HOW CAN DIAGRAMMATIC CONCEPTUAL MODELLING SUPPORT KNOWLEDGE MANAGEMENT?

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Research paper

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Abstract

Traditionally, venues that are publishing Knowledge Management research have been separating concerns between two viewpoints that rarely converge into holistic approaches: one is the tradition of Artificial Intelligence research, where "Knowledge Management" is often employed as an umbrella term in relation to a variety of semantic technologies, knowledge representation and knowledge discovery techniques; the other viewpoint is a specialisation of "intangible asset management", dealing with the business value and the pragmatics of organisational knowledge. Knowledge Management Systems are a catalyst for bridging such complementary perspectives and Design Science artefacts must be employed to facilitate alignments between these viewpoints, specifically between human-oriented and machine-oriented knowledge representations. Motivated by this desideratum and driven by project-based experience, the paper at hand advocates a key role of Diagrammatic Conceptual Modelling methods in enriching the seminal SECI Knowledge Conversion spiral, to the aim of opening it towards Knowledge Management Systems that could not have been envisioned at the time of Nonaka's original SECI proposal, but can now benefit from state-of-the-art semantics-driven practices. By hybridising the SECI model with a machine-oriented Knowledge Distilling cycle, an extended SECI spiral variant is proposed and analysed in the paper, as a reflection on project-based deployments and experience.

Keywords: Agile Modelling Method Engineering, RDF, SECI model, Knowledge Conversion

1 Introduction

By reflecting on the authors' project experience, the work at hand argues how diagrammatic modelling methods can support KM practices by enriching various phases of the seminal SECI (Socialisation-Externalisation-Combination-Internalisation) knowledge conversion spiral introduced by (Nonaka, 1991). The spiral is extended here to accommodate a proposed alignment between machine-oriented and human-oriented KM perspectives, representing two KM research streams of different origins whose developments rarely intersect. Thus, the paper is motivated by a longstanding tradition of segregating KM literature through what is typically perceived as a "separation of concerns", serving two clearly distinguishable viewpoints, each with its own understanding of the term "knowledge":

(a) On one hand, Artificial Intelligence subsumes disciplines such as Knowledge Representation and Knowledge Engineering, where "knowledge" refers to complex data structures aligned to specific formalisms in order to enable machine-interpretability and automated reasoning services;

(b) On a different level of granularity and abstraction, organisational knowledge has been recognised as an intangible asset or as intellectual capital that must be harnessed for competitive advantage, with specific management practices and tools. This perspective encompasses the philosophical, sociological and economic facets of KM identified in (Hong and Ståhle, 2005) as complementary to the technical one.
The distinction between the two perspectives manifests in multiple aspects: (i) *granularity of knowledge* (atomic predicates vs. complex semi-structured knowledge assets), (ii) *addressability* (machine-oriented vs. human-oriented), (iii) *means of knowledge externalisation* (conceptual graphs vs. guidelines, diagrams, content management systems), (iv) *applicability* (domain-specific inference services vs. knowledge capture and sharing).

By hybridising semantic approaches that have emerged under the paradigm of Conceptual Modelling, this paper advocates an alignment of the two KM perspectives and an integration of their concerns. The proposal is grounded in project-based examples; however, the contribution will be generalised on a theoretical level by resorting to a Hybrid Knowledge Conversion cycle that enriches Nonaka’s SECI model in ways that could not have been articulated at the time of its original publication, due to the maturity levels of the two paradigms to be streamlined in this proposal: Agile Modelling Methods (i.e., tailored for domain-specific knowledge externalisation) and the Semantic Web (i.e., means of deriving machine-readable knowledge representations from diagrammatic contents).

The remainder of the paper is structured as follows: Section 2 establishes the working terminology based on Conceptual Modelling notions. Section 3 introduces the underlying methodology. Section 4 instantiates the addressed problem in the form of an exemplary requirement for knowledge-driven process improvement. Section 5 positions the proposal with respect to related works. Section 6 frames the proposed approach relative to Nonaka’s SECI model, extended here to accommodate additional knowledge processes resulting from the proposal. The paper ends with a concluding SWOT analysis.

