Best First Search Planning of Service Composition using incrementally refined Context-Dependent Heuristics

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Abstract. In oder to decide if a agent capability is helpful to achieve a goal, modern search algorithms in AI research use heuristics to narrow the search space by indicating which capability is the best to use. Considering the lack of information about pragmatic meaning, creating sound heuristics automatically out of capability descriptions asks too much of modern reasoning algorithms. Most approaches use semantics in oder to enable the reasoner to improve Word-sense disambiguation in their ontology matching tasks. As semantics are meant to be shared, the information is context independent and quite general. I postulate that context-dependent meaning can play an important role in describing the meaning of concepts used, as some meaning might change with the changes in context. The proposed thesis creates context-dependent heuristics by combining expert knowledge with machine learning. The PhD has the goal of structuring descriptions with a concept introduced in linguistics, introducing a description of domain knowledge and contextual information and thereby enable the automatic creation of context-dependent heuristics. Choosing from the many improvement points of agent planning, this work focuses on the improvement of capability descriptions.

Introduction. To emerge new capabilities in an autonomous manner, agent planners explore a search space of capabilities and compose them into a plan. Since this search space might become large, sometimes infinite, heuristics are used to decide which part of the search space to explore. A learning planner has to calculate heuristics on the information provided by the description of a capability. Thus, making such descriptions a central part of an efficient search of capabilities during planning.

The proposed research, argues that for a reasoner to be able to create sound heuristics, context-dependent meaning has to be formulated. Thus, the presented approach describes meaning in a context-dependent manner to extend the traditional semantic description of meaning e.g. introduced by [1, 12–14] to a pragmatic[1] one. Due to missing context information such semantic information is rather general (context independent) [11]. The approached problem here is the

[1] Pragmatic is defined as context-dependent meaning [11].

mediocre performance of AI algorithms using capability descriptions like service matchers and agent planners [10, 15].

In order to improve such capability descriptions, the goal of my PhD is to investigate the use of a concept introduced in linguistics as a mechanism to structuring semantic and contextual information using a meta-model called **Natural Semantic Metalanguage** (NSM) [8].

The problem at hand is the extraction of sound heuristics out of capability descriptions. The proposed thesis will answer the following questions:

1. How can meaning be described in a context-dependent manner?
2. How can context-dependent heuristics be created by observing capability descriptions?
3. How to improve performance of agent planners by using context-dependent heuristics?

The indispensable extensions of a description language (e.g. OWL2) with concepts from the NSM raise new challenges for artificial reasoners leading to new reasoning algorithms proposed. The results will be evaluated through the precision and recall values of state-of-the-art service matcher and AI planner.

Approach. We approach the problem of describing context-dependent meaning by using NSM expressions with a domain and context-dependent rating. The NSM theory states that every natural language has a semantic crux consisting of semantic primes and that with those semantic primes the meaning of every concept in that language can be explained [8]. The meaning of concepts is broken down in a decompositional manner, until the expressions consists solely of the semantic primes. A schema of the decomposition into NSM semantic primes is shown in figure 1 which presents the approach to the first research question.

The semantic primes are regarded as atomic building blocks of meaning, which means they do not need any further explanation. In AI this can be formulated as a part of the meta language of the reasoner, extending a general ontology language like OWL2 with new concepts. My research provides an extension of the work of *Bouquet* [2], *Giunchiglia* [7] and *Ghidini et al* [6] who contextualize ontologies.

The meaning is then enriched with a domain specific rating. The rating is based on three NSM primes: 'GOOD', 'BAD' and 'VERY' creating five[2] classes of rating. For instance, the concept 'unlocked' might be assigned to 'unsecure' in a security domain. Depending the context a bathroom door might be 'GOOD' to be unlocked, in contrast to a bank vault.

A learning algorithm exploiting such a description to create a context-dependent heuristic is the essence of the proposed research. The first step towards a formal framework including a measure for the degree of self-explaining descriptions have been published [4]. To answer the second research question a reasoner is adapted to create heuristics based on the descriptions utilizing NSM expressions. These heuristics will be simple at first, i.e. a count of 'GOOD' vs. 'BAD', and will be developed towards more sophisticated ones.

