FORT: a modular Foundational Ontological Relations Theory for representing and reasoning over the composition of tangible entities – Observations from cultural heritage

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Doctoral Thesis defended on September 28th, 2023 in front of the jury members:

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I. Patrimalp - the community:

The development of interdisciplinary and integrated centered around a **heritage object**, studied in a cross-disciplinary aspect, within this multidisciplinary field.

II. Patrimalp - the objects

The heritage object is conceived as a boundary object: [1,2]

i. Acquires interpretative flexibility
ii. Structures heterogeneous disciplines
iii. Forms an intersection point facilitating cooperation

→ Recently used in France in the context of emergence heritage sciences [3], and is at the core of Patrimalp.

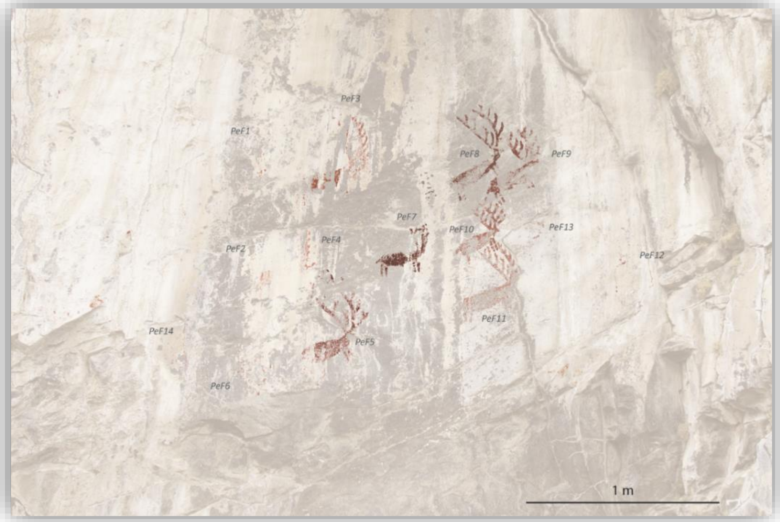
→ **Cross-disciplinary aspect**: unique identity, robust interpretation

➢ Examples:

- parietal paintings on archaeological sites.
- applied brocades on savoyard medieval sculptures.

1. **S. L. STAR, J. GRIESEMER (1989)** “Institutional ecology, ‘Translations’, and Boundary objects: amateurs and professionals on Berkeley’s museum of vertrebate zoologie”, Social Studies of Science, 19(3), p. 387-420.
2. **P. TROMPETTE, D. VINCK (2009)** « Retour sur la notion d’objet-frontière », Revue d’anthropologie des connaissances, vol. 3, n° 1, p. 5-27;
3. **E. ANHEIM et al (2015)** « Micro-imagerie de matériaux anciens complexes (I) », Revue de Synthèse,136(6), p. 329-354 : http://dx.doi.org/10.1007/s11873-014-0249-8

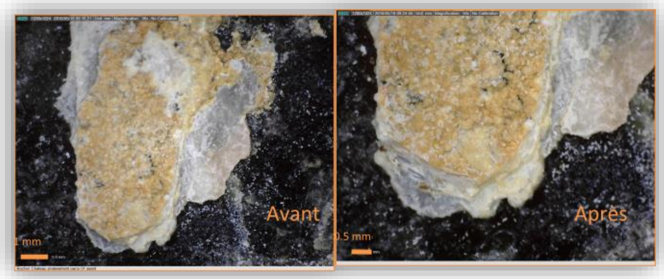
II. Patrimalp - the objects: Rock art sites

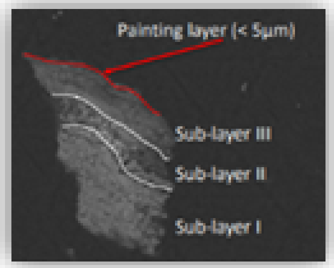


A group of large red deer with oversized antlers painted in a concave area of the cliff forming a niche facing east.

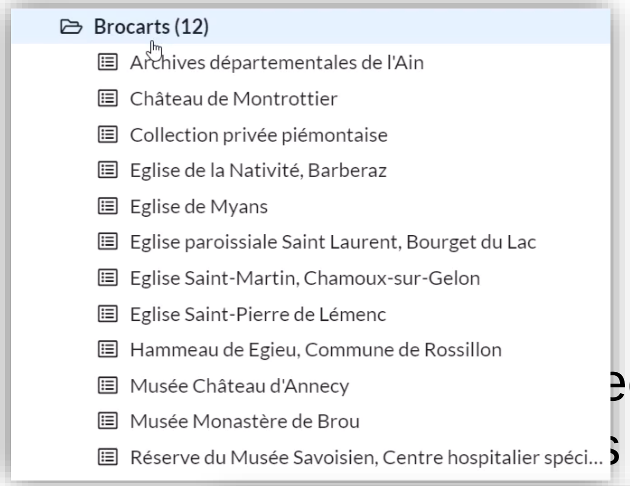
Micro-sample from rock's surface

Schematic figures composed of anchor-shape figures, grids, comb-shape figures…





Patrimalp - the objects: Brocades



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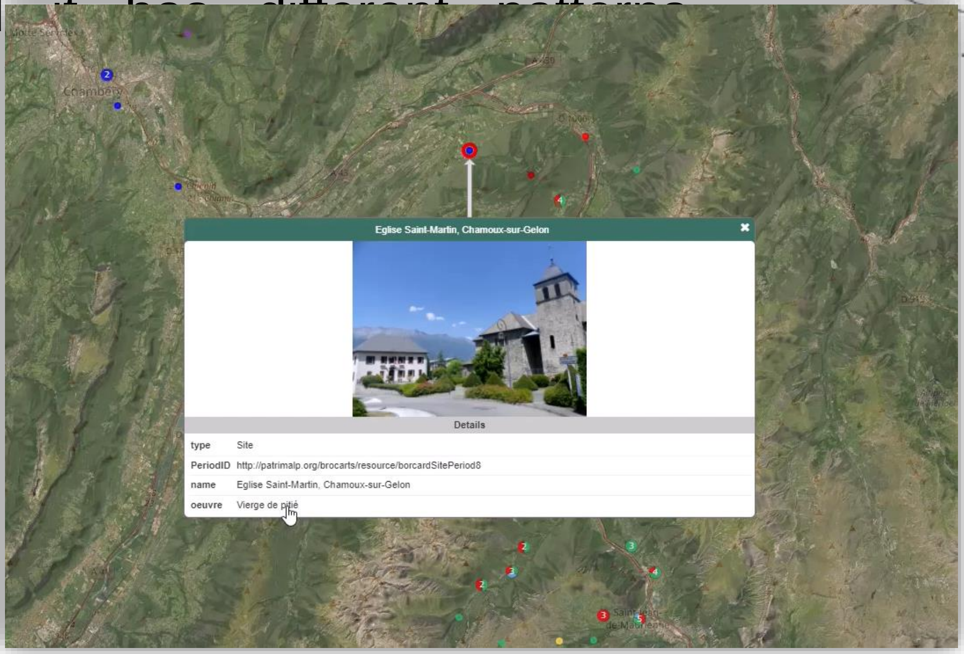

III. Patrimalp - the goal:

→ Heritage entities: **Tangible entities** vs. Intangible entities

→ Aspects of study: Intangible aspects, Spatiotemporal aspects, **Materiality aspect**, etc.

Enabling **the formation and transmission of new knowledge about the materiality** of a tangible entity that is a heritage object.

- Understand the materiality of the tangible entity & link entities that have similar composition
- Document the results & share knowledge across disciplines for re-use and reasoning
- Transmit this knowledge for future generations for preservation & restoration purposes
- Gain insights about the entity's intangible aspects

IV. Patrimalp - the challenge:

To find/build an **ontology** as a formal specification of a shared conceptualization centered on the « **materiality of the entity** » enabling « **understanding and representation** ».

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Common understanding: Ontology

- Common entity: materiality of the tangible entity
- Shared goal: understanding & representation to form new knowledge

"An ontology is a formal and explicit specification of a shared conceptualization" [1,2,3]

Formal and explicit specification: Formal logic e.g. FOL, Conceptual modeling language e.g. UML, Semantic Web language e.g. OWL, etc.

Shared conceptualization: The abstract representation of knowledge (reality)

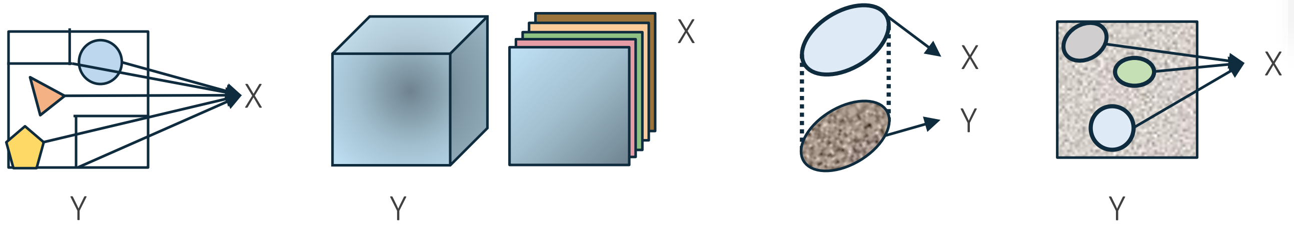
1. **R. Gruber (1993)** "A translation approach to portable ontology specifications." Knowledge acquisition, vol. 5, no. 2, pages 199–220, 1993;
2. **N. Guarino, P. Giaretta (1995)** "Ontologies and knowledge bases", Towards very large knowledge bases, pages 1–2, 1995;
3. **N. Guarino et al. (2009)** "What is an ontology?" Handbook on ontologies, pages 1–17, 2009.

IV. Patrimalp - the requirements:

A. Only an **ontology of composition relations** can represent the materiality of a tangible entity.

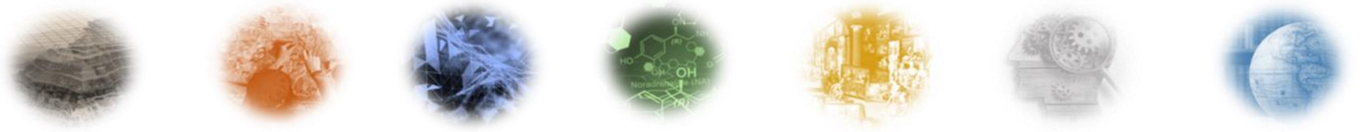
The modeling scope of this ontology?

- An entity and its parts
- An entity its similar entities under specific criteria
- An entity and its location
- An entity and its constitution elements



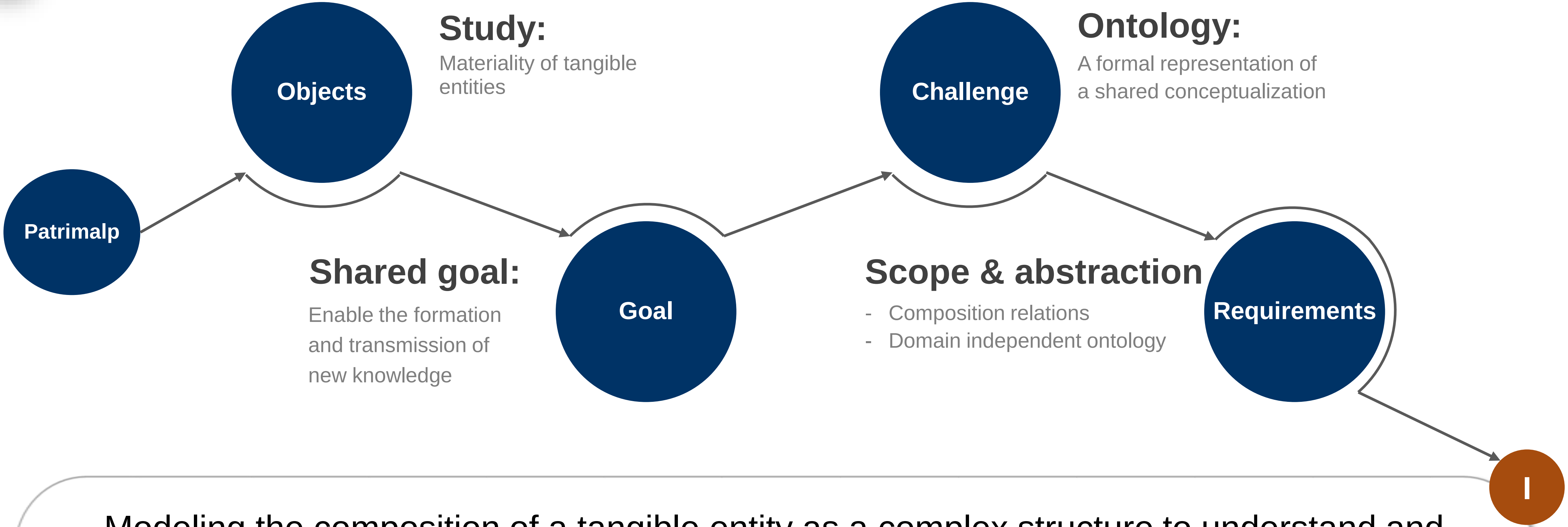
B. The ontology should be **domain-independent** in order to achieve interdisciplinary integration.

The abstraction level of this ontology?



Geological data | Archeological data | Materials data | Colors data | History of Arts data | Social sciences data | Geographical data

VI. Research Proposal:



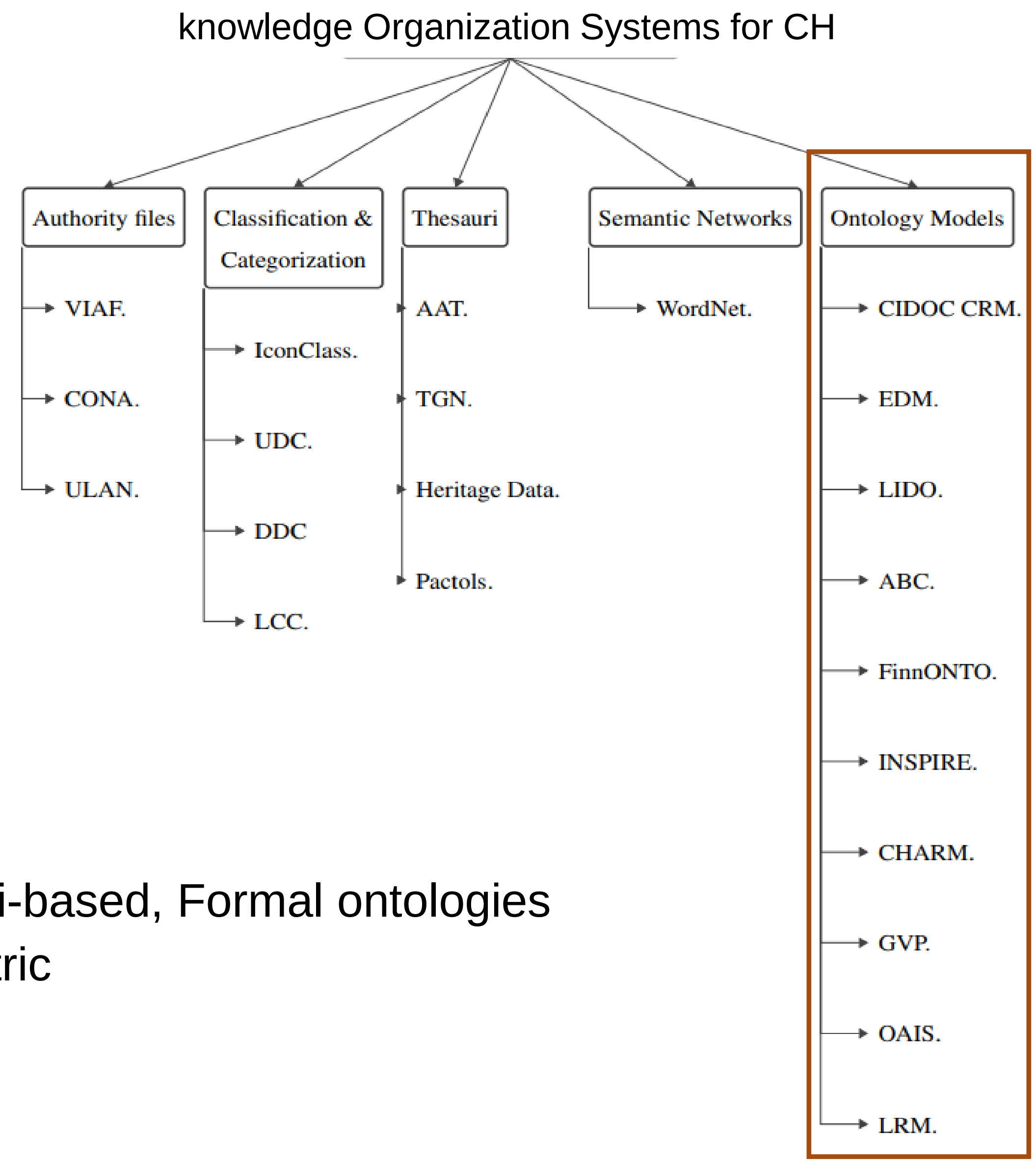
Modeling the composition of a tangible entity as a complex structure to understand and represent its materiality, using composition relations.

