Title:
An Ontology-based tool for supporting the constraining strategy of MCAD objects

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Introduction:
Current 3D modeling strategies focus on the creation of parametric Mechanical CAD (MCAD) models that effectively convey design intent. Design intent admits multiple definitions that all refer to the underlying rationale behind an object and the design decisions for model's geometry, and engineering/manufacturing information that is associated with it [3][4]. We emphasize that the first step to include the design rationale in a 3D model is to establish the geometric design intent of the model, so it has the capacity to follow changes to its structure without rendering to inconsistencies. On this basis, in previous research works [5][6], we proposed the Integrated Design Intent Architecture (IDI Architecture). The IDI Architecture indicates a direct and structured correspondence between different constraining schemas (called meta-constraints) and their inferring design intent (called intention regularities). Under this scope, it provides a structure to gradually capture the design intent of a model while it is being created (bottom – up approach) or signify a set of modeling steps and constraining schemes that comply with a predefined design intent (top-down approach).

In this research work, we further explore the employment of IDI Architecture in the context of the top-down approach. The top-down approach is related to the design of the modeling strategy, and it involves a succession of intention regularities from the upper (model) to the lower (sketch) level [6]. Under this scope, we revisit the IDI Architecture from an ontological perspective. Being oriented around different design intents that are met in MCAD models, we propose an ontological framework, named as IDI Ontology, which represents these design intents with respect to different constraining schemas that establish them and indicates an appropriate sequence of intention regularities at the three design levels. In the context of the top-down approach, the objective of the paper is to employ the ontological structure so to indicate a constraining strategy for the establishment of a predefined design intent. The presented prototype of IDI Ontology is developed by means of WebProtégé.

In the field of engineering design, ontologies find multiple applications, including the representation of a CAD model's geometry [8], the semantic integration of product and manufacturing information [1], and the semantic representation of features [2][7][9-10]. These ontological frameworks are feature-oriented in an effort to depict the variety of semantic meanings of features. Feature types constitute the classes of the ontology, with design intent, geometric description, and functional characteristics to be properties of feature entities. Differently to the above research works, the key classes of the IDI Ontology are intention regularities (i.e., design intents) and constraining schemas. Thus, IDI Ontology is targeted to the representation of design intent and can effectively contribute to the design of a constraining strategy independently of the CAD software that is used. Furthermore, it efficiently supports a strategic knowledge approach in CAD education, since it provides, for a given design intent, a structured set of multiple alternative constraining schemas that can be employed during 3D modeling.

The Integrated Design Intent Architecture (IDI Architecture):

The IDI Architecture is analyzed and discussed in [6]. Here we briefly present the framework in the context of the proposed IDI Ontology. The objective of IDI Architecture is to capture the design intent of a sketch/feature/model as this is generated by the constraining choices of a designer. It sets the design intent, via the pair "meta-constraints" – "intention regularities". Intention Regularities (IR) are defined as geometric or topologic patterns that appear in engineering objects and can be recognized as design intentions. Meta-constraints (MC) are constraints defined by the combination of geometric entities, attributes, and standard constraints that geometrically and/or semantically express an intention regularity. Accordingly, Integrated Design Intent refers to the design intent of a model that is generated by the intention regularities of its sketches and features. Each of the three design levels, i.e., sketch, feature and model, includes a set of meta-constraints and intention regularities, named respectively as SMC/SIR, FMC/FIR, and MMC/MIR.

The data structure and the inheritance of IDI Architecture between modeling levels are shown in Fig. 1. In [6] we identified and analyzed multiple meta-constraints and intention regularities at each design level. Tab. 1 presents indicative meta-constraints/intention regularities and the design intent they convey.

