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DEVELOPMENT OF THE PRODUCT MODEL SCHEMA IN THE DESIGN OF MECHANICAL SYSTEMS¶

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Abstract

In this article, a brief description of the essential elements which interact in a product development activity is provided. The concept of an integrated design support framework (IDF), for supporting the product development activity, which is under development at the Cambridge EDC is briefed. Central to the development of a product is product data. An encompassing definition of product data is provided to describe the scope of the research for producing a product model schema for design support, and potential benefits of such a schema is discussed. Finally, the approaches that are adopted at the Cambridge EDC for developing a product model schema for supporting design of mechanical systems are described.

1 INTRODUCTION

Engineering design may be considered the process of transforming a perceived need into the description of a technical means which satisfy the need. During this process, designer uses various sources of knowledge, tools and methods, to clarify and evolve the product requirements and specification. The primary objective of the EDC at Cambridge is to provide fundamental methodologies in the design of mechanical systems, and a computational framework within which a designer, or a team of designers, would be able to continue design activity in a flexible way, with access to the methods and tools.

Central to the design activity is the evolution of product data, which could be defined as useful data generated about the design product during its design life cycle. Product data modelling research should produce representational constructs that are rich enough to enable product data to be represented, captured and evolved. Typical characteristics of product data, especially so in mechanical systems design, include the following:

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* Data are represented at various levels of abstraction;
* Data changes over the lifetime of the product evolution;
* Data at various levels are coupled;
* Data can be, and often is, looked at from various perspectives.

A unified product model schema should provide, among other benefits, enhanced data sharing among the various knowledge sources which a designer uses within the framework during designing.

The central problem, therefore, is the identification of the various forms that this data and the data in the knowledge sources take, their interrelations, and identification and modification of existing data models, if possible, to meet these demands.

In this article, a brief description of the essential elements which interact in a product development activity is provided. The concept of an integrated design support framework, for supporting the product development activity, which is under development at the Cambridge EDC is briefed. Central to the development of a product is product data. An encompassing definition of product data is provided to describe the scope of the research for producing a product model schema for design support, and potential benefits of such a schema is discussed. Finally, the approaches adopted at the Cambridge EDC for developing a product model schema for design of mechanical systems are described.

2 PRODUCT DEVELOPMENT

Central to the product development is the product to be designed. A (group of) individual(s) identify the perceived need for a product, and uses various processes (such as systematic design processes like the one proposed by Pahl & Beitz [1984], or no processes, such as opportunism proposed by French [1992]), tools (such as CAD tools, calculating machines, FEM packages, etc), and external information (such as books and catalogues) to generate various descriptions of the product. All these activities take place in some design environment (such as drawing board, discussion sessions, libraries, notebooks, etc). For instance, a project at the Cambridge EDC involves developing a *Mobile Arm Support* (product, acronymed as MAS) for wheelchair-bound patients having muscular dystrophy; this is being developed by the ED designers in conjunction with Health-care group and potential manufacturers (people). Place includes meetings, individual notebooks of the people, drawing boards, interviews, etc, and external information includes books on dystrophy, reports of the interviews with the patients, etc. Therefore, the activities involved in product development are interactions between people, process, product and place (environment), so as to accumulate, process and generate information, about the product, sufficient for its realisation. This classification is similar to that used by Van Geffen and Blessing [1992]; the difference is that in our adaptation, place is not just organisational environment of the designers, but includes any medium within which they carry out design, and that processes include methods, tools and techniques used by the designers.

3 INTEGRATED DESIGN SUPPORT FRAMEWORK

A central goal of the EDC at Cambridge is to develop a design environment (place), called Integrated Design Framework (IDF), which would support

- design activities;
- individual as well as team of designers;
- both systematic as well as flexible approach to design;
- storage of, and access to, tools, information sources, and the past, present and future of the product data.

The scope and a possible architecture have been described elsewhere [Chakrabarti & bauert, 1991; Ball, Bauert & Stomph-Blessing, 1991]

4 PRODUCT DATA

Product data is defined here as useful information generated about the design product during its design life cycle. This is not *just* the geometry of the product, but includes

- requirements of the product (in the case of the MAS project, this includes that the support should allow for movement, holding, stopping, and orientation of the arm at various positions, and that it should be safe and aesthetically pleasing to the patients);
- artifact information (for the MAS, this would include the conceptual designs generated to date, and all the embodiments and detail designs to be produced in future).
- rationale / process information; this would include details of the discussions between various people, or the reasons given by the individuals, about various decisions were taken, based on what information, tools or techniques;
- people involved / communication;
- external information (which could include disability of the patients, the sizes of the wheelchairs used by the patients, products available in the market which does similar job, etc).

5 CHARACTERISTICS OF PRODUCT DATA

Some of the characteristics of the product data are:

- data can be at various levels of abstraction; there can be back-of-the-envelope sketches or detailed drawings, or, decisions based on very rough information or very detailed information;
- data in evolving, usually going through numerous modifications, all of which are important;

• same data many times presented in multiple representations, for instance in natural language description, graphical descriptions or equational descriptions;

• data at various levels of abstractions, and those generated at various phases of its life cycle, are coupled;

• the same data can be, and many times are, looked at from different points of view (this includes evaluating a concept, for instance, using different set of criteria by different designers).

The design environment should be able to support all these.

