Guest Editorial: On the Convergence of Enterprise Modelling and Knowledge Graphs

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1 Introduction

The field of Conceptual Modelling has diversified over the years, as more purpose-diverse and domain-specific modelling methods are emerging. One consequence of this diversity is a divergence between (a) diagrammatic enterprise modelling (Archimate, BPMN etc.), placing strong emphasis on visual analysis and management concerns, and (b) engineering-oriented knowledge structuring that focuses on machine readability and understandability, potentially contributing to Artificial Intelligence. A separation of concerns also derives from the distinction between design-time purposes and run-time purposes of conceptual modelling methods or tools (Buchmann 2022), further contributing to a divergence of research streams.

With this special issue we aim to stress the need to reconnect these streams. Towards this goal, we took the pragmatic path of following the uptake of Knowledge Graphs in recent years (Gartner 2022) to encourage investigations on how their underlying technologies can benefit Enterprise Modelling, or conversely, how conceptualizations established in Enterprise Modelling communities can contribute to Knowledge Graph enrichment and more powerful, semantics-driven data management.

Knowledge Graphs (Chaudhri et al. 2022) have emerged from a long line of research that includes

the Semantic Web vision, description logics, computational ontology, Linked Open Data, graph databases, semantic search engines and other semantic technologies. In recent years, Knowledge Graphs have matured to become a topical technique for integrating, organizing, analyzing, and reasoning over many different types of information, especially addressing the need for semantic enrichment of Web content and structured data (Feng et al. 2021). Recent developments are harnessing Knowledge Graphs for machine learning using graph neural networks and graph embedding techniques (Wang et al. 2017), or to compensate for shortcomings of large language models (Yu et al. 2022).

Important connections between Enterprise Modelling and Knowledge Graphs include mining diagrammatic models (Shilov and Othman 2023), making enterprise models available as part of knowledge graphs (Karagiannis and Buchmann 2018), (Glaser et al. 2022), or as semantic enrichment for Linked Datasets (Buchmann and Karagiannis 2016). Knowledge Graphs can also be used to semantically contextualize Digital Twins (Zheng et al. 2021). Furthermore, representing enterprise models as Knowledge Graphs invites new types of analysis and reasoning, such as looking for enterprise architecture smells (Smajevic et al. 2021) or checking for semantic correctness of models (Fellmann et al. 2011). Ontologies can be used to ground the semantics of modelling languages (Guizzardi et al. 2015) (Opdahl et al.

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2012), as enabler for model annotation (Fill 2017) or for model-based graph neural networks (Ali et al. 2023).

This convergence has been advocated by earlier visions such as "active knowledge modelling" (Lillehagen and Krogstie 2008) or the proposal for a unified enterprise modelling language (Anaya et al. 2010); it is also a key ingredient in model-centric teaching and experimentation installations - see the OMiLAB Digital Innovation environment (Karagiannis et al. 2022). Reconnecting design-oriented and machine-oriented aspects of modelling can lead to citizen knowledge capture spaces required for the "grassroots" modelling practice vision of Sandkuhl et al. (2018) or by data architectures dealing with niche semantics such as those investigated in (Stumptner et al. 2018). The growing popularity of Knowledge Graphs and the availability of semantic technologies provide concrete technical ingredients in support of deploying such visions.

For this special issue on Enterprise Modelling and Knowledge Graphs we selected three contributions after a thorough double blind peer review process, for which we are grateful to all reviewers involved through the different revision stages. We are also thankful to the EMISAJ editors-in-chief for guiding us with organizing the editorial process. The three papers selected at the end of this process showcase diverse views on how enterprise models and ontologies or semantic graphs can support and inform one another - with content, semantics or design patterns.

The first paper, by Nour Ramzy, Sören Auer, Hans Ehm and Javad Chamanara, titled "SENS: Semantic Synthetic Integrated Model for Sustainable Supply Chain Analysis and Benchmarking" is an extended version of the conference paper previously presented by the authors at ECIS 2022 (Ramzy et al. 2022). The paper makes a proposal of applying knowledge graphs to supply chain modelling, in order to leverage the complex dependency analysis and navigation facilitated by the graph treatment. A scarcity of end-to-end supply chain data is identified and compensated by introducing a data generator that takes into consideration the SCOR framework's semantics (Supply Chain Council 2010) and supports diverse scenario analysis demonstrated by rich running examples. The proposal makes use of the RDF-star extension (Arndt and Broekstra 2021) to allow for treating supply chain descriptions as labelled property graphs. Thus, the work establishes a foundation for the convergence of Supply Chain Management and master data management based on Knowledge Graphs.

