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Nanotechnology Ontology: Semantic Access to Information in the Nano World

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ABSTRACT

Scientific progress in a domain depends greatly on making use of results of previous research activities. Like human beings, it is difficult for computers to encode and retrieve the expanding web information. The basic answer to this problem is to describe the information explicitly and semantically with ontology. The article presents a brief discussion of the study undertaken to design an ontology for Nanotechnology, which was developed by using the Resource Description Framework (RDF). This paper further describes methodology opted to develop the Nanotechnology ontology, where a semantic structure of Nanotechnology thesaurus was utilised for its creation. The study has further presented the features of nMap software, which was developed specifically for the study by using VB.net as front-end tool and MS-access as back-end tool. Outcome of the study offers a semantic knowledge structure to Nanotechnology researchers in machine readable environment. Further, development of ontology in RDF format serves interoperability and will further support semantic interpretation by machines to facilitate human understanding.

Keywords: Ontology, nanotechnology, knowledge representation, semantic web

1. INTRODUCTION

The web is a techno-social system through which interlinked and hypertext documents are accessed through internet[1]. It was created with an aim to enable anybody, anywhere, anytime to retrieve information. Sir Tim Berners-Lee was the one who created world's first website in 1991[2]. Since 1991, there appeared an immense progress in the manner in which information is published and accessed on the web. On the basis of characteristics and features added, scholars defined various generations of web like web 1.0, web 2.0 and web 3.0[1,3,4,5,6].

The concept 'Semantic Web' was envisioned by Tim Berners-Lee with an idea to design a web such that not only documents are linked together but meaning of information in web documents can also be recognised[6]. Semantic web is considered as an extension of the current web where in addition to human understanding, the documents are marked with meta-information such that it can be processed with the help of machines. Unlike current web, it is not just for displaying the content, but for integrating and reusing of available information across various applications. To achieve semantic web environment, ontologies serve as the central enabling technology[7].

2. LITERATURE REVIEW

Before initiating the work on building a new controlled vocabulary tool, it is essential to establish whether such tools exist for the domain or not[8]. To investigate the existence of related works, a check in the literature particularly current and back issues of 'Knowledge Organisation', a quarterly publication of 'International Society for Knowledge Organisation' (ISKO) as was suggested by Aitchison, Gilchrist & Bawden[9] was undertaken. With the analysis of the publication, it was established that work related with the scope of this study was not listed in the publication. Further, coverage of Nanotechnology concepts in various sources like IET Inspec Thesaurus (2010), Library of Congress Subject Headings (32nd Ed. 2010), DDC 23rd edition, series of vocabulary documents developed by the International Organisation for Standardisation (ISO), and publicly available Glossary of Nanotechnology Terms developed by The Institute of Nanotechnology were also explored. Analysis of these sources revealed very limited coverage of Nanotechnology aspects. With the aid of publicly available web resources, it was further explored that the scholarly works available on internet was confined to Bio-medical field and not with Physical sciences.

Regarding the subject specific ontology, there exists vast literature in the field. Smith & Ceusters[10] proposed ontology of biomedical informatics to overcome the difficulties appearing with different naming conventions for genes, proteins, and other

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molecular structures and to offer a standard terminology for the domain. Similarly, Biasiotti & Tiscornia[11] represented legal concepts in ontological framework to support understanding, re-use and sharing of knowledge in legal domain. Some other studies reflected the development of ontology in various other disciplines. Esbjorn-Hargens[25] proposed an ontology on climate change. A study by Gokhale, Deokattey & Bhanumurthy[26] reported methodology for constructing sample domain ontology on energy amplifiers. As a source for keywords, INIS database was employed in the study. In the same year, Thomas, Pappu & Baker[27] reported the designing and development of Nanoparticle Ontology (NPO), which is executed in Ontology Web Language (OWL). Further, to encode disease treatment information in machine readable environment, Khoo, Na, Wang and Chan[30] explained the development of ontology based on analysis of literature from the Medline database. Hastings, & *et al*.,[29] presented developments of ontology in Chemistry. Similarly, Meenachi & Baba[30] discussed the development of ontology for representation of nuclear reactor knowledge.

3. OBJECTIVES AND SCOPE

Keeping in view the need of the hour, the present study deals with the overview of Nanotechnology and designing an ontology, which consists of a semantic framework of Nanotechnology concepts that can be inferred explicitly both by machines and humans.

Scope of concepts of Nanotechnology ontology is limited to Physical Sciences in depth and touches other associated areas in broader sense.

4. ONTOLOGY

The term ‘ontology’ is frequently appearing in texts. There exist several definitions for ontology:

- In Philosophy perspective, ‘Ontology is the study of kind of things that exists’[8].
- In context of Computer Science, ‘It is a formal representation of the knowledge by a set of concepts within a domain and a relationships between those concepts’[9].
- In Library and information science perspective, ‘It is the field of information management that basically defines a common vocabulary for users who need to share information in a domain’[10].

Further, Guarino, Oberle & Staab[11] cited Studer, Benjamins & Fensel[12] to state that ontology is ‘a formal, explicit specification of a shared conceptualisation’.

This definition includes following characteristics of ontology:

- Conceptualisation: ontology represents domain knowledge in a conceptual manner.
- Explicit: means that the type of concepts used and the constraints on their use are clearly defined.
- Formal: domain knowledge encompassed in ontology should be machine readable.
- Shared: ontology construction should be in shared agreement.

Thus, after analysing these concepts, ontology can be inferred as, a system having its origin in Philosophy which involves categorisation of concepts in a field. It proposes an improved environment with potential to organise, manage, semantically interpret and process data with the help of machines/ computers to facilitate human-machine-human communication. More precisely, ontology is a conceptual and machine executable model for a subject domain.

