Conceptual Modeling Systems: A Vision for the Future of Conceptual Modeling

Roman Lukyanenko[1], Binny M. Samuel[2], Veda C. Storey[3], Arnon Sturm[4]

1 University of Virginia, VA, USA

2 University of Cincinnati, OH, USA

3 Georgia State University, GA USA

4 Ben-Gurion University of the Negev, Beer Sheva, Israel

Abstract

Although conceptual modeling has been integral to information systems development and use, much of its potential remains underutilized. This is evidenced by the lack of a broad adoption of modeling concepts beyond traditional database design and process modeling applications. In this paper, we propose a fundamentally new perspective on conceptual modeling that integrates artificial intelligence (AI) components with conceptual modeling. This perspective enables us to go beyond passive conceptual modeling representations, such as diagrams, to design *conceptual modeling systems* that have the capability to learn and evolve.

Keywords

Conceptual modeling, conceptual model systems (CMS), artificial intelligence

1. Introduction

The pace of human development appears to be accelerating, with new products, technologies, and ideas emerging more rapidly than ever. These trends force information systems to be more capable, agile and flexible. Consider an example of digital twins - digital representations of other systems, such as human organs. Digital twins enable advanced simulation and management of their referent systems, but create new design challenges, including how to model such technologies [1], [2].

Over the past 50 years, conceptual modeling has facilitated the development and use of information systems. However, as the diversity and sophistication of information technologies continues to increase, conceptual modeling has, at times, lagged behind and, in some cases, never caught up to technological developments [3]. Indeed, much of conceptual modeling remains a labor-intensive and manual activity mostly performed by information technology (IT) experts. Typical conceptual models are of low-to-medium complexity, so that various stakeholders can comprehend them (e.g., [4]). Contrast this with the highly-automated field of artificial intelligence (AI), which produces extremely complex, but increasingly effective, decision models. Conceptual modeling is yet to begin effectively leveraging AI, with emerging work only recently beginning to incorporate machine learning and natural language processing capabilities into conceptual modeling methods and applications (e.g., [5]–[8]).

There have been several attempts to provide new directions for conceptual modeling [3], [9], [10]. There have also been efforts to adapt conceptual modeling to new development contexts, such as digital twins, adaptive and self-regulating systems (especially cloud-based and Internet of Things), highly distributed settings (e.g., crowdsourcing), and AI-based cognitive systems [1], [2], [11], [12].

Despite some attempts to rethink the nature of conceptual modeling and progress its capabilities into new areas, much of conceptual modeling adopts a number of traditional assumptions about what conceptual modeling is and how it should be conducted. It is widely assumed (e.g., see [3]) that conceptual modeling: 1) is a phase of information systems development; 2) produces formal or semi-

ER'2022 Forum and Symposium, October 17-20, 2022, Online
EMAIL: romanl@virginia.edu (A. 1); samuelby@ucmail.uc.edu (A. 2); vstorey@bellsouth.net (A. 3); sturm@bgu.ac.il (A. 4)
ORCID: 0000-0001-8125-5918 (A. 1); 0000-0002-3223-4616 (A. 2); 0000-0002-8735-1553 (A. 3); 0000-0002-4021-7752 (A. 4)

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formal models, emphasizing diagrams representing concepts; 3) relates to models that are commonly created by humans (or more rarely, human-led intelligent agents); 4) refers to models that are static and do not possess their own agency; and 5) aims for models that are to be interpreted by analysts or other IT professionals, but who could also be business stakeholders or systems users.

Such characterizations of conceptual modeling, while true of the past, and to a large extent existing practice, miss an opportunity to take full advantage of the exciting new possibilities resulting from recent developments in AI, the growth of data, and computational power. We argue that a new vision of conceptual modeling is needed in response to advances in information technology. We suggest a new paradigm in which conceptual modeling is an activity of designing and managing AI-powered ***conceptual modeling systems (CMS)***. We detail the basic characteristics of a conceptual modeling system and suggest CMS as an agenda for future conceptual modeling research.

2. Conceptual Modeling Systems

Artificial intelligence enables computers to perform tasks that have historically required human cognition and human decision-making abilities, such as learning, abstraction, and inference. Machine learning (ML) is an especially important type of AI technology that uses algorithms and statistical models to enable computers to make inferences from sample data and perform specific tasks without being explicitly programmed. These tools, methods, and techniques are increasingly automating decision making and operations of organizations and individuals. AI has much to offer to society, with virtually every main economic sector being transformed due to the introduction of AI, including medicine, business, government, and science.

Conceptual modeling is an area that is appropriate for an AI infusion and transformation. Research in conceptual modeling has already begun leveraging AI. These efforts have focused on using AI-based techniques to design conceptual models from narratives and use cases [7],[12], or assessing and predicting model quality [14], [15], among others [5], [6], [8], [16]. We suggest to expand these efforts into a full-fledged integration of AI into conceptual modeling, leading to a proposal for developing conceptual modeling systems.

We define **conceptual modeling systems (CMSs)** as information technologies ingrained with AI-based capabilities of *awareness, autonomy, adaptivity,* and *activity* that generate, collect, and use representations to support the use and development of information systems. Before detailing each of the components of a CMS we refer to the core component of a CMS -- represenatation.

A representation, or a script is a collection of concepts and their relationships to capture facts, beliefs, intentions, values and others statements and claims in a relevant domain. The leveraging of AI in conceptual modeling enables us to relax the traditional assumptions about the form and function of representations. Whereas traditionally representations were viewed mainly as tools for human communication and understanding [9], [10], in the age of AI, representations also become tools that could be used by machines, without direct human involvement. Thus, we can relax the assumption that representations are human-facing and need to be *easily* accessible by a broad set of human stakeholders. Still, humans should be able to interpret them, when necessary, which is an important distinction with opaque machine learning models. From this relaxation CMSs can benefits from various AI capabilities.

