SPACETIME DATABASES MODELING GLOBAL SEMANTICS NETWORKS

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ABSTRACT. This paper represents an approach to creating global knowledge systems, using new philosophy and infrastructure of global distributed semantic network (frame knowledge representation system, FRS) based on the space-time database construction. The main idea of space-time database environment introduced in the paper is to bind a document (an information frame, a knowledge) to a special kind of entity, that we call permanent entity, — an object without history and evolution, described by a “point” in the generalized, informational space-time (not an evolving object in the real space having history). For documents (information) it means that document content is unchangeable, and documents are absolutely persistent. This approach leads to new knowledge representation and retrieval techniques. We discuss the way of applying the concept to building a global distributed scientific library and scientific workspace. Some practical aspects of the work are elaborated by the open IT project http://sourceforge.net/gil/.

INTRODUCTION

This paper represents an approach to creating global knowledge systems, using new philosophy and infrastructure of global distributed semantic network (frame knowledge representation system) based on the space-time database construction. We start our investigation with thinking of universal world wide library of scientific knowledge, interpreted mainly as a storage of documents in usual human sense. It is simple to imagine but hard to realize, and technological complexity is just one side of the problem. Today a lot of theories and technologies proposing a way of representing knowledge are drawn up and elaborated, most of them focus on concrete problems of information processing and artificial intelligence and few ones pretend to reform the practice of scientific research and to build a universal scientific workspace for globalized scientific investigations. Since our concept closely connected to the problem of scientific knowledge representation, we emphasize the philosophical and humanitarian aspects which allow to see the problem of knowledge birth and evolution from completely different point of view.

The concepts of document and library as they used in the paper are formally independent but actually develop the concept of semantic network or, in different terminology, frame knowledge representation system (FRS), and sometimes inspired by it.

The fundamental idea of semantic network (see also cteMinsky1) is to create abstract knowledge systems composed by concepts and statements that can be applied to situations of different kind concerning different subjects. Frame knowledge representation systems (FRS) are commonly based on the principle of representing concepts and objects as frames which are entities of special kind joined in a network (graph). Links or relations between nodes symbolize different mutual relations: inheritance, aggregation and so on. As it is noted by Karp in paper [1] containing analysis of more than 50 branches of semantic network and knowledge representation theory, there is a variety of terminologies to be specially compared, so we will use that paper of Karp for a common language to speak about the matter.

The concept of global scientific library proposed in the paper is slightly aside the main stream of semantic network theory. While the frame knowledge theory considers frames and network from abstract point of view, we focus on implementation part of the problem, trying to find a way of

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giving simple and efficient material form for distributed knowledge systems to be used in systems of universal (free world wide interdisciplinary) knowledge access and global framework for scientific investigations. In some sense we would like to propose an approach to taking step from particular and abstract semantic systems to persistent global network similar to step from programming language to GRID infrastructure, but concerning knowledge representation systems.

In this paper we consider computer document and knowledge representation, however the entire knowledge of mankind is formed by different types of information media, huge part of it are the hard copies of books and articles. Today owing to the development of computer technologies and telecommunications the book and the letter (to wide extend) are not the unique information media. Now information takes especial significance. Concept of information itself is evolving and, what is important, not only for special investigations but in mind of an ordinary man (good example is science fiction). Systems are produced specially for handling information and processes over information. New languages for representing information appear.

Now there exists huge variety of technologies of data and knowledge representation, which are usually complex or too much specialized. The problem of knowledge representation has different levels according to the extent of information technologies integration to a concrete science and its specific needs. Bioinformatics uses large data networks for a long time, it demonstrates the high level. At the same time people make science without special computer programs or networking technologies so far. This case is related to the low level of the problem concerning common ways of representing scientific knowledge on a universal basis. Our work concerns this second part of the problem. Simple and sufficiently universal technologies are still to be discovered to get real advantage in using global networks. We guess that an important part of understanding must refer to or include general phylisophical analysis of knowledge phenomenon considering it in some cases as natural (physical) phenomenon (but not as a tool confined by use and tradition!). Our investigation will follow this principle. An ideal goal would be both developing new knowledge management systems and creating new international scientific language which is simple, semantic-oriented and self-organized to be universally applied.

