1 What's in a Schema?

1.1 Introduction

This chapter presents an application of metamodeling[1] to the *Ontolex* interface, intended here as the set of relations (e.g. annotation, reuse, mapping, transformation, etc.), which can hold between the elements of an ontology, and the elements of a lexicon.
The *c.DnS* ontology (Gangemi, 2008) is here extended to formally define an ECG (Feldman, 2006) ontology,[2] and a *semiotic façade*,[3] called *Semion*, which is applied to define a FrameNet (Baker, Fillmore and Lowe, 1998) metamodel (*OntoFrameNet*[4]), and to introduce a formal method for lexical information integration. This application is critical for the *Ontolex* interface, because it addresses sophisticated approaches to lexicon design and linguistic theory, and requires an understanding of the different notions of *schema* (a.k.a. frame, knowledge pattern, etc.) across domains as different as lexicon and ontology design.
In this chapter, schemata are considered as *invariances that emerge from the co-evolution of organisms and environment, and that are exemplified by*

[1] A metamodel, broadly speaking, is a model that describes constructs and rules needed to create specific models.

[2] http://ontologydesignpatterns.org/ont/cdns/ECG.owl

[3] A façade is an architectural object: the frontage of a building, which is used metaphorically in software engineering to talk of an object that provides a simplified interface to a larger body of code (West, Sullivan and Teijgeler, 2008). Here façade means a semiotic metamodel that acts as a layer in between heterogeneous lexical models, and an ontology.

[4] http://www.ontologydesignpatterns.org/ont/ofn/ofntb.owl

neurobiological, cognitive, linguistic, and social constructs. The ontologies presented here are designed according to this assumption.
While specific relations between individual ontologies and lexica are addressed in literature quite often, e.g. (Gangemi, Guarino, Masolo and Oltramari, 2003; Buitelaar, Choi, Gangemi, Huang and Oltramari, 2007; De Luca, Eul and Nürnberger, 2007; Scheffczyk, Baker and Narayanan, 2008; Huang, Calzolari, Gangemi, Lenci, Oltramari and Prevot, 2008), it is far less usual to propose a metamodel to formally describe the *ontolex* interface. Metamodels have been proposed to abridge different lexical resources, starting with OLIF (McCormick, Lieske and Culum, 2004), and recently with reference to lexical semantics, as in LMF (Francopoulo, George, Calzolari, Monachini, Bel, Pet and Soria, 2006), where an attempt has been made to informally align some lexica under a same metamodel.[5] Some steps towards linking lexica and ontologies have been also made in order to manage lexicon reuse in ontologies (Pazienza and Stellato, 2006), multi-linguality in ontologies (Peters, Montiel-Ponsoda, Aguado de Cea and Gómez-Pérez, 2007), as well as to make cookbook-like transforms between syntactic patterns and formal constructs (Cimiano, Haase, Herold, Mantel and Buitelaar, 2007).
The research partly reported here aims at abstracting from individual interfaces, lexical standards or specific transformation methods, by providing a *semiotic façade* in between the intuitive semantics of different lexica, and formal semantics.[6] A semiotic façade is an appropriate metamodel, because its constructs are intuitive enough in order to align the underlying assumptions of different lexical resources, but they can also be made formal by applying a *transformation pattern*[7] to a formal semantic construct. A notable advantage of this intermediate layer is that any interface or translation method can refer to a unique *façade* (West, Sullivan and Teijgeler, 2008), without worrying about the intended conceptualization of the data models used in the original lexical resources, or about how to access them. Moreover, developers of lexical resources can continue developing their

[5] http://lirics.loria.fr/doc_pub/ExtendedExamplesOfLexiconsUsingLMF29August05.pdf

[6] Formal semantics is a theory of meaning based on a formal language, and on its interpretation given by assigning a denotation (e.g. a set extension) to each non-logical construct in that language.

[7] In ontology design, a transformation pattern is a formal guideline to transform a model into another, (Presutti, Gangemi, David, Aguado de Cea, Suarez-Figueroa, Montiel-Ponsoda and Poveda, 2008).

resources without changing their workflow in order to stay tuned with e.g. semantic web applications, which require different data models.

This chapter illustrates the semiotic intermediate layer with reference to a hard problem: integrating the notions of a *schema* (Johnson, 1987), a *verb class* (Kipper, Dang and Palmer, 2000), and a *frame* (Fillmore, Kay and O'Connor, 1988) in (cognitive) linguistics and construction grammar, which are at the basis of lexical resources such as the *Metaphor List* (Lakoff, 1994), *FrameNet* (Baker, Fillmore and Lowe, 1998), and *VerbNet* (Kipper, Dang and Palmer, 2000), with the formal notions of a *relation representation* (Foerster, 1974), a *frame* (Minsky, 1975; Brachman, 1977), an *intensional relation* (Guarino, 1998), a *knowledge pattern* (Clark, Thompson and Porter, 2000), and a *content ontology design pattern* (Gangemi, 2005) in knowledge representation and ontology design.

I show that Semion, the semiotic façade presented here, is compliant with the intuitive social meaning underlying schemata and frames, while retaining the possibility of mapping them to formal notions, which grants desirable computational properties to lexical resources, specially in order to foster the achievement of a generalized *information integration*, which is a main challenge e.g. for "Web Science" (Berners-Lee, Hall, Hendler, Shadbolt and Weitzner, 2006) and the *Linking Open Data* W3C project.[8]

In section 1.2, the background of cognitive linguistics, schemata, and their ontology is presented. In section 1.3, the *c.DnS* ontology is introduced and motivated with reference to the metamodeling task for this chapter. In sections 1.4 and 1.5, the ECG and Semion ontologies are respectively sketched. In section 1.6, the proposal is complemented with five applications of Semion for the formalization of FrameNet and VerbNet, for the integration of lexical resources, for the representation of schemata, and of schema occurrences as denoted by natural language sentences. In section 1.7 the main points of the chapter are summarized with respect to ongoing and future work.

1.2 An ontology for cognitive linguistics

A somewhat "underground" approach in cognitive science, which has been gradually emerging since the late 1980s, stresses the constructive,

[8] http://esw.w3.org/topic/SweoIG/TaskForces/CommunityProjects/LinkingOpenData

context-dependent (or situated) and action-oriented nature of cognition. No longer seen as faithful and exhaustive replicas of an "absolute" reality, the representations with which the mind operates are conceived of as views on the world, emerging from active interaction with the (physical and cultural) environment, and relating only to those aspects which are salient for the perceiver/cognizer (Clark, 1993; Churchland, Ramachandran and Sejnowski, 1994; Gallese and Metzinger, 2003). Focusing on the non-abstract nature of cognition, moreover, has lead to put a new emphasis on the gestaltic aspects of representations and thought, i.e. the need of taking into account "the interconnected whole that gives meaning to the parts" (Light and Butterworth, 1992).

In cognitive linguistics, this approach has come to be known as the *embodiment* hypothesis, i.e. the idea that "the structures used to put together our conceptual systems grow out of bodily experience and make sense in terms of it" (Lakoff, 1987). According to this hypothesis, language understanding and reasoning are carried out by means of basic (both motor and image) schemata and frames, while abstract reasoning is enabled by the use of spatial analogies or metaphors (Lakoff and Johnson, 1980; Lakoff, 1987; Johnson, 1987; Langacker, 1990; Talmy, 2003). Evidence on the use of image schemata such as PATH, SELF-MOTION, CAUSED MOTION, CONTAINMENT as soon as in early infancy comes from developmental and neuropsychological studies (Mandler, 2004). Mathematical characterizations of similarly gestalt-oriented schemata have been proposed in catastrophe-theoretic semantics (Petitot-Cocorda, 1995; Wildgen, 2004). Other work also finds analogies between schemata and neurobiological theories (Gallese and Lakoff, 2005; Rohrer, 2005)). FrameNet implements some general schemata as non-lexical frames (Ruppenhofer, Ellsworth, Petruck, Johnson and Scheffczyk, 2006).

While research greatly differs in depth (schemata are usually given as informal primitives), precision (most approaches lack a formal semantics) across the different disciplines and individual authors, what clearly emerges from that heterogeneous literature is the need to establish some conceptual framework of reference to talk about the different approaches, the phenomena analyzed, and the theories proposed.

An example of how that framework might look like is presented here by reusing the *Constructive Descriptions and Situations* ontology (hereafter *c.DnS*) (Gangemi, 2008) to formally represent some core notions introduced by cognitive linguistics and Embodied Construction Grammar

(ECG), (Chang, Feldman, Porzel and Sanders, 2002; Porzel, Micelli, Aras and Zorn, 2006).
c.DnS is a constructivist ontology[9] that represents the aspects of the human cognitive ability to re-contextualize concepts, entities, and observable facts according to current needs. In the field of developmental psychology, this ability has been described in terms of *Representational Redescription*, "a process by which (implicit) information that is in a cognitive system becomes progressively explicit to that system" (Karmiloff-Smith, 1994), allowing for greater flexibility. *Descriptions* in *c.DnS* are conceived as the social (communicable) counterpart of "reportable" internal representations in Karmiloff-Smith's cognitive architecture, namely so-called E3 (explicit-3) internal representations[10]. In *c.DnS*, redescription originates from extensive reification, and from the representation of other cognitive processes described e.g. by Gestalt psychology (Köhler, 1947), which allow us to refer synthetically to some commonly agreed context labels. This mechanism makes *c.DnS* a tool for representing social (hence, non-physical) objects such as information, frames, concepts, collectives, plans, norms, design, diagnoses, situations, organizations, etc. (see (Gangemi, 2008) for a detailed axiomatization).
c.DnS, however, can also be used as a formalism for representing the descriptive, communicable version of so called *schemata* (Johnson, 1987), *mental spaces* (Fauconnier, 1994; Turner, 2007), and *constructions* (Fillmore, Kay and O'Connor, 1988; Croft, 2001; Feldman, 2006), which are among the fundamental entities that an ECG ontology is supposed to include (Chang, Feldman, Porzel and Sanders, 2002). Within *c.DnS*, schemata are the general structures, by which constructions (made up of information objects) are built, and give rise to mental spaces.
c.DnS formalizes some foundational principles (relationality, situatedness, interpretability, containment, classification, taxonomy, etc.), and some of them are conceived as direct counterparts of some core cognitive schemata. For example, the containment, classification, and taxonomy principles are

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[9]The first-order logic version of the ontology is presented in (Gangemi, 2008); an OWL (W3C, 2004) version of the ontology for application on the Semantic Web can be downloaded from http://ontologydesignpatterns.org/ont/cdns/cdns.owl and http://ontologydesignpatterns.org/ont/cdns/ground.owl.

[10]Following the constructivist paradigm, internal representations are called here *internal constructs*.

counterpart to (or an elaboration of) the CONTAINMENT schema; the relationality and situatedness principles are counterpart to the CONFIGURATION schema, etc. The principles are detailed elsewhere (Gangemi, 2008), and here they are implicitly introduced by means of the projections of the maximal *c.DnS* relation (section 1.3).
In this chapter, schemata are formalized as kinds of descriptions that have a special place in the organization of conceptual spaces and linguistic constructions.

