

# Web Physics Ontology

## Online Interactive Symbolic Computation in Physics

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**Abstract**—Relationships among physical quantities (PQs) express fundamental laws of the Universe. Physics equations represent relationships among PQs and therefore encode the basic knowledge of physics. System of PQs is the natural framework of physics and can be used as a guideline for informational modelling of various scientific aspects of physics. Relationships among PQs can be used for creation of semantic web ontologies that model the knowledge of physics. Leading semantic web ontologies in physics today are based on system of units which directly relies on system of PQs. This paper describes interactive online web application based on symbolic computational ontology (SCO) that models knowledge of physics and which is based on system of PQs primarily, not units. Main SCO design principles can also be applied to other existing physics ontologies and for ontologies in other sciences using formulas. Interactive SCO based web application (SCO-BWA) illustrates dynamic generation of physics equations and numerical calculations.

**Keywords**— *Online, Interactive, Semantic web, Ontology, Physics, Equations, Computation*

### I. INTRODUCTION

Physics is fundamental exact science that is one of the main pillars of our technical civilization. As such it pervades other sciences, technology, arts, and way of life, pushes frontiers further away and advances the civilization. Physics is complex, consists of many fields and for fundamental advances requires scientific facilities like CERN LHC [1] for research in the so called “micro world”, various kinds of telescopes like Hubble [2] and radio telescopes [3], space crafts like Voyager [4], Rosetta & Philae [5] and other equipment for research of the surrounding Universe, the so called “macro world”, with consistent results obtained from all researches. For efficient representation and manipulation of physics knowledge by using of contemporary information science and technology, the adequate approach and formalism is required [6, 7]. Any scientific discipline knowledge can be represented in many ways. Knowledge of physics as being an exact science, can be partially represented in the form of equations and mathematical formulas suitable for coding in programs for numerical calculations. The major drawback of such an approach is that

algorithmically represented knowledge is meaningful only within the application that implements the algorithm and in general case not very convenient for use in other applications, although various libraries of scientific and engineering numerical programs exist like CERN library [8], NAG [9], GSL [10], and are of great practical importance. The complementary classical way of partial representing of knowledge from sciences is within data repositories like NIST [11] and HEPDATA [12] that contain scientific data in various fields of physics with search and retrieval capabilities, and with main purpose to serve as a repository for publishing and distribution of scientific results within scientific community. Scientific knowledge is present in a vast number of various scientific articles, some of them arbitrarily scattered on Internet, with no simple and guaranteed way of finding. Scientific knowledge although quite strictly organized and structured is not so easy to be represented in a standard way, as there can be various study approaches, knowledge sources are scattered, and a significant time and effort might be required for one to introduce with desired scientific concepts and contents. There is an analogy with knowledge that is scattered on the web. The Internet search engines considerably mitigate the problem, but lack the understanding of semantic meaning, and therefore look for the key words that might not always be in desired context. Semantic web [13] offers a new potential to growing problems of representing data and knowledge that is to be understandable and useful for machine processing. Besides enabling machine data and knowledge processing, semantic web supports linking of open data [14] and representing of arbitrary data and knowledge structure. Such characteristics of semantic web technologies, make them a promising choice for modeling and representing of scientific knowledge. Several ontologies exist that model and represent the knowledge of physics as the main subject like OM (Ontology of units of Measure) [15], QUDT (Quantities, Units, Dimensions, and Data Types) Ontology [16] or as part of a larger context like SWEET (Semantic Web for Earth and Environmental Terminology) [17], DOLCE (Descriptive Ontology for Linguistic and Cognitive Engineering) [18], SUMO (Suggested Upper Merged Ontology) [19]. Some of these ontologies, the OM, QUDT and SWEET are compared [20] according to ontology alignment principles [21]. OM, QUDT, SWEET and other mentioned ontologies were not an inspiration for SCO. The main inspiration for SCO was creation of universal ontology for Physics that can power

Work on this paper was partly funded by the SCOPES project IZ74Z0\_160454 / 1 “Enabling Web-based Remote Laboratory Community and Infrastructure” of Swiss National Science Foundation

interactive online application for individual use. Mentioned ontologies were analyzed in detail for reasons of comparison with SCO and eventual discovering of a useful concept. The general approach of providing fundamental physics knowledge represented in OWL (Ontology Web Language) [22] is the same, but there are conceptual differences. OM, QUDT and SWEET are based on systems of physical units, and provide knowledge of PQs relationships based on dimensions that express relationships of some physical quantity only to basic physical quantities, not encompassing the relationships to other non-basic physical quantities. Dimensional relationships hide other relationships having the same dimension. SCO provides knowledge of various relationships among PQs with the same dimensions and includes dimensional relationships as a consequence of general relationships. Number of basic PQs is limited, as there are only seven basic PQs in the SI (System International) [23, 24] system of units, while the number of derived PQs and equations among them is practically unlimited.

