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## Description of the CUDF Format

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► **To cite this version:**

| Ralf Treinen, Stefano Zacchiroli. Description of the CUDF Format. 2008. hal-00340678

**HAL Id: hal-00340678**

**<https://hal.science/hal-00340678>**

Submitted on 21 Nov 2008

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Specific Targeted Research Project  
Contract no.214898  
Seventh Framework Programme: FP7-ICT-2007-1



Deliverable D5.1

## MANCOOSI

Managing the Complexity of the Open Source Infrastructure

# Description of the CUDF Format

November 21, 2008

<b>Project acronym</b>	MANCOOSI
<b>Project full title</b>	Managing the Complexity of the Open Source Infrastructure
<b>Project number</b>	214898
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<b>Workpackage number</b>	WP5
<b>Deliverable number</b>	1
<b>Document type</b>	Deliverable
<b>Version</b>	1
<b>Due date</b>	01/11/2008
<b>Actual submission date</b>	01/11/2008
<b>Distribution</b>	Public
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## Abstract

This document contains several related specifications, together they describe the document formats related to the solver competition which will be organized by Mancoosi.

In particular, this document describes:

**DUDF** (Distribution Upgradeability Description Format), the document format to be used to submit upgrade problem instances from user machines to a (distribution-specific) database of upgrade problems;

**CUDF** (Common Upgradeability Description Format), the document format used to encode upgrade problems, abstracting over distribution-specific details. Solvers taking part in the competition will be fed with input in CUDF format.

## Conformance

The key words “MUST”, “MUST NOT”, “REQUIRED”, “SHALL”, “SHALL NOT”, “SHOULD”, “SHOULD NOT”, “RECOMMENDED”, “MAY”, and “OPTIONAL” in this document are to be interpreted as described in RFC 2119 [Bra97].

# Contents

<b>1</b>	<b>Introduction</b>	<b>7</b>
1.1	Two different upgrade description formats . . . . .	7
1.2	Problem data flow and submission architecture . . . . .	9
1.3	Glossary . . . . .	10
<b>2</b>	<b><i>Distribution</i> Upgradeability Description Formats</b>	<b>13</b>
2.1	Upgrade problems . . . . .	13
2.2	Content . . . . .	14
2.3	Extensional vs intensional sections . . . . .	17
2.4	Serialization . . . . .	18
<b>3</b>	<b><i>Common</i> Upgradeability Description Format</b>	<b>21</b>
3.1	Overview of CUDF (non-normative) . . . . .	23
3.2	Content . . . . .	25
3.2.1	Generalities . . . . .	26
3.2.2	Types . . . . .	27
	CUDF type library . . . . .	28
3.2.3	Property schemata . . . . .	33
	Package description . . . . .	33
	Problem description . . . . .	35
3.2.4	Document structure . . . . .	36
	Global constraints . . . . .	36
3.3	Formal semantics . . . . .	37
3.3.1	Abstract syntax and semantic domains . . . . .	37
3.3.2	Installations . . . . .	38
3.3.3	Consistent package descriptions . . . . .	39
3.3.4	Semantics of requests . . . . .	40

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3.3.5	Comments on the semantics (non-normative) . . . . .	41
3.4	Integrating optimization criteria . . . . .	41
3.5	Serialization . . . . .	43
3.5.1	Overall CUDF file syntax . . . . .	43
3.5.2	Information item serialization . . . . .	44
3.5.3	CUDF file parsing . . . . .	44
3.6	Generating CUDF (non-normative) . . . . .	46
<b>4</b>	<b>Conclusion</b>	<b>47</b>
<b>A</b>	<b>DUDF skeleton serialization example</b>	<b>49</b>
<b>B</b>	<b>RELAX NG schema for DUDF</b>	<b>51</b>
<b>C</b>	<b>CUDF serialization example</b>	<b>53</b>

# List of Figures

1.1	Problem submission data flow . . . . .	9
2.1	DUDF detailed structure . . . . .	16
3.1	CUDF overall structure . . . . .	25
3.2	CUDF types and their relationships. . . . .	29
3.3	CUDF detailed structure . . . . .	36
A.1	XML serialization of DUDF . . . . .	50
B.1	RELAX NG schema for DUDF . . . . .	52



# Chapter 1

## Introduction

The aim of work package 5 (WP5) of the Mancoosi project is to organize a solver competition to attract the attention of researchers and practitioners to the upgrade problem as it is faced by users of F/OSS distributions [DC08]. The competition will be run by executing solvers submitted by the participants on upgrade problem descriptions (or “problems”, for short) stored in upgradeability problem data bases (UPDBs). A substantial part of the problems forming UPDBs, if not all of them, will be real problems harvested on user machines; users will be given tools to submit on a voluntary basis problems to help Mancoosi assemble UPDBs.

