Merging the DOLCE and PSL Upper Ontologies

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Motivation

- DOLCE and PSL appear to have several commonalities in their axiomatizations of time, process, and participation.
- Determine whether one upper ontology can be interpreted in the other by using techniques from ontology verification.
- Examine the model-theoretic properties of both ontologies and how to bridge them together.

The Process Specification Language (PSL)

- Ontology designed to facilitate the correct and complete exchange of process information among manufacturing systems [1].
- Organized into a core theory, T_{psl_core}, and a set of partially ordered extensions ($T_{occtree}$, $T_{subactivity}$, T_{atomic}, $T_{complex}$, and T_{actocc}).
- Only concepts found in T_{psl_core} correspond to the concepts found in DOLCE.

Descriptive Ontology for Linguistic and Cognitive Engineering (DOLCE)

- A *foundational ontology* developed by the Laboratory for Applied Ontology in Trento, Italy.
- Captures ontological categories that underlie natural language and common sense in *first-order logic*.
- Intended to clarify any implicit assumptions between existing ontologies or linguistic resources such as WordNet.
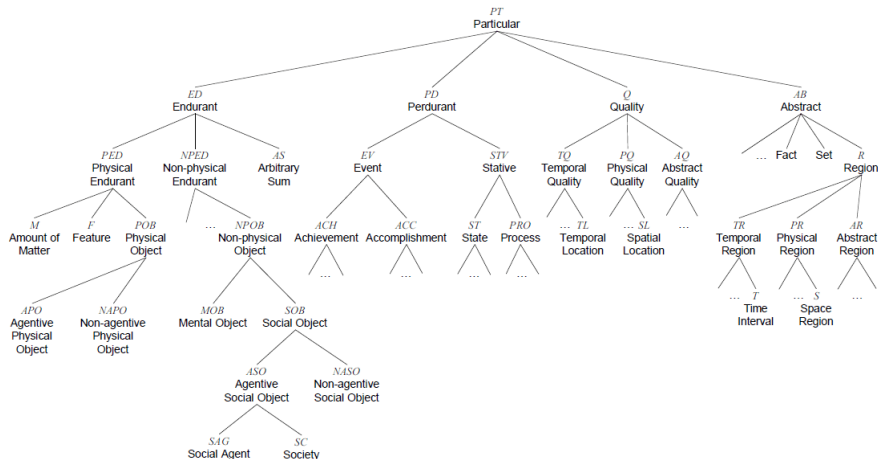
DOLCE's Taxonomy

Figure: The DOLCE taxonomy (Figure 2 in [2]).

Similarities Between the Ontologies

- No relations in PSL intuitively correspond to the concepts of temporary parthood, constitution, or dependence within DOLCE.

- Both ontologies appear to have intuitions of perdurants/endurants and activity occurrences/objects being present and participating in some time construct, yet these intuitions seem to be quite different, and the relationship between the two ontologies is not obvious.

- Focus on three subtheories of DOLCE that axiomatize relationships between perdurants, endurants, and time intervals:

  1. Participation $T_{dolce\_participation}$
  2. Being Present $T_{dolce\_present}$
  3. Time Mereology $T_{dolce\_time\_mereology}$

Existing Techniques

- *Ontology Merging*: a new ontology is created from two ontologies.
- *Ontology Mappings*: formalized correspondences between the entities of two ontologies.
- *Bridge Axioms*: axioms that relate the terms of two or more ontologies together.

Our Approach

- We combine these three existing approaches in a more *formal* way.
- Our approach utilizes *ontology verification* in the process to ensure that the source theories, along with any new intermediary theories, are faithfully interpretable with one another.
- We provide direct mappings between the concepts in the ontologies through the use of *translation definitions* which are first-order axiomatizations of the interpretations between the ontologies.

Obstacles to Merging and Mapping

1. PSL-Core utilizes a time point ontology, which has an ordering but no mereology, and DOLCE utilizes a time interval ontology, which has a mereology but no ordering.

2. Participation in DOLCE is interval-based but, in PSL, it is point-based.

3. Both PSL-Core and DOLCE make different ontological commitments on how objects/endurants participate in activity occurrences/perdurants.

