Knowledge Engineering Tools for Planning in PDDL - Syntax Highlighting, Task Generation and Plan Visualization and Execution - an extensible framework

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Contents

Abstract

Automated planning and scheduling is a key component of artificial intelligent (AI) behavior. A planning language that is widely used for AI task specifications is the Planning Domain Definition Language (PDDL). The aim of this project was to develop tools that simplify the extensive knowledge engineering effort required by PDDL and thus facilitate the construction of planning domains. For this purpose, an extensible interface between the programming language Clojure and PDDL was developed, that supports knowledge engineers in developing PDDL projects. A tool based on this interface visualizes the type hierarchy in PDDL domains, allowing knowledge engineers to keep track of the domain structure and others that may have to work with the domains to understand them at a glance. As further implementation of this interface, a tool that calculates the distances of objects within a problem file to each other was created to show the extent of this tool and to present a way of bypassing PDDL's limited modeling capacity. Lastly, a plug-in for the code editor Sublime Text was implemented to aid developers with efficiently creating new PDDL file, navigating within the code and with finding and fixing mistakes. In order to test the quality of the syntax highlighter and the type diagram generator, a user study was conducted with inexperienced PDDL users that were asked to develop domains with and without the tools and to subsequently evaluate the tools in regard to their usefulness and usability. Both the time on task, number of errors and a post questionnaire were analyzed and it was found that... All tools developed within the scope of this thesis are unique in some regard and they can all be altered very easily to work with other editors and planning languages. An auxiliary tool to transform PDDL code into Clojure code that was needed for the latter two tools, could be relevant for future works in the field, as there are many additional use cases such as...

`https://www.ece.cmu.edu/~koopman/essays/abstract.html`

Chapter 1

Introduction

Assume you are a monkey in a cage. There are some bananas dangling from the ceiling and a bunch of boxes lying around on the ground. You are hungry and those bananas look delicious, but you just cannot reach them. To solve the problem at hand it is important that you figure out that the boxes can be stacked on top of each other and that you can then climb on top of the boxes and reach the bananas, i.e. you need to come up with a sequence of actions that take you from your initial state to your goal state. This famous experiment is described by Wolfgang Köhler in his book "The mentality of apes." and became known (in a similar form) in Artificial Intelligence (AI) research as the *monkey and banana problem*. Importantly, with this experiment, Köhler demonstrated that the monkeys did not acquire the solution by trial and error, but rather that they actually understood the environment enough to devise a plan only by contemplating the problem in the context of their world. As can be seen from the scenario given above, planning is a crucial component of problem-solving. However, while monkeys and humans are able to create and continuously update their mental models of the world thanks to sensors, AI implementations are yet to fully master this skill (SOURCE! WHAT IS STILL MISSING?). 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 (1983). 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). Obviously, the usefulness of such tools depends on the demands of the knowledge engineer. 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 (2008) 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.

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 (2004) + second topic, Glinsk and Barták (2011)) 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

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.

2.1 PDDL Studio

PDDL Studio (Plch et al. 2012), 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 .

2.2 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 (2006) 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 from This translation process has not been fully implemented to date / there is no release with this feature.

This translation process does consider the order of variables as an indicator for the importance.

$Create_{specializations}$ is the function for creating the typing diagram. $Create_{associations}$ creates binary associations between classes, whereby the first argument is considered as the *main argument*. This process requires semantic assumptions: the first argument of

In an e-mail to, Tiago Vaquero (one of the authors), on February 28, 2014,, affirms that, the translation is not functional yet.

Currently there exists no implementation from PDDL to UML. UML.P's semantic associations,

myPDDL allows for a representation of a arbitrary, n-ary predicates, without . On the one hand, one the other hand, this enables the visualization of n-ary predicates.

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. It is not possible to define custom key shortcuts. itSIMPLE is not customizable (without editing the Java source code). There is no possibility to show line numbers, matching brackets or code folding.

myPDDL shell support initial creating of domains (by code snippets) and checking for validity of domains and problem by the type generator.

2.3 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 keywords (and variables ?), regardless of the current context. automatic indentation and completions and bracket matching. Code snippets for the insertion of domains, problems and actions are provided. A declaration menu shows all actions and problems in the current PDDL file.

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.

myPDDL uses Sublime Text, an editor, that is extensible and customizable as well. The syntax highlighting feature of *myPDDL* supports all PDDL versions, up to the most recent version 3.1. in contrast to *PDDL-mode*, *myPDDL-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.

2.4 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.

Chapter 3

Planning Basics and PDDL

Introduction to planing: http://books.google.de/books?id=eCj3cKC_3ikC&printsec=frontcover&dq=automated+planning&hl=en&sa=X&ei=3wgNU5fQIcHx4gSTsoDABA&rec esc=y#v=onepage&q=automated%20planning&f=false

Classical Planning!

Action planning plays a key role in artificial intelligence. Ranging from the control of a (intelligent) household robot (or video game enemy) to the operational procedure of a complex ... , instances of planning tasks can possibly improve and automate work sequences. AP provides reasons for the choice of actions and the coherent deliberation process. By means of a formalization of a planning world by the state space (predicates & actions - operations), AP's declared aim is to generate a sequence of these actions (a *plan*) that can change the predicate values, from an initial state to a goal state, both specified by the value of predicates.

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

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

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* (n.d.) if not otherwise stated.

PDDL planning task specifications 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 -> instance specic

This separation allows for an intuitive process of task modeling: While general instances are described in the domain file, specific instances of problems are created in the problem files.

TODO: Add predicates and actions to domain, init and goal to problem and sequence of actions to plan The PDDL worklow. domain.pddl and prob-

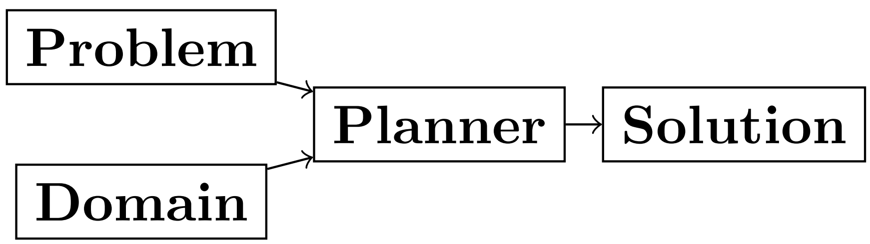


Figure 3.1: PDDL Planning workflow

lem.pddl represent typical planning specification files, with the standard file extension *.pddl*

This thesis is concerned with deterministic planning.

