

Qualitative Behavioral Reasoning of DMUs

A method to infer components functional properties
given their digital mock-up

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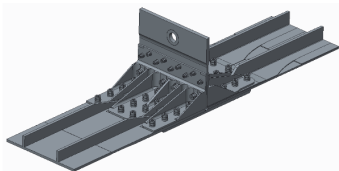


Visionair, Grenoble
November 19, 2012

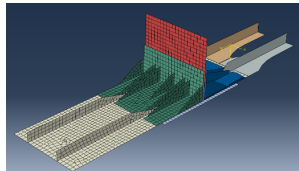
Overview

- 1 Motivation & Objectives - Related Work
 - Finite Element Models for Large Assemblies
 - Problem Addressed
 - Related Work
- 2 From Geometry to Function
 - Geometric Analysis
 - Generating Functional Interfaces
 - Qualitative Behavioral Analysis
 - Rule-based Reasoning
- 3 Results - Functional Designations Annotation
 - Application in Aeronautics
 - Application in Fluid Mechanics
- 4 Conclusions & Perspectives

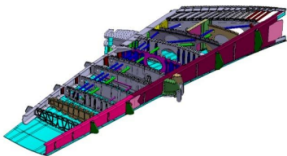
From a Digital Mock-up (DMU) to an FE Model



A DMU of a simple model - courtesy EADS



Simplified, idealized and partially meshed model



Aircraft wing structure - courtesy EADS

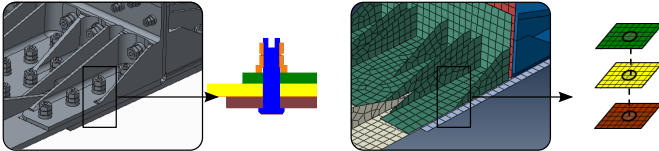


Not workable

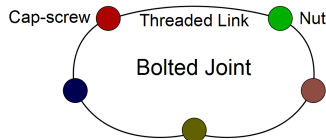
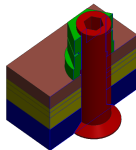
- Starting point: a DMU
 - a set of objects in 3D space without geometric connexions.
- Too many interactive transformations: not applicable.

Need for Component's Function and Structure

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

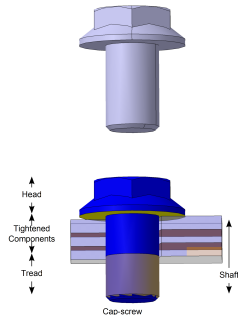


- Shape transformations:
 - Simplifications and idealizations.
- Require geometric interfaces and functions of components.



Structuring the Shape of a Component

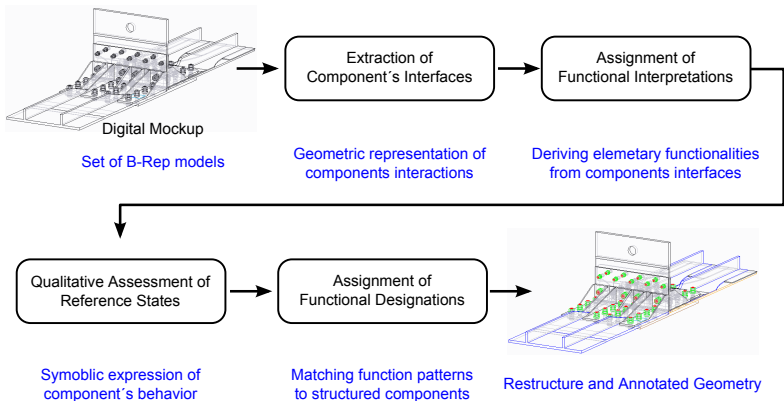
- What do we have?
 - Component shape as B-Rep model.
 - Unreliable and non-standardized textual data, if any.
- What do we need?
 - Explicit component designation expressing its function.
 - Areas of interaction with other components.
 - Boundary decomposition according to elementary functions, i.e.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



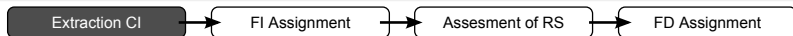
Related Work

- 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



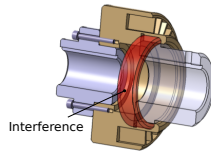
Digital Shapes



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



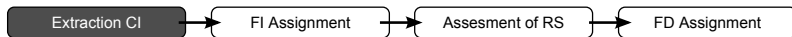
Real spline shaft and bushing



Digital shape of the same components

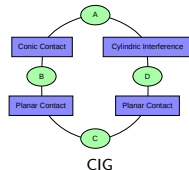
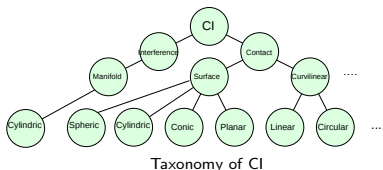
- Interfaces between real components define elementary functions.
 - Contacts and clearances.
- Possible components' geometric interactions in a DMU:
 - Contact
 - Clearance
 - **Interference**

Taxonomy of Component Interfaces



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

Component's geometric interaction → *Conventional Interfaces*.

