KIT, AIFB

February, 2016, Karlsruhe, Germany

Toward a Syndicated Ontology of Time for the Semantic Web

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http://ermolayev.com/

SemData

FP7 Marie Curie IRSES

The Plan ...

- **Motivation**
  - Representing time is important, e.g. for temporal reasoning
  - Do, however, the existing ontologies cope well enough?
  - Which one(s), if any, do(es) best?
- **Requirement Elisitation & Analysis** – using OntoElect
  - What is OntoElect requirements elicitation phase?
  - Who/what are the representative community/ document corpus?
  - How were the requirements elicited?
  - What was the outcome?
- **Do the existing ontologies fit?**
  - Checking against the elicited requirements ...
  - What are the white spots?
- **Developing a S**yndicated **O**ntology of **T**ime – **ongoing work**
  - Mechanistic merge does not fly ...
  - A Syndicated Theory of Time
  - Key Fragments – also re. white spots
- **Final Remarks**

Motivation

… Plenty of It*

> *It is acknowledged that "**when God made time, he made plenty of it**". Remarkably, when it goes about the formal treatment of time, the status is very much following this Irish saying.*

* Ermolayev, V., et al. (2014) Ontologies of Time: Review and Trends. *Int. J. of Computer Science & Applications*, 11(3), 57–115

See Yourselves - Theories

How do We know these are all …?

Most Prominent:

- Lamport (1978) (8651)[1]
- Allen (1983) (7894)
- Pinto (1994) (220) based on Kowalski and Sergot (1986) (1708)
- Prior (1967) (1496)
- McDermott (1982) (1130)
- Sandewall (1995) (404)
- Halpern and Shoham (1991) (389)
- Bacchus and Kabanza (1998) (230) based on Alur *et al.* (1996) (399)
- Williams (1986) (198)
- Koubarakis (1992) (55)
- Iwasaki *et al.* (1995) (52)

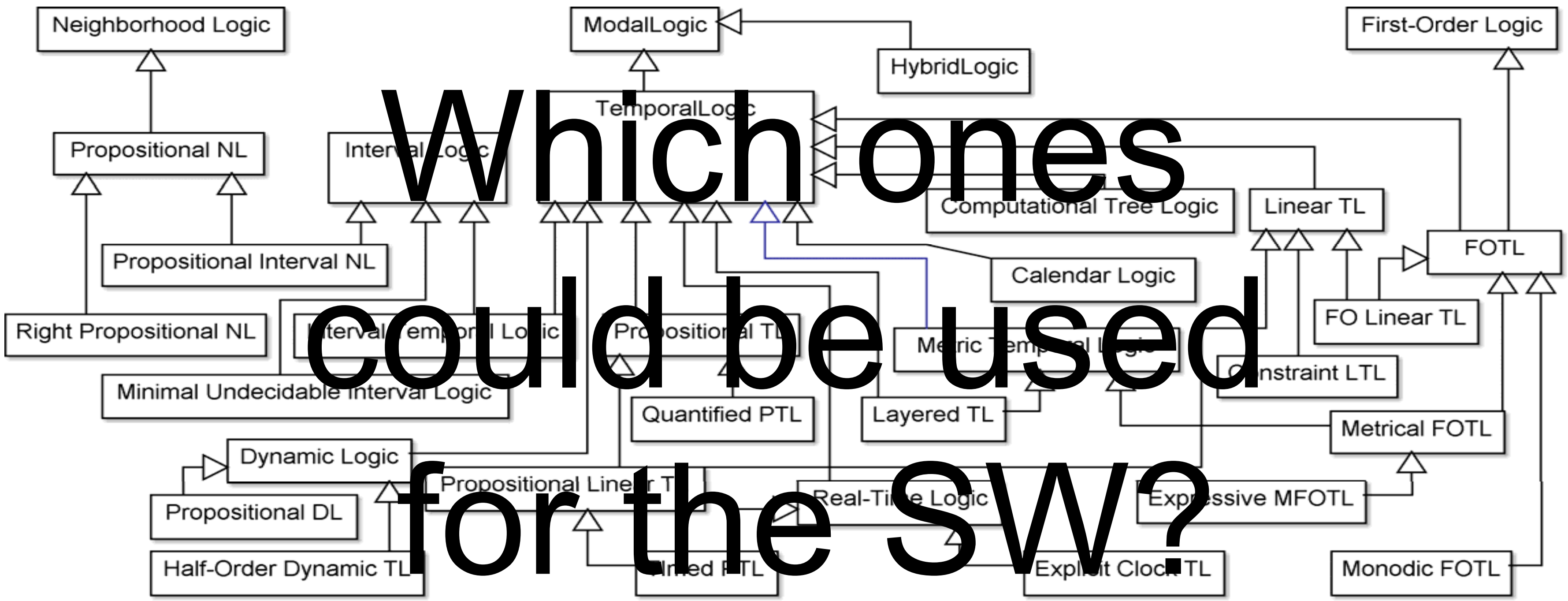
We did ourselves:

- Batsakis, Petrakis (2011) SOWL: Handling Spatio-Temporal Information
- Ermolayev *et al.* (2008) Fuzzy Time Intervals

[1] Ordered by the number of citations (given in round brackets) as of Aug. 24, 2014. Source: Google Scholar.

See Yourselves - Logics

How do We know these are all …?

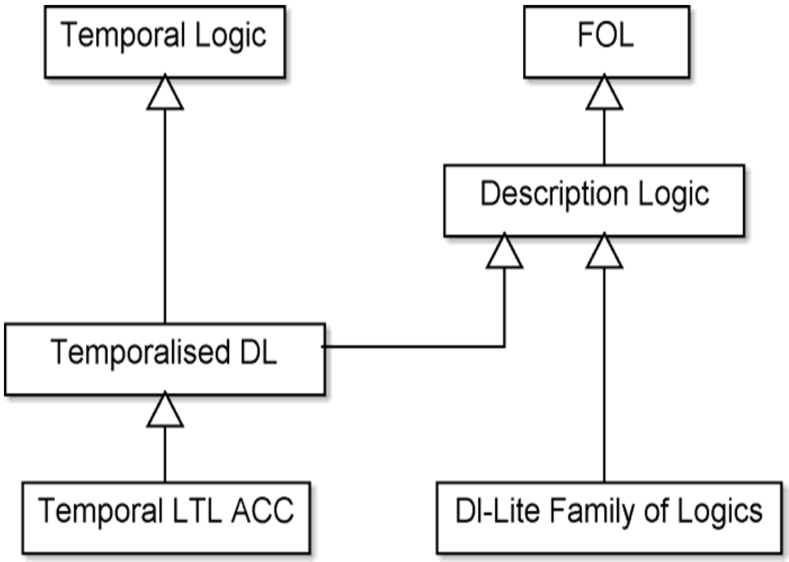


Which ones could be used for the SW?

- FOTL – First Order Temporal Logic
- LTL – Linear-time Temporal Logic
- MFOTL – Metrical First Order Temporal Logic
- NL – Neighborhood Logic
- PTL – Propositional Temporal Logic
- TL – Temporal Logic

Do we Have Instruments?

- Not too many
- Problems with expressive power ...



See Yourselves - Ontologies

- Foundational (Upper-Level) ontologies:
  - Cyc Time
  - SUMO Temporal
  - DOLCE
  - BFO
  - GFO-BT
  - PSI-ULO
- Focused Time ontologies:
  - TimeLine
  - OWL-Time
  - TimeZone
  - Temporal Aggregates
  - AKT Time
  - SOWL
  - SWRL Temporal
- No longer available online:
  - PROTON
  - TOWL ontology
  - MUSING Time
  - CNTRO
- Proprietary:
  - PSI-Time
- Total: 19

Why So Many? – Diverse Apps

Temporal Theory / Application Area	Lamport (1978)	Allen (1983)	Pinto (1994) - Kowalski & Sergot (1986)	Prior (1967)	McDermott (1982)	Sandewall (1995)	Halpern & Shoham (1991)	Bacchus & Kabanza (1998) - Alur et *al*. (1996)	Williams (1986)	Koubarakis (1992)	Iwasaki et *al*. (1995)	Ermolayev et *al*. (2008a)
- Planning					+		+	+				+
- Robot planning		+										
- Histories and historical data		+			+							
- Process modeling and process interaction		+			+		+					+
- Change		+	+		+	+	+					+
- Computer-aided engineering											+	+
- Action			+		+	+						+
- Real-time systems	+							+			+	
- Behavioral prediction									+		+	
- Explanation									+			
- Diagnosis									+			
- Simulation											+	+
- Hybrid systems											+	
- Natural language processing		+		+								

Why Important?

- **Has been** in the focus of scientific thought from ancient times –
  - e.g. **Plato**: the revolution of the celestial spheres

- **Continues to be** an important subject of research for philosophers, physicists, mathematicians, logicians, computer scientists, and even biologists

Geocentric celestial spheres; Peter Apian's Cosmographia (Antwerp, 1539)

- **One reason**: time is a <u>fundamental aspect</u> to understand and react to <u>change</u> in the World, including the broadest diversity of applications

Is it Enough?

... in particular for the Semantic Web community

- What are the **requirements**?
- How are those transformed to the set of required **features**?
- Are those features **covered** by the available:
  - Theoretical frameworks?
  - Implemented ontologies of time?
- Any **white spots**?
- Could the available ontologies be **re-used**/**merged** to cover the needs?

A Collab. Effort (SemData+)

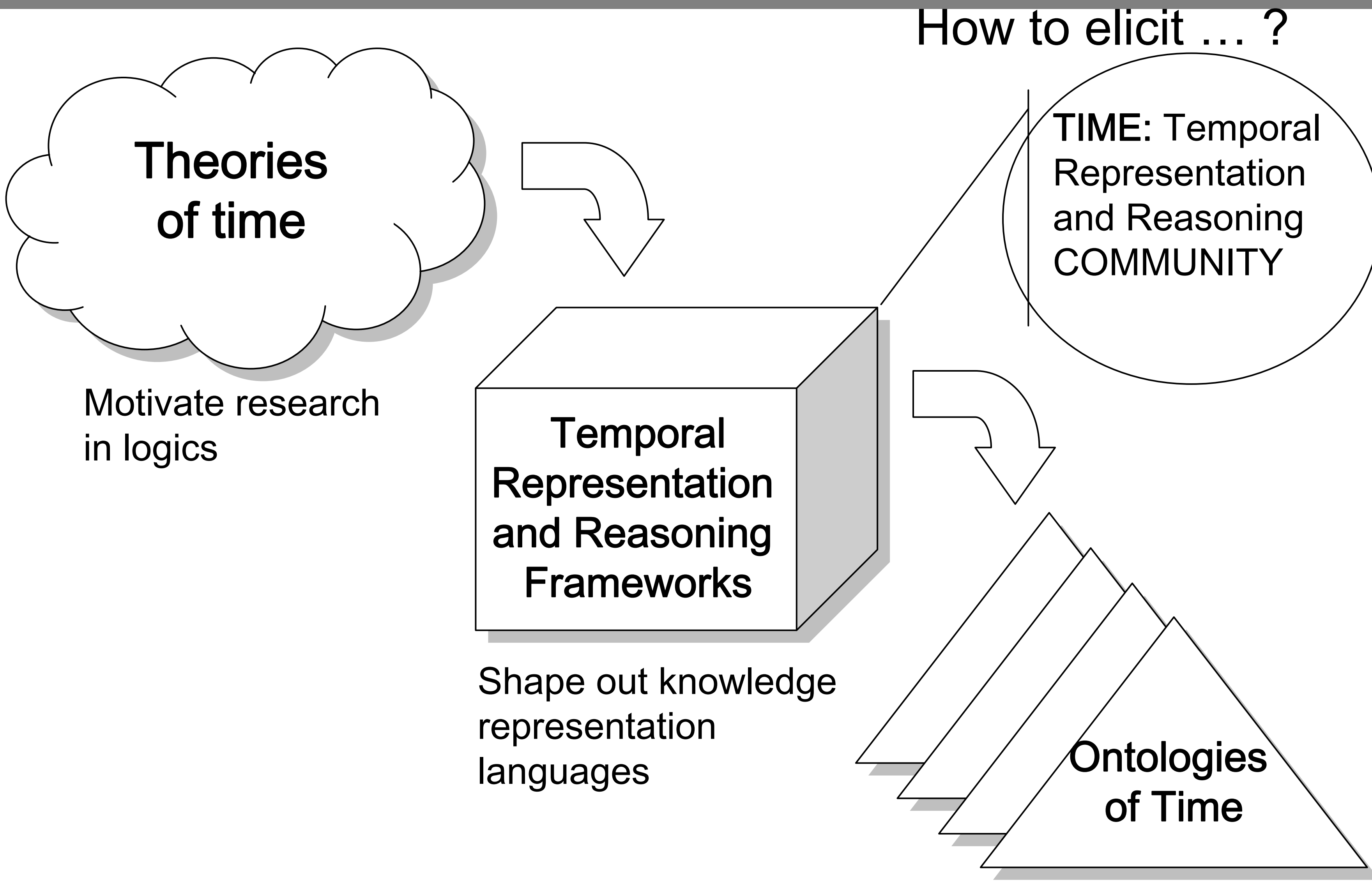
- **Vadim Ermolayev** (ZNU) – req. analysis, temporal theories, SOT theory, key concept models, SOT-wiki, PSI-ULO, PSI-Time
- **Sotiris Batsakis** (HUD) - temporal reasoning frameworks, ontologies, TimeInstant, TimeInterval models, SOWL
- **Frederic Mallet** (UN-SA) – SOT theory, Clock model, OMG Clock
- **Natalya Keberle** (ZNU) - temporal reasoning frameworks, OWL+SWRL compliance check, PSI-Time
- **Olga Tatarintseva** (ZNU) OntoElect, req. elicitation, PSI-ULO





