Semantic-Aware Metadata and Resilience of Socio-Cultural Ecosystems

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Abstract

Resilience is a systemic concept that focuses on the stability of a systemic development context. Data-based monitoring is an important tool of resilience management. However, resilience of a system depends on its external conditions of existence and thus on the relationship of the system to one or more other neighbouring systems, each with its own semantics. Resilience management in socio-cultural ecosystems must therefore be able to evaluate data from subsystems appropriately and "translate" it into its own semantics. The metadata to be generated in this process is semantic-aware, as it transports semantic aspects of the subsystem into the upper system and thus makes it available to the emergent functions developing there. The evaluation of this metadata at the level of the upper system leads to new data, which in turn unfold its effect in the subsystems as semantic-aware metadata.

This paper discusses conceptual aspects of the development of semantics at different systemic levels and its impact on generation and use of metadata in a system to access and manage data collections in subsystems.

Keywords

Semantic-aware metadata, Resilience, Socio-cultural systems, Domain-specific semantics, RDF

1. Introduction

Resilience is an elusive concept. It appeared first in psychology in the 1950s to address questions of the robustness and adaptability of individuals to changing socio-cultural conditions [1]. Since at least the 1970s, the concept has also been applied to questions of ecosystem adaptability [2]. In contrast to approaches in psychology, which primarily address the conditions of possible adaptation of a human subject to external conditions, the study of the adaptability of ecosystems is focused on, if not centered at, formation and design of appropriate internal development conditions. This continues the approach of "shaping nature" as object of transformation by planned development since existing ecosystems have been socio-culturally shaped by human activity for thousands of years and there are hardly any "natural" ecosystems left on our planet. Accordingly, not only descriptive and explanatory approaches play a role in this research, but also modelling, planning and implementation aimed at redesigning ecosystems towards greater resilience under specific "usefulness" purposes. A distinction is often made between adaptive and transitional management approaches [3, 4].

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In the last 20 years, the concept of an ecosystem, and with it the notion of resilience, has been applied also to other socio-cultural systems such as technical ecosystems [5], energy ecosystems [6] or business ecosystems [7] in order to describe networking processes in stakeholder structures of a larger number of legally independent actors. Especially with the concept of business ecosystems and corresponding value networks [7], the topic of resilience is also moving closer to data-intensive communication structures such as Linked Enterprise Data Services (LEDS, [8]).

In such socio-cultural contexts, data stocks play an important role, whose interpretation as *information* has a significant effect in guiding action. The concept of data often remains blurred and is conceptualised in many works in a hierarchy of data – information – knowledge – wisdom [9]. However, this famous DIKW pyramid does not sufficiently reflect the close connection and the joint development of data sets, conceptual worlds and interpretative practices. Therefore, the term *data* is defined here as *formalised information* in order to emphasise the socio-cultural institutionalisation process of the practically proven into proven practices as a general gradient of systemic development. This at the same time revisits older concepts of the relation between syntax, semantics and pragmatics [10].

In addition to the concept of *FAIR Data* [11, 12], which addresses the use of *already existing* data stocks beyond narrow communities in which these data stocks were produced, questions of stable availability as well as production and management structures of this data thus come into focus, and with them more general questions about resilience of the development of systemic structures with valuable data stocks.

The FAIR data movement focuses on the visibility and re-usability of existing data assets across systemic boundaries. Metadata plays an important role in making data assets accessible, which is to be supported by "modelling metadata schemas and ontologies" [11], p. 371. Little attention has so far been paid to the influence of the further development of system-specific conceptual worlds and thus semantic awareness across system boundaries. This essential aspect of the resilience of data usage scenarios will be discussed in more detail below.

2. Resilience in Socio-Cultural Systems

In [13], the diversity of resilience concepts in the context of "complex adaptive systems such as enterprises" is analysed in more detail and a "framework for resilience thinking" for enterprises is proposed, to which this paper refers in the following. It consists of (A) a core definition of resilience (of an enterprise), (B) relevant functions and features to be considered, and (C) aspects to be taken into account (ibid., p. 51).

