MyPDDL - A Modular Knowledge Engineering System for the Planning Domain Definition Language

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Abstract

myPDDL is a toolkit that helps knowledge engineers to develop, maintain, visualize and manipulate planning tasks, specified in the widely used *planning domain definition language* (PDDL). For these purposes, new, structured PDDL projects can be created, consisting of a domain template and associated problem files. An additional tool visualizes the type hierarchy in PDDL domains and the object hierarchy in problems, allowing knowledge engineers to understand the representation structure at a glance and to keep track of developments by a revision control. Distances between objects specified by predicates in a problem file can be calculated with an auxiliary tool, presenting a way of bypassing PDDL's limited modeling capacity. All these tools are based an interface that provides a general way for reading and writing PDDL specifications by the use of the programming language Clojure. These tools are made accessible in the text editor Sublime Text, where two additional features, a syntax-highlighter and the possibility of using code snippets for common PDDL constructs, were implemented. A small user study, conducted with eight inexperienced PDDL users, shows some initial evidence that the syntax highlighting feature and the type diagram generator could support knowledge engineers in the design and analysis process. So, the users detected ..% more errors using the syntax highlighter in the same time as non-users and the average task completion time for questions on a hierarchical domain could be reduced by ..%.

Chapter 1

Introduction

Action planning plays a key role in artificial intelligence. By means of a formalization of a planning world, the declared aim of action planning is to generate a sequence of actions (a *plan*) that declares change the predicate values, from an initial state to a goal state, both specified by the value of predicates. Ranging from the control of a video game enemy to that of a spacecraft, instances of planning tasks can improve and automate work sequences. Action planning provides reasons for the choice of actions and the coherent deliberation process. (Classification of Concrete Textual Syntax Mapping Approaches - Nice Paper

Obviously, the usefulness of planning largely depends on the formalization of the underlying problem. Yet, the question arises, whether it is not better to develop tools that facilitate text-based programming to such a degree that it is as easy to use as graphical interfaces while still allowing the user full functionality and the necessary insight into the code to edit it (Classification of Concrete Textual Syntax Mapping Approaches - Nice Paper). As can be seen from the two problems described above, tools that ensure greater usability of planning language editors and thus help in producing standardized, high-quality domains and problems that not only planners but also other knowledge engineers can easily work with are greatly needed. The main focus of this thesis is on the development of such handy tools that support (and partially automate) the planning process. At first, already existing planning tool are reviewed in order to put this thesis in context. The body of this thesis consists of three parts. The first part introduces the basics of planning and the PDDL syntax. This is followed by the second part, which presents a extensible interface between the programming language Clojure Hickey [5] and PDDL. Based on this interface, a plug-in for the text and code editor Sublime Text (ST) was implemented that consists of a type diagram generator and a distance calculator. Furthermore, the development, application and customization of a sophisticated syntax highlighter for ST will be presented. The third part is devoted to the evaluation of the type diagram generator and the syntax highlighter in terms of their usefulness and usability. As means to this end, a small user study was conducted with subjects that had no prior PDDL experience. The results and their implications will be discussed before an outlook for future research and developments in the field concludes this thesis (perhaps mention results and outlook here). This thesis refers to deterministic planning and typed domains.

In the course of the development of the PDDL/Clojure interface, great potential was seen for facilitating the PDDL design process and thereby pushing the acceptance and usage of PDDL in real world models.I needed tools to help me create the great diversity of domains needed to test the possibilities and limitations of PDDL, i.e. tools to implement domains faster and with less errors.

PDDL Thus, the most common and extensive approach to planning in AI to this day is by means of knowledge engineering (KE). In KE, a human expert that is familiar with the underlying syntax integrates world information into a computer system Feigenbaum and McCorduck [2]. In automated planning, this is usually done using a planning language applied in an editor. A standard Both the world and the problem are modeled with the planning language and are then fed to the planning software as inputs. The software produces the solution to the problem in the form of a plan, that means a sequence of action, leading from the initial state to the goal state as output. Naturally, the process of creating these modeled worlds, from here on after called domains, and problems is error-prone and time consuming. While it cannot be denied that the planning systems are improving steadily as computer processing times decrease and algorithms are altered to work even better, the human factor in the knowledge engineering approach cannot be ignored (SOURCE). Performances of planners are largely dependent on the input they receive and the manner in which it is written (SOURCE). Therefore, focusing on the usability of planning languages and hence facilitating the knowledge engineering process is worthwhile. Although recent PDDL extensions increased the expressiveness of PDDL and thus allowed for real-world applications (SOURCE!!!), they also demand a higher level of knowledge and attention on the part of the knowledge engineer. Particularly during the first International Competition on Knowledge Engineering for Planning and Scheduling in 2005, advances were made in shifting the modelling process from a text-based to a graphical programming environment. Even though such tools seem more user-friendly at first, they also demonstrated considerable drawbacks such as limited functionality, expenditure of time and editing difficulty (SOURCE).

TODO: Add inspecting of domains as main focus of my work

1.1 Finding of the research topic

During the research for this thesis, it turned out, that the tools for writing and expanding extensive PDDL descriptions in a reasonable time are limited, while tools for checking plans (Howey, Long, and Fox [6] + second topic, Glinsk and Barták [4]) and applying PDDL descriptions (broad range of planner)s, are far more matured. While the original research interest was concentrated on possibilities and limitations of artificial intelligence planning using PDDL, a focus shift was performed, recognizing, that the main PDDL limitation is still the *basic* modeling process, meaning that efficient modeling of useful domains and problems *by hand* is hardly possible by the existing tools (that's too hard!). Anymore, PDDL's general representation ability is already limited through the missing support of mathematical operations besides basic arithmetics. On this account, a possibility for *extending* PDDL was searched and found in Clojure, using the relatedness of both languages embellished by PDDL's LISP-derived notation. In the course of the development of this PDDL/Clojure interface between great potential was seen for facilitating the PDDL design process and thereby push the acceptance and usage of PDDL in real world models. The customizability and extensibility of the ST editor as well as the broad variety of build-in editing features, constituted a convenient basis for the design of a development environment for PDDL. A large variety of language-independent plug-ins exist and is constantly developed, like package managers, git connection . This project focuses the A key concept for the development was the ease of application, so that new users should be able to effectively use the majority of functions intuitively within a short time.

Chapter 2

Planning Basics and PDDL

In KE, a human expert that is familiar with the underlying syntax integrates world information into a computer system Feigenbaum and McCorduck [2]. In automated planning, this is usually done using a planning language applied in an editor. While humans can sense and represent their environment in a way given by nature (and make choices), automated software based planning systems need a artificial formalization of a planning problem. Planning is the decision making process that finally leads to a sequence of actions.

Planning tasks can model all kind of problems, however, one needs a way of representing. For this purpose, one needs diverse constructs that can represent the state and change of planning tasks.

Consider the following (fictional) world that should be integrated into a computer system :

If a hacker is hungry, he has to eat some pizza in order to exploit vulnerable software.

In this description, we can identify several constructs, that should somehow be modeled in PDDL. There are *types* of entities (hackers, software, pizza), logical states, that means predicates, that can be true or false (a hacker can be hungry or not, software can be vulnerable or not) and actions that a hacker can perform, exploit (that means hack into) software and *eat pizza.*

This world description would be modeled in PDDL, using a domain file. While this description provides general, abstract specifications and conditions, no problem is yet declared.

In order to be able to solve a problem in this world, one first needs to specify a problem particular to this domain.