## 2 Working Terminology

We understand *Diagrammatic Conceptual Modelling* as an abstraction effort which has: specific means of representation (diagrams); specific goals (to support both people and machines to understand, evaluate or communicate the properties of a system under study); and a metamodelling-based approach – i.e., the graphical representations must comply to some formal conceptualisation.

(Thalheim, 2014) subsumes two interpretations, their distinction being obscured in the literature by using the term "conceptual" for both: (i) the *modelling of concepts* (i.e., the acquisition of domain knowledge, expressing an epistemological consensus for subsequent usage) produces "conceptional models"; (ii) *modelling using concepts* (i.e., the acquisition of case knowledge, describing a system by instantiating the previously defined "models of concepts"). Both the creation of "models of concepts" and "models that use concepts" qualify as knowledge externalisation efforts, as both aim at producing knowledge representations that will exist as assets, independently of the knowing subject, thus becoming transferrable and reusable between different entities (humans or machines). From a Knowledge Management Systems (KMS) engineering perspective these representations are still data structures – their quality of "knowledge" is given by how they can be interpreted and used by their recipients (i.e., combined with tacit knowledge of humans or with reasoning capabilities in machines).

A *Modelling Method* is a Design Science artefact typically deployed as a modelling tool tailored for a domain or class of requirements. The notion is employed here in the sense defined in (Karagiannis and Kühn, 2002), as comprising several building blocks: (i) a *modelling language* defined in terms of notation (graphical symbols), syntax (language grammar and syntactic constraints) and semantics (language vocabulary mapped on graphical symbols and their machine-readable properties); (ii) a *modelling procedure* to guide the modeller towards achieving modelling goals; (iii) *mechanisms and algorithms* to provide model-based functionality (model transformations, interactivity, automation etc.)

## 3 Methodology

The proposal resulted from project-based applications of the *Agile Modelling Method Engineering* (AMME) framework, introduced in (Karagiannis, 2015). AMME provides an iterative methodology for the agile engineering of modelling methods, "agility" being understood here as responsiveness to
(possibly evolving) knowledge externalisation requirements (i.e., the semantics that must be externalised in diagrammatic form). It also includes support for fast prototyping of modelling tools – an aspect to be emphasised in Section 6 together with additional insight regarding the iterative nature of AMME. AMME contrasts the traditional ambition of modelling language standardisation, which is driven by several common assumptions: (i) modelling requirements are fixed over time; (ii) the modelling language should dictate what model-driven systems can expect from models; (iii) the domain to be modelled is fully understood and conceptualised when the language is released; (iv) modelling languages must be widely adopted, potentially reusable across domains. Such assumptions have determined specific ways of employing models, as a means-to-an-end for model-driven software engineering (e.g., code generation relies on the stability / standardisation of the modelling language). Consequently, they obscure certain benefits that AMME brings into light, pertaining to the general value of models as knowledge artefacts that can support KM systems or contribute to the success factors of KM ("knowledge strategy that identifies users, sources, processes,..." (Jennex et al., 2008)), enabling a model base to fulfil the role of "enterprise-wide knowledge structure that is clearly articulated" (Jennex et al., 2008). Modelling method evaluations are typically guided by evaluation criteria for Design Science artefacts - see an overview in (Prat et al., 2014) – and in AMME evaluation outcomes feed the method increments in subsequent engineering iterations.

One example of an AMME result is the ComVantage method, to be referred as a supporting case in this paper. Its specifications are available in deliverables (Karagiannis et al., 2014a) and (Karagiannis et al., 2014b) and its evaluation protocol was subordinated to project-level goals – e.g., understandability, interoperability with other systems and alignment to project requirements. A documented evaluation was published in (Karagiannis et al., 2014b) based on an evaluation protocol currently being refined in the follow-up project (EnterKnow, 2017), which instantiates the knowledge conversion cycle hereby discussed in a different context, towards the goal of diagrams-ontology integration.

