The E-$\mathcal{SHIQ}$ Contextual Logic Framework*

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To deal with autonomous agents' knowledge and subjective beliefs in the open, heterogeneous and inherently distributed settings concerned by Agreement Technologies, we need special formalisms that combine knowledge, taking also into account disagreements and heterogeneity from multiple interconnected contexts. For agents to reason jointly, they need to combine knowledge by means of correspondences and links between context elements. Each context contains a chunk of knowledge defining a logical theory, that we call *ontology* or *ontology unit*. While standard logics may be used, to deal with the issues of subjectiveness and heterogeneity in the semantic web, special knowledge representation formalisms based on web standards have been proposed, sometimes called *contextual logics* or *modular ontology languages* (e.g. [1] [2]). Among others, assumptions about the domains covered by the distinct ontology units affect the expressivity of the languages used for defining correspondences. Nevertheless, in distributed and open settings we may expect that different units should be combined in many different, subtle ways. Towards this goal, we have been motivated to propose the representation framework $E^{DDL}_{HQ^+}$ $\mathcal{SHIQ}$ (or simply $E-\mathcal{SHIQ}$). The proposed framework alleviates the assumptions for overlapping or disjoint domains posed by DDL and $\mathcal{E}$-connections, respectively.

The E-$\mathcal{SHIQ}$ framework. Given a finite index set of units' identifiers I, each unit M_i consists of a TBox $\mathcal{T}_i$, RBox $\mathcal{R}_i$, and ABox $\mathcal{A}_i$ in the $\mathcal{SHIQ}$ fragment of Description Logics (DL)[3]. $\mathcal{SHIQ}$ provides role transitivity and hierarchy, qualified cardinality restrictions and inverse roles. For each unit $i \in$ I, let N_{C_i}, N_{R_i} and N_{O_i} be the sets of concept, role and individual names respectively. Each term $C \in N_{C_i}$ is interpreted by an interpretation function $\mathcal{I}_i = \langle \Delta_i^{\mathcal{I}_i}, \cdot^{\mathcal{I}_i} \rangle$ to a set of elements in the domain $\Delta_i^{\mathcal{I}_i}$ modelled in the unit. Each term $R \in N_{R_i}$ is interpreted as a relation of elements $R^{\mathcal{I}_i} \subseteq \Delta_i^{\mathcal{I}_i} \times \Delta_i^{\mathcal{I}_i}$, and each $x \in N_{O_i}$ as a single element $x^{\mathcal{I}_i} \in \Delta_i^{\mathcal{I}_i}$. It holds that for each C $\sqsubseteq$ D $\in \mathcal{T}_i$, $C^{\mathcal{I}_i} \subseteq D^{\mathcal{I}_i}$, where C, D are possibly complex concepts, and for each $R \sqsubseteq S \in \mathcal{R}_i$, $R^{\mathcal{I}_i} \subseteq S^{\mathcal{I}_i}$, where $\{R, S\} \subseteq N_{R_i}$. Each $\mathcal{A}_i$ contains concept and role assertions i.e. $C(x)$, $R(x, y)$, that are interpreted to membership $x^{\mathcal{I}_i} \in C^{\mathcal{I}_i}$ and relation $\langle x^{\mathcal{I}_i}, y^{\mathcal{I}_i} \rangle \in R^{\mathcal{I}_i}$ of elements in the domain. An element, axiom or assertion c in unit M_i is denoted by $i : c$.

Towards combining knowledge of different units, the proposed framework allows: (a) concept-to-concept subjective correspondences [4], [1], specified by *onto*-bridge rules $i : C \stackrel{\sqsupseteq}{\rightarrow} j : D$, or *into*-bridge rules $i : C \stackrel{\sqsubseteq}{\rightarrow} j : D$, where $i \neq j$ $\in$ I, $C \in N_{C_i}, D \in N_{C_j}$; (b) Individual subjective correspondences $i : a \stackrel{=}{\mapsto} j : b$,

* AT2012, 15-16 October 2012, Dubrovnik, Croatia.

where $a \in N_{O_i}$ and $b \in N_{O_j}$, from the point of view of M_j; (c) Link-properties [2] that can be related via ij-property inclusion axioms, be transitive and, if they are simple[3], be restricted by qualitative restrictions. The sets of ij-properties' names, i.e. ϵ_{ij}, $i, j \in$ I, are not necessarily pairwise disjoint, but disjoint with respect to N_{C_i}, and N_{O_i}. ij-properties are being used for specifying concepts (so called $i-$concepts) in the M_i unit and are interpreted by the interpretation function $\mathcal{I}_{ij} = \langle \Delta_i^{\mathcal{I}_i}, \Delta_j^{\mathcal{I}_j}, \cdot^{\mathcal{I}_{ij}} \rangle$, $i, j \in$ I. A *domain relation* relates the elements of domains of different units, s.t. $r_{ij} \subseteq \Delta_i^{\mathcal{I}_i} \times \Delta_j^{\mathcal{I}_j}$, $i \neq j$, where for each $d \in \Delta_i^{\mathcal{I}_i}$, $r_{ij}(d) \subseteq \{d' | d' \in \Delta_j^{\mathcal{I}_j}\}$, and in case $d' \in r_{ij}(d_1)$ and $d' \in r_{ij}(d_2)$, then $d_1 = d_2$ (the domain relation represents only equalities). For $D^{\mathcal{I}_i} \subseteq \Delta_i^{\mathcal{I}_i}$, $r_{ij}(D^{\mathcal{I}_i})$ denotes $\cup_{d^{\mathcal{I}_i} \in D^{\mathcal{I}_i}} r_{ij}(d^{\mathcal{I}_i})$. The distributed knowledge base contains the knowledge of the indexed units, as well as their correspondences and ij-property restrictions and assertions, and is interpreted by *Distributed Interpretation* $\mathfrak{I}$ s.t. $\mathfrak{I} = \langle \{\mathcal{I}_i\}_{i \in I}, \{\mathcal{I}_{ij}\}_{i,j \in I}, \{r_{ij}\}_{i \neq j \in I} \rangle$.

The implemented distributed tableau algorithm extends the Pellet reasoner with new expansion rules for distributed reasoning, allowing local reasoning chunks to be combined. These rules allow nodes in the completion graph of a reasoning chunk for unit i labelled with concepts of a unit j, s.t. $i \neq j \in$ I, to be projected to corresponding nodes in j. These nodes are locally exploited by j. When the knowledge of multiple units is being combined, an inconsistency may be detected in any of the local reasoning chunks. This reasoning chunk cannot further participate in the collaborative reasoning process, since any projection in it will lead to a clash. For the definition of the framework and the instance retrieval algorithm we refer the reader to previous work [5], [6].

Acknowledgement: This research project is being supported by the project "IRAKLITOS II" of the O.P.E.L.L. 2007 - 2013 of the NSRF (2007 - 2013), co-funded by the European Union and National Resources of Greece.

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[3] As in standard DL, a simple ij-property is neither transitive, nor has a transitive sub-property.