The second paper, by Andrei Chiș, Ana-Maria Ghiran and Steven Alter, titled "Informing Enterprise Knowledge Graphs with a Work System Perspective", reports on a Design Science project that adopted the conceptualization of S. Alter's theory of work systems (Alter 2013) as a semantic lens for retrieving and reasoning on operational data available in an enterprise knowledge graph. The paper is valuable in demonstrating how management theories can inform machine-readable knowledge structures that govern master data management in information systems. The Work Systems Theory has evolved from a pragmatic approach to work system analysis (Köhler et al. 2018), through gradually refined proposals of increasingly rigorous metamodels (Alter 2022) and a design-time modelling method (Bork and Alter 2020) – therefore the paper is a natural phase of this evolution.

The third paper, by Emanuele Laurenzi, titled „An Agile and Ontology-based Meta-Modelling Approach for the Design and Maintenance of Enterprise Knowledge Graph Schemas" presents another project organized within the Design Science frame – AOAME, a metamodelling environment that serves the dual purpose of enabling diagrammatic enterprise modelling and of building ontologies derived from the involved metamodels. It evolved from earlier conference reports (Laurenzi et al. 2018) as a possible answer to the question raised by (Corea et al. 2021) and provides an alternative to the semantic annotation and processing approaches for enterprise models previously discussed in the literature – e. g. (Fill 2017), (Karagiannis and Buchmann 2018).

With this special issue, we hope to show that the research on the convergence between Enterprise Modelling and Knowledge Graphs is gaining traction and is expanding its scope. The conceptualizations underlying existing management theories or enterprise modelling methods can offer a valuable semantic lens to Knowledge Graph development; at the same time, the toolset of Knowledge Graph-based data management can be valuable in establishing novel means of analysis over semantically rich enterprise models.

References

Ali S., Guizzardi G., Bork D. (2023) Enabling representation learning in ontology-driven conceptual modeling using graph neural networks. In: Proceedings of CAISE 2023. LNCS Vol. 13901. Springer, pp. 278–294

Alter S. (2013) Work system theory: Overview of core concepts, extensions, and challenges for the future. In: Journal of the Association for Information Systems 14(2), pp. 72–121

Alter S. (2022) Extending a work system meta-model using a knowledge graph to support IS visualization and development. In: Proceedings of the ER forum and PhD symposium @ ER 2022. CEUR-WS Vol. 3211

Anaya V., Berio G., Harzallah M., Heymans P., Matulevičius R., Opdahl A. L., Panetto H., Verdecho M. J. (2010) The unified enterprise modelling language—overview and further work. In: Computers in Industry 61(2), pp. 99–111

Arndt D., Broekstra J. (2021) RDF-star and SPARQL-star https://w3c.github.io/rdf-star/cg-spec/editors_draft.html Last Access: 2024-01-10

Bork D., Alter S. (2020) Satisfying four requirements for more flexible modeling methods: Theory and test case. In: Enterprise Modelling and Information Systems Architectures (EMISAJ) 15(3), pp. 1–25

Buchmann R. A. (2022) The Purpose-Specificity framework for domain-specific modeling. In: Domain-Specific Conceptual Modeling: Concepts, Methods and ADOxx Tools. Springer, pp. 67–92

Buchmann R. A., Karagiannis D. (2016) Enriching linked data with semantics from domain-specific diagrammatic models. In: Business & Information Systems Engineering 58(5), pp. 341–353

Chaudhri V. K., Baru C., Chittar N., Dong X. L., Genesereth M., Hendler J., Kalyanpur A., Lenat D., Sequeda J., Vrandecic D., Wang K. (2022) Knowledge graphs: introduction, history and perspectives. In: AI Magazine 43(1), pp. 17–29

Corea C., Fellmann M., Delfmann P. (2021) Ontology-based process modeling -will we live to see it? In: Proceedings of ER 2021. LNCS Vol. 13011. Springer, pp. 36–46

Fellmann M., Hogrebe F., Thomas O., Nüttgens M. (2011) Checking the semantic correctness of process models - an ontology-driven approach using domain knowledge and rules. In: Enterprise Modelling and Information Systems Architectures 6(3), pp. 22–35

Feng Z. W., Xu J. K., Mayer W., Huang W. Y., He K. Q., Stumptner M., Grossmann G., Zhang H. Y., Ling L. (2021) Automatic semantic modeling for structural data source with the prior knowledge from knowledge graph. In: IEEE 23rd Int Conf on High Performance Computing & Communications; 7th Int Conf on Data Science & Systems; 19th Int Conf on Smart City; 7th Int Conf on Dependability in Sensor, Cloud & Big Data Systems & Application (HPCC/DSS/SmartCity/DependSys). IEEE CS, pp. 2034–2041