1.3 The *c.DnS* ontology

The core structure for the *c.DnS* ontology is represented as a relation with arity=8 (see (Gangemi, 2008) for an axiomatization):

$$c.DnS(d,s,c,e,a,k,i,t) \rightarrow \\ D(d) \wedge S(s) \wedge C(c) \wedge E(e) \wedge A(a) \wedge K(k) \wedge I(i) \wedge T(t) \qquad (1.1)$$

where D is the class of *Descriptions*, S is the class of *Situations*, C is the class of *Concepts*, E is the class of *Entities*, A is the class of *Social Agents*, K is the class of *Collections*, I is the class of *Information Objects*, and T is the class of *Time intervals*.
c.DnS classes are structured as follows: *E is the class of everything that is assumed to exist in some domain of interest, for any possible world.*
E is partitioned in the class SE of "schematic entities", i.e. entities that are axiomatized in *c.DnS* (D, S, C, A, K, I), and the class $\neg SE$ of "non-schematic entities", which are not characterized in *c.DnS* (T, as well as classes such as those introduced in section 1.3.1). Schematic entities include concepts, roles, relationships, information, organizations, rules, plans, groups, etc. Examples of non-schematic entities include time intervals, events, physical objects, spatial coordinates, and whatever is not considered as a schematic entity by a modeller.
G is another subclass of E, and includes either schematic or non-schematic entities. Its definition is: *any entity that is described by a description in c.DnS*.[11] The formal definition of G will be given in section 1.3.3.

[11] When an entity is *described* in *c.DnS*, it gets a "unity criterion": a property that makes that entity an individual, distinct from any other one. For example topological self-connexity, perceptual saliency, functional role in a system are typical unity criteria

In intuitive terms, *c.DnS* classes allow to model how a social agent, as a member of a certain community, singles out a situation at a certain time, by using information objects that express a descriptive relation that assigns concepts to entities within that situation. In other words, these classes express the constructivist assumption according to which, in order to contextualize entities and concepts, one needs to take into account the viewpoint, for which the concept is defined or used, the situation that the viewpoint "carves out" from the observable environment, the entities that are in the setting of said situation, the social agents who share the viewpoint, the community, of which these agents are members, the information object by which the viewpoint is expressed, and the time-span characterizing the viewpoint.

The key notion in *c.DnS* is *satisfiability* of a description within a situation. Situations (*circumstantial* contexts) select a set of entities and their relations as being relevant from the viewpoint of a description (*conceptual* context). In mainstream terms, a situation is the context in which a set of entities *count as* the concepts in the context of a description. The *countsAs* relation (Searle, 1995), originally defined as holding between an entity, a concept, and a generic context, is then revised in order to allow for two types of contexts, which are orderly paired to entities and concepts.

For example, the relation:

$$countsAs(John, Student, University) \tag{1.2}$$

saying that John counts as a student in a university context, can be refined in *c.DnS* as:

$$c.DnS([John, JohnAtUniversity], [Student, UniversityRules]) \tag{1.3}$$

i.e. that $John \in E$) in the circumstantial context of a university ($JohnAtUniversity \in S$), is a student ($Student \in C$) according to the conceptual context of the rules of that university ($UniversityRules \in D$).

The other classes in *c.DnS* represent two additional context types: informational, and social.

Informational contexts are the ones encompassing the information objects that are used to express descriptions and concepts, for example the sentence:

(1.4) John goes to the university

in the context of a family conversation about John respecting course duties gets appropriate circumstantial and conceptual contexts, while a context like this resume of a TV episode in which John is a policeman does not:

(1.5) John goes to the university and while undergoing an MRI, they discover that he has something metallic inside him which is preventing the MRI scan

Social contexts like communities, groups, etc., are the ones encompassing agents that conceptualize entities. E.g. the online community of death metal fans could fit the conceptual context of John as a university student, while a local group of knitted lace shawl makers is far less typical.

1.3.1 Physical grounding of c.DnS

Some types of entities can be postulated in order to represent the physical grounding (i.e. the physical counterpart) of schematic entities:

$$grounded.DnS(d, s, c, e, a, k, i, t, ic, pa, ir, ag) \rightarrow$$
$$c.DnS(d, s, c, e, a, k, i, t) \wedge IC(ic) \wedge PA(pa) \wedge IR(ir) \wedge AG(ag) \quad (1.6)$$

where IC is the class of *Individual Constructs*, PA is the class of *Physical Agents*, IR is the class of *Information Realizations*, and AG is the class of *Aggregates*.
Intuitively, grounding classes allow to represent (1) IC: physical and individualized counterparts to descriptions, concepts, or situations, (2) PA: physical counterparts to agents, (3) IR: physical counterparts to information objects, and (4) AG: physical counterparts to collections.
These additional classes ground *c.DnS* in physical reality. In other words, we are enabled to represent the fact that physical agents, as parts of agent aggregates, and produce internal constructs of a context, by manipulating concrete realizations of information objects.
The grounding assumption can also be used to encode the embodiment hypothesis, i.e. that conceptualization grows out of bodily experience, and reflects it.
On the other hand, grounding is not primary in *c.DnS*, because *c.DnS* assumes that conceptual systems are grown *while* interpreting an environment. (Gibson, 1979) puts it as a *co-evolutionary system*: "The affordances of the environment are what it offers the animal, what it provides

or furnishes, either for good or ill ... [they imply] the complementarity of the animal and the environment". In *c.DnS*, a contextualized entity will only be such if experienced in a circumstantial context and interpreted in the conceptual context of an agent. The rationale is that circumstantial contexts emerge because they fit conceptual contexts, but concepts are evolved to appropriately interact with circumstances.[12]

In *c.DnS*, in order to accommodate different hypotheses (including the embodiment one), we simply need a commitment to whatever entities $e_{1...n} \in E$ one wants or needs to assume as given, because the identity and unity of given entities is ultimately provided by the way they are situated and conceptualized in context.

To this purpose, the descriptive framework of *c.DnS* provides four context types (conceptual, circumstantial, informational, and social), which are summarized in the class diagram of Figure 1.1, together with the projections of the $grounded.DnS$ relation, which are summarized in section 1.3.3. The co-evolutionary-based interpretation of the embodiment hypothesis also supports validation of schemata. If conceptual systems are artifacts for successful interaction between our bodies and the environment, and environments share invariances, social construction of reality will reflect shared invariances in the conceptual systems of the agents' bodies, which have evolved appropriate ways of interacting with their environment. The quest for invariances in the world (Nozick, 2001) may then be coupled with a quest for conceptual invariances (Lakoff, 1990), which is a way of testing the validity of hypothetical *schemata* that are central in most cognitive linguistics proposals.

The quest for conceptual invariances is not exclusive to cognitive linguistics. Besides the philosophical and mathematical literature, which is naturally devoted to establish or revise reusable structures that ultimately help us in organizing our knowledge, other areas of research have specifically addressed the task of describing and cataloging schemata, patterns, frames, etc. as conceptual invariances for many different purposes. These areas of

[12]Cf. (Gangemi, 2008) for a longer discussion; (Gibson, 1979) is the natural starting point to these ideas; (Gero and Smith, 2008) applies an interactionist approach to embodiment in the context of design; (Quine, 1951) is the originator of this kind of ontological relativism, and (Searle, 1995) defends the pragmatic view, by which entities created by cognitive systems are *epistemologically objective*, even if some of them are *ontologically subjective*, and even for those that can be considered *ontologically objective*, from this fact one cannot derive much more than "they are what they are".

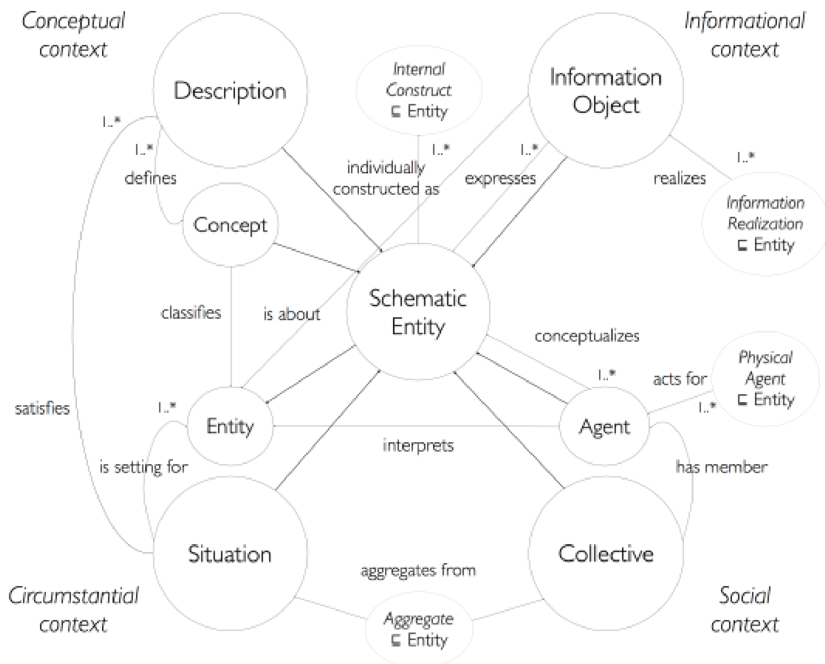

Figure 1.1: The contextual bindings for the representation of a conceptualization in grounded.DnS (following the OWL version of the ontology). Ovals denote classes, bold arrows denote subclass relations, regular arrows denote relations holding between members of the linked classes. The cardinality of a relation and its inverse is by default 0...*, except when indicated explictly. Classes with names in italics are classes of grounded entities.

research range from cybernetics and artificial intelligence (Foerster, 1974; Minsky, 1975) and knowledge engineering (Clark, Thompson and Porter, 2000; Gangemi, 2005) to architecture and design (Alexander, 1979; Gero and Smith, 2008), linguistics (Fillmore, 1982), and cognitive sciences (Bartlett, 1932; Piaget, 1968; Rumelhart, 1980; Chi, Glaser and Farr, 1988; Mandler, 2004; Gallese and Metzinger, 2003).
Devising a common framework for all these heterogeneous approaches to schemata has not been attempted yet, and it is the focus of *c.DnS* metamodeling in section 1.3.2, and projections (relations) in section 1.3.3. Strictly speaking, a formal framework for ECG does not need a metamodel that acts as a hub or a *façade* to integrate different schematic notions. On

the other hand, a desirable application and validation of ECG may use that framework in a strategic way. Examples include integration of heterogeneous lexical resources, modeling of NLP experiments, customized transformation of informal lexical knowledge into formal ontologies, etc.
A minimal axiomatization for *grounded.DnS* is given in section 1.3.3, the ECG extension is described in 1.4, the semiotic extension is described in 1.5, and some examples are included in 1.6.

1.3.2 Metamodeling with c.DnS

Within this chapter, *c.DnS* metamodel is positioned with reference to semiotics, cognitive linguistics, and formal semantics.

Semiotics The expressive power of *c.DnS* lies at the level where semiotic activity of cognitive systems occurs: where agents encode expressions that have a meaning in order to denote or construct reference entities in the world. From this perspective (Peirce, C.S., 1958; Jakobson, 1990; Eco, 1975), *c.DnS* informational context matches the *expression layer*, circumstantial context matches the *reference layer*, social context matches the *interpreter layer*, while all contexts together, and especially the conceptual one, match the *meaning* layer.
For example, I can represent statements such as

(1.7) When João says he's rich, he means he has a lot of friends.

which applies both referential and metalinguistic functions (Jakobson, 1990) in a same speech act (Searle, 1969); João is an agent in the social context, and uses contextualized information objects ("rich") that have a contextualized meaning ("having a lot of friends") and contextualized circumstances (João's linguistic act and his situation of having a lot of friends). This is the case for most linguistic acts that are implicit in lexica, thesauri, explanatory texts, web tags, etc. I will examine semiotic matching in section 1.5.
When leveraging semiotics, *c.DnS* can be used to align and integrate models that have heterogeneous semantics and (implicitly) encode different linguistic acts, e.g. different lexical models: WordNet (Fellbaum, 1998), FrameNet (Ruppenhofer, Ellsworth, Petruck, Johnson and Scheffczyk,

2006), VerbNet (Kipper, Dang and Palmer, 2000); different theories of meaning: frame semantics (Fillmore, 1982), semiotic theory (e.g. (Eco, 1975)), formal languages such as OWL (W3C, 2004); different texts: explanatory, metalinguistic; tagging (e.g. in Web2.0 applications, (Gruber, 2007)) vs. topic assignment (e.g. in subject hierarchies, (Welty, 1999)), etc.