## II. EXISTING PHYSICS ONTOLOGIES

Physics ontologies [25 - 30] can offer a way for definition of standardized knowledge source for both human and machine use regarding physical quantities, symbols, dimensions, definitions, systems of units for scientific, engineering, educational purposes, and general public use. Ontologies like OM and QUDT are lower level, domain ontologies with physics in focus, while some other ontologies that include physics as one of many other domains, such as SWEET, SUMO and DOLCE are higher level or upper ontologies. Upper level ontologies favor top down ontology development paradigm by providing general framework [31, 33] which can be used and further developed by ontologies that are more domain oriented. In that way, the upper ontologies contribute to standardization and help starting new ontology development from provided general ontology. Middle level ontologies are more domain oriented, and in general serve as a connection between top level and domain ontologies.

Lower level or domain physical ontologies, OM and QUDT are based on systems of physical units. Alignment of these ontologies [21] was also based on physical units. Any measurement of PQs is based on selecting the appropriate units. The measurement result is a numerical value that has meaning only with specified measurement unit. Historically and geographically various measurement units were used for the same PQs which made the expressing of measurement results sometimes confusing and error prone. Such a situation naturally led to establishing of the International System of Units [23, 24, 34] (System International - SI) with definitions of standards – unit measures for basic PQs that ensure maximal possible measurement accuracy (minimal error) and precision (maximal reproducibility) with wide international official recognition and practical use. Although the SI exists for more than a century, units from other measurement systems like various CGS versions, US, Imperial, and others are still in use in some geographical areas, and extensively present in OM and QUDT ontologies. The SI itself is in the perpetual process of reconsideration and constant improvement following the scientific and technological development [35, 36].

## III. SYMBOLIC COMPUTATIONAL ONTOLOGY

Symbolic Computational Ontology (SCO) was developed from scratch, quite independently from previously mentioned OM, QUDT and SWEET ontologies. There are similarities as the modeled system is the same, the system of physical quantities. The main idea of designing and implementation of SCO is defining of relationships among physics quantities, that model physics formulas which express the physics laws of the Universe. Existing physics ontologies mainly have the focus on units, systems of quantities, dimensions of physical quantities with possible applications such as automatic check of correct units and dimensions in software and documents (LaTeX for instance), data analysis [26, 29]. With adequate ontology extensions that can be added in a uniform way and when needed, physics ontologies can be provided with knowledge required for extraction and inference of physical quantities relationships that is directly applicable for units also, modelling respective relationships among units of physical quantities.

As the mentioned existing physical ontologies are mainly based on units and dimensional aspects, a simple new generic physics ontology, the GPO, was developed, containing only necessary notions and resources for specifications of knowledge required for modeling relationships and physics formulas. In a similar, analogous way, any of the previously mentioned ontologies can be extended to provide a new knowledge for expression of various relationships and formulas.

### A. SCO structure

The main idea and methodology for modelling of Physics quantities in OWL which is used in Semantic web for knowledge representation, is that PQs are notions that can be treated as classes in OWL. Classes are the main and most important components of OWL. There is a general similarity between notion of classes in OWL and OOP (Object Oriented Programming) with OWL classes being much more versatile especially with defining relationships. PQs are not independent as they are naturally connected by the laws of physics which are expressed as equations and formulas. SCO represents relationships among physics quantities qualitatively and quantitatively using OWL. Qualitative relationships can be expressed as class – subclass relationship in OWL, for quantities that are of same kind. Example is Energy class that can take various forms such as potential, kinetic, or mechanical work which are represented as subclasses of Energy. Formulas in physics connect PQs of various types, where class – subclass relationship is not semantically adequate for modelling relationships defined in formulas. Properties are used for defining relationships between classes of different types. There are two kinds of properties, the object, and data properties. Data properties have a range of simple values, therefore connecting object from a domain class to a value. Object properties have a range of class instances, connecting two objects or class instances, one from domain class and other from range class. OWL allows an object to be both class and class instance at the same time. Object properties that define relationships between instances / classes corresponding to PQs, have data properties that further define the relationship between PQs.