→ Literature review on **ontologies in the CH field** that can respond to this **modeling problem**.

Table of contents

- Managing Cultural Heritage (CH) data:
  Memory institutions, Organizational institutions and infrastructures, Information systems

- Organizing CH data: knowledge Organization Systems
  Authority files, Classification and categorization systems, Thesauri, Semantic Networks, Ontology models



Classification Criteria for ontology models:

- Geographical scale: National, International
- Semantics and formality level: Metadata-based, Thesauri-based, Formal ontologies
- Modeling scope: Data-centric, Spatial-centric, Entity-centric

A criteria-based selection of relevant approaches:

Geographical Scale	Ontology Model
National	FinnONTO
International	CIDOC CRM, Europeana, LIDO, ABC,Inspire, CHARM, GVP, OAIS, LRM

Semantics & Formality level	Ontology Model
Metadata-based models	EDM, LIDO, ABC
Thesauri-based models	FinnONTO, GVP
Formal Ontologies/CDM	CIDOC CRM, CHARM, Inspire, EDM, OAIS, LRM

Modeling scope	Ontology Model
Data-centric	LIDO, ABC, LRM, OAIS
Spatial-centric	Inspire, CRMarchaeo
Entity-centric	CIDOC CRM, EDM, FinnONTO, CHARM

- **CIDOC CRM**
- **EDM**
- **CHARM**

Investigate their **composition relations** (structural & spatial)

Composition Relations

An analysis of the relevant models: CIDOC Conceptual Reference Model (CRM) V7.1.2

"An 'ontology' for CH information i.e. it describes in a formal language the explicit and implicit concepts and relations relevant to the documentation of CH". (https://cidoc-crm.org/node/202)

Structural relations:

- P45 consists of
- P46 composed of

Spatial relations:

- P53 has former or current location
- P54 has current permanent location
- P55 has current location (currently holds)
- P59 has section (is located on or within)
- P89 falls within (contains)

CIDOC CRM could be used as a complementary model for representing the spatiotemporal aspects of a CH entity.

Composition Relations

An analysis of the relevant models: The Europeana Data Model (EDM)

"Its goal is to collect metadata about CH entities from European CH institutions, and to enable the search and discovery of these items. It is aimed at being an integration medium for collecting, connecting and enriching the descriptions provided by Europeana's content providers". (Europeana Data Model | Europeana PRO)

Structural relations:

- ore: aggregates – from the OAI Object Reuse and Exchange (ORE) namespace
- dcterms: has Part – from the Dublin Core namespaces

Spatial relations:

- edm: current Location
- dcterms: spatial

EDM could be used as a complementary data model for describing other representations as descriptive properties for the object.

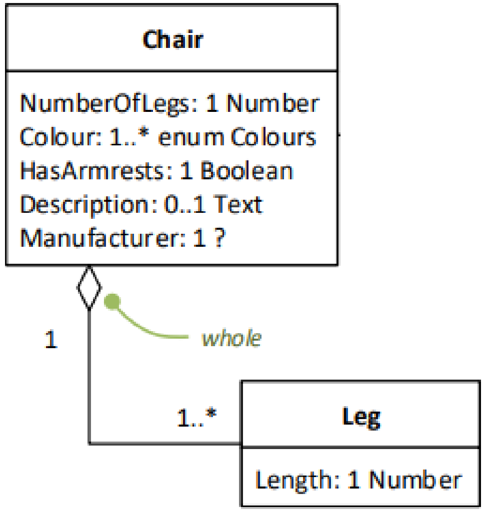
Composition Relations

An analysis of the relevant models: The Cultural Heritage Abstract Reference Model (CHARM)

"It is an abstract reference model intended to be used by a wide and diverse range of organizations and individuals in order to achieve a common understanding about anything that may be the recipient of cultural value". (Overview of CHARM (charminfo.org))

Aggregation relationships:

- SubPlace (a Place and itself)
- SubDivision (a LandDivision and itself)
- Support (a MaterialEntity and a MaterialAspect)
- Content (a StructureEntity and a MaterialEntity)
- Fragment (a CompleteStructure and a StructureFragment, etc.)
- Substructure (a CompleteStructure and itself)
- SubOject (a CompleteObject and itself)
- Element (a ConstructedStructure and a ConstructiveElement)



CHARM could be used as a user-friendly complementary model to construct domain-specific CH ontologies enabling its employment by domain institutions.

III. Synthesis:

I

Modeling the **composition** of a tangible entity as a **complex structure** to understand and represent its **materiality**, using **composition relations**.

→ Literature review on ontologies in the CH field that can respond to this modeling problem.

COMPLETED

	CIDOC CRM	EDM	CHARM
Pros	Spatiotemporal elements	Descriptive elements	Domain-specific elements
Cons	Composition (structural and spatial) relations		

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II

Acquiring a number of foundational ontological, structural and spatial, relations that enable representing the composition of a tangible entity, within a theory.

→ Literature review on studies on foundational relations to find a taxonomy/theory.

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I. Overview:

What?

Formal and (often) **primitive** relations that play a fundamental role in ontologies.

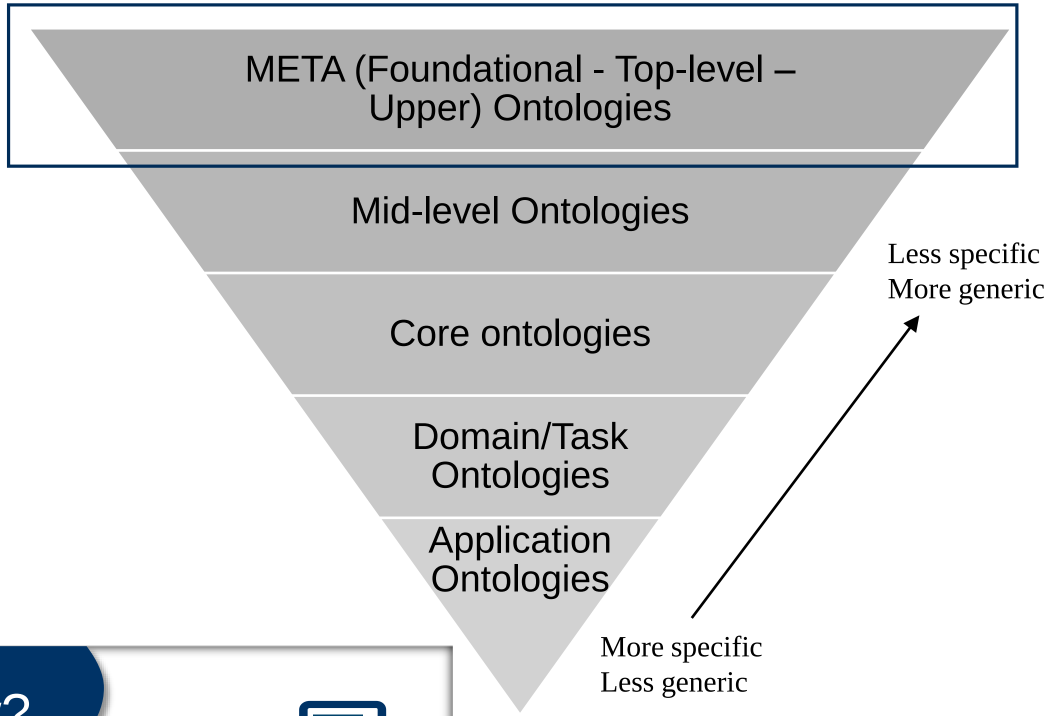
Where?

Applied Ontology field:

- Entities & entities
- Entities & properties

How?

- Taxonomies
- Theoretical Frameworks



II. Categorization:

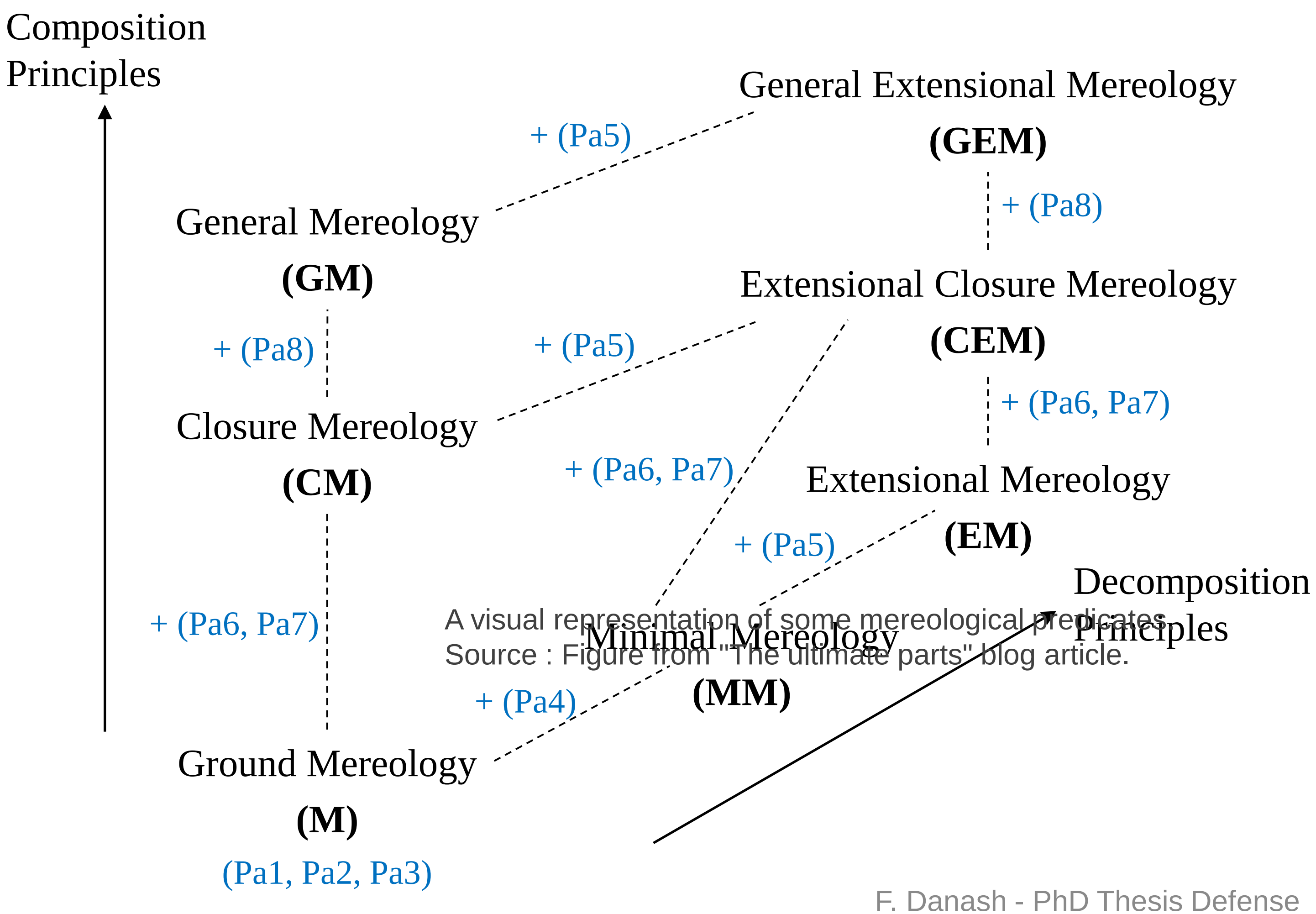
- **Spatial Relations**
  - Formal Applied Ontological studies
    - Spatial Location
      - **Location**
        - Varzi, 1996
        - Casati, 1999
        - Varzi, 2007
    - Spatial Connection
      - **Topology**
        - Randell, 1992
        - Randell, 1989
        - Cui, 1993
    - Formal Parthood
      - **Mereology**
        - Simons, 1987
        - Varzi, 2003
    - **Mereotopology**
      - Varzi, 1993 – 1996 - 2007
      - Casati, 1999
- **Structural Relations**
  - Cognitive Sciences
    - Part-Whole Taxonomies
      - **Meronomy**
        - Iris, 1986
        - Winston 1987
        - Gerstl & Pribbenow 1995 - 1996
  - Combining both Meronomy & Mereology
    - Conceptual Modeling Lang
      - UML
        - Odell
        - Opdahl
        - Barbier
        - Shanks
        - Berardi
        - Pitrick. M.
      - ER/ ORM
        - Keet, 2006
    - Knowledge Representation Lang
      - DL
        - Schulz
        - Sattler
        - Artale
      - FOL
        - Guizzardi, 2005
        - Keet, 2008
      - Bittner, 2005
    - Properties of part-whole relations

Legend:

- Relation
- Field of study
- Approach

II. Categorization:

Mereology : Formal theories of Parts P(x,y)



A visual representation of some mereological predicates.
Source : Figure from "The ultimate parts" blog article.