Fill H. (2017) SeMFIS: a flexible engineering platform for semantic annotations of conceptual models. In: Semantic Web 8(5), pp. 747–763

Gartner (2022) What's new in Artificial Intelligence from the 2022 Gartner Hype Cycle https://www.gartner.com/en/articles/what-s-new-in-artificial-intelligence-from-the-2022-gartner-hype-cycle Last Access: 2024-01-10

Glaser P. L., Ali S. J., Sallinger E., Bork D. (2022) Model-based construction of enterprise architecture knowledge graphs. In: Proceedings of EDOC 2022. LNCS Vol. 13585. Springer, pp. 57–73

Guizzardi G., Wagner G., Almeida J. P. A., Guizzardi R. S. (2015) Towards ontological foundations for conceptual modeling: the unified foundational ontology (UFO) story. In: Applied Ontology 10(3–4), pp. 259–271

Karagiannis D., Buchmann R. A., Utz W. (2022) The OMiLAB Digital Innovation environment: Agile conceptual models to bridge business value with Digital and Physical Twins for Product-Service Systems development. In: Computers in Industry 138, p. 103631

Karagiannis D., Buchmann R. A. (2018) A proposal for deploying hybrid knowledge bases: the ADOxx-to-GraphDB interoperability case. In: Proceedings of HICSS 2018. Association for Information Systems https://aisel.aisnet.org/hicss-51/ks/ks_creation/4/

Köhler T., Alter S., Cameron B. H. (2018) Enterprise modeling at the work system level: evidence from four cases at DHL express Europe. In: Proceedings of PoEM 2018. LNBIP Vol. 335. Springer, pp. 303–318

Laurenzi E., Hinkelmann K., van der Merwe A. (2018) An agile and ontology-aided modeling environment. In: Proceedings of PoEM 2018. LNBIP Vol. 335. Springer, pp. 221–237

Lillehagen F., Krogstie J. (2008) Active knowledge modeling of enterprises. Springer

Opdahl A. L., Berio G., Harzallah M., Matulevičius R. (2012) An ontology for enterprise and information systems modelling. In: Applied Ontology 7(1), pp. 49–92

Ramzy N., Auer S., Ehm H., Chamanara J. (2022) SENS: semantic synthetic benchmarking model for integrated supply chain simulation and analysis. In: Proceedings of ECIS 2022. Association for Information Systems https://aisel.aisnet.org/ecis2022_rp/61/

Sandkuhl K., Fill H. G., Hoppenbrouwers S., Krogstie J., Matthes F., Opdahl A., Schwabe G., Uludag O., Winter R. (2018) From expert discipline to common practice: a vision and research agenda for extending the reach of enterprise modeling. In: Business & Information Systems Engineering 60(1), pp. 69–80

Shilov N., Othman W. (2023) Application of machine learning techniques to enterprise model classification: an approach and first experimental results. In: Proceedings of CoMeSySo 2022, LNNS Vol. 597. Springer, pp. 186–196

Smajevic M., Hacks S., Bork D. (2021) Using knowledge graphs to detect enterprise architecture smells. In: Proceedings of PoEM 2021. LNBIP Vol. 432. Springer, pp. 48–63

Stumptner M., Mayer W., Grossmann G., Liu J., Li W., Casanovas P., De Koker L., Mendelson D., Watts D., Bainbridge B. (2018) An architecture for establishing legal semantic workflows in the context of integrated law enforcement. In: Proceedings of AICOL 2018. LNAI Vol. 10791. Springer, pp. 124–139

Supply Chain Council S. (2010) Supply Chain Operations Reference (SCOR) Model: Overview – Version 10.0. Report. Cypress, TX

Wang Q., Mao Z., Wang B., Guo L. (2017) Knowledge Graph embedding: A survey of approaches and applications. In: IEEE Transactions on Knowledge and Data Engineering 29(12), pp. 2724–2743

Yu W., Zhu C. L. Z., Hu Z., Wang Q., Ji H., Jiang M. (2022) A survey of knowledge-enhanced text generation. In: ACM Computing Surveys 54(11), pp. 1–38

Zheng X., Lu J., Kiritsis D. (2021) The emergence of cognitive digital twin: vision, challenges and opportunities. In: International Journal of Production Research 60(24), pp. 7610–7632