4 Problem Statement and Context

The paper's proposal addresses situations that can be generalised as follows: (i) when the same knowledge assets must be made available for both humans and knowledge-based systems, with representation and communication means that are adequate to each type of recipient; (ii) when management practices have employed enterprise modelling methods and a conceptual redundancy exists between the employed modelling language and some run-time information systems (i.e., common entities present in both the language vocabulary and run-time data models).

We instantiate these conditions in an exemplary case derived from the ComVantage research project (ComVantage, 2016), which proposed an IT architecture based on mobile apps sharing Linked Enterprise Data in support of collaborative business processes. The run-time architecture was complemented by design-time support in the form of the ComVantage modelling method – its agile development was discussed in (Buchmann and Karagiannis, 2015a) and details on different snapshots of the evolving method are available in (Buchmann, 2016), (Buchmann and Karagiannis, 2017) and public deliverables (Karagiannis et al., 2014a), (Karagiannis et al., 2014b). This paper will isolate only a domain-specific method fragment to support the argumentation with examples.

A modelling prototype was implemented in the collaborative OMiLAB environment (OMiLAB, 2016a) to enable collaborative modelling, including the management of modelling rights for users sharing access to the same tool and the same model repository (see Figure 1). The model repository, in combination with a wiki accumulating various media content (written documents, videos) formed the knowledge base for the duration of the project.

Mobile maintenance was one of the application areas in the project, reflected in domain-specific language concepts for modelling maintenance processes, maintained assets (machines with embedded systems and expected defect classes), resources (human resources, their competence profiles, mobile app requirements).
A typical application scenario involves a maintenance company who sells or leases machines with embedded systems and provides maintenance services during which technicians must be (i) assigned based on their competence profiles and (ii) supported with procedural knowledge (testing/repair processes) adequate to the class of defect or machine that must be repaired. We present in Figure 2 a simplified maintenance coordination process and a possible optimisation based on the KM strategies and systems covered by this paper's proposal. The example uses the custom ComVantage notation for a process model with swimlanes, decisions and (only in the top variant) parallelities. The initial version of the process involves three lines of intervention, represented by different actors:

(a) A Customer-site technician who identifies a faulty machine, initiates a maintenance ticket, then performs testing and repairing processes under the remote supervision of a 3rd line support specialist ("machine expert");

(b) A Maintenance coordinator who checks the validity of the request, i.e., the customer's service level agreement (SLA), provides support by analysing the request and assigns the problem to the machine expert. At the end, the coordinator is also responsible for closing the maintenance ticket;

(c) A 3rd level expert is notified by the maintenance coordinator based on availability and competence profile. First the expert tries to remotely guide the customer-site technician through testing processes and, if the problem appears to be solvable in this manner, also through the repair process. If not, the machine expert must travel on site to bring additional parts or to handle the problem himself.

The knowledge-based version (the lower part) shows several idealised improvements:

(a) The defect is reported directly by the machine, through embedded systems containing sensors that are polled remotely via Web protocols and middleware adapters. Statistical analysis of sensor value trends may indicate imminent defects, thus making it possible for the company to offer preventive maintenance services (this aspect involves sensor middleware and machine learning techniques that fall outside the scope of this paper's proposal);
(b) The maintenance coordinator is replaced by an automated service that can check the SLA validity, followed by a fault analysis based on semantic descriptions of the machine, its sensors and foreseen types of defects. Various levels of automation may be enabled, based on either computational or semantic techniques; for this paper's argumentation, the coordination service must be enabled to query and infer upon a machine-readable description of the faulty machine / defect that initiated the request;

(c) Testing and repair knowledge are retrieved from a knowledge repository containing an accumulated portfolio of intervention procedures that have been semantically linked to the machine and the defect that must be addressed;

(d) If the technician notifies the coordinator that he/she cannot handle the problem, the coordinator automatically selects and notifies machine experts based on machine-readable descriptions of their competence profiles (i.e., descriptions of their skill and knowledge levels relative to a type of machine/defect);

(e) The machine expert travels on site and performs the repair. He/she also queries the knowledge repository for guidance on intervention procedures and updates them to reflect learned lessons or unforeseen exceptions.