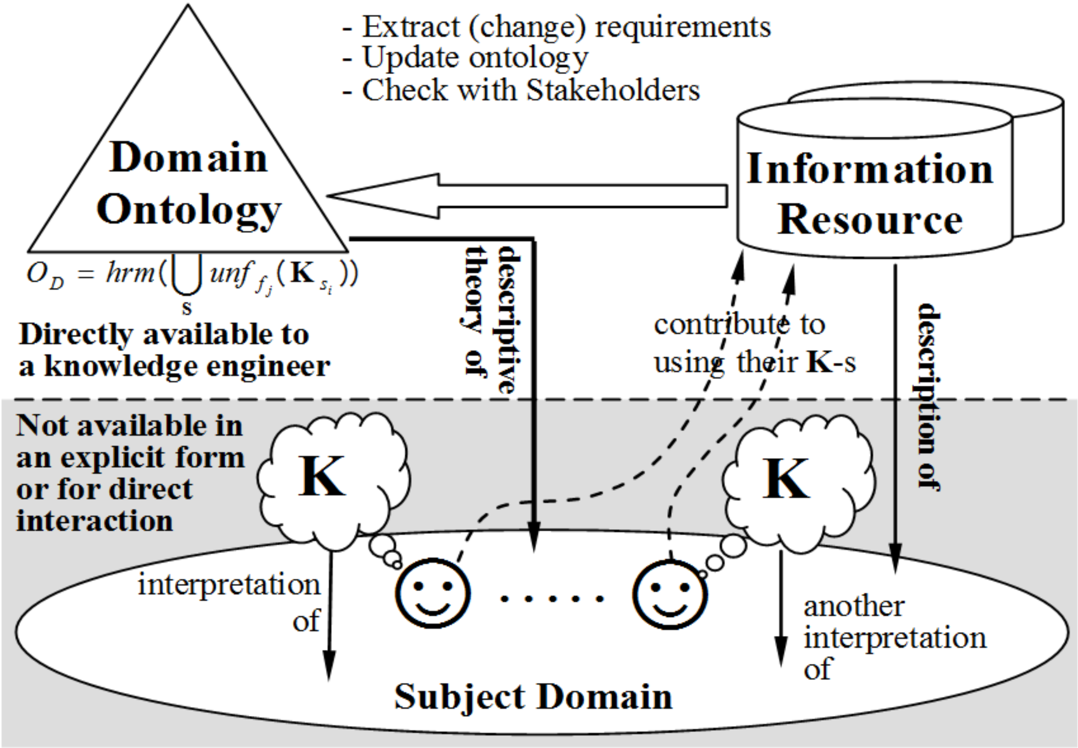
Eliciting Requirements Using OntoElect

Where to Go for Requirements?



Problems with Elicitation

- Acquiring a complete and accurate collection of Domain knowledge (requirements) is difficult:
  - **K**-s are subjective
  - **K**-s are tacit
  - **K**-s are partial
  - **K**-s are hard to get / not available
  - **K**-s specs are rarely explicit and formal
    - Contradictory interpretations
  - *unf* – challenging – expressive power



- A way to go: extract from a (**good quality**) document collection – authored by the **stakeholders**

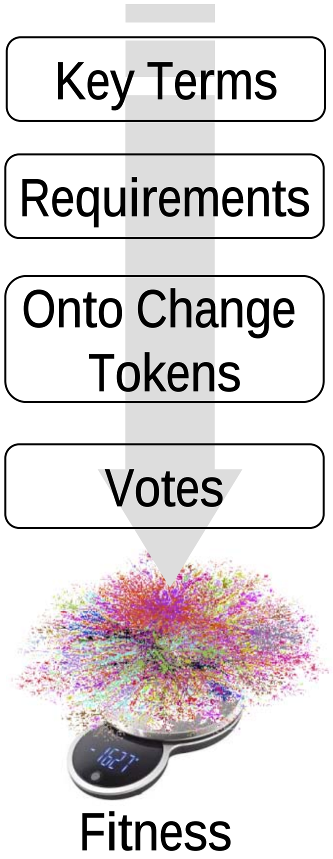
How to Elicit - OntoElect

- **OntoElect** *: understanding requirements as **votes** of the Domain Knowledge Stakeholders regarding the Ontology
  - Ontology fitness (**Φ**) is understood as proportional to the **ratio** of positive and negative **votes** of the Stakeholders
  - Votes collected **indirectly** – using a statistically representative Document Collection:

Requirements Elicitation
    - Extract a **saturated** set of multi-word key terms
    - Select the most **influential** key terms – Requirements

Conceptua-lization
    - Transform the natural language definitions of the terms to formalized **structural contexts** – Ontology Change Tokens

Evaluation
    - Map the structural contexts to the ontology – positive and negative Votes
    - Compute the change in **Φ** – more or less positive Votes



* Tatarintseva, O. et al. (2013) Quantifying Ontology Fitness in OntoElect Using Saturation- and Vote-Based Metrics. In: Ermolayev et al. (eds.) *ICT in Education, Research, and Industrial Applications. Revised Selected Papers of ICTERI 2013*, CCIS 412, pp. 136–162

Document Collection

- **Stakeholders**: TIME Symposia series authors
- **Document collection**: TIME Proceedings series, 1994-2013, ~440 papers, chronologically ordered
  - **Good quality** documents
  - **Incremental slices** of the document collection:

Slice ID	1994	1995	1996	...	2012	2013
D1						
D2						
...						
D19						
D20						

* Ermolayev, V., et al. (2014) Ontologies of Time: Review and Trends. *Int. J. of Computer Science & Applications*, 11(3), 57–115