For, e.g., business ecosystems resilience aspects must be considered both at the level of individual business units and at the level of the entire business ecosystem. Both come with their own terms and notations. This raises the question of integrating data from one system into the conceptual world of another system.

It should be kept in mind that resilience cannot be a static concept, but must encompass the possibility of a fundamental "disruptive" reconstruction of the system under changing environmental conditions in order to ensure its future viability. The concept of a business ecosystem is well suited to illustrate the complexity of interdependencies between the business ecosystem and individual business units on the one hand, and the business ecosystem and other socio-cultural and "natural" ecosystems on the other. Each of these systemic levels has its own tipping points at which behaviour fundamentally changes. Holling [14] developed a four-phase process model of such structural transformations. He examined in more detail how such transformational disruptions propagate both horizontally and vertically across systemic components and system levels and developed the concept of *panarchy* for this purpose.

Data which resides on a systemic level and is embedded and continuously updated in this conceptual world is often also significant on other systemic levels. To operate such significance, the data must be prepared for the abstractions of this other conceptual world. This preparation process also develops dynamically and thus becomes a subject of resilience management. Such cross-system semantic transports are considered below.

3. Systems, Data and Semantics

In contrast to classical engineering tasks, the delimitation of systemic units within ecosystems is less the target of a designer's consideration about purposes but rather determined by processual characteristics of eigentimes and eigenspaces of existing reproductive contexts (closed loops of processes). In such a systemic delimitation requirement, at least three dimensions meet – the system as a unit of analysis (systemic functions), as a unit of operation (systemic processes) and as a unit of development (systemic contradictions). In addition to the system's intrinsic laws, all three dimensions are essentially shaped and reproduced by an external throughput of substance, energy and information (metabolism) as structure-preserving operating condition.

In socio-cultural units of cooperative action such reproductive contexts are accompanied by complex forms of description, communication and interaction in which not only data plays a role, but also shared conceptual worlds as a prerequisite of both forms of collection and interpretation of data and the socio-technical requirements and conditions of maintenance and further development of those data collections. The apparent chicken-and-egg problem – which appeared earlier, data or conceptual world – simply dissolves in a systemic developmental context of co-evolution of forms of data collection and shaping the domain-specific conceptual world, forming together the system-specific semantics.

In a systemic interpretation, the shaping of a cross-domain socio-cultural ecosystem as an upper system of such systemic units follows similar development patterns. In this process, the semantics of the subsystems involved meet, but they only have to be present in the upper system to such an extent as it is required for the description of emergent, cross-domain processes. At the same time, it must be possible to identify domain-specific problems in the upper system, to transfer them to the subsystem for further detailing and to take over results into the communicative context of the upper system.

The connection between the semantics of the upper system and the subsystems is therefore complex and cannot be reduced to the union of the semantics of the parts. The emergent, cross-domain processes refer to the flow of substance, energy and information in the upper system, which are at the same time external conditions of existence for the subsystems and thus mark conditions for resilience at the level of the subsystems. Semantic details from the subsystems are therefore present in abbreviated form in the upper system, just as semantic details of emergent processes from the upper system are present in abbreviated form in the subsystems.

RDF as a universal description framework is of particular importance in the formal representation of such relationships. The terms resource, data as (formal) description of the resource and information as content of the description are in a close and quite complicated interrelationship. Thus, “This is a cube of 12 cm edge length” is the description (“data”) of a real-world material resource as the object of the statement, which is referred to situationally (“this”). The content of the description (“information”) can only be understood in a context in which the meaning of the terms cube, edge length and the abbreviation cm are known. Data are thus closely connected with reference structures on the one hand and with form aspects (in the example provided by “natural language”) on the other, through which content aspects can only be inferred as information. RDF resolves the first problem since it works with URIs as textual representations of resources in the form of standardised character strings as globally unique reference structures.

