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RPM PACKAGE QUERY RESOLVER

DOTAZOVÁNÍ NAD RPM BALÍKY

BACHELOR'S THESIS

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Abstract

The goal of this thesis is to create a tool allowing effective retrieval of data about RPM packages and perform queries both about their data and relations which exist between them. Tool has to be able to outperform speed of currently existing tools and allow easy extension for preservation of more data or relations. Another of required features is visualization of results according to user settings or providing of results in machine readable format.

Abstrakt

Cílem této práce je vytvořit nástroj umožňující efektivně získávat data o RPM balících a dotazovat se jak na data jednotlivých balíčků tak na vztahy, které mezi nimi existují. Nástroj musí být schopen předčít dosavadní rychlost dotazování existujících nástrojů a umožňovat snadné rozšíření o ukládání dalších dat nebo vztahů. Další z požadovaných funkcí je vizualizace výsledků podle nastavení uživatele nebo poskytnutí výsledku v strojově zpracovatelném formátu.

Keywords

Packages Queries Python RPM

Klíčová slova

Balíky Dotazování Python RPM

Reference

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Rozšířený abstrakt

RPM packages are basically compressed archives containing software and metadata about their contents. When user wants to install software with RPM package manager, dnf for example, dnf looks through its configured repositories and locates package which provides function that the user requires. RPM package in its metadata contains information about what package provides, for example library, and list of packages which are required on host system for software to be working properly.

As the distribution grows bigger and more complex, so does its RPM repositories and more maintenance is required to keep distribution in good state and useful to its users. This directly involves cooperation of developers which maintain particular pieces of distribution and their ability to access information quickly.

While the most important information as dependencies and lists of files can be accessed in matter of seconds through dnf alone, information which involves data that is not necessary for package to be functional or is useful mainly to developers, often has to be searched for manually or through slow scripting. This fact leads us to the goal of this thesis and that is to invent a tool which will be able to quickly retrieve any data about packages, save this data in a cache and allow us to ask any question that we can think of.

Example of this is a situation which frequently occurs during development and maintenance of every Fedora release. Fedora is maintained by community and thus it is no surprise when some of the members have no longer time to maintain packages owned by them. When this happens, maintainer has the ability to either pass the ownership to secondary maintainers or if there are none, orphan the package. Orphaned package is kept in official repositories for another 8 weeks and then is removed if no maintainer acquires it. Problem is that packages which depend on it, can not be installed. Normally maintainer of dependent package steps up and takes ownership of dependency but first he must know that such event occurred. Maintainers can be contacted but first we must know who should we contact. This is the moment when user has to individually query repositories about dependent packages and has to connect them with appropriate developers. Operation like this took tens of minutes with current state of dnf api and scripting. With proper caching and optimization, it could be possible to cut this time down to seconds.

Another problem which this thesis is supposed to solve is resolving complicated queries. For example to assess how many frequently used packages will be affected by removal of some library. This requires that packages are connected with counts of their individual downloads and we choose only those packages that meet specified threshold. This way we can prioritize maintenance of heavily used libraries and fulfill the true requirements of distribution users.

First of the greatest challenges of this project is to find an efficient data structure to store package data in such way that queries will be able to walk them quickly over and use algorithms which are able to quickly process relations. Another requirement is that this structure is well understandable and in best case serializable to file which we can later use as a cache. Cache should allow user to not retrieve and build structure every time the project is run but increase speed of query by avoiding this time consuming operation.

Second is to choose how should the queries be specified. It has to be complex enough to be able to express complicated queries but easy to learn and read, so users do not have to spend long time studying the tool before they can use it for something useful. In the same time it is very important to assert that the queries will be optimized in such a way that there will not be any unnecessary evaluations to accelerate the whole execution process.

Foundations on which any real life usable tool stands is an accurate documentation. The project has to be properly documented so users can find every information they need and are not slowed down by asking developers or studying how the project behaves in different situations.

Last but not least requirement is the need for tool to be properly tested. Combination of unit and functional testing will be needed to ensure projects stability and to make long time maintenance easy. Developer has a lot choices when it comes to choosing testing technology but since language of project is Python it is only fitting that verified framework with great community such as Pytest is used.

Project has a real life use case scenarios which came up during maintenance of packages in Fedora and RHEL distributions which will allow author and lead to identify whether it has fulfilled its purpose or not. To solve all these problems is the final goal of this thesis which is meant to prove that creation of such powerful tool is possible and it can accelerate work of package maintainers while making the dependent distribution more stable and secure.

RPM Package Query Resolver

Declaration

I hereby declare that this Bachelor's thesis was prepared as an original work by the author under the supervision of Mr. Miroslav Hrončok The supplementary information was provided by Mr. Adam Rogalewicz I have listed all the literary sources, publications and other sources, which were used during the preparation of this thesis.

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Tomáš Korbař

April 5, 2022

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Chapter 1

Introduction

Linux distributions are build upon packages which provide software to their users. It is these packages that make particular distribution different or similar to other one. All these packages require maintenance, in the case the distribution is developed commercially, as well as it is developed by community. The fact that the whole system is stable and comfortable to use is a result of a good work of maintainers who work together to ensure that all packages are working and their requirements are met.

An efficient maintenance requires accurate information which maintainers get from multiple sources and are using many tools to retrieve. For example, which packages depend on their own packages and thus which maintainers should they communicate with when encountering disturbing changes. Often the information is not easy to acquire and slows down developers by forcing them to manually search through different places. To solve this problem a new tool which is able to store and filter any information about packages is required as no other exist in the moment of making this thesis.

RPQR is an originally proposed tool which is supposed to make maintainers life easier by allowing them to describe how to acquire the data only once and then being able to retrieve it on demand. It is flexible enough to store any new kind of data and to search packages based on combination of any of them while also providing the option to accelerate queries by making specialized commands. RPQR also lets users build a cache which makes further queries faster and thus saves time while doing everyday work.

the tool is able to be directly used by other projects through provided API or it can be used by user as any other command line project. Users are also able to visualize their results for faster understanding of the results.

Chapter 2

Theory and current state

While crucial information about a RPM package is stored directly inside it within the header section, additional information as who maintains it or which bugs are currently known has to be searched in external sources of information. This chapter describes RPM packages and technologies which currently exist for working with them. Then we continue with a description of other subjects which are needed to successfully design and implement RPQR project.

2.1 RPM package

RPM packages have their own file format[5]. It is composed of four parts with their specific purposes. The parts are (i)lead, (ii)signature, (iii)header and (iv)archive. Here are described and explained all parts relevant to the RPQR project.

