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Supporting connectivism in knowledge based engineering with graph theory, filtering techniques and model quality assurance

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ABSTRACT

Mass-customization has forced manufacturing companies to put significant efforts to digitize and automate their engineering and production processes. When new products are to be developed and introduced the production is not alone to be automated. The application of knowledge regarding how the product should be designed and produced based on customer requirements also must be automated. One big academic challenge is helping industry to make sure that the background knowledge of the automated engineering processes still can be understood by its stakeholders throughout the product life cycle.

The research presented in this paper aims to build an infrastructure to support a connectivistic view on knowledge in knowledge based engineering. Fundamental concepts in connectivism include network formation and contextualization, which are here addressed by using graph theory together with information filtering techniques and quality assurance of CAD-models. The paper shows how engineering knowledge contained in spreadsheets, knowledge-bases and CAD-models can be penetrated and represented as filtered graphs to support a connectivistic working approach. Three software demonstrators developed to extract filtered graphs are presented and discussed in the paper.

1. Introduction

Engineering knowledge refers to the knowledge that engineers apply when they are involved in developing products and their corresponding production systems. This broad definition excludes curiosities and emphasizes applicability, as long as it implies that the knowledge is part of decision-making processes. Engineering knowledge further refers to any reason for why, how, when, where, what, and by whom something is to be done or constituted. The sum of engineering knowledge formally represented for one product is referred to as product knowledge and may reside in any available product representation, provided that it is made available and interrelated.

The practical need to capture and automatically utilize such a wide and disperse amount of engineering knowledge derives from the fact that describing the purpose of a design and the justifications for specific decisions made when creating it are essential tasks for engineers and design professionals. As summarised by Otey et al. [1], previous researchers have determined that 48% of CAD models fail during design exploration [2] and according to the 2013 State of 3D Collaboration and Interoperability Report, 49% of engineers spend more than 4 h per week repairing design data with 14% spending more than 24 h per week [3]. The same report states that 32% of organizations miss deadlines due to design data problems [3].

Mass-customization has been a steady driving force to capture and automatically utilize such engineering knowledge. Many companies have, for instance, put significant efforts to parametrize CAD-models to quickly and accurately respond to changes in product requirements and specifications. This has caused engineers to not only focus on developing single products but product families with wide and flexible design spaces. In parallel to parametrized CAD-models, knowledge management and knowledge based engineering (KBE) systems have for decades strived to capture, digitize, and automate the application of this kind of knowledge within product and production development.

The problem has also received academic attention. Visualization of interdependencies of elements in CAD-models is an active research subject. Kozlova et al. reviewed how graph visualization can be used for CAD-models of architectures [4]. In that work prototypes for interactive graph visualization were also developed. The focus of that work was the visualization of the graphs and functions. Tsygankov et al. [5] studied how to semantically represent the building process of CAD assemblies

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containing multi-body components. Camba et al. [6] developed methods to traverse CAD-models of components to identify and visualize dependencies between features. Marchenko et al. [7] developed a tool to represent CAD-models as graphs in CATIA, which considered how the elements of the CAD-models were connected not only as parent/child relations but also through mathematical formulas. Graph rendering and filtering based on CAD-models, spread sheets and KBE-rules in order to support connectivistic learning in product development has been presented by Johansson et al. [8–10].

Even though KBE-systems have gained much attention through the last three decades, industries still find them hard to develop and even harder to maintain over time. It has been stated that arbitrarily small changes in the initial conditions of chaotic systems can lead to large changes in the results [11]. A KBE system can indeed be deterministic chaotic. For instance, changing angular dimensions in a CAD-model may cause arcs to flip inside-out (chaos due to topology). Also, slightly changing initial parameter values may trigger rules with mathematical expressions combined with if-statements (which are common in KBE-systems) so that the output is far different than the original (deterministic mathematical chaos). Further, when considering how manufacturing equipment is affected by changes further increases the chaotic effect. Consequently, in this paper, we suggest taking a connectivistic view on knowledge to contribute on defining a better way to help industries to maintain their product knowledge continuously.