Consider the following problem: *Gary* is a *hungry* hacker who should somehow exploit the vulnerable software *MagicFailureApp*. Some pepperoni pizza is laying on his desk.

Gary wants to have help of an automated planning system, tn order to plan the sequence of required actions (*Who has to eat pizza and when?*, *When* *and what to hack?*), leading from the initial state (Gary is hungry) to the goal state (software is hacked). The problem has to be formalized again, this time in a problem file. Finally, he can fed the domain and problem file into a planner and generate the sequence of actions.

Summing up, PDDL planning tasks are composed of two separate files:

Domain file Description of general types, predicates, (functions) and actions ⇒ uninstanciated problem independent

Problem file Description of a concrete problem environment within a particular domain ⇒ instance specic

This separation allows for an powerful process of task modeling: While general instances are described in the domain file, specific instances of problems are created in the problem files. So, one abstract modeling of a *world* can be used for solving many problem instances. Planning is concerned with the automatic generation of plans, that means sequences of actions for the solution of a problem, specified with a specific domain file.

Gary uses the tools presented in this paper and the planning software SGPlan$_6$.

Gary is a *hungry white-hat* hacker who should exploit Gisela's vulnerable *application* software *MysteriousTexMexMix* on behalf of her. In order to plan the sequence of required actions, Gary uses the tools presented in this paper and the planning software SGPlan$_6$.

Hackers can be further divided by their intention (*white hats black hats*, *gray hats*).

Software can be *application* software, *system* software or programming *tools*. System software can be further divided into drivers and operating systems.

In order to represent the planning problems in a way, so that planning software can use it, standardized planning formalization are needed. The de facto planning language is pddl (SOURCE).

The planning domain definition language (PDDL) is a formal language and the quasi standard for the description of planning tasks. PDDL was first described in PDDL-the planning domain definition language (1998) and has been in constant development since then, . This thesis makes use of *PDDL 3.1* [14] if not otherwise stated.

In order to represent situations

Following this definition, in PDDL this there would be three parts:planner and use the generated solution file (*plan*).

TODO: Add predicates and actions to domain, init and goal to problem and sequence of actions to plan The PDDL worklow. domain.pddl and problem.pddl represent typical planning specification files, with the standard file extension *.pddl*

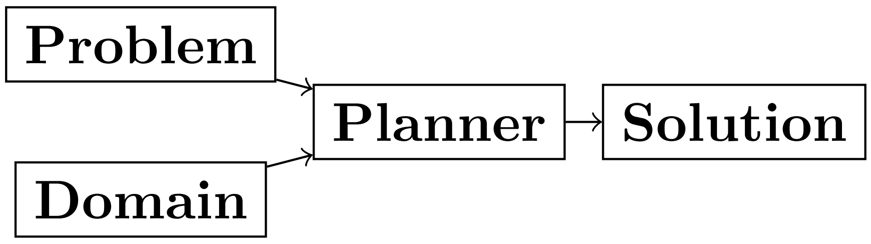


Figure 2.1: PDDL Planning workflow

PDDL is manifold and not all parts are mandatory components of task specifications, nevertheless, most domains used by ICAPS follow the here described format. More complete descriptions as well as a formulations in Backus-Naur form (BNF) can be found in Fox and Long [3] for PDDL 2.2 and Kovacs [9] for PDDL 3.1. The rest of this section will give an rather informal overview of PDDL, to provide a basis for the rest of this thesis.

2.1 Analysis

How to Design Classes, describes a incremental process for designing class hierarchies in object oriented programming (OOP). The general principles will be transferred to PDDL, so that In accordance to the *good principles* of object oriented programming (HTDC), designing new analysis of writing new task specifications basically is a stepwise, iterative process:

Analysis Every task specification begins by an analysis of the informal world and the problem statement. In this design step, one determines relevant types, adequate examples and identifies both the initial and the goal state. One keeps track of the analysis using any kind of list.

Type diagram Based on the preceding analysis, the relationship of the identified types is represented, using a diagram. This can be done by pen and paper or by means of a graph editor.

Domain definition In this step, the (graphical) diagrams are translated into PDDL. Furthermore predicates and actions are declared.

Problem definition After completing the domain definition, objects can be instantiated in the problem file. By means of the predicates, declared in the domain file, the initial and goal logical values are defined.

Two further steps

Planning Provide domain and problem definition to a planner

Plan analysis

Plan analysis can be supported by VAL or Visplan A further convenient method is the use of itSimple, so that the hierarchy can be translated to PDDL.

The syntax of basic and common constructs of these two files shell be investigated further in this section, in a step-by-step approach, where both domain and problem file are described by an example: *Gary's Hacker World*, a short, yet adequate task specifications for the hacker *Gary* that tries to *exploit* vulnerable software.

2.2 Domain File

The domain file contains the frame for planning tasks and determines, which types and predicates are available and which actions are possible.

(Usually, domain files have a strict format: All keyword arguments must appear in the order specified in the manual (an argument may be omitted, according to 1998, only the strict part requires this order) and just one PDDL definition (of a domain, problem, etc.) may appear per file (same here). [3, p. 6].)

2.2.1 Define

Every domain file starts with `(define (domain NAME) ...)` where, `NAME` is a string that starts with a character, and then contains further characters(`a-z`), numbers (`0-9`), hyphens (`-`) or underscores (`_`). PDDL's syntax is case insensitive.

```
; Gary's Hacker world - A realistic example
(define (domain garys-hacker-world)
```

2.2.2 Requirements

- PDDL: Levels of expressivity (level 1 .. 4)
- Formal description of PDDL tasks

PDDL supports different "levels of expressivity", that means subsets of PDDL features McDermott et al. [12, p. 1]. As most planners only support a subset of PDDL the requirements part is useful for determining if a planner is able to act on a given problem. They are declared by the `(:requirements ...)` part. Some often used requirements include `:strips` and `:typing`. Lists of requirement flags and their meaning can be found in Fox and Long [3] for PDDL 2.1 and Kovacs [9] for PDDL 3.1 It should be mentioned, that almost no planner supports every part of PDDL.

```
(:requirements :typing
               :negative-preconditions)
```

2.2.3 Types

In the `(:types ...)` part, PDDL allows for structuring and typing the domain. Typed lists are used to assign types to entity lists. Relations can be expressed by a type hierarchy. whereby types can be subtypes of Like that, parameters in actions can be typed, as well as arguments in predicates, functions [extra source!]. Later, in the problem file, objects will be assigned to types, like objects to classes in Object Orientated Programming (OOP). Adding to the (:requirement ...) part of the file guarantees, that typing can be correctly used. Strips (no types) vs ADL (types).

Copied: A typed list is used to declare the types of a list of entities; the types are preceded by a minus sign ("), and every other element of the list is declared to be of the

rst type that follows it, or object if there are no types that follow

If order to be able to use type hierarchys in a domain file, the requirement :typing should be declared.

As

```
(:types hacker non-hacker - person
        white-hat gray-hat black-hat - hacker
        application system tool - software
        driver os - system
        pizza person software - object)
```

Listing 1: Always this gary

Every PDDL domain includes the built-in types `object` and `number`, whereby every defined type is subtype of `object`.