[2] Reaching from 'VERY BAD' to 'VERY GOOD', including no rating as neutral

In order to evaluate the heuristics we extend a planner with a learning component, which will add context-dependent heuristics to the action description by learning the quality of the executed plan. In more detail, we extend a Hierarchical Task Network (HTN) planner as shown in Figure 2.

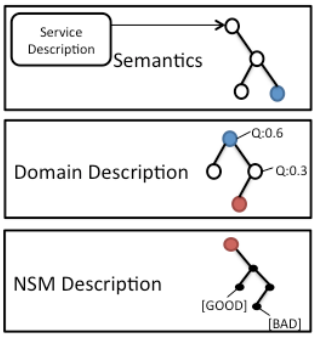

Fig. 1: Decomposition of meaning into NSM Primes

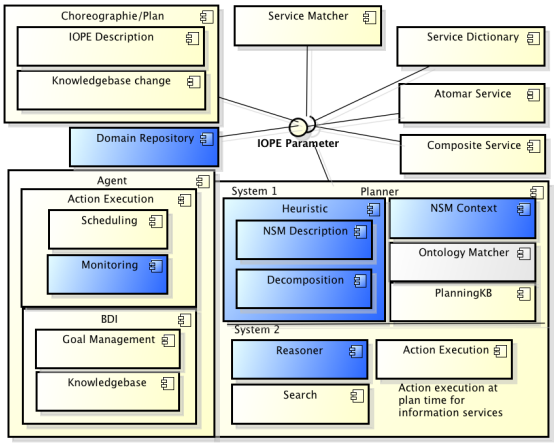

Fig. 2: Component diagram of the extended AI planner

In Figure 2 the emphasized elements are components that will be modified during the implementation of this work. In the extended AI planner, the $SeMa^2$ [10] is used as a Service Matcher to match capabilities with required subgoals. The *Domain Repository* holds the domain specific descriptions of the semantic concepts. The *NSM Context* component holds the context-dependent descriptions of meaning, which can be decomposed into the NSM concepts that hold domain specific meanings made available through the *Domain Repository*. The *monitoring* component measures the quality of the plan/orchestration and enables the heuristic to adapt to changes. The output of the monitoring is used as feedback for the learning input (reinforcement). A truncated multi-step Q-learning algorithm [3] is used to learn a heuristics function $Q : A \times S \rightarrow \mathbb{R}$, where the action A is an applicable action and the system state S consists of the set of all preconditions and effects. The *Heuristic* component *decomposes* the capability description and enriches them with *NSM Descriptions* including the action-value-function learned which adapts the context-dependent meaning and with that create sound heuristics, evaluating the third research question.

Contribution. The contribution of the proposed thesis is based on the analysis of the benefit of NSM as a semantic meta-model for the generalize over capability descriptions. The thesis outlines an approach able to create NSM-based explanations that can be used by artificial reasoners to search on them. This search is guided by context-dependent heuristics that will be provided by

a learning component monitoring the plan execution. The extension of semantic meaning to a context-dependent meaning is argued. Further the proposed thesis tackles the problem of evaluating high level descriptions of capabilities in regard to a given goal (producing a context-dependent heuristic). One outcome is a method of describing the context-dependent meaning. Another outcome is the extension of a planning system with a learning component that will learn context-dependent heuristics given NSM descriptions which is one step towards filling the performance gap between static and learning planners [5].

Evaluation. Since it is the goal of this research to foster context dependent heuristics created from capability descriptions, the evaluation of such heuristics will be a quantitative analysis of the created learning planner. As a evaluation goal, the 1080 services and appropriate queries in the S3 contest will be described using the NSM approach. Established measures of success and planner performance are use i.e. *percent of successful plans*, *average number of capabilities use* and the *average time to create a successful plan* [16] for the plan evaluation. Further a more theoretical evaluation will be based on *Kaddoum* [9] and elicit the effect of the self-explanatory description on the adaptive system using them.

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