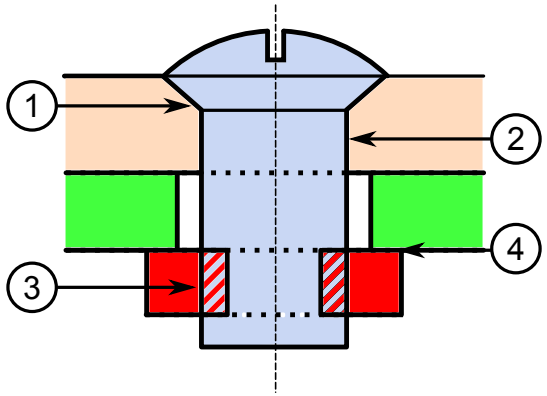


1. Conic Contact
2. Cylindric Contact
3. Cylindric Interference
4. Planar Contact

Conic Contact (1)	Conic Support	Conic Support	Conic Support	Conic Support
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$
Cylindric Contact (2)	Loose Fit	Loose Fit	Snug Fit	Snug Fit
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$
Cylindric Interference (3)	Spline Link	Threaded Link	Spline Link	Threaded Link
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$
Sum	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$

Planar Contact (4)	Planar Support	Planar Support
	$\left\{\begin{array}{c\|c} 0 & * \\ 0 & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} 0 & * \\ 0 & * \\ < & 0 \end{array}\right\}$
Cylindric Interference (3)	Spline Link	Threaded Link
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$
Sum	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$

Filtering out FIs (example)



1. Conic Contact
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1. Conic Support
2. Loose Fit
3. Threaded Link
4. Planar Support

Conic Contact (1)	Conic Support	Conic Support	Conic Support	Conic Support
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$
Cylindric Contact (2)	Loose Fit	Loose Fit	Snug Fit	Snug Fit
	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$
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	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$
Sum	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$

Planar Contact (4)	Planar Support	Planar Support
	$\left\{\begin{array}{c\|c} 0 & * \\ 0 & * \\ < & 0 \end{array}\right\}$	$\left\{\begin{array}{c\|c} 0 & * \\ 0 & * \\ < & 0 \end{array}\right\}$
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	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$
Sum	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & * \end{array}\right\}$	$\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$

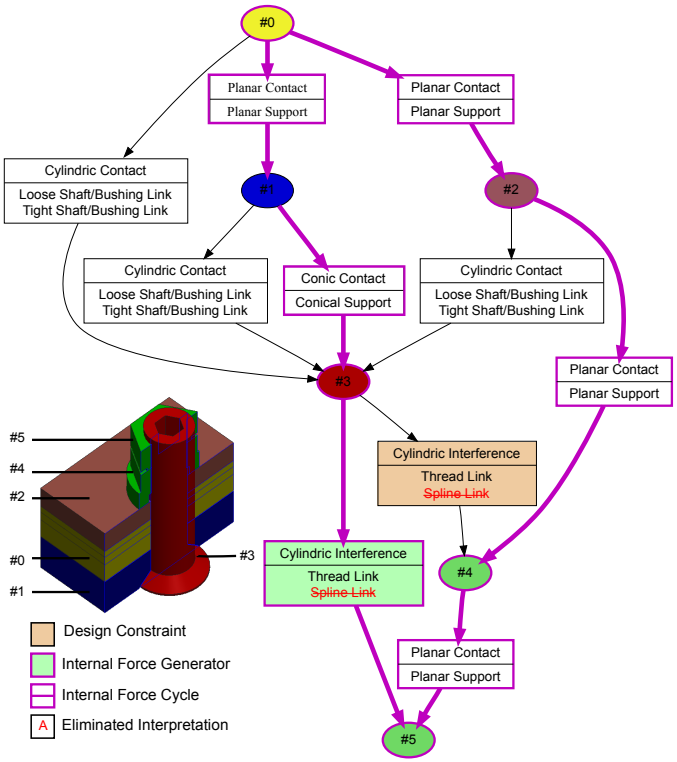
Identification of Functional Subsets

Extraction CI → FI Assignment → Assesment of RS → FD Assignment

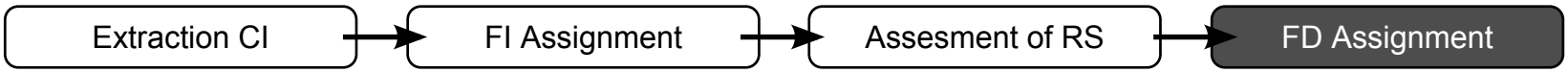
Functional Group

A set of component contributing to a function with reference to a FI.