2.2.4 Predicates

Predicates are templates for logical facts (therefore can be true or false) and describe the properties of objects. This part declares names, number of arguments, together with the corresponding type. The general syntax is `(p ?v1 - t1 ?v2 - t2 ...)`, whereby `?` followed by a name, declares a variable, and the expression after the hyphen (`-`) determines the type of this variable (that has to be declared in the typing section first). The number of variables determines the arity of a predicate, ranging from zero arguments (0-ary predicate) to any positive integer (n-ary predicate). Type assignments for variables that have the same type and are declared side by side can be grouped, so that `(p ?v1 ?v2 - t)` is similar to `(p ?v1 - t ?v2 - t)`.

```
(:predicates (has ?s - software ?p - person)
             (hungry ?p - person)
             (vulnerable ?s - software)
             (exploited ?s - software))
```

Listing 2: This section declares four predicates: has (2-ary), hungry, vulnerable and exploited (1-ary).

2.2.5 Actions

Actions are the operators in PDDL and are able to change the truth value of predicates (and therefore properties of objects), so that problems can be solved (if there exists a solution). Actions usually consist of three parts

`:parameters` A (typed) argument list that determines which variables can be used in the precondition and effect part.

`:precondition` The logical expression that is expressed in this section has to be `true`, before an action can be applied.

`:effect` The effect describes the post-condition of an action, that means it assigns new truth values to the mentioned predicates.

Since PDDL2.2, two types of actions are supported: durative-actions and the 'regular' action.

```
;; Eat a delicious pizza
(:action eat-pizza
  :parameters (?pi - pizza ?p - person)
  :precondition (hungry ?p)
  :effect (not (hungry ?p)))

;; Exploit vulnerable software of a victim
(:action exploit
  :parameters (?h - hacker ?s - software ?p - person)
  :precondition (and (has ?s ?p)
                     (vulnerable ?s)
                     (not (hungry ?h)))
  :effect (exploited ?s)))
```

2.3 Problem File

Problems declare the initial world state and the goal state to be reached on the basis of the logical values of the instantiated predicates. Furthermore, they instantiate types and their hierarchy, in they way that they create *objects*.

2.3.1 Define (define (problem NAME) ...)

Analog to the domain definition, problem files are initiated with `(define (problem NAME) ...)`.

```
(define (problem garys-huge-problem)
```

Listing 3: Initiating the problem file with the name garys-huge-problem

2.3.2 Domain (:domain NAME)

Problems are designed with respect to a domain, which has to be declared here (that means the NAME in `(:domain NAME)` and `(define (domain NAME) ...)` have to be equal.

```
(:domain NAME)
```

2.3.3 Objects (:objects ...)

Objects represent the instantiating of abstract types.

```
(:objects big-pepperoni-pizza - pizza
          gary - white-hat
          gisela - non-hacker
          mysterious-tex-mex-mix - application)
```

Listing 4: The instantiated objects. For example, `gisela - non-hacker` means that the object gisela is a non hacker.

2.3.4 Init (:init ...)

```
(:init (hungry gary)
       (vulnerable mysterious-tex-mex-mix)
       (has mysterious-tex-mex-mix gisela))
```

2.3.5 Goal (:goal ...)

```
(:goal (exploited mystERIOUS-TEX-MEX-MIX)
```

2.4 Planning

A planning solution is a sequence of actions that lead from the initial state to the goal state. PDDL itself does not declare any uniform plan layout.

The input to the planning software is a domain and a belonging problem, the output is usually a totally or partially ordered plan. Due to the yearly ICAPS, there is a broad range of available planners. This thesis uses the planner SGPlan$_6$ Hsu and Wah [7], a 'extensive' (in the sense of its supporting features) planner for both temporal and non-temporal planning problems.

An overview of different planners is given at `http://ipc.informatik.uni-freiburg.de/Planners`.

Additionally, the quality of error messages is very diversified. While some simple state: error occured, other list the problem and the line.

Chapter 3

Related Work

Related work primarily compromises knowledge engineering tools, consisting of at least the possibility to edit PDDL files in a textual environment and providing supporting functionality or checking the correctness of PDDL.

3.1 PDDL Studio

PDDL Studio [15], is an application for creating and managing PDDL projects. A project is regarded as a collection of PDDL files. Its IDE is inspired by Microsoft Visual Studio and imperative programming paradigms. Its core function is the PDDL project management, consisting of managing PDDL projects and creating, adding , so that corresponding as well as inspecting, analyzing and modifying the underlying domain and problem files. Besides general editing features like line counting, bracket matching and auto-save, it supports PDDL specific editing features including syntax highlighting, code folding (collapse code blocks to see only a single visible line) and context aware code completions, all based on a PDDL to XML parser. This parser can also be used to convert PDDL to XML files and vice versa for domain and problem file editing. Also based on this parser is a included, sophisticated on the fly error detection, recognizing both syntax errors (missing keywords, parentheses, etc.) and semantic errors (wrong type of predicate parameters, misspelled predicates, etc.). As semantic errors can be of a *interfile nature*, meaning that there is a mismatch between domain and problem file, PDDL Studio can detect such errors. TODO: Explain further. The code completion feature allows for the selection of completion suggestions for a for standard PDDL constructs and dynamic list completions, that were used in the current project (TODO: technical terms!). An interface allows the integration of command line planners in order to run and compare different planning software. that means syntax and semantic checking, syntax highlighting, code completion and project management. While colors for highlighted code can be customized, the background color of the tool is always white. In its most recent version (of 15.6.2012), PDDL Studio's parser supports PDDL 1.2, the official language of the first and second IPC in 1998 and 2000 respectively. Since then, PDDL has largely evolved, the most recent and most powerful version is PDDL 3.1, supporting amongst others durative actions. PDDL Studio does not support the insertion of larger code skeletons (called *snippets* in this thesis). The customization features (without editing the C source code) are limited to the choice of font style and color of highlighted PDDL expressions. PDDL Studio is written as standalone program, meaning that there are no PDDL independent no extensions .

3.2 ItSIMPLE

The ITSIMPLE project is a graphical interface that allows for designing planning models in an object-oriented approach, using Unied Modeling Language (UML) diagrams. UML was invented in order to standardize modeling in software engineering (SE). It consists of several part notations, the here presented tool uses the 'class diagram' notation, as PDDL types and classes in OOP have strong resemblance (see Tiago 2006, p 535). ITSIMPLE proposes UML.P (UML in a Planning Approach), a UML variant that specifies a structure for Class (domain specification), Object (problem specification) and StateChart Diagrams (dynamic behavior of actions).

ITSIMPLE's main focus is to support knowledge engineers in the initial stages of the design phase by providing an opportunity for the transition of the informality of real world requirements to domain models as formal specifications. The assertive statement is to provide a tool for a "{"disciplined process of elicitation, organization and analysis of requirements}. Petri Nets can be generated from the UML model and be used to validate the planning domain's static and dynamic bevahior. Finally, a PDDL representation can be generated from the UML diagram, if required, edited, and finally used as input to a variety of planning systems. The generated plan can be inspected using the in-build plan analysis, consisting of a plan visualization and plan simulation (TODO: write some more info). ITSIMPLE's mdoeling workflow is unidirectional, as changes in the PDDL domain do not affect the UML model and UML models have to be modeled manually, meaning that they cannot by generated using PDDL.

Starting in version 4.0 (currently in beta status as of writing of this thesis) ITSIMPLE expanded its features to allow the creation of PDDL projects from scratch (i.e. without UML to PDDL translation process). Thus far, the PDDL editing features are basic (see YouTube video). A minimal syntax highlighting feature recognizes PDDL keywords and variables. Furthermore, ITSIMPLE provides templates for PDDL constructs (similar to the code snippets presented in this thesis), consisting of requirement specifications, predicates, actions, goals and initial definitions.

itSimple's original and main design approach is reversed to the process presented in this paper. While itSimple generates pddl models from UML specifications, mypddl generates type diagrams from pddl. So, while itSimple focuses on the initial design phase, the tools presented here are made for later stages.