TIME Papers

http://ermolayev.com/TimeOnto/TimePapers.zip

Decisive Minority Vote

TIME Papers (impact).xls

Row	Year	Authors	Author Affiliations	Paper Title	Pages	Complete Citation	Abstract	Category: Reasoning	Category: Representation	Category: Application	Category: Ontology	Key phrases	No Citations	Citations per year	Impact: (0.2*CpY) upper Int Part	paper file name (TimeOnto DropBox)	mark
3								263	277	193	14						
46	1996	Y. Shahar	Stanford Univ., CA, USA	Dynamic temporal interpretation contexts for	64-71	Y. Shahar, "Dynamic temporal interpretation	The temporal-abstraction task is the task of abstracting higher-level concepts from time-	1	1		1	temporal logic; temporal interpretation; temporal	62	3.4444	1	96-paper-14.pdf	http://doi.ieeecomputersociety.org/10.1
47	1996	E.T. Keravnou	Dept. of Comput. Sci.	Engineering time in medical knowledge-based systems	160-169	E.T. Keravnou, "Engineering time in medical knowledge-	Starting from the premise that time representation and temporal reasoning must constitute integral			1	1	medical expert systems; medical knowledge-based systems; time-	10	0.5556	1	96-paper-22.pdf	http://doi.ieeecomputersociety.org/10.1
48	1996	D. Gagne, A. Trudel	Alex Inf., Lachine, Que.	A topological transition based logic for the qualitative motion	176-181	D. Gagne, A. Trudel, "A topological transition based	The authors present a spatio-temporal ontology suitable for representing and reasoning about the	1	1		1	temporal reasoning; spatio-temporal ontology; qualitative	2	0.1111	1	96-paper-24.pdf	http://doi.ieeecomputersociety.org/10.1
49	1996	A. Fusaoka	Dept. of Comput. Sci.	Nonmonotonic reasoning on a constructive time structure	190-195	A. Fusaoka, "Nonmonotonic reasoning on a constructive	The author introduces a temporal logic called interval division logic, IDL, based on the constructive	1	1		1	nonmonotonic reasoning; constructive time structure; interval	1	0.0556	1	96-paper-26.pdf	http://doi.ieeecomputersociety.org/10.1
50	1996	Choong-Ho Yi	Dept. of	Reasoning about concurrent	6-13	Choong-Ho Yi, "Reasoning	E. Sandewall (1994) proposed a systematic	1	1			temporal reasoning;	1	0.0556	1	96-paper-07.pdf	http://doi.ieeecomputersociety.org/10.1
51	1996	L. Vila, E.	Dept. of Inf. &	A theory of time and temporal	21-29	L. Vila, E. Schwalb, "A theory	Time is fundamental in representing and reasoning	1	1			temporal reasoning; time; temporal	26	1.4444	1	96-paper-09.pdf	http://doi.ieeecomputersociety.org/10.1
52	1996	E. Schwalb, R.	Dept. of Inf. &	Processing disjunctions of	30-35	E. Schwalb, R. Dechter,	Describes new algorithms for processing	1				temporal reasoning; disjunctions	1	0.0556	1	96-paper-10.pdf	http://doi.ieeecomputersociety.org/10.1
53	1996	R. Wetprasit, A.	Sch. of Comput.	Reasoning with sequences of	36-38	R. Wetprasit, A. Sattar, L.	Proposes the modeling of recurring events as multi-	1	1			temporal reasoning; point event	6	0.3333	1	96-paper-01.pdf	http://doi.ieeecomputersociety.org/10.1
54	1996	S. Badaloni, M.	Dept. of	Hybrid temporal reasoning for	39-44	S. Badaloni, M. Berati,	This paper address the problem of representing	1	1	1		temporal reasoning; hybrid	18	1.0000	1	96-paper-11.pdf	http://doi.ieeecomputersociety.org/10.1
55	1996	A. Cesta, A. Oddi	CNR, Rome,	Gaining efficiency and	45-50	A. Cesta, A. Oddi, "Gaining	Deals with the problem of managing quantitative	1				temporal reasoning; efficiency;	78	4.3333	1	96-paper-02.pdf	http://doi.ieeecomputersociety.org/10.1
56	1996	E. Schwalb, L.	Dept. of Inf. &	Logic programming with	51-56	E. Schwalb, L. Vila, "Logic	Combines logic programming and temporal	1	1			temporal logic; TCLP language;	7	0.3889	1	96-paper-12.pdf	http://doi.ieeecomputersociety.org/10.1
57	1996	A. Isli, H.	Lab. d'Inf., Univ.	Networks of qualitative interval	57-63	A. Isli, H. Bennaceur,	We first define the concept of circuit consistency for	1				backtracking; qualitative interval	1	0.0556	1	96-paper-13.pdf	http://doi.ieeecomputersociety.org/10.1
58	1996	E. Mota, D.	Dept. of Artificial	Representing interaction of	72-79	E. Mota, D. Robertson,	In this paper we describe NatureTime logic which		1	1		temporal logic; NatureTime logic;	9	0.5000	1	96-paper-15.pdf	http://doi.ieeecomputersociety.org/10.1
59	1996	D. Cukierman,	Univ., Burnaby,	Characterizing temporal	80-87	D. Cukierman, J. Delgrande,	This paper is a preliminary investigation of temporal		1			artificial intelligence; temporal	16	0.8889	1	96-paper-16.pdf	http://doi.ieeecomputersociety.org/10.1
60	1996	C. Combi, F.	Dipartimento di	Managing time granularity of	88-05	C. Combi, F. Pinciroli, G.	In the database field, the need of time management		1	1		time management; temporal data	13	0.7222	1	96-paper-17.pdf	http://doi.ieeecomputersociety.org/10.1
61	1996	M.A. Orgun,	Dept. of	A recursive temporal algebra	96-103	M.A. Orgun, "A recursive	This paper introduces a recursive temporal algebra		1			relational algebra; recursive	5	0.2778	1	96-paper-03.pdf	http://doi.ieeecomputersociety.org/10.1
62	1996	C. Bettini, X.S.	Dept. of Inf. Sci.,	A general framework and	104-	C. Bettini, X.S. Wang, S.	This paper presents a general framework to define	1	1			temporal reasoning; time	40	2.2222	1	96-paper-18.pdf	http://doi.ieeecomputersociety.org/10.1
63	1996	A. Gal, D. Dori	Fac. of Ind. Eng.	Combining simultaneous	112-	A. Gal, D. Dori, "Combining	In temporal databases there are situations where		1			temporal databases; temporal data	2	0.1111	1	96-paper-04.pdf	http://doi.ieeecomputersociety.org/10.1
64	1996	C. Dixon	Dept. of	Temporal resolution: a	120-	C. Dixon, "Temporal	An approach to applying clausal resolution, a proof	1				temporal logic; breadth-first	4	0.2222	1	96-paper-05.pdf	http://doi.ieeecomputersociety.org/10.1
65	1996	E. Lamma, M.	Dipartimento di	Temporal reasoning in a meta	128-	E. Lamma, M. Milano, P.	Constraint Logic Programming (CLP) is a powerful	1				temporal reasoning; constraint	4	0.2222	1	96-paper-19.pdf	http://doi.ieeecomputersociety.org/10.1
66	1996	C. Martin, J.	Dept. de	An integrity constraint	136-	C. Martin, J. Sistac, "An	The authors propose a method for integrity checking	1	1			deductive databases; temporal	7	0.3889	1	96-paper-20.pdf	http://doi.ieeecomputersociety.org/10.1
67	1996	G. Brajnik, D.J.	Dipartimento di	Guiding and refining	144-	G. Brajnik, D.J. Clancy,	We illustrate TeQSIM, a qualitative simulator for	1	1	1		temporal logic; TeQSIM; qualitative	6	0.3333	1	96-paper-06.pdf	http://doi.ieeecomputersociety.org/10.1
68	1996	I. Bichindaritz, E.	Univ. Rene	Temporal knowledge	152-	I. Bichindaritz, E. Conlon,	The article presents the temporal knowledge		1			temporal knowledge	23	1.2778	1	96-paper-21.pdf	http://doi.ieeecomputersociety.org/10.1
69	1996	G. Becher	Caen Univ.,	First order modal temporal	170-	G. Becher, "First order modal	Following the work of G. Ligozat (1991) who	1	1			temporal logic; first order modal	3	0.1667	1	96-paper-23.pdf	http://doi.ieeecomputersociety.org/10.1
70	1996	K.P. Jantke, O.	Fachbereich	A modal temporal logic and its	182-	K.P. Jantke, O. Arnold, "A	The focus of the paper is on the introduction of some		1	1		temporal logic; modal temporal	10	0.5556	1	96-paper-25.pdf	http://doi.ieeecomputersociety.org/10.1
71	1996	A.Y. Tawfik, E.M.	Dept. of	Irrelevance in uncertain	196-	A.Y. Tawfik, E.M. Neufeld,	In the presence of uncertainty, relevance of	1	1			temporal reasoning; uncertain	11	0.6111	1	96-paper-27.pdf	http://doi.ieeecomputersociety.org/10.1
72	1996	Minglu Li,	Dept. of	Temporal representation for	204-	Minglu Li, Yongqiang Sun,	The paper focuses on temporal representation for		1	1		multimedia systems; multimedia	2	0.1111	1	96-paper-28.pdf	http://doi.ieeecomputersociety.org/10.1
73	1996	R. Guillen, D.	Dept. of	Handling temporal relations in	217-	R. Guillen, D. Farwell, J.	Handling temporal information has been a main		1	1		language translation; temporal	4	0.2222	1	96-paper-30.pdf	http://doi.ieeecomputersociety.org/10.1
74	1996	M.R. Sanchez,	Sch. of Comput.	Time accountability for lattice	211-	M.R. Sanchez, A.M. Shende,	Computers that emulate reality must be bound by			1		digital simulation; time		0.0000	0	96-paper-29.pdf	http://doi.ieeecomputersociety.org/10.1
75	1997	Yuval Shahar	Stanford University, CA	Knowledge-Based Temporal Interpolation	102-111	Yuval Shahar, "Knowledge-Based Temporal	Temporal interpolation is the task of bridging gaps between time-oriented concepts in a context-		1	1	1	Temporal reasoning, Temporal Interpolation, Temporal databases	37	2.1765	1	97-paper-14.pdf	http://doi.ieeecomputersociety.org/10.1
76	1997	Clare Dixon	Manchester	Temporal Resolution:	4-11	Clare Dixon, "Temporal	The generation of too much information prohibits	1					7	0.4118	1	97-paper-01.pdf	http://doi.ieeecomputersociety.org/10.1
77	1997	A. Kellett, M.	Dept. of	Automata representations for	12-19	A. Kellett, M. Fisher,	Concurrent METATEM is a language based on the	1				Concurrent METATEM language;	5	0.2941	1	97-paper-02.pdf	http://doi.ieeecomputersociety.org/10.1
78	1997	A. Bolotov, M.	Dept. of	A resolution method for CTL	20-27	A. Bolotov, M. Fisher, "A	We extend our clausal resolution method for linear	1	1			temporal logic; resolution method;	22	1.2941	1	97-paper-03.pdf	http://doi.ieeecomputersociety.org/10.1
79	1997	Vittorio Brusoni	Dipartimento di	An Efficient Algorithm for	28-30	Vittorio Brusoni, Luca	In the paper, we consider the following form of	1				nondeterministic algorithm for	23	1.3529	1	97-paper-04.pdf	http://doi.ieeecomputersociety.org/10.1

TIME Symposia / Other Papers

For Each Incremental Slice

- Bag of terms extracted * and sorted by normalized term scores (ns)

* Using TerMine service by the UK National Centre for Text Mining (NaCTeM, http://www.nactem.ac.uk/).

Bags of Terms

Flat-TIME-94-13 (~150 000 terms) - very noisy

2097.292969 temporal logic 961.849976 temporal constraint 860.008362 artif
temporal representation 762.130432 temporal reasoning 748.005737 temporal
checking 566.246094 temporal database 458.699402 international conference
379.297150 modal logic 376.742493 query language 350.921875 normal form
303.727264 temporal query 300.608704 temporal datum 298.344543 temporal
satisfiability problem 259.454529 expressive power 255.666656 basic relation
237.834778 datum model 233.982941 linear temporal logic 232.862030 ieee c
interval 213.044937 temporal object 204.711716 logic programming 203.4615
relation 202.875198 thirteenth international symposium 202.478867 transition
instance 194.446808 interval algebra 190.472519 constraint network 182.0731
logic 175.401962 constraint propagation 170.188232 ieee computer 167.7187
161.502762 fourth international conference 161.001144 temporal query langu
symposium 156.376251 first-order temporal logic 155.326324 10th internatio
151.607147 kripke structure 151.545456 temporal type 150.571442 14th inter
computer society 147.157898 ltl formula 146.517853 temporal granularity 14
138.593491 constraint satisfaction 137.454544 inference rule 136.194656 tem
r t snodgrass 133.596893 information systems 133.111115 minimal network 1
data currency model 130.250000 atomic proposition 130.104477 international
checking problem 123.714287 propositional variable 123.117645 resolution m
symposium 122.000000 min-max ctl 121.928574 atomic formula 121.666664
118.280487 relational database 117.818184 temporal dimension 117.793098 c
117.277779 interpretation context 116.352943 event calculus 116.287224 nint
temporal problem 114.666664 ieee computer society press 113.928574 new yo
111.021736 mit press 110.434784 temporal attribute 110.230766 temporal pro
109.020546 international joint conference 108.706894 g t 108.625000 real-tim
107.963852 theoretical computer 107.656250 temporal formula 106.647057 1
propagation algorithm 103.734695 loop search 103.476189 state formula 102.
101.857140 qualitative relation 101.000000 free variable 100.793106 non-con

• • • • • • • • •

Flat-TIME-Termhood.xls

	A	B
1	2097.292969	temporal logic
2	961.849976	temporal constraint
3	860.008362	artificial intelligence
4	815.737549	computer science
5	806.451599	temporal representation
6	762.130432	temporal reasoning
7	748.005737	temporal relation
8	686.428589	international symposium
9	626.972046	model checking
10	566.246094	temporal database
11	458.699402	international conference
12	448.051941	temporal operator
13	413.074066	temporal information
14	379.297150	modal logic
15	376.742493	query language
16	350.921875	normal form
17	321.367340	linear order
18	316.660004	temporal expression
19	303.727264	temporal query
20	300.608704	temporal datum
21	298.344543	temporal resolution
22	271.244446	decision procedure
23	262.740753	satisfiability problem
24	259.454529	expressive power
25	255.666656	basic relation
26	250.501785	interval temporal logic
27	240.478256	initial state
28	237.834778	datum model
29	233.982941	linear temporal logic
30	232.862030	ieee computer society
31	227.428574	lecture notes
32	226.837204	temporal interval
33	213.044937	temporal object

Flat-TIME-94-13

For Each Incremental Slice

- Bag of terms extracted * and sorted by normalized term scores (ns)
- Termhood created by retaining
  - Valid terms – manual filter
  - Important terms – $ns > \varepsilon$ (such that the sum of ns above is a little higher than 50% - elections)
- Termhood difference values computed using the THD algorithm **:
  - Absolute: $thd(T_{i-1}, T_i)$
  - Relative: $thdr = thd(T_{i-1}, T_i) / \sum_{T_i} ns_j^i$

* Using TerMine service by the UK National Centre for Text Mining (NaCTeM, http://www.nactem.ac.uk/).

** Tatarintseva, O. et al. (2013) Quantifying Ontology Fitness in OntoElect Using Saturation- and Vote-Based Metrics. In: Ermolayev et al. (eds.) *ICT in Education, Research, and Industrial Applications. Revised Selected Papers of ICTERI 2013*, CCIS 412, pp. 136–162

Termhood Comparisons

Algorithm THD. Compute Termhood Difference

Input: the termhoods T_i, T_{i+1}

Output: $thd(T_i, T_{i+1})$

for $k = 1, \|T_{i+1}\|$

$ident := .F.$

for $m = 1, \|T_i\|$

if $(t_m^i, t_k^{i+1})_\equiv$ **then do** $thd := thd + \left|ns_m^i - ns_k^{i+1}\right|$; $ident := .T.$ **end do**

