Architecture and Performance Methods of A Knowledge Support System of Ubiquitous Time Computation

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Abstract— An architecture and main performance methods of a knowledge support system of ubiquitous time computation based on relativity are proposed. As main results, modern time theories are described as certain relations of term-nodes in a tree, and some space-time computation models in a large scale and time computation models in different time measurement systems (institutions) are programmed as interfaces for time computation in complex conditions such as time-anisotropic movement systems or gravity-anisotropic environments.

Index Terms—Space-Time, Relativity, Real Time Communication, Time Ontology, Time Measurement

I. INTRODUCTION

Time computation is so ubiquitous nowadays, not only in analyzing texts with time terms, but also in real time computation even in circumstance across time zones or in quantum application such as satellite positioning systems, time-anisotropic movement systems, gravityanisotropic environments, or space scale in the cosmos. As the relativity theory and quantum mechanics, which we call modern time theories, have made great advances, time computation is desirable to be made on the new time knowledge. It is well known that an ontology made up of specific terms in relations can succinctly represent knowledge homogeneously structured in syntactic pattern and stratified in entailments or in contents with stembranch relations, and easily be applied to navigate knowledge by relational calculus, so a time knowledge support system based on time ontology with some computational models is proposed here to suffice requirement of time computation based on modern time theories.

II. EXTENSION OF TIME EXPRESSION

Time mostly is expressed in a form of natural number and suitable for a unified time measure system in the Earth. For example, Dan Ionescu & Cristian Lambiri^[1], E.-R.Orderog & H.Dierks^[2], and Merlin ^[3] respectively gave time definitions or expressions for the real-time system, which, however, relativity of time, time computation models which define how to calculate time

units, are omitted. In contrast to some software application fields' research, some time science organizations give serial time expressions based on modern time theories, among which the International Astronomical Union (IAU,1991) made time definition widely accepted in a reality frame ^[4]. Thus we need to integrate these definitions and expressions in a complete and standard form for ubiquitous time. To do this, we give a time expression as follows.

The physical quantity of time can be expressed as a 4-tuple:

$$T = < D, U, M, I > \tag{1}$$

where,

D: Data about time in quantity, it may be numbers or circle physical signals indicating time, or symbols expressing a time in quantity; that is, $D \in \{$ time reading, tick, time number expression $\}$.

U: Unit, the measure unit such as "second"," day".

M: Model, the mathematical formulae, using which you get a time quantity by mathematical computations.

I: Institution, it may be indicated by a code which stipulates what unit U is meaningful, from which start time point S an interval can be fixed, according to what model M about time can be computed. So we use I() to indicate determining a time physical quantity by some parameters.

For example, you say "2 seconds", you might refer to two units of the Universal Time i.e., of coordinated universal time (CUT, or UTC) set by IAU and the finally arbitrated by the International Telecommunication Union (ITU). Of course, you probably might not refer to that, but to an atomic time (AT), as it may. Both the quantities can be computed by the corresponding models issued by the related organizations. Here, the institution determines the meanings of the time as a physical quantity and gives the computation methods, so we can give an expression similar with a programming expression as T=I(D,U,M), here, T serves as a return value ,and I, a function for the other parameters.

Clearly, to set up a knowledge support system, we need to consider this time expression, its elements in the tuple will constitute the main profiles.

III. ARCHITECTURE OF THE KNOWLEDGE SUPPORT SYSTEM

We designed such an architecture for the knowledge support system developed by the author for the time computation in the complex systems.



Figure 1. The architecture of the knowledge support system of ubiquitous time computation.

The system mainly made up of the 4 components that ① Time Knowledge Navigation, ② Time Measurement and Computation Models, ③ Time Expression Semantics Computation Models, ④ Time Institution Knowledge Texts.

Component ① accepts users' requests for knowledge relating to the time measuring data, for example, a user requests for a model for computing the derivation between its time readings and a time unit in another space or in a time measurement system. The kernel of Component (1) is a tree describing time knowledge profiles, say its branches are classifications of the time knowledge in certain relations. It is a catalogue of classification and relations of time knowledge, and also mappings between the classification and the knowledge in Component 2 and Component 3. It contains institutions I in (1), which determines Component 2 and Component 3 in logic, however, Component (2) and Component (3) are listed for directing call not through the nodes of institutions.