A collection of examples for this integration task is collected under the LMM (Lexical MetaModel) umbrella[13] (Picca, Gangemi and Gliozzo, 2008), as a formal infrastructure for "extreme information integration" over the Web.[14] Here I only show two examples that are relevant for this chapter: (1) integration of the FrameNet database schema under *c.DnS*, with a sample formalization of frames and their occurrences as *c.DnS* descriptions, and (2) integration of ECG framework under *grounded.DnS*.

Cognitive linguistics From the point of view of cognitive linguistics, the basic intuition of *grounded.DnS* can be rephrased as follows: descriptions can be seen as corresponding to (the communicable version of) schemata, situations as corresponding to applied schemata (occurrences of schemata in the interaction between agents and environment), concepts as corresponding to aspects of schemata, and entities as corresponding to applied aspects of schemata (occurrences of aspects of schemata in the interaction between agents and environment, see section 1.4).

For example, the FrameNet frame "Desiring" can be formalized as a description, the frame element "Event" can be formalized as a concept, an occurrence of the frame in a real agent desiring some event, e.g. expressed by the sentence

(1.8) Susan really wishes that Marko would listen to her

can be formalized as a situation, and the desired event (e.g. expressed by the sentence

(1.9) Marko is listening to Susan

can be formalized as an entity (see section 1.6).

[13]http://ontologydesignpatterns.org/ont/lmm/opensourcex2lmm.owl

[14]Extreme information integration aims at creating knowledge bases from any information source, in a way that makes them interoperable.

Formal semantics From a formal perspective, the basic intuition of *c.DnS* can be interpreted in the context of a procedure of logical reification:[15] a *description* can be understood as the reification of 1) $\rho \in T$, with ρ being an intensional relation of any arity, either mono- or polymorphic, and T being an ontology (a typed logical theory), and 2) the axioms $\alpha_{1...n}$ that characterize ρ (i.e. the sub-theory $T_\rho \subseteq T$ with $\alpha_{1...n} \in T_\rho$).
On the other hand, *situations* result from reifications of (1) each of the individuals $r_{1....n} \in R^I$, R^I being the extensional intepretation of ρ, and of (2) the assertions $a_{1...n}$ that characterize r_i in accordance with the extensional interpretation of the axioms $\alpha_{1...n} \in T_\rho$. A *situation class* is consequently the reification of the set $\{r_1, ..., r_n\}$ where $r_i \in R^I$.[16]
c.DnS is able to formally represent the entire FrameNet knowledge base. This is ensured by the assumption that frames, schemata from cognitive linguistics, patterns from knowledge engineering, etc. can all be considered as n-ary relations, with typed arguments (either mandatory or optional), qualified cardinalities, etc. For example,

$$Desiring(x, y, e) \rightarrow Agent(x) \wedge Agent(y) \wedge Event(e) \tag{1.10}$$

An occurrence of a frame is straightforwardly treated as an instance of an n-ary relation, e.g.:

$$Desiring(Susan, Marko, ListeningToHer) \tag{1.11}$$

The logical representation of frames as n-ary intensional relations is elegant and clear, but hardly manageable by automated reasoners on large knowledge bases. A hard design problem is constituted by the polymorphism of many n-ary relations, which can vary in number of the arguments that can be taken by the relation. For example, the same frame Desiring can be assumed with four arguments:

$$Desiring(x, y, e, t) \rightarrow Agent(x) \wedge Agent(y) \wedge Event(e) \wedge Time(t) \tag{1.12}$$

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[15]See also (Masolo, Vieu, Bottazzi, Catenacci, Ferrario, Gangemi and Guarino, 2004) for an alternative, but compatible axiomatization of a part of *c.DnS*.

[16]Notice that *reification* is used here in two different senses, as pinpointed in (Galton, 1995): *type-reification* of classes to individuals, metaclasses to classes, etc., versus *token-reification* of tuples to individuals, sets of tuples to classes, etc.

This problem was originally evidenced by Davidson with reference to a logic of events (Davidson, 1967).
A formal semantics for frames that is also computationally manageable has been provided by description logics (Baader, Calvanese, McGuinness, Nardi and Patel-Schneider, 2003). Due to their limited expressive power – e.g. they can only represent relations with arity=2 – that is balanced by desirable computational complexity properties, description logics represent frames as classes, with *roles* (binary relations) that link a class to the types of the arguments of the original n-ary relation. Those types are classes as well, so that a graph of frames emerges out of this semantics. The example in 1.12 can be reengineered in DL as follows:

$$T \sqsubseteq \forall R_1.Agent, T \sqsubseteq \forall R_1^-.Desiring \quad (1.13)$$
$$T \sqsubseteq \forall R_2.Agent, T \sqsubseteq \forall R_2^-.Desiring \quad (1.14)$$
$$T \sqsubseteq \forall R_3.Event, T \sqsubseteq \forall R_3^-.Desiring \quad (1.15)$$
$$T \sqsubseteq \forall R_4.Time, T \sqsubseteq \forall R_4^-.Desiring \quad (1.16)$$
$$Desiring \sqsubseteq (=1R_1 \sqcap\ =1R_2 \sqcap\ =1R_3 \sqcap\ =1R_4) \quad (1.17)$$

The computational features of description logics make them a reasonable choice to formally represent linguistic frames, and this is the approach adopted by (Scheffczyk, Baker and Narayanan, 2008). On the other hand, even the description logic solution hits the ceiling of formalizing the metalevel conceptualization of frames and schemata. For example, the intended semantics of FrameNet relations between frames, between frame elements, and between frames and frame elements, lexical units, and lexemes is hardly representable in a description logic.
Frames can be subframes of others, can have multiple linguistic units that realize them, multiple lexemes that lexicalize those units, can have frame elements that are core or peripheral, words can evoke frames, etc. Logically speaking, these are second-order relations, and cannot be rebuilt into regular description logic semantics, which is basically first-order. However, recent advancements in higher-order description logics (De Giacomo, Lenzerini and Rosati, 2008) are very promising in order to represent the full range of frame-related relations. See also section 1.6.1.
The ontology outlined here makes use of a stratified approach that takes advantage of the reified higher-order expressivity of *c.DnS*. The ontology is represented in both first-order logic and OWL-DL (Bechhofer S., Harmelen F., Hendler J., Horrocks D., McGuinnes I., Patel-Schneider P. and Stein

L.A., 2004), the Web Ontology Language in its description logic variety[17]. Reification does not allow the same detail of representation and automated reasoning functionalities as the one enabled by a real higher-order logic, but the resulting "signature" (the intensional classes and relations of a theory) can still be applied within an actual higher-order theory. Future work includes applying the *c.DnS* vocabulary to a higher-order description logic (De Giacomo, Lenzerini and Rosati, 2008).

1.3.3 Projections of the grounded.DnS relation

Some relevant projections of the *c.DnS* and *grounded.cDnS* relations can be defined as binary or ternary relations, and axioms. Here I list, informally, the ones that I deem necessary in order to introduce a metamodel for the lexicon-ontology interface, and its application to frames and ECG. For a more complete axiomatization, and technical details on how *c.DnS* is applied in domain ontology projects, I refer to (Gangemi, 2008).
The following is the signature of the projections:

$$\begin{gathered}\Pi_{g.cdns} = \{defines, usesConcept, satisfies, classifies, about,\\ describes, conceptualizes, redescribes, expresses, memberOf,\\ isSettingFor, deputes, instantiates, covers, characterizes,\\ unifies, hasInScope, specializes, assumes, aggregatesFrom,\\ individuallyConstructedAs, actsFor, constructs, realizes, \}\end{gathered} \tag{1.18}$$

The rationale for the introduction of projections is such that each projection implies the full *grounded.DnS* relation, according to the axiom schema in 1.19.

$$\begin{aligned}\pi(x_1 \;...\; x_{n\geq 2} \,|\, x_i \in \{d, s, c, e, a, k, i, t, ic, pa, ir, ag\}) \rightarrow\\ grounded.DnS(d, s, c, e, a, k, i, t, , ic, pa, ir, ag)\end{aligned} \tag{1.19}$$

Descriptions are schematic entities that reify (the intension of) n-ary relations; for example, the *give(x,y,z,t)* relation (some x gives some y to

[17]The OWL-DL ontologies presented here can be downloaded from: http://ontologydesignpatterns.org/ont/cdns/index.html

some z at time t) can be reified as *D(giving)*. The axioms of the original relation, e.g. domain restrictions, are reified accordingly, by using the $defines$ or $usesConcept$ relations. For example,

$$defines(giving, donor) \tag{1.20}$$
$$usesConcept(giving, timespan) \tag{1.21}$$

In $c.DnS$, descriptions must be $conceptualizedBy$ social agents, $internallyConstructedBy$ some physical agent, and $expressedBy$ some information object, i.e. they should be communicable (Masolo, Vieu, Bottazzi, Catenacci, Ferrario, Gangemi and Guarino, 2004). Examples of descriptions include theories, regulations, plans, diagnoses, projects, designs, techniques, social practices, etc. Descriptions can $unify$ collections, and $describe$ entities. For example,

$$unifies(giving, /donor\ collection/) \tag{1.22}$$
$$describes(giving, /my\ recent\ birthday\ gift/, t_1) \tag{1.23}$$

Descriptions, as any schematic entity, can be $specialized$ (the reification of the formal subsumption relation) and $instantiated$ (the reification of the formal inclusion relation) by other descriptions.

Situations are schematic entities that reify instances of n-ary relations; for example, the relationship implicit in the sentence:

(1.24) Ali gave a puppet to Amélie on Sunday

can be formalized as:

$$give(Ali, puppet, Amelie, Sunday) \tag{1.25}$$

and can be reified as:

$$S(/Ali\ gave\ a\ puppet\ to\ Amelie\ on\ Sunday/) \tag{1.26}$$

Similarly to conceptual axioms for descriptions, the assertional axioms for situations need also to be reified accordingly, typically as elementary situations that are part of the complete situation, e.g., if the assertional relation axiom: $receives(Amelie, puppet)$ is reified as the assertional class axiom: $S(/Amelie\ receives\ a\ puppet/)$, the following holds:

$$hasPart(/Ali\ gave\ a\ puppet\ to\ Amelie\ on\ Sunday/,\ /Amelie\ receives\ a\ puppet/) \quad (1.27)$$

In $c.DnS$, situations must $satisfy$ a description and are $settingsFor$ entities, e.g.:

$$satisfies(/Ali\ gave\ a\ puppet\ to\ Amelie\ on\ Sunday/, giving) \quad (1.28)$$

$$settingFor(/Ali\ gave\ a\ puppet\ to\ Amelie\ on\ Sunday/, Ali) \quad (1.29)$$

Examples of situations include facts, plan executions, legal cases, diagnostic cases, attempted projects, technical actions. Situations can $haveInScope$ other situations. Situation classes project n-ary relation extensions into class extensions. For example, the *give(x,y,z,t)* relation can be projected as the situation class $Giving \subseteq S$, so that the following holds:

$$Giving(/Ali\ gave\ a\ puppet\ to\ Amelie\ on\ Sunday/) \quad (1.30)$$

Concepts are schematic entities that reify (the intension of) classes; for example, the $Person(x)$ class can be reified as $C(person)$. Concepts are *defined* or $used$ in descriptions, for example in order to reify the domains of n-ary relations. The axiom:

$$give(x, y, z, t) \rightarrow person(x) \quad (1.31)$$

can be reified as

$$D(giving)$$
$$C(person)$$
$$defines(giving, person) \quad (1.32)$$

Concepts typically $classify$ entities, e.g.

$$classifies(person, Ali) \quad (1.33)$$

and can $cover$ or $characterize$ collections, e.g.:

$$covers(person, personCollection) \quad (1.34)$$
$$characterizes(person, Italians) \quad (1.35)$$

Collections are schematic entities that reify the extension of classes; for example, the $\{x_1 \dots x_n\}$ extension of class $Person$ can be reified as $K(personCollection)$, so that:

$$\forall(x)(Person(x) \rightarrow (memberOf(x, personCollection, t_1))) \quad (1.36)$$

Collections are $coveredBy$ or $characterizedBy$ concepts, and can have members, e.g.

$$memberOf(Ali, personCollection, t_1) \quad (1.37)$$

Collections capture the common sense intuition underlying groups, teams, collections, collectives, associations, etc.