The lead

The lead is the first part of the RPM package. It contains magic number and version of RPM file format. It also contains whether the package type is binary or source and other information relevant for system using it. The difference between binary and source package is that source package contains source code from which software can be built or the whole downloaded project, while binary package contains the actual software. The lead is no longer used internally by RPM because of its inflexibility and is noted here only for completeness of file format description.

The signature

The signature is allowing package integrity and optionally authenticity to be verified. It holds little purpose for RPQR but it is important because dnf uses it and RPQR is using dnf API.

The header

The header is the most interesting part from perspective of RPQR project, because it contains detailed crucial information about the package. It is composed of tags which describe different aspects of the bundled software. Examples of these tags can be *RPMTAG_VERSION* specifying version of the package or *RPMTAG_RELEASE* which specifies what release of this version this is. Header is parsed by a software which is making metadata structure of RPM repositories and this structure is then used by the dnf package manager to find appropriate packages that the user needs.

```
00001198 8e ad e8 01 00 00 00 00 00 00 00 3e 00 00 0f dd |.....>....|
```

The first 16 bytes of header part are describing attributes of this header. Three bytes are magic number identifying header, one byte says that header conforms to version 1 of specification. Four another bytes are reserved and then there is count of entries stored in this header (00 00 00 3e to decimal is 62). The last four bytes mean how many bytes is stored in this structure (00 00 0f dd to decimal is 4061).

```
000011c8 00 00 03 e8 00 00 00 06 00 00 00 02 00 00 00 01 |.....|
```

For best example, we will describe name tag. 00 00 03 e8 identifies presence of name tag and 00 00 00 06 says that value is string. 00 00 00 02 means that value is located 2 bytes after the start of store and 00 00 00 01 indicates that there is just one value, which is the only allowed possibility for string value stored in the header.

The store is just values after each other and are distinguished only by their respective offsets.

The archive

The archive is a set of files and folders compressed with a compression algorithm. Its integrity can be verified with signature specified.

2.2 RPM repository

RPM repositories are directory structures which contain RPM packages and metadata which are needed to quickly locate packages that user needs. Metadata are created by createrepo [7] utility and accessed by dnf package manager.

Repodata

Every RPM repository contains folder *repodata* which contains data about contents of the repository. There is a file *repomd.xml* containing xml structure indicating where should package manager look for databases with information about packages.

Important databases:

- **primary** database which specifies all crucial information about each package as version, description or file list.
- **other** database which contains other less important information e.g. changelog of a package

2.3 Package managers

Work with RPM packages can be done by multiple tools. Their general responsibility is to recognize package dependencies and being able to install or uninstall software contained in the package. Most frequently used are RPM package manager and DNF package manager (successor of the old YUM package manager).

RPM package manager

RPM package manager supports more low level operations with packages than DNF does [6]. It allows to build source of a project according to specfile and create distributable packages. More of the important operations are also reading of the metadata and verification of installed software, in case that it is not working properly. Installation of dependencies would have to be handled by user manually so rpm utility is not often used by end users of the systems.

YUM package manager

Yum package manager is historically the first manager that allowed easy downloading of packages from remote repositories and handling their dependencies [11]. It is currently deprecated and has been replaced by DNF. Reasons for deprecation and replacement were that YUM was not properly documented, it was not ready for switch to python3 and algorithm for dependency resolution was not strong enough to handle all problems that withstand in modern RPM based linux distributions.

DNF package manager

DNF package manager is a successor of the older YUM package manager [1]. It allows user to install and remove software on system comfortably by handling all of the operations that are needed to retrieve package dependencies and resolve any of the possible conflicts. Very often used feature is also system upgrades, when DNF is able to migrate system from old versions of distribution to new ones. Very important fact that needs to be stated is that DNF provides python API which can be used by other projects to retrieve metadata from repositories and distinguish them.

DNF is the only tool that is currently able to query repositories for metadata which are specified in packages. An example of frequently used query is:

```
$ dnf repoquery --whatprovides /usr/bin/bash
```

This command issues that dnf should execute command `repoquery` filtering by tag *provides* and find all packages that provide file `/usr/bin/bash`. DNF is able to search for packages based by attributes which are supplied within the package, but it is not able to retrieve additional information or query based on complex relationships. It is not its job to resolve more difficult queries and it would be wrong to force it to by extending its capabilities.

2.4 DNF API

DNF provides python API through which developer can interact with repositories and retrieve information. At first instance of *Base* class has to be created and then specify repositories from which metadata should be retrieved. Call to *fill_sack* method after that will load the metadata and API can then execute queries which the dnf tool supports.

Example of how is dnf API used in RPQR project:

```
base = dnf.Base()
for (name, url) in self.repositories:
    base.repos.add_new_repo(name, base.conf, baseurl=[url])
base.fill_sack(load_system_repo=False, load_available_repos=True)
return base.sack.query().available()
```

2.5 Storing techniques and query language

As was stated before, it is crucial to choose the right technologies to store package metadata in such a format that they can be read by human reader while also easily parsable and serializable. This section will describe possible formats. Another part will be explaining existing query languages which could be used for RPQR queries and their pros and cons in context of describing package metadata.

Data structures

While RPM repositories store metadata as a list in XML format or sqlite database, for use cases that are oriented about relationships between packages list does not have to be appropriate data structure for internal representation of package metadata.

- List

Pros:

Easy to work with Python

Simple algorithms to process its members

Cons:

Bad handling of relationship representation

- Dictionary

Pros:

Faster accessing of members

Cons:

Forcing packages to be identified by the same attribute

- Graph

Pros:

Great representation of relationships between packages

Fast algorithms for searching and filtration

Cons:

More complex algorithms for processing of nodes

To filter packages according to attributes, dictionary or list is still needed since there is no package that we could consider as proper root of the graph.

Data formats

Appropriate data format needs to be chosen for storing of data. Currently there are many massively used formats which could be suitable for RPQR use case. Data format should be chosen accordingly to how much readability it can provide for human developer and whether it can be used within versioning repositories such as git or mercurial.

XML

Extensible markup language[9] is used by repocreate utility which is parsing package metadata and creating their collections for package managers. It is natively supported by Python and relatively easy to read. XML is using tags to distinguish individual elements of serialized data. Its advantage is that it supports various encodings and even can contain comments so some things in serialized data could have additional explanations when needed.

Example of XML data:

```
<?xml version="1.0" encoding="UTF-8"?>
<element>
  <innerElement>
    Example text
  </innerElement>
  <!-- Explanation comment -->
</element>
```

JSON

JavaScript Object Notation[3] is widely used format for data serialization which represents objects with pairs of named attributes and their values. One of the big advantages is that it also natively supports arrays and consists of minimal syntax which allows most data to be stored and transferred with less required space. Unfortunately there is no support for comments but readability of JSON data is generally good so they are not needed in most cases.