Component ② is the mathematical models for time measurement and computation, written in software programs and can be called for other time computation programs.

Component 3 and 4 are discussed in number V and VI.

IV. TIME ONTOLOGY.

4. 0 General Description s

The tree in Component ① is a time ontology based on modern time theories for logically showing and saving all the knowledge term nodes in certain relations. These relations are potential information for deeper application such as inference based on relational calculus. On time ontology, most studies focus on time expressions and computations of relations between these expressions. For example, Moen's time ontology is about time concepts in linguistics^{[5][6]}.; Frank etc. came up with a plan and principles building space-time in 4 dimensions and 5 tiers^[7]. The typical extant time ontology see WordNet in the part of time, DAML time sub-ontology^[8], Time Ontology in OWL built by W3C^[9], and NASASWEET (Semantic Web for Earth an Environmental Terminology)^[10]. In addition, ISO 19111 ^[11] and ISO 19112^[12] set out the conceptual schema for spatial references based on geographic identifiers. This work shows various profiles of data structure of time description, yet has the limitations that

(1) Time it describes is in the periphery of the Earth, but not in cosmos large scales;

(2) The time properties are unraveled only on nonsymmetry (non-back as an arrow), a little on relativity, singularity and quantum property.

This might lead to difficulties in computations based on modern time theories.

In contrast with this work, the time knowledge tree in Component ① is a time ontology based on modern time theories (hereafter "TOboMTT", the main branches see attachment).

The nodes between any two levels in top-bottom constitute relations which are propositions (note that when we say "A and B in a certain relation", it just says a proposition) stating the main frame of modern time theories. So, in essence, we have :

$$TOboMTT=\{N,R\}=\{Propositions\}$$
 (2)

here, *N*,*R* refer to nodes and relations respectively.

The root (0- level) and the nodes in the next (1-level) are as following

• Time Space-Time Type Time Type Time Property Time Measure Time Expression

The root "Time" constitutes "**has**" relations with the nodes in the 1-level. That is, "Time **has** the Space-Time Types", "Time **has** the Time Types", "Time **has** the Time Properties", "Time **has** the Time Measures", "Time **has** the Time Expressions". These relations are basic profiles of the up-to-date study on time.

The relations of the nodes between the 1 and 2 levels continue such propositions of those relations between 0 and 1 levels, for example, we can say "Time **has** the Space-Time Types like Euclid Space-Time", here, "Euclid Space-Time" just is a node in the 2nd level. Thus,

the relations between the 1 and 2 levels are "**includes**", like "Space-Time Type **includes** Euclid Space-Time".

In the following contexts, we intuitively explain the main nodes which express some important assertions of modern time theories.

4. 1 SPACE-Time TYPE

According to Einstein's field equation, space and time are integrated. So we must take space as a parameter of time considering the space-time type. Einstein's field equation see $(3)^{[13]}$

$$(R_{\alpha\beta} - \frac{1}{2}Rg_{\alpha\beta}) + \Lambda g_{\alpha\beta} = 8\pi T_{\alpha\beta} \qquad (3)$$

Here, α and β are space-time dimensions, i.e., α , β =0,1,2,3 and 0 denotes time for the left expression; $R_{\alpha\beta}$ is Ricci tensor, it is a 4×4 matrix of the 16 components of second order space-time curvature, *R* is scalar curvature, $g_{\alpha\beta}$ is a 4×4 matrix of metric tensor, Λ is cosmological constant, $T_{\alpha\beta}$ is energy-momentum tensor, a 4×4 matrix too.

From (3), we get (4), i.e., the differentiation of square of space-time intervals:

$$ds^2 = g_{\alpha\beta} dx^{\alpha} dy^{\beta} \tag{4}$$

here, *x*,*y* are curvilineal coordinates, *s* is space-time interval. (4) adopts Einstein summation convention, normally like in physics, that a repeated index (α or β) implies summation over all values of that indexed. (3) and (4) are well confirmed by some experiments in the scale 10⁻¹³ cm (the radius of a fundamental particle) to 10²⁸ cm (the radius of the universe).

A space-time type normally defined by a solution of the equations (3) or (4).See some basic nodes:

Space-Time Type Euclidean space-time (absolute time) Riemannian space-time Inertial reference frame space-time Non-inertial reference frame space-time Friedmann- Walke space-time

.

