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Towards a Linked Open Data TRIZ Ontology

Abstract

We discuss some basic aspects of TRIZ ontology modelling that have emerged from our practical work on semantic concepts and with semantic tools in the context of the TRIZ Ontology Project. Particular emphasis is placed on the distinction between a conceptual and a methodological level of modelling. Concepts and tools are first to be described, designed and modeled before they can be used in a methodological way.

The paper is not about research but about a practical contribution to enhance the common public TRIZ research infrastructure with new tools and data based on modern Semantic Web concepts. All code and data is publicly available at github [25] and waits for new combatants.

Keywords: Linked Open Data, TRIZ Ontology, RDF, Semantic Technologies

1 Aim of this Paper

In this paper we report on the efforts within the WUMM project [26] to apply semantic technologies in the TRIZ domain to relevant methodological as well as social aspects and processes.

The first activities were aimed at building up a semantically supported *TRIZ Social Network*, in which information about important TRIZ activities (conferences, events, presentations, other TRIZ-relevant activities) is collected. A second focus was on the semantic preparation of the TRIZ Body of Knowledge [14, 15] in a multilingual version.

Recently we refocused our activities in favor of a contribution to the TRIZ Ontology Project (TOP) launched at the TRIZ Developer Summit 2019 in Minsk. TOP attempts to model and map the landscape of TRIZ concepts across the whole spectrum of different TRIZ areas. In addition to a common view on fundamental concepts of TRIZ problem solving, it also focuses on areas such as

- laws of evolution of technical and general systems (ZRTS and ZRS),
- development of creative imagination (RTV),
- theory of the development of innovative personalities (TRTL),
- TRIZ history,
- TRIZ application areas etc.

Thus this project is strongly in the spirit of development of a general LOD World[1] and its efforts on terminological, taxonomic and notational standardisation of conceptual worlds in precisely definable areas such as FOAF [7], SKOS [19, 20], ORG [17]. However, TOP does not yet adequately exploit the experience gained in such more general projects how socio-cultural coordination processes can be organised forming an Open Culture environment.

The TOP project is chosen as a reference project because it is one of the first efforts *across* TRIZ schools to apply semantic concepts to and within TRIZ. In section 2, this background is presented in more detail. In section 3 we compare their semantic approaches with modern developments in the rapidly changing field of semantic technologies. In section 4, we discuss in more detail the concept of a *system*, which is central to TRIZ, and shortcomings of various modelling approaches. Such connections between models and concepts in well-defined conceptual worlds form the socio-cultural core of semantic technologies [9]. Finally, in section 5, the central meta-concepts of our ontologisation are presented on this modelling basis as an example.

As an infrastructure project, WUMM is designed for participation and collaboration of interested parties. Section 5 is essential to understand the basic approach if you plan to delve deeper into individual WUMM sub-projects to which you would like to contribute. There is no space in this paper to go into more detail on such individual sub-projects. The interested reader is referred to [10]. The materials are openly available in our github infrastructure [25] in machine-readable RDF format. The concepts can be evaluated on the basis of first practical results, especially our multilingual and provenance-aware combined glossary, in a prototypical web implementation [27].

2 Background

In 2019, a group of TRIZ specialists around A.G. Kuryan and M.S. Rubin launched the *TRIZ Developer Summit Ontology Project* (TOP). It aims at nothing less than to collect detailed information of the status quo of the whole TRIZ theory corpus in an ontological mapping. The work is a natural continuation of earlier efforts by other authors [14, 15] to outline a *TRIZ Body of Knowledge*. While the latter focused on a guide through the literature, the TOP activities are concerned with the identification of essential concepts and relationships between these concepts using a modern semantic approach.

[1] LOD is the abbreviation for Linked Open Data, a world of interlinked data and “worlds of concepts” steadily growing during the last 15 years. See `https://lod-cloud.net/`.

The status of the TOP project was presented at the TRIZ Developer Summits in 2019 and 2020 and fixed in two publications [11, 12]. In a webinar series[2] first approaches of a detailed modelling of several TRIZ sub-areas were presented. The project operates its own website[3] on which consolidated results are published.