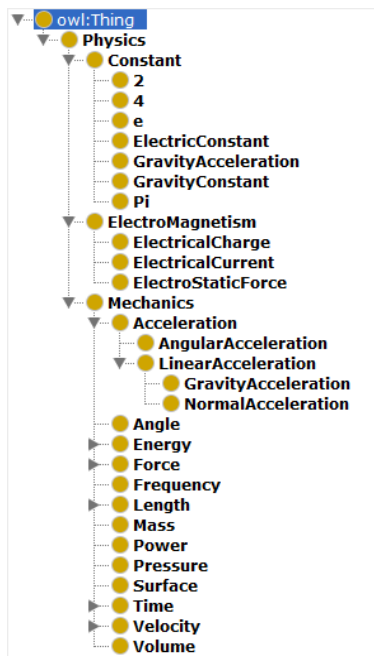


Fig. 1 Part of the SCO structure in Protégé ontology editor

Examples of object properties defining relationships are direct proportional, with exponent 1 as data property, square proportional with exponent 2, cube proportional with exponent 3, inverse proportional with exponent -1, etc. The same property can connect various PQs, thus having various domains and ranges which can be added for new relationships.

The most general top class is “Thing” as can be seen from Fig. 1. Class “Thing” contains any other class in the system. “Thing” has one Subclass “Physics” which contains further subclasses representing various fields in physics such as “Mechanics”, “ElectroMagnetism” and “Constant” which contains physical constants. The SCO is not intended to be an extensive source of physical quantities and relationships, it is more like generic extendable ontology which promotes the new concept, and is available for adding new PQs and relationships. Classes representing physics fields, contain subclasses representing generic physical quantities (GPQ) from the field. Examples of GPQ classified as “Mechanics” are “Acceleration”, “Energy”, “Force”, “Velocity” and similar. GPQ may contain abstract classes which have the more specific physical quantities. For instance, the “Acceleration” class contains “AngularAcceleration” and “LinearAcceleration”, subclasses, while “LinearAcceleration” further contains “GravityAcceleration” which is constant and “NormalAcceleration” as can be seen in Fig. 1.

### B. Ontology using

Semantic web ontologies can be accessed in a standard way by SPARQL (Semantic Protocol And Rdf Query Language) [37] query language which offers sophisticated ways of obtaining required relationships and data from ontology. Ontologies are organized as RDF (Resource Description Framework) [38] graphs consisting of simple SPO (Subject Predicate Object) elements called triples. RDF graphs can be

Fig. 2 View of Turtle encoded SCO text file in web browser

represented using various syntaxes, like RDF/XML which is standard, while Turtle syntax is more simple, human readable and preferred way of representing RDF graphs. Besides SPARQL query language, there are other ways of working with ontologies, which are less standard and depend on implemented software tools for semantic web technologies.

## IV. SCO BASED WEB APPLICATION (SCO-BWA)

Developed SCO requires adequate user interface for remote access which will enable user interaction and exploring of physics ontology. SCO is encoded with Turtle syntax and occupies 18kB in plain text file which can be viewed in any text editor. Besides, such text file with ontology is available for remote access or download by an interested in individual. Fig. 2 shows view of Turtle encoded SCO text file<sup>2</sup> in web browser. That is in accordance with LOD (Linking of Open Data) [14] policy. SCO is free in any aspect, and as it is standard RDF, anybody can use it and create his own interface based on standard SPARQL query language or some other means of access. SCO-BWA (Based Web Application) multi language application<sup>3</sup> was developed on top of SCO for demonstration of SCO features and dynamic inferencing on demand.