Social agents are schematic entities that personify other entities within the social realm: corporations, institutions, organizations, social relata of natural persons. For example, the natural person Ali can be personified as *A(AliAsLegalPerson)*. Social agents must be $introducedBy$ descriptions, for example by legal constitutive rules (Searle, 1995); social agents are also able to $conceptualize$ descriptions, to $redescribe$ situations, and to $depute$ concepts.

Information objects are schematic entities that "naturalize" units of information: the character Q, the German word $Sturm$, the symbol $\otimes$, the text of *Dante's Comedy*, the image of *Francis Bacon's Study from Innocent X*, etc. Information objects $express$ a schematic entity ($se \in SE$): a description, a concept, a situation, a collection, another information object, or even a social agent. For example, *expresses(Sturm,Storm)*. Information objects can also be $about$ other entities, typically situations; for example,

$$about(\text{``}Ali\, gave\, a\, puppet\, to\, Amelie\, on\, Sunday'', /Ali\ gave\ a\ puppet\ to\ Amelie\ on\ Sunday/) \quad (1.38)$$

Internal constructs are non-schematic entities, assumed to be grounded in the physical world, which are $individualConstructionsOf$ schematic entities, and in particular of descriptions and concepts. For example, Ali's embodied knowledge of the Ulysses' Canto XXVI from the Comedy is an individual construct ($ic \in IC$) of an intended meaning ($se \in SE$) of the Canto, as expressed by the Canto's text ($i \in I$).

Physical agents are non-schematic entities, assumed to be grounded in the physical world, which $act\,for$ social agents: organisms, robots, etc. For example, the physical agent $Ali \in PA$ can act for Ali as a legal person ($\in A$):

$$actsFor(Ali, AliAsLegalPerson, t_1) \tag{1.39}$$

Physical agents can $construct$ internal constructions.

Information realizations are non-schematic entities, assumed to be grounded in the physical world, which $realize$ information objects. For example,

$$realizes(ComedyPaperCopy, ComedyText, t_1) \tag{1.40}$$

Aggregates are entities (grounded or not, or mixed), which have as parts entities from either collections or situations. An aggregate $aggregates$ those entities $from$ their being members of a collection. For example,

$$\begin{aligned} &aggregatesFrom(personAggregate, personCollection, t_1) \leftarrow \\ &\quad (Person(x) \leftrightarrow (memberOf(x, personCollection) \leftrightarrow \\ &\quad\quad hasPart(personAggregate, x)) \end{aligned} \tag{1.41}$$

Based on these projections, the axiom 1.43 formalizes the *grounded construction principle* underlying the intuition of the grounded version of *c.DnS*. The axiom 1.43 is quite complex; it expands the basic idea of an entity that is given a unity criterion by being *described* by a description, as encoded in the simple axiom 1.42.

$$G(x) \leftrightarrow E(x) \wedge \exists(y,t)(D(y) \wedge describes(y,x,t)) \tag{1.42}$$

$$
\begin{aligned}
& G(x) \leftrightarrow \\
& \exists(d, s, c, a, k, i, t, c_1, pa, ir, ic, ag, d_1, s_1, t_1)(D(d) \wedge S(s) \wedge \\
& C(c) \wedge A(a) \wedge I(i) \wedge K(kc) \wedge T(t) \wedge C(c_1) \wedge \\
& PA(pa) \wedge IR(ir) \wedge IC(ic) \wedge D(d_1) \wedge S(s_1) \wedge T(t_1) \wedge \\
& classifies(c, x, t) \wedge isSettingFor(s, x) \wedge defines(d, c) \wedge \\
& satisfies(s, d) \wedge conceptualizes(a, d, t) \wedge unifies(d, kc) \wedge \\
& constructs(pa, ic, t) \wedge individuallyConstructedAs(d, ic, t) \wedge \\
& memberOf(a, kc, t) \wedge deputes(a, c_1, t) \wedge classifies(c_1, pa, t) \wedge \\
& expresses(i, d, t) \wedge actsFor(pa, a, t) \wedge realizes(ir, i, t) \wedge \\
& aggregatesFrom(ag, kc, t) \wedge hasPart(ag, pa, t) \wedge \\
& settingFor(s, t) \wedge settingFor(s, pa) \wedge redescribes(a, s, t_1) \wedge \\
& settingFor(s_1, pa) \wedge settingFor(s_1, ir) \wedge settingFor(s_1, ic) \wedge \\
& conceptualizes(a, d_1, t_1) \wedge describes(d_1, d, t_1) \wedge \\
& satisfies(s_1, d_1) \wedge hasInScope(s_1, s))
\end{aligned} \tag{1.43}
$$

Axiom 1.43 verbosely says that any ground entity x (i.e. an entity whose identity and unity are given through the interpretation of a situation, in which it is contextualized) entails the activation of a complex pattern of associations within a physical agent situated in a knowledge community:

- x is always classified at some time by at least one concept that is defined in a description, which results to describe x
- x is always contextualized in a situation that satisfies the description
- both the description and the situation of x are conceptualized by a social agent that is a member of a community whose members share some knowledge
- the description is expressed by an information object that is realized by some information realization
- the social agent that conceptualizes x's description redescribes x's situation by means of describing the description itself into another description. This is equivalent to having x's situation in the scope of

the redescription situation; in practice, this means that the agent has some intention to describe x in a context, with some expectations, assumptions, goals, etc.

- the social agent is acted for by at least one physical agent that is capable of constructing internal constructs for the schematic entities mentioned so far
- the agent's community that share the knowledge about x has a corresponding aggregate at some time, made up of physical agents
- "knowledge" in *c.DnS* is the set of schematic entities that are (partly or wholly) shared by a community, and (partly or wholly) individually constructed in the cognitive systems of the physical agents that are members of that community. E.g. for an expert, having expertise (say practical knowledge) on something is represented as having the ability to apply internal constructs of descriptions to internal constructs of situations with (internal constructs of) some informational and social contexts. The degree at which such internal constructs can be used to observe, reason, and efficiently act in context distinguishes agent capabilities in a community.

The pattern axiomatized in 1.43 is very general, and can be applied to many disparate phenomena: linguistic acts, planning, diagnosing, designing, etc. In this chapter, I am interested in how *c.DnS* can be used to create a façade for different lexical models.

1.4 Schemata, mental spaces, and constructions

An ECG ontology should include *schemata*, *mental spaces*, and *constructions* (Chang, Feldman, Porzel and Sanders, 2002) in its domain. The distinction holds for example when comparing the term "Alice in Wonderland" (a construction), the conceptualization (a mental space) that can be evoked by the term, and the frame (a schema) underlying the mental space, e.g. a frame for conceptualizing action in imaginary locations.
Within *c.DnS*, ECG primitives must be considered from both an individual and a social perspective, because internal constructs are individually constructed as dependent not only on internal and external sensory systems

of a cognitive agent (Karmiloff-Smith, 1994), but also on distributed, collective knowledge. In turn, collective knowledge is said to be dependent on individual internal constructs (section 1.3.3). I will then postulate both individual and collective (public, or at least reportable) versions of constructions, mental spaces, and schemata.
Following the RR framework proposed by Karmiloff-Smith, I assume four levels at which knowledge is present (and re-presented) with different degrees of explicitness and detail: Implicit (I), Explicit-1 (E1), Explicit-2 (E2), and Explicit-3 (E3). At level I, information is encoded in a procedural form, it has no component parts and, as a consequence, no intra- or inter-domain links within the system. At level E1, on the contrary, knowledge result from redescription of the information encoded at level I: it has component parts and possibly representational links; however, they are not yet available to conscious access and linguistic (semiotic) report. At level E2, it is hypothesized that representations gain conscious access and functionality, but still lack reportability. The latter obtains only at level E3, where representations are stored in a communicable format e.g. akin to natural languages (Karmiloff-Smith, 1994).
Based on this assumption, schemata, mental spaces and constructions should be present at various levels in the human cognitive system, i.e.:

1. as instances of neural activation patterns (event-like entities $n_{1...n} \in NE \subseteq E$) in (specific areas of) the perceptual or motor systems (level I knowledge). This is knowledge that is typically learnt from motor routines, or inductively when an agent is exposed to a critical mass of inputs that contain invariances against transformations (Nozick, 2001), and constitute *affordances* for the agent's behavior (Gibson, 1979). Examples include sound constructions, reactive mental spaces, motor schemata. An ontology specific for this level is proposed in (Gallese and Metzinger, 2003);

2. as instances of functional internal constructs ($f_{1...n} \in FE \subseteq IC$), including both conscious and non-conscious non-semiotic formats, i.e. level E1 and E2 knowledge. Examples include phonetic constructions, non-mappable mental spaces, image schemata;

3. as instances of reportable entities ($r_{1...n} \in RE \subseteq SE$), including reportable formats, i.e. level E3 knowledge.[18] Examples include lexical constructs ($co_{1...n} \in I$), mappable (and reportable) mental spaces and blendings (Turner, 2007) ($ms_{1...n} \in SE$), as well as reportable schemata ($sc_{1...n} \in D$).

A schema can then be represented: as an instance of a neural schema in the perceptual or motor system at level I:

$$NeuralSchema \subseteq NE \tag{1.44}$$

as an instance of a functional schema at levels E1 or E2:

$$FunctionalSchema \subseteq FE \tag{1.45}$$

or as an instance of a reportable schema at level E3:

$$ReportableSchema \subseteq (D \cap RE) \tag{1.46}$$

A reportable schema is a description that is individually constructed as a functional schema, and allows the primary organization of public (expressible) conceptualizations into social knowledge. The dependency of reportable on functional schemata, which in turn depend on neural schemata, is then an hypothesis for the grounding of intersubjective knowledge into invariances across the neural circuits of physical agents.

Similarly, a mental space can be represented: as an instance of a neural space:

$$NeuralSpace \subseteq NE \tag{1.47}$$

as an instance of a functional space:

$$FunctionalSchema \subseteq FE \tag{1.48}$$

or as an instance of a reportable space:

$$ReportableSchema \subseteq RE \tag{1.49}$$

[18]The use of *knowledge* for E3 entities corresponds to the one defined in section 1.3.3, as the set of schematic entities and their relations, which are available to a community. On the contrary, embodied knowledge in levels I and E1-2 is the grounding counterpart to schematic knowledge.