The syntax of basic constructs of these two files shell be investigated further in this section. More complete descriptions as well as a formulations in Backus-Naur form (BNF) can be found in Fox and Long (2003) for PDDL 2.2 and Kovacs (2011) for PDDL 3.1.

3.1 Domain File More scientific?

```
(define (domain name)

  (:requirements :requirement1
                 :requirement2...)

  (:types subsubtype1 subsubtype2 - subtype1
          subtype1 - type1
          subtype2 - type2
          ...
```

```
        type1 type2 ...  - object)

  (:predicates (predicateName1 ?var1 - typeOfVar1)
               (predicateName2 ?var2 - typeOfVar2 ?var3 - typeOfVar3)
               ...)

  (:action actionName1
    :parameters (...)
    :precondition (...)
    :effect (...))

  (:action actionName2
    :parameters (...)
    :precondition (...)
    :effect (...))

...)
```

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). Fox and Long 2003, p. 6.)

The in Example 1 declared domain shell be explained by an example.

3.1.1 Define

Every domain file starts with (define (domain NAME) ...) where, NAME is a string that starts with a character, and then contains further characters, number, hyphens (-) or underscores (_).

3.1.2 Requirements

The requirements part is not a mandatory part of a PDDL domain file. However, PDDL supports different "levels of expressivity", that means subsets of PDDL features McDermott et al. (1998, 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 (2003) for PDDL 2.1 and Kovacs (2011) for PDDL 3.1 It should be mentioned, that almost no planner supports every part of PDDL.

3.1.3 Types

In the `(:typing ...)` 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 (TODO: is :adl enough?).

```
(:types subsubtype1 subsubtype2 - subtype1
        subtype1 - type1
        subtype2 - type2
        ...
        type1 type2 ...  - object)
```

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

3.1.4 Actions

Actions are the tools for

PDDL 3.1 supports two types of actions: durative-action and the 'regular' action.

3.1.5 Functions

Functions are not supported by many planners (source!) and, before PDDL 3.1 they could only be modeled as

It is notable that before PDDL 3.0 the keyword functors was used instead

3.2 Problem File

Problems are designed with respect to a domain. Domains usually have multiple problems p01.pddl, p02.pddl, ... Problems declare the initial world state and the goal state to be reached. They instantiate types, in they way that they create objects

3.3 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 (2008), 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 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. (2012). So, the following development tools shell support and facilitate the PDDL task design process and reduce potential errors.

Below, methods are presented for

Syntax Highlighting and Code Snippets Environment for Editing PDDL files

Class Diagram Generator The automation of the PDDL task design process. File input and output and dynamic generation (design level)

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

Problem Generator Mathematical limitations (design level)

4.2 Clojure Interface

4.2.1 Approach

PDDL, as planning language modeling capabilities are limited, a interface with a programming is handy a can reduce dramatically the modeling time. In IPC, task generators are used write extensive domain and problem files.

As PDDL is used to create more and more complex domains (SOURCE1, SOURCE2, SOURCE3, . . .).

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 (Fox and Long 2003, 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 thesis uses Clojure (Hickey 2008), a modern LISP dialect that runs on the Java Virtual Machine. So, PDDL expressions can be extracted and written back in a similar manner, and parts of PDDL files can be accessed in a natural way.

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

4.2.2 Create

The functionality of sublime-PDDL 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). Different tasks can be performed by passing appropriate. New PDDL projects can be generated by invoking the following command:

```
$ java -jar path/to/pddl.jar new NAME
```

This will create a new structured project folder, consisting of a domain and problem file with basic skeletons, a `domain` and `problem` folder for an offline version control and a `png` and `dot` folder for the generated dot language and png type diagrams respectively. This approach should support an structured and organized design process, and should finally lead to a standardized method for a PDDL project structure in the planning community. This directory organization is intended to contain just of couple of domain files in one project keeping domain file per project, stored in the project root directory, while problem files are stores in the subfolder problems. This organization corresponds to the PDDL

```
NAME
├── dot
└── diagrams
```

```
├── domains
├── problems
├── solutions .2 domain.pddl
├── p01.pddl
└── README.md
```

4.2.3 Basics

Through the higher-order filter method in Clojure, parts of PDDL files can be easily extracted. Like that, one can extract parts of the file and handle the constructs in a Clojure intern way.

As an example, the type handling will be represented here, but the basic approach is similar for all PDDL constructs.

The here developed tools should be platform independent with a development focus in UNIX/Linux systems, as most planners (source!) run on Linux.

4.2.4 Functions

As functions have a return value, the modeling possibilities dramatically increase.

4.2.5 Numerical Expressiveness

One might assume that the distance could be modeled as follows:

```
(durative action ...
...
  :duration (= ?duration (sqrt (coord-x )))
...
```

However, PDDL does only support basic arithmetic operations (+, -, /, *).

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 (2012) 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.

1. Alternative #1: Only sqrt exists Assuming that a function sqrt would actually exist, the duration could be modeled as follows:

```
:duration (= ?duration
             (sqrt
              (+
               (*
                (- (pos-x (current-pos))
                   (pos-x ?goal))
                (- (pos-x (current-pos))
                   (pos-x ?goal)))
               (*
                (- (pos-y (current-pos))
                   (pos-y ?goal))
                (- (pos-y (current-pos))
                   (pos-y ?goal))))))
```

2. Alternative #2: sqrt and expt exist Assuming that a function sqrt would actually exist, the duration could be modeled as follows:

```
:duration (= ?duration
             (sqrt
              (+
               (expt
                (-
                 (pos-x (current-pos))
                 (pos-x ?goal)))
               (expt
                (-
                 (pos-y (current-pos))
                 (pos-y ?goal))))))
```

3. Alternative #3: Calculate distance and hard code it, e.g. (distance table kitchen) = 5.9

   - Distance Matrix
   - `http://stackoverflow.com/questions/20654918/python-how-to-speed-up-calculatio`
   - Scipy.spatial.distance (-> Clojure?)
   - Mention that the Taxicab geometry allows different ways that have an equal length

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

TODO: Calculate possibilities
nil

. . . . 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).