(Pa1)	Reflexive	$P(x,x)$
(Pa2)	Transitive	$P(x,y) \land P(y,z) \rightarrow P(x,z)$
(Pa3)	Antisymmetric	$P(x,y) \land P(y,x) \rightarrow x = y$

(D1)	Proper-part	$PP(x,y) =_{df} P(x,y) \land \neg P(y,x)$
(D2)	Overlap	$O(x,y) =_{df} \exists z(P(z,x) \land P(z,y))$
(D3)	Underlap	$U(x,y) =_{df} \exists z(P(x, z) \land P(y, z))$
(D4)	Overcross	$OC(x,y) =_{df} O(x, y) \land \neg P(x, y)$
(D5)	Undercross	$UC(x,y) =_{df} U(x, y) \land \neg P(y, x)$
(D6)	Proper-overlap	$PO(x,y) =_{df} OC(x, y) \land OC(y, x)$
(D7)	Proper-underlap	$PU(x,y) =_{df} UC(x, y) \land UC(y, x)$

(Pa4)	$PP(x, y) \rightarrow \exists z(P(z, y) \land \neg O(z, x))$
(Pa5)	$\neg P(y, x) \rightarrow \exists z(P(z, y) \land \neg O(z, x))$
(Pa6)	$U(x, y) \rightarrow \exists z \forall w (O(w, x) \leftrightarrow (O(w, x) \lor O(w, y)))$
(Pa7)	$O(x, y) \rightarrow \exists z \forall w (P(w, z) \leftrightarrow (P(w, x) \land P(w, y)))$
(Pa8)	$\exists x \phi \rightarrow \exists z \forall y (O(y, z) \leftrightarrow \exists x (\phi \land O(y, x)))$

III. Synthesis:

- Although studies on Mereology have provided a rigid formal framework for representing and assessing parthood relations, however, mereology have been shown
  - too weak to capture the distinctions that mark different types of ((part-whole)) relations
  - too strong to hold as a generalization of a theory of part-whole relations at a conceptual level

- Although studies on Meronomy have allowed for common-sense reasoning over part-whole relations in real life examples, they have been carried out in non-formal frameworks.

- Other efforts that have integrated the strengths of both (Meronomy & Mereology):
  - Guizzardi, 2005: Proposes an extension of mereology with a theory of Integral wholes
    - ➢ Distinguishes four types of relations based on « ontological entities », then types of relations based meta-properties e.g. shareabiliy and separability (using ontological dependence)
    - ➢ its primary objective was to support conceptual modeling tasks, particularly within the context of UML
    - ➢ This contribution evolved later to be the current UFO foundational ontology which we inspect later in
  - Keet and Artale, 2008: Develops a taxonomy of meronymic and mereological part-whole relations
    - ➢ Relies heavily on the axiomatization of DOLCE’s categories, & considers relations as part-whole typologies

- Spatial properties of entities

III. Synthesis:

II

Acquiring a number of foundational ontological, structural and spatial, relations that enable representing the composition of a tangible entity, within a theory.

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→ Literature review on studies on foundational relations to find a taxonomy/theory.

	Mereology	Meronomy	Location
Pros	Formality of relations	Common-sense reasoning on relations	Spatial properties
Cons	Unified theory of relations		

I

Modeling the **composition** of a tangible entity as a **complex structure** to understand and represent its **materiality**, using **composition relations**.

→ Literature review on ontologies in the CH field that can respond to this modeling problem.

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	CIDOC CRM	EDM	CHARM
Pros	Spatiotemporal elements	Descriptive elements	Domain-specific elements
Cons	**Composition (structural and spatial) relations**		

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Acquiring a number of foundational ontological, structural and spatial, relations that enable representing the composition of a tangible entity, within a theory.

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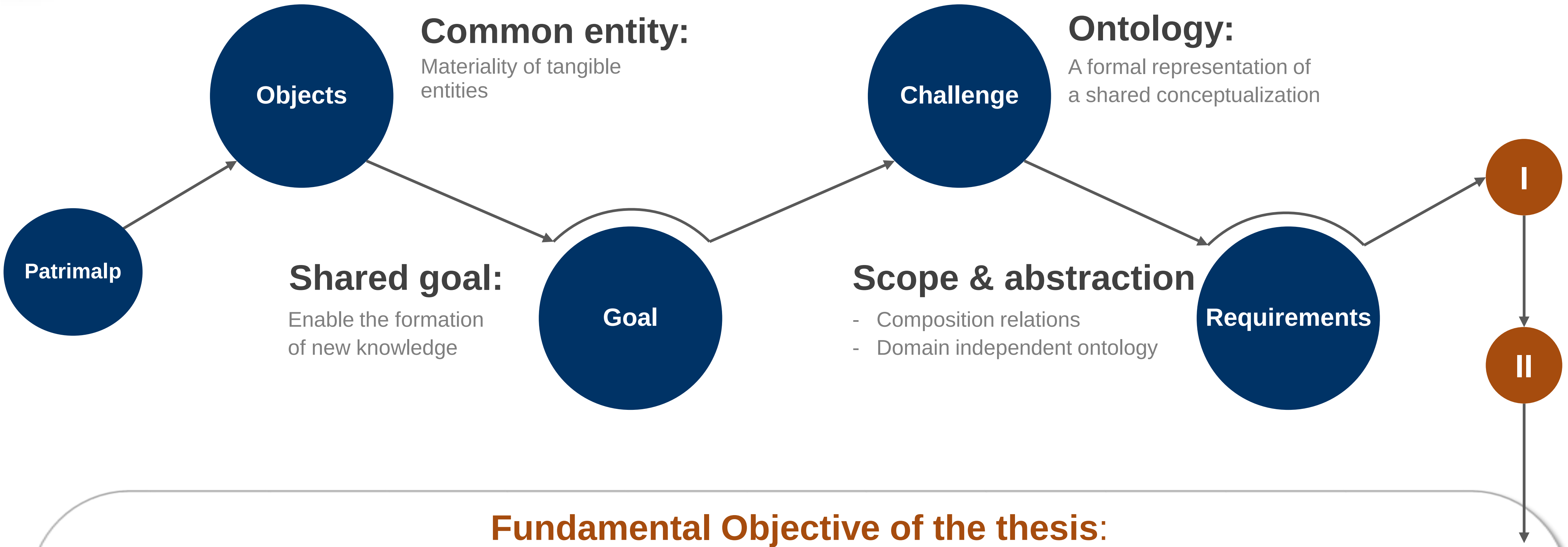
3 Contributions | Approach | I. Fundamental Objective:

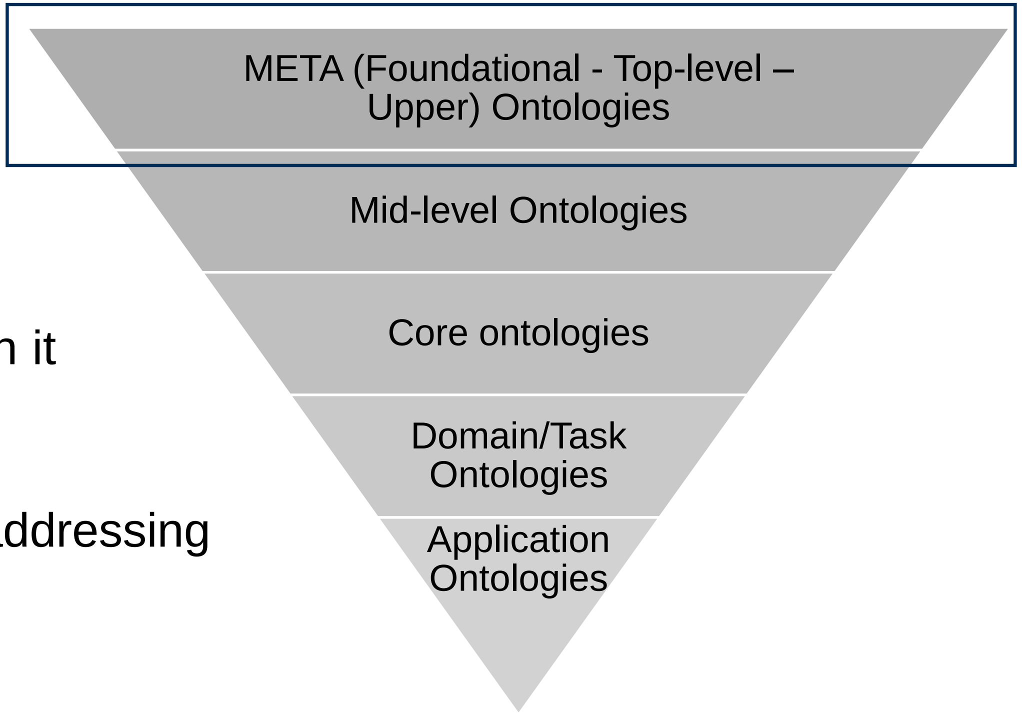


Fundamental Objective of the thesis:

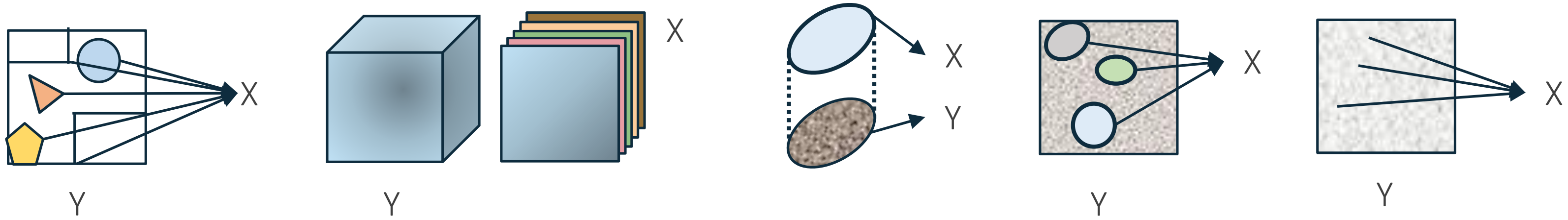
Ontology: Representing and modeling the composition of a tangible entity in general, and a Cultural Heritage tangible entity in particular, using **foundational ontological structural and spatial relations**, within a Applied Ontology approach [F. Danash et al., 2020].

F. Danash, D. Ziebelin, E. Chalmin, **A Parthood Approach for Modeling Tangible Objects' Composition TOC – An application on Cultural Heritage**. In Book: The 17th Extended Semantic Web Conference, ESWC2020. Lecture Notes in Computer Science, vol 12124. Conference short paper.

FORT : Foundational Ontological Relations Theory



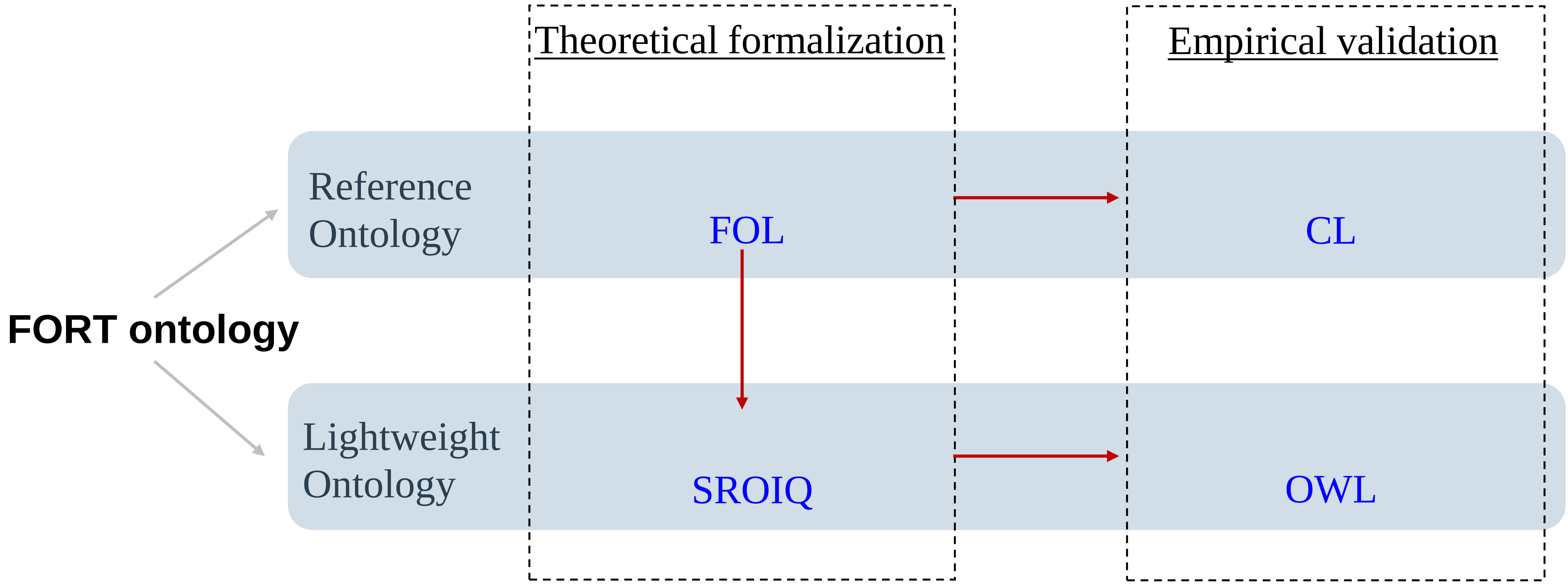
- meta-ontology in terms of both, the conceptualization which it specifies and the modeling language which it uses
- modular ontology i.e. consists of relations modules, each addressing a specific relation:
  - Parthood (& Dependence)
  - Membership
  - Location
  - Entity location
  - Constitution



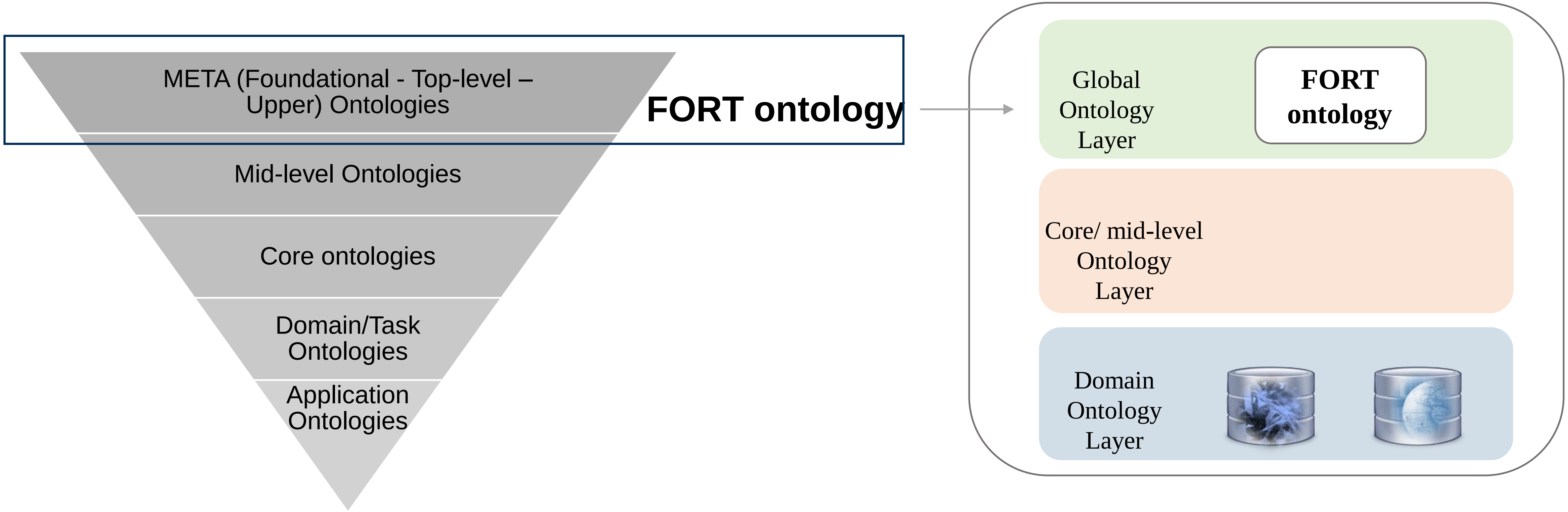
- relations-exclusive ontology i.e. independent of ontological categories