- Fastener thread generates an internal force that propagates across a subset of components.
  - → Bolted joint.
- To detect bolted joints:
  - Force propagation graph.
  - Detect cycles containing a reference thread.



Assignment of Functional Designations



- Reference States →
  - Structured component geometry w.r.t. functional interfaces.
  - Structured DMU w.r.t. functional subsets.
- Matching those structures to reference patterns →
  - Classification of components into *Functional Designations*.

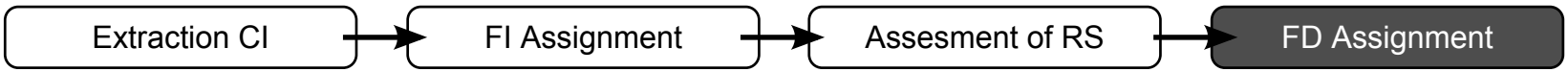
Functional designation

Semantic annotation that uniquely identifies the function of a component.

- Hierarchical structure of component functions.

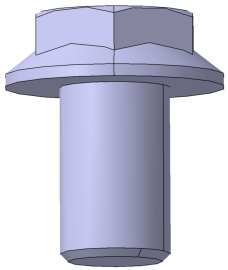
  → Taxonomy of FDs.

Rule-based Matching

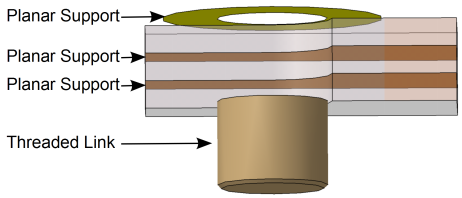


- Ontologies, taxonomies and rules to saturate FDs.
- Apply semantic reasoners to classify components into FDs.

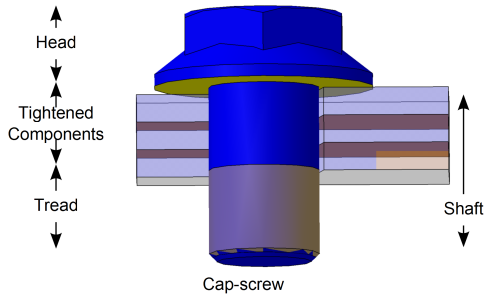
A *cap-screw* is a component that participates to a bolted connection with a threaded link and a planar support. . .