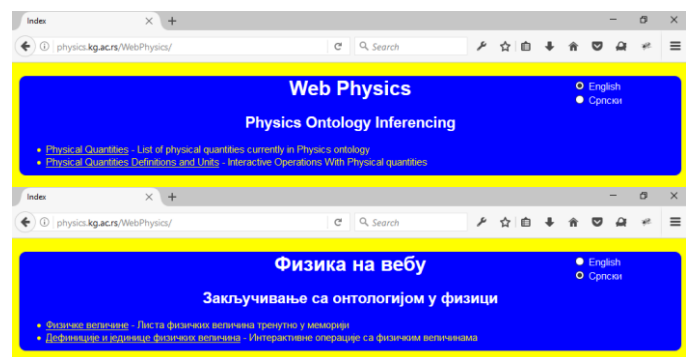
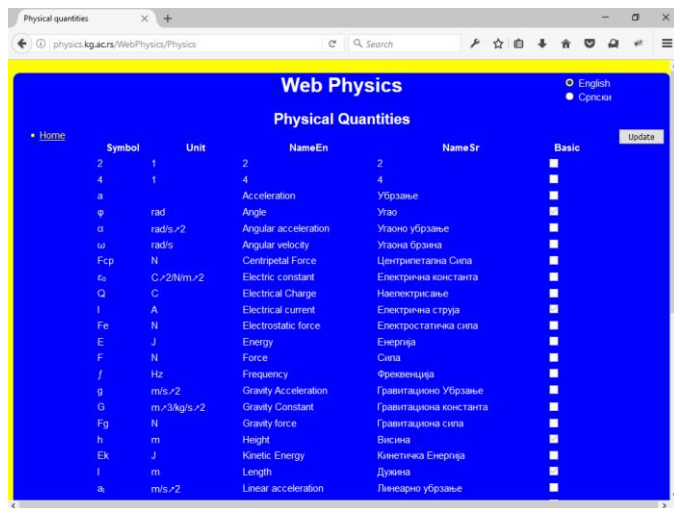


Fig. 3 SCO – BWA home page in two languages

<sup>2</sup> SCO ttl file web address:

<http://physics.kg.ac.rs/webphysics/mechanics.ttl>

<sup>3</sup> SCO-BWA web address: <http://physics.kg.ac.rs/WebPhysics/>



Symbol	Unit	NameEn	NameSr	Basic
2	1	2	2	
4	1	4	4	
a		Acceleration	Убрзање	
φ	rad	Angle	Угао	
ω	rad/s <sup>2</sup>	Angular acceleration	Угаоно убрзање	
u	rad/s	Angular velocity	Угаоно брзање	
F <sub>cp</sub>	N	Centripetal Force	Центрипетална Сила	
ε <sub>0</sub>	C <sup>2</sup> /Nm <sup>2</sup>	Electric constant	Електрична константа	
Q	C	Electrical Charge	Наелектрисање	
I	A	Electrical current	Електрична струја	
F <sub>e</sub>	N	Electrostatic force	Електростатичка сила	
E	J	Energy	Енергија	
F	N	Force	Сила	
f	Hz	Frequency	Фреквенција	
g	m/s <sup>2</sup>	Gravity Acceleration	Гравитационо Убрзање	
G	m <sup>3</sup> /kg/s <sup>2</sup>	Gravity Constant	Гравитациона константа	
F <sub>g</sub>	N	Gravity force	Гравитациона сила	
h	m	Height	Висина	
E <sub>k</sub>	J	Kinetic Energy	Кинетичка Енергија	
l	m	Length	Дужина	
a	m/s <sup>2</sup>	Linear acceleration	Линеарно убрзање	

Fig. 4 Listing of all currently available PQs in SCO

Fig 3 shows SCO-BWA home page in two languages. Adding a new language for the application is modular and is a matter of adding translated text in plain text files (JSON for web page and ttl for ontology).

SCO-BWA was implemented as ASP.NET MVC [39] application. It uses dotNetRDF [40], an open source C#.Net library for RDF, as the ontology API. The ontology was developed and tested with ontology development tools TBC composer free edition [41] and with Protégé [42]. SCO-BWA extracts all PQs from the ontology and creates database table for quick insight of current ontology content. Web page with listing of all PQs currently present in ontology is shown in Fig. 4. PQ symbol is displayed for the each PQ, while the application omitted units for some abstract PQs which have subclass PQs with different units. That is the case with “Acceleration” which can be linear having unit m/s<sup>2</sup> and angular with unit rad/s<sup>2</sup>, and also “Velocity” which can be linear with unit m/s and angular with unit rad/s.

The main application page “Physical Quantities Definitions and Units” is shown in Fig. 5 as it appears when opened for the first time. It is created dynamically and can change significantly depending on user actions.