Challenging aspect of knowledge phenomenon problem is information self-organization. Knowledge produced by scientific community grows exponentially, it is hard to put it into single mind and to analyze using conventional methods base on hand-make analysis. Today researchers work on new types of knowledge bases with high level of self-organization resembling biological or gene constructions.

We are interesting in a close but slightly different side of the question: knowledge autonomy, which means investigating simple and general knowledge meta-model serving as a basis for the knowledge to exist independently (to be explained in the paper). Concerning data autonomy our concept should operate the meta-concept, that we call global, but not distributed (...network, knowledge system etc.). A distributed system is generically considered as whole system represented by plenty of equal particles. We consider elements of the global knowledge base to be much more independent both from semantical and operational point of view.

Consider two examples. First, look at a library inside library network. Information in the library must keep sense if network is disconnected. Furthermore, information must be independent from ways of representation and media types, — knowledge can be printed on paper (serialized) without loss of sense. Semantics must be unchangeable during a long period of time, thousands and millions of years. Thus, an information unit (a library) must have something special (close to concept of meta-data) “gluing” different semantic layers helping a reader to understand the knowledge. Notice that semantics cannot be made completely reader-dependable. This paradox seems to be crucial, but the thesis is explained in next example.

Consider another example of self-organization. Suppose that a library as a part of the knowledge is put on analysis by a Man from another epoch, say, after million of years. We assume that he
has no direct connection to our culture. Library is found as a result of archeological dig. Modern specialists do deep analysis of texts produced by different cultures trying to guess (conjecture) the sense. In case of art and fiction delivering feeling and emotions of the writer, of course, one should know well culture of the writer to compare and track down common sense in our culture. However if we try to reconstruct a description of a mechanism or a complex technological system, this is not the case. We deal with a knowledge which is simple and rigorous, composed of elementary parts in conformity with strict rules and principles. Scientific community developed non-trivial culture of knowledge representation including structuring and using specialized languages. Any library must incorporate this experience on way or another to represent the knowledge of mankind to be understandable and useful to any human or non-human reader.

The idea of universal basis for common scientific language is to choose as elements for the knowledge representation system few simple (primitive) constructions intelligible to any living creature having structural way of thinking and then to extend it consecutively by advanced semantic layers to get complex constructions.

Even if we think of the initial step of library recognition made by an imaginary creature-reader introduced above, the use of extremely simple basic constructions helps to do further semantic analysis more effectively, moreover, now it is possible to handle large amount of information in the library and to involve (computer) automation. Consider the following case. In near future the mankind probably will start exploration of near cosmos, say, planets in solar system. Imagine an isolated station on orbit or a planet, having in its kernel a kind of a library discussed above able to self-organize and self-describe. Any man visiting station after a long period of autonomy (observe that human culture can change completely in hundreds of years) will be able easily communicate the station information system without any deep analysis just having a base constant list presented on a couple of sheets of paper.

Summarizing the paper approaches to discovering a model of universal knowledge representation and to providing the low-level environment for knowledge representation that can be used in high-level knowledge representation systems. Furthermore, the knowledge environment discussed in the paper as a kind of distributed database environment explores new ways of organizing the information as regards: data representation and exchange, tracking versions and providing meta-data. We hope this part of the work will be interesting to people working on distributed information system technologies.

Reader can refer to [2], [1], [4], [5], to [6], [7], [8], [9], [3] for the knowledge representation theory, IT standards and sample applications.