In addition to real-world resources, *universals* can also occur as resources, such as in the sentence “Determine the volume of a cube with an edge length of 12 cm”. The object of this prompt phrase is the mental construct “cube with an edge length of 12 cm”. Such universals can be created as “mind game” on different systemic levels, for example as statistical aggregates of data from a resource pool or as aggregates of only certain descriptive dimensions of such resources.

In the context of the relationship between the semantic levels of system and subsystems to be discussed here, both reinterpretations of domain-specific data in the semantics of the upper system and, conversely, reinterpretations of data aggregated across domains in the upper system (“emergent data” [15]) in the domain-specific semantics of a subsystem are of interest. These reinterpretations do not have to be carried out anew in every use case, but can be stored in the form of *metadata*, i.e., as “structured data containing information about characteristics of other data” [16], on the respective other systemic level in the respective other semantics. Since such metadata transform semantic aspects from one conceptual world into another, we call such metadata *semantic-aware*.

This concept of metadata seems to be somewhat broader than that used in the context of FAIR Data [12]. There, the data-producing community is requested to “publish rich metadata to facilitate discovery” in order to promote cross-community use of this data. This is distinguished from a transformational processing of those data by another community, e.g., when anonymisation is required to use data for purposes other than the original collection [17]. From the perspective of semantic awareness, however, such a distinction seems redundant.

4. An Example

Let’s take a closer look at these interrelationships on the example of the scientific publishing ecosystem. The author information maintained by a publishing house or a library is semantic-aware metadata, since semantic information about publications from different scholarly communities as subsystems is transferred to this system.

Let’s explain the differences between the conceptual worlds at both levels with regard to the role of publications in more detail. In the respective scholarly community, the authors as scientists are researching subjects, the publications serve scientific exchange and the conceptual world of the scholarly community is reflected in the content aspects of the publications. At the level of publishers and libraries, the focus is, among other things, on bibliometric descriptions and measurement procedures in which authors and publications are objects.

At both systemic levels, digital collections of publications are of interest. For the scholarly community, access to these publications is most important as one of the central issues of resilience. This access has been supported within the community by domain-specific journals, conferences and referencing organs for more than 100 years. In the last 30 years the pre-digital practices of preprint distribution have been replaced by practices of digital provision of such preprints. Although the initiative to build such digital structures came initially also from the different scholarly communities the service provided by the publishers and libraries to the community plays an important role to keep these community-internal structures (its "metabolism") running.

In the system of publishers and libraries, the focus is on access to "final" publications. In addition to producing, making available and managing corresponding printed products, the development of access systems to own digital collections of publications is gaining in importance with ongoing digital transformation. Hence the resilience conditions for this service of publishers and libraries to the different scholarly communities are changing, and with it the conceptual world used to describe the practices of publishers and libraries.

One example of the difference of semantic embeddings is the identification of the author of a publication. While in the narrower context of a special scholarly community social contacts are sufficient to unambiguously identify authors of papers as real-world subjects despite different spellings of names, the problem of author disambiguation has long been problematic at the level of libraries and publishers. To solve that problem, each of these systems has originally built up its own internal reference structures with unique textual representations of authors, which have now been merged into two worldwide structures, the VIAF system of the libraries and the ORCID system, which is used and supported by publishers.

The consolidation of this and other metadata in the system of publishers and libraries also allows to design new services that use this metadata to produce new own data. Examples are performance measures for individual authors such as the h-index or the digital extraction of cross-reference structures between different publications.

This data, in turn, is playing an increasingly important role as semantic-aware metadata in the scholarly communities. It is metadata in the understanding developed here, since not only the data, but also the conceptual ideas about, for example, the meaning of the h-index or of impact scores for journals or individual publications are adopted in a socio-culturally broken way in the conceptual worlds of the different scholarly communities. Hence we are dealing not so much with a relation between system and upper system, but rather with a relation between neighbouring systems, see also [18].