Obstacle #1: Merging Time Point and Interval Ontologies

- We utilize existing combined time ontologies to integrate time points and time intervals, and mereologies and orderings.
- Existing temporal ontologies found in COLORE can be used to analyze the interpretations between the DOLCE and PSL.
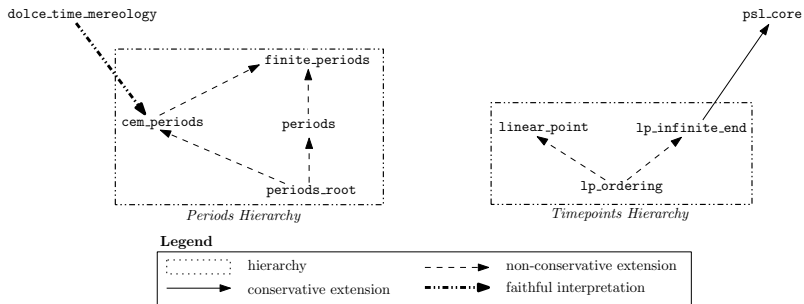
The Time Point & Interval Ontologies

Figure: The time point and interval ontologies.
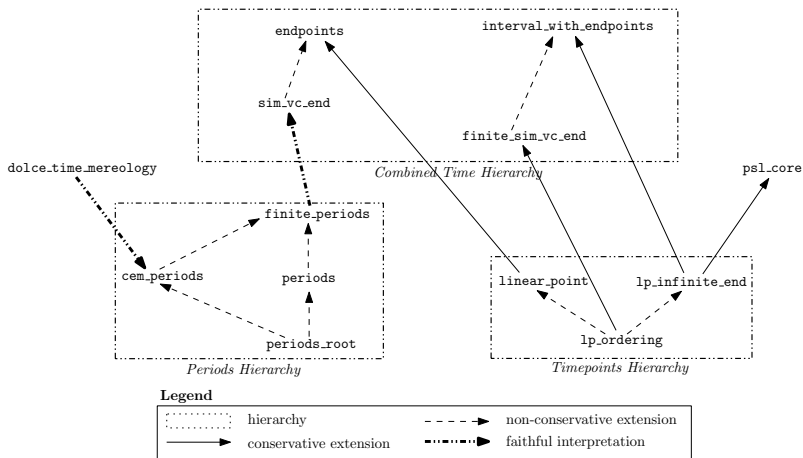
The Time Point & Interval Ontologies

Figure: The time point and interval ontologies.
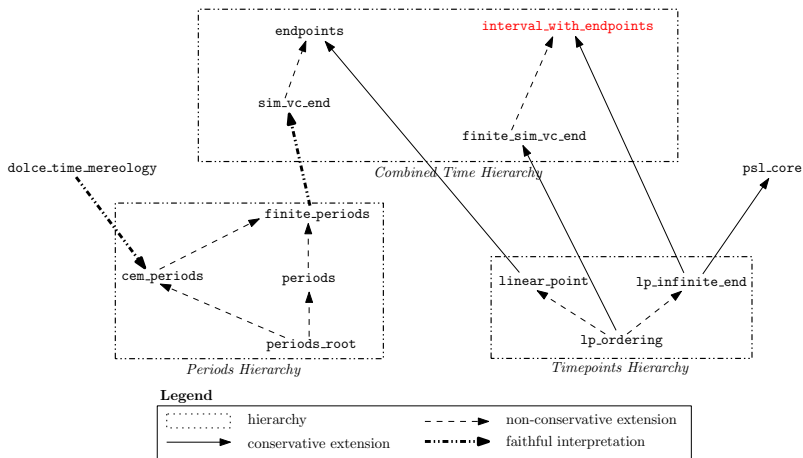
The Time Point & Interval Ontologies

Figure: The time point and interval ontologies.