4. Alternative #4: Use the Manhattan distance

   Allowing the agent to move only vertically and horizontally would be that one can use the so called Taxicab geometry (or Manhattan length) as distance measurement. In the Kitchen domain, this could be modeled as follows:

```
% => Metric: reduce duration

% dKitchenware.pddl
\begin{figure}[t]
\inputminted[mathescape, linenos, numbersep=5pt, frame=lines, framesep=2mm]
            {csharp}
            {Code/dKitchenware.pddl}
\caption{The basic kitchenware domain}
\end{figure}
\section
```

TODO:
TODO Human Planner Interaction

4.3 Syntax Highlighting and Code Snippets

Writing extensive domain and problem files is a cumbersome task: longer files can get quickly confusing. Therefore, it is convenient to have a tool that supports editing these files. Syntax highlighting describes the feature of text editors of displaying code in different colors and fonts according to the category of terms (source: Wiki). A syntax highlighting plug-in for the text and source code editors Skinner (2013a) and Skinner (2013b) is proposed and transferred to the on-line text editor Ace are used to implement this feature, as ST Syntax Highlighting files can easily be converted to Ace Files.

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.

4.3.1 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 is implemented by the use of the ST plug-in *AAAPackageDev* (2014). So, the definitions can be written in YAML in converted to Plist XML later on. *AAAPackageDev* (2014) is a ST plugin, that helps to create, amongst others, ST packages, syntax definitions and 'snippets' (re-usable code).

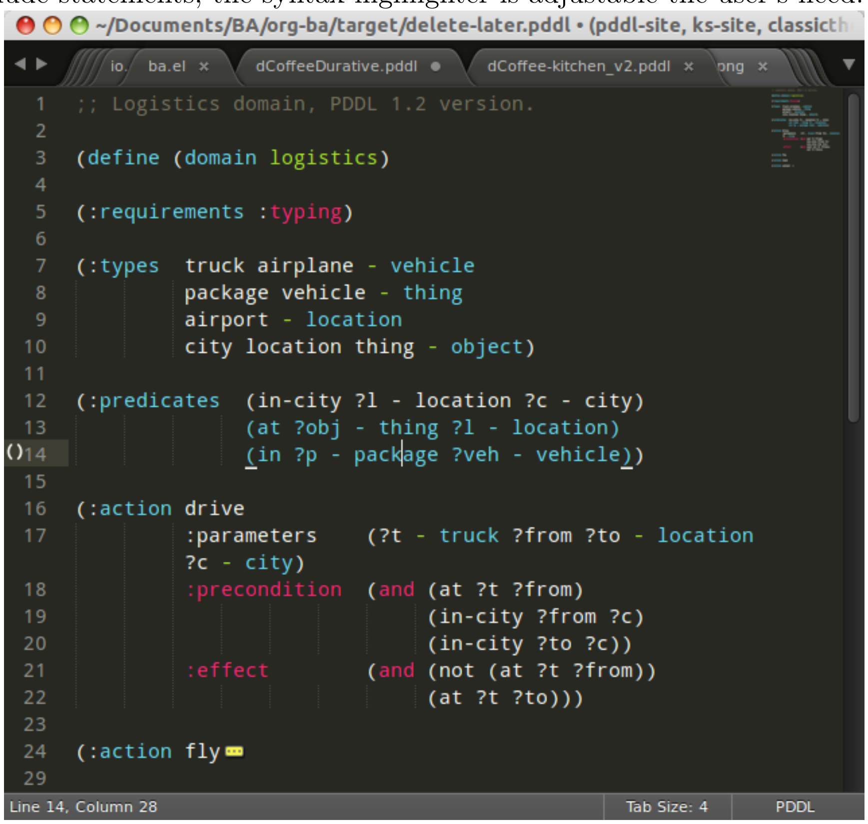
By means of Oniguruma regular expressions (Kosako 2007), scopes are defined, that determine the meaning of the PDDL code block. ST themes highlight different parts of the code through by the use of scopes. Scopes are defined by the use of regular expressions (regexes) in a tmLanguage file. The scope 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 (2011), Fox and Long (2003), and McDermott et al. (1998).

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.



4.3.2 Usage and Customization

After invoking pddl.jar twice with

To enable syntax highlighting and code snippets in ST, 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->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.

4.3.3 Use case

Following, a small use case will be presented, that should represent a typical work flow using the tools presented in this paper.

1. Initial Situation (Domain) Our world consists of two types of persons: hackers and non-hackers. Hackers can be further divided into *white hats* (seeking vulnerabilities on behalf of the system owner), *black hats* (compromise security holes without permission) and *gray hats* (sometimes act legally, other times not). *Software* can be *application* software, *system* software or programming *tools*. System software can be further divided into drivers and operating systems. A hacker must not be hungry (and in that case need some needs some pizza) in order to exploit vulnerable software.

2. Problem *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$_6$.

3. 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

`p` `2` `⇆` `h` `a` `s` `⇆` `s` `⇆` `s` `⇆` `p` `⇆` `p` `⇆`

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

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, Fox and Long 2003, 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 result directory tree looks as follows:

```
  NAME
├── dot
│   ├── dot-diagram0.dot
│   ├── dot-diagram1.dot
│   └── dot-diagram2.dot
├── diagrams
│   ├── png-diagram0.png
│   ├── png-diagram1.png
│   └── png-diagram2.png
└── domains
    └── garys-hacker-world0.pddl
```

```
│
│   │
│   ├── garys-hacker-world1.pddl
│   └── garys-hacker-world2.pddl
├── problems
├── plans .3 plan0.soln .2 domain.pddl
├── p01.pddl
└── README.md
```

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.