Semantic-aware metadata on authors has been further developed in the system of publishers and libraries into a reference structure that resolves the author disambiguation problem. It is not only a theoretical solution but it is implemented as socio-technical practice and the required infrastructure is operated and maintained. Hence the solution can (and is) now also be used in the subsystems of the various scholarly communities.

Semantic-aware metadata with the property that the (foreign) data source itself can be inferred and also be accessed via this reference we call *semantic-aware fingerprints*.

5. RDF or Community Syntax

Usually data collections of a certain community are stored in a specially designed community-internal format, often as plain text, in a special XML notation or as SQL database. Such formats usually employ special formal semantics agreed within the community as an effective way to store domain specific input and output data and are used by commonly developed tools with appropriate parsing functionality.

We first encountered this question with the PoSSo project [19], where, after its end in 1995, the SymbolicData project [20] was concerned with compiling the collected benchmark problems for solving polynomial systems in a reliable form. The aim of the SymbolicData project was to develop concepts and tools for a uniform benchmarking process for the various subcommunities of the Computer Algebra community and, to this end, to take up experiences in the organisation of benchmarking processes from other areas of science and adapt them to the specifics of benchmarking in Computer Algebra. The situation is similar to the publication ecosystem considered above – a narrower function is to be provided in the upper system for a wider range of users.

In implementing this project the relationship between two systemic contexts had to be shaped, the benchmarking context as upper system with its own tools and concepts for the organisation of benchmarking processes and domain-specific socio-cultural systems of individual Computer Algebra subcommunities with the common demand to bring together implementations of algorithms and benchmark data in a comprehensible uniform way for benchmarking.

One challenge at the level of the upper system was to prepare the data of the PoSSo project in such a way that, on the one hand, the data collection could easily be expanded under the responsibility of the subcommunity, and on the other hand, the data collection as a whole could be managed and searched. The latter issue had been neglected in the subcommunity and led to misunderstandings. Most of the benchmark data belonged to example series such as “Katsura”, and it was sometimes unclear whether a reference to “Katsura-5” referred to the data record with 5 variables or that with the variables $x_0, \ldots, x_5$. This question, among others, had to be resolved at the metadata level, see [21] for details.

During the PoSSo project the data had been collected and stored not in a central repository but on various computers of the project partners or were available even in printed form only. In designing a format for a central repository, we were faced also with the question of a transformation of the polynomial notation commonly used in mathematics in a special markup. Already at that time some early adopters of MathML[1] or OpenMath[2] strongly argued in favour of a common markup format. Although these formats, which were standardised later on, allow an exact specification of commonly used mathematical function and operator symbols, they also lead to a significant blow-up of data size.

To store the polynomial systems of the benchmark data in the central repository, for practical reasons the SymbolicData project decided not to use such at that time not yet standardised markup formats but the syntax for polynomials, which is common in the subcommunity and for which sufficient tools, especially parsers, are available to transform this textual representation

[1] https://www.w3.org/Math/
[2] https://openmath.org/

into the inner data structures of the implementations to be evaluated during benchmarks.

Thus, although the data collection was managed in the upper system, it used the syntax common in the subcommunity, which had been extended to include a URI reference system. The identification of data records required for managing the data collection via metadata calculated by means of a simple hash function over the textual representation does not work, since the same polynomial system can be written in different variable orders or even with different variable sets. Thus, there exist different textual representations of the same data record, which can only be distinguished in the context of the semantic concepts and with means and tools of the subcommunity. In order to keep this differentiation effort within limits, semantic invariants for each data record can be stored as RDF metadata, that allow to identify the data record.

In the SymbolicData project such semantic-aware fingerprints of polynomial systems are used as RDF metadata, i.e. invariants that are easily to be computed as well as stored and searched, but achieve a high, though not necessarily complete, discriminatory power on the given collection of polynomial systems. As such fingerprints were used: the number of variables, the set of numbers of terms per polynomial in distributive normal form and the set of degrees of polynomials (both realised as ordered lists of integers). Problems arising from the partial lack of full discriminatory power of the fingerprints were resolved by closer inspection of the examples themselves that could not be distinguished. In all cases it was sufficient to inspect the respective scientific context, since it was known as "general nonsense" within the subcommunity why the examples only slightly differ (for example, because one example had emerged from the other through a misprint).