Figure 2. Knowledge-driven improvement of a maintenance coordination process
Steps (b)-(e) rely on knowledge structures that must be read or edited both by humans (e.g., testing or repair processes) and machines (e.g., the automated assignment of experts based on competence profiles, the retrieval of procedural knowledge based machine-readable relations between defect, machine, required competence, relevant maintenance processes). To facilitate this, a two-stage process is hereby proposed: (i) diagrammatic representations must be tailored to include all relevant concepts and relations and (ii) diagrams must be exposed in machine-interpretable structures that are amenable to semantic queries in knowledge-driven systems running outside the modelling environment. For the first stage, the AMME methodology is employed to agilely create and evolve a modelling tool; the second stage relies on the Resource Description Framework (RDF) prescribed by the Semantic Web paradigm for representing machine-readable knowledge graphs (W3C, 2016a). The two stages are bridged by the ability to transfer diagrammatic contents to RDF knowledge graphs, for which a technical solution was formally described in (Karagiannis and Buchmann, 2016). The remainder of the paper will position these enablers relative to one of the seminal knowledge creation models in KM - the SECI spiral (Nonaka, 1991), which must be updated to accommodate the opportunities of the proposed alignment and its model-driven knowledge conversion processes.

5 Related Works

The venues that publish work addressing KM research challenges and KM systems lean towards one or the other of the two perspectives mentioned in the Introduction, too often tending towards exclusivity - e.g., the ACM's CIKM conference series places emphasis on Artificial Intelligence, whereas the ECKM series is dominantly concerned with organisational knowledge and business cases. The work at hand aims at stimulating a hybridisation and unification of concerns, using as catalyst a streamlining of practices from the paradigms of Conceptual Modelling and Semantic Web.

In a seminal monograph on Knowledge Management Systems (Maier, 2007), the author surveys a variety of systems, as well as knowledge representation techniques - including those stemming from the paradigms of Semantic Web and Business Process Modelling (BPM). We subsume both to the wider paradigm of Conceptual Modelling, as it brings additional opportunities to KM practices:

(a) certain knowledge processes (e.g., acquisition) may be guided by the abstraction layers advocated by Conceptual Modelling (as emphasised in Section 2): first conceptional models capture the relevant domain concepts and their adequate level of detail (i.e., what should be "model-able" and how rich the models should be), thus enabling conceptual models to capture situational knowledge (e.g., work processes, their organisational context or requirements);

(b) business process models, presumably already employed for Business Process Management practices, may be enriched and hybridised with semantic extensions relevant for KM purposes - see (Karagiannis and Schwab, 2013), (Karagiannis and Woitsch, 2015), (Telesko and Karagiannis, 2002);

(c) while BPM typically assumes the modelling language to be a (standardised) invariant acting as a schema for some "process repository", Conceptual Modelling enables a looser perspective, with models forming a Knowledge Base governed by a modelling method / language that can be tailored through Design Science methodologies such as Agile Modelling Method Engineering – see (Karagiannis, 2015); or Situational Method Engineering – see (Henderson-Seller et al., 2014).

These approaches can be drafted on typical knowledge processes identified by popular KM frameworks such as those discussed in (Probst et al., 1999) or (Pawlowski and Bick, 2012), to be framed here under the phases of the overarching SECI knowledge conversion spiral of (Nonaka, 1991).