Obstacle #2: Extending T_{psl_core}

- We extend T_{psl_core} with time intervals and interpret DOLCE in this new ontology.
- Within PSL, *activity occurrences* are considered to be occurrents, while *objects* are represented by continuants [1].
- The relation *participates_in*(x, o, t) is used to specify that an object x participates in activity occurrence o at time point t.
- Since DOLCE does not utilize time points but time intervals in its time mereology, an extension of T_{psl_core} must be created in order to map the *participates_in*(x, o, t) relation to a relation on time intervals.
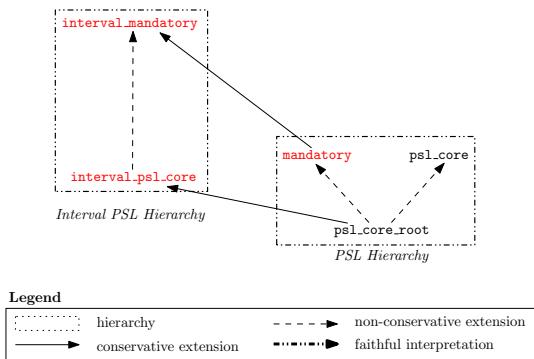
Extending T_{psl_core}

Figure: Extending T_{psl_core} to include time intervals.

Obstacle #3: Interpretations Between PSL-Core and DOLCE

The $T_{interval\_mandatory}$ and $T_{interval\_psl\_core}$ ontologies in $\mathbb{H}^{interval\_psl}$ are able to interpret the DOLCE modules of $T_{dolce\_participation}$ and $T_{dolce\_time\_mereology}$, respectively.
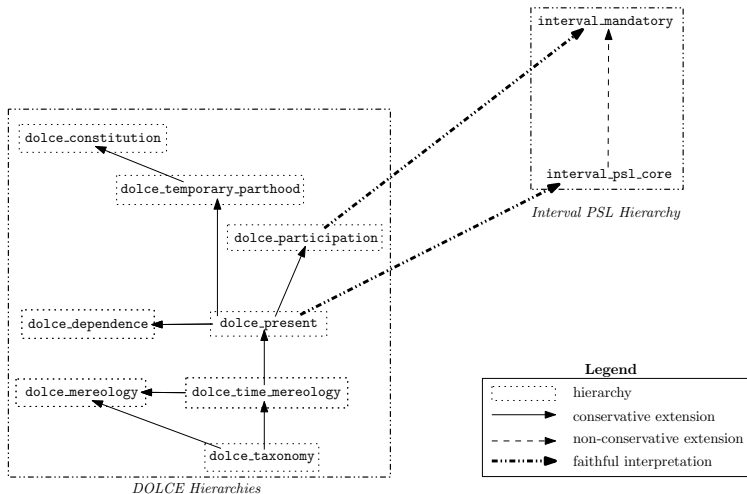
Interpretations Between $T_{interval\_psl\_core}$ and $T^*_{dolce\_present}$

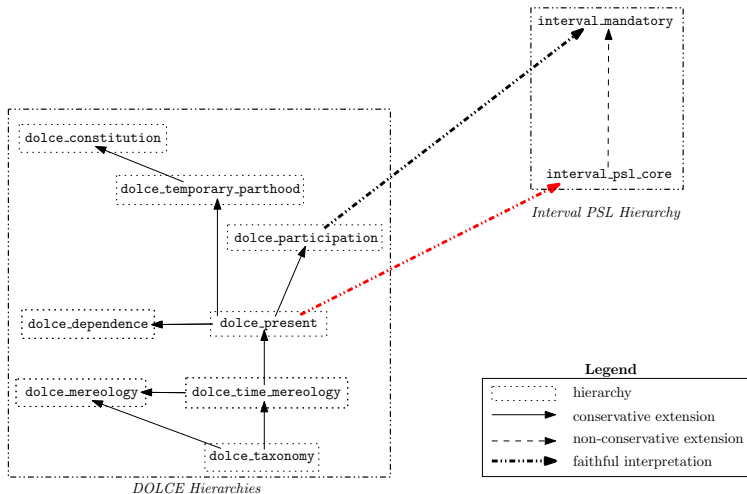### Translation Definition for Being Present