If (3) or (4) are determined as the nonlinear partial differential equations about $g_{\alpha\beta}$, we call *s* is Riemannian space-time, which means space-time is of curvature and might not be flat (flatness is just a special instance, i.e., Minkowski space-time, in which gravity is neglected, it is regarded as inertial). In (3) or (4), if the time in different space places is described as absolutely not different , and independently from its different places and velocities, the space-time is Euclidean space-time or Newton space-time.

Friedmann-Lemaître-Robertson-Walker space-time, simply Robertson-Walker space-time^{[14][15]}, put forwarded by Robertson and Walker, and meet the

inference of Friedman^[16] and Lamaitre^[17], describes homogeneous and isotropic space-time in a non-inertial system, for which, cosmological curvature k and cosmological time t are introduced into (3) or (4). k takes 3 constants 0,1,-1 representing 3 possible space-time types: flatness, positive curvature and negative curvature.

If *R* in (3) is a constant, Robertson-Walker spacetime will become some special instance: when R=0, it will be Minkowski space-time; R>0, de_Sitter space-time; R<0, anti-de_Sitter space-time.

Bianchy I space-time is more general than Robertson-Walker that the space-time is homogeneous but might be anisotropic^[18].

Taub-NUT space-time adds magnetic and electric parameters into (3) or (4)^[19].

Godel space-time adds rotationally symmetric axis into (3) or $(4)^{[20]}$.

Rindler space-time expresses such space-time determined by inertial system and non-inertial system ^[21]

In some special cases, R is not easy to be determined. To solve (3) or (4), some parameters are given for special types of space-time. These special types include spherical and axial space-time, and time's elapse may be neglected for a space spot. For (4), Schwarzschild space-time ^[23] is spherically symmetric beyond a mass sphere. A sphere with great mass and a radius less than Schwarzschild radius is a black hole, which is thought to bear only 3 kinds of information of mass, charge and angular momentum. Schwarzschild black hole is considered as one with only mass, while Ressner-Nordstrom black hole, named as Ressner-Nordstrom space-time, with mass and charge ^{[24][25]}; Kerr black hole, named as Kerr space-time with mass and angular momentum^[26]; Kerr-Newman black hole, named as Kerr-Newman space-time [27]. simultaneously have information of mass, charge and angular momentum. Some spherically symmetric space-time like Vaidya space-time ^[28] and Tolman space-time^[29] consider time as the variable of the function of mass and curvature. As an axial metric space-time, Weyl-Levi-Civita space-time^[30] is typical.

4. 2 Time TYPE

When we solely study time, we can primarily divide time into the 3 types:

Proper time Coordinate time Cosmological time

Proper time is the elapsed between two events as measured by a clock that passes through both events. In other words, proper time value is from the real readings of the clock set by an observer in a definite space spot (if the measured body moves, then the clock spot and the moved body's end spot are considered as one area for the two spots are so near for a large scale space).

Coordinate time is integrated time under a coordinate system. It is not a real readings for a special spot (the difference between the different spots in the system is neglected), but a stipulated (calculated that it should be) time in the system. Proper time multiplied by $(1 - v^2/c^2)^{-2}$ is coordinate time (*v* is the velocity of the body, in which an implied observer is, *c* is light velocity). If we set a clock in a universe coordinate system indicating the integrated time, it would indicate the universal time (*t* in Robertson-Walker equation).

The proper time in the Earth can be expressed in various forms as the follows.

Ephemeris Time (ET) ^[31] was defined in principle by the orbital motion of the Earth around the Sun. Here, ephemeris is based on Julian calendar which had been reformed to be Gregorian calendar lasted to the nowadays.

True solar time (apparent solar time) is given by the daily apparent motion of the true, or observed, Sun. It is based on the apparent solar day, which is the interval between two successive returns of the Sun to the local meridian^[32].

Mean solar time is the mean values of measured time of the intervals between two Sun passing an identical meridian^[33].

Sidereal Time is based on a sidereal day; a sidereal day is a time scale that is based on the Earth's rate of rotation measured relative to the fixed stars, normally to the Sun ^[34]. Sidereal time may be Greenwich Sidereal Time (GST) which calculated by Greenwich Royal Observatory in mean data or Local Sidereal Time (LST) which is computed by adding or subtracting the numbers of timezone ^[35].

