Distributed Reasoning with $E_{HQ^+}^{DDL} SHIQ$.

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To deal with autonomous agents' knowledge and subjective beliefs in open, heterogeneous and inherently distributed settings, we need special formalisms that combine knowledge from multiple and potentially heterogeneous interconnected contexts. Each context contains a chunk of knowledge defining a logical theory, called *ontology unit*). While standard logics may be used, subjectiveness and heterogeneity issues have been tackled by knowledge representation formalisms called *contextual logics* or *modular ontology languages* (e.g. [1] [2]).Nevertheless, in distributed and open settings we may expect that different ontology units should be combined in many different, subtle ways without making any assumption about the disjointness of the domains covered by different units. To address this issue we need to increase the expressivity of the language used for defining correspondences.Towards this goal, we have been motivated to propose the representation framework $E_{HO+}^{DDL} SHIQ$ (or simply E - SHIQ).

The $E_{HQ^+}^{DDL}$ *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 *SHIQ* fragment of Description Logics[3].

Given an $i \in I$, let N_{C_i} , N_{R_i} and N_{O_i} be the sets of concept, role and individual names respectively. For some $R \in N_{R_i}$, Inv(R) denotes the inverse role of R and $(\mathcal{N}_{\mathcal{R}} \cup \{Inv(R) | R \in \mathcal{N}_{\mathcal{R}}\})$ is the set of \mathcal{SHIQ} -roles. The set of \mathcal{SHIQ} -concepts is the smallest set constructed by the constructors in \mathcal{SHIQ} . Cardinality restrictions can be applied on R, given that R is a simple role. An interpretation $\mathcal{I}_i = \langle \Delta_i^{\mathcal{I}_i}, \mathcal{I}_i \rangle$ consists of a domain $\Delta_i^{\mathcal{I}_i} \neq \emptyset$ and the interpretation function \mathcal{I}_i which maps every $C \in N_{C_i}$ to $C^{\mathcal{I}_i} \subseteq \Delta_i^{\mathcal{I}_i}$, every $R \in N_{R_i}$ to $R^{\mathcal{I}_i} \subseteq \Delta_i^{\mathcal{I}_i} \times \Delta_i^{\mathcal{I}_i}$ and each $a \in N_{O_i}$ to an element $a^{\mathcal{I}_i} \in \Delta_i^{\mathcal{I}_i}$. Elements and axioms in unit M_i are denoted by i : c. Each Tbox \mathcal{T}_i contains generalized concept inclusion axioms, RBox \mathcal{R}_i contains role inclusion axioms, and ABox \mathcal{A}_i contains assertions for individuals and their relations [3].

Towards combining knowledge in different units, the proposed framework allows the connection of units via: (a) concept-to-concept subjective correspondences [1] specified by *onto*-bridge rules $i : C \stackrel{\supseteq}{\Rightarrow} j : G$, or *into*-bridge rules $i : C \stackrel{\Box}{\Rightarrow} j : G$, where $i \neq j \in I$. (b) Individual subjective correspondences $i : a_i \stackrel{\Box}{\Rightarrow} j : b_j$, where $a_i \in N_{O_i}$ and $b_j \in N_{O_j}$. The above mentioned subjective correspondences concern the point of view of M_j . (c) Link-properties [2](or *ijproperties*, $i, j \in I$), which can be related via *ij*-property inclusion axioms, be transitive and, if they are simple, be restricted by qualitative restrictions. The sets of *ij*-properties' names, i.e. the sets $\epsilon_{ij}, i, j \in I$, are not necessarily pairwise disjoint, but disjoint with respect to N_{C_i} , and N_{O_i} . A set of *ij*-properties connecting concepts of M_i with concepts of M_j , is defined as the set $\mathcal{E}_{ij} = \epsilon_{ij}$, $i \neq j \in I$, and in case i = j, it is the set $\mathcal{E}_{ij} = \epsilon_{ij} \cup \{Inv(E) | E \in \epsilon_{ji}\}$, where ϵ_{ij} is the set of (local to M_i) role names. *ij*-properties are being used for specifying concepts (so called *i*-concepts) in the M_i unit.

Transitive axioms are of the form Trans(E; (i, j)), where $E \in \mathcal{E}_{ij} \cap \mathcal{E}_{ii}$, E is transitive in M_i and transitive *ij*-property. Transitivity axioms and the finite set of inclusion axioms for *ij*-properties form the *ij*-property box \mathcal{R}_{ij} (if i = j, $\mathcal{R}_{ii} = \mathcal{R}_i$). The combined property box RBox \mathcal{R} is a family of *ij*-property boxes. A combined TBox is a family of TBoxes $\mathbf{T} = \{\mathcal{T}_i\}_{i \in I}$. A distributed ABox $\mathbf{A} = \{\mathcal{A}_i\}_{i \in I}$, includes a collection of individual correspondences, and property assertions of the form $(a \cdot E_{ij} \cdot b)$, where $E_{ij} \in \mathcal{E}_{ij}$. A distributed knowledge base Σ is composed as $\Sigma = \langle \mathbf{T}, \mathcal{R}, \mathfrak{B}, \mathbf{A} \rangle$, where $\mathfrak{B} = \{\mathfrak{B}_{ij}\}_{i \neq j \in I}$ is the collection of bridge rules between ontology units. Each \mathcal{R}_{ij} , is interpreted by a valuation function \mathcal{I}_{ij} that maps every *ij*-property to a subset of $\Delta_i^{\mathcal{I}_i} \times \Delta_j^{\mathcal{I}_j}$. Let $\mathcal{I}_{ij} =$ $\langle \Delta_i^{\mathcal{I}_i}, \Delta_j^{\mathcal{I}_j}, \cdot^{\mathcal{I}_{ij}} \rangle, i, j \in I$. It must be noted that, for a specific $i \in I$ and a property E in the *i*-th unit, this property may be shared between different *ij*-property boxes (i.e. for different j's). In this case, the denotation of E is $\bigcup_{j \in I} E^{\mathcal{I}_{ij}}$. A domain relation $r_{ij}, i \neq j$ from $\Delta_i^{\mathcal{I}_i}$ to $\Delta_j^{\mathcal{I}_j}$ is a subset of $\Delta_i^{\mathcal{I}_i} \times \Delta_j^{\mathcal{I}_j}$, s.t. 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 $d' \in \mathcal{I}_i$ $r_{ij}(d_2)$, then $d_1 = d_2$. For a subset D of $\Delta_i^{\mathcal{I}_i}$, $r_{ij}(D)$ denotes $\bigcup_{d \in D} r_{ij}(d)$. A domain relation represents only equalities, i.e. each $d_1 \in r_{ij}(d)$ is equal to the other individuals in $r_{ij}(d)$. The distributed knowledge base is interpreted by a Distributed Interpretation, \mathfrak{I} s.t. $\mathfrak{I} = \langle \{\mathcal{I}_i\}_{i \in I}, \{\mathcal{I}_{ij}\}_{i,j \in I}, \{r_{ij}\}_{i \neq j \in I} \rangle$.

We have specified a sound and complete distributed Tableau algorithm that has been implemented by extending the Pellet reasoner ³. The instance retrieval algorithm for the framework has been presented in [4].

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³ The full paper describing the framework and the tableau algorithm can be found in http://ai-lab-webserver.aegean.gr/gsant/ESHIQ.Report