However, Tonidandel, Vaquero, and Silva [18] describe a translation process, similar to the approach in this thesis, from a pddl domain specification to an object-oriented UML.P (UML in a Planning Approach) model as possible integration for itSimple. According to an email to one of the authors, there is currently no release with this feature.

This translation process does consider the order of variables as an indicator for the importance and therefore makes semantic assumptions about the structure of the domain. That means that the first argument of an predicate or action is considered as the *main* argument - so that in actions it is considered as the agent of the agent and in predicates as ....

TODO: Describe further!
Agent, environment, problems of semantic assumptions, disadvantages, advantages, associations (many arrows could be distracting),

*my*pddl allows for a representation of a arbitrary, n-ary predicates, without making assumptions about semantics. On the one hand this allows for a visualization of any pddl domain (and n-ary predicates), while one the other hand (that means, if semantic assumptions are made correctly, U

itSimple's modeling process is focused on a graphical design process and the newly added pddl editing features are basic, consisting of highlighted keywords and variables. The templates primarily insert pddl keywords, without showing the required syntax (e.g. `(:predicates ...)` instead of `(:predicates (predicate-name ?x - object)`. itSimple is not customizable (without editing the Java source code). It is not possible to define custom key shortcuts for commands. General editor features, like to displaying line numbers, matching brackets or code folding are not (yet) supported.

*my*pddl shell support both, the initial design process of creating domains (by code snippets and the Clojure interface) and the later step of checking validity of existing domains and problems by the type generator (and possibly extending them).

3.3 PDDL-Mode for Emacs

pddl-mode (announced 2005 in a mailing list) is a major Emacs mode for browsing and editing pddl 2.2 files. It provides syntax highlighting by basic pattern matching of {pddl] keywords, variables and comments, regardless of the current context. Furthermore, its provides automatic indentation and completions and bracket matching. Code snippets for the insertion of domains, problems and actions are provided. A declaration entry in the Emacs menu bar shows all actions in the current PDDL file and allows for jumping to the definition.

Being an Emacs mode, PDDL-mode is highly and easily customizable. Text editor features, like auto-completion, can be extended independently of this mode, by installing further Emacs modes.

*my*PDDL uses Sublime Text, an editor, that is an extensible and customizable editor as well. The syntax highlighting feature of *my*PDDL supports all PDDL versions, up to the most recent version 3.1. in contrast to PDDL-*mode*, *my*PDDL-*h's* syntax highlighting feature is context-dependent and more extensive, as it can recognize almost any PDDL construct and highlight it according to its semantic.

By syntax highlighting, both tools can support code navigation, however, PDDL-*mode* does not allow for an fast and evident error detection.

3.4 Conclusion & Summary

As it can be seen, there is need for an up-to-date, customizable, text editor with PDDL support, that supports the current standard PDDL 3.1. myPDDL integrates and expands features described in this section, while keeping an focus on application, efficiency and customization opportunities.

Chapter 4

Software Engineering Tools for AI Planning

4.1 Statement of Problem

Writing and maintaining PDDL files can be time-consuming and cumbersome Li et al. [10]. To this end, a collection of extensible development tools (*my*PDDL) shell support and facilitate the PDDL task design process and reduce potential modeling errors. Main goals are a fast and reliable (or good) design process that should support the collaboration between knowledge engineers and thereby promote the use of PDDL in real-world applications.

*my*PDDL is a extensible, modular system, designed for supporting knowledge engineers in the process of writing, analyzing and expanding PDDL domains and problems. The following integral parts of *my*PDDL will be presented in the following sections:

myPDDL-i/f A general interface between PDDL and Clojure, allowing for file input (reading PDDL) and output (PDDL domain and problem generation)

myPDDL-new Create a new PDDL project folder with domain and problem skeletons

myPDDL-syn A syntax highlighting feature that colorizes PDDL constructs by its context

myPDDL-snp Code snippets (templates), which can be inserted in PDDL files.

myPDDL-loc Automated distance calculation for PDDL locations

myPDDL-gen A PDDL type diagram generator for analyzing the structure of type and object hierarchies.

myPDDL-sub The integration of *my*PDDL*-syn*, *-snip* and *-gen* into a environment to be used in Sublime Text

Human Planner Interaction An interactive PDDL environment: speech synthesis and recognition.

myPDDL is focused on customizability and extensibility, ranging from the choice of key bindings and themes to the adaptability of the code snippets to the point of adding a new module based on the general interface.

TODO: Mindmap for modular hierarchy.

4.2 General Interface between PDDL and Clojure (/myPDDL-i/f)

Being a planning language, PDDL's modeling capabilities are limited. For this reason, a interface with a programming seems reasonable and can partly automate the modeling process as well as reduce the modeling time (see e.g. distance calculator). Furthermore, In IPC, task generators are used to write extensive domain and problem files. As PDDL is used to create more and more complex domains (SOURCE1, SOURCE2, SOURCE3, . . .).

In this section, a general approach for generating PDDL constructs, but also for reading in domain and problem files, handling, using and modifying the input, and generating PDDL files as output, will be presented.

While it seems to be reasonable to further extend PDDL's modeling capability to at planning time instead of modeling time, a modeling support tool as preprocessor is appropriate in any case (`http://orff.uc3m.es/bitstream/handle/10016/14914/proceedings-WS-IPC2012.pdf?sequence=1#page=47`)

As PDDL's syntax is inspired by LISP [3, p. 64], using a LISP dialect for the interface seems reasonable, as file input and output methods can use s-expressions instead of regular expressions. This way, PDDL expressions can be extracted from a task specification and written back in a similar manner, and parts of PDDL files can be accessed in a convenient way. This thesis uses Clojure [5], a modern LISP dialect that runs on the Java Virtual Machine.

The interface is built on two methods:

read-construct(keyword,file) Allows for the extraction of a PDDL construct, specified by its name.

add-construct(file,position,part) Provides a means for adding PDDL constructs to a specified position, indicated by a keyword.

Once a part is extracted and represented in Clojure, the processing possibilities are manifold. An implementation using the `read-construct` method

```
NAME
├── dot
├── diagrams
├── domains
├── problems
├── solutions
├── domain.pddl
├── p01.pddl
└── README.md
```

Figure 4.1: The project folder structure created by *my*PDDL-*new*.

is myPDDL-gen. The combination of these two methods allows for the manipulation of existing PDDL files, as well as the creation of new files, as shown by myPDDL-loc. Possible further applications could consist of domain and problem generators, …

4.3 Create PDDL Projects (myPDDL-new) p

Prior to each implementation of a PDDL task specification stands the creation of at least one domain and a belonging problem file. In order to facilitate the creation of these files and to keep track of their development, *my*PDDL-*new* creates a structured PDDL project folder. (Figure 4.4) displays the structure of the project folder.

In this project folder, the domain file `domain.pddl` and the problem file `p01.pddl` (in folder `problems`) are filled with basic PDDL skeletons (TODO: remove this sentence or add functionality or even better: specify a template, which can be added!).
The `domains`, `dot` and `diagrams` folders are created for the use with *my*PDDL-*gen*, which will save its generated output to these folders and thereby allows for a basic version control system (see section 123).
As domain files usually have multiple problem files, the `problems` folder is designed for the collection of all associated problem files.
`README.md` is a Markdown file, which is, amongst others, intended for information about the author(s) of the project, contact information, informal domain and problem specifications, TODOs and licensing.