Multiple updates have been applied in the past to the SECI model - e.g., extending it with epistemological aspects in (de Castro et al., 2007), connecting it to activity theory in (Horng-Jyh Wu and Uden, 2014). However, they are limited to the psycho-sociological and economical facets of knowledge conversion, whereas the work at hand originates in technical interoperability challenges and a hybridisation requirement that may open specific opportunities for KMS engineering.
Streamlining machine-interpretable knowledge representations with human-oriented knowledge as an enterprise asset is not a new ambition in Artificial Intelligence. However, the focus was traditionally placed on exposing machine-interpretable representations in some intuitive human-oriented form relying on non-diagrammatic conceptual modelling - see (Speel et al., 2001), (Schreiber et al., 2000). The paper at hand takes the reverse approach of deriving machine-interpretable representations from modelling languages tailored for communicating enterprise knowledge among human stakeholders. Another related approach to knowledge streamlining is (Bork, 2015), where both the conceptual models and the situational models based on them are represented in diagrammatic form; however, that is a case of code generation, with a modelling tool being generated by another modelling tool ("model-driven modelling method engineering") without tackling any interoperability concerns. Although focussing on the ComVantage case, the work at hand builds on past project outcomes reported in (Telesko and Karagiannis, 2002) where business process modelling was employed for KM purposes. Other proposals on the interplay between KM and Conceptual Modelling traditionally took a holistic approach to capture, in model form, enterprise patterns or "blueprints" – see (Loucopoulos and Kavakli, 1999) and (Frank, 2000). Kingston and Macintosh (2000) used Zachman's framework to motivate the need for multiple types of models to manage "organisational memory". Such past proposals are refined here through the lens of semantic technologies – i.e., the RDF knowledge graphs opening new opportunities for the "interface level layer" of KMS envisioned in (Frank, 2000). Additionally, the agility desideratum is transferred to the context of modelling method engineering, thus moving away from the "blueprint thinking" that traditionally considers the modelling method to be an invariant.

6 Proposed Update for the SECI Knowledge Conversion Model

6.1 The Hybrid Knowledge Conversion Cycle

The SECI acronym stands for the 4 knowledge conversion activities indicated in (Nonaka, 1991), in relation to the two fundamental types of knowledge recognised in the KM discipline – tacit and explicit: (i) Socialisation (tacit-to-tacit transfer of knowledge, typically through shared experience and social interaction); (ii) Externalisation (tacit-to-explicit transfer of knowledge, by using some kind of communication media to represent it); (iii) Combination (explicit-to-explicit transfer of knowledge, typically the enrichment of knowledge from multiple sources, possibly in heterogeneous representations); (iv) Internalisation (explicit-to-tacit transfer of knowledge, typically through learning and assimilation of insights derived from the previous phases).

We add to this an improvised Knowledge Distilling cycle (Figure 3) whose elements are fundamental pillars in knowledge engineering research, as machines are required to gain "understanding" and reasoning capabilities for task automation or semantic interoperability. The Externalisation phase of SECI must consider several means of representing the knowledge after it is "harvested" from the knowing subjects: (i) Raw representation refers to weakly structured representations typically expressed in written form (and also in other media such as image and sound), aimed primarily at being transferred directly between humans; (ii) Structured representation refers to representations that are structured-by-design in order to facilitate retrieval and processing with convenient granularity; (iii) Formalised representation refers to representations that comply to some formal theory (e.g., description logics, graph theory) to gain specific guarantees (consistency, decidability, traceability) relative to particular algorithms (e.g., reasoning, retrieval); (iv) Machine-interpretable representation is achieved when a formalised representation is stored in a fitting structured representation on which semantic services (e.g., query/inference services) are implemented.

By mixing the SECI model with the Knowledge Distilling cycle, an updated cycle is hereby proposed, to be instantiated and explained in the following sections with references to the mobile maintenance case.
6.2 Human-to-human socialisation

In this phase the role of diagrammatic modelling is limited, especially in the reductionist view where the notion of tacit knowledge covers strictly knowledge that must be acquired through shared experience (skills developed by shared doing, action learning etc.). In Nonaka's wording there is a particular ambiguity related to tacit knowledge being difficult to articulate and externalise, but not impossible (if it cannot be externalised, the tacit-to-explicit phase would make no sense). The subsequent literature (including Nonaka revisiting the initial notions) interpreted this in several ways – e.g., by adding the category "implicit knowledge" (that which has not been externalised yet) (Speel et al., 2001) or by considering a continuous tacit-to-explicit spectrum from which certain blocks may be detached and stored independently of the knowing subject - see also Nonaka's iceberg metaphor (Nonaka and von Krogh, 2009) (Vartinen, 2013).