Initial component

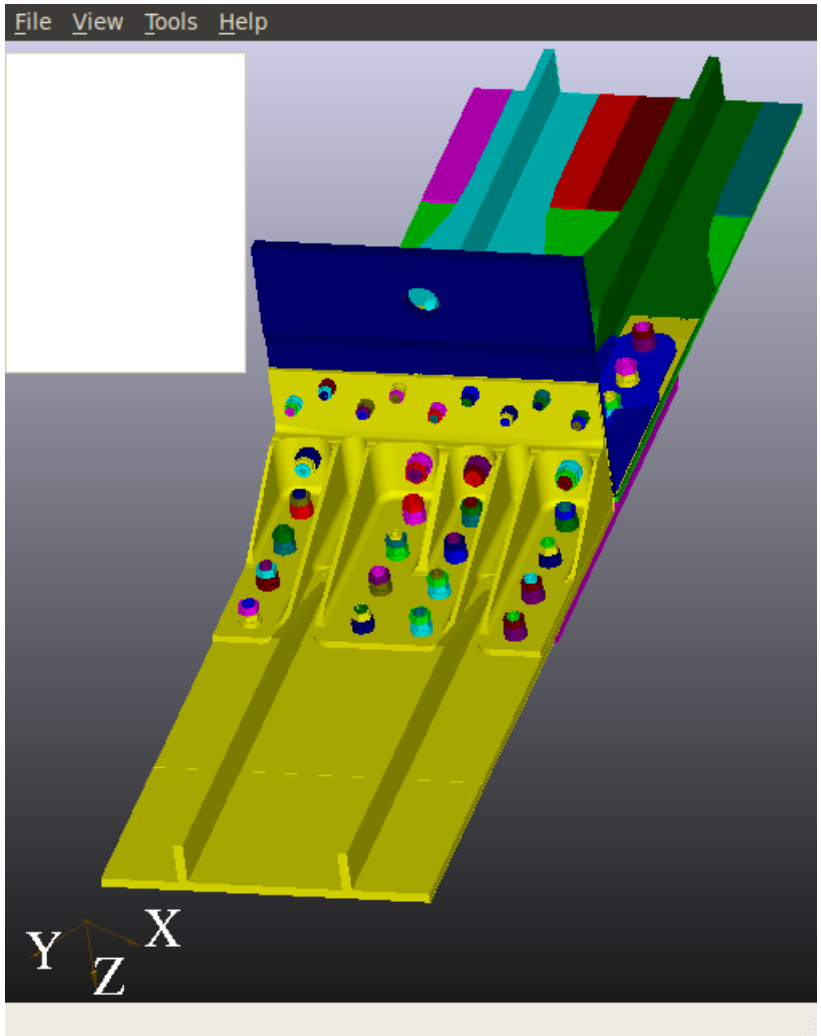


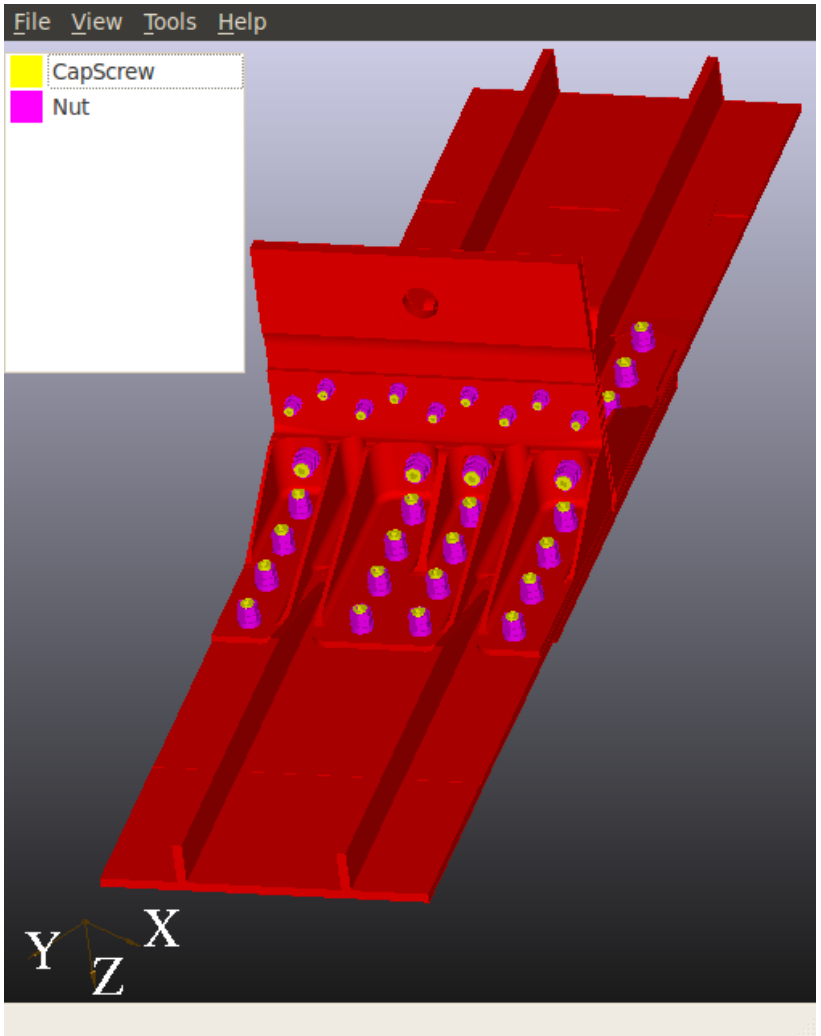
FIs involved in an FD



Structured component after matching

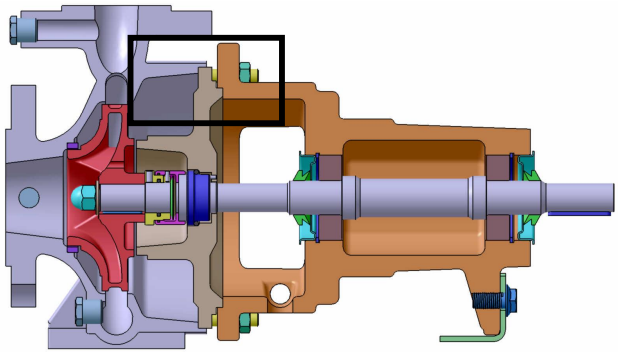