A. Modelisation Phase: Formalization of the FORT ontology

+ Addressing different specification choices: Expressivity & Decidability
+ Formalizing each at multiple levels: Theoretical & Empirical
+ Bridging the two specifications



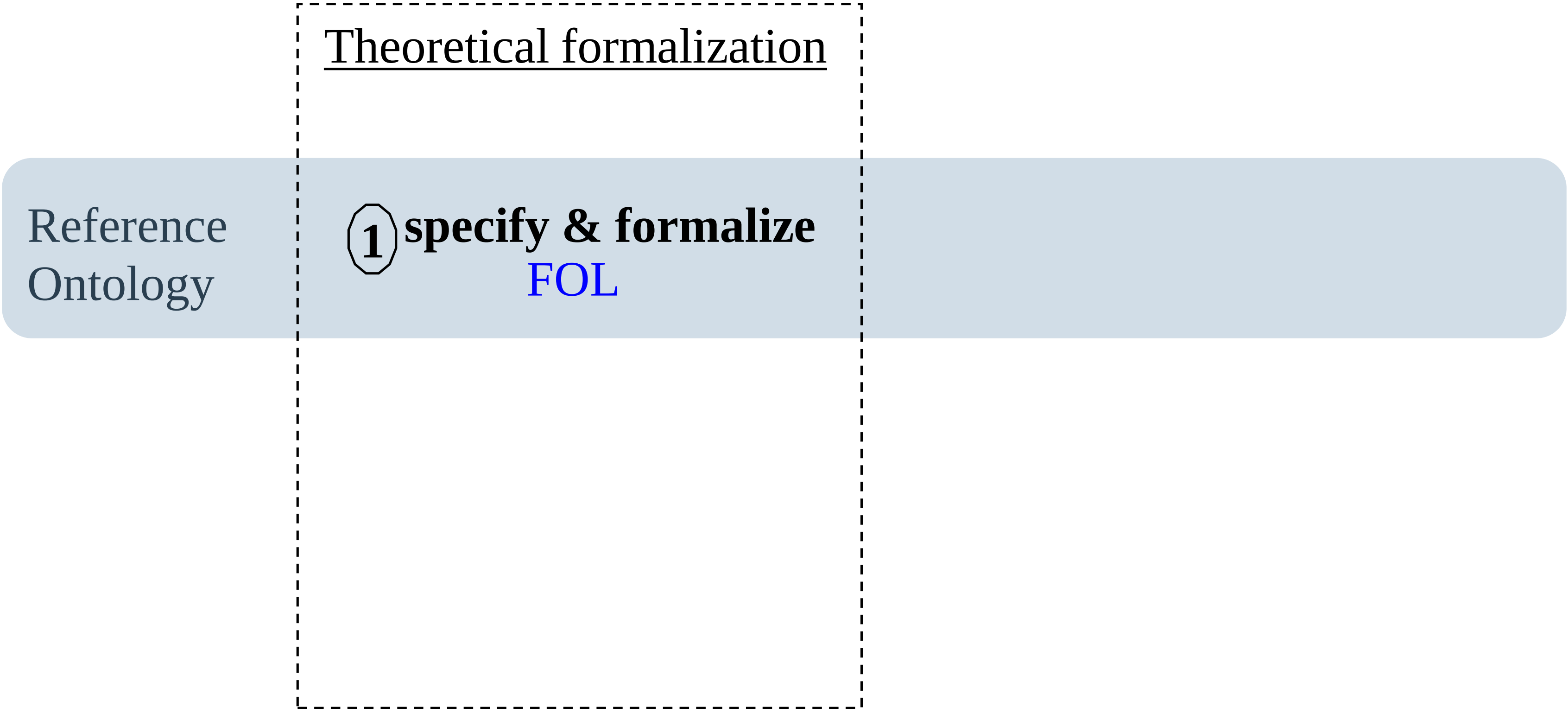
B. Employment Phase: Use of the FORT ontology for an interdisciplinary integration



I. The FORT reference ontology (FOL)

Methodology step 1:

Specify (conceptually) and formalize (logically) the relations of FORT in a highly-expressive formal language that is adequate for the formalization of foundational theories : a first-order logic (FOL) formalization of the FORT reference ontology.



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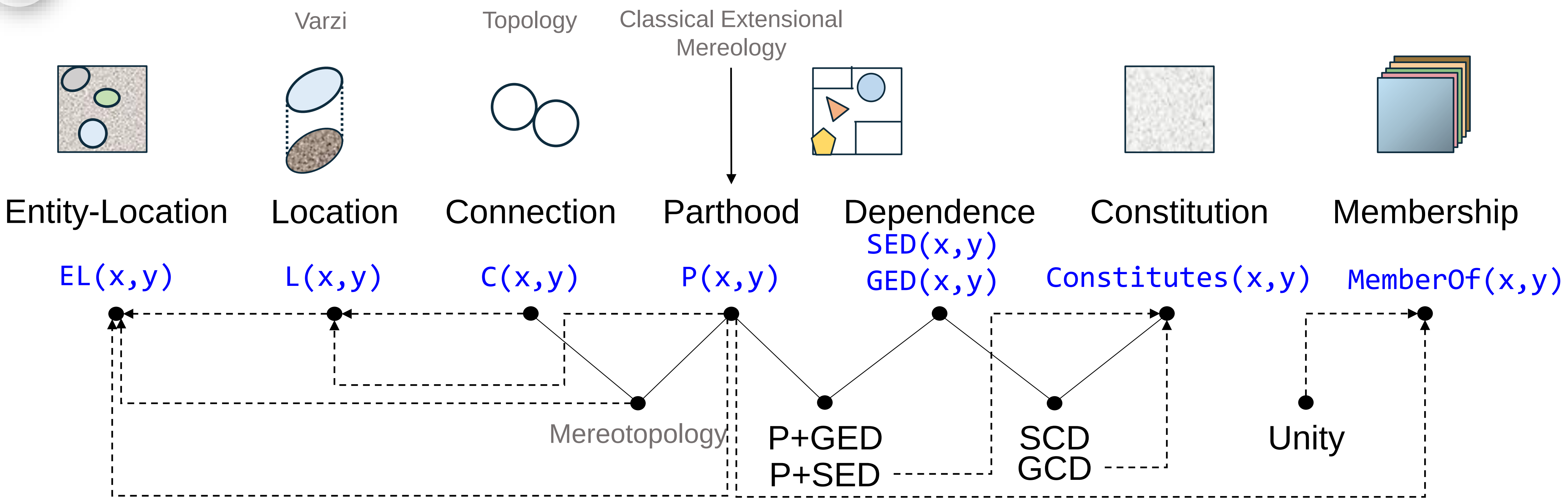


FORT:

- Modular ontology: intralinked & interlinked microtheories
- Meta-ontology
- Ontology of exclusive relations and rules

- Relation's name
- Relation's primitive
- Imported theory's name

——— Definitions

- - - - - Axioms

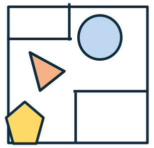
The FORT reference ontology (FOL)

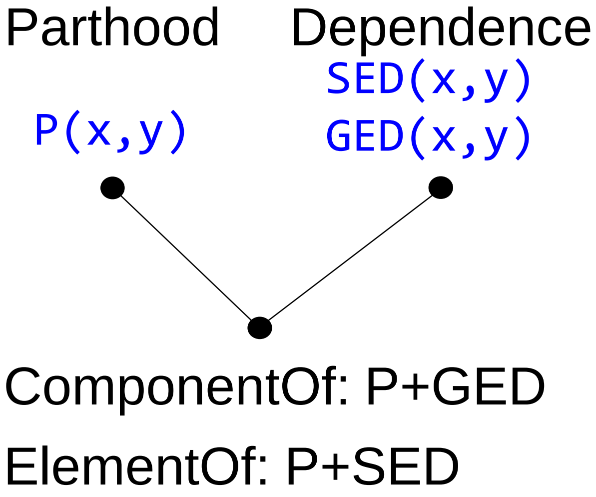
ComponentOf and ElementOf:

$(\forall x, y)\text{ComponentOf}(x, y) =_{df} P(x, y) \land GED(\phi(y), \varphi(x))$ (PDd1)

- $(\forall x, y, z)\text{ComponentOf}(x, y) \land \text{ComponentOf}(y, z) \rightarrow \text{ComponentOf}(x, z)$ (PDt1)
- $(\forall x)\neg\text{ComponentOf}(x, x)$ (PDt2)
- $(\forall x, y)\text{ComponentOf}(x, y) \rightarrow \neg\text{ComponentOf}(y, x)$ (PDt3)
- $(\forall x, y)\text{ComponentOf}(x, y) \rightarrow PP(x, y)$ (PDa1)
- $(\forall x, y)\text{ComponentOf}(x, y) \rightarrow \exists z(P(z, y) \land \neg O(z, x))$ (PDt4)

$(\forall x, y)\text{ElementOf}(x, y) =_{df} P(x, y) \land SED(y, x)$ (PDd2)





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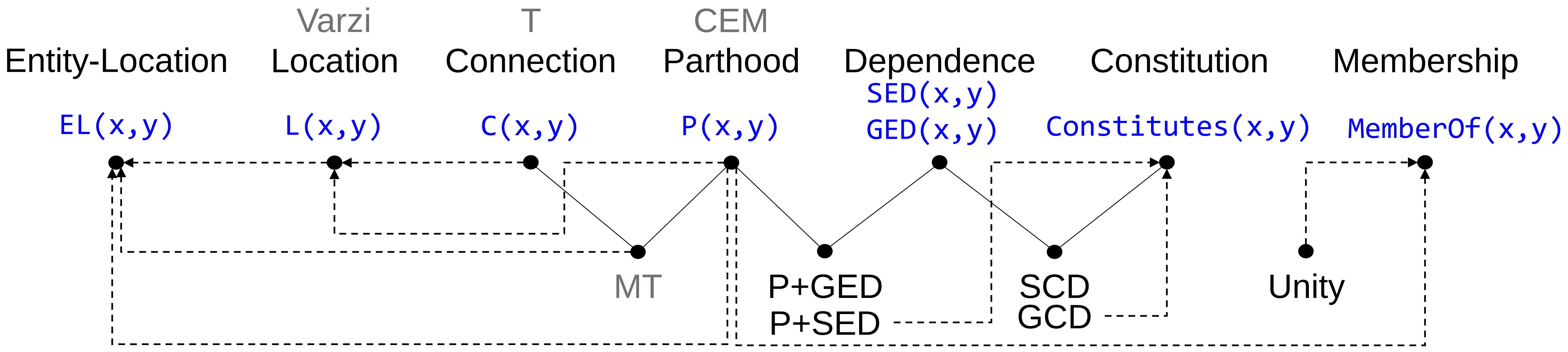

I

	CIDOC CRM	EDM	CHARM
Pros	Spatiotemporal elements	Descriptive elements	Domain-specific elements
Cons	**Composition (structural and spatial) relations**		

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Pros	Formality of relations	Common-sense reasoning on relations	Spatial properties
Cons	**Unified theory of relations**		

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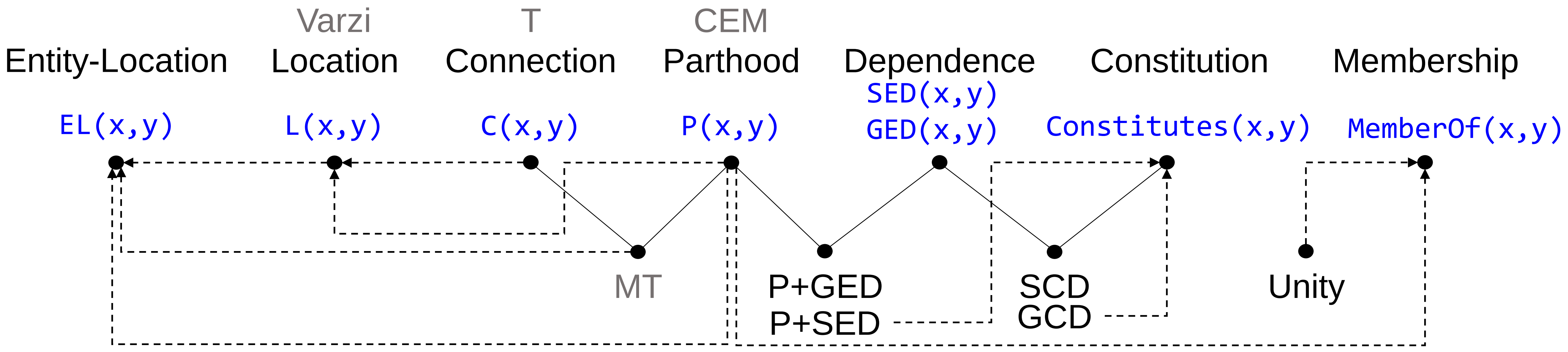
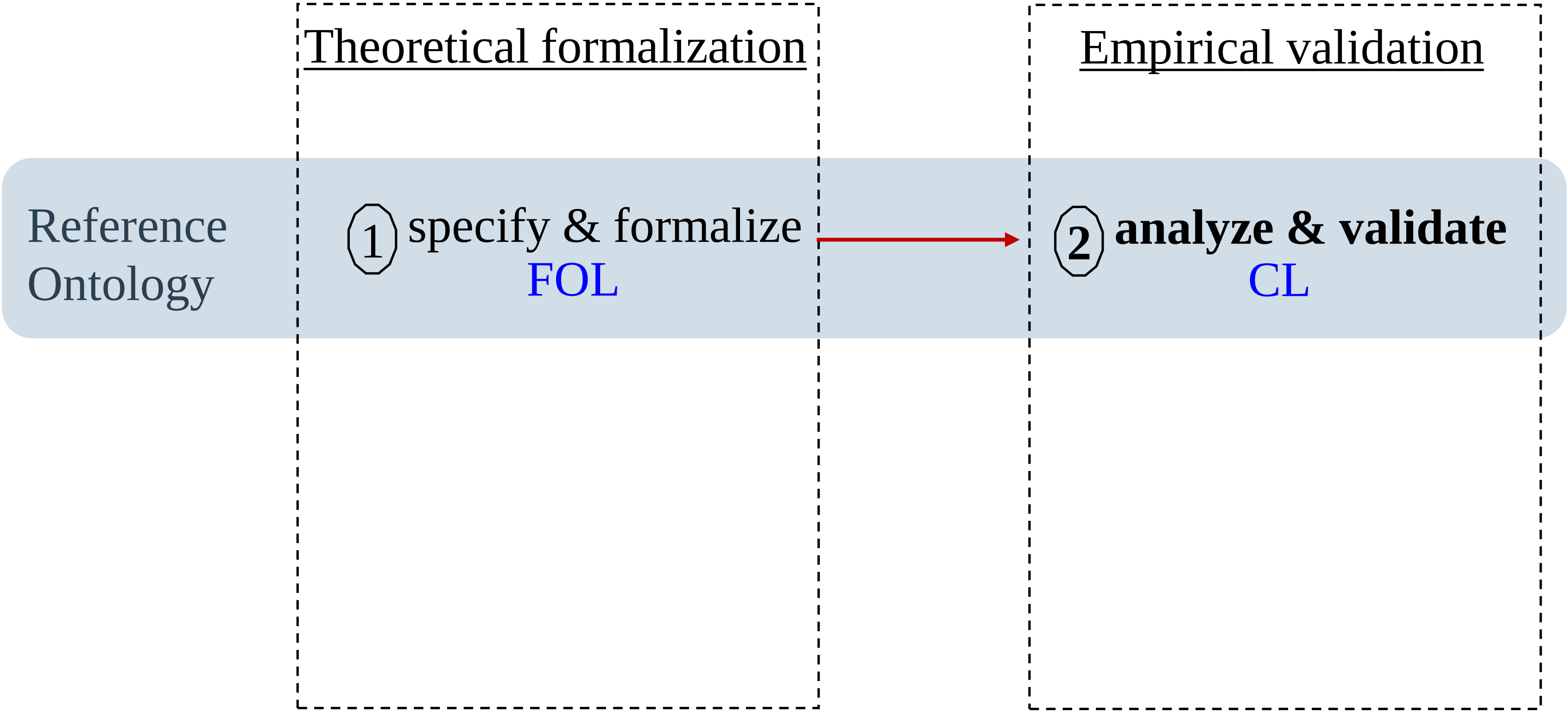


Contribution 1:
We have specified and formalized a **unified** language of minimal set of foundational ontological relations **(structural and spatial),** namely **FORT** [F. Danash et al., 2022].