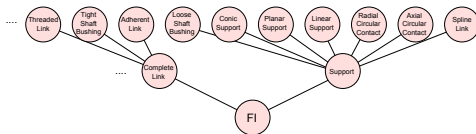


- Taxonomy of CIs according to functional surfaces & geometric interaction types.
- CIs between DMU components produce a graph (CIG).

Taxonomy of Functional Interfaces



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



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

Qualitative Interface Behavior



- 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

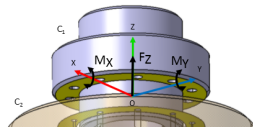
- One qualitative screw per FI.

$$\left\{ \begin{array}{c|c} \begin{matrix} 0 \\ 0 \\ \mathcal{F}_z \end{matrix} & \begin{matrix} M_x \\ M_y \\ 0 \end{matrix} \end{array} \right\}_{O/x,y,z}$$

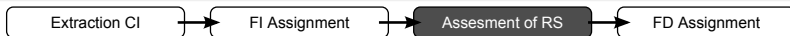
Quantitative Screw

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

Qualitative Screw



Filtering out Functional Interfaces

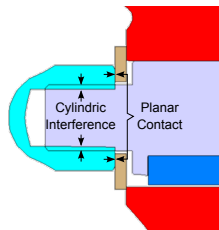
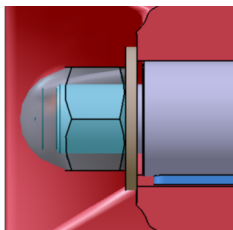


- Shape \leftrightarrow Behavior \leftrightarrow Function
- Setting up a qualitative behavior using independent *states*.

Reference State

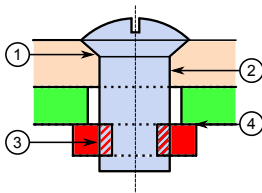
Expresses the behavior of either the whole or a part of a product.

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



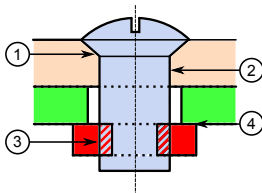
Filtering out FIs (example)

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



Filtering out FIs (example)

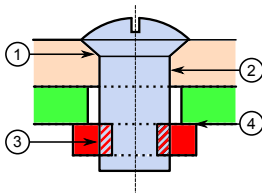
- ① Conic Contact
- ② Cylindric Contact
- ③ Cylindric Interference
- ④ Planar Contact



Conic Contact ①	Conic Support	Conic Support	Conic Support	Conic Support
	$\begin{Bmatrix} * & * \\ < & 0 \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ < & 0 \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ < & 0 \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ < & 0 \\ * & * \end{Bmatrix}$
Cylindric Contact ②	Loose Fit	Loose Fit	Snug Fit	Snug Fit
	$\begin{Bmatrix} * & * \\ 0 & 0 \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ 0 & 0 \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ * & * \end{Bmatrix}$
Cylindric Interference ③	Spline Link	Threaded Link	Spline Link	Threaded Link
	$\begin{Bmatrix} * & * \\ * & * \\ 0 & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ \# & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ 0 & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ \# & * \end{Bmatrix}$
Sum	$\begin{Bmatrix} * & * \\ < & * \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ * & * \end{Bmatrix}$

Filtering out FIs (example)

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

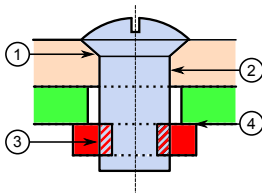


Conic Contact ①	Conic Support	Conic Support	Conic Support	Conic Support
	$\begin{Bmatrix} * & * \\ < & 0 \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ < & 0 \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ < & 0 \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ < & 0 \end{Bmatrix}$
Cylindric Contact ②	Loose Fit	Loose Fit	Snug Fit	Snug Fit
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Cylindric Interference ③	Spline Link	Threaded Link	Spline Link	Threaded Link
	$\begin{Bmatrix} * & * \\ * & * \\ 0 & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ \# & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ 0 & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ \# & * \end{Bmatrix}$
Sum	$\begin{Bmatrix} * & * \\ * & * \\ < & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ * & * \end{Bmatrix}$