The functionality of *my*PDDL-*new* is available trough a command line interface, which allow for an integration of ST (and every other tool that holds an interface for command line). New PDDL projects can be generated by invoking the following command:

```
$ java -jar path/to/my\textsc{pddl}.jar new NAME
```

This approach should support an structured and organized design process. The choice of a folder structure (instead of a project file) has the advantage of being readable and customizable by every editor. This directory organization is intended to contain a single or just a few domain files in one project, stored in the project root directory, while problem files are stores in the subfolder problems.

4.4 Syntax Highlighting

* Statement of Problem

Writing extensive domain and problem files is a cumbersome and time-consuming task Zhuo et al. [19]. Addtionally, longer files can get quickly confusing. Therefore, it is convenient to have a tool that supports editing these files. Syntax highlighting, a common feature of text and code editors, describes the feature of displaying code in different styles (colors, fonts) according to the category of terms. In order to facilitate editing PDDL files, a syntax highlighting plug-in for the text and source code editor Sublime Text [16, 17] is proposed.

The process of writing PDDL files usually involves extending them and making continual amendments to them. SH provides code in a more readable way and can help to find and fix code errors quickly (see evaluation).

4.4.1 Implementation and Customization

ST syntax definitions are written in property lists in the XML format.

For the ease of creation, the PDDL syntax highlighter is implemented by the use of the ST plug-in *AAAPackageDev* [1]. So, the definitions can be written in YAML in converted to Plist XML later on. *AAAPackageDev* [1] is a ST plugin, that helps to create, amongst others, ST packages, syntax definitions and 'snippets' (re-usable code).

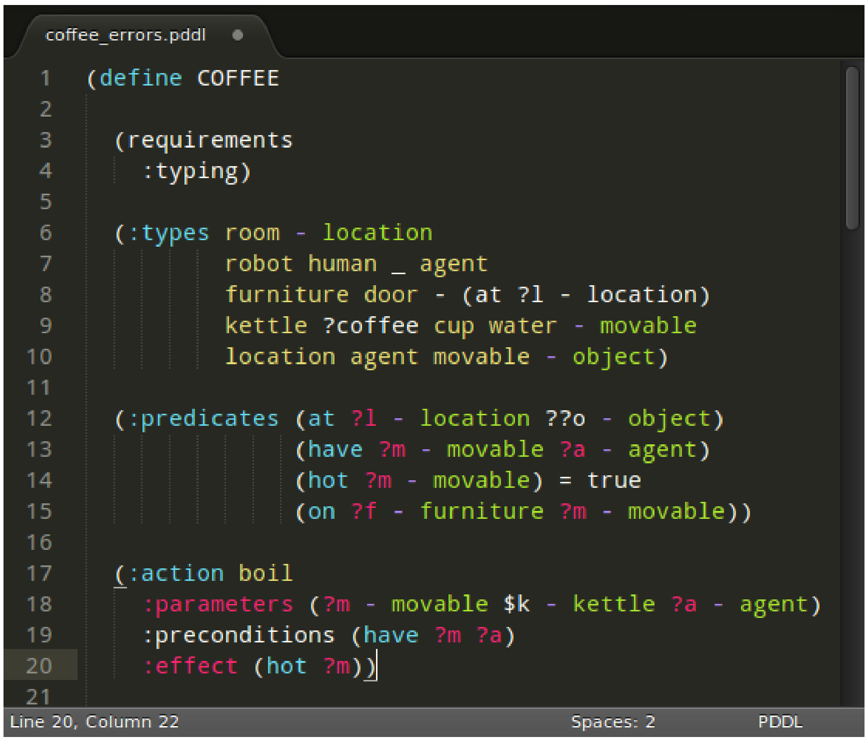
By means of Oniguruma regular expressions [8], scopes are defined, that determine the meaning of the PDDL code block. ST themes highlight different parts of the code by the use of scopes. Scopes are defined by the use of regular expressions (regexes) in a tm-Language file. The scope naming conventions mentioned in the *TextMate 2 Manual* are applied here. By the means of the name, the colors are assigned according to the current used ST theme. That means that colors are not assigned per se, but dependently on the current scheme. Through that, experienced users can use their default theme and all can easily change the colors by changing the scheme. Different ST themes display different colors (not all themes support all naming conventions).

The syntax highlighting is intended for PDDL 3.1, but is backward compatible to previous version. It's based on the Backus-Naur Form (BNF) descriptions, formulated in Kovacs [9], Fox and Long [3], and McDermott et al. [12].

The pattern matching heuristic that is implemented by the use of regular expressions is used for assigning scopes to the parts of the file. As a result of PDDL's LISP-derived syntax, PDDL uses the s-expression format for representing information (SOURCE!). So, the semantic of a larger PDDL part (sexpr) can be recognized by a opening parenthesis, followed by PDDL keyword and finally matched closing parentheses (potentially containing further sexpr). These scopes allow for a fragmentation of the PDDL files, so that constructs are only highlighted, if they appear in the right section.

The YAML-tmlanguage file is organized into repositories, so that expressions can be re-used in different scopes. This organization also allows for a customization of the syntax highlighter. The default

The first part of the PDDL.YAML-tmlanguage describes the parts of the PDDL task that should be highlighted. By removing (or commenting) include statements, the syntax highlighter is adjustable the user's need.



```
(define COFFEE

  (requirements
    :typing)

  (:types room - location
          robot human _ agent
          furniture door - (at ?l - location)
          kettle ?coffee cup water - movable
          location agent movable - object)

  (:predicates (at ?l - location ??o - object)
               (have ?m - movable ?a - agent)
               (hot ?m - movable) = true
               (on ?f - furniture ?m - movable))

  (:action boil
    :parameters (?m - movable $k - kettle ?a - agent)
    :preconditions (have ?m ?a)
    :effect (hot ?m))
```

Figure 4.2: Coffee domain with and without syntax highlighting

`file:///home/pold/Documents/BA/org-ba/thesis/img/coffee_errors_no.pngp`

4.4.2 Usage and Customization

myPddl can be installed via Package Control or by placing the files of this repository (...) have to be placed in the ST packages folder (`http://www.sublimetext.com/docs/3/packages.html`). Following, the features can be activated by changing ST's syntax to PDDL (`View->Syntax->\textsc{pddl}`).

By using ST as editor, language independent ST features are supported, like auto completion of words already used in this file, code folding and column selection, described in the Sublime Text 2 Documentation.

The PDDL.YAML-tmlanguage file is split in two parts:

By default, all scopes are included.

1. Workflow Gary creates a new PDDL project using the command line, to this end he types

   ```
   $ java -jar pddl.jar new hacker-world
   ```

   changes into that directory

   ```
   $ cd bulb-world
   ```

   and renames the file domain.pddl to

   ```
   $ mv domain.pddl garys-hacker-world.pddl
   ```

   To get an overview over the world structure, Gary doodles a quick type diagram with the freely available graph editor and layout program yEd (yFiles software, Tübingen, Germany) that represents the world and its structure. Of course, he could also do this by pen and paper or using any other graph editor.