Example of JSON data:

```
{"Element":{
  "InnerElement": "Example text"
}}
```

YAML

YAML[10] Ain't Markup Language is data format used by many applications for configuration and data transfer. YAML used JSON as a basis for its version 1.2 and it is accepting JSON as its subset. Interesting about this format is that unlike JSON it supports comments and extensible data types. Strings in YAML can be also specified without the starting and ending quotation marks. Individual attributes of objects distinguished by name and indentation style similar to Python. While YAML data sets are generally smaller than JSON, the number of additional syntax features makes their parsers more complex and thus it inevitably takes more time to load them.

Example of YAML data:

```
element:  
  InnerElement: Example text
```

Pickle

For completeness here is mentioned even Python pickle format[4] for object serialization. Because it is binary it can be parsed more quickly and support additional acceleration of RPQR execution. There is an issue with execution of arbitrary code when parsing pickle structures which does not occur in previously mentioned formats. Unlike the previous formats, it is not human readable and thus unfortunately not appropriate to be used for package data structures that should be accessible by different tools. There is not an example because it would not make sense to show binary data.

Query languages

For purposes of RPQR project, there needs to be a specification how to describe queries. Currently there are many approaches. In this section there will be description of some of them and their features which could prove useful for selecting packages and their attributes.

SQL

Structured Query Language[8] is a domain-specific language which is widely used to interaction with relation databases. SQL is able to select records based upon their attributes and relations but is not capable of describing complex recursive queries about graphs. Another caveat is that for Python application, using standard Python libraries, to be able to use SQL, it would need to hold an instance of sqlite database in memory and that could prove to be unnecessary overhead which could slow execution down.

Example of SQL query: *SELECT * FROM table WHERE id = 3*

GraphQL

GraphQL[2] is an open source query language which allows developers to implement their own interpretation of individual query parameters. It is used in REST APIs to allow client applications to retrieve data effectively from a server without it having to transfer any unnecessary data. Its flexibility is a great advantage but queries are not as readable as they would be in SQL language.

Cypher query language

Cypher query language is an implementation of opencypher specification. It is meant for work with neo4j graph database and is developed for such purpose. For application to be able to get advantage of cypher, it needs to use neo4j database which can result in too big an overhead for utilites designed with one specific purpose in mind.

Example of Cypher query language:

MATCH (peter: employee name: 'Peter Parker') RETURN peter

Example of GraphQL query:

```
{
  table(where: {id: {_eq: 3}}) {
    id
    name
    age
  }
}
```

Domain specific language on Python

Creating own query language is always an option and it holds enormous power in the ability to bend the language to the specific purpose that RPQR project needs. Problem is that developing and maintaining language takes time and energy. For a language to be functional, RPQR would need to implement its own components like scanner, parser and interpreter. In the essence, domain specific language for RPQR would need to be relatively simple. There is a requirement to interpret statements which result is always set of nodes that represent packages. These statements consists of commands that take values and other statements as arguments and operators which realize basic set operations as is union or intersection.

Example of how RPQR language could look:

WHATDEPENDSON('libyang', 3) & WHATDEPENDSON('libgcc', 3)

Components that are needed for interpretation of RPQR language:

- **Scanner**

Scanner is used to convert source text of the language to tokens for further processing by parser. Its crucial part is finite state machine which reacts to characters in input and recognizes lexical tokens. Scanner is also able to tell user when some lexical error occurs and query needs to be changed for it to be valid.

- **Parser**

Parser consumes tokens from scanner and handles creation of abstract syntactic tree or some other internal representation of source text on input. Parser is able to recognize syntactic errors which occur during parsing and optionally inform user about them. There are multiple techniques for syntactic analysis as Top-Down Parsing or Bottom-Up Parsing which are basically algorithms how to recognize language unit on input. Both of these techniques are using models for context-less languages such as formal grammatics. Formal grammar is a list of rules which are used to check whether input is written in a language or not.

- **Interpreter**

RPQR does not need to translate query into some other form, it needs to perform it. That is the reason why last part of RPQR language would be its interpreter. Interpreter inside of RPQR would need to be flexible enough for it to be able to accept new commands for searching of packages. Another thing that is important is using optimizations such as short evaluation to make searching of packages as fast as possible.

2.6 Caching

Since one of the most time consuming actions of current approach to queries about RPM packages is network communication and transfer of metadata, it is crucial to download all metadata at once on the start of execution to not need any further downloads. This can be ensured through DNF API by executing query to list all packages that are available to install from specified repositories. DNF package manager uses very similar approach by downloading all metadata to local storage and updating it only when user forces it to or cache expires.

Question of metadata expiration needs to be handled by RPQR itself too.

Approach when metadata are not updated unless user wants to do so could save time for checking of repository but user would be responsible for consistency of metadata and repository state which could prove problematic.

RPQR could stick with the same approach as the DNF one. Rebuild metadata when they expire. The problem is that building internal structure and rebuilding cache could be very time consuming operation maybe even in the matter of minutes.

The third and maybe the most proper approach is to set expiration time of metadata to some longer period of time. After such period the time for rebuilding of cache will not be so important. Also if no change occurred then it is pointless to rebuild the data and it would be highly useful to rebuild only parts of internal data structures which do not longer correspond with the actual state of RPM repositories supplied in configuration.

2.7 Configuration

It is clear that the RPQR tool will need multiple options for it to work properly and accordingly to users notions. There are multiple ways how to supply such configuration to the tool. One of the most common ones is to supply configuration by command line options. While this is easy to implement and Python offers native support for it, this approach could prove to be painful for user when overused. For example six or more commandline options would be difficult to track. That can be solved by providing user with means to set mostly static options through configuration file.

With configuration file withstands more choices which needs to be done.

- Format of the configuration file There are multiple formats which can be used. JSON or YAML are probably the most appropriate ones. Their description was stated in previous sections.
- What options should configuration include Configuration should include only options which does not change often and thus do not force user to change the file frequently.

Chapter 3

Research

With good knowledge about current state of utilities and technologies, this chapter can explore what is the best approach to resolving complex queries about RPM packages. In each section there is described particular approach that was chosen as a best for solution of individual problem.

3.1 Project structure

Python project is most often divided into folders which contain logically related classes and classes that have less dependencies are located deeper in a directory structure. So entire implementation of projects logic has one root folder. Another folder is meant for executable binaries or scripts that are supposed to be installed in path of users system. The last important folder is folder containing tests. There is multiple ways to store projects test but own folder seems to be most clean and tests seeking utilities have easier time to find tests organized in such way.