end for

if $ident := .F.$ **then** $thd := thd + \left|ns_k^{i+1}\right|$

end for

Pick up one

Look for **linguistically similar** in the previous

Found: check the n-scores

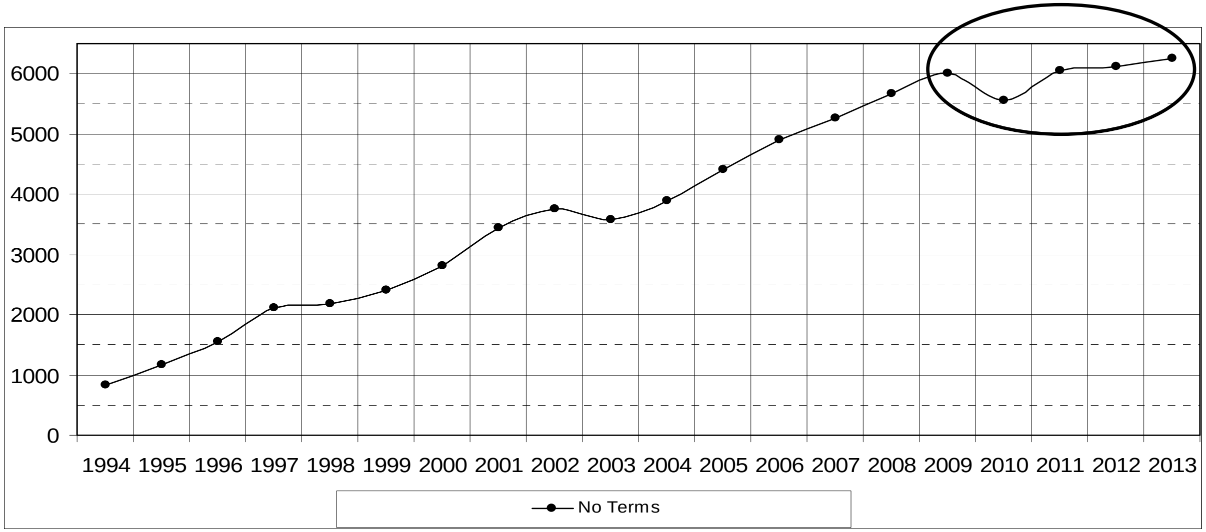
Not found: add the n-score

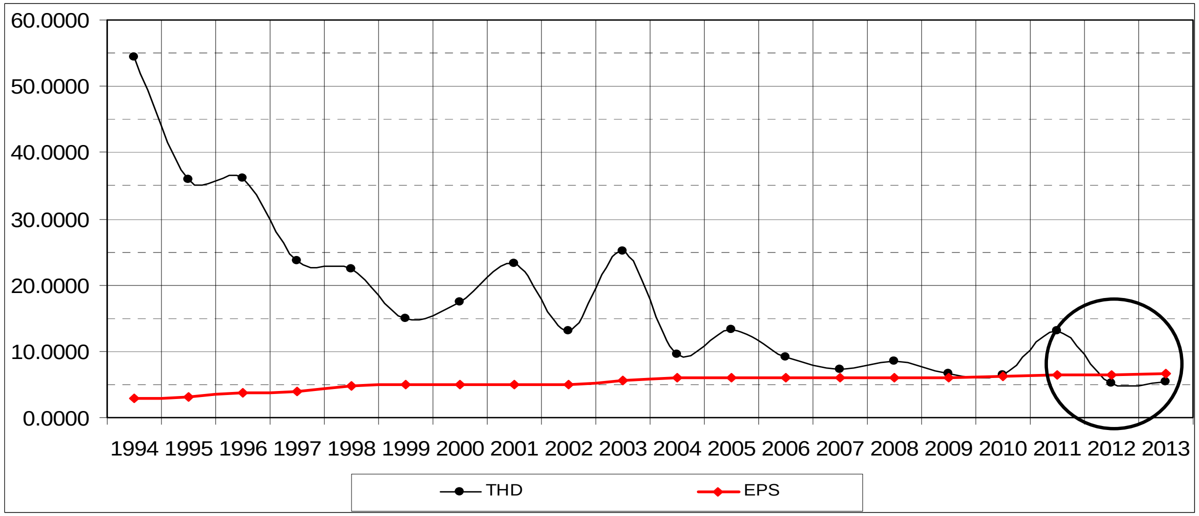
Termhood Comparisons

Collection Slice	Terms in the		*eps*	*thd*, **value**	thdr, **%**
	Bag of Terms	Termhood			
1994	8546	838	3.0000	54.4448	100.0000
1994-1995	14597	1179	3.1699	35.9807	62.3806
1994-1996	23992	1548	3.7549	36.0855	59.6366
1994-1997	31427	2104	4.0000	23.7044	35.4153
1994-1998	38122	2183	4.7549	22.4341	30.7901
1994-1999	42788	2400	5.0000	14.9911	18.7218
1994-2000	49986	2821	5.0000	17.4853	20.7287
1994-2001	59294	3430	5.0000	23.1877	26.9035
1994-2002	65627	3767	5.0000	13.1819	15.3747
1994-2003	75171	3584	5.6147	25.0810	36.7663
1994-2004	81617	3893	6.0000	9.6005	13.8278
1994-2005	91692	4410	6.0000	13.3894	19.7595
1994-2006	101190	4903	6.0000	9.0502	12.6376
1994-2007	108203	5255	6.0000	7.3260	9.8946
1994-2008	115493	5658	6.0000	8.5976	11.7790
1994-2009	121832	6007	6.0000	6.6174	9.0302
1994-2010	128171	5564	6.3043	6.3422	9.0829
1994-2011	137918	6043	6.3399	13.0734	20.2061
1994-2012	145173	6109	6.3549	5.1033	8.0395
1994-2013	151075	6259	6.6667	5.4895	8.7677

Completeness Check

- Observed:
  - **Saturation**:
    - ~6,000 terms in the last 4 termhoods
    - thd below ε
  - Terminological **drift**
    - thd above 0
  - Terminology contribution **peaks**:
    - 2001, 2003, 2005, 2008, and 2011
  - The (representative) **majority vote**
  - Still <u>too many</u> terms retained



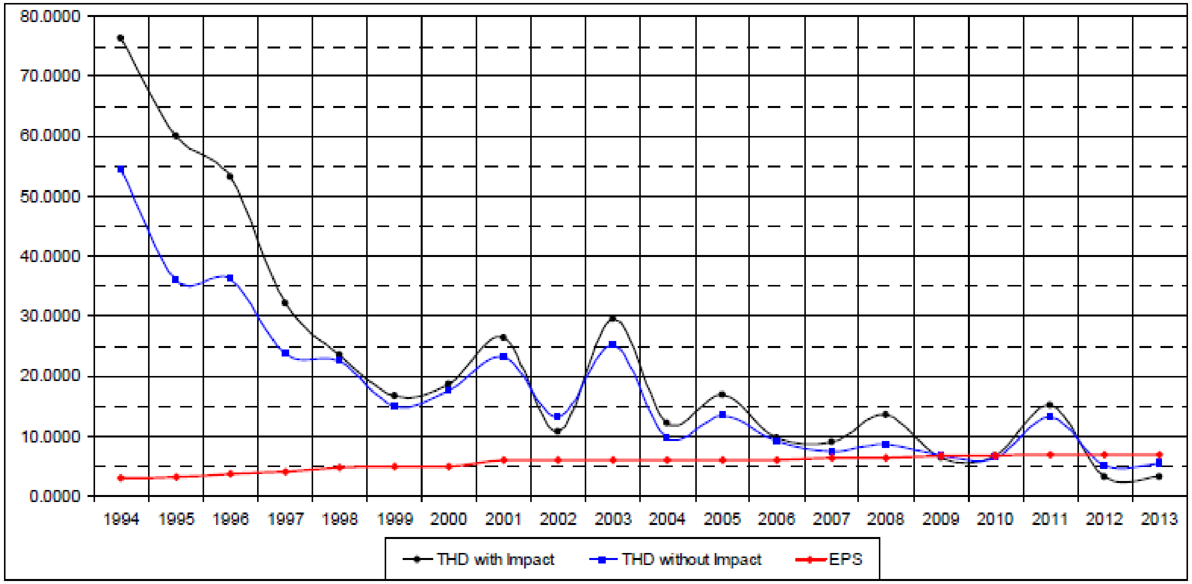


Decisive Minority Vote

- Terminology contribution peaks: 2001, 2003, 2005, 2008, and 2011
- Account for **impact**:
  - Citation info collected (Google Scholar)
  - Paper impact computed based on citation frequency (cfr)

$$imp = \begin{cases} [0.2 \times cfr] + 1, cfr > 0 \\ 0, cfr = 0 \end{cases}$$

  - Papers with $imp = n$ replicated n times – changing the incremental slices
  - thd / $thdr$ / eps re-computed
- **Strong correlation**
- Termhood based on high-impact (**24**) papers only
- **686** Terms vs 6,109



Shortlist

- Bag of terms:
  - High-impact papers only
  - **24** vs ~**440**
- Termhood:
  - **686** Terms
  - Vs **6,109** extracted from the complete dataset

- All **important** terms with high *ns* retained
  - Manual check

Shortlist Dataset - Bag of Terms.xls

	A	B	C
1	147.107147	temporal logic	
2	100.111170	calendar pattern	
3	86.541664	temporal constraint	
4	68.733330	temporal operator	
5	59.583332	fuzzy match	
6	58.000000	interval i	
7	54.000000	interval j	
8	52.250000	temporal structure	
9	49.833332	calendar schema	
10	46.250000	temporal representation	
11	41.000000	temporal reasoning	
12	40.000000	freeze quantifier	
13	39.624062	14th international symposium	
14	39.000000	international symposium	
15	37.727272	fuzzy interval	
16	36.363636	xml document	
17	36.000000	crisp interval	
18	34.000000	satisfiability problem	
19	34.000000	flexible variable	
20	33.297745	first-order temporal logic	
21	31.699249	star calendar pattern	
22	31.352942	computer science	
23	28.142857	search control	
24	27.000000	lola specification	
25	26.944363	ci a c2	
26	26.266666	constraint system	
27	26.000000	ccsl specification	
28	25.961538	artificial intelligence	
29	24.799999	point-interval relation	
30	24.750000	interval interval	
31	23.692307	temporal notion	
32	23.500000	f wolter	
33	23.333334	x x x x	
34	23.114288	x x x	
35	22.799999	collection expression	

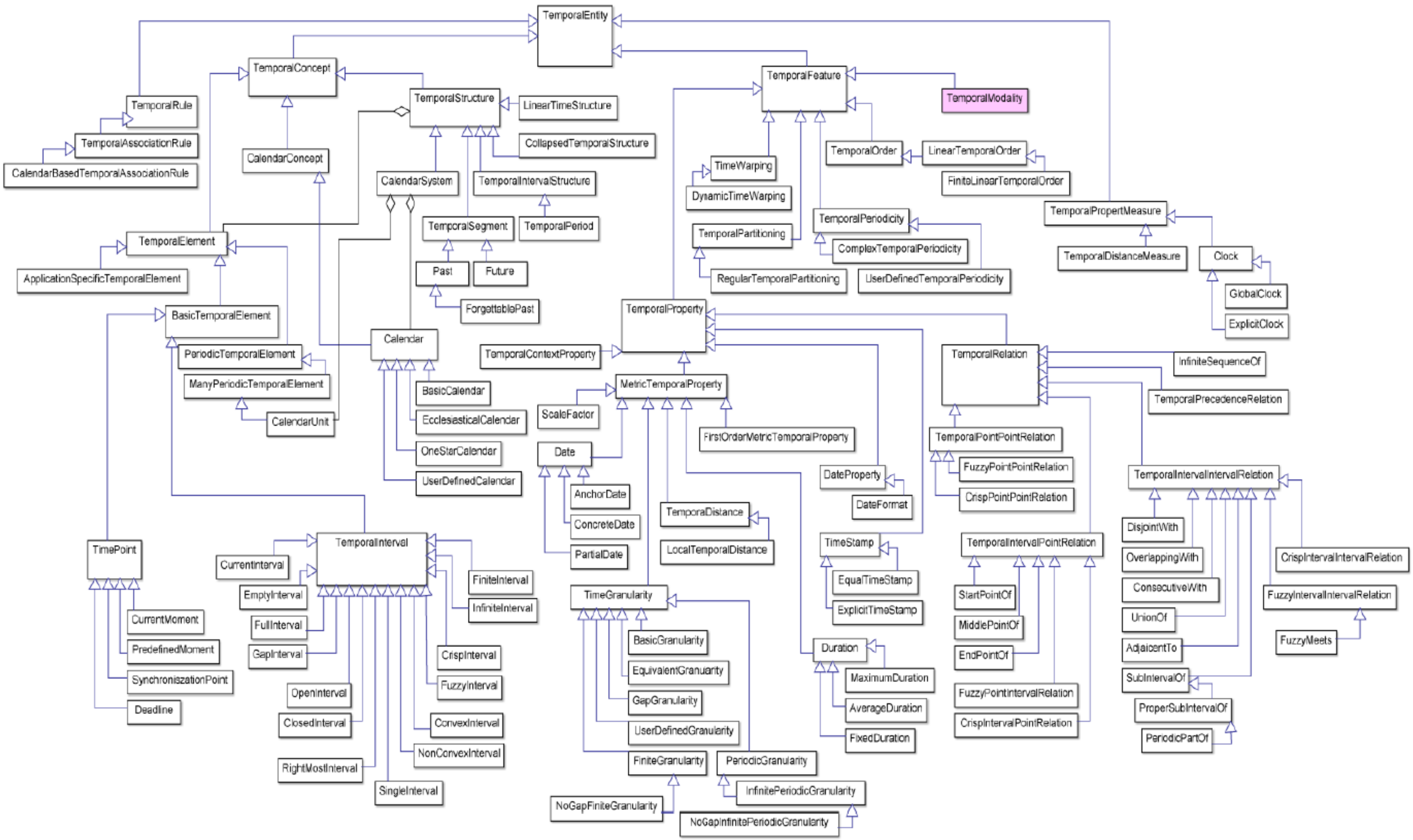
Shortlist Dataset

Manually Categorized Terms

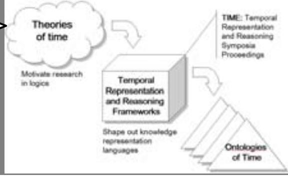
How do We know …

Score	Term	Logic	Problem	Formula	Formalism	Operator	Method	Model	Reasoner	Domain	Language	Feature	Constraint	Instance	Pattern	Application	Project	Author
	Total No of terms: **686**	44	27	6	36	8	22	24	1	4	8	175	28	1	13	110	1	178
147.11	temporal logic	✓																
100.11	calendar pattern														✓			
86.54	temporal constraint												✓					
68.73	temporal operator					✓												
59.58	fuzzy match											✓						
52.25	temporal structure											✓						
49.83	calendar schema											✓						
46.25	temporal representation				✓													
41.00	temporal reasoning						✓											
40.00	freeze quantifier				✓													
37.73	fuzzy interval											✓						
36.36	xml document															✓		
36.00	crisp interval											✓						
34.00	satisfiability problem		✓															