F. Danash, D. Ziebelin, **FORT: a minimal Foundational Ontological Relations Theory for Conceptual Modeling Tasks.** In: The 41st International Conference on Conceptual Modeling (ER2022), Forum track, 2022. Conference paper.

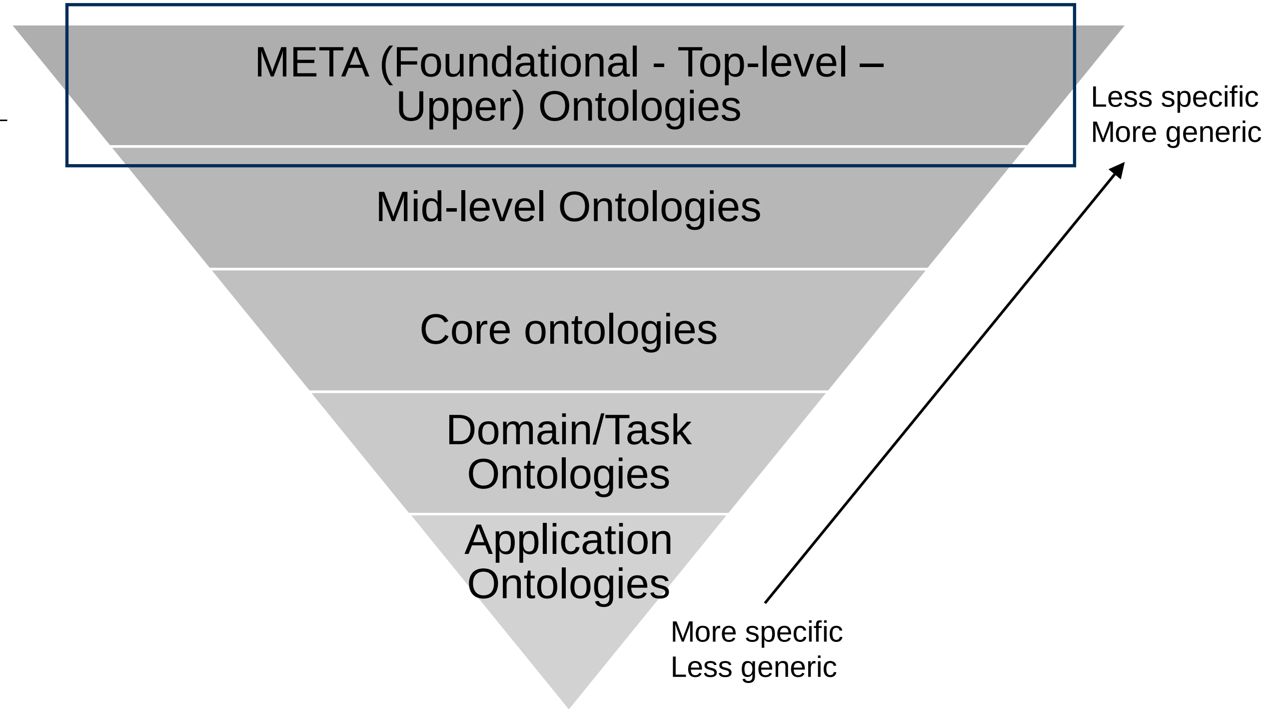
Methodology step 2:

analyze the relations of FORT in the presence of other foundational theories that encompass foundational relations as a relation-based alignment, and validate FORT as a theory by serializing FORT in another formal language that validates the existence of models using consistency checks : a Common Logic (CLIF) serialization of the FORT reference ontology.



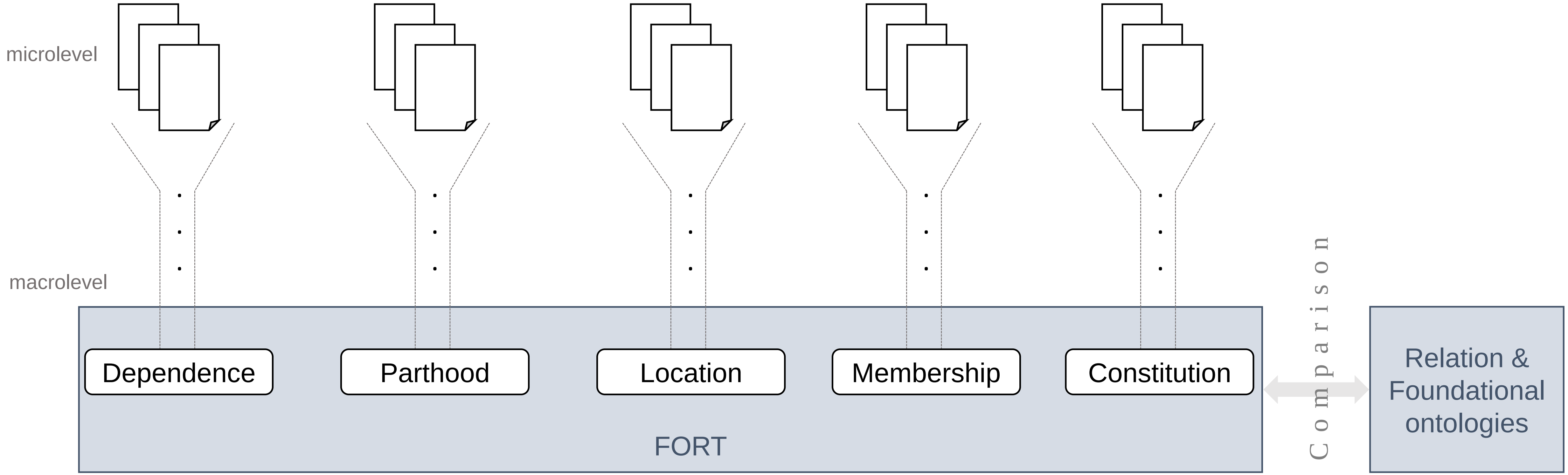
1. Analyzing FORT in view of other meta-ontologies:

- FORT (a meta-ontology of some foundational ontological relations)
- Foundational ontologies (e.g. DOLCE, etc.)
- Top-level ontologies of relations (e.g. the RO)



II. The FORT reference ontology (CL)

1. Analyzing FORT in view of other meta-ontologies:



II. The FORT reference ontology (CL)

1. Analyzing FORT in view of other meta-ontologies:

Relation / Meta-Ontology	Dependence	Parthood	Parthood + Dependence	Parthood + Connection	Entity-to-Region	Entity-to-Entity	Membership	Constitution	Constitution + Dependence
FORT	SED, GED	CEM	ComponentOf ,ElementOf	MT	L (VARZI)	EL	memberOf +U	constitutes	SCD, GCD
BFO	s-depends-on	own mereology	-	-	occupies-SR	located-in	member-of, + Aggregate	-	-
DOLCE	SD, GD …	GEM	-	-	(*qualities*)	-	-	k	SK & GK …
UFO	ed, ind & gfd	GEM	-	-	(*attributes*)	-	member-of, + Collection	constituted-by	GCD

Different consideration of the relation (green)
Similar consideration of the relation (blue)

BFO: The Basic Foundational Ontology |
DOLCE: A Descriptive Ontology for Linguistic and Cognitive Engineering
UFO: the Unified Foundational Ontology

2. Validating FORT using CL:

- Running consistency checks using the CLIF serialization:
  - Import and reuse existing CLIF theories: mereology CEM, mereotopology MT, and location (Varzi)
  - Serialize other micro-theories in order of « what comes first »
  - Use the Hets tool to perform consistency checks on the FORT macrotheory
- Translating FORT into other TPTP, LADR, and CASL syntaxes
- Forming DOL ontologies and running automatic theorem proofs

```
(cl-text https://raw.githubusercontent.com/DanashFatima/FORT/main/FORT-CL-
    ontology/componentOf_definition.CLIF

(cl-imports https://raw.githubusercontent.com/DanashFatima/FORT/main/FORT-
    CL-ontology/colore/mereology/cem_mereology.CLIF )

(cl-imports https://raw.githubusercontent.com/DanashFatima/FORT/main/FORT-
    CL-ontology/dependence_definitions.CLIF )

(cl-comment 'x is a component of y iff x is a part of y and y is
    generically existentially dependent on x')
(cl-comment 'Identifier: FORT_Pd1')
(forall (x y)
  (iff  (componentOf x y)
       (and (part x y)  (exists (PSI PHI) (and (PSI y) (PHI x) (GED (PSI y)
    (PHI x)) ) )
       )
  )
)
(cl-comment 'componentOf is a proper part of relation')
(cl-comment 'Identifier: FORT_Pa1')
(forall (x y)
  (if (componentOf x y)
       (ppart x y)
  )
)

)
```

The “component-of" relation in CLIF.

Contribution 2:
We have demonstrated the **novelty** and **consistency** of FORT by analyzing it in view of other meta-ontologies of relations and validating its consistency [F. Danash et al., 2022].

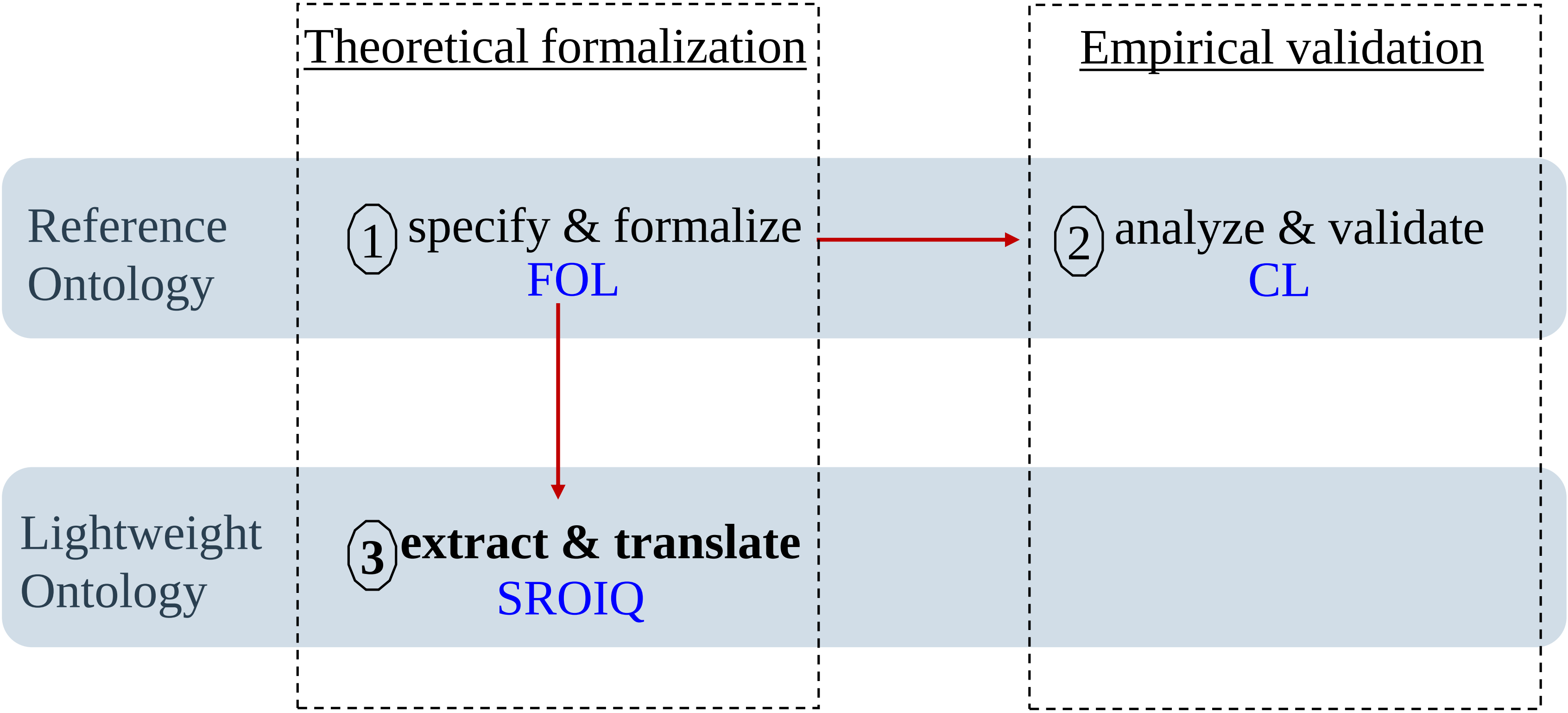
https://github.com/DanashFatima/FORT/tree/main/FORT-CL-ontology

F. Danash, D. Ziebelin, **On the Analysis of FORT; arguments, alignment to FOs, and CLIF validation**. In: The 6th Workshop on Foundational Ontology (FOUST VI),@ The Joint Ontology Workshops (JOWO’2022). Workshop paper.

III. The FORT lightweight ontology (SROIQ)

Methodology step 3:

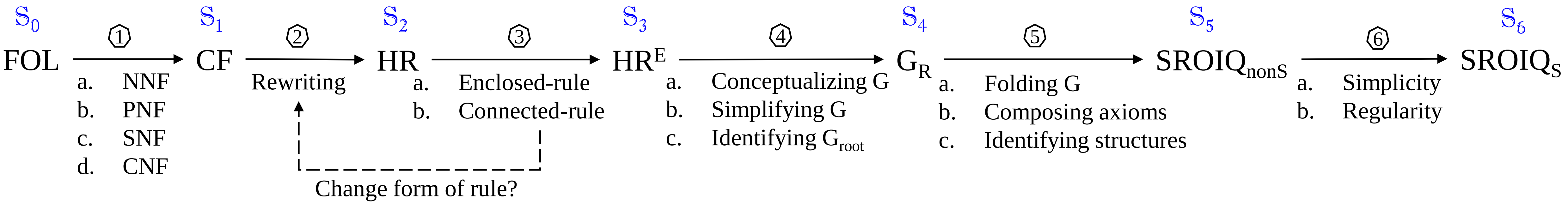
extract a secondary decidable fragment from the original formalization that guarantees desirable computational services, and translate the FOL-formalization into a decidable, yet expressive, knowledge representation and reasoning language : a SROIQ Description Logic formalization of the FORT lightweight ontology.