Sketch Level			
SMC/ SIR	*Sketch Design Intent*	*SMC / SIR*	*Sketch Design Intent*
SMC_Side/ SIR_Side	A sketch placed on one or two adjacent quadrants of the reference planes.	SMC_CenterSymmetric/ SIR_CenterSymmetric	Design of a cycle which coincides with an axes.
SMC_FaceInnerLoop/ SIR_FaceInnerLoop	A sketch that defines an internal loop to a pre-existing face.	SMC_Hole/ SIR_Hole	An inner loop that defines a hole to an outer loop.

Feature Level					
Feature Constraints	*SMC*	*FMC*	*SIR*	*FIR*	*Feature Design Intent*
		FMC_Protrusion	SIR_Center Symmetric	FIR_Axial Symmetric	An axial symmetric feature.
		And	SIR_Face InnerLoop	FIR_OnFace	A feature that lies on the face of a pre-existing feature.
Symmetric		FMC_SPSymmetric		FIR_SP Symmetric	A feature symmetric to its sketch plane.
Angle = 360°	SMC_Side	FMC_AxialSymmetric		FIR_Axial Symmetric	An axis symmetric feature.
Angle< 360°		FMC_AxialShape		FIR_Axial	An axial feature.
Through-All	SMC_Face InnerLoop	FMC_ThroughHole		FIR_Through Hole	A through hole feature.
Blind		FMC_BlindHole		FIR_BlindHole	A blind hole feature.

Tab. 1: Indicative meta-constraints and intention regularities at the sketch and feature level.

The Ontological framework:

The IDI Ontology is a knowledge-based system that is built upon IDI Architecture and aims at capturing the domain knowledge of geometric design intent of 3D MCAD models. For the proper definition of the ontological framework, we specify as principal question: "what conditions/constraints should an MCAD object satisfy to have a certain design intent?". For the design of IDI Ontology, the components of IDI Architecture (Fig. 1) are classified into three classes, that of "Design Intent", "Features", and "IDI Constraints". "Design intent" class includes expressions of

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geometric design intent both in verbalization manner and in the form of Model (MIR) and Feature (FIR) Intention Regularities. "Features" class involves main attributes for the abstract geometric definition of a feature, like the Mathematical Representation (in this work we focus on extrude and revolve) and Feature Constraints. The "IDI Constraints" class includes the meta-constraints in the sketch, feature and model level. SIRs are not included in this ontological framework, because they admit a one-to-one correspondence with SMCs.

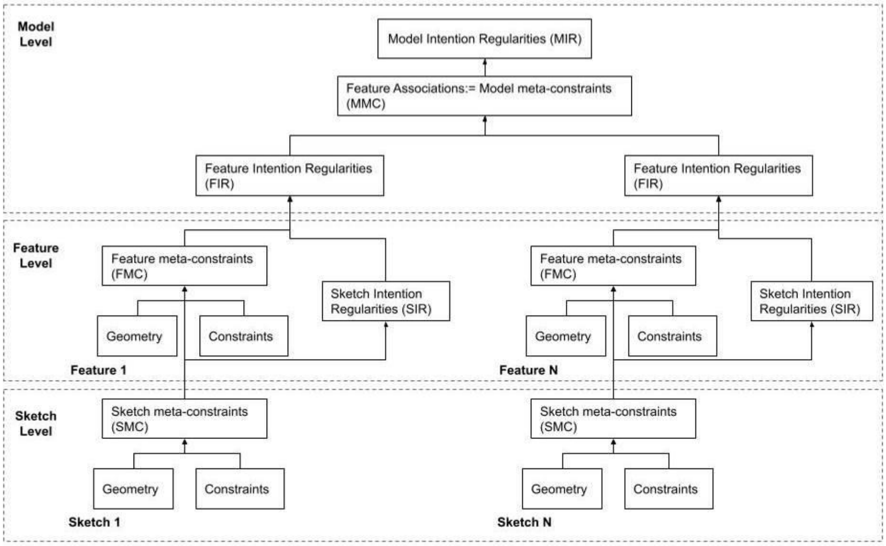

Fig. 1: The components and associations of the IDI Architecture [6].