Root joint example

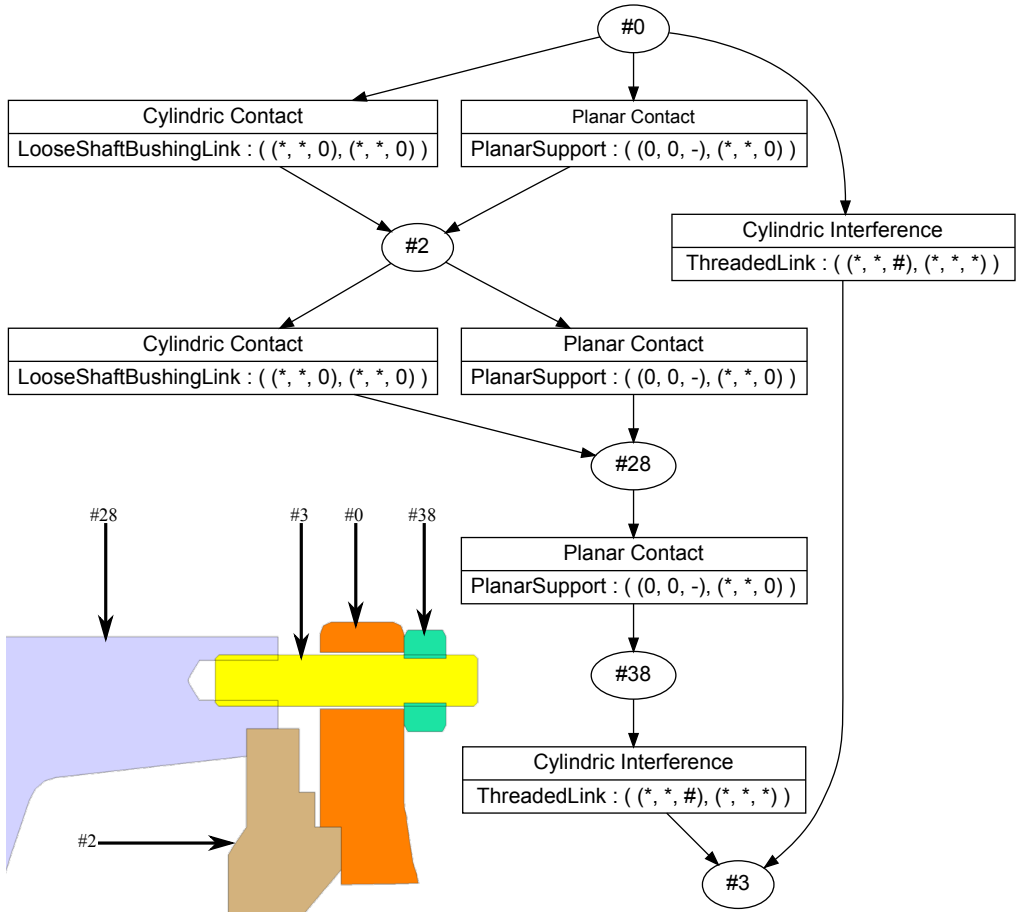




Centrifugal pump - elementary analysis

- Reliable results when processing elementary functions.