A functional schema is probably akin to a "perceptual symbol" (Barsalou, 1999). In this framework, a functional schema allows the primary organization of external, kinesthetic and internal sensory data into efficient (affordance-oriented) internal constructs (Viezzer and Nieuwenhuis, 2005).
Finally, a construction can be represented as an instance of a neural construction:

$$NeuralConstruction \subseteq NE \tag{1.50}$$

as an instance of a functional construction:

$$FunctionalConstruction \subseteq FE \tag{1.51}$$

or as an instance of a reportable construction:

$$ReportableConstruction \subseteq (I \cap RE) \tag{1.52}$$

A bipartite graph is obtained which is summarized in the diagram from Figure 1.2, where constructions $evoke$ (in different senses according to the level) mental spaces, which are $structuredBy$ schemata. The combination of three types of entities (Constructions, Mental Spaces, Schemata), and three levels (Neural, Functional, Reportable) produce nine classes, which constitute a proposal for an ECG ontology of *individual* knowledge. $Evoking$ relations associate Constructions with Mental Spaces, e.g.:

$$evokes\_r(x, y, t) \rightarrow ReportableConstruction(x) \wedge ReportableMentalSpace(y) \wedge TimeInterval(t) \tag{1.53}$$

$$ReportableConstruction(x) \rightarrow \exists (y, t)(evokes\_r(x, y, t)) \tag{1.54}$$

The $evokes\_r$ relation (but not the other evoking relations) is a subrelation of $expresses$:

$$evokes\_r(x, y, t) \rightarrow expresses(x, y, t) \tag{1.55}$$

Reportable constructions get their intuition from the fact that they must be reportable, i.e. $realizedBy$ some information realization, as it holds for all information objects, according to the grounded construction principle. This realization can be public: sounds, bytes, gestures, ink traces, etc., but at the individual level there is at least one realization as a functional

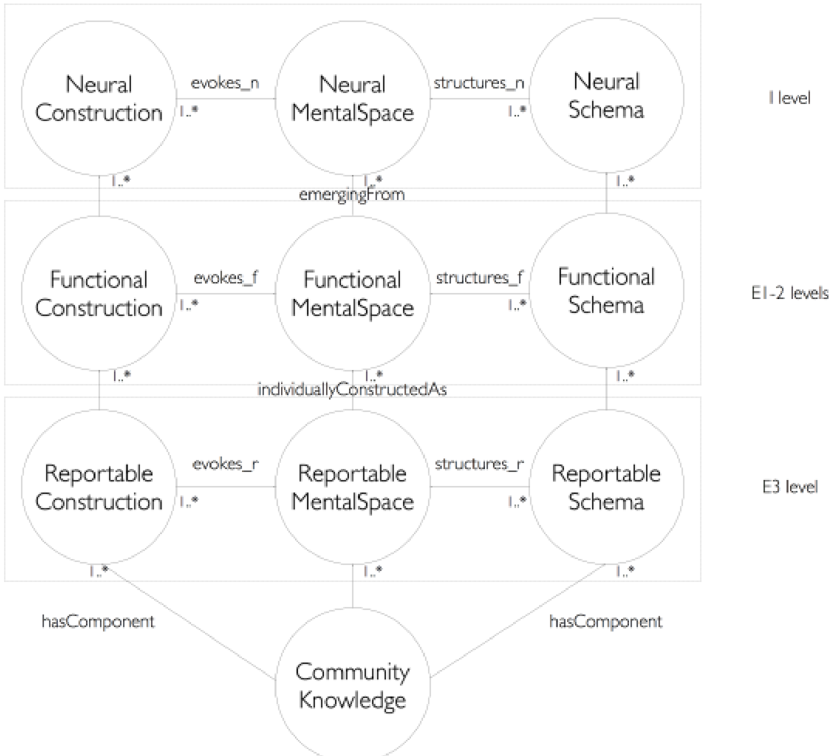

Figure 1.2: The classes and relations of the ECG ontology.

construction, emerging on its turn from a neural construction (see axiom 1.59). A related assumption, i.e. that public and individual realizations of reportable constructions have a common counterpart, is critical, since it founds the possibility of *shared meaning* across the agent members of a community. The assumption can be strong or weak depending on what degree of correspondance is assumed between functional and reportable constructions. Here I do not take any position about this.
$Structuring$ relations associate Schemata with Mental Spaces, e.g.:

$$structures\_r(x, y, t) \rightarrow ReportableSchema(x) \land ReportableMentalSpace(y) \land TimeInterval(t) \quad (1.56)$$

$$ReportableMentalSpace(y) \rightarrow \exists(x, t)(structures\_r(x, y, t)) \quad (1.57)$$

Structuring implies that all situations that satisfy a mental space, must also satisfy the structuring schema (the following example is for structuring applied to reportable spaces only):

$$structures\_r(x, y, t) \rightarrow \forall(s)(satisfies(s, y) \rightarrow satisfies(s, x)) \quad (1.58)$$

The axioms 1.56 and 1.58 about the structuring role of schemata over mental spaces, together with the axioms 1.53 about the grounding of reportable constructions into functional constructions, make formally explicit the embodiment and cognitive invariance hypotheses: mental spaces can be communized because reportable constructions leverage schematic invariances.
The Reportable level is $individually\ constructed$ at the Functional level; the relation is locally axiomatized e.g. as follows:

$$\begin{aligned} ReportableConstruction(x) \rightarrow \exists(y, t) \\ (FunctionalConstruction(y) \wedge \\ individuallyConstructedAs(x, y, t)) \end{aligned} \quad (1.59)$$

The Functional level $emerges$ out of the Neural level, e.g.:

$$\begin{aligned} emergingFrom(x, y, t) \rightarrow FunctionalConstruction(x) \wedge \\ NeuralConstruction(y) \wedge TimeInterval(t) \end{aligned} \quad (1.60)$$

$$\begin{aligned} FunctionalConstruction(x) \rightarrow \\ \exists(y, t)(NeuralConstruction(y) \wedge emergingFrom(x, y, t)) \end{aligned} \quad (1.61)$$

The relation $emergingFrom$ does not imply identity: functional entities at levels E1 and E2 are different (in format, hence in use and in underlying neural patterns) from the original I-level ones. However, evidence from neurophysiological and neuropsychological studies suggests that higher-order representations (e.g. recalled images) involve complex neural circuits, in which patterns located in the so-called association cortices "recruit" other neural patterns from the early sensory cortices (Edelman, 1989; Damasio, 1994). Moreover, damages in the areas where non-verbal knowledge is stored cause drastic alteration of reasoning and linguistic performances (Bisiach, 1988). What emergence does imply, thus, is the necessary co-participation of a lower-level neural entity into the activation of a higher-order, constructed one.

Anyway, emergence of internal constructs from level I neural entities is far less clear in current research. (Gallese and Metzinger, 2003), based on empirical evidence from mirror neurons research results, is an interesting proposal for a *motor ontology* that is specific to nervous systems in creating embodied goals, actions, and "intentional selves". The authors also envision a theory of how such motor ontology could be gradually extended into the subjective and social domains.
Finally, simple componency relations associate individual knowledge with community knowledge, which results to be a whole composed of some reportable entities (individual knowledge):

$$\begin{aligned} CommunityKnowledge(x) \rightarrow \\ \exists(y_1, y_2, t, a_1, a_2)(RE(y_1) \wedge RE(y_2) \ \wedge \\ y_1 \neq y_2 \wedge A(a_1) \wedge A(a_2) \wedge a_1 \neq a_2 \ \wedge \\ conceptualizes(a_1, y_1) \wedge conceptualizes(a_2, y_2) \ \wedge \\ hasProperPart(x, y_1, t) \wedge hasProperPart(x, y_2, t)) \end{aligned} \tag{1.62}$$

While reportable entities (RE) are dependent on functional and neural entities (FE, NE), coherently with the co-evolutionary assumption (cf. section 1.3.2), there is a converse dependency of functional and neural entities on reportable entities too, because neural entities co-evolve with reportable entities, which, as schematic entities, are socially-constructed. This converse dependency is in agreement with constructivist, socio-historical theories of cognitive development (Vigotsky, 1962), and with recent data on the role played by social interaction on the development of cognitive and linguistic skills (Tomasello, 2003).

1.5 An embodied semiotic metamodel

This section introduces *Semion*, an ontology that represents a semiotic pattern that dates back at least to Peirce (Peirce, C.S., 1958) and Saussure (Saussure, 1906), and adapts it to *c.DnS* and the ECG ontology.
Peirce used a peculiar terminology, and the versioning of his theory is not trivial. Semion encodes a pattern that basically conveys his mainstream ideas: meaning as a role, indirectness of reference, and the dialogic nature of thinking. These ideas have slowly found their way into the literature,

and can be formalized by using *c.DnS* as a backbone.
Expressions are information objects used to express a meaning in context at some time. *c.DnS* has contextualization as a primitive assumption in the grounded construction principle, therefore each extension of it assumes a multi-faceted contextualization as depicted in Figure 1.1. The Expression class (that Peirce called "representamen", and Saussure "signifiant") is minimally axiomatized by assuming that an expression is an information object that expresses some schematic entity at some time, and is about some entity at that time:

$$Exp(e) =_{df} ReportableConstruction(i) \wedge \exists(se, x, t) (SE(se) \wedge expresses(e, se, t) \wedge E(x) \wedge T(t) \wedge isAbout(e, x, t)) \quad (1.63)$$

Meanings are schematic entities that are expressed by an expression in context at some time. The Meaning class (that Peirce called "interpretant", and Saussure "signifié") is minimally axiomatized by assuming that a meaning is a schematic entity that is expressed by some information object at some time, and allows the interpretation of some entity at that time:

$$Mea(m) =_{df} SE(m) \wedge \exists(i, e, t)(I(i) \wedge expresses(i, m, t) \wedge E(e) \wedge T(t) \wedge interpretedAs(e, m, t)) \quad (1.64)$$

References are entities, which an expression is about at some time. The Reference class (that Peirce called "object") is minimally axiomatized by assuming that a reference is an entity, which an information object is about at some time, and which is interpreted according to a schematic entity at that time:

$$Ref(r) =_{df} E(r) \wedge \exists(i, se, t)(I(i) \wedge isAbout(i, r, t) \wedge SE(se) \wedge T(t) \wedge interpretedAs(r, se, t)) \quad (1.65)$$

Interpreters are agents, which conceptualize a meaning at some time in an ideal dialogic context with other agents. The Interpreter class is axiomatized by assuming that an interpreter is a physical or social agent, which conceptualizes a schematic entity in the context of a situation at some time, which also involves another agent:

$$Int(a) =_{df} (A(a) \vee PA(a)) \wedge \exists(se, s, t, a_1)(SE(se) \wedge conceptualizes(a, se, t) \wedge S(s) \wedge T(t) \wedge settingFor(s, a) \wedge settingFor(s, se) \wedge settingFor(s, t) \wedge A(a_1) \wedge settingFor(s, a_1)) \quad (1.66)$$