Being present in DOLCE is equivalent to the concept of an object or activity occurrence that exists in a given time interval, where the beginning of the time interval is the time point in which an object or activity occurrence starts, and that the end of the time interval is the time point in which the object or activity occurrence ends.

$$(\forall x \forall y \forall t \ (PRE(x, t) \equiv (object(x) \lor activity\_occurrence(x)) \land$$
$$timeinterval(t) \land beforeEq(beginof(x), beginof(t)) \land$$
$$beforeEq(endof(t), endof(x)))).$$

Interpretations Between $T_{interval\_psl\_core}$ and $T^*_{dolce\_present}$

Interpretations Between $T_{interval\_psl\_core}$ and $T^*_{dolce\_present}$

Interpretations Between $T_{interval\_psl\_core}$ and $T^{*}_{dolce\_present}$

DOLCE Hierarchies

Interval PSL Hierarchy

Parthood
$\forall t_1 \forall t_2 \ (P(t_1, t_2) \equiv timeinterval(t_1) \wedge$
$timeinterval(t_2) \wedge$
$beforeEq(beginof(t_2), beginof(t_1)) \wedge$
$beforeEq(endof(t_1), endof(t_2)))$

Legend

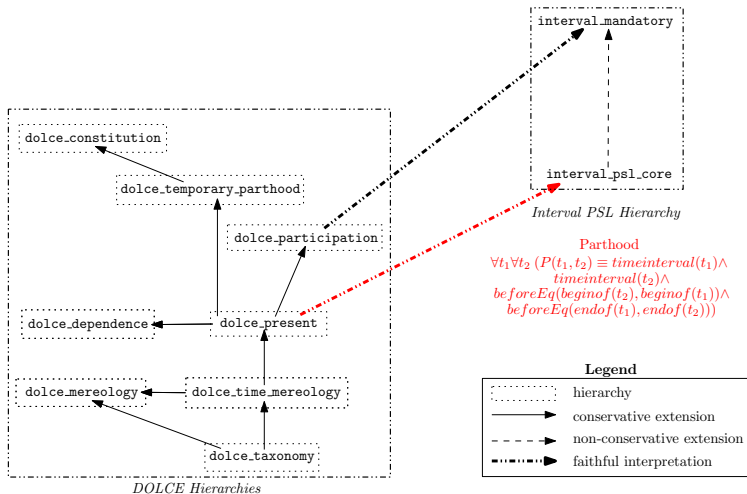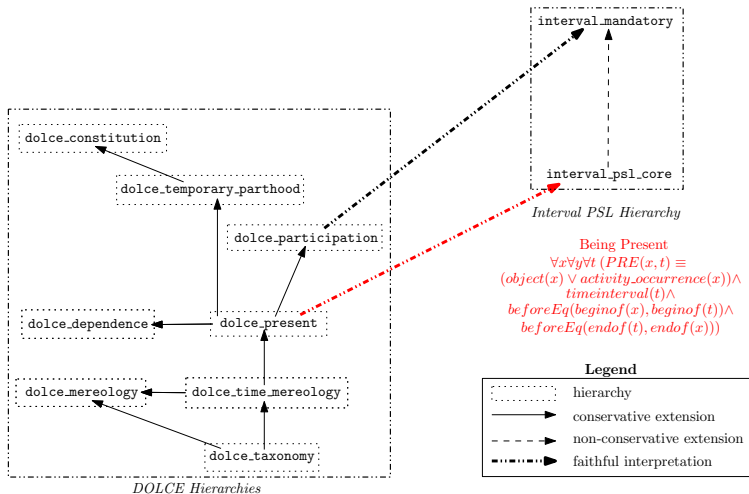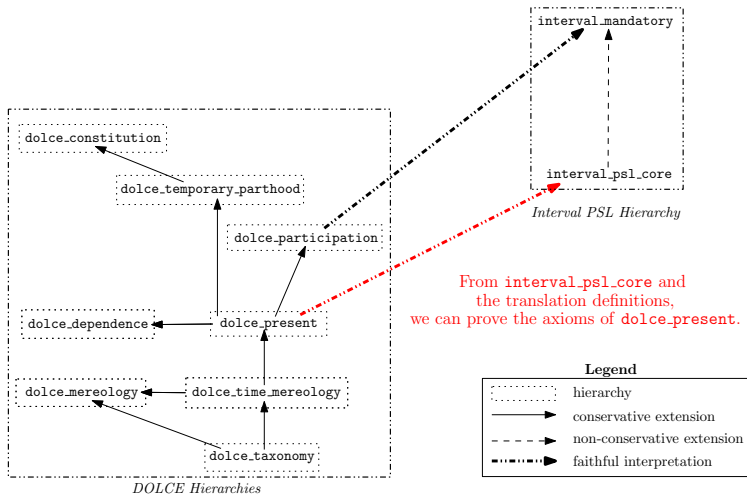|	
....	hierarchy
⟶	conservative extension
– – –▶	non-conservative extension
·■·■·■▶	faithful interpretation