4.1 Ontology Components

Nguyen & Le-Thanh[13] listed following principal components of ontology:

- Classes: represent a set of entities within a domain (general things).
- Individuals/Instances: indicate the concrete example of concepts within the domain (individual things).
- Attributes: properties those concepts/things may have.
- Relations: specify the interaction among concepts.
- Axioms: assertions including rules in a logical form (imposing restrictions on establishing relations between concepts).

4.2 Importance of Ontology

Current web which grows from hypertext systems comprises of huge collection of interlinked documents. It offers freedom to all to contribute something. With such an attitude, quality of information added to Internet and uniformity in information representation on internet, is not guaranteed. Thus, searching for information on the web is becoming increasingly complex. Expecting satisfactory solutions from traditional search engines is impractical. In this situation, Semantic web proposes a layer of intelligence for gathering, sharing and distributing relevant information in a meaningful manner. Thus, semantic web is an attempt to provide extension to current web where information is meaningfully defined, processed with the help of machines, and people work in collaboration. The work of transforming web to semantic web can be carried out with the help of ontologies. Ontologies provide a structured framework for domain concepts, organise concepts in hierarchical and associative association that permits reasoning for knowledge.

Ontologies which are considered as core component of Semantic web serve following purposes:

- In comparison to other member tools of controlled vocabulary, ontologies offer more enriched relationship between domain concepts and are appropriate to support rich structured knowledge.
- Offer provision to define metadata about resources which allow machines and human users to recognise, gather, process, and share relevant information semantically.
- Show integration of information from various sources and supports agreed communication among diverse communities.
- Allow interoperability and reuse of existing information

5. OVERVIEW OF NANOTECHNOLOGY

The concept 'Nanotechnology' is a combination of two sub-concepts, i.e., 'nano' and 'technology'.

The prefix 'nano' was derived from the Greek word dwarf, which has been used since 1960 in the metric system[14]. In scientific context, the scale 'nano' represents 10-9 where one nanometer is equivalent to one thousandth of a micrometer, one millionth of a millimeter, and one billionth of a meter. It is the size where most of the fundamental chemical, physical, electrical properties of materials matched with those experienced at atomic and molecular scale like quantum effect, wave particle duality, etc.[17]. Further, describing the nature of properties at nanoscale, it was unanimously accepted that laws of Physics at nanoscale are governed both by classical as well as quantum mechanics [19,20,21].

The second component of Nanotechnology, i.e., 'technology' which refers to the application of science into practical use to develop structures and tools that can solve the problems of the society. It holds true for Nanotechnology also as it is the technology at nanoscale having applications in the development of society.

5.1 Properties at the Nanoscale

As stated by Filipponi and Sutherland[22], novel properties at nanoscale are due to the following physical changes:

(i) Increased Surface to Volume Ratio: Breaking down of bulk material into number of nanomaterials resulted in increasing the collective surface area, whereas, its total volume remains the same. This feature could help in achieving unique surface activity, catalytic effect, sensing, etc.

(ii) Quantum Confinement: In nanostructured materials, electrons are confined in space and are not free to move in material. This is due to the fact that shrinking of bulk structure to nanoscale resulted in increase of band-gaps. This quantum effect results in altering the electronic and optical properties of materials.

(iii) Random Molecular Motion: At macro level, size of object is comparatively large in comparison to the kinetic energy of molecules. Thus, the motion of molecules is not influential on how an object moves. But, at nanoscale, molecular motion is comparable to the size of the particle and thus has great impact on how particle behaves.

5.2 Role of Nanotechnology

Nanotechnology is considered as one of the most revolutionary technology that has touched almost every aspect of mankind. It has promised great future for diverse areas. Some of them are listed here as under:

(a) Agriculture: Nanotechnology helps in enhancing the crop productivity by imparting genetic improvement in crops.

(b) Electronics and Communication: Cost effective and capable modes for recording of data, flat panel display, wireless communication technology, etc., are all due to the overwhelming research efforts in Nanotechnology.

(c) Energy: Nanotechnology reduces dependency of mankind on fossil fuels by offering renewable energy solutions. It also proposes affordable and efficient energy storage and saving device like light emitting diodes (LEDS), etc.

(d) Machines: Overwhelming properties and prospects of nanoscale machines and engines offers notable benefits in terms of sustainable development, efficient working and energy saving.

(e) Medicine: Nanotechnology increases the survival rate of human beings by providing improved biosensors, smart drugs, and advanced diagnostic imaging techniques.

(f) Water purification: Detection and removal of impurities from water, and treatment of waste water through Nanotechnology provide potable water to all.

(g) Space exploration: Nanotechnology offers light weight, ultra-small and capable space vehicles.

6. METHODOLOGY

6.1 Collection of Terms

The period considered for the study was 2001-2012. To obtain adequate number of candidate terms following source categories were consulted:

I. Printed Resources: Following categories of printed resources were consulted for term collection:

(a) Encyclopedia

- Nalwa, H.S. (Ed.). Encyclopedia of nanoscience and nanotechnology. (10 Vol.). American Scientific Publishers, California, 2004.

(b) Standard Terminologies for Nanotechnology

- ASTM Standard Terminology Relating to Nanotechnology (ASTM E2456-06)
- British Standards Institution (BSI) Terminology
- ISO/TS 80004-1 (Nanotechnologies-vocabulary Part1: core terms)
- ISO/TS 80004-3 (Nanotechnologies-vocabulary Part3: carbon nano objects)
- ISO/TS 80004-4 (Nanotechnologies-vocabulary Part4: nano structured materials)
- ISO/TS 80004-5 (Nanotechnologies-vocabulary Part5: bio/ nano interface)
- ISO/TS 80004-7 (Nanotechnologies-vocabulary Part7: medical, health and personal case applications)
- ISO/TS 27687 (Nanotechnologies-terminology and definitions for nano objects, nanoparticles, nano fibre and nano plate)

(c) Terminological Sources in Standard Form

- Institution of Engineering and Technology Inspec thesaurus. IET, United Kingdom, 2010.