The situation of an interpreter conceptualizing a meaning evoked by an expression, in a context involving another interpreter conceptualizing the same expression, is called here *linguistic act* ($LingAct$). It is related to the notion of *speech act* from (Searle, 1969), and to the notion of *social act* from (Reinach, 1983; Smith, 1990). Linguistic acts are implicit in the grounded construction principle, where the interpretive activity of an agent generates two situations: the observable one, and the linguistic one, which includes the agent in the loop (cf. 1.3.3). The *LingAct* class is axiomatized by assuming that a linguistic act is a situation, in which two agents conceptualize two meanings for a same expression at two given time spans, and referring to two entities (the two agents, meanings, time spans and entities resp. are not necessarily different).[19] Before introducing the class of linguistic acts, the maximal Semion relation is shown, which leverages the grounded construction principle and the previous definitions:

$$\begin{aligned} semion(a,e,m,r,l,t,a_1,m_1,r_1,t_1) =_{df} (Int(a) \wedge Exp(e) \wedge \\ Mea(m) \wedge Ref(r) \wedge S(l) \wedge T(t) \wedge A(a_1) \wedge Mea(m_1) \wedge T(t_1) \wedge \\ Ref(r_1) \wedge conceptualizes(a,m,t) \wedge expresses(e,m,t) \wedge \\ interpretedAs(r,m,t) \wedge conceptualizes(a_1,m_1,t_1) \wedge \\ isAbout(e,r,t) \wedge expresses(e,m_1,t_1) \wedge isAbout(e,r_1,t_1) \wedge \\ settingFor(l,a) \wedge settingFor(l,a_1) \wedge settingFor(l,t) \wedge \\ settingFor(l,t_1) \wedge settingFor(l,m) \wedge settingFor(l,m_1) \wedge \\ settingFor(l,r) \wedge settingFor(l,r_1) \wedge settingFor(l,e)) \end{aligned} \quad (1.67)$$

An instance of the Semion relation is an occurrence of the semiotic pattern in a community of agents that share some common knowledge.
Since schematic entities in *c.DnS* have individual counterparts in the ECG ontology ($RE \subseteq SE$), and communized knowledge is made up of reportable entities (axiom 1.62), Semion acquires an embodied grounding by formally associating meanings with reportable entities (axiom 1.68).

$$semion(a,e,m,r,l,t,a_1) \rightarrow \exists(re)(RE(re) \wedge m = re) \quad (1.68)$$

[19]In the dialogic view of semiotics, even an interpreter alone has an "internal conversation".

Now, the LingAct class is introduced directly by assuming the Semion relation:

$$LingAct(l) =_{df} S(l) \wedge \exists(a,e,m,r,t,a_1,m_1,r_{1,}t_1)$$
$$(semion(a,e,m,r,l,t,a_1,m_1,r_{1,}t_1)) \qquad (1.69)$$

The Semion approach is pragmatic, in the spirit of Peirce's: a meaning can be *any* schematic entity, including expressions, concepts, descriptions, collections, or situations. Therefore, any linguistic act is easily representable by specializing the axiom 1.64. For example, the act performed by lexicographers, by which expressions have other expressions as their meanings specializes ($Mea \subseteq SE$) as $Mea \subseteq I$. Cognitive theories of meaning, which defend the individual dimension of meaning, can be represented by specializing the axiom 1.64 as $Mea \subseteq RE$. Frame semantics (section 1.6.1) can be represented by specializing 1.64 as $Mea \subseteq (D \cap ReportableSchema)$. Extensional formal semantics can be represented by specializing 1.64 as $Mea \subseteq K$, etc.
Moreover, indirectness of reference can be defended or not in some theory of meaning, but in Semion, any such theory can be represented: if some form of conceptualism is taken, the *isAbout* relation can be used with a dependence on a meaning as a mediator; in some form of referentialism, it can be applied directly.
Semion-based models, as exemplified in section 1.6.1, can be transformed into (formal) ontologies by applying a transformation pattern. Since *c.DnS* leverage logical reification, its de-reification is already a transformation pattern; whenever a customization is needed, different patterns can be defined and applied, and the formal choices made are then explicitly represented. See section 1.6.3 for an example.
Since any kind of linguistic act (for example, explanatory text, lexicographic metalanguage, document tagging or indexing, etc.) can be represented as an instantiation of the $LingAct$ class, the coverage of Semion is very broad, and ready to apply within an extreme information integration task, for example over the Semantic Web by using its OWL version.[20]

[20] http://www.ontologydesignpatterns.org/ont/cdns/semion.owl.

1.6 Applying Semion to FrameNet and related resources

In this section, I exemplify the application of Semion to FrameNet. Section 1.6.1 describes a part of the FrameNet metamodel based on Semion, and how it allows to create a formal version of FrameNet, called OntoFrameNet. In section 1.6.2 the same procedure is applied to VerbNet. In section 1.6.3 Semion is applied to mapping and transformation examples. In section 1.6.4, some examples from schematic and non-schematic containment-oriented frames are modeled. In section 1.6.5, grounding example is given by providing a model of a situation that satisfies said frames.

1.6.1 OntoFrameNet

FrameNet is a lexical knowledge base, which consists of a set of *frames*, which have proper *frame elements* and *lexical units*, expressed by *lexemes*. Frame elements are unique to their frame, and can be optional. An occurrence of a frame consists in some piece of text whose words can be normalized as lexemes from a lexical unit of a frame, and which have semantic roles dictated by the elements of that frame. A frame can occur with all its roles filled, or not. Frames can be *lexicalized* or not. The non-lexicalized ones typically encode *schemata* from cognitive linguistics. Frames, as well as frame elements, are related between them, e.g. through the *subframe* relation. FrameNet contains more information, related to parts of speech, *semantic types* assigned to frames, elements, and lexical units, and other metadata.
A complete reengineering of FrameNet (version 1.2) as a *c.DnS* plugin can be found in the OWL version of OntoFrameNet[21]. Another OWL version is presented in (Scheffczyk, Baker and Narayanan, 2008), which translates the first-order fragment of FrameNet 1.3 into an OWL TBox (the conceptual part of an ontology).
A critical difference between the two is that in the first-order translation neither the inter-frame and inter-frame-element relations can be formalized, nor the relations between lexemes and lexical units, lexical units

[21] http://www.ontologydesignpattern.org/ont/ofn/ofntb.owl

and frames, word and frames, etc. In exchange, the full automated reasoning power implemented for description logics can be used. On the contrary, OntoFrameNet is based on *c.DnS*, therefore all FrameNet data are put in the same domain of quantification, by using a reified higher-order approach. This transformation allows to preserve the original schema of the knowledge base, without any loss of information. The only problem is that the automated reasoning over OntoFrameNet occurs mainly at the OWL ABox level, the assertional part of an ontology, (Baader, Calvanese, McGuinness, Nardi and Patel-Schneider, 2003).

There are several reasons why the second approach is better in my opinion. Firstly, the formal semantic assumptions made in order to transform the first-order FrameNet fragment into an OWL TBox are not explicit, and the consequent reasoning is exploited on a case-by-case basis. Secondly, too much information is lost in the process, which characterizes FrameNet relevant (although informal) semantics (Frame Semantics (Fillmore, Kay and O'Connor, 1988)). Thirdly, the OntoFrameNet approach exploits Semion as a semiotic façade that can be shared with other resources and data sets (WordNet, VerbNet, etc.), thus facilitating advanced forms of information integration and ontology matching.

That façade is not available when a direct translation to a TBox is performed. Incidentally, this is also the reason why I abandoned a similar approach with WordNet (see e.g. (Gangemi, Guarino, Masolo and Oltramari, 2003)), and moved to a reified strategy in a porting commissioned by W3C (Assem, Gangemi and Schreiber, 2006).[22] Fourthly, ongoing work on using HiDL-Lite (De Giacomo, Lenzerini and Rosati, 2008) will allow to obtain the best of the two worlds: a *c.DnS*-like vocabulary, and a truly higher-order automated reasoner. Fifthly, by using the full set of semiotic ontologies in the LMM umbrella (Picca, Gangemi and Gliozzo, 2008),[23] a custom translation of selected parts of OntoFrameNet to a TBox can be performed with an explicit semantics (cf. section 1.6.3 below).

The backbone of FrameNet is the notion of a *Frame*. As the authors pragmatically state (Ruppenhofer, Ellsworth, Petruck, Johnson and Scheffczyk, 2006): "with enough time to make a truly in-depth analysis of the data, and enough data to make an exhaustive account of the language, then

[22] http://www.ontologydesignpattern.org/ont/lmm/wn202lmm.owl

[23] http://www.ontologydesignpatterns.org/ont/dul/FormalSemantics.owl
http://www.ontologydesignpatterns.org/ont/lmm/ofn2lmm.owl

undoubtedly each lexical unit could be given its own unique description in terms of the frames and/or subframes which it evokes. The situation is, in a sense, worse than the question suggests: it isn't that every word has its own frame, but every sense of every word (i.e., every lexical unit) has its own frame. It's a matter of granularity. Instead, we are sorting lexical units into groups in the hope that they permit parallel analyses in terms of certain basic semantic roles, i.e., the frame elements that we have assigned to the frame. This allows us (1) to make the sorts of generalizations that should be helpful to the users mentioned above and (2) to provide semantically annotated sentences that can exemplify paraphrase relations within given semantic domains."
In practice, FrameNet is trying to find schematic invariances in the conceptual structures of linguistic usage, in order to reduce the complexity of expliciting all the schemata applicable to each word sense. This hypothesis is compatible with the cognitive linguistics paradigm, with intensional relations in formal semantics, as well as with the *c.DnS* reified relational ontology. The core OntoFrameNet metamodel consists of the following relation (1.70):

$$\begin{aligned} FrameNetRel(f, fe, st, lu, l) \rightarrow \\ Frame(f) \wedge FE(fe) \wedge hasFE(f, fe) \wedge \\ SemanticType(st) \wedge hasSemType(fe, st) \wedge \\ LexicalUnit(lu) \wedge hasLU(f, lu) \wedge \\ Lexeme(l) \wedge hasLexeme(lu, l) \end{aligned} \quad (1.70)$$

For example:

$$\begin{aligned} FrameNetRel(F\_Desiring, FE\_Event\_3363, \\ StateOfAffairs, LU\_desire.v\_6413, LEX\_desire\_10357) \end{aligned} \quad (1.71)$$

The projections of the frame relation characterize its arguments further: for each frame there are one or more elements, but each element is unique to one frame. For each frame there are one or more lexical units (senses), but each unit is unique to a frame. For each frame, frame element or lexical unit there should be a semantic type (in the core relation, only the type of the frame element is mandatory). Moreover, several relations create further ordering between frames, and between frame elements. Unfortunately, FrameNet data are not complete: for example, many frame elements are

still missing a semantic type.
In OntoFrameNet, besides formalizing the metamodel and creating inverse projections where needed, some additions have been implemented; for example, a *generic* frame element has been created for sets of frame elements with the same name: in this way it is possible to run more sophisticated queries in order to measure frame distance (e.g. finding those sharing two generic frame elements except Space and Time). Moreover, situations corresponding to occurrences of frames in the interaction with the environment, as expressed by textual sentences (e.g. those annotated in PropBank with frames and frame elements), have been given room in a newly created class (*FrameOccurrence*).
The alignment is summarized as follows, and a shortened axiomatization is presented in axioms 1.72 and on. *Frames* are aligned as meanings in Semion, and since frames have a relational structure (as conceptual contexts), they are more specifically aligned as descriptions (reified intensional relations). Moreover, from ECG, one can also give frames a (cognitive) schema status, so that frames are also aligned as reportable schemata. The relations between frames have been aligned consequently: the frame *inheritance* relation as *c.DnS* specialization, the *subframe* relation as proper part, etc.
The *evokes* relation between lexemes or lexical units, and frames is aligned to the evokes_r relation.
Frame elements are "FEin" a frame, and are aligned as meanings, and as concepts (uniquely) defined in a frame.
Lexical units are aligned as meanings, and as descriptions, expressed by a specific aggregate of lexemes, which is also a reportable construction.
Lexemes are aligned as expressions, and as reportable constructions.