Planar Contact ④	Planar Support	Planar Support
	$\begin{Bmatrix} 0 & * \\ 0 & * \\ < & 0 \end{Bmatrix}$	$\begin{Bmatrix} 0 & * \\ 0 & * \\ < & 0 \end{Bmatrix}$
Cylindric Interference ③	Spline Link	Threaded Link
	$\begin{Bmatrix} * & * \\ * & * \\ 0 & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ \# & * \end{Bmatrix}$
Sum	$\begin{Bmatrix} * & * \\ * & * \\ < & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ * & * \end{Bmatrix}$

Filtering out FIs (example)

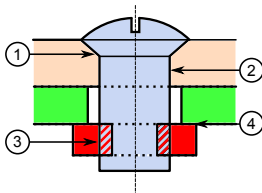
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Conic Contact ①	Conic Support	Conic Support	Conic Support	Conic Support
	$\begin{Bmatrix} * & * & * \\ < & & 0 \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ < & & 0 \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ < & & 0 \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ < & & 0 \end{Bmatrix}$
Cylindric Contact ②	Loose Fit	Loose Fit	Snug Fit	Snug Fit
	$\begin{Bmatrix} * & * & * \\ 0 & & 0 \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ 0 & & 0 \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$
Cylindric Interference ③	Spline Link	Threaded Link	Spline Link	Threaded Link
	$\begin{Bmatrix} * & * & * \\ 0 & & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ \# & & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ 0 & & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ \# & & * \end{Bmatrix}$
Sum	$\begin{Bmatrix} * & * & * \\ < & & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$

Planar Contact ④	Planar Support	Planar Support
	$\begin{Bmatrix} 0 & * \\ 0 & * \\ < & 0 \end{Bmatrix}$	$\begin{Bmatrix} 0 & * \\ < & 0 \end{Bmatrix}$
Cylindric Interference ③	Spline Link	Threaded Link
	$\begin{Bmatrix} * & * & * \\ 0 & & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ \# & & * \end{Bmatrix}$
Sum	$\begin{Bmatrix} * & * & * \\ < & & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$

Filtering out FIs (example)



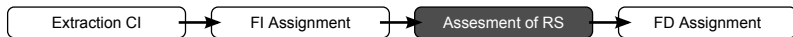
- ① Conic Contact
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- ④ Planar Contact

- ① Conic Support
- ② Loose Fit
- ③ Threaded Link
- ④ Planar Support

Conic Contact ①	Conic Support	Conic Support	Conic Support	Conic Support
	$\begin{Bmatrix} * & * & * \\ < & 0 & \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ < & 0 & \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ < & 0 & \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ < & 0 & \end{Bmatrix}$
Cylindric Contact ②	Loose Fit	Loose Fit	Snug Fit	Snug Fit
	$\begin{Bmatrix} * & * & * \\ 0 & 0 & \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ 0 & 0 & \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$
Cylindric Interference ③	Spline Link	Threaded Link	Spline Link	Threaded Link
	$\begin{Bmatrix} * & * & * \\ 0 & * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ \# & * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ 0 & * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ \# & * & * \end{Bmatrix}$
Sum	$\begin{Bmatrix} * & * & * \\ < & * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$	$\begin{Bmatrix} * & * & * \\ * & * & * \end{Bmatrix}$

Planar Contact ④	Planar Support	Planar Support
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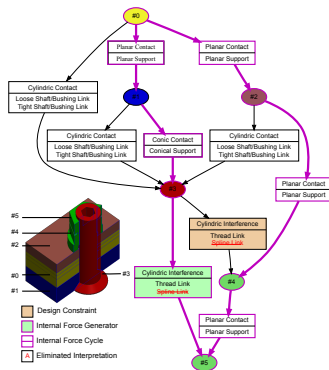
Identification of Functional Subsets



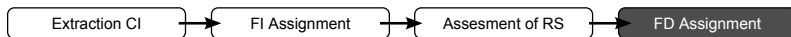
Functional Group

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



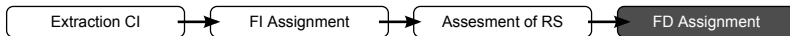
- Reference States →
 - Structured component geometry w.r.t. functional interfaces.
 - Structured DMU w.r.t. functional subsets.
- Matching those structures to reference patterns →
 - Classification of components into *Functional Designations*.

Functional designation

Semantic annotation that uniquely identifies the function of a component.

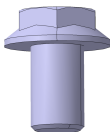
- Hierarchical structure of component functions.
 - Taxonomy of FDs.

Rule-based Matching

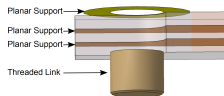


- Ontologies, taxonomies and rules to saturate FDs.
- Apply semantic reasoners to classify components into FDs.

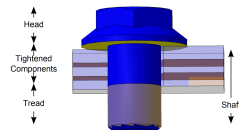
A *cap-screw* is a component that participates to a bolted connection with a threaded link and a planar support. . .