(d) Conference Proceedings and Handbooks

In addition to monographs and journal articles, conference papers and handbooks were scanned for term collection. AdMet Conference Proceedings (A joint venture of CSIR-NPL and Metrological Society of India). Nalwa, H.S. (Ed.). Handbook of Nanostructured Materials and Nanotechnology. Academic Press, USA, 2000. Whitehouse, D.J. Handbook of Surface and Nanometrology. Institute of Physics, Bristol, 2003.

II. Electronic Resources: In addition to various web sources, three databases namely ‘INSPEC’, ‘Scopus’, and ‘Web of Science’ were accessed for term collection.

III. Human Resources: The group of Nanotechnology experts working in Energy Harvesting and Nanometrology divisions of CSIR-NPL were regularly consulted for finalisation. The committee approach for term selection has also been advocated by Lancaster[34].

6.2 Data Cleaning and Evaluation of Candidate Terms

This step deals with the removal of incomplete and outside the scope terms.

(a) Incomplete word forms: In the present study different sources with various output formats were utilised for term collection. Like INSPEC uses '-' as separator whereas in Scopus and Web of Science, concepts are separated with the symbol ';'. Thus, to get the concepts in desired format, i.e., single concept in a single cell of Excel worksheet, manual as well as fundamental formulas of MS Excel were applied. Eg: air may be air gap, air bearings, etc., micro may be micromachines, microscopy, etc.

(b) Out of the Scope Terms: Terms are defined as out of the scope when they did not fall under the scope of the study, i.e., Physical Sciences. Eg: Cameras

Why out of the scope: as the term represents an optical instrument that is used to record images but the study deals with optical devices that have nanoscale resolution.

6.3 Development of Semantic Structure in form of Nanotechnology Thesaurus

Nanotechnology thesaurus with 2585 terms, of which 2124 are preferred terms and 461 are approach terms has been created. The thesaurus served as a semantic structure for ontology creation in the field of Nanotechnology.

6.3.1 Preferred Term Selection

Preferred term in a thesaurus is a focal point where related information about the concept is placed. To perform the task of preferred term selection, Hulme’s principle of literary warrant in addition to user warrant was applied, which means that terms were marked as preferred on the basis of the frequency of their appearance in text and by considering the views of subject experts who would be the people to be served with the knowledge structure.

6.3.2 Semantic Relationships between Concepts

Establishing semantic relationship between the concepts can be described as a practice of assigning meaningful linkage between two or more entities. In the present work following three approaches were applied for defining the semantic association between the concepts:

- Physics Background of the researcher
- Literature available in the field
- Subject expert approach

6.3.3 Standards and Guidelines

To enter a concept as a member of a Nanotechnology semantic structure, researcher has to take decisions regarding the form of terms. Standards and Guidelines help in determining suitable grammatical forms, singular and plural forms, variable spellings, capitalisation, abbreviations and acronyms. Following Standards and Guidelines were consulted:

- National Information Standards Organisation. Guidelines for the construction, format, and management of monolingual controlled vocabulary (ANSI NISO Z39.19-2005 (R2010)). NISO, U.S. 2010.
- Aitchison, J., Gilchrist, A. & Bawden, D. Thesaurus construction and use: A practical manual. (4th ed.). Europa, London, 2000.

7. ONTOLOGY ENGINEERING

Ontology engineering refers to various approaches, tools, and languages involved in building ontology. For ontology engineering Malik, Prakash & Rizvi[35] cited Denny[36] to elaborate following basic steps for ontology modelling:

- Attaining deep insight of the discipline in which domain ontology is to build
- Identification of concepts that represents the domain selected for ontology
- Creation of hierarchical structure by creating classes, and their respective subclasses
- Defining properties to establish relationships between the concepts
- Verification of constructed ontology for consistency
- Deployment of ontology for transfer and sharing of information in machine readable environment

Steps for ontology creation can further be denoted as:

7.1 Concept Naming

Under concept naming, comprehensive list of terms that represents the domain concepts is created. According to Roussey, & *et al*.,[37] process of domain concepts extraction is based on:

- Based on text: Text is considered to be a rich source of information. It can be used for selecting terms. Further, quantitative techniques like co-occurrence may be used to extract core concepts.
- Based on thesaurus: Thesaurus is considered as an organised knowledge structure and can be used in developing ontology.
- Based on relational database: Structural nature of relational database can be used to extract concepts, relationships and properties.
- Based on UML diagram: Unified Modeling Language, a graphic language designed for visualisation purpose can be used by designers to describe their diagrams.

Though, thesaurus and ontology differ from each other in level of semantics, but still of the intrinsic feature of thesaurus to represent the knowledge structure, it can serve as a base for ontology development. In present work, Nanotechnology thesaurus developed by the author served as a base for creation of Nanotechnology ontology.

7.2 CONCEPT HIERARCHY

Kim & *et al*.,[38] suggested three methods to develop concept hierarchy:

(a) Top-down approach: (From generalisation to specific) process begins with one or more general concepts in the domain and successively, it specialise the concepts.

(b) Bottom-up approach: (From specialisation to generalisation) process begins with most specific concepts, with subsequent grouping of these classes into related general concepts.

(c) Middle-out approach: (From most important concepts to generalisation and specialisation) under this approach most important domain concepts are extracted and then these are generalised or specialised as appropriate.

7.3 Concept's Property and Concept Association

Each concept has one or more properties that define its attribute. Properties of domain concepts need to be defined and documented.

Association between concepts denotes the meaningful relationships between concepts. Relationship marked between the concepts should explain how a concept is semantically related to another. In this sense, ontology lead over thesaurus, as in ontology, relationships are comparatively more refined and semantically enriched.