Interpretations Between $T_{interval\_psl\_core}$ and $T^*_{dolce\_present}$

Interpretations Between $T_{interval\_psl\_core}$ and $T^*_{dolce\_present}$

From interval_psl_core and
the translation definitions,
we can prove the axioms of dolce_present.

Legend

⬚⬚⬚	hierarchy
—→	conservative extension
- - →	non-conservative extension
▪▪▪▪→	faithful interpretation

DOLCE Hierarchies

Interval PSL Hierarchy

Interpretations Between $T_{interval\_mandatory}$ and $T_{dolce\_participation}$
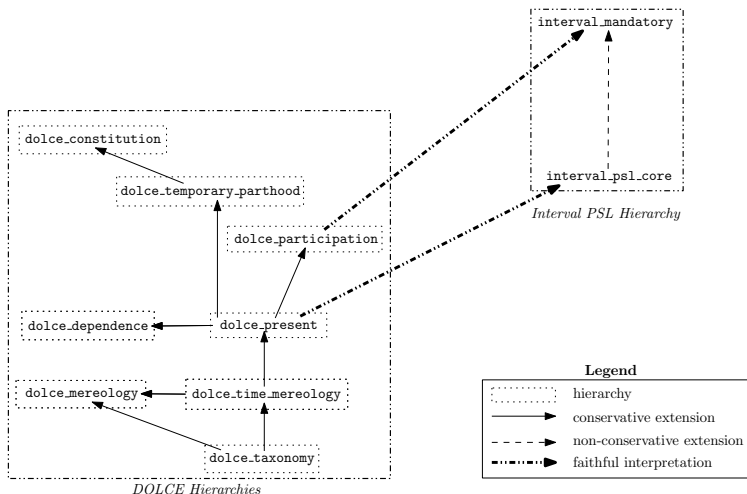
Since DOLCE contains axioms for participation, we make the observation that the participation relation, $PC(x, y, z)$, is similar to the *participates_in*(x, o, t) relation found in PSL.
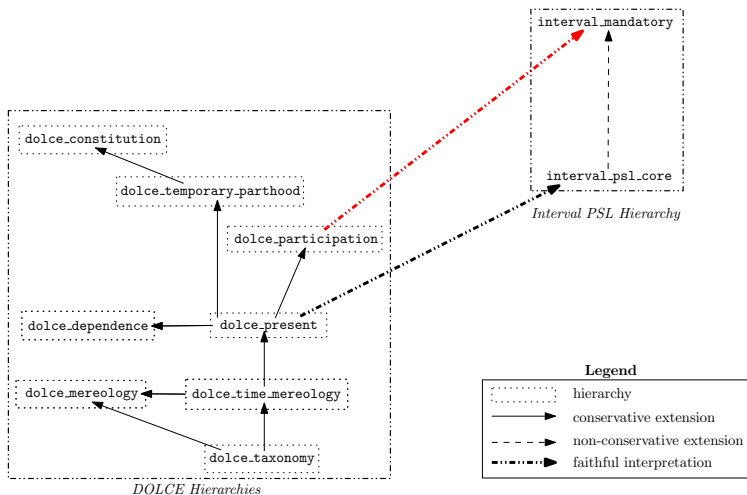
Translation Definition for Participation