Awareness. In the world of sensors, artificial intelligence, and APIs, the task of sensing the environment and collecting the requirements for the development of representations should, at least, be partially automated, and, at times, fully automated. Hence, we propose that CMSs should have an awareness capability; that is, the ability to autonomously or semi-autonomously sense both the system and the environment in order to gather, analyze, and structure requirements, and then prepare them for the development of representations. CMSs should be able to scan and monitor (e.g., via AI automation, advanced sensors) a defined target domain, and proactively understand the evolving needs by eliciting and analyzing the requirements accordingly. In short, as the world changes, CMSs should identify and consider these changes with the goal of building more up-to-date representations.

Autonomy. The autonomy capability in CMS means representations can be generated automatically without needing human intervention. In conjunction with input from the awareness capability, autonomy will provide many efficiencies. In addition to scalability, time savings, and other economies, these automatically generated representations are expected to be more reliable. Indeed, representations can vary dramatically as a result of the difficulty in mapping reality into modeling constructs. This variability may be substantially reduced by incorporating precise guidelines (including those suggested from research in ontology) that would guide CMSs into a consistent generation of representations.

Adaptivity. Traditionally, representations were designed by IT professionals, and followed predefined grammatical rules, predicated mainly on abstraction. However, as more human and artificial agents engage with technologies, perform data management activities, and attempt to understand the rules and facts about the domains represented by conceptual models, it becomes important to tailor the form and contents of representations to their varied needs, backgrounds (such as computer literacy skills, conceptual modeling grammars), domain knowledge and capabilities [17]. Thus, these automatically generated representations should adapt to the skills, needs and tasks of the stakeholders. For example, it should be possible to alter the mode of representation from abstraction (via classes) to instances and even to narratives, depending on the use case and the user. Likewise, representations should adapt the presentation style, taking advantage of the new multimedia formats. They should utilize dynamic graphics, videos, even virtual reality (e.g., metaverse).

Activity. Supported by AI components, CMSs should acquire agency and be able to implement change in the world directly based on the representations. This idea is not new. In fact, Computer-Aided Software Engineering (CASE) tools emerged in 1980s and permitted the development of software code based on the semantics captured in conceptual modeling representations [18], [19]. More recently, automated model generation has been applied in the context of Internet of Things and cloud computing under the models@runtime paradigm [1]. The CMSs underpins these ideas and efforts with a concerted push to adopt AI as a principal technology to make representations active. The intelligence of CMSs can be leveraged to implement specific changes, dictated by the real-world rules embedded in conceptual modeling representations. For example, a future CMS may contain documented outputs with each new modification of a representation that could be implemented automatically. Then, the CMS could generate requisite software code and design interface changes in line with updates to the representation, and, upon verification from a human being, implement these in the production environment. It is also feasible to envision the CMS making requisite modifications to representations and the information system upon identification of changes in the domain.

The notion of CMS rethinks conceptual modeling as concerned with development of meta information systems. These systems should be comprised of different AI components, corresponding to the four capabilities of modern AI outlined here, and any other ones that emerge and gain prominence. A CMS may be a stand-alone software or be embedded as a component of a broader system, such as an ERP. At the heart of the system is a collection of representations needed to support some predefined goals via AI capabilities (e.g., manage property, handle loan applications, analyze medical records, make investment decisions).

Although full-scale CMS remain a visionary idea, attesting to the viability of the Conceptual Modeling Systems we can observe several real-world instances of the CMS components outlined above. Among some examples, as already mentioned, are CASE tools [18], [19], and models@runtime. Likewise, the notion of awareness is becoming increasingly useful in modern organizations. For example, IBM recently developed an Operations Risk Insights (ORI) system. According to the company[2],

> *ORI continually monitors more than 150 data sources, including The Weather Channel and social media, and uses AI to assess threats to the IBM supply chain. Recognizing the value of this capability to help with disaster relief globally, we shared this capability with Day One Disaster Relief, Save the Children, and others. Most recently, we created a COVID-19 overlay for ORI which we also have shared with our non-profit partners.*

The ORI example at IBM demonstrates both the feasibility of a CMS and vast societal promise. Some of our ideas are already being implemented in the industry, albeit as disparate elements, and largely without the support from conceptual modeling research. Therefore, the conceptual modeling community should consider the aspects of CMS identified here and begin evaluating the readiness of existing conceptual modeling languages for CMS, updating these languages as needed, developing methods in support of CMS (e.g., for automated requirements collection), and increasing the emerging collaborations with the AI community.

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[2] See: https://www.ibm.com/blogs/journey-to-ai/2020/09/building-trust-in-ai-getting-the-wizard-out-from-behind-the-curtain/

3. Conclusion

We propose a vision for the future of conceptual modeling to better connect conceptual modeling with AI. Conceptual models (i.e., representations) of the future must be able to better leverage the capabilities of AI (*awareness, autonomy, adaptivity, and activity*) to sense their environment, respond to changes in their environment, accommodate emerging needs by being flexible in their presentation modes, and proactively enact change. These challenges can be addressed by conceptualizing and developing a new kind of artifact, *conceptual modeling systems,* as an intelligent information technology that fuses conceptual modeling outputs with AI. Conceptual modeling systems hold the potential to unleash drastic new opportunities for conceptual modeling research and help ensure that conceptual modeling continues to form the basis of future information systems development and use.

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