7.4 Formalisation

According to Random House Webster's Concise College Dictionary[39] formalise means 'to make formal, especially for the sake of official or authorised acceptance: to formalise an agreement with a legal contract'. In context of ontology, it refers to the process involved in making the sematic domain knowledge structure into machine readable form. For this transformation, there exist number of Web technologies to represent semantic knowledge structure into machine readable form, and ontology editors designed for creating and editing ontologies.

- **Web Technologies**

Discussing about the markup languages used in Semantic Web environment Zhang[40] cited Robu, Robu & Thirion[41] to mention the semantic web technologies employed during different intervals. As stated in the contribution, in the year 2001, XML (eXtensible Markup Language), and RDF (Resource Description Framework) were the two technologies used for the development of Semantic Web. The contributor further stated that in the year 2004, the revised RDF and OWL (Web Ontology Language) were the two technologies announced by W3C (World Wide Web Consortium) as the key technologies for Semantic Web. By 2006, RDF, RDFS (RDF schema), and OWL were considered as the W3C approved semantic web technologies[42]. In the present work, RDF has been utilised as a base for ontology creation.

Table 1. Extended relations for semantic enrichment

Relationships	Thesaurus	Ontology	
Hierarchical	BT & NT	class	Subclass
Equivalence	USE/UF	USE	UF
Associative	RT	application-for	application-of
		base-for	based-on
		cause	Effect
		determined-with	used-to-determine
		fabricated-with	used-to-fabricate
		has-parameter	parameter-of
		has-property	property-of
		has-structure	structure-of
		manipulated-with	used-to-manipulate
		measured-with	used-to-measure
		obtained-with	used-to-obtain
		phenomenon	Tool
		present-in	may-have
		removed-with	used-to-remove

- **Ontology Editors**

These are the applications developed to support the development and manipulation of ontologies. Substantial efforts in this direction resulted in the appearance of number of tools worldwide. However, some of tools are available free on Web. Discussing the tools that can be used for implementing metadata for ontologies by using ontology languages Youn and McLeod[43] briefed several applications in their study- Protege 2000, OilEd, Apollo, RDFedt, OntoLingua, OntoEdit, WebODE, KAON, ICOM, DOE, WebOnto, Medius Visual Ontology Modeler, LinKFactory Workbench, and K-Infinity. Khondoker & Mueller[44] conducted a survey to compare various ontology development tools. This comparative study covered Protege, SWOOP, Internet Business Logic, Top Brand Composer, Onto Track, and IHMC Cmap ontology editors, for analysis. While discussing ontology development methodologies along with tools and languages used in ontology construction, Mizoguchi[45] discussed Onto Edit, WebODE, Protege, and Hozo in the contribution. Similarly, Gokhale, Deokattey & Bhanumurthy[46] have discussed various tools and methods for developing ontology in their study. The study listed Ontolingua, WebOnto and Cys under ontology development tools. Further, while discussing the role of ontology in semantic web, Giri[47] covered Protege, DOME, Knoodl, and Onto Edit in his work.

8. DEVELOPING NANOTECHNOLOGY ONTOLOGY BY USING 'NMAP' SOFTWARE

To retrieve the semantic word map of Nanotechnology in RDF format, nMap application which was developed specifically for the study was employed. The application nMap is a graphical user interface (GUI) software that uses VB.Net as front-end tool and MS-Access as back-end tool. As compared to the other existing ontology editors, nMap is more user friendly and can be used by a person with little computer knowledge.

8.1 Features of nMap

nMap offers the following features:

- **Term Relationship:** This feature helps in defining and displaying various semantic relationships between terms. It also offers flexibility to add new associations between terms, i.e., property, attribute, characteristic, etc.
- **Predictive Searching**: nMap provide autonomy to users to perform random searching on term/ concepts. This feature offers the dropdown just under the search box which displays selectable suggestions for search query.

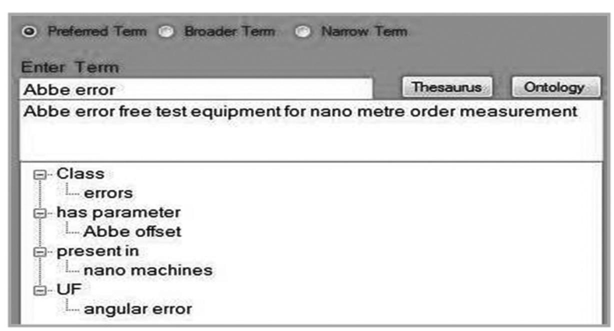

Figure 1. Term relationship feature of nMap.

- **Data Export facility**: Output retrieved can be exported in various semantic machine readable formats like XML and RDF. This feature will support reusability of exported data in other applications for further research.
- **Data Portability**: nMap provides the facility to read the data from file received in the prescribed

format. This feature reduces the user(s) efforts in data entry.

- **Graph Plotting**: Graph can be generated for each approached concept and can be saved as image.
- **Data Modification**: This feature allows the user to edit the terms/concepts.

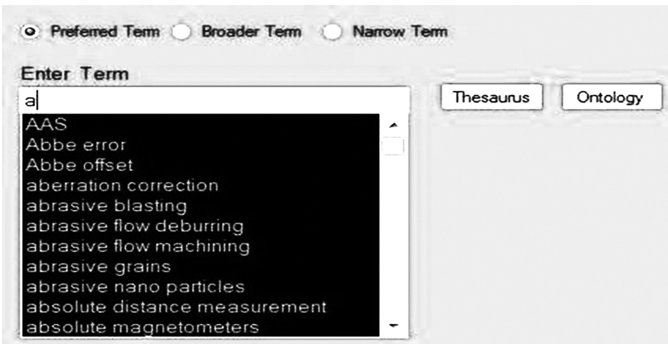

Figure 2. Predictive searching feature of nMap.

Figure 3. Data export feature of nMap.