The class hierarchy of the ontology is shown in Fig. 2. The subclasses that are included in this figure are those related to the indicative cases of IDI Architecture, as presented in Tab. 1.

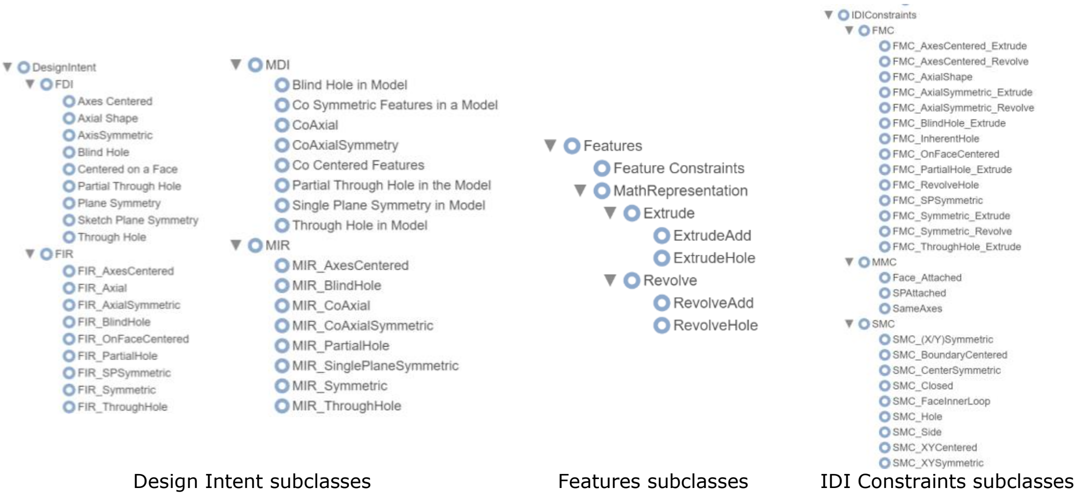

Fig. 2: The class hierarchy of IDI Ontology.

The classes FDI (Feature Design Intent) and MDI (Model Design Intent) include the verbalization form of design intentions. A query is set on terms of model or feature design intents (subclasses of Design Intent class), and the results expand to constraining schemas from the feature level (FMCs) towards to the sketch level (SMCs) combined with standard constraints or proper annotations when needed (IDI Constraints and Features classes). For the above classes, we define the following object properties (Tab. 2) to represent their connections and relations and the annotation property *hasFIR* with domain the IDI Constraints class and range the FIR class that associates FIRs with FMCs.

Property	*Domain*	*Range*	*Scope*
hasDesignIntent	MIR/Features/FIR	MDI/FDI	Vocabular form of Design Intent.
haspFDI/hassFDI	MIR	FDI	The design intent of primal and secondary feature in the model.
hasMMC/hasFMC/hasSMC	MIR/Design Intent/& Features	MMC/FMC/SMC	The model/feature/sketch meta-constraints that establish a FIR.
hasMathRepres	Features/ IDIConstraints	MathRepresentation	Determine constraints and attributes at the feature level.
hasDepth/Attribute/Angle		Feature Constraints	

Tab. 2: The object properties of the IDI Ontology are used to convey design intent of 3D Model.

<u>Example - Usage Scenario:</u>
During the phase of MCAD parametric design, a key challenge is to find the proper constraining schema that establishes the geometric design intent of the model. IDI Ontology supports the development of constraining schemas that establish the desired design intent. Due to space limitation, we present a usage scenario of IDI Ontology of a 3D model with eight features (Fig. 3(a)), and we focus only on “Axial Symmetry”, “Through Hole”, and “On Face Centered” design intents.