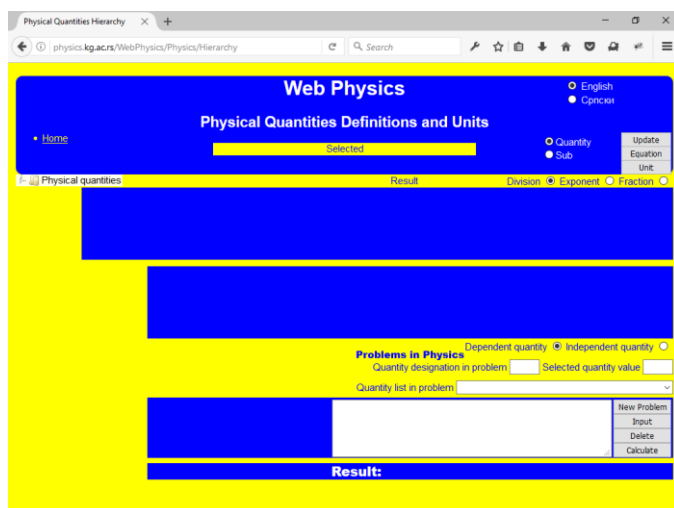


Fig. 5 SCO-WBA main application web page

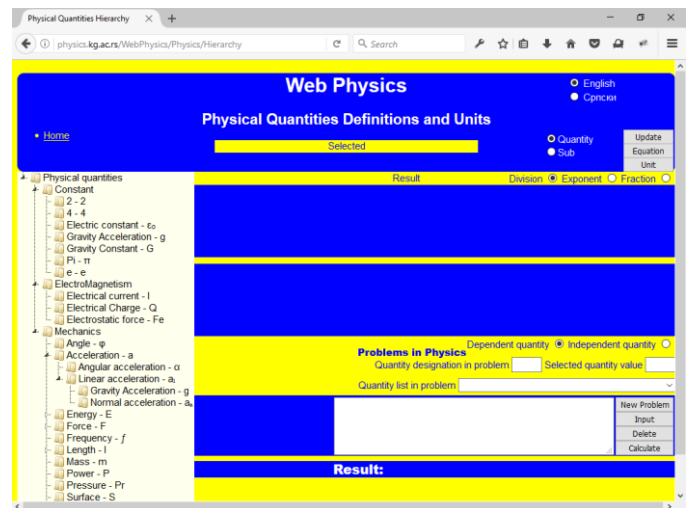


Fig. 6 SCO-WBA main application web page with PQs

On the left in Fig. 5 is the root for physical quantities which can be gradually opened by a user selecting areas and PQs of interest. Fig. 6 shows opened tree with physics areas and PQs. Left part of Fig. 6 is similar to PQs showed as subclasses of SCO in Fig. 1. Although it looks like hierarchical tree, it is important to note that the SCO structure of PQs is not a tree. Closer observation shows that some PQs are present at more than one place in the “tree”. That is the case for instance with constant Gravity acceleration g, which also appears as the subclass of Linear acceleration a<sub>l</sub>, as it is the linear acceleration and has dimension of linear acceleration.

For selected PQ on the “tree” on the left a defining formula and unit can be obtained from SCO. Fig. 7 shows a case when the constant Pi is selected. Brackets [ ] around PQ symbol designate the unit. Defining formula for a PQ can appear in three different mathematically equivalent forms. Default selected form is called “Division” which has all PQ exponents positive with forward slash for division, as can be seen in Fig. 8 for selected Electrostatic force F<sub>e</sub>. The unit for F<sub>e</sub> is “Newton” [N] as it has force dimension. The “Exponent” view of the same formula is presented in Fig. 9. The third equivalent view “Fraction” is shown in the upper part of Fig. 10.

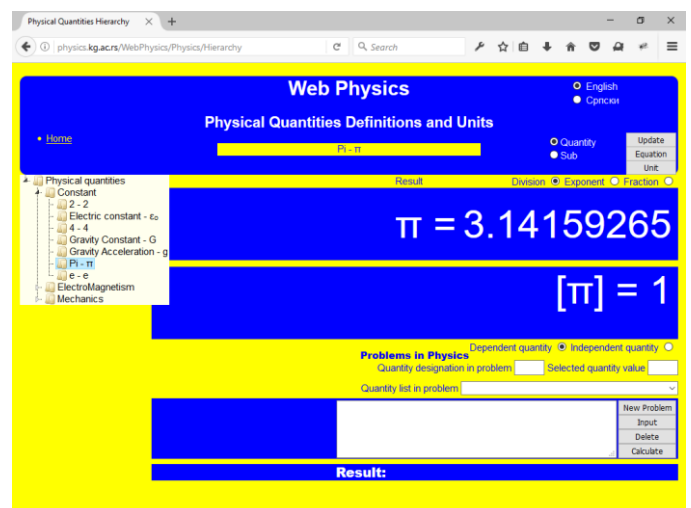


Fig. 7 Web page showing selected const Pi.