Universal Time (UT) is computed by truly measured time data based on rotation of the Earth, it is a Greenwich Mean Time (GMT) and computed from the start of a midnight of Prime Meridian at Greenwich, and it has different such versions as UT0,UT1,UT2 and Coordinated Universal Time (UTC) for the computations from varying data on non-exact time scales of the Earth rotation. UT0 is Universal Time determined at an observatory by observing the diurnal motion of stars or extragalactic radio sources. It is uncorrected for the displacement of Earth's geographic pole from its rotational pole. This displacement, called polar motion, causes the geographic position of any place on Earth to vary by several metres, and different observatories will find a different value for UT0 at the same moment.UT1 is the principal form of Universal Time. While conceptually it is mean solar time at 0° longitude, precise measurements of the Sun are difficult. UT1R is a smoothly tuned version of UT1, filtering out periodic variations due to tides. UT2 is a smoothed version of UT1, filtering out periodic seasonal variations. UTC is an atomic timescale that approximates UT1. It is the international standard on which civil time is based ^[36].

Atomic time applies the principle of stimulated atom radiation in a constant frequency. The Thirteenth General Conference of Weights and Measures define a second that "the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine levels of the ground state of the caesium 133 atom ^[37] ". That is a unit of International Atomic Time (ATI).The results of atomic time computed by different local laboratories are called local atomic time.

Dynamical Time (DT) ^[38] is inferred from the observed position of an astronomical object via a theory of its motion, ET is a DT based on revolution of the Earth in replace of UT based on rotation of the Earth meet Newton's time theory; to meet Einstein's time theory IAU builds two versions of ET respectively in the system of Terrestrial Dynamic Time (TDT) Barycentric Dynamical Time (TDB).

Local civil time is the corrected version of UTC by adding timezone numbers and adjusting daylight saving time^[35].

Coordinate time includes centroid coordinate time and Earth-centered coordinate time, they are set by IAU.

4. 3 Time property

The time properties are divided into 4 kinds as follows.

Time Property Asymmetry Relativity Singularity Quantum property

Asymmetry is the property human first discovered, it refers to what seems to be an arrow went out in one direction and not back.

Relativity means anisotropy against gravity or in a light-like velocity.

Singularity is the property of some places, where the present physical laws break down, or it can be thought of as the property of edge of space-time ^[39].

The quantum property of time refers to that of time in the particle-scale, where time appears the stranger phenomena far from the macro-scale as we see. For example, the former -latter sequence in macro-scale might be isochronous in the quantum –scale ^[40].

4. 4 Time measure

4.4.1 Coordinator

The space-time expressed in (3) or (4) can't always be indicated by Cartesian system, mostly due to some properties which are difficult to be indicated by Cartesian system, and also due to the singularity in the space-time which normally cannot be indicated by the real number system. So two kinds of coordinates are mainly introduced, they are general coordinates and special coordinates. The former are popular in common sense, and transforming them for a special purpose we get the latter----special coordinates, which mainly for describing some new metrics -solutions of (3), (4) with some singularity variables, or for some particular space-time areas.

The coordinates special for the metrics are introduced as follows.

Schwarzschild coordinate indicates spherical symmetry, it sometimes becomes degeneratation of some more general conditions. Schwarzschild coordinate uses sphere coordinate with the radius $r\neq 2GM/C^2$ and $r\neq 0$, here, *G* is universal gravitational constant, *M* is the mass. The coordinate is divided into two areas by $r > 2GM/C^2$ and $r < 2GM/C^2$ and leads to the two metrics in (3): $g_{00} = -(1-2GM/rC^2)$ and $g_{11} = (1-2GM/rC^2)^{-1}$.

In Schwarzschild coordinate, there is not the expression that $r=2GM/C^2$ (this is a singularity), but tortoise coordinate covers this singularity.

Eddington coordinate does not diverge in $r=2GM/C^2$ and r=0 by the linear transformation of the variables.

Kruskal coordinate covers $r=2GM/C^2$ and r=0 too, and more general in indicating space-time than tortoise and Eddington coordinate.

Lemaitre coordinate covers $r=2GM/C^2$ with a different method to Kruskal coordinate.

Rindler coordinate indicates the space-time determined by both inertial and non-inertial system.

Weyl coordinate indicates the function of metric and allows to indicate imaginary numbers.

