# The Combined Approach to Query Answering in Horn-$\mathcal{ALCHOIQ}$ (Extended Abstract)*

David Carral, Irina Dragoste, and Markus Krötzsch

Knowledge-Based Systems Group, TU Dresden, Dresden, Germany

Answering conjunctive queries (CQs) over Description Logics (DL) ontologies is an important reasoning task with many applications in knowledge representation. Intensive research efforts in recent years have significantly improved our understanding of this problem, and led to efficient algorithms and implementations for many DL languages [2,3]. *Query rewriting* was an important step towards widespread practical implementation in legacy databases, but it is limited to DLs of sub-polynomial data complexity. This limitation was overcome by the so-called *combined approach*, which answers CQs in two steps:

1. *Materialisation*: data is augmented to build a query-independent interpretation, which may not be a model but is complete for CQ answering.
2. *Filtration*: queries are evaluated over this interpretation and unsound answers are discarded in a filtration step.

This approach has made CQ answering feasible for many DLs [5,7,9,15].

However, for many expressive DL languages, the problem remains challenging in theory and in practice. All previously cited works for DL are restricted to languages with polynomial complexity of reasoning. For $\mathcal{SROIQ}$, it is unknown if the problem is decidable at all [13]. Concrete complexity bounds are known for fragments of this logic, e.g., for Horn-$\mathcal{SROIQ}$ [11], but these results have not yet given rise to practical implementations.

We address this limitation by proposing a new combined approach to CQ answering over ontologies of the DL Horn-$\mathcal{ALCHOIQ}$ [8], for which CQ answering is ExpTime-complete [12]. Our procedure generalises previous works on tractable DLs [5,7,9,15], and at the same time exhibits worst-case optimal behaviour: our algorithm runs in ExpTime for Horn-$\mathcal{ALCHOIQ}$ and in NP for $\mathcal{ELHO}$ [1]. The pay-as-you-go behaviour is embodied in our materialisation step, which extends ideas on consequence-based reasoning [6,14] to a DL that combines nominals, at-most quantifiers, and inverse roles. The filtration step then adapts a technique of Feier et al. [5], which is comparatively lightweight.

In summary, our main contributions are:

– We present the first combined approach for a non-tractable DL fragment.
– We show that our approach is worst-case optimal for standard reasoning and CQ answering for the DLs Horn-$\mathcal{ALCHOIQ}$ and $\mathcal{ELHO}$.
– We develop an efficient implementation to solve standard reasoning tasks.
– We conduct an empirical evaluation with three data intensive ontologies that shows performance gains over the DL reasoner Konclude.

* The full version of this paper is part of the KR 2018 proceedings [4].

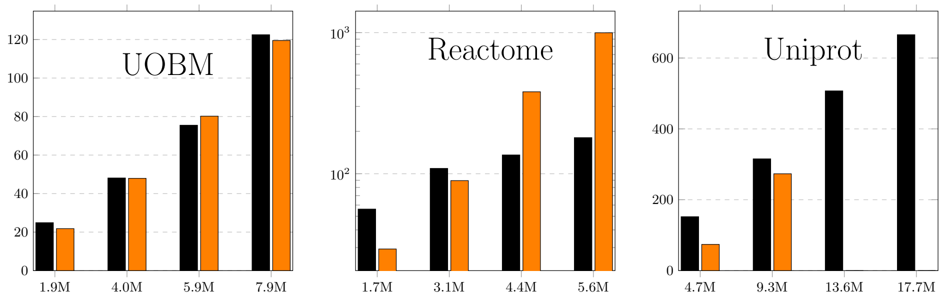


**Fig. 1.** Times for ABox materialisation in seconds for our implementation (dark) and Konclude (bright), each over four ABoxes with increasing numbers of assertions

*Proof of Concept.* We evaluate a prototype implementation of the materialisation phase, which we consider the performance-critical part of our algorithm. In contrast, our filtration phase uses a polynomial algorithm, which is computationally similar to the filtration in other combined approaches that have already been shown to be efficient in practical cases [5]. Since materialisation decides fact entailment for Horn-$\mathcal{ALCHOIQ}$, we can meaningfully compare performance against standard DL reasoners. We use our implementation to solve assertion retrieval, that is, the reasoning task that consists in computing all assertions that are entailed by an ontology. We compare performance with that of Konclude (v0.6.2) [16], which we use as a command-line client on local input files.

Since CQ answering is most relevant in data-intensive applications, we consider ontologies with large sets of assertions (ABoxes). We select a standard benchmark, *UOBM* [10]; and two real-world ontologies, *Reactome* and *Uniprot*, which are used in the evaluation of PAGOdA [17]. The resulting ontologies contain 254 (UOBM), 481 (Reactome), and 317 (Uniprot) terminological axioms, respectively. None of these ontologies belong to a known tractable fragment of Horn-$\mathcal{ALCHOIQ}$. For each ontology, we consider ABoxes of various sizes, generated by using the size parameter for the benchmark (UOBM), and by sampling the real-world ABoxes (Reactome, Uniprot).

Our test system is a commodity laptop (16GB RAM, 500GB SSD, CPU i7-8550U/4 cores/1.8GHz, Windows 10), where we configure the operating system to allow up to 28GB of virtual memory. We measure wall-clock times spent during reasoning, ignoring the time required for parsing and loading. Konclude reports detailed times, while for our implementation we measure the time from within our prototype. Figure 1 shows the results. Note the logarithmic scale in the case of Reactome. Konclude ran out of memory for the two largest of the Uniprot samples, hence no times are reported here. The performance results show that our prototype can already achieve competitive performance.

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