   [./gary$_{\text{sketch.svg}}$]

   He then opens this domain file in the Sublime Text 2 editor

   ```
   $ sublime gary-hacker-world.pddl
   ```

   and starts to model his world. To this end, he uses the code snippets `domain` for creating the domain skeleton, navigates inside the domain file with ⇆ , creates new type definitions with the snippets `t2` and `t3`. After completing his first draft, he presses f8 , for saving his file and displaying the PDDL type diagram and sees the following diagram:

   [../../hacker-world/diagrams/png-diagram3.png]

   He recognizes, that he forgot to model that system software can be sub-divided into drivers and operating systems. Therefore he closes the diagram and adds the missing type declaration. He continues to write the PDDL domain and adds the required predicates with `p1` and `p2`, for example he types

The syntax highlighter shows Gary, if the uses incorrect PDDL syntax or if the forgets to close a parenthesis, as then parts don't get highlighted.

A final check show that everything is as expected:

[../../hacker-world/diagrams/png-diagram3.png]

Gary knows, that the type diagram generator uses the Clojure interface. So, adding `#_` just before the predicates s-expression (that means `#_(:predicates ...)` excludes the predicates from the type diagram, as this is the Clojure notation for commenting out s-expressions (and more convenient than commenting every single line). However, the `#_` construct is *not* correct PDDL, so Gary generates the diagram without the predicates, checks and sees that everything is fine, removes the `#_`, saves and closes the file.

The final version in the ST editor now looks like this: [./domain2.pdf]

In the command line, he now opens the PDDL problem file p01.pddl

```
$ sublime p01.pddl
```

and adds the problem skeleton by typing `problem` and pressing ⇆ .

The relevant output lines of the output file are

The planner SGPlan$_5$ can be invoked by

```
$ ./sgplan -o garys-hacker-world.pddl \
          -f p01.pddl \
          -out plans/solution0.soln
```

where -o specifies the domain file, -f the problem file and -out the output file. The extension `.soln` for `solution0.soln` is used to show that solution files are not specified by PDDL per se, however, [3, p. 91] specifies plan syntax as a sequence of timed actions.

TODO: Possibly change planner to one that does not use time stamps.

```
0.001: (EAT-PIZZA BIG-PEPPERONI-PIZZA GARY) [1]
1.002: (EXPLOIT GARY MYSTERIOUS-TEX-MEX-MIX GISELA) [1]
```

Gary now definitely knows, that he first has to eat the pepperoni pizza, before he can exploit Gisela's application *MysteriousTexMexMix*.

The numbers to the left of the actions (`0.001`, `1.002`) and to the right (both `[1]`) specify the start time and the duration of the actions, respectively. They are dispensable in this case, as only the sequence of actions is relevant.

The generated files (`dot-diagram[0-2].dot`, `png-diagram[0-2].png`, `garys-hacker-world[0-2].pddl`) are the revision control versions, generated each time the Clojure script is invoked (by pressing F8).

It can probably be seen, that this rather short description of the world and in problem results in rather extensive PDDL files.

4.4.3 Evaluation

A key challenge of creating a sophisticated syntax highlighter without the availability of a lexical parser, is the use of regular expressions for creating a preferably complete PDDL identification. While this a not possible by the expressiveness of regexes, this syntax highlighter tries to come as close as possible.

The consistency and capability to highlight every PDDL construct in a color according to its meaning, were checked by 320 (syntax error-free) PDDL files, consisting of 87 domain and 230 problem files (list of files). In that, no inconsistencies nor non-highlighted words could be found.

While syntax highlighting can improve the time and ability to get along in code files, it is mainly intended to distinct language structures and syntax errors.

4.5 Code Snippets (*my*PDDL-*snp*)

While writing and extending pddl files, knowledge engineers are supposed to use the same constructs many times. To facilitate and fasten the implementation of standard constructs, my-PDDL-snp provides code snippets. These snippets are templates for often used pddl constructs, like domain and problem definitions, predicates and actions. They can be inserted by typing a trigger keyword. The inserted content contains fields with placeholders, that can be accessed and filled in consecutively. PDDL constructs with a specified arity can be inserted by adding the arity number to the trigger keyword.

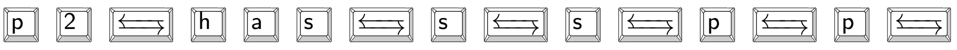


Figure 4.3: Example for the use of snippets. =p2= creates a binary predicate template that can filled in.

And gets `(has ?s - software ?p - person)` and `action` for the action definition.

Every snippet is stored in a separate file, located in the `PDDL/` folder. New snippets can be added and existing snippets can be customized there.

```
(:action actionName
        :parameters (?x - <objectType>)
        :precondition (<conditions>)
        :effect (<effects>))
```

4.6 Distance Calculation for PDDL Locations (myPDDL-loc)

While one might assume that , However, PDDL does only support basic arithmetic operations (+, -, /, *). A planning problem In temporal domains, it could be desirable to One might assume that the Euclidean distance could be modeled using `sqrt`

myPDDL-loc uses the PDDL-Clojure interface and reads a problem file and extracts all locations, defined in the `:init` part. In Clojure, the Euclidean distances between all locations are calculated and then written back to an extended problem file.

The calculator works on any dimension, so that locations can be specified both two dimensionally and three dimensionally (or n-dimensionally).

```
...
(:init (location home-gary 7 3)
       (location home-gisela 10 5))
...
```

Listing 5: Before

```
(:init
 (location home-gary 7 3)
 (location home-gisela 10 5)
 (distance home-gary home-gary 0.0)
 (distance home-gary home-gisela 3.6056)
 (distance home-gisela home-gary 3.6056)
 (distance home-gisela home-gisela 0.0))
```

Listing 6: After

An Euclidean distance function that uses the square root would be convenient for distance modeling and measurement. However, PDDL 3.1 supports only four arithmetic operators (+, -, /, *). These operators can be used in preconditions, effects (normal/continuous/conditional) and durations. Parkinson and Longstaff [13] describe a workaround for this drawback. By declaring an action 'calculate-sqrt', they bypass the lack of this function and rather write their own action that makes use of the Babylonian root method.

Another alternative is to make use of an external helper and, instead of calculating every entry of the distance matrix. the distance only if needed, incorporate every possible combination of two locations. This approach has certainly a major drawback: With an increasing amount of locations, the number of combinations increases exponentially. That means, if there are 100 locations, there will be xyz distance entries in the problem file.

The native approach would be to iterate over the cities twice and calculate only the half of the matrix (as it is symmetric, that mean distance from A to B is the same as the distance from B to A).

Inspect problem file and calculate distances while planning calculating.

4.7 Type Diagram Generator (*my*PDDL-*gen*)

As stated by the adage "A picture is worth a thousand words" graphical representations can have some advantages compared to textual representations. In computer science, they should simplify the communication between developers and help to quickly grasp the connection of related system units (source!). graphical representations are not always superior to textual representations (see introduction for a short discussion on this topic), both text and graphics can complement each other and facilitate the understanding of complex problems. To support this theory, a user test was performed, showing that . . .)

The extended expressive power provided by `ADL` includes the ability to express a type hierarchy in the domain and a object hierarchy in the problem file.

Assuming that `:typing` or `:adl` is declared, object types play a major role in the PDDL design process: they constrain the types of arguments to predicates and determine the types of actions. So, a fine grasp of their hierarchy, as well as their involved predicates becomes handy and assists knowledge engineers in the planning process. Furthermore, in order to understand, use and extend available domains, a crucial part is the grasping of types, their hierarchy, and the predicates they that make use of them. Types strongly resemble classes in object oriented programming, as mentioned in chapter (. . .), the type definitions follow a specific syntax. For example `truck car - vehicle` would indicate, that both `truck` and `car` are subtypes of the super-type vehicle (TODO: possibly move to basics part).