1. Global scientific library

**Definition 1.1.** Speaking of the *global scientific library* we mean the world wide scientific environment consolidating investigations belonging to different sciences and schools with help of global networked knowledge exchange system\(^1\). In other words, the notion of the *global scientific library* includes a set of concepts: information storage, network, basis for integrating heterogeneous research systems and knowledge bases, scientific workplace and so on.

**Definition 1.2.** A *library* is a specially designed storage of information in the wide sense: books, articles (including their computer representation), algorithms etc.

Today a *library* is not only a storage of hard-copied books, it can be a library server or just a directory of home computer. Generally we can consider all the knowledge in the world (contained in separate libraries) as the one (global) world library. There is certain analogy with the Internet connecting workstations and stations.

\(^1\) As well as common philosophy of how the Knowledge is organized.
In most cases it makes not matter for reader (library user) which library has provided the desired information to him. Thus, a library providing universal access to the entire knowledge must be treated as one integral object. From this global point of view the nodes of the global library network differ only by information completeness and accessibility (including time necessary to get some information).

**Definition 1.3.** We call the *global library* the entire set of all knowledge in the world (or universe). We use the short term *library domain* for any amount of knowledge, in particularly for the knowledge in the global library. The term *global scientific library* if used for a system managing the *global library*. For brevity short term *scientific library* is used.

## 2. Scientific document

Here we talk about the main idea of knowledge representation in a space-time database.

**Definition 2.1.** An *abstract document* is any information (knowledge) represented in some way: on paper, photo-film, computer file etc. As a rule, an *abstract document* possesses the structure and is composed of a set of *elementary documents*: plain text, mathematics, schemes and diagrams, graphics and other construction. The main purpose of the document, especially as regards scientific one, is to pass (to give) to a reader a certain amount of knowledge, and do it most adequate. Therefore an *abstract document* can be characterized, from system point of view, by the following properties:

- having the unambiguous sense (semantics);
- use of common (standard) *elementary document* types to be recognized by all readers.

As a corollary, we see that documents are formed by simple and standard *elementary documents* using a small collection of simple rules of structuring.

Let us take the following definition of the computer document representation.

**Definition 2.2.** *Computer document* is any information (knowledge) — representing an *abstract document* — designed for reading by a reader or processing by an automated system and able to be copied and transmitted (over communication networks).

Following this definition we base our *formalism of the scientific library* on a special definition of a *document*, which properties are different form that of computer document in usual sense.

**Definition 2.3.** To explain this let us observe that the most objects in an information system environment have the following fundamental behavior:

- An object is localized somehow in the space (for example, it can be a row in a database table, identified by a key);
- It has or can have properties that called *attributes* (or slots) of the object.
- It is borned and exists *evolving* until death. Object’s evolution is usually change of its attributes. An attribute value can be reconstructed for now or for any moment in the past, if we track object’s history.

We call an object with such behavior an *evolving entity*.

A document in a usual sense is also a kind of information system entity evolving, for example, in process of editing. We pay strong attention to document editing issues from the global scientific workspace point of view. To our opinion, a document acquire value from the start of editing process, long before the publishing point.

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2The term *Global Intellectual Library, GIL*, is reserved for the project [http://sourceforge.net/gil/](http://sourceforge.net/gil/).

3Of course, we mean a network of systems functioning together.

4More exactly a document is supposed to be precise and one-valued even in case when something is implicitly subtended, semantics include it as well. — several meanings are the set of meanings. In any case document must be evaluated to the same for any attentive reader.
Definition 2.4. A *document* of the scientific library is a permanent and persistent object corresponding to a certain, given once and for all, non-changeable information (knowledge).

This is formalized in the following definition.

Definition 2.5. *Permanent entity* is an object which is not considered to have history. A *permanent entity* is eternal and constant, more rigorously, living in the generalized, *informational space-time*.