Illustration of proposed structure:

```
bin
bin/script
project
project/example_module
test
test/example_module
```

3.2 Retrieval of information from repository

While there are approaches which would allow individual retrieval of metadata from repositories, such as custom downloading of xmls and database archives, there is no reason for that, because DNF provides API that allows application to use its already implemented downloading of metadata. The best way to use it for this purpose is to create query which matches with every package accessible through configured repositories.

3.3 Customization and modification of functionalities

RPQR project needs to be able to adapt to changing demands on queries and the most simple way to achieve that is to create a system of loading plugins in a form of python modules. There is no out of the possibility for Python script to dynamically load another module but because of a very high level of introspection that Python provides, it is possible to achieve something very similar. When plugin upholds certain defined rules, such as that class for load is named the same as the file, then it is possible to easily create efficient algorithm for searching and importing of accessible plugins.

Illustration of plugin importing:

- Gather all directories for inspection from configuration or use hard coded paths
- For each folder walk over files and check if they fulfill naming rules
- Try to import classes by names devised from file names

Naming conventions for files containing plugins:

- File name can not start with underscore (Python uses `__init__` files in directories and we need to omit them, also there has to be a possibility to add supplementary files without importing them)
- Class that should be imported has to have the same name as the file (this way we can avoid implementing unnecessary overhead by looking through the module and searching for class by some more rules)

Plugin will contain one main class that can define how to retrieve data that it needs and commands that can be used to filter packages by this attribute or relationship. Enforcing of good structure will be done by providing base classes which plugins need to extend.

3.4 Internal structure of data representation

For RPQR to be able to effectively walk through packages and filter them by attributes and relationships, there has to be an appropriate way to access them as quickly as possible. That is why by nature, graph is the best way. Using graph will allow RPQR project to use graph algorithms such as breadth first search or depth first search. Python itself does not have builtin graph support, so RPQR project can either contain its own implementation or use a library.

Networkx seems to be a very quick and easy to use implementation of graph abstract data type which is also capable of rendering a graph with multiple algorithms when needed. Another very useful feature is that networkx is able to save graph to JSON formatted string and load it again from this string.

Example of building graph with Networkx:

```
import networkx as netx
graph = netx.Graph()
graph.add_node(1)
graph.add_node(2)
graph.add_edge(1,2)
```

Configuration

Some options are uncomfortable to enter through commandline repeatedly and because of that should be stored in persistent file. Structure of configuration file can have many forms but Python has built-in module named configparser which defines human readable format appropriate for RPQR project. Configparser uses section to divide configuration into logically related blocks, there will be main section for global options like urls of repositories. Each plugin will have its own section where it will be possible to disable it or provide individual information necessary for its proper function.

Example of configparser configuration file:

```
[first_section]
option1 = 1
option3 = filepath
[second_section]
option2 = 2
```

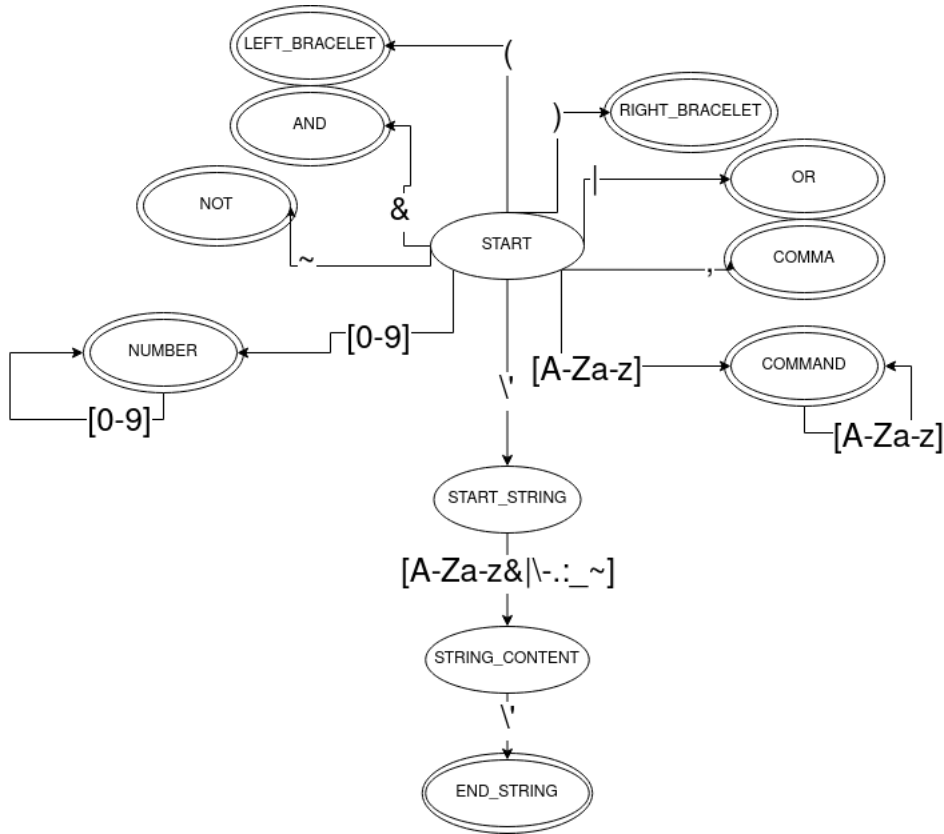
3.5 Query language design

RQPR language is by nature of its use oriented on filtering sets and thus will be constructed from statements and operations between them. This section will thoroughly describe the language and its formal description from the view of formal language theory.

Lexical analysis

RPQR will use finite state machine for scanning of tokens present in entered query and putting them in list that can be further processed. Each of the lexical tokens is defined by regular expression and when not recognized can be marked as invalid.

Finite state machine graph:



The lexical tokens that occur in RPQR language are:

- left bracelet (
- right bracelet)
- and operator &
- or operator |
- negation operator
- number (consisting only of numeric characters e.g 123)
- string (hyphen separated string of alphanumeric and special characters e.g 'hello')
- command (command contains only alpha characters and has to be described by a plugin e.g NAMELIKE)
- comma used mainly as a separator for command arguments ,

Syntactic analysis

RPQR language syntactic analysis will be mainly precedent syntactic analysis because the language is statement oriented. Precedent syntactic analysis uses algorithm with symbol stack and acts accordingly to precedent syntactic table. This table defines what operators can be used at particular places and their respective priorities. This solves the problem of evaluation of statement but there is still the matter of command recognition and validation of argument types. Every command has to define what arguments it needs to work properly. Initial configuration of RPQR will load commands and create context less grammar for them. Because every command has different name and there is no need for dynamic arguments, distinction should be straightforward and effective.