Occurrences of frames are aligned as reportable mental spaces that are expressed (evoked_r) by reportable constructions (as sentences).

$$Frame \subseteq (Mea \cap D \cap ReportableSchema) \quad (1.72)$$

$$inheritsFrom(f_1, f_2) \rightarrow specializes(f_1, f_2) \wedge Frame(f_1 \wedge Frame(f_2) \quad (1.73)$$

$$isSubFrameOf(f_1, f_2) \rightarrow isProperPartOf(f_1, f_2) \wedge Frame(f_1 \wedge Frame(f_2) \quad (1.74)$$

$$evokes(x, y) \rightarrow evokes\_r(x, y) \quad (1.75)$$

$$hasFE(f, fe) \rightarrow defines(f, fe) \wedge F(f) \wedge FE(fe) \quad (1.76)$$

$$FE(fe) =_{df} Mea(fe) \wedge C(fe) \wedge \exists!(f) (Frame(f) \wedge defines(f, fe)) \quad (1.77)$$

$$GenFE(gfe) =_{df} Mea(gfe) \wedge C(gfe) \wedge \exists(fe) (FE(fe) \wedge specializes(fe, gfe) \wedge \neg\exists(f)(Frame(f) \wedge defines(f, gfe))) \quad (1.78)$$

$$LexicalUnit(lu) \rightarrow Mea(lu) \wedge D(lu) \wedge \exists(ag, l, t) (Aggregate(ag) \wedge Lexeme(l) \wedge hasProperPart(ag, l) \wedge expresses(ag, lu, t)) \quad (1.79)$$

$$Lexeme(le) \rightarrow ReportableConstruction(le) \quad (1.80)$$

$$SemanticType \subseteq (Mea \cup C) \quad (1.81)$$

$$FrameOccurrence(fo) =_{df} S(fo) \wedge ReportableMentalSpace(fo) \wedge \exists(f, ag, lu, t)(Frame(f) \wedge Aggregate(ag) \wedge satisfies(fo, f) \wedge ReportableConstruction(le) \wedge hasProperPart(ag, le) \wedge evokes\_r(ag, fo, t)) \quad (1.82)$$

Superficially, the linguistic act involved in FrameNet consists in a *metalinguistic* function (Jakobson, 1990), typical of lexica, dictionaries, etc., in which an agent assigns meanings to expressions, and the observable situation of the act is a linguistic situation. On the other hand, frame semantics tries to reach out to language usage, not only to an abstract characterization of linguistic items; as a matter of fact, frame occurrences, as denoted by annotations made over the PropBank corpus, are real world situations (explanatory, expressive, etc.), not metalinguistic ones. This

hybrid nature of frame semantics distinguishes it from e.g. WordNet-based annotations of corpora, where real world situations cannot be denoted in a relational way.
While other lexical resources, such as WordNet and VerbNet, have not the same groundedness as FrameNet, nonetheless they are widely used and contain a lot of reusable content that can be combined effectively with FrameNet. Additional alignments from other resources to Semion show how to use it as a semiotic façade.

1.6.2 OntoVerbNet

VerbNet (Kipper, Dang and Palmer, 2000), has a different metamodel from FrameNet; it is focused on verb syntax and semantics, rather than frame semantics, which abstracts out of parts of speech. A new metamodel (called OntoVerbNet) has been created, which is shown partly in the maximal semantic relation 1.83 (some names from the original relational database schema have been changed for readability):

$$\begin{aligned} VerbNetRel(vn, fr, pr, ar, ca) \rightarrow \\ VNClass(vn) \wedge VNFrame(fr) \wedge hasFrame(vn, fr) \wedge \\ Predicate(pr) \wedge hasPred(fr, pr) \wedge Argument(ar) \wedge \\ hasArg(pr, ar) \wedge Category(ca) \wedge hasType(ar, ca) \end{aligned} \quad (1.83)$$

$$VNClass(vn) \rightarrow \exists(v)(Verb(v) \wedge hasMember(vn, v)) \quad (1.84)$$

For example:

$$\begin{aligned} VerbNetRel(battle\_36.4, fr_{8.1}, social\_interaction, \\ Actor1, animate) \end{aligned} \quad (1.85)$$

$$hasMember(battle\_36.4, argue) \quad (1.86)$$

The OntoVerbNet interpretation over VerbNet represents different lexical semantics for each "verb class", trying to catch the basic semantic structure of VerbNet, consisting of typed arguments holding for a predicate in a "frame" that contributes to the complete semantics of a verb class; frames also have syntactic constructs applicable to the verb, to which the frame is applied.

In the example 1.85, the verb class *battle* has a frame (including both syntactic and semantics specifications), with some predicates (*social_interaction*, *conflict*, *about*), each having arguments (e.g. *Actor1*), with a category (e.g. *animate*). One or more verbs are member of the verb class. For each verb class, more than one frame for a verb class, predicate for a frame, and argument/category for a predicate can be asserted.
VerbNet relies on a small amount of primitives (about 100 predicates, 70 arguments and 40 categories in version 2.1) to account for the semantics of verbs. No assumption of uniqueness of arguments or predicates for a frame are made. The VerbNet approach is therefore closer to traditional linguistic theories, and it is not trivial to match it to FrameNet construction grammar. Here some alignment suggestions are shown[24] which can help

[24] http://www.ontologydesignpatterns.org/ont/lmm/ovn2lmm.owl

on achieving that task, and demonstrate the role of Semion as a semiotic façade.

$$VNClass \subseteq (Mea \cap D) \tag{1.87}$$

$$subClass(x,y) \rightarrow specializes(x,y) \wedge VNClass(x) \wedge VNClass(y) \tag{1.88}$$

$$VNFrame \subseteq (Mea \cap D) \tag{1.89}$$

$$hasFrame(vn,fr) \rightarrow hasProperPart(vn,fr) \wedge VNClass(vn) \wedge VNFrame(fr) \tag{1.90}$$

$$Predicate \subseteq (Mea \cap D) \tag{1.91}$$

$$hasPredicate(fr,pr) \rightarrow hasProperPart(fr,pr) \wedge VNFrame(fr) \wedge Predicate(pr) \tag{1.92}$$

$$Argument(ar) \subseteq (Mea \cap C) \tag{1.93}$$

$$Argument(ar) \rightarrow \exists(pr)(usesConcept(pr,ar)) \tag{1.94}$$

$$hasArg(pr,ar) \rightarrow usesConcept(pr,ar) \wedge Predicate(pr) \wedge Argument(ar) \tag{1.95}$$

$$Category \subseteq (Mea \cap C) \tag{1.96}$$

$$hasType(ar,ca) \rightarrow specializes(ar,ca) \wedge Argument(ar) \wedge Category(ca) \tag{1.97}$$

$$Verb \subseteq Exp \tag{1.98}$$

$$hasMember(vn,v) \rightarrow expresses(v,vn) \wedge Verb(v) \wedge VNClass(vn) \tag{1.99}$$

In practice, a VerbNet predicate is comparable to a FrameNet frame, but it is not unique to a verb class, while a VerbNet argument is comparable to a FrameNet frame element, but again it is not unique to a predicate. The semantic part of VerbNet frames is comparable to a composition of FrameNet frames. These differences are due to the fact that VerbNet focuses on verb classes rather than on conceptual structures.

On the other hand, based on OntoFrameNet and OntoVerbNet, it is easier to compare the two lexical knowledge bases on a formal basis, e.g. by restricting the matching to VerbNet arguments against FrameNet generic frame elements, or by finding recurrent arguments in VerbNet predicates, and trying to approximate core predicate structures.

Now, since FrameNet frames can be matched against VerbNet predicates,

one can check the consistency between core frame elements and arguments shared across the predicates that hold for different verb classes. Moreover, FrameNet frames can be matched against VNFrames: we will check the consistency of the about 100 predicates from VerbNet as a top-level for FrameNet frames.
VerbNet arguments seem to match frame elements: in that case, argument categories can be matched to or used to populate FrameNet semantic types for frame elements when missing. Whatever matching pattern is taken, one will know what entities are involved in the matching, and what consequences will derive. For example, VerbNet arguments are not unique to predicates, while frame elements are unique to frames, therefore it is more appropriate to match OntoVerbNet arguments with OntoFrameNet generic frame elements.
Additional metamodels can be added in order to increase the matching redundancy. WordNet is a first-class candidate because it is extensively used, its metamodel is already built, and an alignment would be straightforward, e.g. the Synset class can be aligned as in axiom 1.100, and it can be used to feed argument and frame element with semantic types of a finer granularity. VerbNet categories can then be matched against synsets, and possibly proposed as an alternative top-level for synsets, comparable to WordNet *lexical names*, also known as "super-senses". The following sample axioms make it viable to map VerbNet categories to super-senses, synsets to super-senses, and therefore synsets to categories:

$$Synset \subseteq (Mea \cap C) \quad (1.100)$$

$$SuperSense \subseteq (Mea \cap C) \quad (1.101)$$

$$\forall(x)(SuperSense(x) \rightarrow \exists(y)(Synset(y) \wedge specializes(x,y)) \quad (1.102)$$

$$\forall(x,y,z)((mappableTo(x,y) \wedge specializes(z,x)) \rightarrow specializes(z,y)) \quad (1.103)$$

How Semion supports well-founded mappings and transformations is explained shortly in section 1.6.3.

1.6.3 Mapping and transformation patterns

Comparison between Semion-based elements can be formalized by defining appropriate relations, which are used as *mapping patterns* between elements from different lexical resources:

$$mappableTo(x, y, r_1, r_2) \rightarrow Mea(x) \wedge Mea(y) \wedge Resource(r_1) \wedge Resource(r_2) \wedge belongsTo(x, r_1) \wedge belongsTo(y, r_2) \qquad (1.104)$$

$$mappableConcept(x, y, r_1, r_2) =_{df} mappableTo(x, y, r_1, r_2) \wedge C(x) \wedge (C(y) \qquad (1.105)$$

$$mappableConceptFN2VN(x, y, r_1, r_2) =_{df} mappableConcept(x, y, r_1, r_2) \wedge (r_1 = FrameNet) \wedge (r_2 = VerbNet) (GenFE(x) \wedge Argument(y)) \vee (SemanticType(x) \wedge Category(y)) \qquad (1.106)$$

for example, based on the mapping pattern in 1.106, one can safely assert that a certain generic frame element abstracted from FrameNet, e.g. ofn:Agent, is mappable to a VerbNet argument, e.g. ovn:Agent:

$$mappableConceptFN2VN(Agent, Agent, FrameNet, VerbNet) \qquad (1.107)$$

I finally include the encoding of a sample transformation pattern that constrains what Semion construct (e.g. a $Mea \cap C$) can be transformed to what formal semantic construct, e.g. a $Class$:

$$\forall(x, y)(transformableTo(x, y) \rightarrow ((Mea(x) \wedge C(x)) \rightarrow Class(y)) \qquad (1.108)$$

When adopting axiom 1.108, we accept that any lexical element y can only be encoded as any ontology element that has $Class$ semantics, e.g. an `owl:Class` (in the Web Ontology Language). In addition, we know that

all FrameNet, VerbNet, or WordNet elements that are aligned to ($Mea \cap C$) must be encoded as classes, so that formal operations on them will be founded on a shared semantics.
Appropriate recipes including transformation patterns can be used to manage large integration scenarios on heterogeneous lexical knowledge.