Socialisation becomes more complex in the modern context as people at different locations may perform their "shared experience" with the support of some communication medium that involves ancillary digital representations – e.g., video streaming of actions mixed with diagrammatic guidelines; however, in such a case we may consider that the Externalisation phase was already initiated. In Figure 2, the initial process version shows two parallelity structures where the machine expert supervises remotely the Perform tests and Perform repairs tasks of the on-site technician. The improved version replaces these with automated retrieval of maintenance process diagrams from a model-based knowledge repository. Depending on the skill gap between the two actors, in general cases it is realistic to assume that the Socialisation would be supported by the externalised knowledge base.

6.3 Externalisation in raw form

In its most rudimentary forms, explicit knowledge may be harvested as weakly-structured or non-structured descriptions in natural language (written or spoken), contributed to a shared repository.
Such representations may be chunks of content distributed at the right time to the right people - e.g., through a content management system, a wiki, or a Q&A social platform. However, their granularity imposes certain limitation on how they can be transferred and exploited by machines. Syntactic searching and tagging are the typical usage scenario. More advanced knowledge discovery scenarios may involve text mining, voice or image recognition; however, these are efforts of teaching the machine how to make sense of raw human communication, whereas this paper's proposal works in the reverse direction - by educating humans to create knowledge structures that are amenable to more sophisticated processing (e.g., reasoning) than what raw data or natural language allows.

6.4 Externalisation in diagrammatic form

The role of diagrammatic conceptual modelling in creating representations that are human-oriented (i.e., intended to be created and understood by humans), structured (i.e., granular enough for the required processing) and formal (i.e., non-ambiguously specified) has been promoted by the paradigm of Business Process Management and process-aware information systems (Dumas et al., 2005). We refine this role by addressing modelling requirements of a wider scope, more aligned to knowledge processes than those assumed by BPM. As discussed in the brief introduction to the AMME methodology (Section 3), modelling methods enable knowledge harvesting on two levels of abstraction depicted in the left part of Figure 4 as the meta layer (for the modelling of concepts) and the models layer (for modelling with concepts).

![Diagram](image)

Figure 4. Externalised knowledge and the Conceptualisation cycle of AMME – adapted from (Buchmann and Karagiannis, 2017)

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For the modelling of concepts (the "domain knowledge" or "metamodel"), AMME includes a conceptualisation phase where the modelling language (and, consequently, the deployed modelling tool) can be tailored for KM requirements, to ensure that the right (domain-specific) semantics can be captured in diagrammatic form. Relevant concepts, relations, constraints are identified and abstracted to the properties and constraints that are deemed relevant for knowledge assets and for the Internalisation phase (i.e., for knowledge retrieval queries or inferences). This is achieved through traditional knowledge acquisition techniques such as laddering, card sorting, "20 questions" etc. (extensive surveys are available in (Speel et al., 2001) or (Burge, 2016)) complemented with evaluations of the cognitive expressivity for the graphical symbols associated to each concept (Moody, 2009). The spiralling nature of SECI synchronises with a similarly spiralling conceptualisation cycle of AMME (bottom of Figure 4), so that any insufficiencies (or evolving requirements) detected during Internalisation lead to an agile redesign of the language and reimplementation of the modelling software, benefitting from the fast prototyping tools recommended by AMME – i.e., the metamodelling platform ADOxx (BOC, 2017).

After the domain knowledge is captured in the governing language of a modelling tool, the Externalisation activities move to the diagrammatic level, where stakeholders must articulate with a limited terminology (the language) the description of a particular situation and its context.