We can state that any x and y that participate in z in DOLCE is equivalent an object x that participates in an activity occurrence y in a given time interval z and, at *every* time point in that interval, x *participates* in y.

$$\forall x \forall y \forall z \forall t \, (PC(x, y, z) \equiv object(x) \wedge$$
$$activity\_occurrence(y) \wedge timeinterval(z) \wedge$$
$$(beforeEq(beginof(z), t) \wedge beforeEq(t, endof(z)) \supset$$
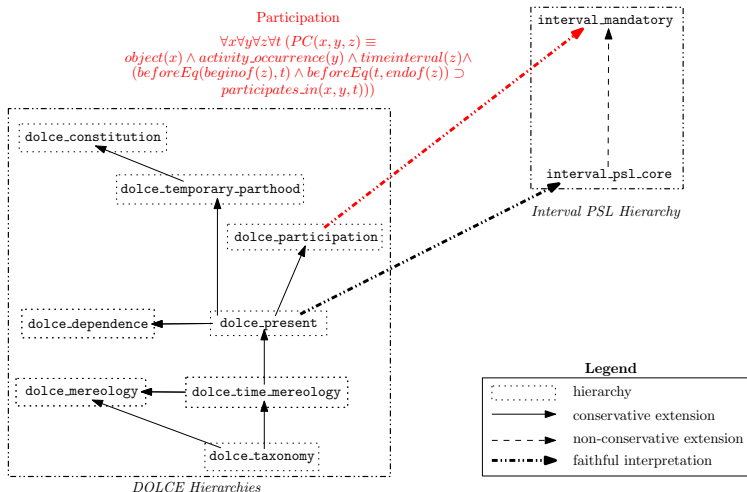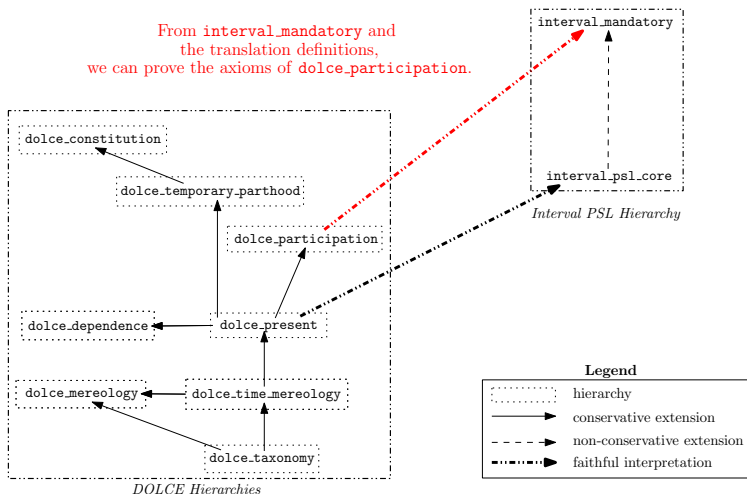$$participates\_in(x, y, t)))$$

Interpretations Between $T_{interval\_mandatory}$ and $T_{dolce\_participation}$

Interpretations Between $T_{interval\_mandatory}$ and $T_{dolce\_participation}$

Interpretations Between $T_{interval\_mandatory}$ and $T_{dolce\_participation}$

Participation

$$\forall x \forall y \forall z \forall t \, (PC(x, y, z) \equiv$$
$$object(x) \wedge activity\_occurrence(y) \wedge timeinterval(z) \wedge$$
$$(beforeEq(beginof(z), t) \wedge beforeEq(t, endof(z)) \supset$$
$$participates\_in(x, y, t)))$$