Fermi normal coordinate indicates space-like geodesic which is the trajectory that its covariant differential is 0 for (4). "space-like" denotes the velocity in the area is far less than light speed. And its time axis indicates proper time for a non-inertial or locally inertial conditions.

Harmonic coordinate indicates harmonic conditions that coordinates in curved space satisfy a D' Alembert equation, it is a Cartesian-coordinate-like one in curved space.

Local inertial coordinate indicates Minkowski spacetime.

The special coordinates for the particular space-time areas are introduced as follows.

Centroid coordinate (center-of-mass coordinate system) is one taking the centre of a space area as the origin of coordinate. These coordinates include nonrotating geocentric reference system, rotating geocentric reference system, Barycentric Celestial Reference System (BCRS), International Celestial Reference System (ICRS).

Non-rotating geocentric reference system takes the Earth centre as the origin of coordinate . IAU provides the metric and methods for computing proper time.

Rotating geocentric reference system is supposed as rotated with the Earth together, its X^3 axis is the rotation axis of the Earth, and it is taken as International Terrestrial Reference System (ITRS) by IAU. For the rotation direction is not considered, the time in non-rotating geocentric reference system and rotating geocentric reference system is the same.

Barycentric Celestial Reference System (BCRS) is recommended by IAU, its origin is the mass centre of the solar system, its third axis is approximately the rotation axis of the Earth.

International Celestial Reference System is a centroid coordinate, it is made up of circle of right ascension and circle of declination of approximate 600 quasars, the coordinates are provided by International Earth Rotation and Reference Systems Service (IERS)

Most general coordinates are introduced by the mathematical textbooks, so they are omitted here.

4. 4.2 Measure UNIT

The frame of time measure unit is as follows:

Measure of time

Units of measure Time interval Dynamical time interval Duration fixed time interval Time interval with the duration fixed by an ephemeris Integral time scale

Dynamical time scale is referred to as measured values of time parameters by physical quantities in a physical system. Basically, a proper time interval is a dynamical time scale.

The main units of dynamical time scales in the ontology are concerned with ephemeris time units. A second in ephemeris time is defined as the fraction 1/31,556,925.9747 of the tropical year in Julian calendar for 1900 January 0 at 12 hours ephemeris time by International Committee for Weights and Measures (CIPM), from this unit, Julian century, year, week and day can be worked out.

An integral time scale is accumulated value copied from a contracted time start point, for example, atomic time scale. So it may be proper time or coordinate time.

V. TIME MEASURE AND COMPUTATION MODELS

Component ② is the set of the measure and computation models, which are from two resources: one is from the institutions put forward by some organizations such as IAU stipulating how to measure and computation, another resource is from the exact solutions of the (3) or (4). The models are programmed in Mathematica as the Application Programming Interface (API) so that a users' programs can call these API.

EXAMPLE 1^[41]: a model (group) to compute a coordinated universal time

$$UTC (t) - TAI(t) = ns$$
(5)

$$UTC (t) - UT_{1}(t) = <0.9s;$$
(6)

Here, UTC (t) is a time expressed in coordinated universal time' institution unit, TAI(t) means a time of Atomic Time International, n is natural number; s is the second, $UT_{1}(t)$ is a time expressed in UT_{1} . EXAMPLE 2 is calling from a user's application for the interface of a model, which is drawn from reference [42] and re-wrote by the author, to get an exact solution of Einstein's field equation given Roberson-Walker Metric:

- 1 /*An application from users in pseudo-code calling the model-interface. See the tree in the attachment */
- 2 enum Space-Time in non- inertial system
- 3 {
- 4 Bianchi I Space-Time,
- 5 ..
- 6 Robertson-Walker Space-Time
- 7 /*Here, all the 16 Space-Time in non- inertial system in the tree enumerated */
- 8 } Metric[16];
- 9 for(i=0;i<16;i++){
- 10 switch(Metric [i])
- 11 case Robertson-Walker Space-Time:
- 12 input and assign vector:
- 13 $v = \{t, r, e, phi\};$
- 14 $M = \{-1, R[t]^2/(1 K (r^2), (r^2) (R [t]^2), (r^2) (Sin[e]^2) (R [t]^2)\};$
- 15 Call Einstein [M, v]
- 16 }

"Einstein.m"