A permanent entity may be attached to an *evolving entity* in some way, however, the evolution, change of the document is not considered as evolution or dynamics in usual, physical sense. Further, to formalize if we introduce the notion of *information development* which means, first, that new information grows from the “existing” information and, second, that the new is connected to the preceding, not replaces it. For insight see physical models below.

An abstract example of permanent entity is an identifier, generated randomly at time $t$, if it is unique. Another example, which is most important for us, is a text which state is fixed at time $t$, say, Bethoven’s Sonata no. 1. Principally, we may assume that the contents of this text is uniquely defined even there are no media — somewhere another copy of the text would exist.

From this point we put into base of consideration the permanent model of scientific document. This approach leads to new knowledge representation and retrieval techniques. For some information processing scenario it gives good performance thank to different way of the knowledge representation.

3. Physical models. Space-time databases physical origin

Let us consider an example of mechanical system: a single mass point moving in a force field (no matter what). *Dynamical system* is a law describing the evolution of a system, given by a differential equation, transformation group or stochastical process. From the classical mechanics point of view the motion is described by a dynamical system, representing the evolution of system’s state — in our case — point $x(t)$ in the phase spaces given by coordinates $q$ and impulse $p$ of the point. Evolution of a state is described by $x(t)$ expressing the denendance on time $t$. The phase space is set $\mathbb{R}^3 \times \mathbb{R}^3$.

Relativistic theory consider the *world curve* which is the full history of the mass point, represented by the curve $(t, q(t))$.\(^5\) If the space-time is supposed to be non-curved (having simple topology) then the *space-time* is given by the product $\mathbb{R}^4 = \mathbb{R} \times \mathbb{R}^3$ of the time axis and the space in each inertial system.

Suppose that an observer makes sequential observation of the mass point states. Each observation happens and correspond to “a time” and locates the mass at “a point in the space”. We draw quotation marks to indicate that everything depends on inertial system coordinate system. At the same time from geometrical point of view the construction is simpler: the world curve is just a curve on the space-time manifold and observations correspond to points on this curve.

Now returning to the global library consider an abstract document evolving (developing) in editing process. We consider any change of the document as birth of a new revised document. It is natural to index it by the time of the revision and a pseudo-space coordinate, say, a unique random identifier mentioned above.\(^6\). Thus, the sequence of the revised documents can be called the world curve of the document.

Now consider the measurements of mass point state as documents of the global knowledge base, stating that the mass is at point $q(t)$ at time $t$. Assume that our information about the mass is restricted by these documents (mass is enfluenced by external factors). Then the document pseudo-curve interpolate the real world curve of the mass.

\(^5\)Here the reader may be confused by the fact, that the state seems to be defined by the coordinate, but the impulse contained implicitly in the model as $\dot{m}(t)$.

\(^6\)It would make sense to complement it by the space coordinate, though it would be needed only to estimate the simultaneity of events happened at opposite sides of the Galaxy. Observe however that the concept of knowledge developing is less sensible to the simultaneity problem.
Notice that the sequence of documents is discrete. Thus, we have no information on how the mass evolve outside that world points. From mechanical point of view we just approximate the continuous world curve, but as regards information we just know that at some times $t_k$ we observe something at point $q(t_k)$, but we cannot be sure that we see the same object! This example demonstrates the relativity of such concepts as existence and evolution of information. Indeed, if we deal with quantum theory object, say, electron then the relations between measurements become non-trivial.

4. Formalism of the global scientific library

The purpose of our investigation is to show how one can formalize the space-time database environment providing the global scientific knowledge representation environment and the universal scientific workspace. We use the term formalism or formal system for a system of formal meta-concepts logical constructions describing the matter. A model is a system of real or imaginary objects and processes demonstrating the structure and behavior satisfying a formal system. In mathematics any system is studied as abstract object existing in world of abstract mathematical constructions based on a fundamental mathematical formalism such as Cermello–Frenkel axiomatics for Kantor set theory. Thus, a mathematical model of a phenomenon deals with an image of the phenomenon, not the “real” object.