*my*PDDL-*gen* uses `get-\textsc{pddl}-part(file,types)`, declared in *my*PDDL-*i/f* for extracting the textual type hierarchy declared in a PDDL file. These extracted types get separated in are then separated in subtypes and supertypes, using regular expressions (regex).

```
garys-hacker-world.pddl
├── dot
│   ├── dot-diagram0.dot
│   └── dot-diagram1.dot
├── diagrams
│   ├── png-diagram0.png
│   └── png-diagram1.png
└── domains
    ├── garys-hacker-world0.pddl
    └── garys-hacker-world1.pddl
```

Figure 4.4: Folder structure after two invocations of textitmyPDDL-gen.

PDDL side	Clojure side
(:types . . . . . . — . . .)	

1. Visualization

   The visualization is generated using dot from the GraphViz package, a collection of programs for drawing graphs. dot is a scriptable, graphing tool, that is able to generate hierarchical drawing of directed graphs in a variety of output format (png, pdf, . . .), from specific text files, written in the DOT language.

   From this representation, the description of a directed graph (`digraph`) in the dot language is created and saved in the folder `dot/`. This file is then passed to the command line program `dot` and a PNG graphic is created in the folder `diagrams/` and immediately opened and displayed in a window. In addition, a copy of the domain file is stored in the folder `domains/`. Every time *my*PDDL-*gen* is invoked, these steps are executed and the saved file names are extended by a ascending revision number. This way, one cannot only identify associated pddl, dot and png files, but also use this feature for basic revision control. The structure and revision number of a previous version can be identified by the png type diagram and then, one can revert to a previous revision, stored in the `domains/` folder. All folders are created if necessary.

   Figure xyz displays a type diagram generated from the `Gary's Hacker World` domain. In the diagram, types are represented with boxes, whereby every box consists of two parts:

   - The header displays the name of the type.
   - The lower part displays all predicates that use the corresponding type at least once in their arguments. The predicates are written in the same way, as they appear in the PDDL code.

Generalization relationships ("is a", for example "a driver *is a* type of software") are expressed by arrows from the specialization (the subtype, here: driver) to the generalization (the super type - here: software), where the arrow head aims at the super type. This relationship expresses, that every subtype is also an instance of the illustrated super type.

4.7.1 Limitations

myPDDL-gen does not display predicates without argument (nullary or 0-ary predicates), like `(is-rainy)`, as they have no assigned type. Furthermore, it does not support predicates defined by `(either ...)` and types that have to super type.

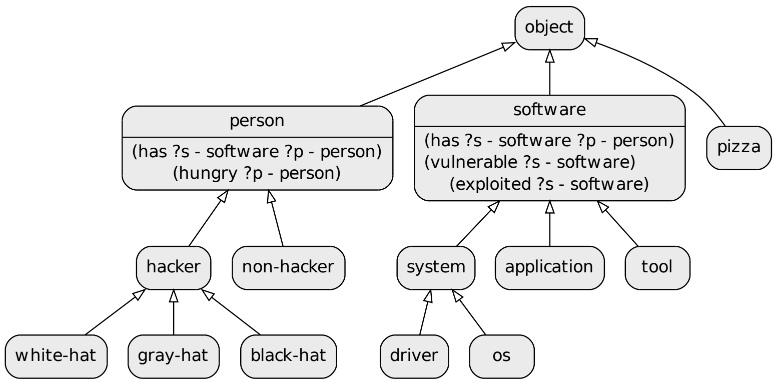


Figure 4.5: The type diagram that was generated from `garys-hacker-world.pddl` using myPDDL-gen.

4.8 Syntax Highlighting and Code Snippets (myPDDL-sub)

While *snp* and *syn* are devised explicitly for ST and therefore integrated from the outset, the other tools (new, gen, loc) can be used independently of ST utilizing the command line interface and any PDDL file. To provide a central interface for using myPDDL, *-sub* integrates new, gen and loc, aiming at a a user-friendly execution and use of the system.

The three tools can be invoked using the ST command palette (ctrl + ⇧ + P), and then choosing one of the PDDL menu entries:

***PDDL: Create Project* for myPDDL-new** *PDDL: Create Project* requires the user to specify a project name in the then displayed input panel.

PDDL: Calculate Distances for myPDDL-loc Saves and

PDDL: Display Diagram for myPDDL-dia

Extending a available editor. Furthermore, ST was used as it provides a framework for general code editing. Features include code folding,

For Mac user, TextMate (TM) is very similar to ST and the syntax highlighting file can be used there, too. Besides, the general principles (e.g. regular expressions) outlined here, apply to most of other editors as well. So, a Pygments extension was written, that allows for syntax highlighting in LaTeXdocuments.

Chapter 5

Analysis

5.1 Participants

Eight non-paid students (two female, Mean$_{\text{age}}$=23, SD$_{\text{age}}$=2) took part in the experiment. All had knowledge about at least one LISP dialect, and therefore about program code written as parenthesized lists, but nobody had faced PDDL or any other planning language prior to this study. Furthermore, nobody has used Sublime Text before that test.

5.2 Material

The usability of myPDDL-syn (Syntax Highlighter, see 4.4) and myPDDL-gen (Type Diagram Generator, see `Type Diagram Generator`) were tested. For this purpose, two domains (*Planet Splisus*, *Store*) with fantasy type names were created. Participants were asked to answer five questions that required to understand the PDDL type hierarchy. Subjects were asked to work on questions, while time on task (per question) was measured without subjects' knowledge, by asking the S to say out loud the regarding answer.

Furthermore, two deliberately incorrect domain files were provided to the S, each containing 17 errors in total (consisting of X semantic errors and Y syntax errors). Participants were asked to detect as many errors as possible in six minutes and immediately correct found errors in the code (as this could change the syntax highlighting of other code parts) and write down the line and a description or the correction of the error on a sheet of paper for an easy identification in the analysis of test results.

TODO: Include /home/pold/Documents/BA/org-ba/thesis/img/coffee$_{\text{errors.png}}$

5.3 Design

S	**Order**			
A	*Planet Splisus*	*Logistics*	Store	Coffee
B	Store	Coffee	*Planet Splisus*	*Logistics*
C	Planet Splisus	Logistics	*Store*	*Coffee*
D	*Store*	*Coffee*	Planet Splisus	Logistics
E	*Logistics*	*Planet Splisus*	Coffee	Store
F	Coffee	Store	*Logistics*	*Planet Splisus*
G	Logistics	Planet Splisus	*Coffee*	*Store*
H	*Coffee*	*Store*	Logistics	Planet Splisus

Italic: Tools part

5.4 Procedure

At the earliest, 24 hours ahead testing date, participants received a link [1] to a 30-minute video tutorial and were asked to watch this video before the test, if possible. This tutorial comprised a general introduction to planning and a more specific introduction to PDDL's domain syntax. In the video, participants were also asked to fulfill tasks regarding PDDL and check their answers with the provided solutions in the video.

At testing date, participants were asked to sign a consent form and to take a seat in front of a Laptop with a 13" display and a connected monitor with a 17" display. If they did not already watch the PDDL tutorial the participants first were asked to watch the tutorial then. After that, any open questions regarding PDDL and the general testing procedure were clarified.

