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

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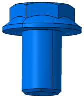
October 18, 2012

Overview

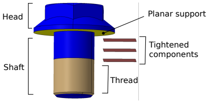
1. Introduction
   - Motivation
   - Related Works
2. Contribution
   - Conventional Interfaces
   - Reference States
   - Rule Based Reasoning
   - Results
3. Conclusions and Perspectives

Motivation

- Structuring initial geometric models and extracting semantic informations.
  - Functional interfaces; e.g. `Threaded Link`, `Planar Support`.
  - Functional Designations; e.g. `Cap-screws`, `Nuts`, `Gears`, etc.
  - Functional Groups/Mechanisms; e.g `Bolted Joint`, `Rack and Pinion`.



Screw M12



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Fitter cap-screw

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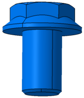

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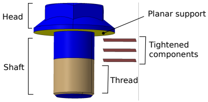
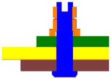
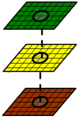


Screw M12
Fitter cap-screw

- Applications.
  - Simplification of geometric models in preparation of the generation of FEM.
  - Structural and thermal simulations.



CAD model of bolted joint



Simplified geometry for FEA

Related Works

- Use of textual information to deduce semantics.
  - No standards or norms; thus, unreliable results.
- Analyzing form features.
  - Addresses standalone components;
  - Limited geometric complexity;
  - Require user intervention.
- Using assembly constraints to deduce geometric interactions.
  - Constraints are not always explicitly available;
  - One configuration can be expressed in different ways;
  - Constraints are omitted for large DMUs.
- Relation between shape, function and behavior is well-established.

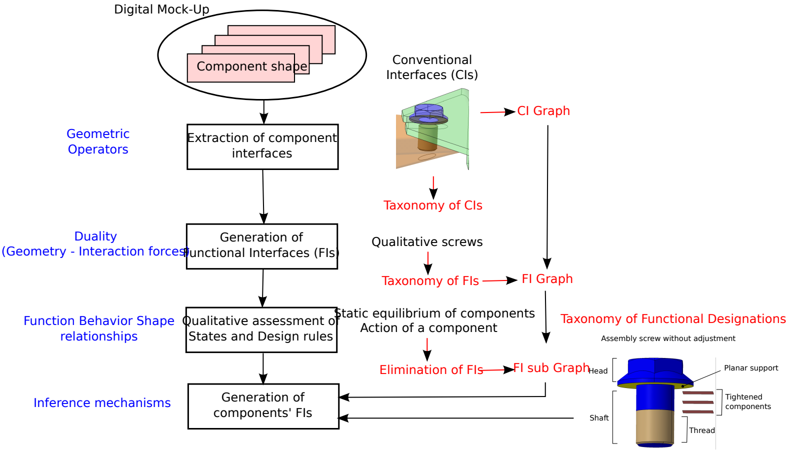
Overview

Input Geometric model of a product; i.e. its DMU.

Output Semantic annotations and restructuring of the geometry, including mechanical and kinematic information.

- Contextual analysis of components: *Conventional Interfaces* (CIs).
- Functional interpretation of an interface: *Functional Interface* (FI).
- Qualitative behavioral reasoning: *Reference States* (RS).
- Ontology of Functional Designation (FD): *Rule-based reasoning*.

Overview



Digital Mock-Up
Component shape
Extraction of component interfaces
Generation of Functional Interfaces (FIs)
Qualitative assessment of States and Design rules
Generation of components' FIs
Geometric Operators
Duality
(Geometry - Interaction forces)
Function Behavior Shape relationships
Inference mechanisms
Conventional Interfaces (CIs)
CI Graph
Taxonomy of CIs
Qualitative screws
Taxonomy of FIs
FI Graph
Static equilibrium of components
Action of a component
Elimination of FIs
FI sub Graph
Taxonomy of Functional Designations
Assembly screw without adjustment
Head
Planar support
Tightened components
Shaft
Thread

DMU Contents

- 3D representation of components as volumes defined by bounding surfaces (B-REP).
- Components usually have absolute positions; mating constrains are missing.
- Real shape vs. digital shape.

Real shape of a ball bearing

Digital shape of the same component

Conventional Interfaces

- Digital shape is a matter of convention. This has a direct impact on interfaces between components.

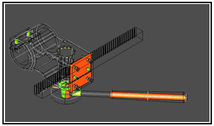
Conventional Interfaces

are the result of geometric interaction between components.

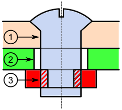
- CIs can be seen as binary relations between components.

Conventional Interface Graph

is a graph $CIG = (C, CI)$ where C is the set of all components in a DMU, and CI is the set of conventional interfaces linking those components.

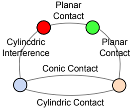


Geometric interaction between components in a DMU. Contacts are in green, and interferences are in red.



A CIs can either be:

1. a contact;
2. a clearance; or
3. an interferences.



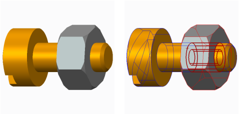
CIG

Functional Interface

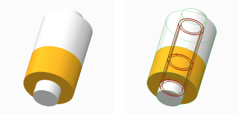
- In mechanics, component's functionality is determined by its mating surfaces with its environment (usually other components).