Some features of the global knowledge environment concept are to be considered in the real world context. Namely, some objects like document are provided with global meaning and existence independent on formalized view. This leads to certain mixture of formal and physical models. Roughly speaking, we will use mathematical language to speak about the formal constructions, though they refer to absolute physical objects such as the knowledge graph. To be precise we follow the following assumption. The formalism of the scientific library (formalism) extends the mathematical formal language by adding several categories of symbols referring the objects from the physical context. These external objects are constant terms of the language. The main categories are permanent and evolving entities and relations between them, more exactly a restricted set of these objects described as follows.

**Axiom 1.** For all the permanent entities it is convenient to use one category and one common term considering any permanent entity as a document. Further we always use the term document. A sequence of documents may be joined using relations marked by the relation type which is also a document. The sequence is joined or not joined, if yes then this fact is represented by a relation instance, a document as well.

**Axiom 2.** As for the category of evolving entities gathering all entities describing objects evolving in the real world, a common simplified formal representation will be used. Namely, the state an evolving entity is represented by attributes — a kind of marked binary relations involving both evolving entities and documents.

In our case evolving entities are primarily used for real world objects managing the scientific library as well as actors observing and influencing the library via the managing system.

Now we consider a preliminary model of the global knowledge representation which helps to understand where the concept originates and how it works.

Consider again an abstract document: a book or an article. An important feature of any document is structuring — the document is composed from parts, each part has its own structure and so on. Moreover each part, in most cases, has independent syntactical value and can be considered as smaller document.

For a document in usual sense we distinguish the graphical and logical structure. The graphical structure is a way of representing document on paper, screen or other readable media. Obviously the
logical structure is of most importance to understand the document (document semantics), and the
graphical structure is derivative of the logical. This principle is explicitly used in markup languages
TeX, HTML, XML etc. Furthermore, a document may be organized non-trivially, though the logical
structure is expressed by elementary, mostly hierarchial, construction like list, dictionary (map) etc.
If some information is represented in different way then it is probably too special to fit in the common
concept of document. However, the basic “bricks” we usually operate are sufficient to cover 99.9% of
constructions we could imagine, the remainder can be classified as elementary document (“black
boxes”) so far.

4.1. Document hierarchy. So, the structure of the document is hierarchial: document is composed
by first-level parts. These parts are childs of the initial document, which is called container. Thus
documents can be viewed as nodes forming a tree. This approach allows to consider all docu-
ments as nodes of potentially infinite graph (the knowledge graph). A document can be reconstructed
from the graph by tracking all descendants.

4.2. Local document model.

Axiom 3. A document as a node of an hierarchy satisfies the following conditions:
– Document can be empty.
– Document can be associated with an elementry content having special semantics: integer,
real and complex numbers, string, graphical images etc.
– Document can be associated with a container structure — a way of organizing child nodes.
– The following container structures are used: dictionary (map), list, set.
– Dictionary or (map) associated with a document $d_1$ is a map $m(d_1) : d_2 \mapsto d_3$, where $d_2$
called a key, $d_1$, $d_2$, $d_3$ are documents. An element of the dictionary, $m(d_1)(d_2)$ is called the
d_2-attribute of the document $d_1$.
– List associated with a document $d_1$ contains ordered list of child documents which call elements of the list. There are no principle obstacles for a list to be infinite.
– Set associated with a document $d_1$ contains finite or countable setordered list of child docu-
ments which call elements of the list.
– There are not principle obstacles for a list or a set to be infinite.
– Container structures may be combined in the following way: Any node is a dictionary. How-
ever other pairs, where both elements are not a dictionary, are forbidden.