Feature Taxonomy



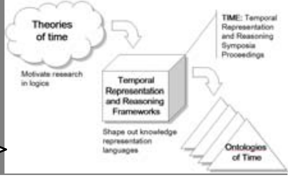
Theories vs Features



A fragment:

Feature of Time \ Temporal Theory	Lamport (1978)	Allen (1983)	Pinto (1994) - Kowalski & Sergot (1986)	Prior (1967)	McDermott (1982)	Sandewall (1995)	Halpern & Shoham (1991)	Bacchus & Kabanza (1998) - Alur *et al.* (1996)	Williams (1986)	Koubarakis (1992)	Iwasaki *et al.* (1995)	Ermolayev *et al.* (2008a)	Synthetic Theory
Temporal Elements													
- Points (Instants)	+	-	+	+	+	+	+	+	+	+	+	+	+
- Intervals		+		+	+		+	+	+			+	+
- Convex(C), Non-convex(N)					C			C					CN
- Open (O), Closed (C)		O		OC	OC		OC	OC	C			OC	OC
- Bounded (B), Unbounded (I)				BU	BU			BU	B			BU	BU
- Fuzzy(F), Crisp (C)									C			FC	FC
- Periodic Temporal Elements				+								+	+
Temporal Structures													
- Point(P)-, Interval(I)-Based Structures		I		PI	PI	P	P	PI				PI	PI
- Temporal Segments							+					+	+
- Temporal Periods												+	+
- Calendars		+										+	+

Ontologies vs Features



A fragment:

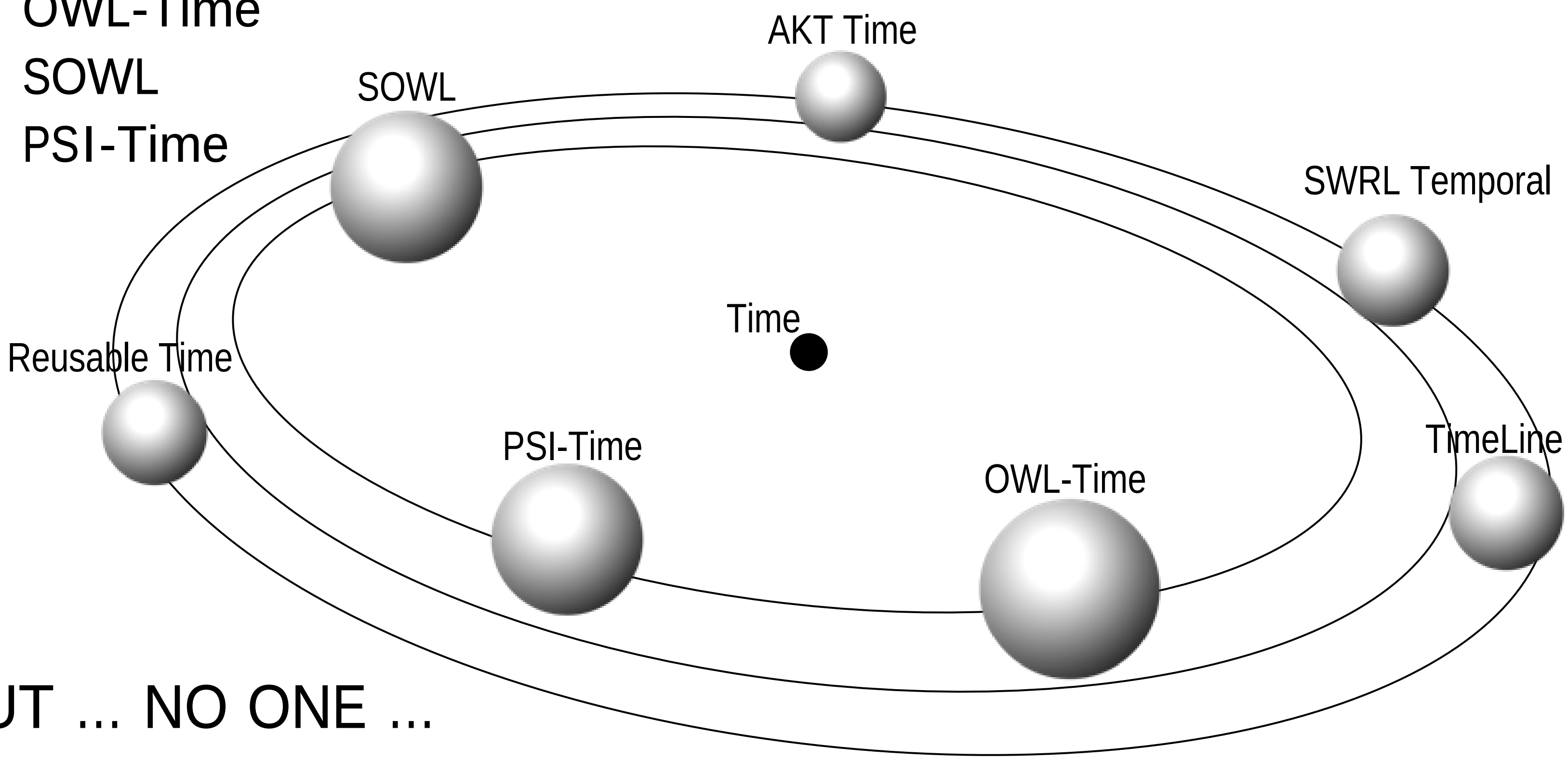
Synthetic theory	Feature of Time \ Ontology of Time	Cyc Time	SUMO Time	DOLCE	BFO	GFO-BT	PSI-ULO	OWL-Time	TimeLine	Reusable Time	PSI-Time	AKT Time	SWRL Temporal	SOWL
	Temporal Features													
OZ	- Open (O), Closed (C), Closed at the Beginning (Z)		O				O	O	OZ	O	O			O
+	- Anisotropy						+	+			+			+
IDR	- Density: Discrete(I), Dense(D), Continuous (R)	D			R	D	I		DR	R	I			
+	- Partitioning	+			*1				*2	+	+			
+	- Periodicity										+			
L*3	- Linear (L), Branching (B)	L	L			L	L	L			L			L
AR	- Absolutist (A), Relativist (R)	AR	AR					AR		AR	AR	A		AR
F	- Uncertainty(U), Fuzziness (F)	UF*4						F*4		U*5				FU
	Temporal Elements													
+	- Points (Instants)	+	+		+	+	+	+	+	+	+	+	+	+
+	- Intervals	+	+	*6	*6	+	+	+	+	+	+	+	+	+
CN	- Convex(C), Non-convex(N)							C		CN			C	C

Notes:
*1 Time - the whole time; Temporal Region - the part of time
*2 TimeLine only
*3 A relaxed linearity allowing a number of parallel independent time lines
*4 Fuzzy duration. E.g. TimeML introduces the tags for the lower bound and upper bound duration annotations (lowerBoundDuration and upperBoundDuration attributes).
*5 For Time-Points only

.....

Which one Does the Best?

- Focused time ontologies:
  - OWL-Time
  - SOWL
  - PSI-Time



- BUT ... NO ONE ...
  - Even taken mechanistically together
  - Do NOT cover all the required features

Summary of Analysis 1/2

- **NO** single ontology that covers all the features

- All the ontologies taken together do **NOT** satisfactorily cover some features:
  - **Density** of time
  - **Relaxed linearity** of time
  - **Scale** factors
  - **Proper** and **periodic** subintervals
  - Temporal **measures** and **clocks**

- Some of the ontologies offer their unique contribution:
  - **TimeLine** – time line which is closed at its beginning – **Origo**
  - **ReusableTime** – convex and **non-convex** time intervals
  - **SOWL** – **uncertainty** in time, esp. in relations;
  - **PSI-Time** – temporal **periodic structures** and **segments**
  - **SWRL Temporal** – **date/time stamps/formats**

Summary of Analysis 2 / 2

- Available temporal logics and specification languages have **sufficient expressive power** to cover the required temporal features
  - **Uncertainty** and **Fuzziness** may be not easy ...
- A **cross-disciplinary effort** is required to address the features that are not covered
  - E.g, the results in formal verification and distributed run-time systems could be useful to cover the representations of **clock**s and **measure**s of time
- Mechanistic **merging** for re-use **does not** really **fly**: ⇨
  - **Different** and partially **contradictory** models and principles
  - **Harmonization** effort is required to put together all the available bits for re-use
  - To begin with a harmonized (**SYNDICATED**) **theoretical model** of time

Merging does not Fly ...

- Different models are based on different theories
  - Incorporating different: features, elements, structures

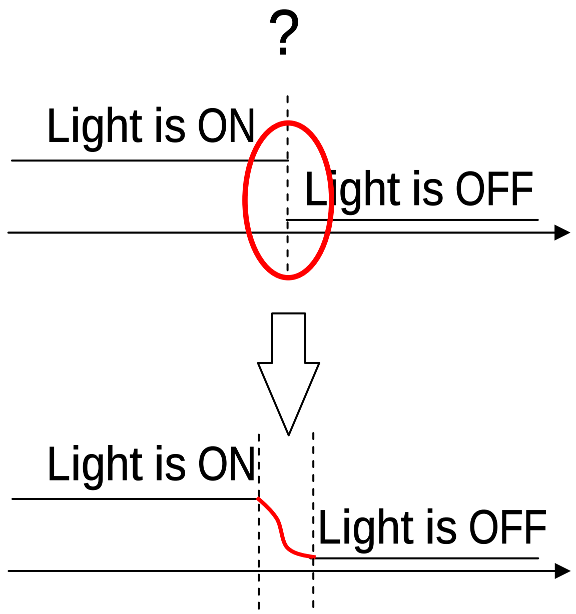
- Scope and Focus:
  - **Time** vs Temporal **Incidence** * (like event calculi, spatio-temporal ...)
  - **Instants** vs **Intervals** (aka punktlich vs luego)
  - **Dense** vs **Sparse** Domains (e.g. Discrete vs Continuous)
  - **Branching** vs **Linear** (e.g. for distributed and embedded systems)
  - With or without an **Origo** (was there the beginning of times? ...)
  - **Convexity**, **periodicity**, ...
  - ...

- Logical inconsistencies, e.g.:
  - Dividing Instance Problem (e.g. Allen's light switch)
  - Instantaneous Fluents (e.g. tossing a ball)

* L. Vila, E. Schwalb, A theory of time and temporal incidence based on instants and periods. In: 3rd W-shop on Temporal Representation and Reasoning (TIME'96), pp.21-28 1996

Dividing Instant Problem

- Instantaneous event of switching the light off
  - Allen*:
    - If both time intervals are <u>closed</u>, then light is **on** and **off** at this moment
    - <u>Open</u> – **neither on**, **nor off**...
    - Does not happen instantaneously
      - No need for Time Instants
      - These are Time Intervals (though short)
- Dense Time ...
  - What if Discrete?
- Punktlich vs relaxed and blurred (luego) ...



* Allen, J. (2013): Maintaining knowledge about temporal intervals. CACM, 26(11), 832–843

Tossing a Ball ...

- When does the ball have its vertical speed == 0?
  - **Instantaneous**
  - Also for any other fluents with **EXACT** parameter values being of interest
  - Both in Dense and Sparse domains
- Vila & Schwalb*:
  - **Time Instants** are the same class citizens as **Intervals**

* L. Vila, E. Schwalb, A theory of time and temporal incidence based on instants and periods. In: 3rd W-shop on Temporal Representation and Reasoning (TIME'96), pp.21-28 1996

Design Principles for a Time Onto

- Careful **scoping**:
  - Time is just about TIME, nothing more broad – any temporal incidence is not relevant
- Allowing for modeling **alternatives**:
  - For different incidence theories
  - For different applications
  - Providing necessary features as completely as possible in a coherent theory
- Keeping it (language) **standard compliant**
  - W3C: OWL 2 DL + SWRL
- Which is ALL ...
  - Difficult
  - Prohibiting a mechanistic merge
  - A theory should come first ...