III. The FORT lightweight ontology (SROIQ)

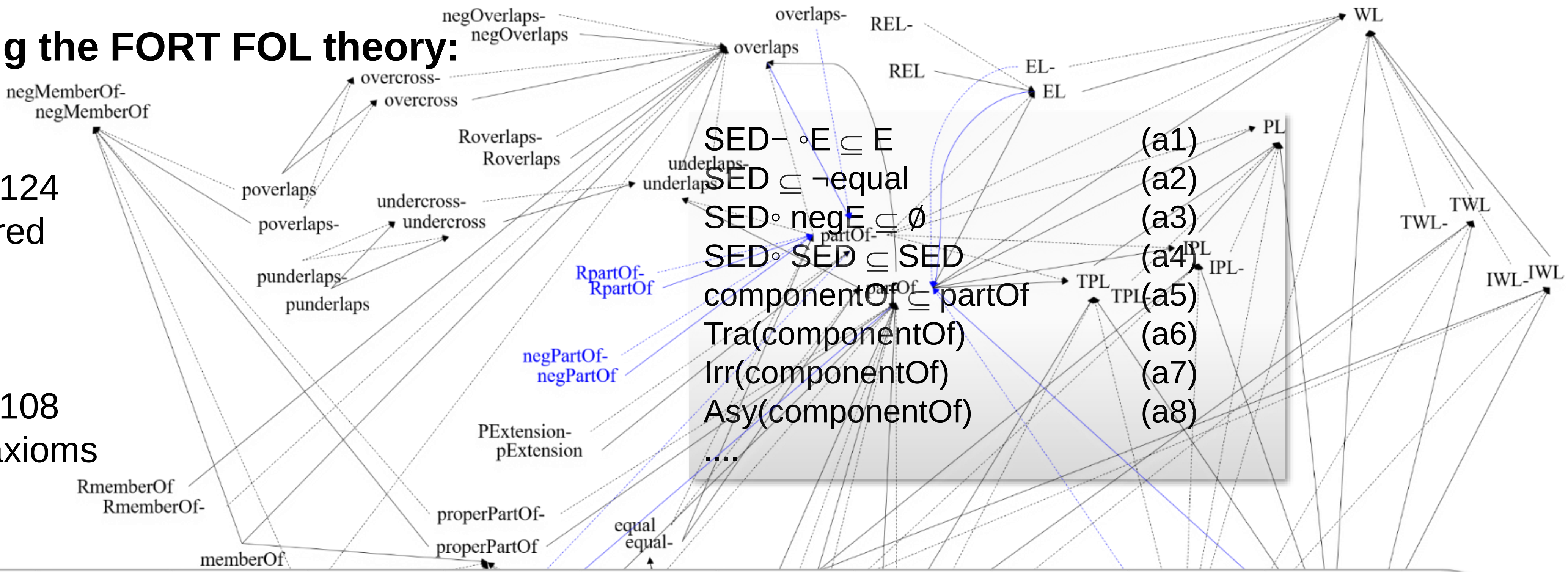
1. The proposed translation procedure:

- Input: a set of FOL formulas: S_0
- Six steps:
  - Clausal Form (CF): S_1
  - Horn Rules (HR): S_2
  - Expressible Horn Rules (HR^E): S_3
  - Graph Rules (G_R): S_4
  - Non structured set of SROIQ axioms ($SROIQ_{nonS}$): S_5
- Output: a structured set of SROIQ axioms: S_6



III. The FORT lightweight ontology (SROIQ)

2. Translating the FORT FOL theory:



- Steps 1 → 5
  S_5: a set of 124 non-structured axioms

- Step 6:
  S_6: a set of 108 structured axioms

SED− ◦E ⊆ E	(a1)
SED ⊆ ¬equal	(a2)
SED◦ negE ⊆ ∅	(a3)
SED◦ SED ⊆ SED	(a4)
componentOf ⊆ partOf	(a5)
Tra(componentOf)	(a6)
Irr(componentOf)	(a7)
Asy(componentOf)	(a8)
....	

Contribution 3:

We have extracted a **decidable fragment** of FORT by translating the FOL theory into the decidable SROIQ, based on a generic and systematic procedure [F. Danash et al., 2023].

https://github.com/DanashFatima/FORT/tree/main/FORT-SROIQ-formalization

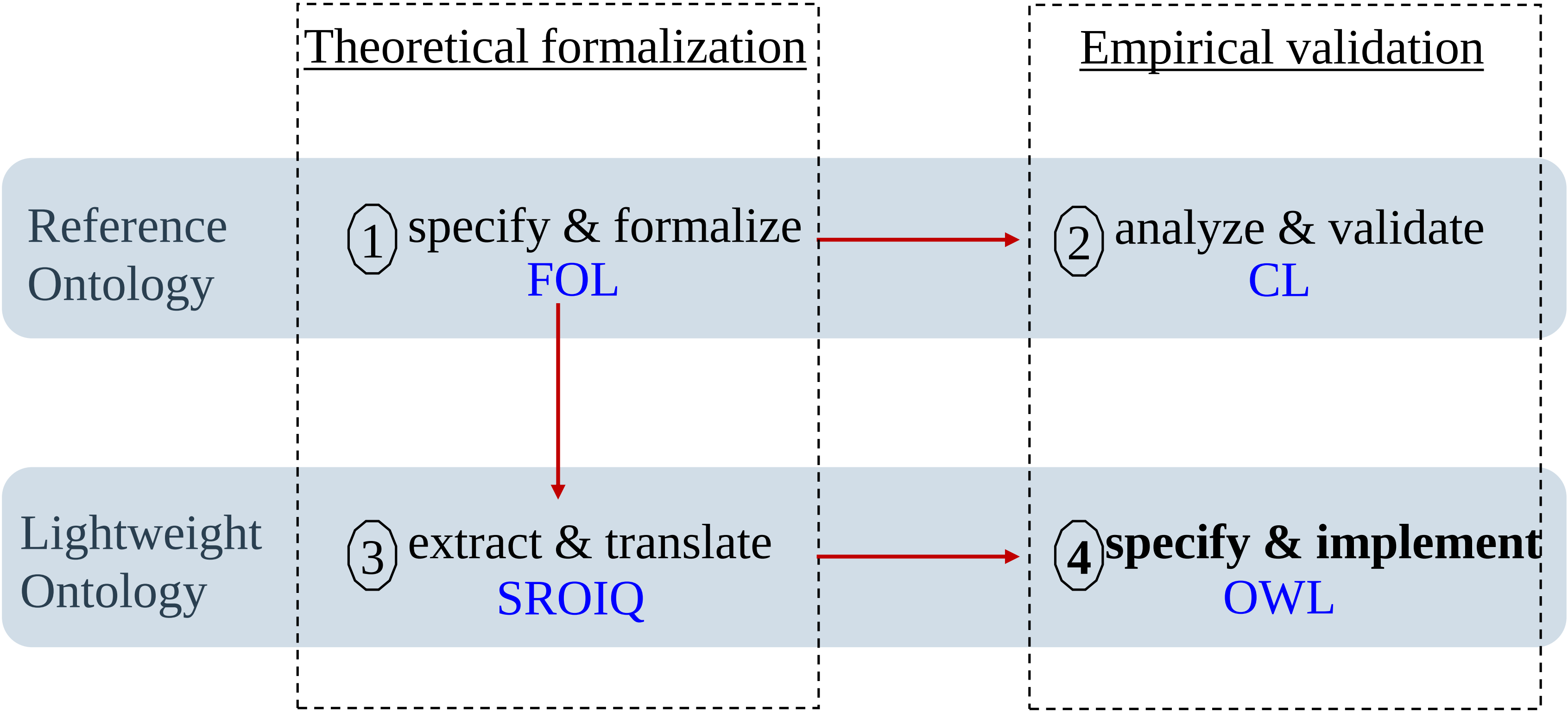
→ : Regular order
→ : Irregular order

F. Danash, D. Ziebelin, **Translating FOL-theories into SROIQ-TBoxes**. In: The ACM/SIGAPP Symposium On Applied Computing Modeling (SAC2023), Knowledge Representation and Reasoning track, 2023. Conference short paper.

IV. The FORT lightweight ontology (OWL)

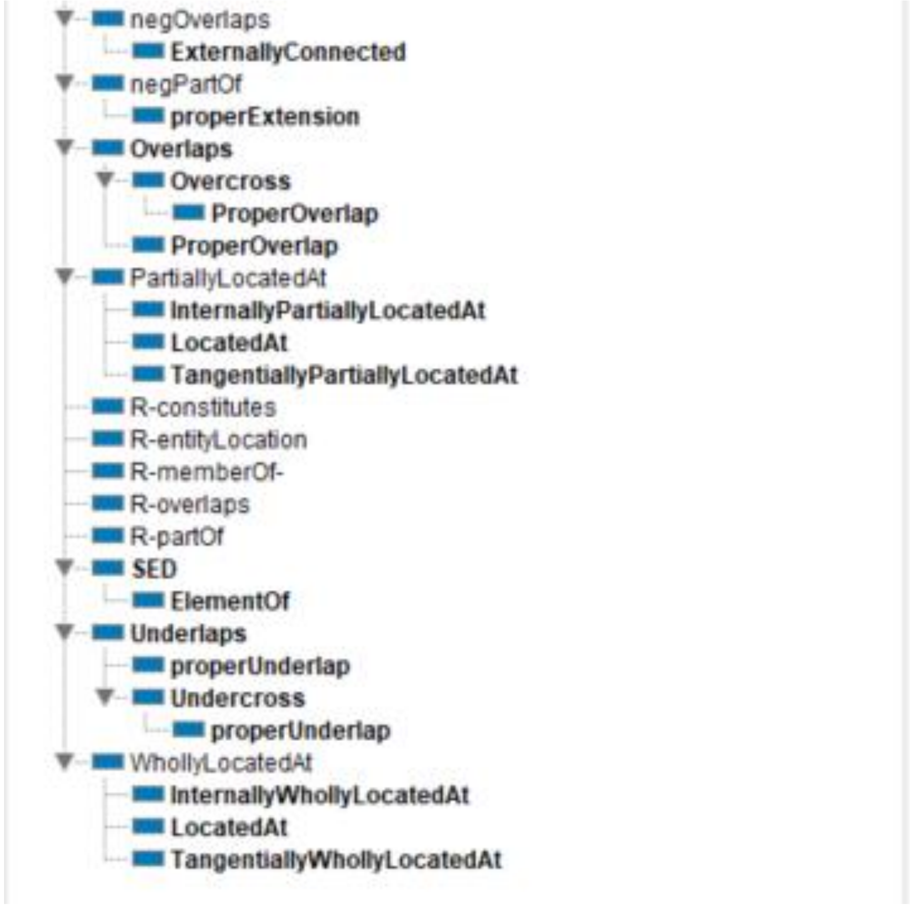
Methodology step 4:

specify and implement the T-boxes of the SROIQ formalization into a semantic web ontological model: an OWL2-DL implementation of the FORT lightweight ontology.



IV. The FORT lightweight ontology (OWL)

Implementing the OWL ontology using Protégé:

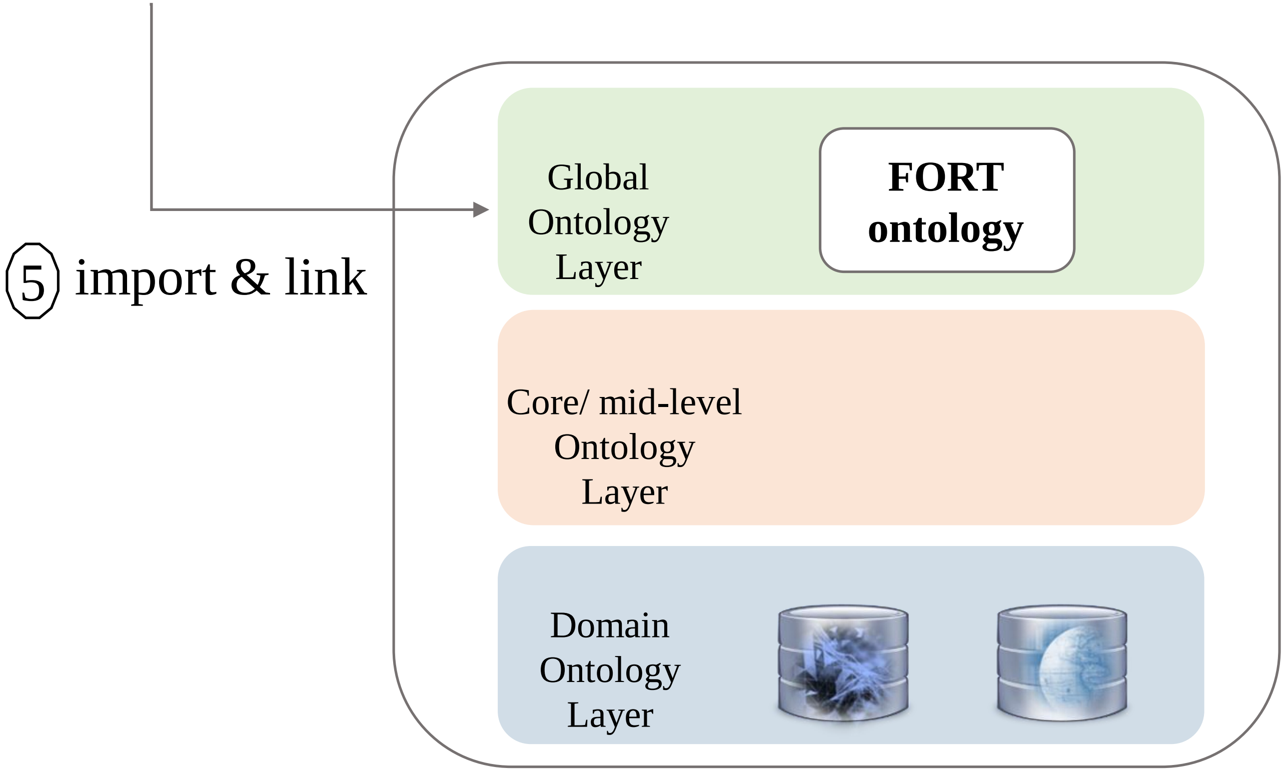


https://github.com/DanashFatima/FORT/tree/main/FORT-OWL-ontology

Direct and Indirect scenarios

Methodology step 5:

import the ontology in practice according to the application setting, and link it to other ontologies based on an employment method : a proof of FORT's applicability.