![Figure 1. Simplified document structure](image)

7Of course, hierarchy is just one of the approaches to data representation. For example, widely used relational
database phylosophy is orthogonal in some sense to hierarchial representation, as it deals with graph that is rarely a
tree, objects are strongly cross-referenced. As regards the knowledge graph, hierarchy is just one possible behavior, but
most important to document structuring model.
4.3. **Example of document life cycle.** Here we consider an example of document life cycle — how it is defined according to the principle of permanent evaluation and influenced by the editing process. Consider a document $d_1$ which is structured as shown on the figure 4.2: The full content of the document $d_1$ is everything that is aggregated in it: children, children of the children and so on. A document can enter different kinds of relations but there is a restricted set of relations which, roughly speaking, evaluate the document — define its properties those change would imply change of the document meaning (this process we call development to distinguish with evolution applied to real world-like objects).

Any document change is related to an actor that performed it and can be considered as a special kind of revision object associated with a time and a place. An idea how to keep the permanent evaluation is well-known. We just produce branches according to editing process. What is interesting is how to do it globally in a potentially infinite world of knowledge both in “horizontal” (complexity, network) and “vertical” (hierarchy) direction?

![Figure 2. Document revision scenario](image)

An idea is to track the revision everywhere where it can affect. Namely, a revision of a document (which is a node of the knowledge graph) produces new revised documents for this document and all the ancestors of it. In other words, if somebody (an investigator) is importing a text and starting to edit he is supplied with his own copy of the text, though it of course connected to the original document.

**Axiom 4.** This is to realize principle “Knowledge for people” — any reader can access to the knowledge system of mankind and develop it.\(^8\)

Using such kind of revisions expressed by knowledge development allows to exploit different technological principles of managing data. Consider two investigators working with different domains: each domain is a materialized part of the abstract global knowledge system (associated with a workstation, a server or a storage). Suppose they are editing the same document, for example, a medical health history of a patient (‘same’ means branched from the same document — node of the knowledge graph). Let they enter different observation, which are probably different, but may be concurrent. The problem of doing work in a client-server or distributed environment is rather non-trivial. Actions are to be performed by specially designed API, put in transactions, monitored and logged, checked for user rights and so on. Our case anything is considered as new knowledge just to be added to the knowledge graph. More exactly, our knowledge approach to information management assumes that we distinguish two tasks: 1) processing document and 2) managing document status. The first deals with document structure, relations, non-trivial context (e.g. mathematics, physical

\(^8\)It would be interesting to discuss security and privacy issues here. Knowledge created (sometimes randomly) in a universal environment need additional instruments to control privacy and reliability, the same way like serious networked application overcome the Internet democracy.
measurements, graphical design etc.), but the second concerns resolving revision status, privacy and security issues. In our examples, to record the information is more important process (one investigator would be an anaesthesist who has several seconds to do that) than tracking observation branches and resolving status, which can be proceeded later.

Thus, our two investigators just separately develop a copy of a document, which is a revision of the original document. How they cooperate? Information synchronization is rather simple here. Two domains can be joined any time. We can take new documents from one and to attach to another, and no collisions happen since editing (development processes) produces new documents, having different identification.

**Axiom 5.** This can be formulated as “Principle of knowledge grows”: abstractly the knowledge can only grow, anything known (at or from some point of the space-time) cannot be canceled or reversed.

Of corse, one may argue that any information system behaving like that will collapse when information media cannot store more data which is never erased. Evidently, here we follow the general idea of referencing and garbage collection. This idea is realized in some programming languages like Java or Python operating with references to objects. An object is holded in memory until reference count reaches zero, i.e. nobody needs this object more and, what is important, nobody don’t know more about this object and cannot refer it. In a simmilar manner if a document is not needed — neither readed nor investigated more — it can be erased. If a document is refered and blocked by a reader or investigator we say that it is *observed*. Some restrictions arise concerning collecting garbage. For example, if an object is a child of an observed document it should be blocked as well and so on. This restrictions need predicate calculus to be expressed.

Sure mentioned aspects concerning knowledge life cycle are not exhaustive but, we hope, sufficient to understand the main ideas. We return to this discussion further.