The main results so far have been a mapping of the "continents" of the TRIZ world as a *Top Level Ontology* as well as a (still developing) division of that world into *Ontomaps* as specifically defined areas, which are to be modeled in more detail. Moreover, a *thesaurus* of about 500 terms as essential TRIZ concepts has been identified, which are also to be defined in more detail. V. Souchkov's glossary in its version 1.2 [21] serves as basis for this work. In the meantime a first list of 100 terms [23] has been published on the TOP website.

The efforts differ significantly from earlier approaches to develop a TRIZ ontology [3, 4, 5, 6, 31, 32]. In those earlier works, the focus was rather on models of elements of a concrete TRIZ problem solving strategy based on IDM. The model was mainly used to develop corresponding tools, e.g. [5], or processual elements in flow charts, e.g. [4]. The efforts were not directed towards a community infrastructure effort and – different to the WUMM project – the material was not released to the public domain.

3 Ontology Modelling Basics

The basis for these and the more recent modelling in the TOP project is the OWL ontology. Although being very powerful, OWL has several disadvantages. OWL was designed as a unified tool for multiple tasks. The associated high complexity proved counterproductive, as it leads to algorithmically unsolvable tasks in sufficiently meaningful contexts. It has proven successful not to fully formalise meanings and to use different concepts and tools for different aspects.

Limits for the cardinality of attribute values of a predicate, which are required to validate data and implement a web interface, are expressed in more recent developments of the Semantic Web on the basis of SHACL [18]. The inference possibilities of OWL that go beyond this are hardly used in practice. The modelling restrictions of weaker OWL variants as OWL-DL do not meet the requirements of real-world modelling even of *structural* relationships in TRIZ.

Our approach therefore returns to RDF as modelling base and consistently relies on the SKOS ontology as a lightweight modelling framework for structural relationships in conceptual systems. Such a restriction is reasonable also according to general insights into the development of conceptual systems in a first stage of ontological modelling. On this basis we model structural aspects and relationships between TRIZ concepts and tools. *Proces-*

[2] See `https://wumm-project.github.io/OntologyWebinar` for links to the presentations and an English summary of the talks and discussions.

[3] `https://triz-summit.ru/onto_triz/`

sual relationships as in [4] or questions of an implementation of web interfaces as in [5] are initially not covered. Note that comprehensive experience from other application areas is available using SHACL especially for the second question.

The main disadvantage of the TOP approach so far is the inconsistent use of semantic means. They play a role in background and internal processes within the TOP team, but even a clear namespace concept for URIs[4] , the public availability of the results in an RDF store or at least as files in a relevant format and even a SPARQL endpoint for querying the concepts – all this is missing.

Such an infrastructure was developed and set up in the context of the WUMM project [26]. The data is publicly available at github [25] and forms the basis for a prototypical web site [27] that uses simple semantic tools to present different facets of the data. Via a SPARQL endpoint [29] experts can make their own complex queries to the data set.

This technical basis is the starting point for our contribution to the TOP project as *WUMM TRIZ Ontology Companion Project* (WOP) [30]. This project accompanies the TOP activities in order

1. to carry out a remodelling according to semantic standards,
2. to enhance the material multilingually and
3. to compile a Linked Open Data infrastructure on this basis,

and thus to improve the basis for the necessary social coordination processes. Note that WOP is not an integral part of the TOP activities.

In addition to our own modelling (so far of the TRIZ Principles, the TRIZ Inventive Standards and the TRIZ Business Standards), the *Top Level Ontology* and the division into *Ontomaps* are available in this format. The work on a *thesaurus* as well as the presentation of different approaches to a common glossary is actively accompanied with own efforts, including RDF versions of glossaries developed by Lippert/Cloutier [13], Matvienko [16] and in the VDI norm 4521 [24]. Different explanations of the same term can coexist within our system since the provenance of the definitions of different TRIZ schools is stored. This aspect, together with the focus on multilingualism based on relevant RDF concepts, are essential add ons of the WOP approach to TOP.

In the following we explain the basic modelling and semantic assumptions, concepts and settings of the WOP approach in more detail.

[4] URI – Unique Resource Identifier, one of the basic RDF concepts. This string is the digital identity of a concept and allows to add independently information about "the same thing" in a distributed environment.