Another more problematic matter is that for RPQR language to be able to handle all necessary use cases, commands need to be able to accept results of other commands as arguments. This is problematic, since it requires new instance of precedent syntactic analysis to parse this statement. Fortunately this can be solved by cutting substatement out of original statement and putting it queue of statements that have to be yet parsed.

After all these problems are solved, RPQR will have abstract syntactic tree containing all the information that is necessary for execution of statement e.g. commands that need to be executed first and operators located in depth accordingly to their precedence. This tree will be later processed by semantic analysis e.g. interpreter.

Precedent syntactic table used for RPQR language:

	()	&		~	\$
(<	=	<	<	<	#
)	#	>	>	>	>	>
&	<	>	>	<	<	>
	<	>	<	>	<	>
~	<	>	>	>	<	>
\$	<	#	<	<	<	X

Explanation of symbols

Algorithm which handles syntactic analysis is driven by the precedent syntactic table. It always looks at the first terminal symbol at the top of the stack and performs operation that is specified in table by what symbol is in input.

- < means that special symbol marking start of particular statement needs to be put onto stack and new symbol loaded from input
- = means only load new symbol
- > means that particular sub statements should be collapsed into one parent statement
- # means that syntactic error occurred and provided input is not a valid RQPR language statement

Semantic analysis

Semantic analysis e.g. interpreter will be implementation of depth first search algorithm for processing of abstract syntactic tree provided by syntactic analysis. It is walking through the tree and putting found nodes in a stack until it finds command or statement that can be already resolved. When command that is defined by accessible plugin is encountered, then interpreter will filter loaded packages and either provide them as final result or use them as an operand to one of the operators.

When command is executed or statement can be evaluated accordingly to type of operator that it contains, part of abstract syntactic tree related to it is marked as resolved and temporary result is saved into the appropriate node. This means that the final result will be present as a root of the tree.

As in syntactic analysis, there is a problem with subsets used as an arguments. These subsets have to be executed in similar manner as they were processed into abstract syntactic tree. When encountered interpreter will stop command processing and proceed to resolving the substatement with higher priority.

3.6 RPQR language and its use

This section should provide usage examples of RPQR language and results that should be expected. RPQR statement always consists of at least one command.

Simple command

COMMAND()

This command will receive the entire graph of packages as input and will be responsible for providing set of packages that conform to its filter. Since this command does not accept any arguments, as there are no arguments supplied, the filter is static and can not be affected by user.

Command with arguments

ADVANCEDCOMMAND('package', 3)

Command used like this accepts two arguments which alter his behaviour. The first one is a string and the second is a number. RPQR language does not consider whitespace characters, so there is no difference or problem with their presence in query. Commands like this can have more advanced behaviour and are generally more useful.

Command accepting subset as an argument

SUBSETCOMMAND(NAMELIKE('cups'), 3)

This is the most complex command that RPQR language supports. This query will at first filter the entire graph with command *NAMELIKE('cups')* and then supply its result to the *SUBSETCOMMAND* command. The second command will have possibility to work with subset and thus does not have to work with the entire graph which results in ability to work more efficiently or perform operations with specific context. For better explanation how the query could work. The first command could gather packages which contain string *cups* in their name. The second could then filter only three first by their name in alphabetical order.

Operators

Intersection

FIRSTCOMMAND() & *SECONDCOMMAND()*

Operator & can be used as a intersection between sets provided as outputs of two commands or sets. Packages returned by query specified like this have to be present in both left and right set.

Join

FIRSTCOMMAND() | *SECONDCOMMAND()*

Operator | can be used to join sets provided by two commands or statements. It has lower priority than intersection and means that resulting sets will contain packages that are present in either left or right set of this statement.

Negation

~*FIRSTCOMMAND()*

Operator ~can be used to specify that result set of packages can contain only such packages that does not conform to conditions specified by *FIRSTCOMMAND*. It is important to keep in mind that input of the command is always the entire graph.

Complex queries and explanation of their semantics

When in need of complex conditions and combination of commands, it is very useful to use bracelets to force priority of evaluation and to avoid confusion between what user expects as a result and what is the real result.

Example of bracelet use:

FIRSTCOMMAND() & *SECONDCOMMAND()* | *THIRDCOMMAND()*

Explanation of this query is: return packages that conform to conditions of *FIRSTCOMMAND* and *SECONDCOMMAND* or packages that conform to *THIRDCOMMAND*. This is caused by priority of operators.

FIRSTCOMMAND() & (*SECONDCOMMAND()* | *THIRDCOMMAND()*)

This query looks very similar but there are bracelets that change its meaning very significantly. Packages in result set has to conform to *FIRSTCOMMAND* and to *SECONDCOMMAND* or *THIRDCOMMAND* in the same time. Bracelets allow us to form more complex descriptions of packages that we are looking for.

3.7 Plugin architecture and its interface

Since the whole project will be written in Python which is object oriented language, all plugins will be inheriting from class that will provide standard interface expected by RPQR project. There should be initialization method allowing plugin to prepare helper structures and then method responsible for inserting information into the plugins. Packages have attributes and relationships, so there will have to be two type of plugins, one inserting proper attributes to nodes and another one that will construct relationships between them. RPQR will work with attribute plugins as if they had a higher priority so relationship plugins will be able to work with already prepared attributes and there will be no unnecessary overhead.

Commands supplied by plugin will also conform to interface specified by their base class. Each will have to list types of arguments that they need and implement function that contains logic of their filtering operations. Since many commands will be working with similar graph algorithms such as depth first search or breadth first search, base class will provide optimized implementation that just needs specification of filter in a form of function.

3.8 Caching

As was stated in previous chapter, RPQR will need to use cache to save time consumed by building information about packages contained in configured repositories. After careful consideration, the approach with using JSON as a format of cache was chosen. This way, even third party tools will be able to manipulate with it and users will be able to read it if necessary. Cache will be invalidated only by users request to do so and when new plugin is found. Presence of plugins will be tested by special record in cache. Fortunately all this is supported by networkX library.

3.9 API design

RPQR needs to have Python application programming interface so external developers can use its plugins and features even more efficiently than through command line interface and create their own solutions. API will be using the same RPQR language as command line interface and queries will be returning networkx graphs. This way, applications using the API can walk through nodes that represent packages and perform any transformation of graph that they deem useful.

3.10 Command line interface design

RPQR tool will be using one main positional option that has to be provided and that is a query written in RPQR language. By default the output will go into standart output and log messages to standard error output.