- 1 Einstein [g, v] := Block[
- 2 {invsg, dg1, dg2, dg3, Christf2, dChristf2, Ruv1,
- Ruv2, Ruv3, Ruv4, RicciTensor, R, EMTensor} 3 EMTensor = {}; (*Save return value.*)

(*Calculate the inverse metric of g.*)

- 4 g = DiagonalMatrix[M];
- 5 invsg = Inverse[g];

(*Calculate the affine connection.*)

- $6 \quad dg1 = Outer[D, g, v];$
- 7 $dg2 = Transpose[dg1, \{1, 3, 2\}];$
- 8 $dg3 = Transpose[dg1, \{2, 3, 1\}];$
- 9 Christf2 = (1/2) invsg.(dg1 + dg2 dg3);

(*Calculate the Ricci tensor.*)

- 10 dChristf2 = Outer[D, Christf2, v];
- 11 Ruv1 = Table[Sum[dChristf2[[k, i, k, j]], $\{k, 4\}$], $\{i, 4\}, \{j, 4\}$];
- 12 Ruv2 = Table[Sum[dChristf2[[k, i, j, k]], $\{k, 4\}$], $\{i, 4\}, \{j, 4\}$];
- 13 Ruv3 = Table[Sum[Christf2[[k, i, j]] Christf2[[h, k, h]], {k, 4}, {h, 4}], {i, 4}, {j, 4}];
- 14 Ruv4 = Table[Sum[Christf2[[k, i, h]] Christf2[[h, j, k]], $\{k, 4\}, \{h, 4\}$], $\{i, 4\}, \{j, 4\}$];
- 15 RicciTensor = Ruv1 Ruv2 Ruv3 + Ruv4;

(*Calculate the Curvature Scalar.*)
16 R = Sum[invsg[[i, i]] RicciTensor[[i, i]], {i, 4}];

(*Calculate the field equation left part.*)

- 17 EMTensor = RicciTensor (1/2) g R;
- 18 return [EMTensor]
- 19]
- 20 End[]
- 21 EndPackage[]

This program is divided into two parts: the first part is user's input for computation, which is space-time dimensions v in a spherical coordinator, in which, t is the cosmological time (see 4. 2 Time Type), M is Roberson-Walker Metric. Users can input similar metrics for calling the function Einstein[],which is saved in the second part, a document Einstein.m, starting from the sentence BeginPackage["Einstein`"]. mathlink.h in VC++ enables to run Mathematica programs in VC++ environment

The section Block[] is a function of local variables for calling.

Outer[] is to give the partial derivative $\partial f / \partial x$.

Transpose $[dg1, \{1, 3, 2\}]$ is to transposes dg1 so that the k^{th} level in dg1 is the n_k^{th} level in the result.

D [] is to get partial differential.

Table [] is to generate a list of the expression *Sum*[]. Sum[] is to get sum.

The line 19 is the computation result of left part of (3), yet the cosmological constant is omitted. The right part of (3) is considered as zero.

VI. MECHANISM AND RUNNING OF THE ARCHITECTURE

TOboMTT is designed to be a tree not only for satisfying the structure and classification of knowledge of time, but also for developing the knowledge in Web Ontology Language (OWL), which is based on Resource Description Framework (RDF) in a tree. Thus we can divide TOboMTT into some sub-trees and further expressed them in OWL or RDF. Figure 2 is a sample of Class—SubClass relation in RDF. As a result, navigation of knowledge of time, based on TOboMTT, become navigation of resources and serves, based on eXtensible Markup Language (XML) compatible with both OWL and RDF.

A query for a sub-class or property value will give the corresponding answer by rational calculus on a XML scheme. For the example in Figure 2, "Space-Time Type includes Euclid Space-Time" will be the answer for the query "What kind does the Space-Time Type include?" Therefore, query and answer is the first and direct results of navigation of knowledge of time by TOboMTT.

<?xml version="1.0"?>

<rdf:RDF

```
<rdf:Description rdf:ID="Space-Time Type">
```

<rdf:type

</rdf:Description>

<rdf:Description rdf:ID=" Euclid Space-Time">

<rdf:type

<rdfs:subClassOf rdf:resource="#Space-Time Type "/> </rdf:Description>

</rdf:RDF>

Figure 2. TOboMTT in RDF.