4 Modelling a TRIZ Ontology

4.1 TRIZ and the World of (Technical) Systems

Main TRIZ concepts revolve around the central notion of a *system*, its planning, creation, operation, maintenance, further development, etc. Following the widely accepted understanding of that concept in the TRIZ community, TOP defines this notion as follows:

> A *system* is a set of elements in relationship and connection with each other, which forms a certain integrity, unity. The need to use the term "system" arises when it is necessary to emphasize that something is large, complex, not fully immediately understandable, yet whole, unified. In contrast to the notions of "set" and "aggregate", the concept of a system emphasizes order, integrity, regularities of construction, functioning and development. The notion of system is part of the system and functional approach, and is used in the system operator.

Usually, however, the definition of a system refers to the concept of a *component*, as in Souchkov's glossary [21]:

> *Technical System:* A number of components (material objects) that were consciously combined to a system by establishing specific interactions between the components. A technical system is designed, developed, manufactured, and assigned to perform a controllable main useful function or a number of functions within a particular context. A technical system can include subsystems which can be considered as separate technical systems.
>
> *Component:* A material object (substance, field, or substance-field combination) that constitutes a part of a technical system or its supersystem. A component might represent both a single object and a group of objects.

In both concepts a system is essentially a collection of components that interact in a specific way to produce the characteristic functionalities of the system. The subsystems referred to as components provide own functions, but the functionalities of the system do not result from a simple addition of the functions of the components, but as an emergent system property from their interaction. For the modelling of systems, their *structural* organisation and their *processual* organisation are equally important. The systemic approach is thus self-similar and fractal; the terms "system" and "component" are largely used synonymously depending on the respective modelling focus.

In TRIZ, an *engineering problem* is always conceptualised as the design of a new system or the improvement of an existing one. The design of a new system can be considered as a special case of further development, since also in this case concepts of a model of the "system as it is" do exist, how vague they may be.

The delimitation of meaningful systems as modelling units has many facets and points of view, see for example [22, section 8]. In the TRIZ concepts, a certain functional completeness plays a major role in this delimitation, even if a defined throughput of energy, material and information is required to operate the system.

For a system, its *design* and *operation* have to be distinguished, as explained in [8] in more detail. This also applies to *components* of a system. In the white-box analysis of a system, its components are considered as viable black-boxes, which are characterised in the design dimension by a *specification of their functionality* and in the operational dimension by its *guaranteed specification compliant operation*, provided that the operating conditions (in particular the throughput of material, energy and information required for its operation) are ensured within the system. The description of these operating conditions is part of the specification, which thus consists of an input and an output part (also referred to as import and export interfaces in Computer Science).

The components thus constitute a *world of technical systems* in the sense of the explanations in [8], to which we refer for further details of this conceptualisation.

4.2 Abstraction Levels of Modelling

An ontology is about "modelling of models", because the clarification of terms and concepts of an ontology is intended to be practically used in real-world modelling contexts. This "modelling of models" references a typical engineering context, in which the modelling of real systems plays a central role and serves as basis of further planned action (including project planning, implementation, operation, maintenance, further development of the system).

In this process, several levels of abstraction are to be distinguished.

0. The level of the *real-world system* as the target of the engineering task. This level is only *practically* accessible. The model to be developed at level 1 must be appropriate to cover all problems arising in the process of development and use of the real system and to express its inherent contradictory character.

This contradictory nature of the system can be formulated only in language terms, i.e. on the model level and *applying* the concepts available there. These concepts must therefore not only be able to describe the structure of the system itself, but have also to cover a description of the necessary aspects of its operation.

1. The level of *modelling the real-world system.* The worlds of *several* conceptual systems often meet in the modelling of a real-world system with its *core and cross-cutting concerns* (concepts known from Software Engineering [22]). In addition to the methodological dimension of a TRIZ ontology, this regularly includes the conceptual world of a domain-specific technical ontology and possibly other conceptual worlds such as a company-internal compliance etc.

These different conceptual systems (ontologies) provide the language means, concepts (RDF subjects) and properties (RDF predicates), which are to be *applied* at this level. This level is also the *level of methodological practice*.

2. The *level of the meta-model* is the actual (TRIZ) ontology level (and also of domain-specific ontologies) on which the systemic concepts are *defined*.