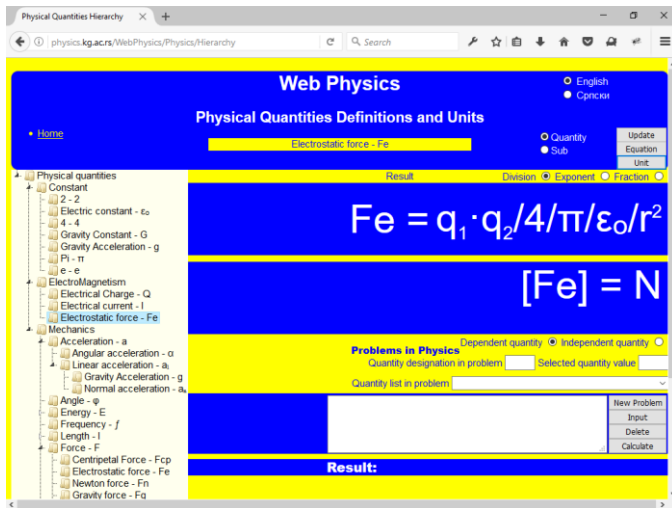


Fig. 8 Expression and unit for selected Electrostatic force Fe

As the force is not the basic PQ, the N unit can be transformed and expressed using only units for basic PQs, in this case mass unit [kg], length unit [m] and time unit [s]. Lower part of Fig. 10 shows decomposed Newton unit [N] as a product of basic PQs units. Mathematical form of expression for units can be only “Division” and “Exponent”. Besides gradual transformation by substitution of expression for unit, gradual transformation is also possible for selected PQ definition formula. For selected PQ “Pressure” the definition equation and unit “Pa” are presented in Fig. 11a. “Sub” option yields decomposed “Pa” unit to “Nm<sup>-2</sup>” as shown in Fig. 11b. Replacing F with “Weight” force, yields decomposition of “F” to “gm” as shown in Fig. 11b. Additional decomposition of unit and replacement of “S” gives the final decomposition in Fig. 11c.  $l_1$  and  $l_2$  are width and length of decomposed surface S, as the S is defined as  $l_1 l_2$ . Further decomposition of equation and unit are not possible, as they consist of basic PQs and a constant gravity acceleration  $g$  (9.81m/s<sup>2</sup>).

For PQs defined as derivatives, such as velocity and acceleration, the corresponding relationships were defined in ontology. Velocity is defined as a derivative of length over time, and acceleration as a derivative of velocity over time. Fig. 12 a) illustrates the formula for linear acceleration  $a_l$  as a derivative of linear velocity  $v_l$  over time. If the  $v_l$  which is defined in ontology as a derivative of length over time, is replaced in formula for  $a_l$ , SCO-WBA infers that  $a_l$  should be a second derivative of length over time as shown in Fig. 12 b).

Besides symbolic operations with PQs and units, SCO-WBA can also perform numerical calculations based on the same relationships among PQs in SCO that were used for obtaining formulas and units. Fig. 13 illustrates simple numerical calculation of the gravity force between two spherical bodies with masses, distance, and result in SI units.

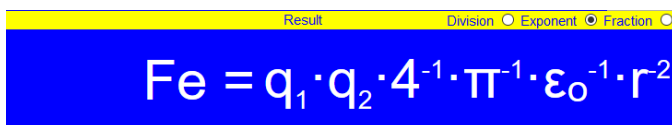


Fig. 9 “Exponent” view for selected Electrostatic force Fe

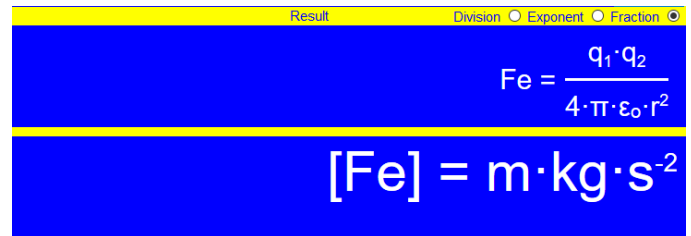


Fig. 10 “Fraction” view for Fe and decomposed Newton unit

Required PQs for formula to be calculated are selected in the “tree” on the left, and added as independent quantities designated with “true”, the  $m_1$ ,  $m_2$  and  $r$ , in this case, for which the numerical values are to be supplied. “false” designates dependent PQ for which the result is to be calculated, in this case the gravitational force  $F_g$ .