interval_mandatory

dolce_constitution

dolce_temporary_parthood

interval_psl_core

Interval PSL Hierarchy

dolce_participation

dolce_dependence   dolce_present

dolce_mereology   dolce_time_mereology

dolce_taxonomy

Legend

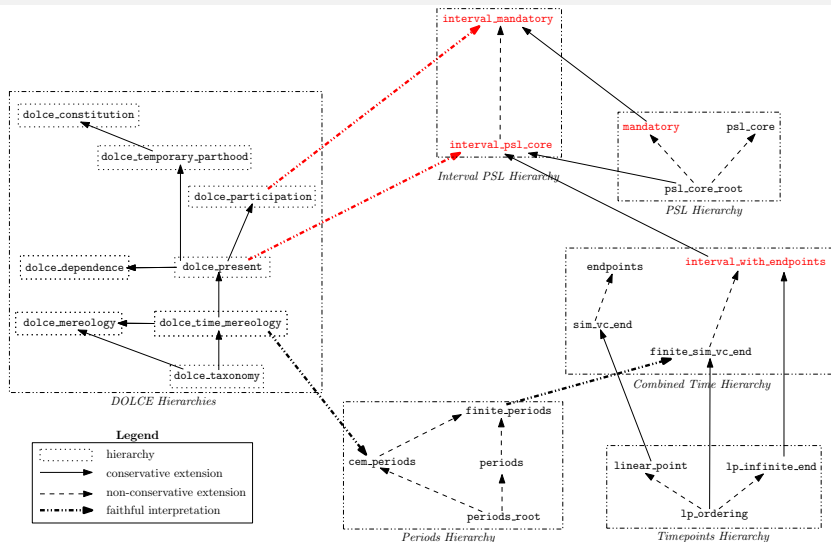|	
┈┈┈▶	hierarchy
───▶	conservative extension
---▶	non-conservative extension
■·■·■▶	faithful interpretation

DOLCE Hierarchies

Interpretations Between $T_{interval\_mandatory}$ and $T_{dolce\_participation}$

From `interval_mandatory` and
the translation definitions,
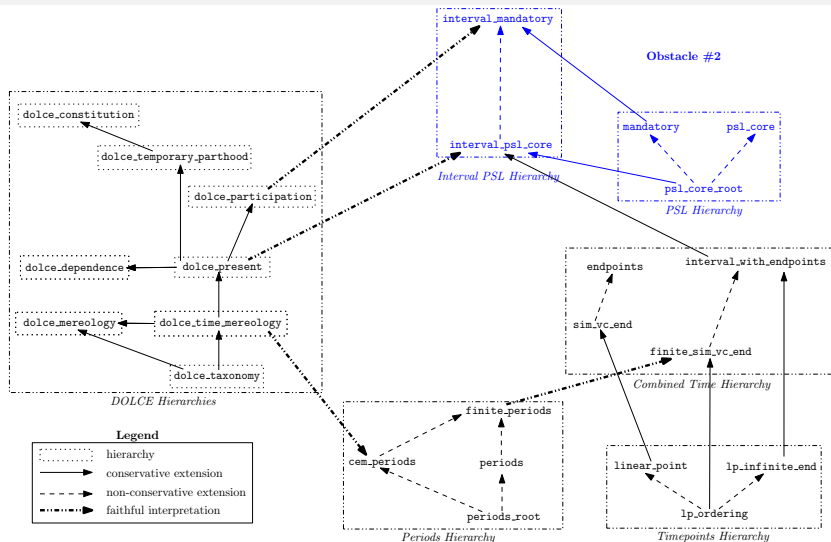we can prove the axioms of `dolce_participation`.