These definitions are processed *applying* the methodological concepts whose linguistic means are made available on meta-level 2.

3. The *modelling meta-level 2* is the level at which the methodological concepts are *defined*.

4.3 The TOP Concept of a System

A central concept in TOP modelling is the distinction between the stages of

(1) the system as it is,
(2) the TRIZ model of the system as it is,
(3) the TRIZ model of the system as required, and
(4) the system as required.

The TOP glossary [23] explains the differences as follows

(1) The *system as it is* is a system in its original state before it is analysed and transformed into a new "system as it is".
(2) The *TRIZ model of the system as it is* is formed from the "system as it is" by means of various TRIZ models: component-structural and functional models, su-field or ele-field models, description of contradictions or of typical conflict schemes, etc. Depending on the chosen model type, the model will be transformed into the "TRIZ model of the system as required".
(3) The *TRIZ model of the system as required* is formed from the "TRIZ model of the system as it is" by procedures which correspond to the selected model transformation method (functional, su-field, ele-field, solution of the contradictions in requirements and properties, etc.). The transition is performed along the line

$$\text{System as it is} \to \text{TRIZ model of the system as it is}$$
$$\to \text{TRIZ model of the system as required} \to \text{System as required}$$

(4) The *system as required* is a system derived from the "system as it is" through a transformation, based on the "model of the system as required".

In stage (1) "system" can only mean a *model of the system* in which, in addition to the ontology of the TRIZ methodology, domain-specific ontologies play a central role. A system can only be described via a model.

In stage (2) the "TRIZ model of the system as it is" is derived by application of specific structural TRIZ concepts and instruments. How is this to be understood? Is the (model of the) "system as it is" initially a domain-specific model that is to be enriched by an appropriate TRIZ model in this stage (2)? Such an understanding would contradict TRIZ modelling practices, which methodically are to be applied already in the creation of the domain model. For example, modelling the specific application at stage (1) the schema of a *minimal technical system* as template is to be filled in to get the problem-specific model. According to the hill schema, in stage (2) rather the specific TRIZ structure of the problem-specific model is to be determined. This requires to strengthen the domain-specific model from stage (1) in a targeted manner at points to be identified (operative zone and operative time).

This TRIZ model as a *prototypical abstraction* of the problem-specific model of the real-world problem determines at the same time the *abstract TRIZ tools* to be applied at stage (3) and thus provides the context for the transition to the abstract solution model "on the top of the hill", the *TRIZ model of the system as required*. In the end, this abstract solution model has to be "rolled down the hill" to obtain the (problem-specific model of the) "system as required" in stage (4).

The TRIZ model is thus a *context* for all four stages of real-world modelling. In this way the notion of TRIZ model is also explained in [23]:

> A *TRIZ model* is a schematic notation of a gradual transition from the problem to TRIZ model of the problem, then to TRIZ model of the solution and then to the solution itself; or from the system to TRIZ model of the system, then to TRIZ model of the new system and then to actual change of the system ("system as required"). The TRIZ model includes the basic components of inventive thinking: analysis, synthesis, evaluation.

Hence a *TRIZ model* is the common (developing during the stages) abstract TRIZ context of the four model stages described above, including the modelling process itself. However, these four stages all refer to abstraction level 1 models of a real-world system in the meaning developed in section 4.2; no distinction is made between application of concepts from level 2 of a *TRIZ ontology of tools* (present at level 1 as concept instances) and level 3 of a *TRIZ ontology of methods* (present at level 1 only in a methodological-practical way).

What does this mean for the scope of a TRIZ ontology? The modelling of any system starts at stage (1) with a problem-specific model of the "system as it is" based on domain-specific concepts. If this modelling is practically performed on the methodological basis of TRIZ principles, the domain-specific system of concepts must be enriched with TRIZ methodological concepts such as MPV, conflicting pairs, operative zone and operative time, etc. Stage (2) requires a special abstraction from domain-specific concepts for the extraction of abstract TRIZ patterns as a "TRIZ model of the system as it is" (TRIZ task model) according to the hill schema. Hence the modelling of the real-world system requires the domain-specific concepts of the problem-specific model to be compatible with the requirements of TRIZ modelling. Both ontologies – the domain-specific and the TRIZ ontology – have a similar relationship of the specific to the general and thus stand in a relationship of mutual complementarity of their modelling languages at the level of the problem-specific model.