Figure 5 shows a cluster of exemplary models represented in the ComVantage notation for the mobile maintenance scenario introduced in Section 4. Several types of models are highlighted: (i) Models of maintained assets describe machine types in terms of their parts, sensors and common defect types (linked to the sensors that can signal them). The maintained machine instances are also attached to each type, therefore the models also act as an inventory of maintained assets; (ii) Models of work processes describe the test and repair processes prescribed for each defect and machine type (the procedural knowledge base to guide the customer-site technician through his intervention procedures); (iii) Models of available human capital describe the organisational structure and the available human resources, including their competence profiles (descriptions of their skill and knowledge levels, according to a skill and knowledge taxonomy built by the modeller in the same modelling tool); (iv) Models of apps and app usage procedures describe mobile apps that are available or required to support specific maintenance tasks; if they are "required", these models become a requirements elicitation facilitator.

Lengthy discussions in the literature on the nature of "tacit knowledge" (Vartinen, 2009) have shown that the ambiguity of its definition made it possible to include in this category knowledge that the knowing subject does not know how to express (rather than not being able to). This has specific causes in the practice of diagrammatic modelling, e.g.: the modeller is not experienced with the modelling tool (hence the "modelling procedure" component of the method must provide guidance); or, the modelling method does not capture all the properties and concepts that the modeller wants to express. To address such situations, AMME becomes essential in order to incorporate the missing semantics or syntactical improvements in subsequent iterations of the modelling method deployment.

6.5 Combination

"Combination" is an umbrella term for a variety of knowledge aggregation, transformation and hybridisation techniques. A possible streamlining of diagrammatic knowledge assets that is amenable to further machine-readable integration (by way of Linked Data queries or reasoning) is suggested in Figure 4, where the diagrammatic contents on the left side are converted to the RDF knowledge graph on the right side.

The technical solution for this conversion was described in (Karagiannis and Buchmann, 2016) and was implemented as plug-in for any modelling tool implemented on the ADOxx fast prototyping platform (BOC, 2017), therefore the schema of the derived knowledge graphs is kept in sync with the
modelling language terminology, as it evolves to fulfil KM requirements. An extensive inventory of transformation patterns to guide implementations for other platforms is available in (Buchmann and Karagiannis, 2015b).

Figure 5. Externalised and Combined knowledge in diagrammatic form

The transformation to RDF knowledge graphs is based on the following principles:
(a) Semantic links are established between elements of different models (manifested as hyperlinks in the modelling tool, for cross-model navigation). Examples of such links are shown in the legend of

Figure 5 (e.g., relating a defect type to the maintenance process prepared for it and to the competence profile required to perform the process);

(b) Semantic links are established between model elements and external Web resources (URIs). These may include links to ancillary KM assets (documentation) but also to live run-time resources for which models act as a semantic annotation. Going back to the process improvement requirement in Figure 2, such links will allow the automated maintenance coordinator to retrieve knowledge assets based on their relations to live resources—e.g., from the live machine that triggered the request to the model-based description of that machine (and, further following the inter-model links in

Figure 5, to the recommended procedures and relevant competence profiles linked to the machine defect);

(c) All these links, combined with the graphical connectors in models and any user-editable attributes made available in the tool are exported to RDF graphs, building up a knowledge structure that is traversable by queries and can be enriched by inferences (rule-based or ontology-based). The right side of Figure 4 isolates the graph structure that is derived from the decision node in the process diagram on the left side, also suggesting its relevant schema fragment across abstraction layers.

6.6 Internalisation at machine level

In the Hybrid Knowledge Conversion cycle, not only humans are subject to the Internalisation phase, but also machines, since knowledge-based systems will benefit from the derived machine-readable representations to automate decisions and orchestrate calls/access to addressable resources (e.g., the automated service in Figure 2). In our case these representations are the RDF knowledge graphs, therefore the Internalisation can be achieved through semantic queries using the graph-querying language SPARQL (W3C, 2016b). The cross-model links in the legend of

Figure 5 suggest key RDF predicates that may be traversed by SPARQL queries initiated by client knowledge-based systems. In the general case, the application of AMME will evolve these links in accordance to the evolving requirements and domain-specificity of the client application. Examples of queries are application-specific and their details belong to a lower level of abstraction compared to the KM-focused scope of this paper—examples may be consulted in complementary, engineering-oriented publications delving in domain-specific applications, e.g., (Buchmann and Karagiannis, 2017), (Karagiannis et al., 2014c).