Centrifugal pump - elementary analysis

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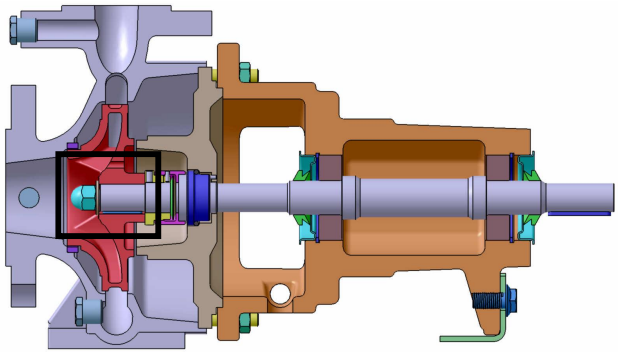
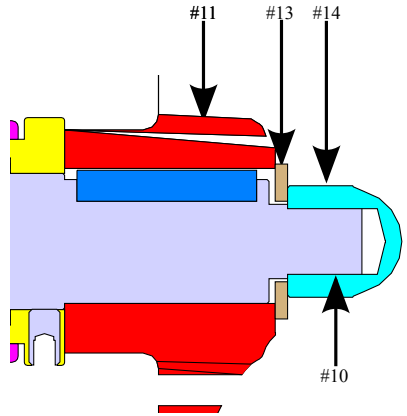
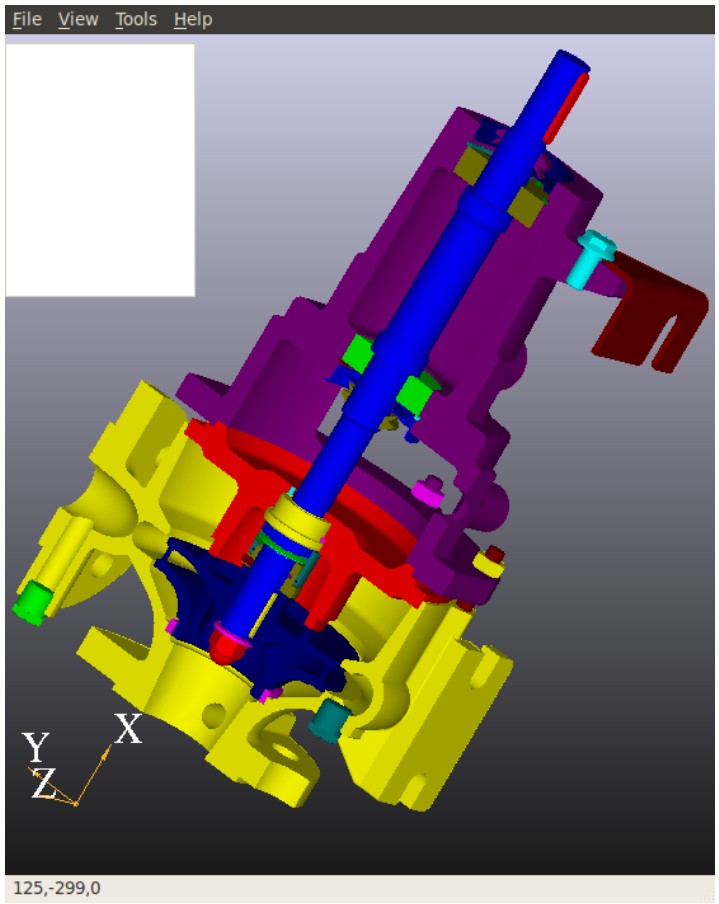
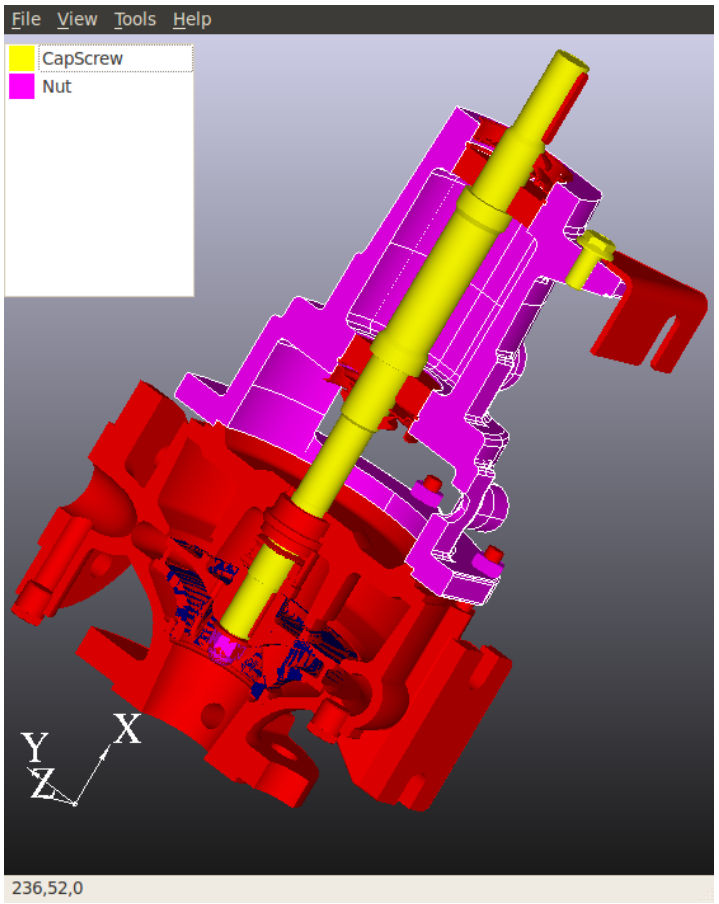




Centrifugal pump example

- Rules expressivity limitations
  - Ongoing work...





Conclusions - Perspectives

- Pathway to robustly connect 3D shapes and functional semantics.
- Structured and functional component models.d
- Efficient component clustering according to functionality.
- Perspectives
  - Consider new reference states.
  - Incorporate more dynamic rules.
  - Scale up the complexity of DMUs.
- Work performed within **ROMMA**, an ANR-funded project.

Questions?

- Thanks for your attention.