1.6.4 Containment-related schemata from FrameNet

In (Gangemi, 2008), the *containment* frame, inspired by the CONTAINER schema (Johnson, 1987) is associated with the containment principle underlying the *c.DnS memberOf* relation, holding between entities and collections (cf. section 1.3.3).
FrameNet version 1.2, for example, includes four containment-related schemata, represented as *frames*: F-Containment, F-Containment-relation, F-Containing, F-Containers. Semion and OntoFrameNet are used in order to formalize these schemata and apply them to real-world frame occurrences. The following is a summary of the four frames in terms of their frame elements:

(1.109) F-Containment: {FE-Container, FE-Boundary, FE-Interior, FE-Exterior, FE-Portal}

(1.110) F-Containing: {FE-Contents, FE-Container}

(1.111) F-Containment-relation: {FE-Profiled-region, FE-Landmark, FE_Trajector }

(1.112) F-Containers: {FE-Container, FE-Content, FE-Use, FE_Construction, FE-Part, FE-Descriptor, FE-Relative-location, FE_Material FE-Owner, FE-Type}

Following the transformation pattern applied to OntoFrameNet, the formalization of the schemata is straightforward (FrameNet name prefixes have been removed for simplicity).

$$\begin{aligned} & Frame(ContainmentSchema), \\ & FE(Container), defines(ContainmentSchema, Container), \\ & FE(Boundary), defines(ContainmentSchema, Boundary), \\ & FE(Interior), defines(ContainmentSchema, Interior), \\ & FE(Exterior), defines(ContainmentSchema, Exterior), \\ & FE(Portal), defines(ContainmentSchema, Portal) \end{aligned} \quad (1.113)$$

The ContainmentSchema (1.113) introduces the basic building blocks of many schemata, and can be used to provide a cognitive basis to intensional relations such as *membership* and *part* (Gangemi, 2008).

$$\begin{aligned} & Frame(ContainingSchema), \\ & FE(Container), uses(ContainingSchema, Container), \\ & FE(Content), defines(ContainingSchema, Content) \end{aligned} \quad (1.114)$$

ContainingSchema is the minimal schema for containment, and if matched to the ContainmentSchema (e.g. by assuming $Boundary \approx Container$ and $Interior \approx Content$), it results to be a *subFrameOf* it.

$$\begin{aligned} & Frame(TrajectorLandmarkSchema), \\ & FE(ProfiledRegion), \\ & FE(Landmark), FE(Trajector), \\ & defines(TrajectorLandmarkSchema, ProfiledRegion), \\ & defines(TrajectorLandmarkSchema, Landmark), \\ & defines(TrajectorLandmarkSchema, Trajector) \end{aligned} \quad (1.115)$$

$$Frame(ContainersSchema),\\ FE(Type), FE(Use), FE(Construction), FE(Content),\\ FE(RelativeLocation), FE(Part), FE(Descriptor),\\ FE(Container), FE(Material), FE(Owner),\\ defines(ContainersSchema, Type),\\ defines(ContainersSchema, Use),\\ defines(ContainersSchema, Construction),\\ defines(ContainersSchema, Content),\\ defines(ContainersSchema, RelativeLocation),\\ defines(ContainersSchema, Part),\\ defines(ContainersSchema, Descriptor),\\ defines(ContainersSchema, Material),\\ defines(ContainersSchema, Container),\\ defines(ContainersSchema, Owner) \quad (1.116)$$

FrameNet assumes that frame elements in different frames are different by default. For example, FrameNet does not make an identity assumption between Container defined in the ContainmentSchema and Container used in the ContainersSchema, or between Content defined in the ContainingSchema and Content used in the ContainersSchema.
A possible matching between these schemata can only be made between generic frame elements. For example, by using the generic level, we can hypothetically infer that, since the ContainersSchema has localizations of both Content and Container generic frame elements, which are also localized in the ContainingSchema, then ContainersSchema is a specialization of ContainingSchema.
Moreover, we may want to support more complex inferences. For example, a $superordination$ relation among concepts can be introduced, by which a concept - when reused - always carries other concepts with it, and then it can be applied to Container as defined in the ContainmentSchema:

$$superordinatedTo(x, y, z) \rightarrow C(x) \wedge C(y) \wedge Frame(z) \quad (1.117)$$

$$superordinatedTo(Container,\\ \{Boundary, Interior, Exterior, Portal\},\\ ContainmentSchema) \quad (1.118)$$

This will cause the use of Container in the ContainingSchema to inherit the concepts subordinated to Container from the ContainmentSchema.
Descriptions, hence also schemata and frames, can define or use either *required* or *optional* concepts. For example, ContainmentSchema defines the frame element Portal with the *optional* parameter:

$$parametricallyDefines(ContainmentSchema, Portal, optional) \quad (1.119)$$

while ContainersSchema defines the following concepts as optional: Type, RelativeLocation, Material, and Owner.
The optional parameter, a second order property that is represented in *c.DnS* through reification, is used to restrict the scope on how many entities of a situation are checked against a description.

1.6.5 Sentences, situations, and schemata: an example

Provided with this background, the use of *c.DnS* is now exemplified with respect to occurrences of schemata and frames. Given the example sentence s:

(1.120) Chuck's money is in his waterproof leather suitcase hidden in the company's backroom

s is annotated with FrameNet frame elements: ['Owner' Chuck's] ['Content' money] ['Container' is in his ['Construction' waterproof] ['Material' leather] suitcase]. Then, the reference (Ref in Semion) of s is represented as a situation and as a reportable mental space CMS (for Chuck's Money Situation) that satisfies the ContainersSchema (1.121):

$$E(money_{cms}), E(suitcase_{cms}), E(backroom_{cms}),$$
$$E(leather_{cms}), A(Chuck), E(waterproof), T(time_{cms})$$
$$S(CMS), ReportableMentalSpace(CMS) \quad (1.121)$$
$$settingFor(CMS, \{money_{cms}, suitcase_{cms},$$
$$leather_{cms}, waterproof, Chuck, backroom_{cms}, time_{cms}\}) \quad (1.122)$$
$$classifies(Container, suitcase_{cms}, time_{cms}) \quad (1.123)$$
$$classifies(Material, leather_{cms}, time_{cms}) \quad (1.124)$$
$$classifies(RelativeLocation, backroom_{cms}, time_{cms}) \quad (1.125)$$
$$classifies(Owner, Chuck, time_{cms}) \quad (1.126)$$
$$classifies(Content, money_{cms}, time_{cms}) \quad (1.127)$$
$$classifies(Construction, waterproof, time_{cms}) \quad (1.128)$$
$$\models$$
$$satisfies(CMS, ContainersSchema) \quad (1.129)$$

The inference holds because all non-optional frame elements from ContainersSchema classify some entity from CMS at the same time.
The reference of s can be represented as a situation on the assumption that a sentence constitutes a unity criterion for a set of entities under a certain interpretation. By hypothesis, we know that the unity criterion underlying that sentence is the reportable mental space that is expressed by s (cf. section 1.6.1), and which is structured by a reportable schema.
From the examples, CMS satisfies the ContainersSchema and the schemata specialized by it: ContainmentSchema, ContainingSchema.
Since s can be represented as a (complex) reportable construction, as well as its component phrases, words, morphemes, etc., it is now possible to assert explicit relations between s, the reportable mental space it evokes, and the schemata that provide a structure to that space. A sample of

such representation is provided below. Firstly, a sample of the constructions needed to represent the sentence is included here (RC stands for ReportableConstruction, Sen for Sentence, Ph for phrase, W for Word:

$$Sen(x) \rightarrow RC(x) \wedge \exists(y)(Ph(y) \wedge partOf(y,x)) \quad (1.130)$$
$$Ph(x) \rightarrow RC(x) \wedge \exists(y)(W(y) \wedge partOf(y,x)) \quad (1.131)$$
$$W(x) \rightarrow RC(x) \quad (1.132)$$

Secondly, words can be axiomatized with reference to morphemes, morphemes to phonemes, and so on. Hence, these classes can be assigned to the constructions from s:

$$\begin{aligned} &Sen(s), W(money), Ph(Chuck's), \\ &Ph(is\,in\ his\ waterproof\ leather\ suitcase), \\ &Ph(hidden\ in\ the\ company's\ backroom), \\ &W(waterproof), W(leather), W(suitcase), etc. \end{aligned} \quad (1.133)$$

Finally, the association between a reportable construction, a mental space (RMS), and a schema can be exemplified as follows:

$$RMS(rms_s) \quad (1.134)$$
$$evokes\_r(s, rms_s, time_{cms}) \quad (1.135)$$
$$isAbout(s, CMS, time_{cms}) \quad (1.136)$$
$$satisfies(CMS, rms_s) \quad (1.137)$$

and, since CMS also satifies the ContainersSchema, we can infer that:

$$structures\_r(x,y,t)(ContainersSchema, rms_s, time_{cms}) \quad (1.138)$$

The pile including Semion with ECG ontology and *c.DnS* has been exemplified as a formal proposal to represent how constructions are shared based on a common grounding, and embodied into the neural systems of the agents from a community. When the situations (frame occurrences) that a construction is about can satisfy both reportable mental spaces and schemata, the *structures_r* relation can be inferred automatically. This is purely representational, but contributes to the construction of a common framework to discuss and integrate the theories, resources, and experiments aiming at a cognitively-founded, rich explanation of semiotic phenomena at the *Ontolex* interface.

1.7 Conclusions

I have presented a formal framework to represent (some) primitives from Embodied Construction Grammar, and have used them to design Semion, a semiotic ontology, which has been applied to FrameNet and related resources, thus contributing a foundation to the *Ontolex* interface. The framework enables a linguist or a knowledge engineer to represent frames, frame elements, constructions, mental spaces, and schemata, to map and transform them, to apply them to realistic modeling situations as conveyed by natural language sentences (or other encodings), and to reason on them with inference engines and knowledge management tools.
I have specialized the *c.DnS* ontology, and in particular the notions of Description, Concept, Information object, Situation, and the relations holding between them. An ECG-related ontology for constructions, mental spaces and schemata has been introduced, with axioms to represent the relations between the public (social), private (cognitive) and grounded (neural) entities involved in the theory. This layered approach is an advantage compared to the existing literature, where a huge amount of evidence on the validity of ECG is sometimes hampered by a lack of design at both the theoretical and the experimental level. A formal-ontology framework for ECG can be a useful tool for formulating research hypotheses, creating experimental settings, and deploying ECG resources in information and communication technology. A first example of how to do it is shown with FrameNet and related resources and corpora.
Future work will investigate on one hand basic research areas, including the representation of metaphors and conceptual integration (Turner, 2000). Research will also focus on the pragmatical aspects of information integration by providing façades for existing resources, based on Semion. Another area that can benefit from a semiotic façade is the design of NLP experiments, which are often silent on which commitments to what entities are being made.
While the classification of entities by means of schematic concepts has been done manually in the examples from this chapter, ongoing work within the EU NeOn[25] project, aimed at building a robust platform for

[25] http://www.neon-project.org

knowledge management and ontology engineering for industrial, business, and organizational tasks, aims at exploring the feasibility of semi-automatic annotation of constructions with schematic structures, and to match them to ontology design patterns (Gangemi, 2005) from existing repositories. In addition, a new repository of patterns[26] (Presutti and Gangemi, 2008) will be partly populated with frames and schemata after they are reengineered by applying the methods presented here.

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[26] http://www.ontologydesignpatterns.org

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