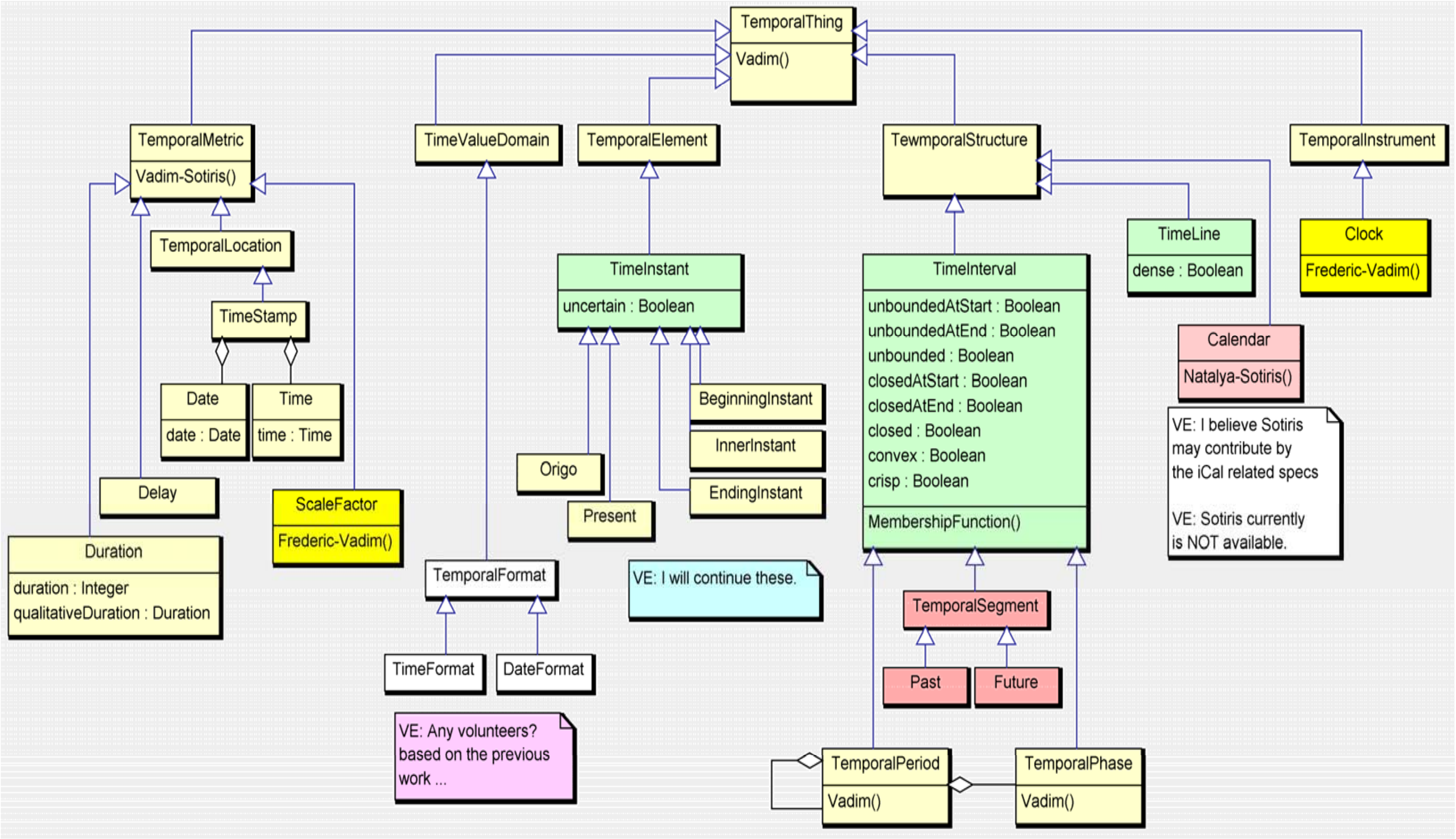
Syndicated Model of Time

Methodology

OntoElect **Conceptualization** Phase:

- Develop the **Backbone Taxonomy**
  - Based on the Requirements (**features**)
- Develop the **Seed**:
  - Focus on **Key Concepts** (Taxonomy)
    - E.g.: TimeLine, TimeInstant, TimeInterval, Clock
  - Develop/refine **theoretical descriptions**
    - Check if **implementable** using the available (W3C) languages
  - Harmonize – check **consistency**
  - Transform to Ontology (**Change Tokens**)
    - Visualize in a UML Class Diagram
    - Produce a **W3C compliant** code (OWL 2 DL + SWRL)
  - Document (**SOT-Wiki**)
  - Evaluate against required features (OntoElect: **Fitness,** Evaluation phase)
- **Expand**
  - Add concepts (Taxonomy)
  - Repeat the cycle until:
    - All the requirements are met (OntoElect: **Fitness,** Evaluation phase) OR
    - The limits of expressive power are reached (W3C **compliance**)

Backbone Taxonomy



Ongoing work …: SOT Backbone Taxonomy Model. Revision 4.

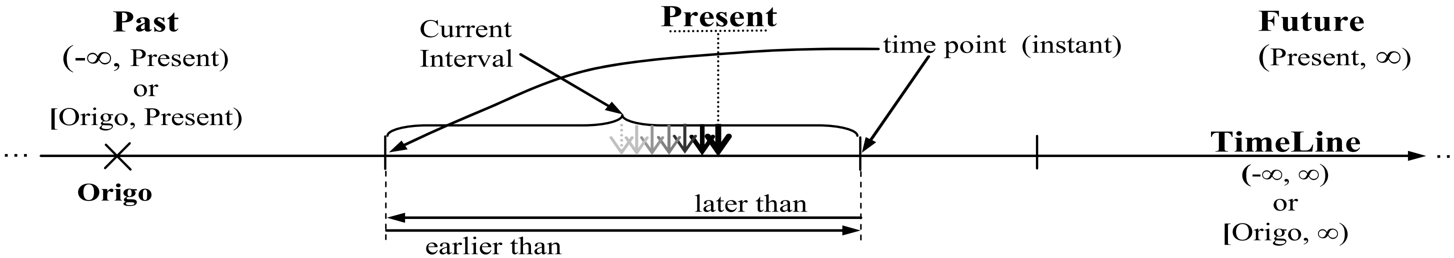
TimeLine: Relevant Req-s

Requirement	Syndicated Temporal Theory	Relevant Parts of the Model
High-Level Temporal Features		
- Open (O), Closed (C), Closed at the Beginning (Z)	OZ	TimeLine
- Anisotropy	+	TimeLine
- Density: Discrete(I), Dense(D), Continuous (R)	IDR	TimeLine, TimeValueDomain
- Linear (L), Branching (B)	L[1]	TimeLine
- Partitioning	+	TimeLine, Phase, TemporalSegment
Temporal Properties		
- Metric(M), Non-metric(N) Time	M	TimeLine, TimeValueDomain
Temporal Measures		
- Global (G), Local (L) Clocks	GL	TimeLine, Clock

- A **TimeLine** is a major **TemporalStructure**:
  - Putting together all the temporal elements and structures (**TimeInstant**s, **TimeIntervals**, segments) by allowing relativist and absolutist relationships among them; and
  - Providing a mapping through a **TimeValueDomain** (Integers, Reals, Super-Reals, etc.) for **TimeStamp**s of those elements

…

TimeLine: Theory (Fragment)



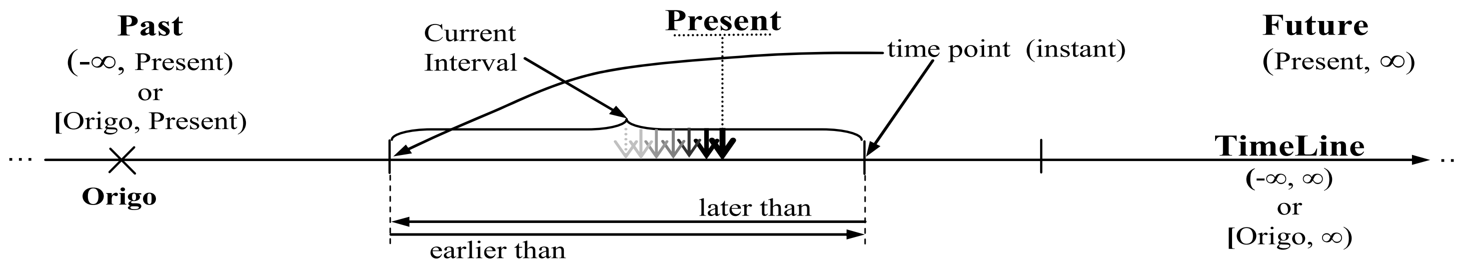
- **Density** of Time
  - Each individual **TimeLine** has one and only one **TimeValueDomain** associated with it to which the **TimeInstant**s in this **TimeLine** are mapped to. Regarding this association, a time line may be sparse or dense. For a dense **TimeLine**, with the two arbitrary **TimeInstant**s t_1 and t_2 in it, the following statement holds true:

$$\forall t_1, t_2 : before(t_1, t_2), \exists t_3 : before(t_1, t_3) \wedge before(t_3, t_2)$$

  - It does not hold true for sparse **TimeLine**s, e.g. those mapping **TimeInstant** locations to Integers.

SOT Theoretical Framework. Revision 5

TimeLine: Theory (Fragment)



- **Anisotropy** of Time
  - Our model reflects the **anisotropic** nature of time by postulating the <u>anti-symmetry</u> of the relationships between **TemporalElement**s. For example, if any `t1` and `t2`, are **TimeInstant**s on the <u>same</u> **TimeLine** `T` then

$$before(t_1, t_2) \leftrightarrow after(t_2, t_1)$$

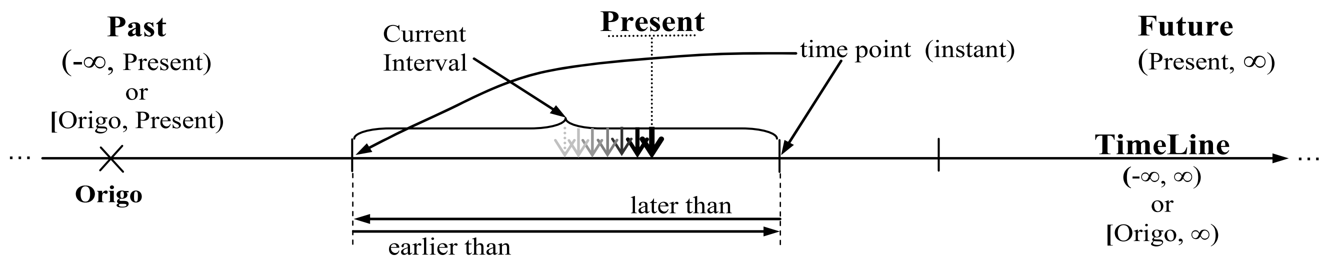
  - In SWRL the rules are as follows:
    - TimeLine (?T) ∧ TimeInstant(?t1) ∧ TimeInstant(?t2) ∧ on(?t1,?T) ∧ on(?t2,?T) ∧ before(?t1,?t2) -> after(?t2,?t1)
    - TimeLine (?T) ∧ TimeInstant(?t1) ∧ TimeInstant(?t2) ∧ on(?t1,?T) ∧ on(?t2,?T) ∧ after(?t2,?t1) -> before(?t1,?t2)