Functional Interfaces

augments CI with functional interpretations based on their geometric properties.



Screw/nut cylindric interference



Spline shaft cylindric interference

- CI are conventional representations of mating surfaces. However the idealization process leads to more than one possible functional interpretation.

Reference States

The question remains

How to identify *the correct* functional interpretation?

- More information is needed! This knowledge is provided as *Reference States*.

Reference State

is a set of hypotheses that are assumed to hold truth in a functional product.

- Functional interpretation that invalidates one of those assumptions are discarded. Ideally reducing the number of interpretation to one per CI.

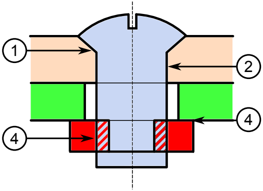
Qualitative behavioral reasoning

- Mechanical reference state assumes that the product is at an idle state. Thus, each of its component is in a *static equilibrium*.
  1. All external forces sum up to zero.
  2. All external moment around any given axis sum up to zero.
- However, qualitative values of forces and moments are never available in a DMU. Thus, the reasoning upon the validity of certain configuration is made by qualitative values.

`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

Qualitative behavioral reasoning (example)

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



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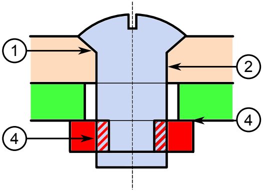

Conic Contact (1)	Conic Support $\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	Conic Support $\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	Conic Support $\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	Conic Support $\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$
Cylindric Contact (2)	Loose Fit $\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & 0 \end{array}\right\}$	Loose Fit $\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & 0 \end{array}\right\}$	Snug Fit $\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$	Snug Fit $\left\{\begin{array}{c\|c} * & * \\ * & * \\ * & * \end{array}\right\}$
Cylindric Interference (4)	Spline Link $\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	Threaded Link $\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$	Spline Link $\left\{\begin{array}{c\|c} * & * \\ * & * \\ 0 & * \end{array}\right\}$	Threaded Link $\left\{\begin{array}{c\|c} * & * \\ * & * \\ \# & * \end{array}\right\}$
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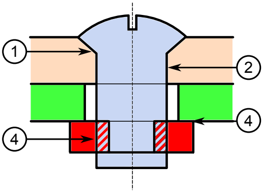

Conic Contact (1)	Conic Support $\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	Conic Support $\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	Conic Support $\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$	Conic Support $\left\{\begin{array}{c\|c} * & * \\ * & * \\ < & 0 \end{array}\right\}$
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Planar Contact (3)	Planar Support $\left\{\begin{array}{c\|c} 0 & * \\ 0 & * \\ < & 0 \end{array}\right\}$	Planar Support $\left\{\begin{array}{c\|c} 0 & * \\ 0 & * \\ < & 0 \end{array}\right\}$
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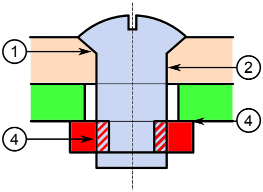
Qualitative behavioral reasoning (example)



1. Conic Contact
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4. Cylindric Interference

Conic Contact (1)	Conic Support $\begin{Bmatrix} * & * \\ * & * \\ < & 0 \end{Bmatrix}$	Conic Support $\begin{Bmatrix} * & * \\ * & * \\ < & 0 \end{Bmatrix}$	Conic Support $\begin{Bmatrix} * & * \\ * & * \\ < & 0 \end{Bmatrix}$	Conic Support $\begin{Bmatrix} * & * \\ * & * \\ < & 0 \end{Bmatrix}$
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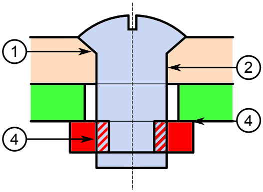
Planar Contact (3)	Planar Support $\begin{Bmatrix} 0 & * \\ 0 & * \\ < & 0 \end{Bmatrix}$	Planar Support $\begin{Bmatrix} 0 & * \\ 0 & * \\ < & 0 \end{Bmatrix}$
Cylindric Interference (4)	Spline Link $\begin{Bmatrix} * & * \\ * & * \\ 0 & * \end{Bmatrix}$	Threaded Link $\begin{Bmatrix} * & * \\ * & * \\ \# & * \end{Bmatrix}$
Sum	$\begin{Bmatrix} * & * \\ * & * \\ < & * \end{Bmatrix}$	$\begin{Bmatrix} * & * \\ * & * \\ * & * \end{Bmatrix}$

Qualitative behavioral reasoning (example)



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

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

Conic Contact (1)	Conic Support $\left\{\begin{matrix} * & * \\ * & * \\ < & 0 \end{matrix}\right\}$	Conic Support $\left\{\begin{matrix} * & * \\ * & * \\ < & 0 \end{matrix}\right\}$	Conic Support $\left\{\begin{matrix} * & * \\ * & * \\ < & 0 \end{matrix}\right\}$	Conic Support $\left\{\begin{matrix} * & * \\ * & * \\ < & 0 \end{matrix}\right\}$
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Sum	$\left\{\begin{matrix} * & * \\ * & * \\ < & * \end{matrix}\right\}$	$\left\{\begin{matrix} * & * \\ * & * \\ * & * \end{matrix}\right\}$

Functional Groups

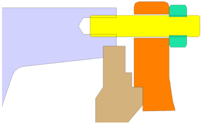
- The propagation of mechanical or kinematic properties through CI may reveal some functional groups in an assembly.