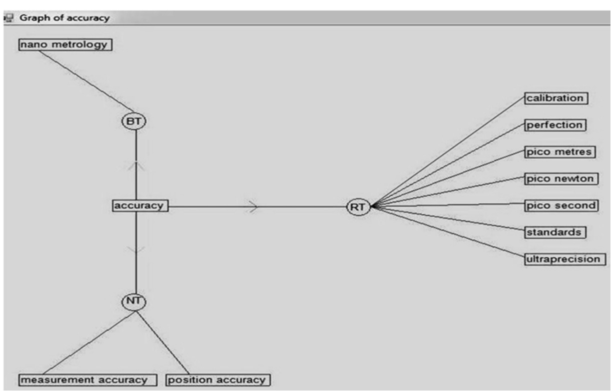

Figure 4. Graph plotting feature of nMap.

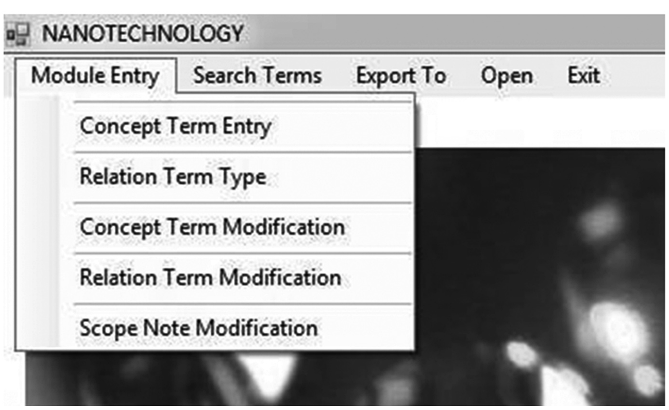

Figure 5. Data modification feature of nMap.

9. FINDINGS

The study comes out with Nanotechnology ontology in RDF framework for which semantic structure of around 2585 Nanotechnology terms was utilised in combination with nMap software. The tool offers a semantic knowledge structure to Nanotechnology researchers in machine readable environment. Further, development of ontology in RDF format serve interoperability and will further support semantic interpretation by machines to facilitate human understanding.

10. EVALUATION OF RDF SYNTAX

To establish quality assurance for RDF structure that appeared as the outcome of ontology, World Wide Web Consortium (W3C) RDF validation platform was approached. This W3C platform helps in attaining structural validation for RDF syntax.

11. SAMPLES OF ONTOLOGY

In the following section ontology samples for two Nanotechnology concepts, i.e., 'contact free measurement' and 'nano scopes' are represented in distinct formats, i.e., RDF XML Syntax, RDF Triplet Table, and RDF Triplet Graph.

11.1 Contact Free Measurement

(a) RDF XML Syntax

- <?xml version='1.0'?>
- <rdf:RDF xmlns:rdf=http://www.w3.org/1999/02/22-rdf-syntax-ns# xmlns:pt="http://purl.org/pt/elements/1.1/">
- <rdf:Description rdf:about="localhost/pt/contact free measurement">
- <pt:SN>contact free measurement of nano objects by using cold atom scanning probe microscope</pt:SN>
- <pt:application-of>non contact atomic force microscopes</pt:application-of>
- <pt:application-of>capacitive nano sensors</pt:application-of>
- <pt:application-of>non destructive analytical techniques</pt:application-of>
- <pt:application-of>contactless techniques</pt:application-of>
- <pt:application-of>cold atom scanning probe microscopes</pt:application-of>
- <pt:Class>nano measurement</pt:Class>
- </rdf:Description>
- </rdf:RDF>

(b) RDF Triplet Table

RDF triplet tables as illustrated in Table 2 is used to store RDF XML triplets for the concept 'contact free measurement' in there columns, i.e., subject, predicate and object, where subject and predicate must be resource URIs and object is a constant value.

(c) RDF Triplet Graph

11.2 Nano scopes

(a) RDF XML Syntax

uses a beam of atoms instead of light</pt:SN>

- <pt:Class>nano optical devices</pt:Class>
- <pt:has-parameter>numerical apertures</pt:has-parameter>
- <pt:Sub-Class>optical nano scopes</pt:Sub-Class>

Table 2. RDF triplet table for 'contact free measurement'

S. No.	Subject	Predicate	Object
1.	http://www.w3.org/RDF/Validator/run/localhost/pt/contact free measurement	http://purl.org/pt/elements/1.1/SN	'contact free measurement of nano objects by using cold atom scanning probe microscope'
2.	http://www.w3.org/RDF/Validator/run/localhost/pt/contact free measurement	http://purl.org/pt/elements/1.1/application-of	'non contact atomic force microscopes'
3.	http://www.w3.org/RDF/Validator/run/localhost/pt/contact free measurement	http://purl.org/pt/elements/1.1/application-of	'capacitive nano sensors'
4.	http://www.w3.org/RDF/Validator/run/localhost/pt/contact free measurement	http://purl.org/pt/elements/1.1/application-of	'non destructive analytical techniques'
5.	http://www.w3.org/RDF/Validator/run/localhost/pt/contact free measurement	http://purl.org/pt/elements/1.1/application-of	'contactless techniques'
6.	http://www.w3.org/RDF/Validator/run/localhost/pt/contact free measurement	http://purl.org/pt/elements/1.1/application-of	'cold atom scanning probe microscopes'
7.	http://www.w3.org/RDF/Validator/run/localhost/pt/contact free measurement	http://purl.org/pt/elements/1.1/Class	'nano measurement'