6.7 Machine-to-human socialisation

We include here any Internalisation process that is facilitated by the interaction between a human and an information system harnessing the knowledge graphs previously derived. A specific example manifests in the process improvement in Figure 2, where the socialisation between the remote expert and the customer-site technician is replaced by an interaction between the technician and a support app that retrieves (via Internalisation queries) the maintenance process models that are relevant (semantically linked) to the machine and defect class that triggered the request.

On implementation level, the ComVantage project advocated two approaches: (i) an app orchestration engine that chains predefined single-task apps in an "app ensemble" according to the precedence described by the process flow (Ziegler et al., 2012); (ii) a "knowledge stepper" that emulates the user-app interaction during a process to train a new employee or a technician unfamiliar with the process
The term "socialisation" is somewhat pretentious for such implementations but it is introduced as a placeholder in the Hybrid Knowledge Conversion cycle, for a future when the "shared doing" might involve more sophisticated human-machine collaboration – e.g., robots acting as training agents driven by the knowledge graphs.

7 Conclusions

The paper presents a specific approach to supporting KM practices and KM systems with diagrammatic modelling methods. The proposal is grounded in project-based use cases and is generalised by positioning it in a refined SECI Knowledge Conversion model, extended for the emerging requirement that knowledge assets must be interpretable and query-able with adequate granularity by both human stakeholders and KM systems; ideally, this should not rely on entirely disconnected systems, especially if model-based management practices are already in place. The Agile Modelling Method Engineering framework is referenced as a methodological enabler for knowledge externalisation, expanding the traditional goals of modelling in a software engineering context (e.g., code generation).

A summative SWOT analysis summarises the proposal's strengths, limitations and outlook:

Strengths: The paper updates the SECI cycle to accommodate an alignment between KM practices and technological paradigms underlying KM systems by employing modelling languages that are agilely tailored for knowledge externalisation, to bridge a traditional separation of concerns between two streams of KM research. Consequently, the proposal also stimulates a business-IT alignment with respect to the knowledge processes envisioned by KM frameworks. Project experience was referenced to instantiate various phases in the updated cycle, with additional references detailing domain-specific implementation details or design decisions. Weaknesses: Potential shortcuts across the proposed cycle are neglected here since they have not been investigated during the project experience, although they are plausible extensions – e.g., knowledge discovery from raw contents, or non-diagrammatic conceptual modelling. Also, the referenced evaluation protocol was limited by project goals and is being refined in the follow-up project EnterKnow (EnterKnow, 2017) which builds on lessons learned from ComVantage in order to tackle the integration of diagrammatic models and ontologies for elevated semantics-awareness in information systems. Opportunities: Integration with fully-fledged ontologies is enabled by the proposal of streamlining diagrammatic contents and knowledge graphs. Also, the
machine-to-human socialisation phase is, in the discussed case, far from the "shared experience" envisioned by Nonaka, but relevant in light of current trends in knowledge-based systems and robotics. **Threats:** The generalised situations formulated in Section 4 may also be addressed by machine learning techniques – e.g., by harnessing through mining methods some knowledge representations that are strictly human-oriented ("raw form"). The work at hand proposes a meet-in-the-middle approach that may leverage an already existing enterprise modelling culture (e.g., for enterprise architecture management), thus recommending that "by-design" a knowledge structuring effort should be placed in the responsibility of stakeholders, implicitly generating side benefits regarding sense-making of the analysed system and guided descriptions of reduced ambiguity.

**Acknowledgment:** The work of Dr. Robert Buchmann is supported by the Romanian National Research Authority through UEFISCDI, under grant agreement PN-III-P2-2.1-PED-2016-1140.
References


OMiLAB (2016a). The OMiLAB ComVantage implementation webpage. URL: http://austria.omilab.org/psm/content/comvantage/info (visited on 11/21/2016).