SCO can be incrementally extended as required with new PQs and relationships by adding new classes and properties in ontology ttl text file from Fig. 2, while the web application remains the same. Such a modular approach can be applied to some other area besides physics. Knowledge of arbitrary discipline with arbitrary complexity can be represented as ontology. Adequate web user interface for other discipline can be developed to naturally represent the knowledge structure.

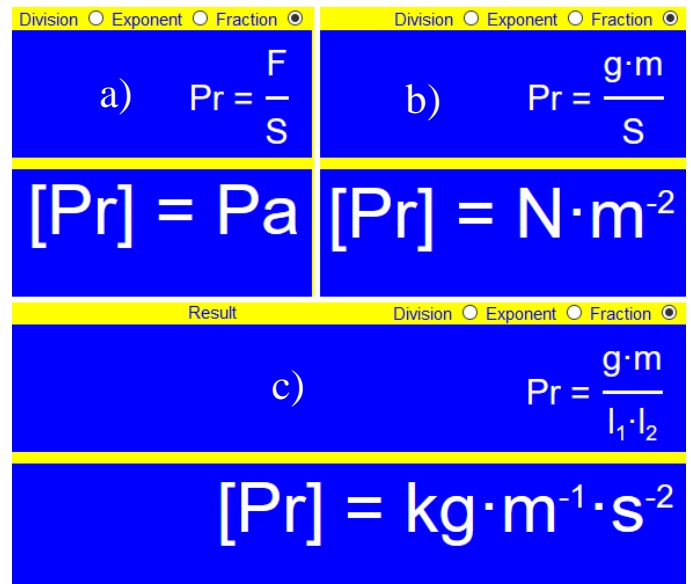


Fig. 11 a) Pressure and unit b) decomposition of unit and force to weight c) Final decomposition

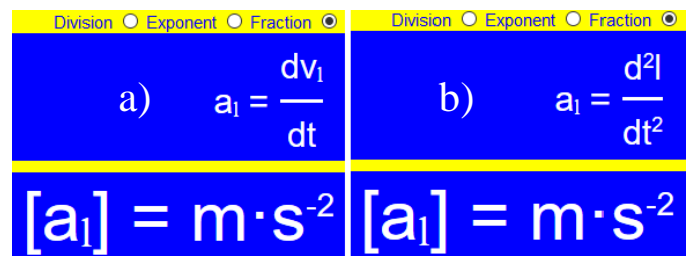


Fig. 12 a) Acceleration defined as first derivative of velocity and b) second derivative of length, obtained by replacement of velocity in acceleration formula

Result:  $F_g = G \cdot m_1 \cdot m_2 / r^2$   
 $[F_g] = N$

Problems in Physics  
 Quantity designation in problem:  Selected quantity value: 100  
 Quantity list in problem: Fg Fg false 0

Fg	Fg false 0
m1	m true 2
m2	m true 3
r	m true 100

New Problem  
 Input  
 Delete  
 Calculate

Result: 4.0044E-14

Fig. 13 Simple ontology based calculation

For physics, it is convenient to use formulas, while for some other area, a different approach may be more convenient, with text, tables, figures, graphical symbols, charts, multimedia, animations or any method of expression supported by the contemporary web.

### CONCLUSION

Motivation for development of SCO-BWA application is convenient presenting of knowledge structure with many features that contemporary web and semantic web technologies can offer, with implications that can be anticipated or yet to emerge. Besides physics thematic, design principles of SCO-BWA can be applied to other disciplines for convenient interactive on line presenting of knowledge and relationships among notions that constitute some area of interest. Obvious usage of such an application is educational with important new dimension of online interaction with user. It can be used outside of regular classes at appropriate educational level. There is an analogy with on line educational experiment or web laboratory. User can observe, demand transformations from the system, and see what the system will do. SCO-BWA can contain PQs and formulas required by remote lab web experiment, supporting it that way.

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