6 GOALS AND BENEFITS OF PRODUCT DATA MODELLING RESEARCH

The goal of product data modelling research is to produce constructs for supporting

• representation;

• capture, and

• manipulation of evolving data.

Potential benefits include

• enhanced data sharing (for instance, in the case of the MAS, its geometric information would be required for doing kinematic analysis, detailed stress-analysis and process planning and execution);

• enhanced information management (this includes Dependency, Viewpoint and Precedence managements [see Lee, 1991]).

7 CENTRAL PROBLEMS

The central problems in producing product model schema are:

• Identify the various forms that product data takes in design activity, especially in the information sources to be used by designers (in the case of MAS project, this includes the Functional Synthesizer, Embodiment Generator, Configuration Optimiser, etc);

• Identify existing product models;

• Modify existing models (or produce new model, if modification is impossible), to support the forms of data identified above.

8 APPROACHES

Three complimentary approaches are taken at Cambridge EDC, which are continued simultaneously. Each is discussed below.

8.1 Top-Down Approach

In this approach, we first identify what the activities and information generated in a real design are, and then search for specific information model, ie, what the objects, relations, decisions, etc, are which need to be supported. Only then are enquired what specific data types, data structure, and soft/hardware required for its implementation of the information model. For the MAS project, this has been started with a *White-Board-and-Yellow-Sticker* experiment. A white board is used as the recorder for design events that take place in the MAS project. This has two axes, one showing events of various types (such as concept generation, concept evaluation, etc.), and the other axis showing time. Whenever an event takes place at the EDC (or elsewhere), an yellow sticker is stuck at the relevant time point and event slot of the whiteboard. The sticker includes brief information regarding the event-type, people involved, place involved, results, rationale and source where more detailed description about the event can be found. The partition of the whiteboard (ie, the event-types that are put on the event axis) is changeable, and one of the tasks of this exercise is to find what (or whether there is any) the most suitable partition is to capture all design activities which took place.

8.2 Bottom-Up Approach

The product model schema should be able to support, among others, the inputs and outputs of the software modules that are being developed at the EDC, and their correspondences. In this approach, we analyse, to start with, the following three modules:

- Functional Synthesizer, which generates schematic layouts of solution concepts to upto multiple input-output mechanical transmission problems. The input to the software is a problem description, containing a set of input characteristics (positions, directions and magnitudes of input forces and torques, for instance), a set of output characteristics, and constraints. The output of the software is a database of schematic layouts, of functional elements (such as generic levers, transmission rods, etc) and connections, of solution concepts.
- Embodiment Generator, which aims to take such layouts and convert it to embodiment layouts of standard components with rough dimensions. The input to the software, at the moment, is a layout of standard components and interfaces, and a specification stating some values of the variables describing the components and interfaces, and some (overall) constraints. The output is a set of (range of) values for all the variables describing the components and interfaces.
- Configuration Optimiser, which will eventually take these embodiment layouts and optimise them with respect to a given set of optimisation criteria. Its input consists of the assembly of components, interfaces and features under consideration, the problem

boundary which focuses on the portion of the assembly currently being optimised, and a specification of the criteria for optimisation. The output is the best configuration, and the values of its optimisation indices (such as duty, reliability and cost).

The modules have overlapping functions, and the information used by them overlap. The eventual aim of the Bottom-Up approach is to produce a metamodel of product information which allows these modules to share information.

8.3 Reviewing Existing Models

We classify the existing product models into four categories. These are:

• Artifact Models. These models essentially deal with information about the geometry, materials and layout of the design artifact. IGES, STEP, and product data model by Eastman et al. [1991] are some such examples.

• Rationale Models. These models view designing as an argumentation/discussion activity whereby the artifact information is generated/modified/changed. Examples include IBIS [Kunz & Rittel, 1970], Potts & Bruns' model [1988], DRL [Lee, 1991], QOC [Maclean et al., 1991], etc. They *do not* focus into the exact nature of the artifact information.

• Communication Models. These models (in fact there is only one that we are aware of, which is [Minneman, 1991]) try to look into the effect of communication (between members of the same group, and between different groups) on the design.

• Hybrid Models. In these models, constructs for representing the structures combinations of the above exist. One such model is O-RE-O model by Ullman [1992], where artifact information is proposed to be represented by objects, relations and operational steps, and argumentation by IBIS constructs.

One goal of the product modelling research at the Cambridge EDC would be to test whether O-RE-O model can be adapted to support modelling of the MAS project data. Two central reasons for taking O-RE-O model as the first test model are: one, considerable effort has gone into it to support both the product and processes of mechanical design (while many of the other models are designed primarily for software engineering design), and two, it claims to support empirical data in mechanical design.

9 SUMMARY AND CONCLUSIONS

This article provides an overview of the Cambridge EDC's view about the definition of product data, and the prime goals to be pursued in research towards producing a product modelling schema for supporting mechanical design. Also outlined are the approaches taken to pursue these goals, and the current state of of research at our EDC in these issues. The main points are:

• The overall goal of the centre is to develop a design environment (place) for supporting mechanical design activity, which involves interactions between people, processes and information sources in a place leading to the production of information about the product required for its realisation.

• Product data is central to this activity. It includes artifact information as well as process information, communication and external information relevant to the product.

• Product data modelling research should lead to the development of constructs that would be sufficient for representation, capture and manipulation of evolving product data. Benefits include enhanced information sharing and management.

• The approaches taken at the EDC at Cambridge are Top-Down, Bottom-Up, and review of Existing Models.

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