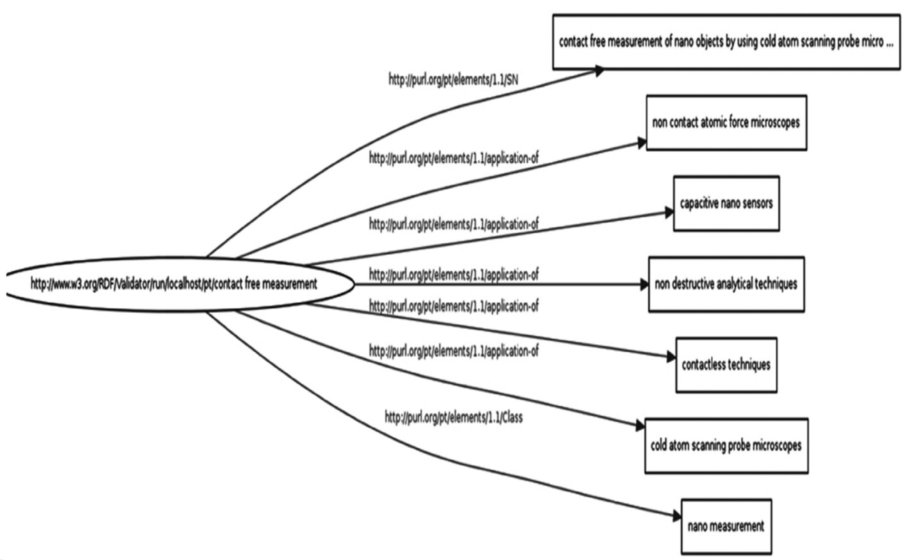

Figure 6. Graph for 'contact free measurement'.

- <?xml version='1.0'?>
- <rdf:RDF xmlns:rdf=http://www.w3.org/1999/02/22-rdf-syntax-ns# xmlns:pt="http://purl.org/pt/elements/1.1/">
- <rdf:Description rdf:about="localhost/pt/nano scopes">
- <pt:SN>nano scope is any microscope that has its resolution in nano metre and which
- <pt:Sub-Class>attosecond nano scopes</pt:Sub-Class>
- <pt:tool>nano scopy</pt:tool>
- </rdf:Description>
- </rdf:RDF>

(b) RDF Triplet Table

RDF triplet tables as illustrated in Table 3 is used to store RDF XML triplets for the concept

Table 3. RDF Triplet for 'nano scopes'

Subject	Predicate	Object
http://www.w3.org/RDF/Validator/run/localhost/pt/nano scopes	http://purl.org/pt/elements/1.1/SN	'nano scope is any microscope that has its resolution in nano metres and which uses a beam of atoms instead of light'
http://www.w3.org/RDF/Validator/run/localhost/pt/nano scopes	http://purl.org/pt/elements/1.1/Class	'nano optical devices'
http://www.w3.org/RDF/Validator/run/localhost/pt/nano scopes	http://purl.org/pt/elements/1.1/has-parameter	'numerical apertures'
http://www.w3.org/RDF/Validator/run/localhost/pt/nano scopes	http://purl.org/pt/elements/1.1/Sub-Class	'optical nano scopes'
http://www.w3.org/RDF/Validator/run/localhost/pt/nano scopes	http://purl.org/pt/elements/1.1/Sub-Class	'attosecond nano scopes'
http://www.w3.org/RDF/Validator/run/localhost/pt/nano scopes	http://purl.org/pt/elements/1.1/tool	'nano scopy'

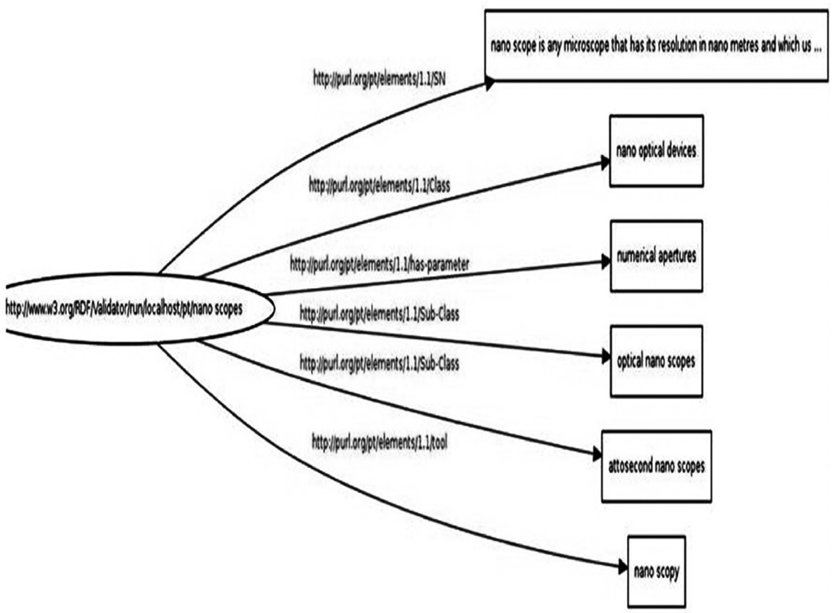

Figure 7. Graph for 'nano scopes.'

'nano scopes' in there columns i.e. subject, predicate and object, where subject and predicate must be resource URIs and object is a constant value.

(c) RDF Triplet Graph

15. CONCLUSIONS

Amount of Nanotechnology information that is appearing and added daily on Web make it difficult for scholars to retrieve all the relevant information. The ultimate solution to this problem is to manage and chart this widely available information with the help of semantically rich structures like ontologies that could enhance the understanding and reasoning capabilities of both human and computers.