interval_mandatory

interval_psl_core

Interval PSL Hierarchy

dolce_constitution

dolce_temporary_parthood

dolce_participation

dolce_dependence ← dolce_present

dolce_mereology ← dolce_time_mereology

dolce_taxonomy

DOLCE Hierarchies

Legend

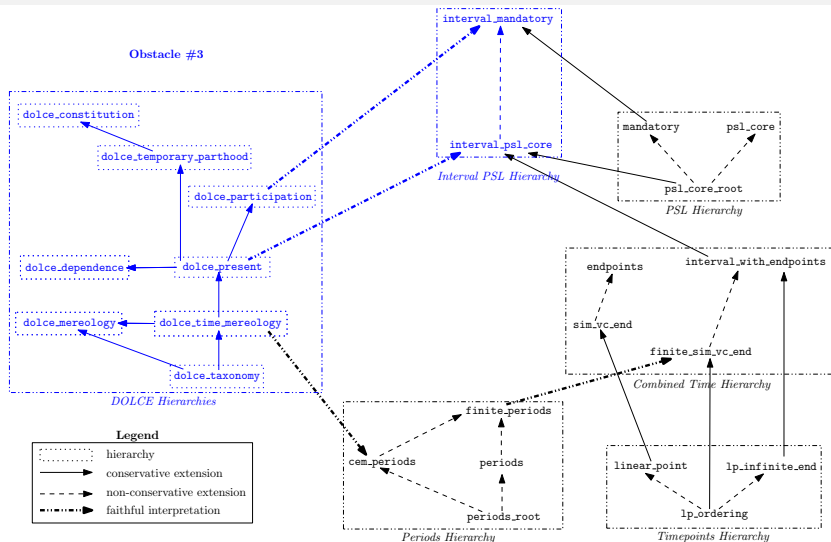|	
....	hierarchy
——→	conservative extension
- - -→	non-conservative extension
·—·—·→	faithful interpretation

Putting It All Together

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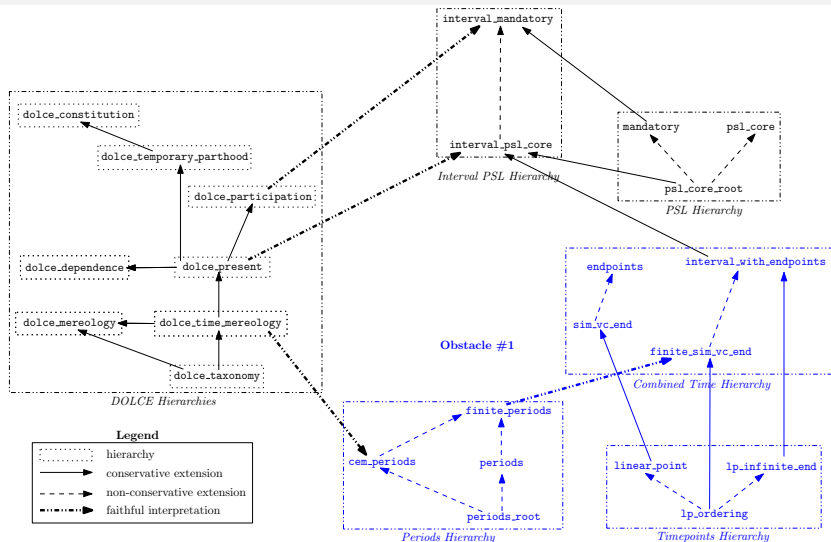
Putting It All Together

Putting It All Together

Ontologies & Mappings as Bridges I

- When direct mappings cannot be specified between ontologies, new ontologies can be designed to serve as *bridges* between the ontologies, and which then allow mappings to be specified.
- Faithful interpretations specified between DOLCE and ontologies within COLORE have shown that multiple 'bridges' were needed to analyze $T_{dolce\_participation}$ and $T_{dolce\_present}$ with theories in COLORE:
  1. The Combined Time hierarchy *bridges* the Time Points and Periods hierarchies together to allow us to merge ontologies of time points and time intervals.
  2. The Interval PSL hierarchy *bridges* both the PSL and DOLCE ontologies together to allow us to do the mapping between them and to identify the faithful interpretations of mereology and orderings in both time points and time intervals.

Ontologies & Mappings as Bridges II

- The methodology presented in this paper is based on techniques for ontology verification that use an ontology repository to specify faithful interpretations among ontologies. It should therefore be applicable to any set of ontologies which have been verified.

- Ontologies which have not been explicitly modularized still pose a challenge, and the interplay between ontology merging and decomposition merit further exploration.

- We were able to look at the DOLCE and PSL ontologies *modularly* and focus on modules where there was overlap.

References & Additional Links

[1] GRÜNINGER, M.

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[2] MASOLO, C., BORGO, S., GANGEMI, A., GUARINO, N., AND OLTRAMARI, A.

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