Initial component

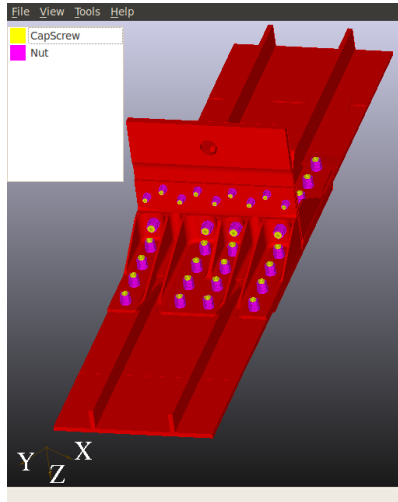
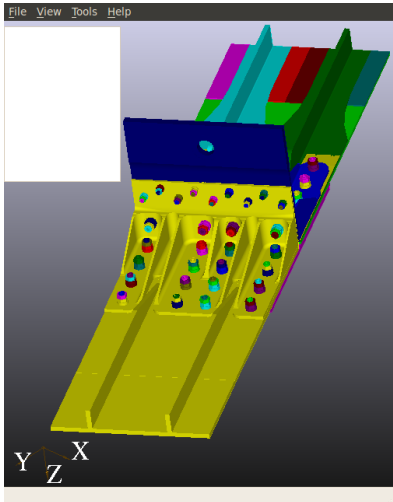


FIs involved in an FD



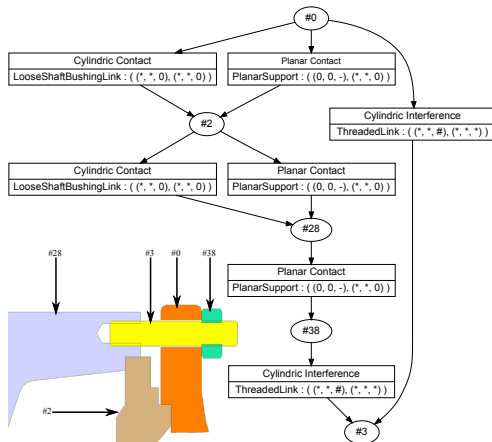
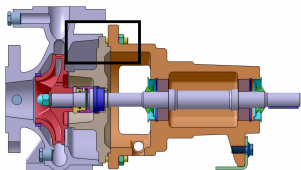
Structured component after matching

Root joint example



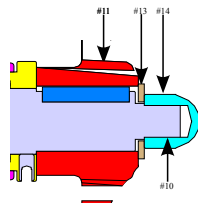
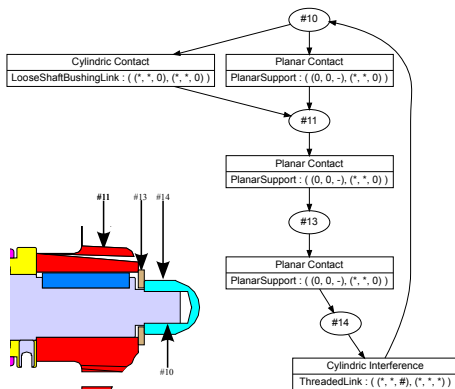
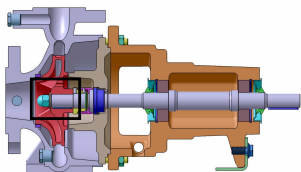
Centrifugal pump - elementary analysis

- Reliable results when processing elementary functions.



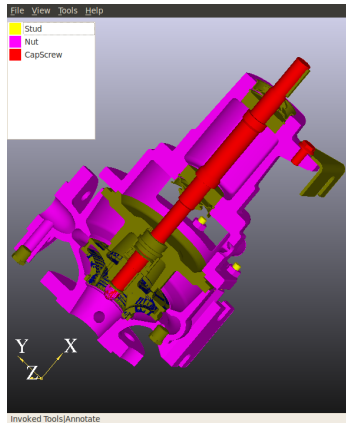
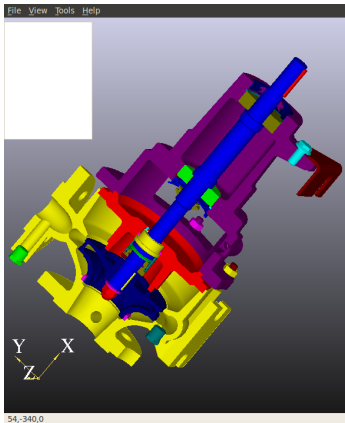
Centrifugal pump - elementary analysis

- Reliable results when processing elementary functions.



Centrifugal pump example

- Rules expressivity limitations
 - Ongoing work...



Conclusions - Perspectives

- Pathway to robustly connect 3D shapes and functional semantics.
- Structured and functional component models.
- 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.