It is obvius, however, that the (problem and domain specific) "model of the system as it is" (MSI), the abstract "TRIZ model of the system as it is" (TSI), the resulting "TRIZ model of the system as required" (TRIZ solution model, TSO) and finally the (again problem and domain specific) "model of the system as required" (MSO) call up largely the same language constructs from the point of view of a TRIZ ontology and are thus four instances of the (developing through the four stages) model of the real-world system related by consecutive instance transformations. These instance transformations can be characterised as follows:

- **MSI** → **TSI**: Consolidation and refinement of TRIZ-relevant concepts in the MSI.
- **TSI** → **TSO**: Description of an abstract transformation and execution of the parts of the transformation that are possible at this level, i.e. without interaction with the domain-specific parts of the model.
- **TSO** → **MSO**: Detailing the model, completion and execution of the domain-specific part of the transformation.

For the level 2 ontology (it answers the question "Which TRIZ tools are available and how do they relate to each other?"), the distinction between these four system models is therefore not relevant. Corresponding language tools are only required at level 3, when it comes to the *description* of the application of the TRIZ methodology itself.

Concerning the balance between the new and the old, as suggested by relevant methodologies for the further development of conceptual systems, we see the requirement to clearly distinguish between these two levels of ontologisation and limit our ontological modelling to level 2.

5 Basics of the WUMM Ontology Project

5.1 SKOS Basics

The SKOS ontology [19, 20] allows to express concepts and their relations in a lightweight way. The class `skos:Concept` and the predicates `skos:narrower`, `skos:broader` and `skos:related` are used for this purpose. The first two predicates describe hierarchical relationships between concepts, the third one is used for non-hierarchical relationships.

Relationships between concepts can be of very different nature. Hierarchical relationships, for example, can model (transitive) subconcept relationships in taxonomies as well as whole-part relationships, which are inherently non-transitive when concepts of different qualities are related. Both types of conceptualisation have an intentional as well as an extensional aspect – the new units of meaning, especially their emergent properties, can neither be adequately described by mere enumeration of their subconcepts nor by the "legitimate interpretation of sense" of the intentions of their constitution in the meaning developed by Berger/Luckmann in [2]. In the SKOS primer [20] these modelling aspects are described in more detail, especially the modelling of class-instance and whole-part relationships. We follow the recommendation in [20, sect. 4.7] and introduce subpredicates of the generic SKOS predicates listed above for different modelling contexts. More detailed modelling rules for such contexts are described and discussed below.

The WUMM project aims to model a unified level 2 space of TRIZ concepts without "concepts of concepts". Hence we limit the concepts used from the SKOS universe to those described above and do not use further SKOS aggregation concepts such as `skos:ConceptScheme`, `skos:Collection`, `skos:OrderedCollection` etc. The aggregation of different concepts in collections (assignment to TRIZ generations [12, Table 1], in concept classes Basic, Model, Rule and TermGroup [12, Fig. 4] or Categories in [21]) is realised via special predicates.

SKOS provides an initial descriptive framework for conceptualisations. We use the following concepts (K) from the SKOS ontology [19]

- `skos:Concept`, `skos:prefLabel`, `skos:altLabel` – concept naming
- `skos:definition`, `skos:example`, `skos:note` – concept properties
- `skos:narrower`, `skos:broader`, `skos:related` – concept relations.

For the meaning and usage of the different SKOS concepts, we refer to [19] and the explanations below.

5.2 URIs and Namespaces

The allocation of meaningful URIs is one of the central problems of transferring the existing stock of data on TRIZ concepts, since the individual glossary entries in the existing TOP sources are identified solely by their labels. This applies even to the OSA platform[5] since the URIs assigned there (both for the nodes and the edges of the RDF graph) are not publicly visible.