4.3.4 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.

4.4 Type Diagram Generator

Graphical notations, have some advantages compared to textual notations, as they simplify the communication between developers and help to quickly grasp the connection of related system units (source!).

But for all that one disadvantage has to be accepted:

Object types play a major role in the PDDL design process: they are involved, besides their definition in the `(:types ...)`, in the constants, =(:predicates ...) and =(:actions ...) part. 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.

Subtypes and corresponding super-types can be extracted using regular expressions (regex). The regex

```
#"((?:(?:\b[a-zA-Z](?:\w|-|_)+)\s+)+)-\s+(\b[a-zA-Z](?:\w|-|_)+)
```

matches every kind of that form and a Clojure-friendly representation in form of a hash-map can be created.

PDDL side ———————————— Clojure side

'(:types ... ... — ...) {... [... ... ...], ...}

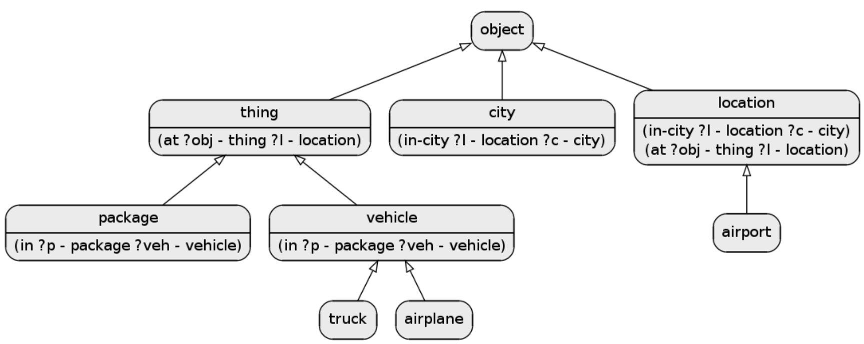


Figure 4.1: Part of a PDDL domain and the corresponding, generated UML diagram

Chapter 5

Analysis

5.1 Participants

Eight non-paid students (two female, Mean_{age}=23, SD_{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 one had faced PDDL prior to this study. One participant had used the ST editor.

5.2 Material

The usability of myPDDL-s (Syntax Highlighter, see 4.3) and myPDDL-t (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.

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 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 theirs answers with the provided solutions in the video.

Upon arrival participants were asked to sign a consent form and to take a set 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 were clarified.

Immediately before the tools part, a three minute video introduction to the functionality of myPDDL-syn and the usage of myPDDL-gen was given. Subsequently, participants were asked to work on the tools parts, meaning that participants were not confronted with the tools before the actual test.

5.5 Results

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

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

Task	Time	Points
1		
2		
3		
4		
5		
Sum		

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

Conclusion and Outlook

The tools (Clojure interface (I), type diagram generator (T), syntax highlighting (S), distance calculation (C)) presented in this thesis have been designed to support knowledge engineers in modeling planning tasks as well as in understanding, modifying, extending and using planning domains. The user study has been conducted to examine the utility of I and T. There is some evidence that they can support engineers in the design process, in particular in error detection and in keeping track of the domain structure, the type hierarchy and grasping predicates using these types. The faster understanding of the domain structure could be beneficial for the maintenance and application of existing domains and problems. The communication between engineers can be facilitated and

7.1 Outlook

As

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 of semantic errors besides syntactic errors (as in PDDL 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.

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.

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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 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 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)

  (:types\n"
   (pprint/cl-format nil "~{~&~5@T~a~}" (read-objs objs-file objs-type))
   ")
```

```
  (:constants

  )

  (:predicates

  )

  (:functions

  )

  (:durative-action actionName
     :parameters (?x - <objectType>)
     :duration (= ?duration #duration)
     :condition (at start <effects>)
     :effect (at end <effects>))
)"
   ))

(defn split-up
  "Split a PDDL type list (:types obj1.1 obj1.2 - objT1 obj2 - objT2 ...)
  into strings of subtypes and associated types,
  [[subytype1 subtype 2 ... - type][subtype1 subtype2 ...][type]"
  [coll]
  ;; Remove ':types' if it is present.
  (let [coll (if (= :types (first coll))
               (rest coll)
               coll)]
    ;; Capturing group 1 is type1.1 type1.2.
    ;; Capturing group 1 is type1.
    (re-seq #"((?:(?:\b[a-zA-Z](?:\w|-|_)+)\s+)+)-\s+(\b[a-zA-Z](?:\w|-|_)+)"
            (clojure.string/join " " coll))))


(defn types->hash-map-helper
  "Convert splitted type list (['<expr>' '<subtype1.1> <subtype1.2> ...' '<type1>']
  to a hash-map {'<type1>': ['<subtype1.1>' '<subtype1.2>' ...], '<type2>': ...}"
  [coll]
```

```
  (reduce (fn [h-map [_ objs obj-type]]
            (let [key-obj-type (keyword obj-type)
                  existing-vals (key-obj-type h-map)]
              (assoc h-map
                key-obj-type
                (concat existing-vals
                        (clojure.string/split objs #"\s")))))
          {}
          coll))

(defn types->hash-map
  "Splits types and converts them into a hash-map"
  [pddl-types]
  (types->hash-map-helper (split-up pddl-types)))

(defn map-entry->TikZ-seq
  "Converts a hashmap entry (:key [val1 val2 ...])
to a TikZ string (key -- { val1, val2 })"
  [entry]
  (str
   (name (key entry))
   " -- "
   "{" (clojure.string/join ", " (val entry)) "}"))

(defn hash-map->TikZ-out
  "Converts complete PDDL type hash-map to TikZ file"
  [h-map]
  (str
   "\\documentclass[tikz]{standalone}

\\usepackage[utf8]{inputenc}

\\usepackage{tikz}

\\usetikzlibrary{graphdrawing}
\\usetikzlibrary{graphs}
\\usegdlibrary{layered,trees}