For the expansion of the collection with new examples, a closer inspection of the candidates is necessary, but again only against examples in the collection with the same fingerprint. This drastically reduced the required domain-specific workload.

6. Storing Metadata

In the literature, it is repeatedly emphasised that a distinction between data and metadata is only possible to a limited extent and depends on the viewpoint of the observer. One reason for this is the usually weak distinction between the conceptual worlds, systemic levels and application contexts of cooperative actions in which data and metadata unfold their meaning. This is particularly present in the design of storage formats for data and metadata.

Usually such formats store metadata, in particular fingerprints, together with the data in a single resource as, e.g., in the IEEE Learning Object Metadata (LOM) Standard [22]. This has one benefit and two drawbacks:

- *Benefit:* Metadata can be computed immediately by the commonly used tools or with their slight extension during data storage, and are easily available with the resource itself.
- *First Drawback:* Metadata unfold its full expressiveness only if it can be searched and navigated. Storing metadata together with the resource itself implies high extraction costs for navigation and access to the data collection as a whole.
- *Second Drawback:* The very different formats prevent an easy combination of metadata from different communities and even from different sources in the upper system.

The first drawback can be addressed if the metadata are extracted in the upper system into a database accompanying the data collection and provide intracommunity domain-specific tools for search and navigation within that metadata. Such an approach for LOM data based on a web interface was realised, e.g., in the ELMAT project [23] within the Saxonian E-Learning Platform OPAL. The metadata is stored in a database and is available only as intracommunity tool.

Such a solution has two further drawbacks:

- The search and navigational functionality is not or only in a restricted way adapted for machine-readable interaction and thus cannot be integrated into more comprehensive search and navigational processes.
- The search and navigational functionality cannot be adapted by the user for her own needs.

A well known general solution to avoid these drawbacks proposes to extract the metadata information from the resource data, to transform it to RDF and thus to make it available for interlinking within the *Linked Open Data World* as a worldwide distributed database that can be globally queried and navigated using SPARQL endpoints and the SPARQL query language in a similar unified way as SQL allows to navigate in local relational databases.

7. Converting Metadata to RDF

When extracting metadata from existing data collections and transforming them to RDF, there is always the question of whether more complex substructures, such as e.g. structured data or geodata, should be transformed or is it better to keep them in the given domain-specific conceptualisations and serialisation formats, since such domain specific representations are often both optimised in terms of storage space and there exist already sufficient powerful tools for their visualisation and processing based on that domain-specific serialisation format.

Transformation to RDF and use of such RDF data faces two main problems:

1. Required effort and losses during transformation are sometimes high. Especially the restrictions resulting from the concept of RDF data as *sets* of three-word sentences often do not support a representation of sequential and operational relationships in the data.
2. There are no tools for the transformed data that are comparable in their performance with those from the domain.

On the other hand, the use of original or even links to data formats from the domain makes cross-domain search processes considerably more difficult. This suggests to define a well-defined record of semantic-aware metadata as RDF predicates to be collected at the level of the upper system that has the required discriminatory power on the data collection. Such a representation of semantic aspects in metadata requires the collaboration with domain-specific expertise.

Since metadata is closely related to the practice of using the data itself also beyond the given domain of expertise, and this in turn to the knowledge of selected domain-specific concepts as well as the use of selected standardised domain-specific tools, the general user is also required to be aware of such selected domain-specific concepts.

Instead of a data-focused solution as just suggested, a functional solution is also conceivable by integrating subcommunity functions and tools into the RDF tools. This path is taken with

GeoSPARQL [24], since geolocal applications are widely used and therefore corresponding extensions of RDF search to their domain-specific syntax are developed. However, this requires extensions of the SPARQL query concept.