Direct and Indirect scenarios

1. Direct Employment

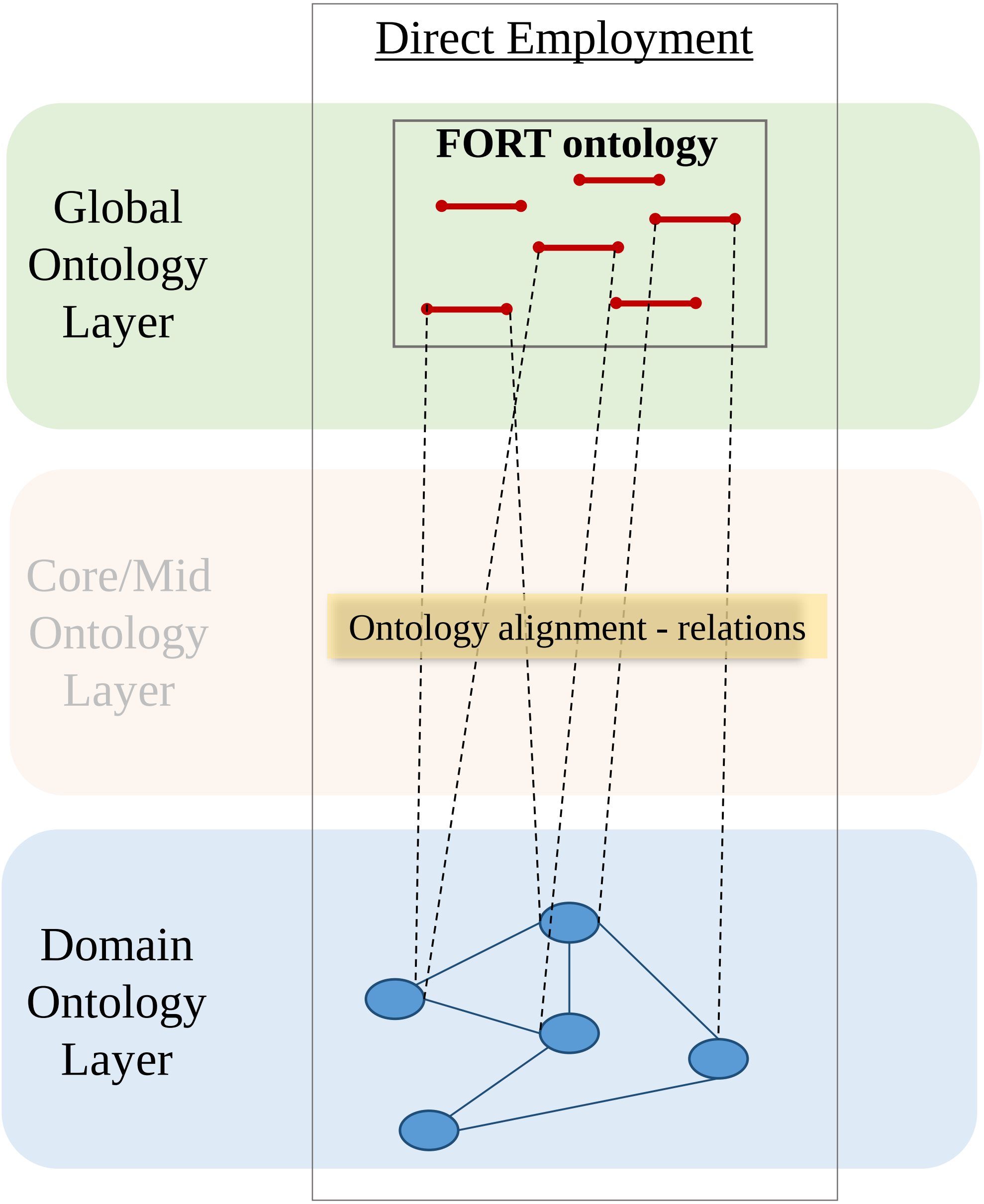
Goal:

Use FORT's relations as an expressive language to semantically enhance the domain relations of the domain/task ontology.

Task:

Alignment between the domain's relations (R_{domain}) and FORT's relations (R_{FORT})

$<R_{domain}, (\equiv, \leq, \geq), R_{FORT}>$



Direct and Indirect scenarios

2. Indirect Employment

Goal:

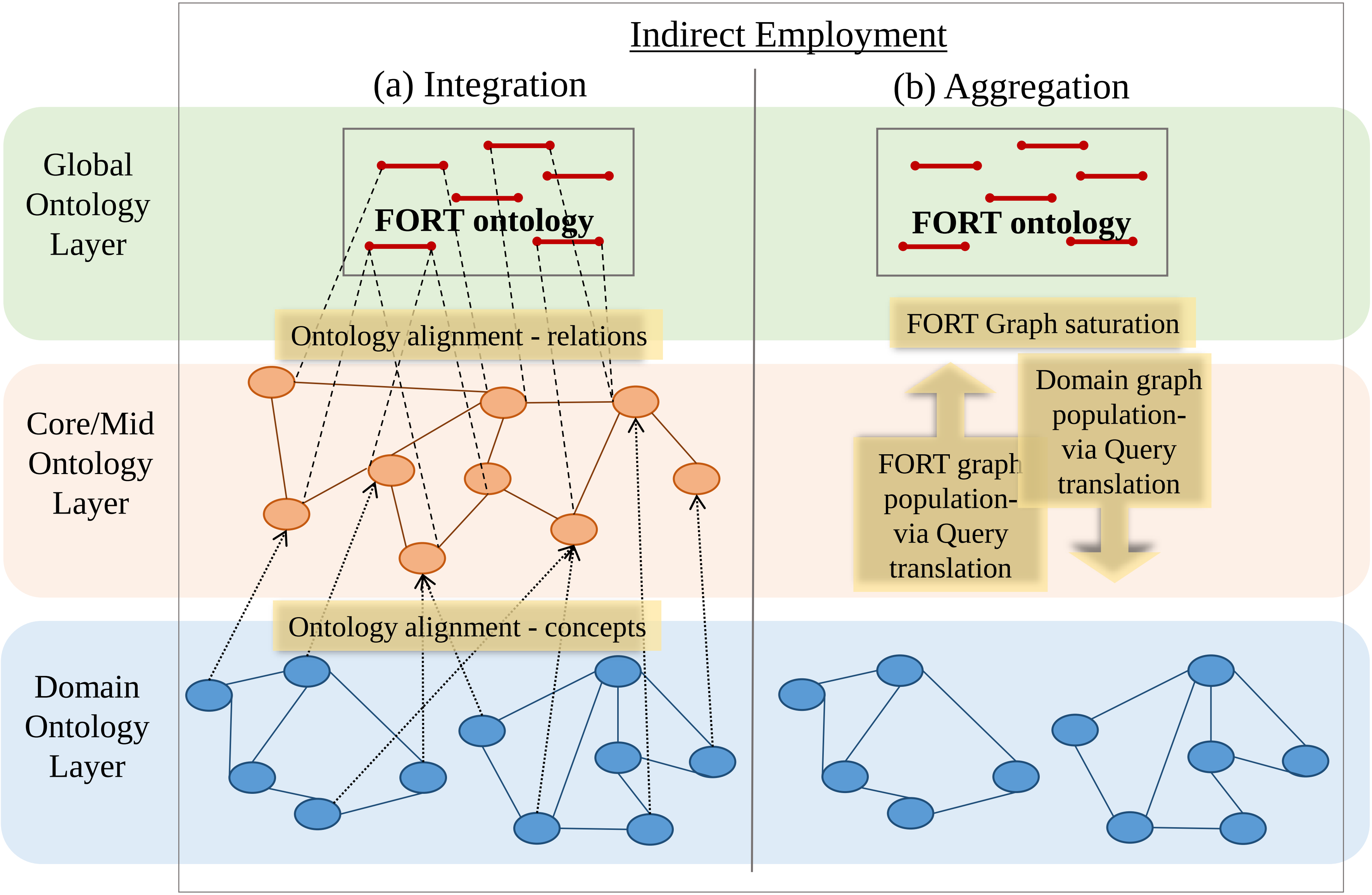
Exploit the semantics of FORT within an interdisciplinary application in which multiple domain ontologies exist.

Integration-based:

- Relations alignment
- Concepts alignment

Aggregation-based:

- Query translation
- Graph saturation
- Query translation



Direct and Indirect scenarios

Methodology step 4:

specify and implement the T-boxes of the SROIQ formalization into a semantic web ontological model: an OWL2-DL implementation of the FORT lightweight ontology.

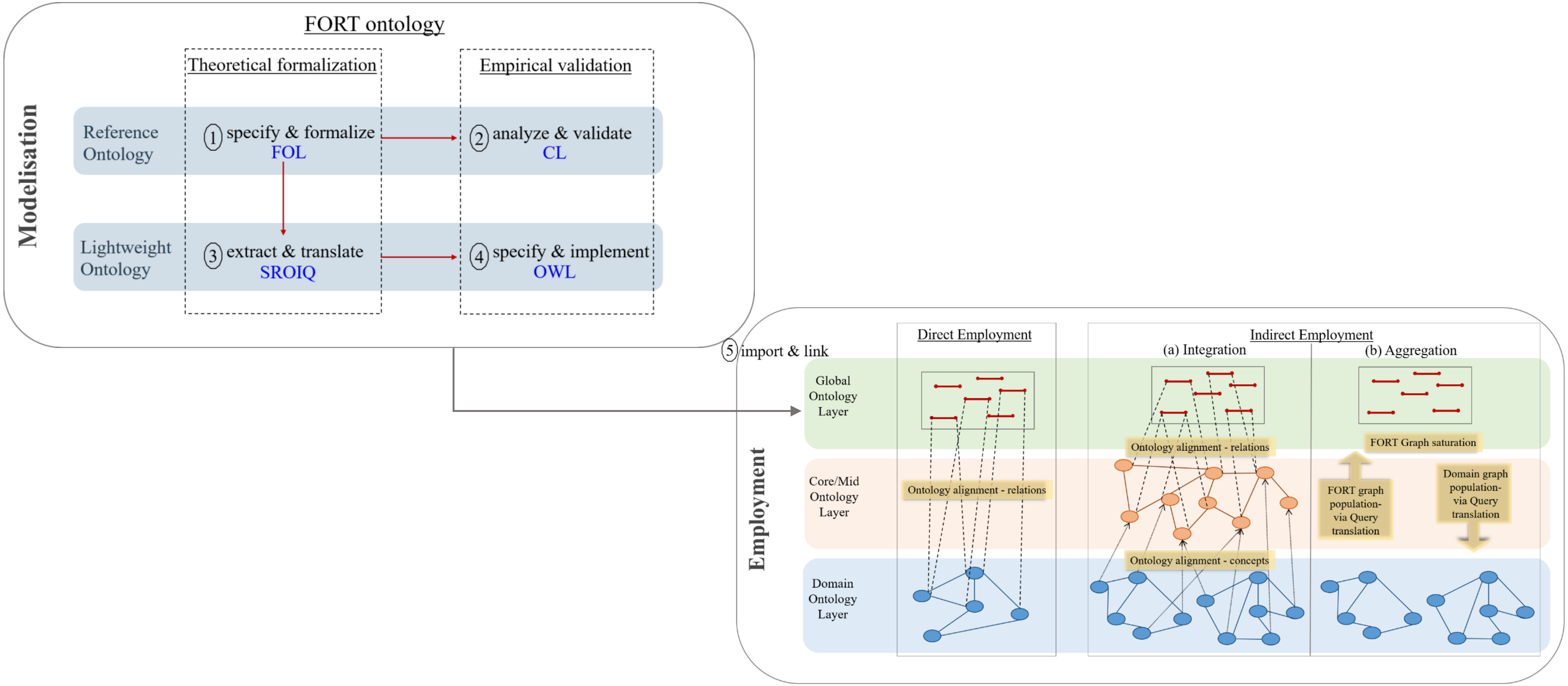
Methodology step 5:

import the ontology in practice according to the application setting, and link it to other ontologies based on an employment method : a proof of FORT's applicability.

Contribution 4:
We have **provided an OWL** ontology and **designed its possible employment methods** to supported the practice of FORT in the Semantic Web**.**

Table of contents

Applied Ontological Approach & Ontology engineering Methodology:



Applied Ontological Approach & Ontology engineering Methodology:

I. Proposed an unified and well-founded language of relations and rule constraints: FORT_{FOL} reference ontology [methodology-step-1]

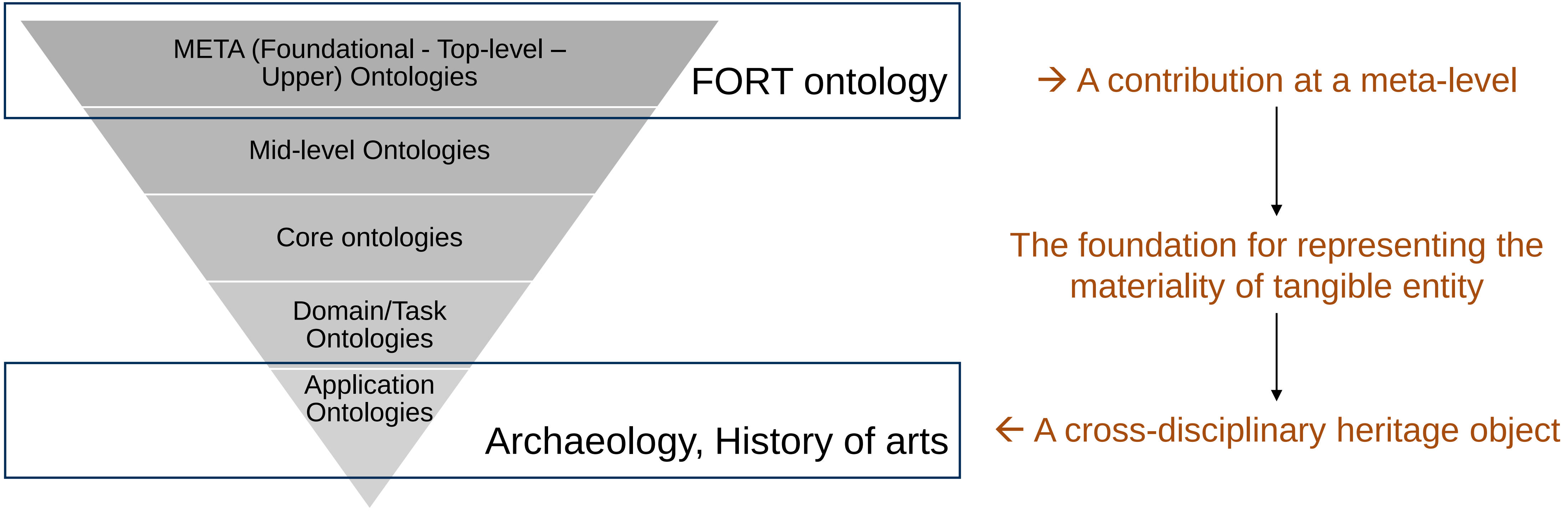
II. Demonstrated the novelty and consistency of our proposed language in view of existing theories: FORT_{CL} reference ontology [methodology-step-2]

III. Established a decidable formalization of our proposed language with a generic translation procedure: $\text{FORT}_{\text{SROIQ}}$ lightweight ontology [methodology-step-3]

IV. Supported the practice of our proposed language in the SW and designed its employment methods: FORT_{OWL} lightweight ontology + practice design [methodology-steps-4+5]

Going back to Patrimalp's research problem:

FORT has laid the foundation for representing the materiality of a cross-disciplinary tangible entity, providing thus the primary element of this representation and making it available for future architectural development in CH applications.