We start with an introduction to connectivism, its principles and cornerstones, were singularities detected in applying connectivism to KBE context are highlighted. Then a brief review is given on how product knowledge is formalized and represented. After that, our connectivistic view is introduced by way of a detailed description of how three of the most common knowledge carriers in manufacturing companies (CAD-models, spreadsheets and KBE-rules) are constituted and how their constituents are connected. Then three examples are described: two where product knowledge was penetrated to gain understanding of the relations within parametric CAD-models connected to KBE-systems or spreadsheets and one where a CAD-model was penetrated to evaluate its modelling quality. Finally, the results are discussed, before the paper is concluded.

2. Connectivism and KBE

Connectivism is a teaching strategy embracing that knowledge in the modern society is connected, distributed and changing. This teaching strategy has been developed and applied relating to massive open online courses (MOOC), where anyone on the globe can attend the course which occurs on the Internet.

The connectivistic view of knowledge was introduced by George Siemens and Stephen Downs and was vividly described by Siemens in [12]. Connectivism is defined by Downs as “the thesis that knowledge is distributed across a network of connections” [13], and address learning that is located within technology and organizations, a learning that KBE ultimately is intended to support. Siemens defines connectivism as “the integration of principles explored by chaos, network, complexity, and self-organization theories”, and introduces its nine principles (described but not numbered by Siemens [12]):

- Learning and knowledge require a diversity of opinions to present the whole…and to permit selection of the best approach.
- Learning is a network formation process of connecting specialized nodes or information sources.
- Knowledge rests in networks.
- Knowledge may reside in non-human appliances, and learning is enabled/facilitated by technology.
- Capacity to know more is more critical than what is currently known.
- Learning and knowing are constant, on-going processes (not end states or products).
- Ability to see connections and recognize patterns and make sense between fields, ideas, and concepts is the core skill for individuals today.
- Currency (accurate, up-to-date knowledge) is the intent of all connectivistic learning activities.
- Decision-making is learning. Choosing what to learn and the meaning of incoming information is seen through the lens of a shifting reality. While there is a right answer now, it may be wrong tomorrow due to alterations in the information climate affecting the decision.

2.1. Cornerstones of connectivism

Five components are identified within connectivism. Central in the connectivistic view on knowledge is that learning is a *network formation process* [12]. Networks in this context refer to online social networks which are adaptive, fluid, and readily scalable in size and scope.

Context in the connectivistic view includes elements like emotions, recent experiences, beliefs, and the surrounding environment. Each element possesses attributes, which, when considered in a certain light, inform what is possible in the discussion. The object is tied to the nature of the discussion, framework or network of thought [12]. Context in this broad definition is not typically considered in theories for knowledge management, knowledge engineering, and KBE. However, context influences how the knowledge is implemented in KBE and how it can be understood by stakeholders.

Conduits are the mediums through which knower (i.e., experts) and seeker (i.e., knowledge consumers) communicate and through which the known entity finds expression [12]. Conduits are the facilities making the knowledge relevant, current, and available. In manufacturing companies, these conduits today include e-Mail, PLM-systems, intranet, wikis, and shared file servers.

Filtering is important to connectivists. Siemens [12] briefly reviews the history of how information has been consumed and concludes that we used to go to one source of information to get a thousand points of information (for instance newspapers). Now, we go to a thousand sources of information to create our own view. He continues by saying that we have become the filter, mediator, and the weaver of the networks. Since we as humans have a limited possibility to focus our attention (we can only do one or a few things at a time, and we just have a limited time per day) and since the amount of information and knowledge is ever increasing there is a great need for filtering the content, which (in our view) may be done based on individualized filters and current context (as defined previously).

Content is of course of central importance (even if it is told that the capacity of learning is more important than what we already know). Relevance, however, is not only about the nature of the content. The process of ensuring currency of content/information is critical to managing knowledge growth and function effectively. Content has to blend with conduit and context [12] which means that content should be perceived to be very close. Engineers today put much time to seek for content, but rather the content should seek for the engineers.

2.2. Main activities in connectivistic learning

There are four main activities that take place in the connectivistic learning process. The first step is *aggregation* [14,15], where the learner searches relevant sources of information and gets into the relevant information. Second step includes evaluation and reflection of the information harvested in the first step. The second step is referred to as *relation* [14] and *remixing* [15]. In the third step the information and reflections are used to create something own out of the information. This is why the third step is called *create* [14] or *repurposing* [15]. Finally, the fourth step, *sharing* [14] or *feed forward* [15], is where the gained knowledge is shared with peers or others.

All four activities are involved when developing and maintaining KBE-systems.