\\begin{document}
```

```
\\begin{tikzpicture}

\\graph[layered layout, nodes={draw,circle,fill=blue!20,font=\\bfseries}]
{
  " (clojure.string/join ",\n  " (map map-entry->TikZ-seq h-map))
  "
};

\\end{tikzpicture}
\\end{document}"))

(defn types-map-entry->dot-language
  "Converts one hash-map entry
to the dot language"
  [entry]
  (str
   "\"" (name (key entry)) "\""
   " -> "
   "{" (clojure.string/join " " (map #(str "\"" % "\"")  (val entry))) "}"))


(defn types-hash-map->dot-language
  "Converts a PDDL types hash-map
to the dot language notation"
  [pddl-types-map]
  (clojure.string/join "\n" (map types-map-entry->dot-language pddl-types-map)))

;;; Read PDDL predicates and generate UML 'type' diagram
(defn get-types-in-predicate
  "Takes a PDDL predicate,
  e.g. '(at ?x - location ?y - object)
  and returns the involved types, e.g.
  '(location object)"
  [pddl-pred]
  (remove
   (fn [s]
     (let [first-char (first (name s))]
       (or (= \- first-char)
           (= \? first-char)))) (rest pddl-pred)))
```

```clojure
(defn pddl-pred->hash-map-long
  "Takes a PDDL predicate, e.g.
  '(at ?x - location ?y - object) and returns a
  hash-map, that assigns the involved types
  to this predicate, e.g.
  {location [(at ?x - location ?y - object)],
   object [(at ?x - location ?y - object)]}"
  [pddl-pred]
  (reduce (fn [h-map pddl-type]
            (assoc h-map
              pddl-type
              (list pddl-pred)))
          {}
          (get-types-in-predicate pddl-pred)))


(pddl-pred->hash-map-long '(at ?x - location ?y - object))

;;; TODO: Create short version wiht prolog predicate style
;;; e.g. at/2
(defn all-pddl-preds->hash-map-long
  "Takes a list of PDDL predicates and
  returns a hash-map of types and the
  assigned predicate"
  [pddl-preds]
  (let [pddl-preds (if (= :predicates (first pddl-preds))
                     (rest pddl-preds)
                     pddl-preds)]
    (apply merge-with concat
           (map pddl-pred->hash-map-long pddl-preds))))

(defn hash-map->dot
  "Converts a hash-map to
  dot language for creating
  UML diagrams"
  [h-map]
  (map (fn [map-entry]
         (str (key map-entry)
              "[label = \"{"
              (key map-entry)
```

```
              "|"
              (clojure.string/join "\\l"  (val map-entry))
              "}\"]\n"))
       h-map))

(defn hash-map->dot-with-style
  "Adds dot template to
hash-map>dot"
  [h-map]
  (str
   "digraph hierarchy {
node[shape=record,style=filled,fillcolor=gray92]
edge[dir=back, arrowtail=empty]
\n"
   (clojure.string/join (hash-map->dot h-map))
   "}"))


(defn PDDL->dot-with-style
  "Adds dot template to
hash-map>dot"
  [preds types]
  (str
   "digraph hierarchy {
node[shape=record,style=filled,fillcolor=gray92]
edge[dir=back, arrowtail=empty]
\n"

   (clojure.string/join (hash-map->dot (all-pddl-preds->hash-map-long preds)))
   (types-hash-map->dot-language (types->hash-map types))

   "}"))

;;; Example for Predicate:
(def predicates
  '(:predicates (at ?x - location ?y - object)
                (have ?x - object)
                (hot ?x - object)
                (on ?f - furniture ?o - object)))
```

```
;;; Example invocation:
(hash-map->dot-with-style (all-pddl-preds->hash-map-long predicates))


(defn get-PDDL-construct
  "Takes a PDDL keyword and a PDDL domain/problem
file and returns all parts of the file that
belong to the PDDL keyword."
  [pddl-keyword pddl-file]
  (filter #(and (seq? %)
                (= (keyword pddl-keyword)
                   (first %)))
          (read-lispstyle-edn pddl-file)))


                                        ; TODO: Throw error if length != 1
(defn get-PDDL-predicates
  "Get all predicates in a PDDL file"
  [pddl-file]
  (first (get-PDDL-construct 'predicates pddl-file)))

(defn get-PDDL-init
  "Get all predicates in a PDDL file"
  [pddl-file]
  (first (get-PDDL-construct 'init pddl-file)))


                                        ; TODO: Throw error if length != 1
(defn get-PDDL-types
  "Get all types in a PDDL file"
  [pddl-file]
  (first (get-PDDL-construct 'types pddl-file)))

(defn PDDL->dot
  "Takes a complete PDDL file
and generates a UML type diagram"
  [pddl-file]
  (PDDL->dot-with-style (get-PDDL-predicates pddl-file)
                        (get-PDDL-types pddl-file)))
```

```
(defn PDDL->dot-commandline-input
  "Assumes that the PDDL input is
a string and 'reads' this string"
  [pddl-file]
  (print "The type is " (type pddl-file))
  (PDDL->dot (edn/read-string pddl-file)))


(defn PDDL->dot-file-input
  "Reads PDDL file"
  [pddl-file-name]
  (PDDL->dot pddl-file-name))

;;;; math helper functions

(defn sqr
  "Square of a number"
  [x]
  (* x x))

(defn round-places [number decimals]
  "Round to decimal places"
  (let [factor (math/expt 10 decimals)]
    (double (/ (math/round (* factor number)) factor))))

(defn euclidean-squared-distance
  "Computes the Euclidean squared distance between two sequences"
  [a b]
  (reduce + (map (comp sqr -) a b)))

(defn euclidean-distance
  "Computes the Euclidean distance between two sequences"
  [a b]
  (math/sqrt (euclidean-squared-distance a b)))

;;;; End math helper functions

(defn calc-distance-good
  "Calculates the distance and writes
the calculated distances to a string
```