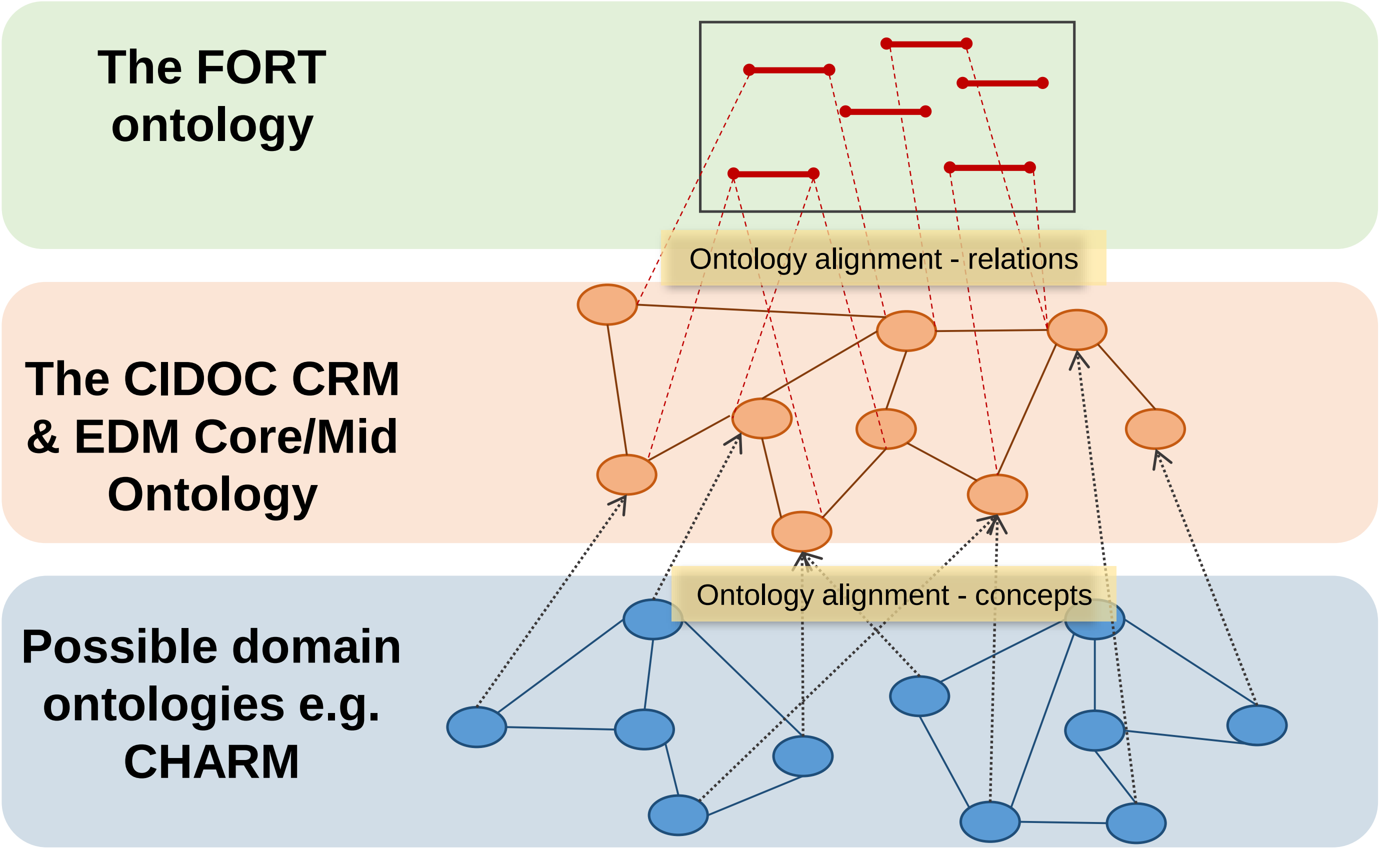
1. An ontology architecture for a CH interdisciplinary application using FORT

INDIRECT Employment: using the strength of each of FORT, CIDOC CRM, EDM, and CHARM

- Composition relations

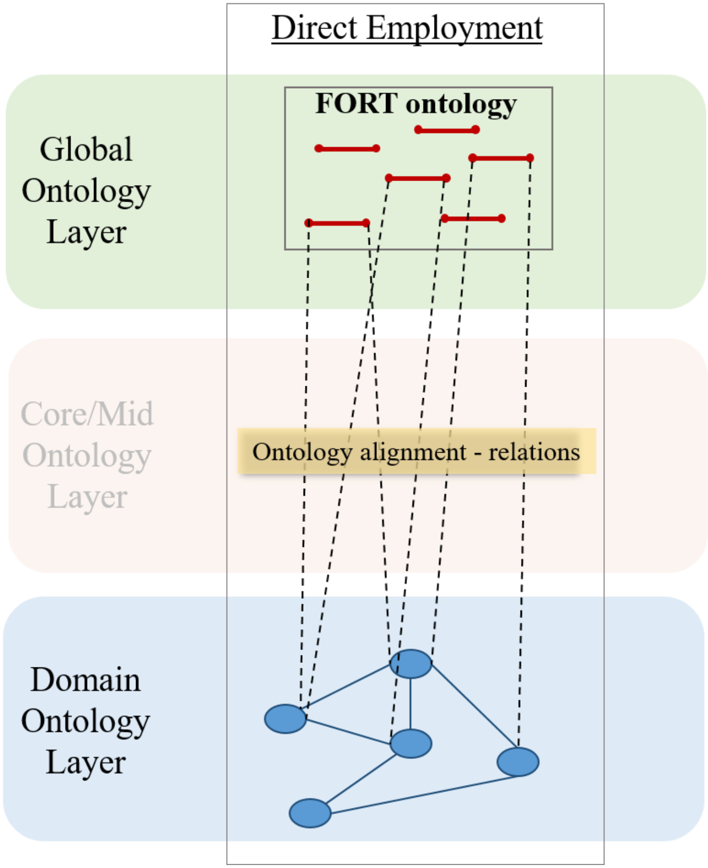
- Spatiotemporal elements
- Descriptive elements
- categories

- User models



2. Demonstrate FORT's convenience for materiality representation of entities in Patrimalp

DIRECT Employment examples



Two examples:

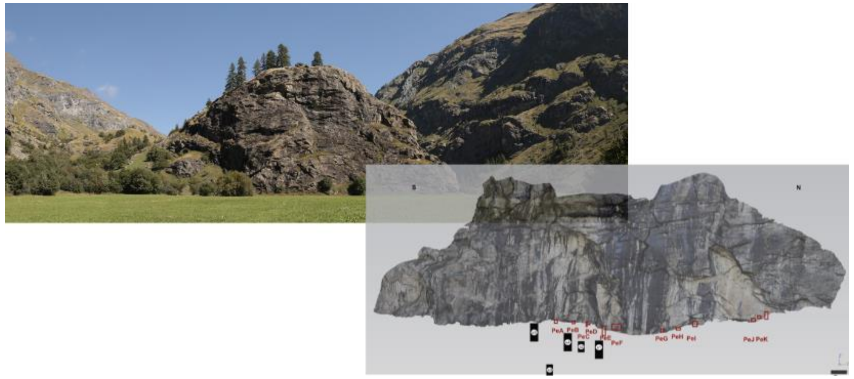
- **Archaeology Ontology**
- **Brocades Ontology**

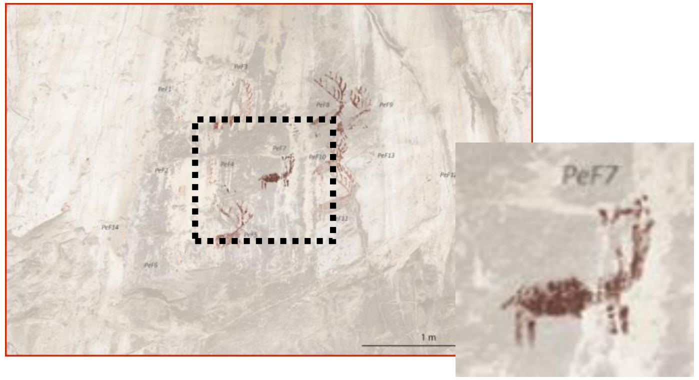
2. Demonstrate FORT's convenience for materiality representation of entities in Patrimalp

DIRECT Employment: (1) Archaeology example

Query 1: Find the red deers on panels of the north face of RDC.

```
Select distinct ?figure Where {
   ?rdc rdf:type archeo:ArchaeologicalSite;
        rdfs:label "Rocher du Château"@fr .
   ?rdc fort:hasTPP   ?nf.
   ?nf  rdfs:label "Face Nord"@fr;
        fort:hasPP ?panel .
   ?panel fort:hasEL  ?figure .
   ?figure fort:memberOf ?c;
           fort:hasPP ?ms.
   ?c   fort:unifiedBy ?p.
   ?p  archeo:hasShape archeo:dearShape.
   ?ms fort:constitutedBy  ?cm.
   ?cm fort:hasElement chemicals:Hematite.
}
```



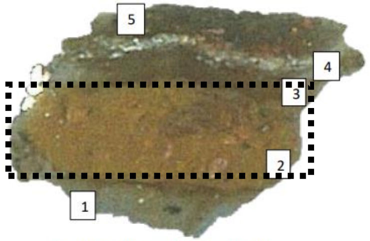


2. Demonstrate FORT's convenience for materiality representation of entities in Patrimalp

DIRECT Employment: (2) Brocades example

Query 2: Find the brocades which are located on the "Saint Jean" personage of the "Vierge de Pitié" statue and have "Cl" in the tin layer.

```
Select distinct ?b Where {
  ?s1 a brocades:Statue;
      rdfs:label "Vierge de Pitié".
  ?s2 fort:partOf ?s1 ;
      rdfs:label "Saint Jean"@fr.
  ?b  a brocades:Brocade ;
      fort:EL ?s2 .
  ?ms a brocades:MicroSample;
      fort:partOf ?b ;
      fort:hasMember ?l .
  ?l  fort:constitutedBy ?m .
  ?m  brocades:layerType brocades:TinLayer ;
      fort:hasElement chemicals:Chlorine .}
```



Ecaille en coupe, vue optique, échantillon n°161+

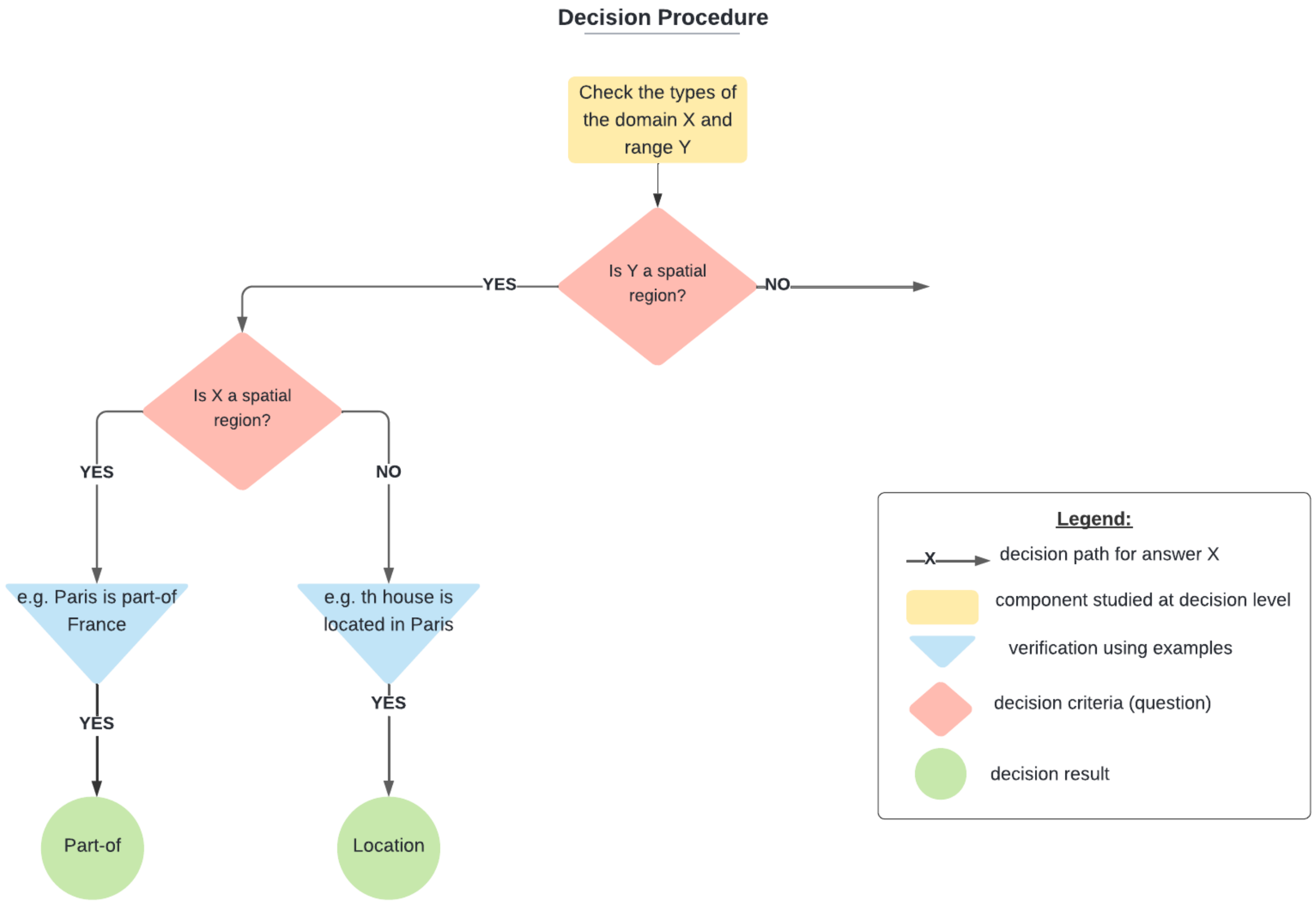
3. From an atemporal to a temporal framework

a. Incorporating time e.g. using a time variable and ternary relations, interval-based temporal logic, temporal constraints using that extend some logics (DLR with “since” and “until”)
b. Study the events that affect the structural and spatial representation of a tangible entity e.g. LODE ontology
c. Model the behavior between a relation R and an event E

4. Composition of foundational ontological relations

R1\R2	SED(y,z)	Component-of(y,z)	Element-of(y,z)	Located-at(y,z)	Entity-located(y,z)	Member-of(y,z)	Constitutes(x,y)
SED(x,y)	T						
Component-of(x,y)		T					
Element-of(x,y)			T				
Located-at(x,y)				$\neg T$			
Entity-located(x,y)					T		
Member-of(x,y)						$\neg T$	
Constitutes(x,y)							T

5. A semi-automatic decision procedure for the Direct employment of FORT



Publications:

- F. Danash, D. Ziebelin, **Translating FOL-theories into SROIQ-TBoxes**. In: The ACM/SIGAPP Symposium On Applied Computing Modeling (SAC2023), Knowledge Representation and Reasoning track, 2023. Conference short paper.

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- F. Danash, D. Ziebelin, **FORT: a minimal Foundational Ontological Relations Theory for Conceptual Modeling Tasks.** In: The 41st International Conference on Conceptual Modeling (ER2022), Forum track, 2022. Conference paper.

- F. Danash, D. Ziebelin, E. Chalmin, **A Parthood Approach for Modeling Tangible Objects' Composition TOC – An application on Cultural Heritage**. In Book: The 17th Extended Semantic Web Conference, ESWC2020. Lecture Notes in Computer Science, vol 12124. Conference short paper.

Thank You!

Fatima DANASH

Doctoral Thesis defended on September 28th, 2023

*My most profound gratitude is to **God**.*