At this point we note that Semantic Web technologies are not only concerned with the production of a Linked Open Data Cloud as an artefact but also with a process of cooperative action of developing and consolidating common conceptual worlds as a prerequisite for the decentralised collection and use of semantically significant data and the development and enhancement of supporting tool concepts. The focus is thus not so much on the data collection as the result, but rather on the complex cooperative socio-technical process of collecting the data, using it *and* further development of the underlying conceptual world.

8. Conclusion

Semantic-aware metadata is an important concept to combine semantics in different systemic contexts for a semantic-aware management of a domain-specific data collection for cross-domain use. The question to determine more precisely which domain-specific concepts and to what degree of detail are relevant in a cross-domain application can only be answered in a discoursive negotioation process between data providers and data users. Only in such an organisational framework of resource management of data stocks the stable availability of up-to-date data sources can be organised, which in turn forms the basis for not only qualitative but also quantitative change management and thus provides the semantic means to base resilience management in socio-cultural ecosystems on a data-driven and thus scientific foundation.

In this context, action and negotiation are closely related: the practical creation and management of domain-specific data stocks in the interplay of a domain-specific inner logic and the outer logic of the use of these data stocks in other contexts with other domain-specific inner logics initially manifest themselves in the concurrent, parallel action of several subsystems and must be condensed into a new overarching systemic context through negotiation and standardisation, as discussed in more detail in [18, 25].

The explanations in this paper are limited to relationships between domain-specific and cross-domain semantics in their respective current forms. In [16], the additional question is discussed how to deal with the harmonisation of domain-specific data collected at *different* time in the context of an evolving domain-specific semantics that develops over time both formally and semantically. The concept of a "metadata registry" as meta-metadata is proposed to formally describe the different versions of the domain-specific semantics, to develop tools and to generate uniform semantic-aware metadata. Such questions can be solved if the version information of the domain-specific semantics is part of the fingerprint.

An alternative would be to harmonise the data itself through extensive data transformations in the domain from version to version. Both approaches have their advantages and disadvantages. Transforming the data collections harmonises the domain-specific formal semantics used in practice, but is costly and involves transformation losses at the data level. The coexistence of different versions has the advantage of preserving the original data, but the disadvantage that older versions of the domain-specific formal semantics may be no longer supported by recent tools. Such resilience aspects are the subject of research on long-term archiving.

Semantic awareness at the meta-level is well suited to localise or even identify problematic resources based on suitable parameters. The concept of semantic-aware fingerprints can thus be well integrated into resilience management based on *Systematic Innovation Methodologies* such as TRIZ [26], which are not based on pure brainstorming and trial-error concepts as many adaptive approaches, but pursue clear transitional concepts and rely on concise modelling, Ideal Final Results, identification of core contradictions and problem solving on this basis.

References

[1] M. Haas, Stark wie ein Phönix (in German), 2015.

[2] C. S. Holling, Resilience and stability of ecological systems, Annual Review of Ecology and Systematics 4 (1973) 1–23.

[3] T. Foxon, M. Reed, L. Stringer, Governing long-term social-ecological change: what can the adaptive management and transition management approaches learn from each other?, Environmental Policy and Governance 19 (2009) 3–20. doi:10.1002/eet.496.

[4] H.-G. Gräbe, K. Kleemann, Seminar Systemtheorie (in German), Berlin, 2020.

[5] E. Eppinger, D. Ehls, A framework for analyzing technology ecosystems – adopting insight from biology, in: R. Tiwari, S. Buse (Eds.), Managing Innovation in a Global and Digital World, Springer Gabler, Wiesbaden, 2020, pp. 323–331. doi:10.1007/978-3-658-27241-8_20.

[6] V. Panyam, H. Huang, K. Davis, A. Layton, An ecosystem perspective for the design of sustainable power systems, Procedia CIRP 80 (2019) 269–274. doi:10.1016/j.procir.2018.12.005.