```
IS VERY GOOD !!!"
  [locations]
  (for [[ _ loc1 & xyz-1] locations
        [ _ loc2 & xyz-2] locations]
    ;; Euclidean distance rounded to 4 decimal places.
    (list 'distance loc1 loc2 (round-places (euclidean-distance xyz-1 xyz-2) 4))))

(defn get-specified-predicates-in-pddl-file
  "Extracts all locations in the predicates part
(by the specified name) in a PDDL file"
  [pddl-file predicate-name]
  (filter #(and (seq? %)
                (= predicate-name (first %)))
          (get-PDDL-predicates pddl-file)))

(defn get-specified-inits-in-pddl-file
  "Extracts all locations in the init part
(by the specified name) in a PDDL problem"
  [pddl-file predicate-name]
  (filter #(and (seq? %)
                (= predicate-name (first %)))
          (get-PDDL-init pddl-file)))

(defn calc-distance
  "Calculate distances of PDDL objects"
  [locations]
  (for [[ _ loc1 & xyz-1] locations
        [ _ loc2 & xyz-2] locations]
    ;; Euclidean distance rounded to 4 decimal places.
    `(~'distance ~loc1 ~loc2
                 ~(euclidean-distance xyz-1 xyz-2))))

; LOOK UP: extended equality: 'hello = :hello

(defn add-part-to-PDDL
  "Takes a PDDL domain or problem
and add the specified part to the
specified position"
  [pddl-file position part]
```

```
  (map #(if (and (seq? %)
                 (= (keyword position) (first %)))
          (concat % part)
          %)
       (read-lispstyle-edn pddl-file)))

(defn find-new-file-name
  "Take a filename and determines, the new number
that has to be added to create a new file. E.g.
file1.img file2.img file3.img means that, file4.img
has to be created"
  [filename extension]
  (loop [n 0]
    (if-not (io/.exists (io/as-file
                         (str filename n extension)))
      (str filename n extension)
      (recur (inc n)))))


;;; Copied from https://www.refheap.com/9034
(defn exit-on-close [sketch]
  "Guarantees that Clojure script will be
exited after the JFrame is closed"
  (let [frame (-> sketch .getParent .getParent .getParent .getParent)]
    (.setDefaultCloseOperation frame javax.swing.JFrame/EXIT_ON_CLOSE)))


(defn extract-locations-from-file
  "Read a Blender LISP file and write object positions to out-file"
  [file-in file-out]
  (let [map-destructorer-local (fn [[_addgv _furniture object
                                    [_make-instance _object-detail
                                      _pose [_tfmps
                                             _type-name
                                             _type-num
                                             [_vector-3d x y z & more]
                                             & _more1]
                                     & _more2]]] (list "location" (name object) x y z
    (with-open [rdr (java.io.PushbackReader. (io/reader file-in))]
      (println
```

```
    (doall
        (map map-destructorer-local
             (filter #(and (seq? %) (= 'addgv (first %)))
                     (take-while #(not= % :end)
                                 (repeatedly  #(edn/read {:eof :end} rdr)))))))))


;; Main method
;; TODO: Command line options
(defn -main
  "Runs the input/output scripts"
  [& args]

  (cond
   ;; Create a new PDDL project
   (= "new" (first args))
   (let [project-name (second args)]
     (fs/mkdir project-name)
     (fs/mkdir (str project-name "/dot"))
     (fs/mkdir (str project-name "/diagrams"))
     (fs/mkdir (str project-name "/domains"))
     (fs/mkdir (str project-name "/problems"))
     (fs/create (io/file (str project-name "/domain.pddl")))
     (fs/create (io/file (str project-name "/p01.pddl"))))

   ;; -l flag for adding locations in PDDL file
   (= (second args) "-l")
   (let [content (add-part-to-PDDL (first args)
                                   'init
                                   (calc-distance-good
                                    (get-specified-inits-in-pddl-file (first args)
                                                                      'location)))
         new-filename (clojure.string/replace-first (first args)
                                                    #"(.+).pddl"
                                                    "$1-locations.pddl")] ; TODO: loca

     (write->file new-filename (pprint/pprint content)))


   ;; Write dot graph to file.
```

```clojure
:else
(let [input-domain (first args)
      new-dot-filename (find-new-file-name "dot/dot-diagram" ".dot")
      new-png-filename (find-new-file-name "diagrams/png-diagram" ".png")
      input-domain-filename (fs/name input-domain)
      domain-version (find-new-file-name
                      (str "domains/" input-domain-filename) (fs/extension input-dom

  ;; Save input domain version in folder domains.
  (fs/copy+ input-domain domain-version)

  ;; Create folders for dot files and png diagrams
  (fs/mkdir "dot")
  (fs/mkdir "diagrams")

  ;; Create dot language file in dot folder.
  (doall
   (write->file new-dot-filename
                (print (PDDL->dot-file-input input-domain))))

  ;; Create a png file from dot
  (fs/exec "dot" "-Tpng" "-o" new-png-filename new-dot-filename)

  ;; Settings for displaying the generated diagram.
  (def img (ref nil))

  (defn setup []
    (quil/background 0)
    (dosync (ref-set img (quil/load-image new-png-filename))))

  (def img-size
    (with-open [r (java.io.FileInputStream. new-png-filename)]
      (let [image (javax.imageio.ImageIO/read r)
            img-width (.getWidth image)
            img-height (.getHeight image)]
        [img-width img-height])))

  (defn draw []
    (quil/image @img 0 0))
```

```
    ;; Display png file in JFrame.
    (exit-on-close
     (quil/sketch
      :title (str "PDDL Type Diagram - " input-domain-filename)
      :setup setup
      :draw draw
      :size (vec img-size))))))
```

```
# [PackageDev] target_format: plist, ext: tmLanguage
---
name: 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 ###
#####################


  function-keyword:
    name: support.function.pddl
    match: (assign|scale-up|scale-down|increase|decrease)


  # TODO
  other-keyword:
    name: support.other.pddl
    comment: "Remove parent or do sth that the paren isn't highlighted"
    match: \b(forall|(at\s+(start|end))|over)\b
```