REFERENCES

1. Aghaei, S.; Nematbakhsh, M.A. & Farsani, H.K. Evolution of the world wide web: From web1.0 to web 4.0. *Int. J. Web Semantic Tech.*, 2012, **3**(1), 1-10. http://airccse.org/journal/ijwest/papers/3112ijwest01.pdf (accessed on 12 June 2014).
2. The Huffington Post. World's first website, created by Tim Berners-Lee in 1991, is still up and running on 21st birthday, 2012. www.huffingtonpost.com/2012/08/06/worlds-first-website_n_1747476.html?ir=India (accessed on 6 February 2015).
3. Patel, K. Incremental journey for world wide web: Introduced with Web 1.0 to recent Web 5.0: A survey paper. *Int. J. Adv. Res. Comput. Sc. Softw. Eng.*, 2013, **3**(10), 410- 17. www.ijarcsse.com/docs/papers/Volume_**3**/10_October2013/V3I10-0149.pdf (accessed on 06 February 2015).
4. Meilender, T.; Lieber, J.; Palomares, F. & Jay, N. From web 1.0 to social semantic web: Lessons learnt from a migration to a medical semantic wiki. *In* the semantic web: Research and applications, edited by E. Simperl, P. Cimiano,

A. Polleres, O. Corcho, & V. Presutti. Springer, Berlin-Heidelberg, 2012, pp. 618-32. http://link.springer.com/chapter/10.1007/978-3-642-30284-8_48 (accessed on 11 February 2015).

5. Choudhury, N. World wide web and its journey from web 1.0 to web 4.0. *Int. J. Comput. Sc. Inf. Tech.*, 2014, 5(6), 8096-8100. www.ijcsit.com/docs/Volume%205/vol5issue06/ijcsit20140506265.pdf (accessed on 06 February 06, 2015).
6. Kuck, G. Tim Berners-Lee's semantic web. S. Afr. J. Inf. Mgmt., 2004, 6(1). https://www.google.co.in/url?sa=t&rct=j&q=&esrc=s&source=web&cd=7&cad=rja&uact=8&ved=0CFIQFjAG&url=http%3A%2F%2Fsajim.co.za%2Findex.php%2FSAJIM%2Farticle%2Fdownload%2F297%2F288&ei=n0LYVKujMNO3uASM6IDgDw&usg=AFQjCNEfKtXpBWKuRxxizKVaGiEM49oGfA&sig2=3ap-DcdoqotJQFW16737dg (accessed on 09 February 2015).
7. Davies, J.; Fensel, D. & Harmelen, F. van. Introduction. *In* Towards the semantic web: Ontology-driven knowledge management, edited by J. Davies, D. Fensel & F.van Harmelen. John Wiley, Chichester, England, 2003, pp. 1-10. http://khabib.staff.ugm.ac.id/downloads/lecture/S3/Toward%20The%20Semantic%20Web.pdf (accessed on 09 February 2015).
8. Chandrasekaran, B. & Josephson, R. What are ontologies and why do we need them?. *IEEE Intell. Sys.,* 1999, **14**(1), 20-26. http://www.csee.umbc.edu/courses/771/papers/chandrasekaranetal99.pdf (accessed on 01 August 2014).
9. Man, D. Ontologies in computer science. DIDACTICA MATHEMATICA, 2013, **31**(1), 43-46. http://www.math.ubbcluj.ro/~didactica/pdfs/2013/didmath2013-06.pdf (accessed on 01 August 2014).
10. Patkar, V. A passage to ontology tool for information organisation in the digital age. *DESIDOC J. Lib. Inf. Tech.,* 2011, **31**(2), 90-102. http://publications.drdo.gov.in/ojs/index.php/djlit/article/download/861/362 (accessed on 1 August 2014).
11. Guarino, N.; Oberle, D. & Staab, S. What is an ontology? *In* Handbook on ontologies, edited by S. Staab & R. Studer. Springer-Verlag, Berlin, 2009, pp. 1-17.
12. Studer, R.; Benjamins, V.R. & Fensel, D. Knowledge engineering: Principles and methods. *Data & Knowledge Engineering*, 1998, **25**(1-2), 161-197. DOI: 10.1016//S0169-023X(97)00056-6
13. Nguyen, Thi-Hoa-Hue & Le-Thanh, N. An ontology-enabled approach for modelling business processes. *In* Beyond databases, architectures, and structures, edited by Stanislaw Kozielski, *et al.,* Springer International, Switzerland, 2014, pp. 139-47.
14. Beumer, K. A matter of scale: The visual representation of nanotechnologies. *Spontaneous Generations: A J. for the Hist. & Phil. of Sci.,* 2012, **6**(1), 65-74. http://spontaneousgenerations.library.utoronto.ca/index.php/SpontaneousGenerations/article/view/16139/15602 (accessed on 1 August 2014).
15. Ratner, M. & Ratner, D. Nanotechnology: A gentle introduction to the next big idea. Pearson Education, New Jersey, 2003, pp. 5.
16. Poole, C.P. & Owens, F.J. Introduction to nanotechnology. Wiley, New Delhi, 2006, pp. 9.
17. Allhoff, F.; Lin, P. & Moore, D. What is nanotechnology and why does it matter? From science to ethics. Wiley-Blackwell, UK, 2010, pp. 8.
18. Kaekamnerdpong, B. & Bentley, P.J. Computer sciences for nanotechnology: Needs and opportunities. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.95.4960&rep=rep1&type=pdf (accessed on 30 June 2015).
19. Saxton, J. Nanotechnology: The future is coming sooner than you think. Joint Economic Committee, United States Congress, Washington, 2007, pp.1-20. http://www.thenewatlantis.com/docLib/20120213_The future is coming sooner than you think.pdf (accessed on 30 June 2015).
20. Filipponi, L. & Sutherland, D. Nanotechnologies: Principles, applications and hands-on activities-a compendium for educators. Publications office of the European Union, Luxembourg, 2012, pp. 65-66. https://ec.europa.eu/research/industrial_technologies/pdf/nano-hands-on-activities_en.pdf (accessed on 12 February 2015).
21. Lancaster, F.W. Thesaurus construction and use: A condensed course. UNESCO, Paris. 1985. http://unesdoc.unesco.org/images/0007/000703/070359eb.pdf (accessed on 09 February 2015).
22. Aitchison, J.; Gilchrist, A. & Bawden D. Thesaurus construction and use: A practical manual. Europa, London, 2000.
23. Smith, B. & Ceusters, W. Ontology as the core discipline of biomedical informatics: Legacies of the past and recommendations for the future direction of research. *In* Computing, philosophy, and cognitive science, edited by G.D. Crnkovic & S. Stuart. Cambridge Scholars Press, Cambridge, 2007, pp.104-122. ontology.buffalo.edu/medo/Recommendations_2005.pdf (accessed on 09 February 2015).
24. Biasiotti, M.A. & Tiscornia, D. Legal ontologies: The linguistic perspective. *In* Law, governance and technology series: Vol. 1. Approaches to legal ontologies: Theories, domains, methodologies, edited by G. Sartor; P. Casanovas; M. Biasiotti & M. Fernandez-Barrera. 2010, pp. 143-66. doi:

10.1007/978-94-007-0120-5_9 (accessed on 03 June 2015).