First two options that can, but does not have to be specified will be whether user wants to see visualization of result created by his query and what attributes or relations should be included in the output. Filtering of attributes and relations is helpful because with multiple plugins, there can be a lot of unnecessary data in the output that take a lot of space. Another important option is location of configuration file if user does not want to use the default location which is */etc/rpqr.conf*. The last option is whether the tool should invalidate cache and build it again.

Chapter 4

Implementation and evaluation

With research and design complete, RPQR project can now be implemented in a best way possible. This chapter will cover deep description of projects code and algorithms it uses to fulfill the assigned task. Each section will cover limitations of presented solution and what could be done in the future to overcome them. Usage of RPQR project will also be described in a form of user manual and description of a way how new plugins are supposed to be developed using RPQR interface.

4.1 Important parts of implementation

This section will show the most important parts of implemenation and structure of Python code.

RPQRConfiguration

RPQRConfiguration class serves for purposes of loading plugins and creating RPQR language structures necessary for its successful parsing and interpreting. Instance of this class has to be created for every use of RPQR project and is used by all following components and their diverse operations.

Initialization of plugins

```
def _initializePlugins(self):
    """ Load plugins from supplied directories
    """
    for dir in self.pluginDirectories:
        sys.path.append(dir)
        pluginModules = os.listdir(dir)
        for file in pluginModules:
            moduleName = file[:-3]
            # if file name starts with _ then it is most likely not a plugin
            if moduleName.startswith("_"):
                continue
            cfg = None
            if moduleName in self.userConfiguration.keys():
                cfg = self.userConfiguration[moduleName]

            if (cfg != None and cfg.get("disabled") == "1"):
                self._logger.info(
                    "%s plugin was disabled in configuration" % moduleName)
                continue
            module = importlib.import_module(moduleName)
            pluginClass = getattr(module, moduleName)

            pluginInstance = pluginClass(rootLogger=self.rootLogger,
                                         config=cfg)
            self.plugins.append(pluginInstance)
```

This is the centerpiece of plugin loading. This method walks through all configured directories which according to configuration should contain plugin modules and if its file does not start with an underscore then attempts to import them and create their instance. There are two conditionals which relate to plugin configuration. The first one is checking whether a configuration related to this plugin exists and thus should be provided to it and the second one is there for a case when user does not want to use plugin at all, to save space for example or to speed up processing.

RPQRLoader

RPQRLoader is a class responsible for loading of data about packages through plugins and constructing graph structure out of them. It is taking advantage of DNF API to retrieve the data as efficiently as possible and access them in the same way as package manager would.

Construction of graph

```
def createDatabase(self, cache: str = None) -> networkx.MultiDiGraph:
    """ Get graph of packages with data and relations described by plugins

    :param cache: path to cache file, defaults to None
    :type cache: str, optional
    :return: Graph of packages
    :rtype: networkx.MultiDiGraph
    """
    graph = networkx.MultiDiGraph()
    dataPlugins = [plugin for plugin in self.plugins if isinstance(
        plugin, RPQRDataPlugin)]
    relationPlugins = [plugin for plugin in self.plugins if isinstance(
        plugin, RPQRRelationPlugin)]

    pluginRecords = []
    for plugin in dataPlugins + relationPlugins:
        pluginRecords.append((plugin, plugin.__class__.__name__))

    ...

    av_query = self._getAvailableQuery()
    q_avail = av_query.run()

    for id, pkg in enumerate(q_avail):
        graph.add_node(id)
        for pluginInstance in dataPlugins:
            pluginInstance: RPQRDataPlugin
            pluginInstance.fillData(id, pkg, graph)

    for id, pkg in enumerate(q_avail):
        for pluginInstance in relationPlugins:
            pluginInstance: RPQRRelationPlugin
            pluginInstance.fillData(id, pkg, graph, av_query)

    graph.graph["plugins"] = [name for (_, name) in pluginRecords]
    ...
    return graph
```

This method distinguishes between plugins that are supposed to add attributes to package nodes and plugins that create relations between individual packages. The first kind is executed first so relationship plugins can depend on them later. Each instance of plugin has its fillData method which is called for each package that was retrieved by DNF API. After the graph is build, list of plugins that were present during creating of this structure is saved into plugins list for easier detection of invalid cache.

RPQRScanner

RPQRScanner is a class responsible for scanning of query entered in RPQR language format. It is able to recognize when there is a lexical error in the query and is used to parse string into tokens.

Implementation of finite state machine

```
def getTokens(self, input: str) -> Optional[List[RPQRToken]]:
    ...
    while curInputIndex < len(input) + 1:
        if curInputIndex < len(input):
            c = input[curInputIndex]
        else:
            c = ''
        if curState == States.START:
            if c == '':
                break
            elif c == '(':
                curToken = RPQRToken(self.tokenTypes["leftBracelet"], c)
                curState = States.LEFTBRACELET
            elif c == ')':
                curToken = RPQRToken(self.tokenTypes["rightBracelet"], c)
                curState = States.RIGHTBRACELET
            elif c == '&':
                curToken = RPQRToken(self.tokenTypes["and"], c)
                curState = States.AND
            ...
            curInputIndex += 1
        elif curState == States.AND:
            tokens.append(curToken)
            curState = States.START
        elif curState == States.OR:
            tokens.append(curToken)
            curState = States.START
        elif curState == States.NUMBER:
            if c.isnumeric():
                curToken.appendToContent(c)
                curInputIndex += 1
            else:
                tokens.append(curToken)
                curState = States.START
```

Method getTokens is responsible for creating a list of tokens out of input. It is composed out of while cycle which parses characters and switches state of the machine accordingly. It is strictly implemented accordingly to graph of FSM which was mentioned earlier.