All participants were provided with a one page summary of PDDL domain syntax (*cheat sheet*) that they could always refer to. Furthermore, they were allowed to take any hand-written notes that they took during the video tutorial. (and to rewatch the video tutorial at any time).

Participants were then tested, according to a assigned order of tasks.

The participants did not and that there will be a *tools* part. Immediately before the tools part, a three minute video introduction to the functionality of the syntax highlighter (myPDDL-syn) and the usage of (myPDDL-gen) was given. Directly after his, participants were asked

[1] `http://www.youtube.com/playlist?list=PL3CZzLUZuiIMWEfJxy-G6OxYVzUrvjwuV`

to work on the tools parts. so that they faced the tools were not confronted with the tools before the actual test.

5.5 Results

Table 5.1: Planet Splisus **Aggregated processing time of tasks with correct answers**

Task	Time	Points
1		
2		
3		
4		
5		
Sum		

The questionnaire used The mean System Usability Scale (SUS) score was XX, arguing for a high usability.

Chapter 6

General Discussion

As seen in the conducted study, missing actions in the type diagram can confuse. So, it is possibly helpful to exclude predicates in the diagram and only display the plain type hierarchy (as all participants were faster) before actions have not been added. Nevertheless, it is worth noting that only PDDL novices were tested, after watching a introduction video, without ever writing a domain by scratch.

Very likely, a learning effect will occur, so that tasks are more easily to fulfill if they are done for the second time.

Chapter 7

Outlook and Conclusion

7.1 Limitations and Future Work

The plug-in for the editor ST could be further extended to provide features of common integrated developing environments (IDE). A build script for providing input to a planner for auto-matching domain and matching problem(s) (or problem and matching domain) in ST could be convenient.

Detecting semantic errors besides syntactic errors \{ plch2012inspect} Studio could be the next step to detecting errors fast and accurate. Possible semantic errors could be undeclared variables or predicates in a domain specification.

Either construct not supported!

In the diagram, predicates are only added to the types that are explicitly mentioned in the argument of the predicate. However, as subtypes of types declared in the predicate arguments, can also be used as argument to the predicate, this means, that all specializations of a type can also be used for this predicate. This can be seen in Figure xyz . . . :For example, a the PDDL domain file could declare `(hungry ?p - person)`, although men and women can be hungry.

7.2 Outlook

Besides ICKEPS, as mentioned in the introduction, also the yearly workshop Knowledge Engineering for Planning and Scheduling (KEPS) will promote the research in planning and scheduling technology. Potentially, the main effort of for implementing models in planning will be shifted from the manual KE to the automated knowledge acquisition

(KA). Perception systems, Nevertheless, a engineer who double-checks the generated tasks will be irreplaceable.

7.3 Conclusion

MYPDDL - Modular Auxiliary for the Planning Domain Definition Language, has been designed to support knowledge engineers in modeling planning tasks as well as in understanding, modifying, extending and using existing planning domains.

MYPDDL has been implemented as an interface between Clojure and PDDL, where PDDL editing features are fulfilled in the text editor Sublime Text. It is designed as an modular architecture, which is extensible, customizable and easy usable system. myPDDL-gen can visualize any PDDL domain, without making semantic assumptions and n-ary predicates.

Implemented features comprise code editing features, namely syntax highlighting and code snippets, a type diagram generator and a distance calculator,

The user study shows some initial evidence that the syntax highlighting feature (MYPDDL-SUB) and the type diagram generator(MYPDDL-GEN) can support knowledge engineers in the design and analysis process, in particular in error detection and in keeping track of the domain structure, the type hierarchy and grasping predicates using these types.

A faster understanding of the domain structure could be beneficial for the maintenance and application of existing domains and problems, and, possibly for the communication between engineers. Finally, real world usage of PDDL can be promoted so that the focus of artificial intelligence planning can also be shifted towards the design of plans, following the citation "Plans are worthless, but planning is everything".

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Chapter 8

Appendix

This code can also be found on the enclosed CD, and on the Internet page `https://github.com/pold87/sublime-pddl` (most recent version).

The website `http://pold87.github.io/sublime-pddl/` is the accompanying website for this project.

```
(ns org-ba.core
  (:gen-class :main true)
  (:require [clojure.tools.reader.edn :as edn]
            [clojure.java.io :as io]
            [clojure.pprint :as pprint]
            [dorothy.core :as doro]
            [rhizome.viz :as rhi]
            [clojure.math.numeric-tower :as math]
            [quil.core :as quil]
            [clojure.java.shell :as shell]
            [me.raynes.conch :as conch]
            [me.raynes.conch.low-level :as conch-sh]
            [fipp.printer :as p]
            [fipp.edn :refer (pprint) :rename {pprint fipp}]
            [me.raynes.fs :as fs])
  (:import [javax.swing JPanel JButton JFrame JLabel]
           [java.awt.image BufferedImage BufferedImageOp]
           [java.io File]))

(defn read-lispstyle-edn
  "Read one s-expression from a file"
  [filename]
  (with-open [rdr (java.io.PushbackReader. (clojure.java.io/reader filename))]
    (edn/read rdr)))

(defmacro write->file
  "Writes body to the given file name"
  [filename & body]
  `(do
     (with-open [w# (io/writer ~filename)]
     (binding [*out* w#]
       ~@body))
  (println "Written to file: " ~filename)))

(defn read-objs
  "Read \textsc{pddl} objects from a file and add type
  (e.g. 'table bed' -> (list table - furniture
                      bed - furniture))"
  [file object-type]
  (as-> (slurp file) objs
        (clojure.string/split objs #"\s")
        (map #(str % " - " object-type) objs)))



(defn create-pddl
  "Creates a \textsc{pddl} file from a list of objects and locations"
  [objs-file objs-type]
  (str
   "(define (domain domainName)

  (:requirements
     :durative-actions
     :equality
     :negative-preconditions
     :numeric-fluents
     :object-fluents
     :typing)
```

```
# [PackageDev] target_format: plist, ext: tmLanguage
---
name: \textsc{pddl}
scopeName: text.pddl
fileTypes: [pddl]
uuid: 2aef09fc-d29e-4efd-bf1a-974598feb7a9

patterns:

####################
### Customization ###

- include: '#domain'
- include: '#problem'
- include: '#comment'

##################
### Repository ###

repository:


##############################
### General specifications ###
##############################

  built-in-var:
    match: \?duration
    name: variable.language.pddl

  variable:
    match: '(?:^|\s+)(\?[a-zA-Z](?:\w|-|_)*)'
    # name: variable.other.pddl
    name: keyword.other.pddl # TODO: changeback again to variable.other.pddl
    # this is just a dirty hack for highlighting

  pddl-expr:
    match: '(?:^|\s+)([a-zA-Z](?:\w|-|_)*)(?!:|\?)\b'
    captures:
      '1': {name: string.unquoted.pddl}
    #name: string.unquoted.pddl

  comment:
    comment: "Comments beginning with ';'"
    name: comment.line.semicolon.pddl
    match: ;.*

  number:
    name: constant.numeric.pddl
    match: \b((0(x|X)[0-9a-fA-F]*)|(([0-9]+\.?[0-9]*)|(\.[0-9]+))((e|E)(\+|-)?[0-9]+)?

  keyword:
    name: storage.type.pddl # TODO: UPDATE
    match: :(constraints|metric|length)


######################
### Domain Helpers ###
######################
```