### 4.4. Modeling relations.

**Definition 4.1.** A *relation* between elements of a set $M$ is a map $r: M^n \rightarrow \{\text{True}, \text{False}\}$. The relation can be equivalently represented by a set of sequences $(d_1, \ldots, d_n)$ of elements, such that $r(d_1, \ldots, d_n) = \text{True}$, we say that *these elements are in relation $m$*.

**Definition 4.2.** We call a *marked relation instance* (or a *link*) corresponding to a *relation type* $m$ a finite sequence of documents $(m, d_1, \ldots, d_n)$.

From mathematical point of view we may consider all the relation instances as elements of the set which called *relation* of type given by $m$.

We reduce this notion to one ternary relation.

Indeed, the link can be viewed as an instance of *one universal* $(n + 1)$-ary relation instance $(d_0, d_1, \ldots, d_n)$ where the beginning element plays role of relation type. Furthermore, $(n + 1)$-ary can be reduced to the marked binary relation as follows. The relation is modeled by a *dictionary* instance representing the map $k \mapsto d_k, k = 0, 1, \ldots, n$.

Observer that a *dictionary* as we has defined it is a kind of ternary relation between container, key and item. However we cannot go this way as we occupy the ternary relation just for representing dictionaries and loose universality. We use the following solution. Let us introduce the constant document named ’IsADictionaryAnchorOf’ marking the binary relation (IsADictionaryAnchorOf, ·, ·) attaching to a document $d_1$ no or one document $d_2$ 10 called *dictionary anchor* of special meaning: a relation instance $(k_j, d_j, d_2)$ says that $d_j$ is the $k_j$-attribute of $d_1$.

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9 Other containers are build the same manner.
10 By instance (IsADictionaryAnchorOf, $d_2$, $d_1$)
5. Semantics

The key idea of the global knowledge environment is rather evident: to build complex things with help of simple elements. A delicate feature is a way of understanding this common principle. The universal knowledge graph introduced above, based on plain node set and the universal ternary relation is just an example of a simple and fundamental construction. Other well-known examples are: representing mathematics formal logics on paper as a text — a finite sequence of letters and symbols, and formal models of algorithms like Turing machine (cf. Church-Turing thesis). These constructions can be materialized in the real world without loss of meaning, and different ways can be used: latin capital ‘A’ drawn with any font in a mathematical text means the same symbol, which is distinguished from ‘B’. Our knowledge graph can be also represented in different ways: in computer format as described above or elsewise (say, in XML), on paper or even as metallic construction with labelled balls and segments.

It is important that the primitive structure of the knowledge graph is understandable to any, possibly non-human, reader able to perceive a construction like graph. This is a minimal requirement to make exchange of knowledge possible. Though a reader would take a long time to reconstruct it.

Definition 5.1. We call a real or imaginary process of interaction between the knowledge graph and a being (creature) unfamiliar with it the non-human reader test.

Thus the knowledge graph can be considered as a material, physical object. This is explained as follows. The knowledge graph understood as described above need no additional semantics to deal with. Anything that does not concern nodes and the relation is outside the concept. At the same time the knowledge graph supporting by a knowledge management system must be outlined according to it natural meaning.

To improve the understanding we must explain to the reader more complex constructions step by step. For doing this we introduce special semantical extensions called micro-models, which allow to build advanced constructions on the base of the knowledge graph: hierarchy, revision, inheritance, metrics and so on.

Definition 5.2. A micro-model of the scientific library is a formal requirement and semantic system to be applied to the knowledge graph (more exactly, to a domain). A micro-model is a general notion, it is represented by a document and included to the set of domain micro-models. A micro-model attaches extra human semantics as well as constraints, constants etc. Formally a micro-model is a part of the knowledge graph (constants and fundamental relations) and a collection of rules in a human logics (predicate calculus) involving both documents and human abstract constructions introduced in micro-models.

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