25. Esbjorn-Hargens, S. An ontology of climate change: Integral pluralism and the enactment of multiple objects. *J. of Int. The. & Prac.*, 2010, 5(1), 143-74. https://foundation.metaintegral.org/sites/default/files/Esbjorn-Hargens_Ontology.pdf (accessed on 05 May 2015).
26. Gokhale, P.; Deokattey, S. & Bhanumurthy, K. Ontology development methods. *DESIDOC J. Lib. & Inf. Tech.*, 2011, **31**(2), 77-83.
27. Thomas, D.G.; Pappu, R.V. & Baker, N.A. Nanoparticle ontology for cancer nanotechnology research. *J. of Biomedical Infs.*, 2011, **44**(59-74). doi: 10.1016/j.jbi.2010.03.001 (accessed on 10 February 2015).
28. Khoo, C.S.G.; Na, J.C.; Wang, V.W. & Chan, S. Developing an ontology for encoding disease treatment information in medical abstracts. *DESIDOC J. Lib. & Inf. Tech.,* 2011, **31**(2), 103-115.
29. Hastings, J.; Magka, D.; Batchelor, C.; Duan, L.; Stevens, R.; Ennis, M. & Steinbeck, C. Structure-based classification and ontology in chemistry. *J. of Cheminformatics*, 2012, **4**(8), 1-20. DOI:10.1186/1758-2946-4-8 (accessed on 07 December 2015).
30. Meenachi, N.M. & Baba, M.S. Development of semantic web-based knowledge management for nuclear reactor (KMNuR) portal. *DESIDOC J. Lib. & Inf. Tech.,* 2014, **34**(5), 426-34.
31. Schulte, J. Scientific development and industrial application of nanotechnology in China. *In* Nanotechnology: Global strategies, industry trends and applications, edited by Jurgen Schulte. John Wiley, England, 2005, pp.1.
32. Lancaster, F.W. Vocabulary control for information retrieval. Information Resources Press, Washington, DC, 1972.
33. Malik, S.K.; Prakash, N. & Rizvi, S.A.M. Developing an university ontology in education domain using Protege for semantic web. *Int. J. Eng. Sc. Tech.,* 2010, **2**(9), 4673-81. http://www.researchgate.net/publication/50346425_developing_an_university_ontology_in_education_domain_using_protg_for_semantic_web (accessed on 10 February 2015).
34. Denny, M. Ontology building: A survey of editing tools. XML.com, 2002. www.xml.com/pub/a/2002/11/06/ontologies.html?page (accessed on 07 December 2015).
35. Roussey, C.; Pinet, F.; Kang, M.A. & Corcho, O. An introduction to ontologies and ontology engineering. *In* Advanced information and knowledge processing. Ontologies in urban development projects, edited by Gilles Falquet, Claudine Metral, Jacques Teller & Christopher Tweed. Springer-Verlag, London, 2011, pp. 9-38.
36. Kim, Jung-Min, Choi, Byoung-Il, Shin, Hyo-Phil & Kim, Hyong-Joo. A methodology for constructing of philosophy ontology based on philosophical texts. *Com. Std. & Interfaces*, 2007, **29**(3), 302-15. http://www.sciencedirect.com/science/article/pii/S0920548906000523 (accessed on 10 February 2015).
37. Random House Webster's Concise College Dictionary. Random House, New York, 1999, pp. 329.
38. Zhang, J. Ontology and the semantic web. *In* Proceeding of the north American symposium on knowledge organisation, edited by Joseph T. 2007, pp. 9-20. https://journals.lib.washington.edu/index.php/nasko/article/download/12830/11311 (accessed on 06 August 2014).
39. Robu, I.; Robu, V. & Thirion, B. An introduction to the semantic web for health sciences librarians. *J. Med. Lib. Assco.,* 2006, **94**(2), 198-205. www.ncbi.nlm.nih.gov/pmc/articles/PMC1435839 (accessed on 07 December 2015).
40. Glowacki, A.F. Development of taxonomy for indexing Web-based mining safety and health research. *In* Proceedings of the first international future mining conference and exhibition, edited by Saydam S. The Australasian Institute of Mining and Metallurgy, Australia, 2008, pp. 125-29. http://www.cdc.gov/niosh/mining/userfiles/works/pdfs/doatf.pdf (accessed on 8 August 2014).
41. Youn, S. & McLeod, D. Ontology development tools for ontology- based knowledge management. 2006. http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.387.915&rep=rep1&type=pdf (accessed on 08 August 2014)
42. Khondoker, M.R. & Mueller, P. Comparing ontology development tools based on an online survey. *In* Proceedings of the World Congress on Engineering. 2010, pp. 188-92. www.iaeng.org/publication/WCE2010/WCE2010_pp188-192.pdf (accessed on 10 February 2015)
43. Mizoguchi, R. Tutorial on ontology engineering: Ontology development, tools and languages. *New Generation Compu.*, 2004, **22**(1), 61-96.
44. Giri, K. Role of ontology in semantic web. *DESIDOC J. Lib. & Inf. Tech.,* 2011, **31**(2), 116-20.

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