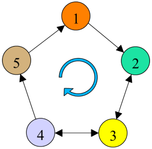
Fuctional Groups

are sets of components that complete or share the same functionality.

example Bolted connection, kinematic chain, etc.

- Studying cycles in a directed graph representing internal forces propagation leads to the recognition of bolted connection.





Rule Based Reasoning

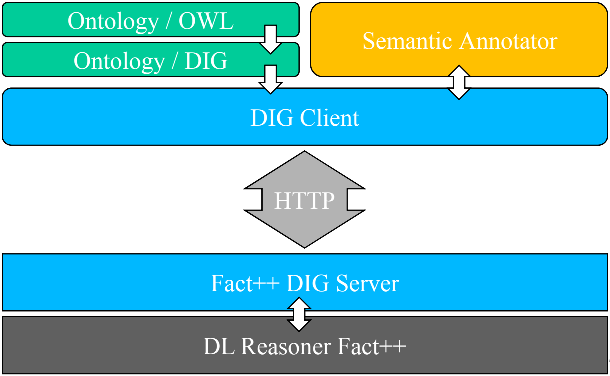
- Once the functional interfaces of a components are uniquely determined, it's functional designation can be deduced, given the proper rule.

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

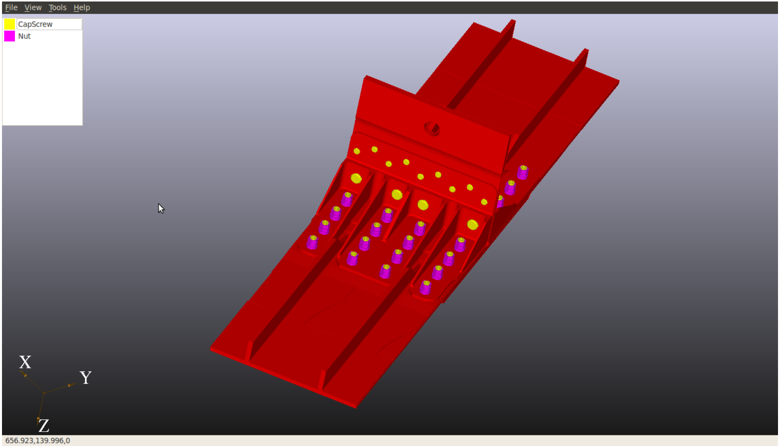
- To enable dynamic modification of rules, they are presented as an *ontology*, containing domain knowledge about mechanical components.
- The ontology is then initialized with knowledge coming from the reference state analysis phase (such as functional interfaces and functional groups).

Rule Based Reasoning

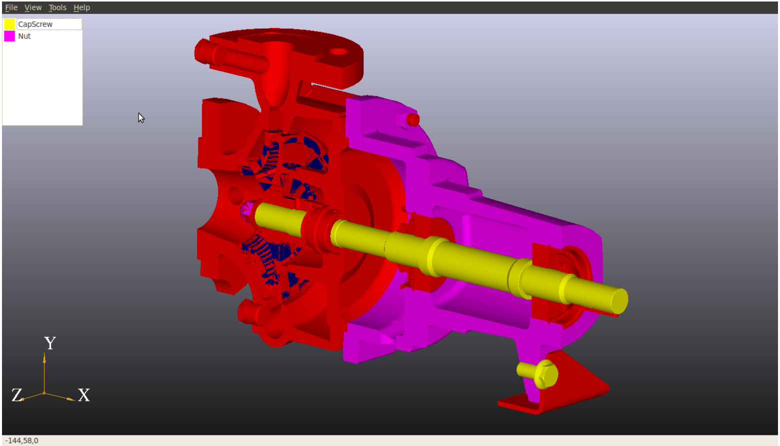
- Reasoning upon the enriched knowledge base leads to the classification of components into their FD classes. This is done Description Logic reasoner such as FaCT++.



Root joint example



Centrifugal pump example



Conclusions

- We provide an algorithm based on qualitative simulation to deduce functional properties of components out of their pure geometry.
- Functional designations are then derived based on reasoning upon dynamic rules, using well-established algorithms.
- The work shows the merit of exploiting geometric interactions between components instead of their mere intrinsic geometry.
- Restructuring and annotation of components geometry according to the newly derived functional information.

Perspectives

- Other reference states than mechanical equilibrium can be identified and analyzed; e.g. kinematic reference state.
- Address the issue of expressivity of DL languages, and the use of other logics; e.g. FOL.
- Provided semantic information, a variety of other applications rather than FEA can be though of:
  - Direct Design.
  - Assembly/disassembly analysis.
  - Virtual reality application.