[7] P. Leviäkangas, R. Öörni, From business models to value networks and business ecosystems – what does it mean for the economics and governance of the transport system?, Utilities Policy 64 (2020). doi:10.1016/j.jup.2020.101046.

[8] W. Abramowicz, S. Auer, T. Heath, Linked data in business, Business & Information Systems Engineering 58 (2016) 323–326. doi:10.1007/s12599-016-0446-0.

[9] J. Rowley, The wisdom hierarchy: representations of the DIKW hierarchy, Journal of Information and Communication Science 33 (2007) 163–180. doi:10.1177/0165551506070706.

[10] K. Fuchs-Kittowski, Information and human mind, in: J. Berleur, A. Clement, R. Sizer, D. Whitehouse (Eds.), The Information Society: Evolving Landscapes, Springer New York, New York, NY, 1990, pp. 460–466. doi:10.1007/978-1-4757-4328-9_27.

[11] N. Hartl, E. Wössner, Y. Sure-Vetter, Nationale Forschungsdateninfrastruktur (NFDI), Informatik Spektrum 44 (2021) 370–373. doi:10.1007/s00287-021-01392-6.

[12] M. Wilkinson, M. Dumontier, I. Aalbersberg, et al., The FAIR guiding principles for scientific data management and stewardship, Scientific Data 3 (2016). doi:10.1038/sdata.2016.18.

[13] C. Wright, V. Kiparoglou, M. Williams, J. Hilton, Framework for resilience thinking, Procedia Computer Science 8 (2012) 45–52. doi:10.1016/j.procs.2012.01.012.

[14] C. S. Holling, Understanding the complexity of economic, ecological, and social systems, Ecosystems 4 (2001) 390–405.

[15] A. J. Onwuegbuzie, J. P. Combs, Emergent data analysis techniques in mixed methods research: a synthesis, in: A. Tashakkori, C. Teddlie (Eds.), SAGE handbook of mixed methods in social & behavioral research, SAGE Publications, Inc., 2010, pp. 397–430. doi:10.4135/9781506335193.n17.
[16] M. Löpprich, J. Jones, M.-C. Meinecke, H. Goldschmidt, P. Knaup, A reference data model of a metadata registry preserving semantics and representations of data elements, in: C. Lovis, et al. (Eds.), e-Health – For Continuity of Care, 2014, pp. 368–372. doi:10.3233/978-1-61499-432-9-368.
[17] M. Mostert, A. Bredenoord, M. Biesaart, et al., Big data in medical research and EU data protection law: challenges to the consent or anonymise approach, Eur J Hum Genet 24 (2016) 956–960. doi:10.1038/ejhg.2015.239.
[18] H.-G. Gräbe, Components as resources and cooperative action, 2022. To appear in the Proceedings of the Second German TRIZ Online Conference 2022.
[19] PoSSo, The PoSSo Project. Polynomial Systems Solving – ESPRIT III BRA 6846, 1992–1995. URL: https://cordis.europa.eu/project/id/6846.
[20] SymbolicData, The SymbolicData Project, 1998–2018. URL: https://symbolicdata.github.io.
[21] H.-G. Gräbe, Semantic-aware fingerprints of symbolic research data, in: G.-M. Greuel, T. Koch, P. Paule, A. Sommese (Eds.), Mathematical Software – ICMS 2016, volume 9725 of *LNCS*, Springer, Heidelberg, 2016, pp. 411–418. doi:10.1007/978-3-319-42432-3.
[22] LOM, IEEE standard for learning object metadata, 2020.
[23] BPS Sachsen GmbH, ELMAT – Elektronische Übungs- und Bewertungstools für Mathematikveranstaltungen (in German), since 2014.
[24] Open Geospatial Consortium, OGC GeoSPARQL – a geographic query language for RDF data. Version 1.0, 2012.
[25] H.-G. Gräbe, Systems, resources and systemic development in TRIZ, 2022. To appear in the Proceedings of the TRIZ Future Conference 2022.
[26] D. Mann, Hands-On Systematic Innovation for Business and Management, IFR Press, 2007.