RPQRParser

RPQRParser is a class responsible for processing of lexical tokens and construction of abstract syntactic tree that can be interpreted in a strictly defined way. The class contains helper methods for easier manipulation with list of tokens and methods considered as call-backs to certain operations encountered in source query. These operations are uses of operators like \mathcal{E} or \sim which need the abstract syntactic tree to be constructed in a certain way.

parsing algorithm

```
while True:
    while True:
        if curInput.type in self.config.commandTypes.values():
            commandRule = None
            for rule in self.rules[4:]:
                if rule[0] == curInput.type:
                    commandRule = rule
            childList = [curInput]
            for indexMember, member in enumerate(commandRule[1:]):
                # if command requires substatement, then cut its tokens
                # and put it into queue
                if member == self.nonTerminalTypes["statement"]:
                    ...
                if argToken.type != member:
                    ...
                if argToken.type in [self.config.tokenTypes["number"], self.config.tokenTypes["end"]]:
                    childList.append(argToken)
            newStatement = RPQRStackSymbol(
                self.nonTerminalTypes["statement"], childList)
            self.stack.append(newStatement)
            curInput = tokens.pop(0)
            continue

        lastTerminalIndex = 0
        ...

        requiredAction = precedencTable[self.stack[lastTerminalIndex].type][curInput.type]
        ...

    # decide whether we need to keep parsing or everything is already done
    if len(substatementQueue) == 0:
        return rootStatement
    else:
        curStatement = substatementQueue.pop(0)
        self.stack = [RPQRStackSymbol(self.config.tokenTypes["end"])]
        tokens = curStatement.children
        curInput = tokens.pop(0)
```


Parsing algorithm is based on processing of statement queue that contains all individual statements that need to be parsed. The first cycle is going through queue of statements and the inner one is performing precedent syntactic analysis and calling appropriate call-backs. Interesting operation is that when substatement is encountered (command accepts statement as an argument) algorithm cuts this substatement out of the source and inserts it into the queue for further resolution. Because of trees structure, it is possible to resolve rest of the statement even when construction of substatement is not yet known.

Current parsing algorithm is not able to handle commands that take dynamic number of arguments. This is a known limitation but because this feature was not needed in any relevant testing scenario, RPQR will not in time of this thesis contain such option.

RPQRInterpreter

RPQRInterpreter is a class responsible for interpretation of RPQR language. It is mainly composed out of an algorithm which performs depth first search of abstract syntactic tree and resolves nodes from bottom to up direction.

Interpretation algorithm

```
while len(stack) > 0:
    curNode = stack[-1]
    curResult = resultStack[-1]
    if curNode.operator is not None:
        if len(curResult.childResults) < 1:
            ...
        elif curNode.operator != '~' and len(curResult.childResults) < 2:
            ...
        else:
            # now we have all operands, we can begin resolution
            validNodes = []
            ...
            stack.pop()
            resultStack.pop()
    else:
        ...
        notResolvedStatementFound = False
        for argIndex, argType in enumerate(commandClass.args):
            if argType == str or argType == int:
                # literals can be resolved right away
                if (argIndex > len(curResult.childResults)-1):
                    curResult.childResults.append(RPQRResultTree(
                        curNode.children[1:][argIndex].content, []))
                else:
                    continue
            elif argType == list:
                if (argIndex > len(curResult.childResults)-1):
                    ...
                    break
                else:
                    continue
        if notResolvedStatementFound:
            continue
        arguments = []
        for partResult in curResult.childResults:
            arguments.append(partResult.result)
        curResult.result = commandClass.execute(graph, arguments)
        stack.pop()
        resultStack.pop()
```

Algorithm distinguishes between nodes that represent statement composed out of operator and operands and commands that filter packages. Processing of such nodes differs, because operators are built in and have fixed number of arguments while commands are defined by plugins and every command can have different number of arguments. Algorithm walks through abstract syntactic tree and performs partial operations by calling `execute` method of plugins with already loaded arguments. When the root node is reached by resolution and its result is known, then the result can be returned by *performCommands* method and formatted by users requirements.

RPQR script

RPQR script is a command line utility which allows user to use RPQR project comfortably. It is designed to take advantage of the whole project and its features while providing user with the ability to controll for example when a cache file should be invalidated and overwritten.

RPQR script implemenation

```
rpqrcfg = RPQRConfiguration(pluginDirectories, namexrepository, cfgParser)
loader = RPQRLoader(rpqrcfg)

graph = loader.createDatabase(cacheFile, args.clearcache)
# we will not be performing empty query
if len(args.query) == 0:
    sys.exit(0)
result = RPQRQuery.performQuery(args.query, graph, rpqrcfg)

if result is None:
    sys.exit(1)

# we will filter result attributes according to supplied parameters
if len(args.filterattributes) != 0 or len(args.filterrelations) != 0:
    ...
    if len(args.filterattributes.split(";")[0]) != 0:
        for node in result.nodes:
            for key in list(result.nodes[node].keys()):
                if not key in args.filterattributes.split(";"):
                    del result.nodes[node][key]
    if len(args.filterrelations.split(";")[0]) != 0:
        for node in result.nodes:
            for u, v, edge_key in graph.out_edges([node], keys=True):
                if not edge_key in args.filterrelations.split(";"):
                    graph.remove_edge(u, v, key=edge_key)

# if result should not be visualized then just print it in JSON format to stdout
if not args.visualize:
    print(json.dumps(json_graph.node_link_data(
        result), indent=4, sort_keys=True))
    sys.exit(0)

# labeling requires some more processing
...
pos = networkx.spring_layout(result)
networkx.draw_networkx(result, pos=pos, with_labels=True, labels=labelDict)
edgeLabels = dict([(n1, n2), key) for n1, n2, key in result.edges])
networkx.draw_networkx_edge_labels(result, pos=pos, edge_labels=edgeLabels)
plt.show()
```

Implementation of RPQR script uses RPQR API and allows user to specify whether the result should be visualized or printed out through the standard output. Another very useful feature is filtering of attributes and relations that should be included in the output. Script is using matplotlib python library to render graph of packages if required.

4.2 User manual

This section contains manual of RPQR tool and detailed description of a way how it is intended to be used. Another part provides information about developing of plugins and scripts that are using RPQR API to retrieve and filter package metadata.

NAME

RPQR - RPM package query resolver

SYNOPSIS

RPQR [-h] [-cfgpath CFGPATH] [-filterattributes FILTERATTRIBUTES] [-filterrelations FILTERRELATIONS] [-visualize] [-clearcache] query

DESCRIPTION

RPQR utility is supposed to make querying RPM repositories about package metadata easy by providing user with means to filter them by such metadata and individual types of relations that occur between them. Utility is configurable through configuration file which is located by default in */etc/rpqr.conf*.

OPTIONS

- -h, -help
Show help message and exit
- -cfgpath CFGPATH
Path to configuration file
- -filterattributes FILTERATTRIBUTES
Specify list of attributes which interest you in the result. If left empty, then all attributes will be present in result
- -filterrelations FILTERRELATIONS
Specify list of relations which interest you in the result. If left empty, then all relations will be present in result
- -visualize
Visualize result

- `-clearcache`
Clear cache

CONFIGURATION FILE

Following configuration file should illustrate general principles of how the RPQR utility behaviour can be changed with it.

```
[RPQR]
pluginDirectories=["./rpqr/loader/plugins/implementations"]
cache=/var/tmp/rpqr.json

[RPQRRepo_f34-repo]
url=http://ftp.fi.muni.cz/pub/linux/fedora/linux/releases/34/Everything/x86_64/os/

[RPQRMaintainerPlugin]
url=https://src.fedoraproject.org/extras/pagure_owner_alias.json
```

First section named *RPQR* is main configuration section that contains the most important setting. *pluginDirectories* is array of directories which contain python modules with RPQR plugins. *cache* is path to cache file, when this path is not supplied then RPQR utility will not use cache.