```
  language-constant:
    name: constant.language.pddl
    match: (start|end|all)

  action-keyword:
    name: keyword.operator.pddl
    match: ':(?i:(parameters|vars|precondition|effect))(?!:|\?)\b'

  durative-action-keyword:
    name: keyword.operator.pddl
    match: ':(?i:(parameters|vars|duration|condition|effect))(?!:|\?)\b'



#############################
### Domain specifications ###
#############################

  domain:
    patterns:
    - comment: "domain definition "
      name: meta.function.pddl
      begin: '\(\s*((?i:define))\b(?!\s+\(problem)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      end: '\)'
      patterns:
        - include: '#comment'
        - include: '#domain-name-in-define'
        - include: '#requirement'
        - include: '#types'
        - include: '#constants'
        - include: '#predicates'
        - include: '#new-functions'
        - include: '#action'
        - include: '#durative-action'
        - include: '#any-sexpr'
```

```
domain-name-in-define:
  patterns:
    - comment: "Domain name in problem file"
      name: meta.type.pddl # TODO: NAME
      begin: '\(\s*(?i:(domain))\b'
      end: '\)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - include: '#comment'
        - name: invalid.illegal.pddl
          match: (\s+(?:\w|-)+){2,}
        - include: '#pddl-expr'

requirement:
  patterns:
    - comment: "Requirement"
      name: meta.type.pddl # TODO: NAME
      begin: '\(\s*(?i:(:requirements))\b'
      beginCaptures:
        '1': {name: storage.type.pddl}
      end: '\)'
      patterns:
      - name: keyword.other.pddl
        match:  :(?i:(strips|typing|negative-preconditions|disjunctive-preconditions

types:
  patterns:
    - comment: "Types"
      name: meta.type.pddl # TODO: NAME
      begin: '\(\s*(?i:(:types))\b'
      end: '\)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - name: meta.keyword.pddl
          captures:
            '1': {name: constant.character.pddl}
            #'1': {name: string.unquoted.pddl}
            '2': {name: entity.name.function.pdd}
```

```
     match:  (-)(?:^|\s+)([a-zA-Z](?:\w|-|_)*)
    - include: '#either'
    - include: '#pddl-expr'
    - include: '#any-sexpr'

constants:
 patterns:
  - comment: "Constants"
   name: meta.type.pddl # TODO: NAME
   begin: '\(\s*(?i:(:constants))\b'
   end: '\)'
   beginCaptures:
    '1': {name: storage.type.pddl}
   patterns:
    - name: meta.keyword.pddl
     captures:
      '1': {name: entity.name.function.pddl}
      #'1': {name: string.unquoted.pddl}
      '2': {name: entity.name.tag.pddl}
     match:  (-)(?:^|\s+)([a-zA-Z](?:\w|-|_)*)
    - include: '#either'
    - include: '#pddl-expr'

predicate:
 patterns:
  - begin: '\(\s*((?:\w|-)+)'
   end: '\)'
   beginCaptures:
    '1': {name: storage.type.pddl}
   patterns:
    - include: '#variable'
    - name: meta.name.function.pddl
     captures:
      '1': {name: constant.character.pddl}
      '2': {name: entity.name.function.pddl}
     match: (-)(?:^|\s+)([a-zA-Z](?:\w|-|_)*)

init-predicate:
 patterns:
  - begin: '\(\s*((?:\w|-)+)'
```

```
      end: '\)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - include: '#pddl-expr'
        - include: '#number'
        - include: '#init-predicate-other'

init-predicate-other:
  patterns:
    - begin: '\(\s*((?:\w|-)+)'
      end: '\)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - include: '#pddl-expr'
        - include: '#number'
        - include: '#init-predicate'

applied-predicate-other:
  patterns:
    - begin: '\(\s*((?:\w|-)+)'
      end: '\)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - include: '#variable'
        - include: '#pddl-expr'
        - include: '#applied-predicate'

applied-predicate:
  patterns:
    - begin: '\(\s*((?:\w|-)+)'
      end: '\)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - include: '#variable'
        - include: '#pddl-expr'
        - include: '#applied-predicate-other'
```

```
function:
  patterns:
    - begin: '\(\s*((?:\w|-)+)'
      end: '(\)\s+-\s+((?:\w|-)+))'
      endCaptures:
        '2': {name: storage.type.pddl}
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - include: '#variable'
        - name: meta.name.function.pddl
          captures:
            '1': {name: entity.name.function.pddl}
          match: '-\s+((?:\w|-)+)'


function-with-either:
  patterns:
    - begin: '\((\w+)'
      end: '(\)\s+-\s+((?:\w|-)+))|\)'
      endCaptures:
        '2': {name: storage.type.pddl}
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - include: '#variable'
        - name: meta.name.function.pddl
          captures:
            '1': {name: entity.name.function.pddl}
          match: '-\s+((?:\w|-)+)'

predicates:
  patterns:
    - comment: "Predicates"
      name: meta.type.pddl # TODO: NAME
      begin: '\(\s*(?i:(:predicates))\b'
      end: '\)'
      beginCaptures:
```

```
      '1': {name: storage.type.pddl}
    patterns:
      - include: '#predicate'
      - include: '#any-sexpr'


connected-predicate-other:
  patterns:
    - comment: "Predicates that are connected via and, or, etc."
      #name: string.unquoted.pddl # TODO: NAME
      begin: '\((and|or|eq|neq|not|=|>=|<=|assign|increase|decrease|scale-up|scale-do
      end: '\)'
      beginCaptures:
        '1': {name: string.unquoted.pddl}
      patterns:
        - include: '#typed-variable-list'
        - include: '#connected-predicate'
        - include: '#applied-predicate'
        - include: '#variable'
        - include: '#pddl-expr'

connected-predicate:
  patterns:
    - comment: "Predicates that are connected via and, or, etc."
      name: meta.type.pddl # TODO: NAME
      begin: '\((and|or|eq|neq|not|=|>=|<=|assign|increase|decrease|scale-up|scale-do
      end: '\)'
      beginCaptures:
        '1': {name: string.unquoted.pddl}
      patterns:
        - include: '#typed-variable-list'
        - include: '#connected-predicate-other'
        - include: '#applied-predicate'
        - include: '#variable'
        - include: '#pddl-expr'