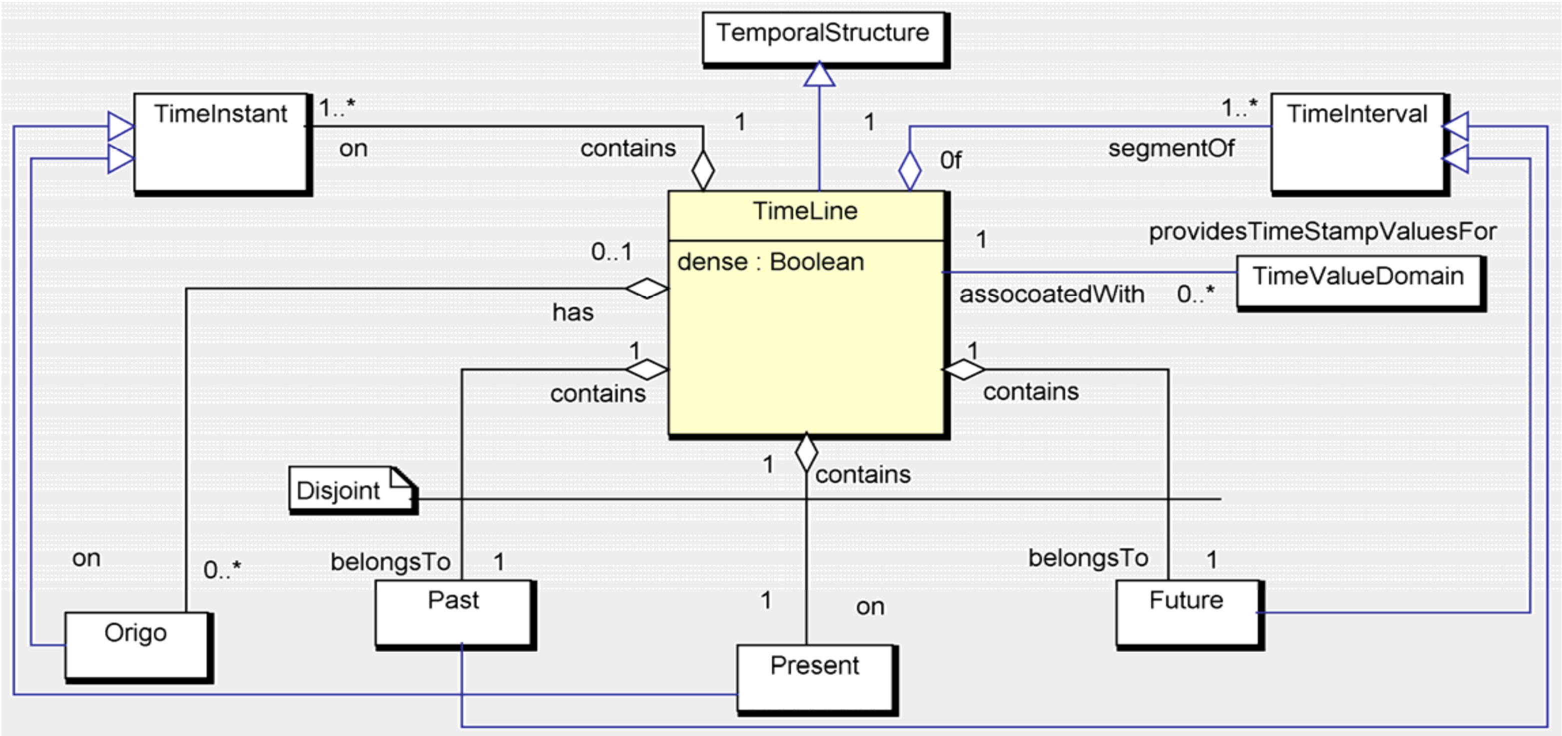
TimeLine: Theory (Fragment)

- **Linear / Branching** Time
  - Our model assumes the independent existence of several **TimeLine**s
    - Each of these **TimeLine**s is individually linear – i.e. a total linear ordering is established on the set of **TimeInstant**s positioned on the same **TimeLine**.
  - Different **TimeLine**s are not directly related to each other in the sense that only a partial ordering could be indirectly established between the **TimeInstant**s positioned on different **TimeLine**s.
    - This partial ordering is the way to model branching time structures.

SOT Theoretical Framework. Revision 5

TimeLine: (UML) Model





SOT TimeLine Model. Revision 3

TimeLine: Wiki Page

- http://isrg.kit.znu.edu.ua/sot-wiki/index.php/SOT-TimeLine

SOT-TimeLine

Contents [hide]

TimeInstant: Relevant Req-s

Requirement	Syndicated Temporal Theory	Relevant Parts of the Model
High-Level Temporal Features		
- Absolutist (A), Relativist (R)	AR	TimeInstant, TimeInterval (relationships), TimeStamp
- Uncertainty(U)	U	TimeInstant, TimeStamp
Temporal Elements		
- Instants	+	TimeInstant
Temporal Properties		
- Metric(M), Non-metric(N) Time	M	TimeInstant
- Temporal Distance	+	TimeInstant, TimeStamp
Temporal Relations		
- Interval-Point Relations	+	
- Start (S), Middle (I), End (E) Points	SIE	TimeInstant, TimeInterval
- Fuzzy(F), Crisp(C) Relations	CF	TimeInstant
- Point-Point Relations	+	
- Fuzzy (F) and Crisp (C) Relations	CF	TimeInstant
Temporal Measures		
- Duration (D), Location (L), Delay (E)	DLE	TimeInstant, TimeInterval

TimeInstant: Relativism

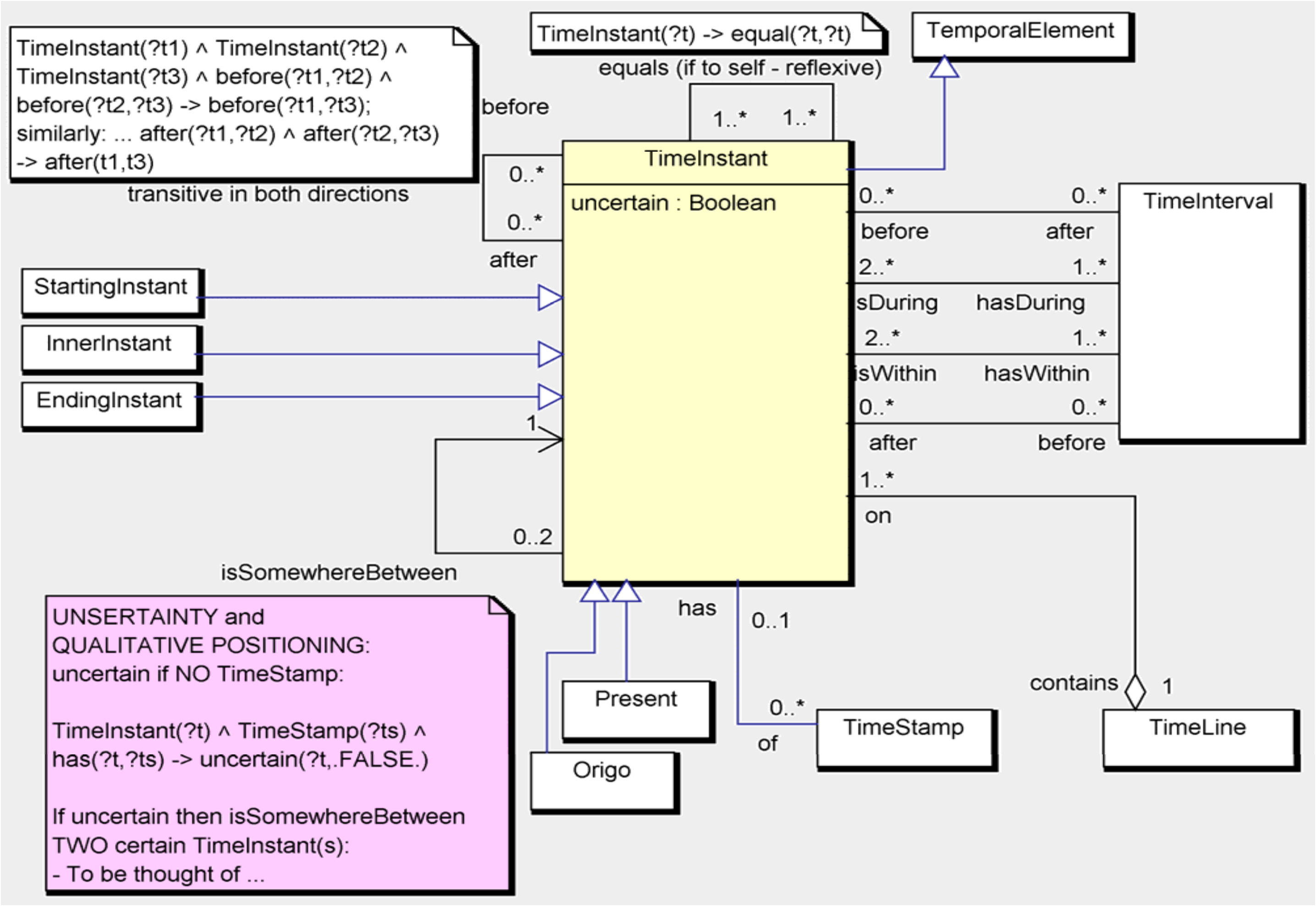
Let `t1` and `t2` be any two **TimeInstant**s positioned on the same **TimeLine** (`T`). Then one and only one of the following three statements holds true reflecting the total linear ordering on the set of **TimeInstant**s :

$$before(t_1, t_2) \qquad equals(t_1, t_2) \qquad after(t_1, t_2)$$

- The total linear ordering imposes that the following hold true:
  - **Anisotropy**:
    - `TimeLine (?T) ∧ TimeInstant(?t1) ∧ TimeInstant(?t2) ∧ on(?t1,?T) ∧ on(?t2,?T) ∧` **`before(?t1,?t2)`** `->` **`after(?t2,?t1)`**
  - **Reflexivity**:
    - `TimeLine (?T) ∧ TimeInstant(?t1) ∧ on(?t1,?T) ->` **`equals(?t1,?t1)`**
  - **Transitivity**:
    - `TimeLine (?T) ∧ TimeInstant(?t1) ∧ TimeInstant(?t2) ∧ TimeInstant(?t3) ∧ on(?t1,?T) ∧ on(?t2,?T) ∧ on(?t3,?T) ∧` **`before(?t1,?t2) ∧ before(?t2,?t3)`** `->` **`before(?t1,?t3)`**
    - `TimeLine (?T) ∧ TimeInstant(?t1) ∧ TimeInstant(?t2) ∧ TimeInstant(?t3) ∧ on(?t1,?T) ∧ on(?t2,?T) ∧ on(?t3,?T) ∧` **`after(?t1,?t2) ∧ after(?t2,?t3)`** `->` **`after(?t1,?t3)`**

SOT Theoretical Framework. Revision 5

TimeInstant: (UML) Model



SOT TimeInstant Model. Revision 7

TimeInstant: Wiki Page

- http://isrg.kit.znu.edu.ua/sot-wiki/index.php/SOT-TimeInstant

Contents [hide]

TimeInterval: Relevant Req-s

Requirement	Syndicated Temporal Theory	Relevant Parts of the Model
High-Level Temporal Features		
- Absolutist (A), Relativist (R)	AR	TimeInstant, TimeInterval (relationships), timeStamp
- Uncertainty(U)	U	TimeInstant, timeStamp
- Fuzziness (F)	F	TimeInterval
Temporal Elements		
- Intervals	+	TimeInterval
- Convex(C), Non-convex(N)	CN	
- Open (O), Closed (C)	OC	
- Bounded (B), Unbounded (I)	BI	
- Fuzzy(F), Crisp (C)	FC	
Temporal Structures		
- Point(P)-, Interval(I)-Based	PI	TimeInterval
Temporal Properties		
- Duration	+	TimeInterval
Temporal Relations		
- Interval-Interval Relations	Allen's relationships	TimeInterval
- Disjoint		
- Overlapping		
- Consecutive		
- Adjacent		
- Meets		
- Union		
- Subinterval	+	TimeInterval
- Proper (R), Periodic (E) Subinterval	RE	TimeInterval
- Fuzzy (F), Crisp(C) Relations	FC	TimeInterval
- Interval-Point Relations	+	
- Start (S), Middle (I), End (E) Points	SIE	TimeInstant, TimeInterval
- Fuzzy(F), Crisp(C) Relations	CF	TimeInterval
Temporal Measures		
- Duration (D), Location (L), Delay (E)	DLE	TimeInterval

TimeInterval: Theory

A **TimeInterval** is a segment of a particular **TimeLine**, thus having **Duration**. A **TimeInterval** is regarded as a **TimeInstant** based **TemporalStructure**:

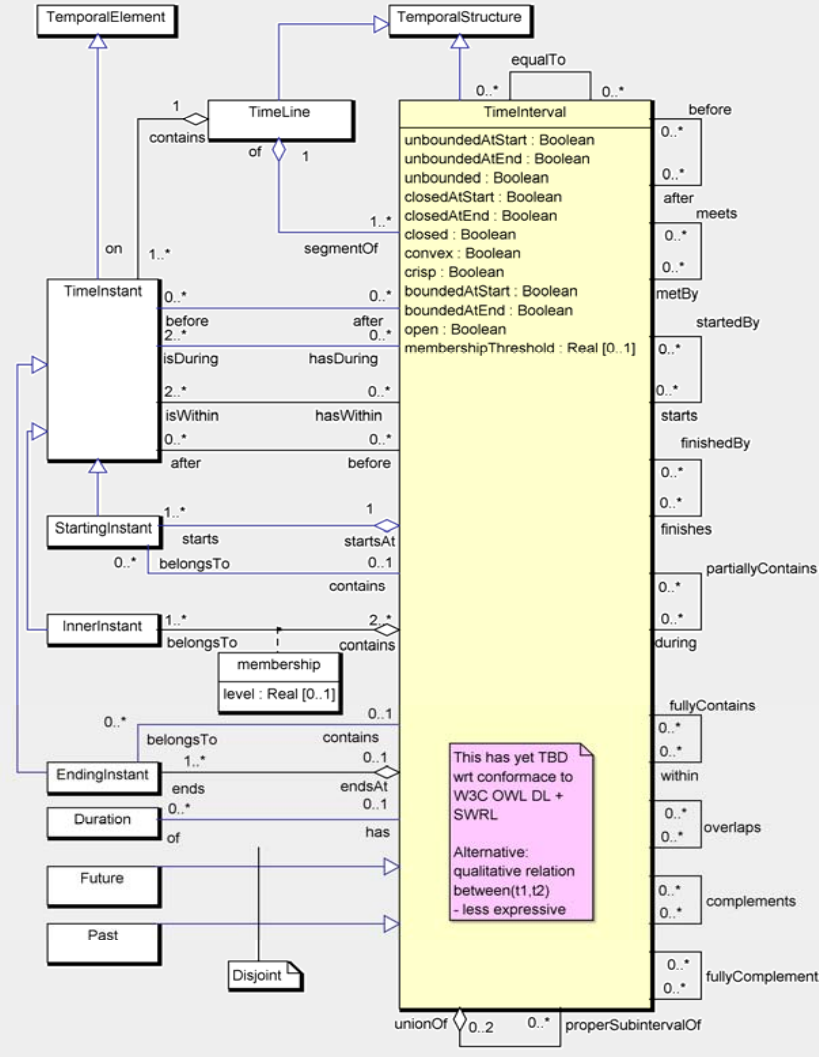
$$i =< T_i,[t_i^s],[t_i^e],\mu_i(t \in T_i)>$$

- $T_i = \{t_i\}$ – the set of **TimeInstant**s which conditionally belong to the **TimeInterval** as its members.
- t_i^s – the starting **TimeInstant**. This **TimeInstant** may not belong to T_i if i is *open* at start. This **TimeInstant** does not exist [...] if i is *unbounded* at the start, which applies only to the **TimeLine** s without an **Origo**.
- t_i^e – the ending **TimeInstant**. This **TimeInstant** may not belong to if T_i if i is *open* at end. This **TimeInstant** does not exist [...] if i is *unbounded* at the end.
- $\mu_i(t \in T_i)$ – the membership function over the **TimeInstant**s $t \in T_i$ ...

SOT Theoretical Framework. Revision 5

TimeInterval: (UML) **Model**

- Bounded / Unbounded
- Open / Closed
- Convex / Non-Convex
- Crisp / Fuzzy
  - Membership Function
- Relationships to a **TimeInstant**
- Relationships between **TimeInterval**s
  - Meronymy
  - Allen's (incl. extension for non-convex)
- **Past** and **Future** (**TimeLine**)



SOT TimeInterval Model. Revision 7

TimeInterval: Wiki Page

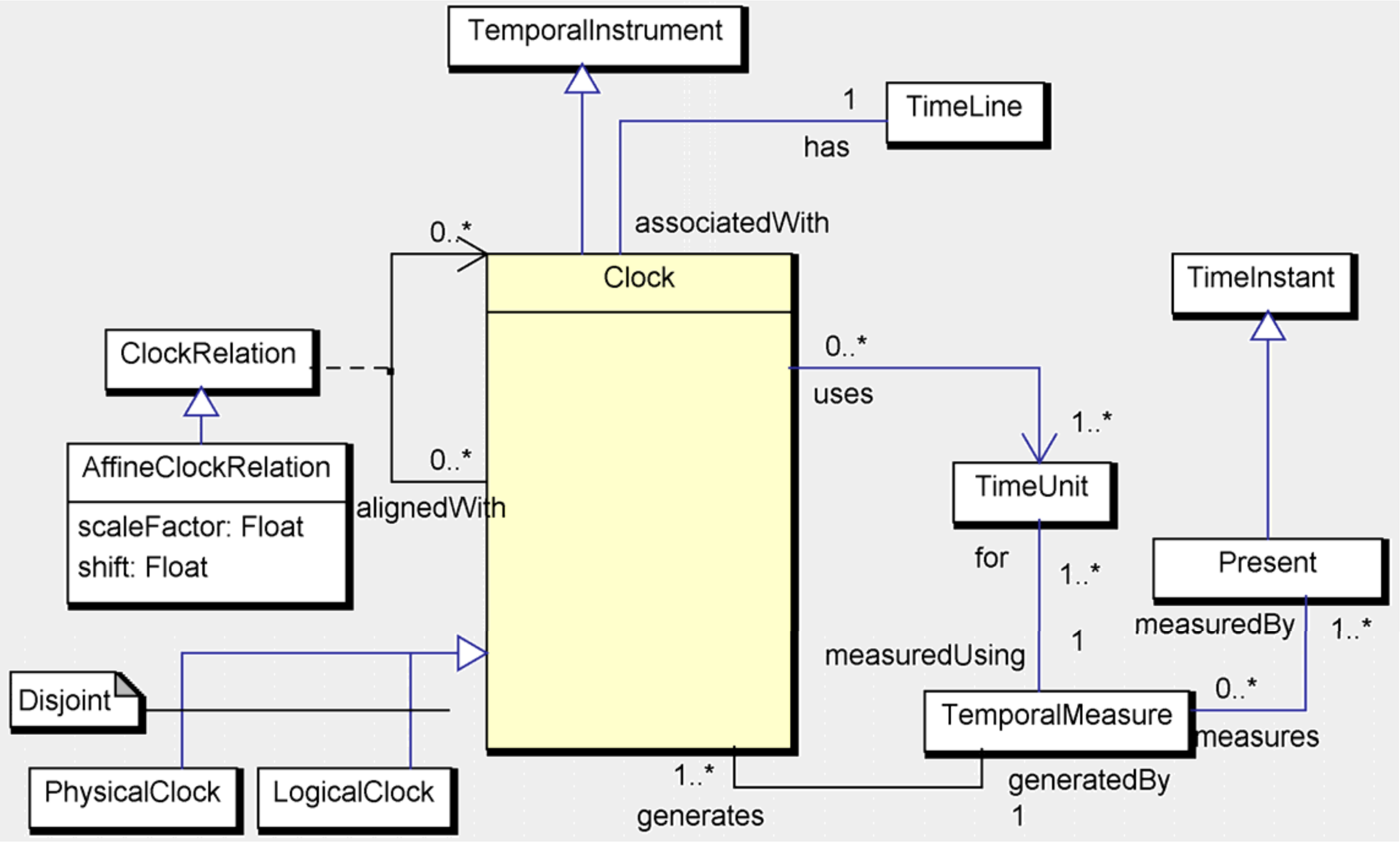
- http://isrg.kit.znu.edu.ua/sot-wiki/index.php/SOT-TimeInterval

Contents [hide]

Clock: Theory

- Is a **TemporalInstrument** to generate the instances of a **TemporalMeasure** of a **Present**
- Is always associated with a particular single **TimeLine.** Different **Clock**s, associated with the same **TimeLine** or different **TimeLine**s may “run” differently, e.g. quicker or slower and also with offsets compared to each other.
- Some **Clock**s may be related to each other – with **ClockRelation** – to compare the values they return.
  - A specific (widely used) kind of a **ClockRelation** is **AffineClockRelation** which allows aligning:
    - Different time velocities (using the *scaleFactor* property); and
    - Time offsets, like delays (using the *shift* property)
- A **Clock**, returns a **TimeStamp** which parts correspond to particular **TimeUnit**s
- A **PhysicalClock** and a **LogicalClock** are the two disjoint specializations of a **Clock**

Clock: (UML) Model



SOT Clock Model. Revision 3

Clock: Wiki Page

- http://isrg.kit.znu.edu.ua/sot-wiki/index.php/SOT-Clock

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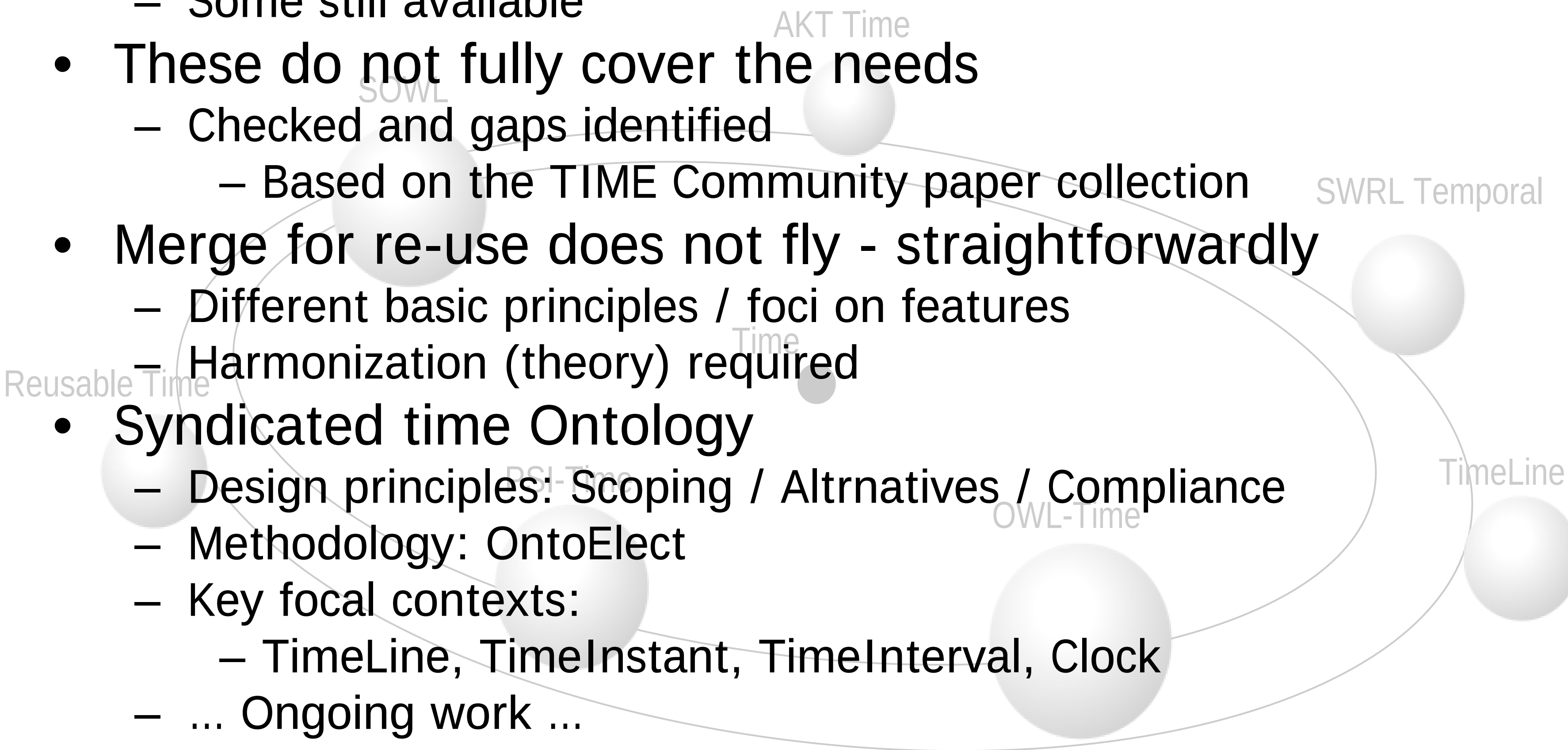
Final Remarks

Some Concluding Remarks



- ~20 Time Ontologies developed to date
  - Some still available
- These do not fully cover the needs
  - Checked and gaps identified
    - Based on the TIME Community paper collection
- Merge for re-use does not fly - straightforwardly
  - Different basic principles / foci on features
  - Harmonization (theory) required
- Syndicated time Ontology
  - Design principles: Scoping / Altrnatives / Compliance
  - Methodology: OntoElect
  - Key focal contexts:
    - TimeLine, TimeInstant, TimeInterval, Clock
  - ... Ongoing work ...

- Yeah, no “evangelistic” questions to offer so far ...

Will be happy to answer your questions …

Will be also happy to continue discussions

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