Second section named *RPQRRepo_f34-repo* is meant to set up repository which user wants to query. There can be one to n number of repositories and they all have to be configured in their own section with prefix *RPQRRepo_* and member *url* which specifies base URL of the repository.

The third section is required for *RPQRMaintainerPlugin*. Each plugin can have its own section of configuration and member *disabled*, which when set to *1* will prevent this plugin from working. Plugin configuration is described by plugins individually and is mentioned here only for clarification of example.

RPQR language

RPQR language serves as a means to specify what packages user wants to see in result. Take advantage of operators to create appropriate combination of commands to get the results that you want.

Operators

- `&` - package has to conform to both right and left statements
- `|` - package has to conform to either left or right statements
- `~` - package must not conform to statement located on the right

Parenthesis

RPQR also supports parenthesis to provide further means to set priority of statements that are specified. Use parenthesis to make your query more readable and to make sure that the result is what you expect. *statement1 & (statement2 | statement3)* This statement is not equal to the version without parenthesis specified like this *statement1 & statement2 | statement3*. Semantic of the first statement is: **Find packages that conform to statement1 and in the same time conform to either statement2 or statement3**. On the other hand, the second statement meaning is: **Find packages that conform to both statement1 and statement2 but if package conforms to statement3 then it does not have to conform either to statement1 or statement2**

Official distributed plugins documentation

This section of the manual contains documentation about behaviour of plugins that are officially distributed with the RPQR tool and supported by the maintainers.

RPQRNamePlugin

RPQRNamePlugin is one of the most important plugins for RPQR utility. It gathers complete name of the package, meaning its name, version, release and architecture. It is an attribute plugin and inserts attribute *name* into the package.

- Added attribute: 'name'
- Added commands: 'NAME', 'NAMELIKE', 'SUBSETNAMELIKE'
- Depends on plugins: None

Commands provided by RPQRNamePlugin

NAME

Required arguments: name (string literal)

NAME command filters out only package that has the exact same name attribute as was specified with the name argument.

Example of use: *NAME('libyang-1.0.225-1.fc34.x86_64')*

NAMELIKE

Required arguments: name (string literal)

NAMELIKE command filters out packages that contain substring specified with the argument *name*.

Example of use: *NAMELIKE('libyang')*

SUBSETNAMELIKE

Required arguments: name (string literal), statement (RPQRLanguage statement)

SUBSETNAMELIKE command filters out packages returned by argument *statement* that contain substring specified with the argument *name*.

Example of use: *SUBSETNAMELIKE('x86_64', NAMELIKE('libyang'))*

Explanation of the example semantics: This query returns packages that contain *libyang* in their name and in the same time *x86_64* substring. Difference between this statement and *NAMELIKE('x86_64')* & *NAMELIKE('libyang')* is that the first query will be faster, because it has to go through only subset of packages.

RPQRDependencyPlugin

RPQRDependencyPlugin is relation plugin which gathers information about package dependencies and creates dependency relations between nodes that represent them in RPQR graph of packages.

- Added relation: 'depends'
- Added commands: 'ONWHATDEPENDS', 'WHATDEPENDSON'
- Depends on plugins: RPQRNamePlugin

Commands provided by RPQRDependencyPlugin

ONWHATDEPENDS

Required arguments: name (string literal), depth (numeric literal)

ONWHATDEPENDS command filters out packages on which package, with name attribute matching *name* argument, depends. *depth* argument is controlling the depth to which RPQR should go when gathering dependencies from the graph. Depth zero means that only the package specified by name will be present in output, value one causes that only direct dependencies will be present and so on.

Example of use: *ONWHATDEPENDS('libyang-1.0.225-1.fc34.x86_64', 1)*

WHATDEPENDSON

Required arguments: name (string literal), depth (numeric literal)

WHATDEPENDSON command filters out packages that depend on package, with name attribute matching *name* argument. *depth* argument is controlling the depth to which RPQR should go when gathering dependent packages from the graph. Depth zero means that only the package specified by name will be present in output, value one causes that only directly dependent packages will be present and so on.

Example of use: *WHATDEPENDSON('libyang-1.0.225-1.fc34.x86_64', 1)*

RPQRMaintainerPlugin

RPQRMaintainerPlugin is an attribute plugin which gathers information about maintainers which work on packages. It inserts attribute *maintainer* into packages. Plugin unfortunately depends on the format of list of maintainers which has to be in JSON.

- Added attribute: 'maintainer'
- Added commands: 'MAINTAINER', 'DEPENDSONUSER'
- Depends on plugins: RPQRDependencyPlugin

Commands provided by RPQRMaintainerPlugin

MAINTAINER

Required arguments: maintainers name (string literal)

MAINTAINER command filters out packages that have maintainer specified with argument maintainers name in list of their maintainers.

Example of use: *MAINTAINER('tkorbar')*

DEPENDSONUSER

Required arguments: maintainers name (string literal), depth (numeric literal)

DEPENDSONUSER command filters out packages that depend on work of maintainer specified with argument *maintainers name*. That means that depth zero will retrieve packages that have specified maintainer in list of its maintainers as *MAINTAINER* command would. Values higher than zero will retrieve packages that depend on those retrieved with depth zero.

Example of use: *DEPENDSONUSER('tkorbar', 1)*

RPQRMaintainerPlugin configuration

RPQRMaintainerPlugin has one additional variable for configuration not included in the default set for all plugins. It is variable `url` which specifies location of maintainer list.

Example:

```
[RPQRMaintainerPlugin]
url=https://src.fedoraproject.org/extras/pagure_owner_alias.json
```

LICENSE

You may copy, distribute and modify the software as long as you track changes/dates in source files. Any modifications to or software including (via compiler) GPL-licensed code must also be made available under the GPL along with build & install instructions.

4.3 API documentation and example of scripting

Chapter 5

Conclusion

Hello, here is some text without a meaning. This text should show what a printed text will look like at this place. If you read this text, you will get no information. Really? Is there no information? Is there a difference between this text and some nonsense like “Huardest gefburn”? Kjift – not at all! A blind text like this gives you information about the selected font, how the letters are written and an impression of the look. This text should contain all letters of the alphabet and it should be written in of the original language. There is no need for special content, but the length of words should match the language.

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