Meanwhile, it is well known that OWL can be expressed in First-Order Logic (FOL) for processing variables in expressions. Considering (1), U,M, and I, as term nodes, are listed in TOboMTT. For example: U:Time Type/proper time/universal time/universal time 0; M:see (5) and (6); I: UTC etc.. If we set variables as D in (1), TOboMTT will call the models to compute the variables input from users. It performs navigation by TOboMTT calling the API (models). An example is EXAMPLE 2, which can be navigated by TOboMTT node Space-Time Type/Riemann Space-Time/Space-Time in non- inertial system/Robertson-Walker Space-Time in component (2), when users choose this node and set D: $v = \{t, r, e, phi\}$ (see EXAMPLE 2, column 13). The output is viewed as the navigation result of (3), which performs a serves by a deriving of FOL expression (model in component 2, i.e., API).

In summary of this section, TOboMTT is a tree as a data structure for OWL and FOL mapping between nodes and the resources like component ① itself and component ③, as well as between nodes and services (running API in component 2).

VII. CONCLUSIONS

A general knowledge support system for time computation based on modern time theories is proposed. The key methods are to develop a time ontology as the time knowledge structured in relations, which serves as knowledge set for calling some models for computing time models.

APPENDIX A TOBOMTT (SIMPLE VERSION)

	Time
•	THIL

- ⊢ Space-Time Type
- | | Euclid Space-Time
 - ⊢ Riemann Space-Time
 - Space-Time in inertial system (Minkowski Space-Time)
 - | Space-Time in non- inertial system
- | | | | Bianchi I Space-Time
- Godel Space-Time
- │ │ │ ├ Kerr-Newman Space-Time
- | | | | ⊢ Kerr Space-Time

- Ressner-Nordstrom Space-Time | - Schwarzschild Space-Time - Kruskal Space-Time - Schwarzschild Space-Time - Rindler Space-Time - Robertson-Walker Space-Time - de Sitter Space-Time Anti- de Sitter Space-Time - Taub-NUT Space-Time | - Tamburino-Unit Space-Time ⊢ Tolman Space-Time
 - ⊢ Weyl-Levi-Civita Space-Time

⊢Time Type

-proper time

- universal time \vdash universal time 0
- ⊢ universal time 1
- ⊢ universal time 1R
- universal time 2
- universal time Coordinated
- ⊢ local civil time
- Greenwich time
- ⊢ atomic time
- ⊢ international atomic time
- ⊢international atomic time
- ephemeris time
- ⊢ true solar time
- ⊢ mean solar time
- ⊢ sidereal time
- \vdash local sidereal time
- Greenwich sidereal time
- Terrestrial Time
- barycentric dynamical time
- \vdash coordinate time
- geocentric coordinate time
- barycentric coordinate time
- \vdash cosmological time)
- ⊢ Time Property
- -asymmetry
- ⊢ relativity
- ⊢ strangeness
- \mid \mid quantum property

ΓI	11	me	Measure
	\vdash	C	oordinator
│ │ ├ special coordinator			
			⊢ coordinator for special objects (areas)
			│
			│
			⊢ International Celestial Reference System
			- barycentric coordinate
			⊢ coordinator for special metrics
			- Boyer-Linquist coordinator
			- Edington coordinator
			│ │ ├ Schwarzschild coordinator

Fermi coordinator	watch
Kruskal coordinator	
⊢ Schwarzschild coordinator	+ time scale (event mark)
	- event scale
	- birth of the universe (13.7 b. years ago)
	the first three minutes after the
	F the first three minutes after the
F tortoise coordinator	universe birth
F Schwarzschild coordinator	- solar system birth (5.0 b. years ago)
harmonic coordinator	Earth formed (4.6 b. years ago)
general coordinator	- Geologic time scale
⊢ oblique axis coordinator	Hadean
- curvilinear coordinator	- Archean
	- Proterozoic
	- Phanerozoic
+ ellipsoidal coordinator	
	FCenozoic
F Gaussian coordinator	Paleogene
Cartesian coordinator	
– centroid coordinator	
	Pleistocene
- unit of measure	-Holocene
space-time interval	historical era
- time interval	
\downarrow \downarrow kinetic time scale	
L L uncertain or fuzzy interval	L interval vector
doily store	
Fully stage	
- afternoon	
- dusk	- time expression (in linguistics)
night	(Omitted)
- time interval with a certain start or end	
- time interval with a certain duration	
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