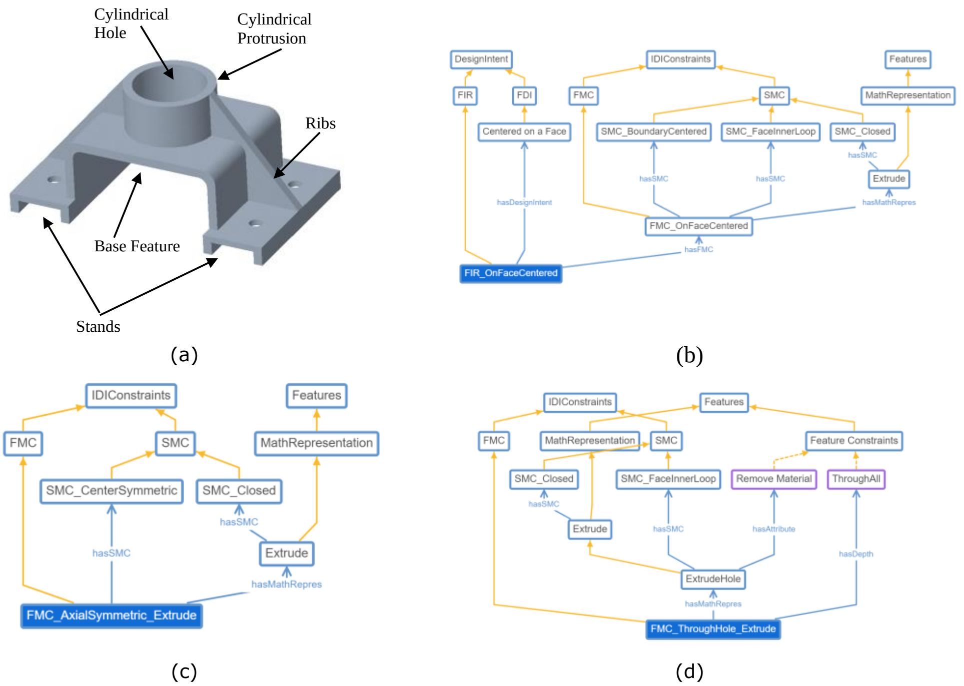

Fig. 3: (a) For a given 3D model and a specific design intent, (b-e) the IDI Ontology proposes a set of meta-constraints / constraining schemas.

The cylindrical protrusion is centered to the upper face of the base feature. The query for the creation of a feature with design intent “FDI: Centered on a Face” results to the FIR_OnFaceCentered intention regularity. The constraining schema that establishes this IR is indicated by FMC_OnFaceCentered (Fig. 3(b)). Alongside, the cylindrical protrusion is coaxial with a cylindrical hole. For this design intent the designer queries for the creation of two coaxial symmetric features and the creation of a through hole. The corresponding constraint schemas that are compatible with the design intent for the specific model are given by FMC_AxialSymmetric_Extrude (Fig. 3(c)) and FMC_ThroughHole_Extrude meta-constraints (Fig. 3(d)). The constraint schema that is designated by IDI Ontology for the creation of the centered cylindrical protrusion is SMC_BoundaryCentered, SMC_FaceInnerLoop and SMC_Closed. This schema establishes the creation of a closed sketch that is centered to the boundary of a selected face and is constraint to always be placed inside of it. The constraint schema that is designated for the cylindrical hole includes the SMC_Closed, SMC_CenteredSymmetric and SMC_FaceInnerLoop meta-constraints, which establish the creation of a closed cyclic sketch where its center coincides with the center of cylindrical protrusion. The sketch will also define an internal loop to the face of cylindrical protrusion, a constraint that along with the through all attribute establishes the creation and preservation of the through hole.

<u>Conclusions:</u>
The proposed IDI Ontology is a novel tool that supports the design of a modeling strategy for MCAD objects. The proposed framework provides designers with proper constraining schemas that establish pre-defined design intents. It can be used by both novice and expert designers, and for CAD education purposes. The presented prototype will be further extended as a complementary tool for the communication of design intent in a parametric MCAD system.

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