# TODO:
functions:
  patterns:
    - comment: "Functions"
```

```
      name: meta.type.pddl # TODO: NAME
      begin: '\(\s*(?i:(:functions))\b'
      end: '\)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - include: '#function'
        - begin: '\((either)'
          beginCaptures:
            '1': {name: entity.name.function.pddl}
            '2': {name: storage.type.pddl}
          patterns:
            - include: '#pddl-expr'
          end: '\)'
       #- include: '#function-with-either'

either:
  patterns:
    - begin: '(-)\s+\((either)'
      beginCaptures:
        '1': {name: entity.name.function.pddl}
        '2': {name: storage.type.pddl}
      patterns:
        - include: '#pddl-expr'
      end: '\)'

new-functions:
  patterns:
    - comment: "Functions"
      name: meta.type.pddl # TODO: NAME
      begin: '\(\s*(?i:(:functions))\b'
      end: '\)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - include: '#either'
        - include: '#predicate'
        - include: '#pddl-expr'

typed-variable-list:
```

```
  patterns:
    - begin: '\((\?((?:\w|-)+))'
      end: '\)'
      beginCaptures:
        '1': {name: keyword.other.pddl}
      patterns:
        - include: '#variable'
        - name: meta.name.function.pddl
          captures:
            '1': {name: constant.character.pddl}
            '2': {name: entity.name.function.pddl}
          match: '(-)(?:^|\s+)([a-zA-Z](?:\w|-|_)*)(?!:|\?)\b'

 precondition:
   patterns:
     - name: entity.name.function.pddl
       begin: ':precondition\s*'
       end: \b

# any-sexpr:
#   patterns:
#     - match: \(.*\)
#       patterns:
#         - include: '$self'


 any-sexpr:
   patterns:
     - begin: '\('
       end: '\)'
       patterns:
         - include: '#any-sexpr-other'
         - match:  (?:\s)*

 any-sexpr-other:
   patterns:
     - begin: '\('
       end: '\)'
       patterns:
         - include: '#any-sexpr'
```

```
        - match: (?:\s)*

  action:
    patterns:
      - comment: "Action"
        name: meta.type.pddl # TODO: NAME
        begin: '\(\s*(?i:(:action))\b'
        end: '\)'
        beginCaptures:
          '1': {name: storage.type.pddl}
        patterns:
          - include: '#connected-predicate'
          - include: '#applied-predicate'
          - include: '#pddl-expr'
          - include: '#comment'
          - include: '#typed-variable-list'
          - include: '#action-keyword'
          - include: '#built-in-var'
          - include: '#any-sexpr'

  durative-action:
    patterns:
      - comment: "Durative Action"
        name: meta.type.pddl # TODO: NAME
        begin: '\(\s*(?i:(:durative-action))\b'
        end: '\)'
        beginCaptures:
          '1': {name: storage.type.pddl}
        patterns:
          - include: '#connected-predicate'
          - include: '#applied-predicate'
          - include: '#pddl-expr'
          - include: '#comment'
          - include: '#typed-variable-list'
          - include: '#durativ-action-keyword'
          - include: '#built-in-var'
          - include: '#any-sexpr'

######################
### Problem Helpers ###
```

```
######################

  problem-name-in-define:
    patterns:
      - comment: "Domain name in problem file"
        name: meta.type.pddl # TODO: NAME
        begin: '\(\s*(?i:(problem))\b'
        end: '\)'
        beginCaptures:
          '1': {name: storage.type.pddl}
        patterns:
          - include: '#comment'
          - name: invalid.illegal.pddl
            match: (\s+(?:\w|-)+){2,}
          - include: '#pddl-expr'

  domain-name-in-problem:
    patterns:
      - comment: "Domain name in problem file"
        name: meta.type.pddl # TODO: NAME
        begin: '\(\s*(?i:(:domain))\b'
        end: '\)'
        beginCaptures:
          '1': {name: storage.type.pddl}
        patterns:
          - include: '#comment'
          - name: invalid.illegal.pddl
            match: (\s+(?:\w|-)+){2,}
          - include: '#pddl-expr'

##############################
### Problem specifications ###
##############################


  problem:
    patterns:
    - comment: "problem definition"
      name: meta.function.pddl
      begin: '\(\s*((?i:define))\b'
```

```
    beginCaptures:
      '1': {name: storage.type.function-type.pddl}
    end: '\)' # Paren after the domain/problem name.
    patterns:
      - include: '#comment'
      - include: '#problem-name-in-define'
      - include: '#domain-name-in-problem'
      - include: '#inits'
      - include: '#objects'
      - include: '#goal'

objects:
  patterns:
    - comment: "Objects"
      name: meta.type.pddl # TODO: NAME
      begin: '\(\s*(?i:(:objects))\b'
      end: '\)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - name: meta.keyword.pddl
          captures:
            '1': {name: entity.name.function.pddl}
            #'1': {name: string.unquoted.pddl}
            '2': {name: entity.name.tag.pddl}
          match:  (-)(?:^|\s+)([a-zA-Z](?:\w|-|_)*)
        - include: '#either'
        - include: '#pddl-expr'

inits:
  patterns:
    - comment: "Initalized predicates"
      name: meta.type.pddl # TODO: NAME
      begin: '\(\s*(?i:(:init))\b'
      end: '\)'
      beginCaptures:
        '1': {name: storage.type.pddl}
      patterns:
        - include: '#init-predicate'
        - include: '#connected-predicate'
```

```
        - include: '#any-sexpr'

  goal:
    patterns:
      - comment: "Goal"
        name: meta.type.pddl # TODO: NAME
        begin: '\(\s*(?i:(:goal))\b'
        end: '\)'
        beginCaptures:
          '1': {name: storage.type.pddl}
        patterns:
          - include: '#connected-predicate'
          - include: '#applied-predicate'
          - include: '#comment'
          - include: '#any-sexpr'


# TODO: Metric
```