For a concise concept of URIs we first define *namespaces* which correspond to the different modelling contexts. Since *ontology modelling* has the basic purpose to be applied in problem-specific *modellings of real-world systems*, at least these two modelling contexts have to be distinguished. In our application the modelling context of a (prototypical) real-world system is present only in examples which practically demonstrate the effect of

[5] The OSA platform is used as an TOP internal ontology editor, see `https://wumm-project.github.io/TOP` for more information about the platform, its odds and evens.

ontology modelling decisions. At the level of ontology modelling, we further distinguish between the parts of the concepts that are largely uncontroversial[6] and the parts of the concept for which special conceptual approaches have been developed within the WUMM Ontology Project (WOP). For these different abstraction layers we use the following namespaces:

- `ex:` – the namespace of a problem-specific model of a special real system.
- `tc:` – the namespace of the TRIZ concepts (RDF subjects).
- `od:` – the namespace of WUMM's own concepts (RDF predicates, general concepts).

5.3 Provenance of Explanations

Another problem of this ontological modelling is the representation of the provenance of the individual explanations. For this purpose the SKOS concepts listed under (K) are replaced for each individual source by subconcepts in the namespace `od:` in order to separate the "worlds" of the individual TRIZ schools. The same applies to the use of provenance-dependent subclasses of `skos:Concept`.

Such notational variations are for example

- `skos:Concept` → `od:GSAThesaurusEntry`, `od:VDIGlossaryEntry` ...
- `skos:definition` → `od:SouchkovDefinition`, `od:VDIGlossaryDefinition` ...
- `skos:example` → `od:VDIGlossaryExample` ...

etc. Here `GSAThesaurus` stands for the thesaurus published on the Altshuller website [1], `VDIGlossary` for the VDI glossary [24] and `SouchkovDefinition` for V. Souchkov's glossary [21]. All these data were available or provided in a machine-readable format, transformed into suitable RDF formats and stored as open source both as files in the github repo *RDFData* at [25] and in our RDF Store [28]. See the RDF data itself, which can also be queried via our SPARQL Endpoint [29].

This is used to build a *combined glossary* where definitions from different TRIZ schools of the same concept co-exist. This is implemented prototypically[7] in such a way, that for each concept represented by a URI, a link displays all RDF triples in which this concept occurs as a subject or object. Further links in this representation can be used to navigate in the entire RDF graph.

6 Conclusion

We presented in this paper some of our experiences within the WUMM project [26] as a contribution to an Open TRIZ Research Infrastructure based on modern Semantic Web

[6] These are mainly the concepts to be included in a glossary. We assign URIs of a `skos:Concept` to them and model their names as `skos:prefLabel`.

[7] See `http://wumm.uni-leipzig.de/ontology.php`.

technologies.

The theoretical explanations focus on a critical consideration of the modelling of a TRIZ system concept as proposed in the context of the TOP project. We justify in more detail why, in our view, it makes sense to distinguish between the *conceptual level of model structures* and the level of *methodological concepts* of the *application* of model structures in the course of modelling a TRIZ ontology.

This distinction is in the core of the WUMM project, which initially concentrates on the conceptual-taxonomic level of TRIZ. Collecting conceptual-taxonomic data we use the features of RDF to preserve the provenance of different interpretations in a machine-readable dataset. Thus we avoid to take our own position in the dispute over the exact meaning of individual glossary terms. This lays the foundation for a (potentially) broader process of understanding and standardisation. Moreover, RDF's multilinguality concepts can be used to support such a process also across different languages. Of course, this raises additional hurdles of cross-cultural understanding also at the semantic level. The WUMM project uses the technical infrastructure of github which is well suited to offer a practical technical basis also for such a socio-cultural communication process.

This paper is not a research paper, but takes the opportunity to report to the audience of the *TRIZ Future Conference* as the leading annual conference in the field of systematic innovation methodologies on the status of our research infrastructure project.

7 Postscript

The paper was accepted by the reviewers for presentation at the *TRIZ Future Conference 2021*, but it does not meet the "novelty" criteria for a paper to be included in the Conference Proceedings, as 63% of the material presented here[8] can also be found on the pages of the WUMM project (in particular in various preprint publications) and hence „is not new“. Such rules massively hinder the further development of scientific ideas and call into question the discursive character of scientific work. *LIFIS-Online* is a scientific journal that stands on clearly different positions. Hence this survey is published in this journal.

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