In such a scenario, problem descriptions need to be saved on filesystems (for long term storage) and transmitted over the network (to let them flow from user machines to UPDBs). This document gives the specifications of document formats used to represent problem instances in the various stages of their lives.

### 1.1 Two different upgrade description formats

Upgrade description formats serve at least two different purposes:

**Problem submission** problems will be created on distant user machines and need to flow to more centralized UPDBs. Both the user machine itself and the network connection may have only limited resources.

**Problem description** problems will be stored by Mancoosi to form a corpus of problems on which the solvers taking part in the competition will be run.

In the Mancoosi Description of Work we announced the definition of a so-called *Common Upgradeability Description Format*, abbreviated CUDF, that would serve these two purposes. It turned out that having one single format for both purposes is not practical since both purposes come with contradicting constraints: problem submissions should take as few resources as possible on a user’s machine, and they may contain references that are meaningful only in the context of a particular distribution. On the other hand, problem descriptions as used for the competition are not subject to strong resource limitations but must be self-contained and must have a formally defined semantics that is independent from any particular distribution.

As a consequence, we decided to define two different formats, one for each of the main purpose:

**DUDF (Distribution Upgradeability Description Format)** This is the format used to submit a single problem from user machines to a UPDB. DUDF is specialized for the purpose of problem submission.

DUDF instances (or “DUDFs” for short) need to be as compact as possible in order to avoid inhibiting submissions due to excessive bandwidth requirements. To this end, the DUDF specification exploits distribution-specific information, such as the knowledge of where distribution-wide metadata are stored and where metadata about old packages can be retrieved from mirrors that may or may not be specific to Mancoosi.

Since a DUDF is by its very nature distribution dependent there cannot be a a single complete DUDF specification. We rather present in Chapter 2 a generic specification of DUDF documents, the *DUDF skeleton*, which has to be instantiated to a full specification by all participating distributions. Documents to be published separately, one per distribution, will describe how the general scheme is instantiated by the various distributions.

All in all we have a *family of DUDF specification instances*: Debian-DUDF, RPM-DUDF, etc.; one for each possible way of filling the holes of the generic DUDF specification. How many instances should be part of the DUDF family? We recommend to have one instance for each distribution taking part in the competition. While different distributions may share a common packaging format, they may also allow for different means of compact representations, for example due to the different availability of mirrors with historical information. Furthermore, there are sometimes subtle semantic differences from distribution to distribution, hidden behind a shared syntax. To discriminate among different distributions, an appropriate distribution information item is provided. Of course, nothing prohibits different distributions to agree upon the same DUDF specification instance in case they find that this is feasible.

**CUDF (Common Upgradeability Description Format)** This is the *common* format used to abstract over distribution-specific details, so that solvers can be fed with upgradeability problems coming from any supported distribution. The CUDF format is specifically designed for the purpose of self-contained problem description.

The conversion from a given DUDF to CUDF expands the compact representations that have been performed for the purpose of submission, exploiting distribution-specific knowledge. At the end of such a conversion, a problem described in CUDF is self-contained, only relying on the defined semantics of an upgradeability problem, which includes the starting state, the user query, and probably non-functional quality criteria.

**Structure of this document** This document is structured as follows: Chapter 1 gives introductory information about the various kinds of documents involved in the organization of the competition and about the problem submission infrastructure. Chapter 2 contains the actual specification of the DUDF skeleton, while Chapter 3 contains the specification of both syntax and semantics of CUDF; both those chapters are normative and define what it takes for a document to be valid with respect to its specification. Appendixes to this document contain various non-normative information, which may be helpful to implementors of DUDF or CUDF. Documents to be made available separately will describe how each distribution is instantiating the DUDF skeleton.

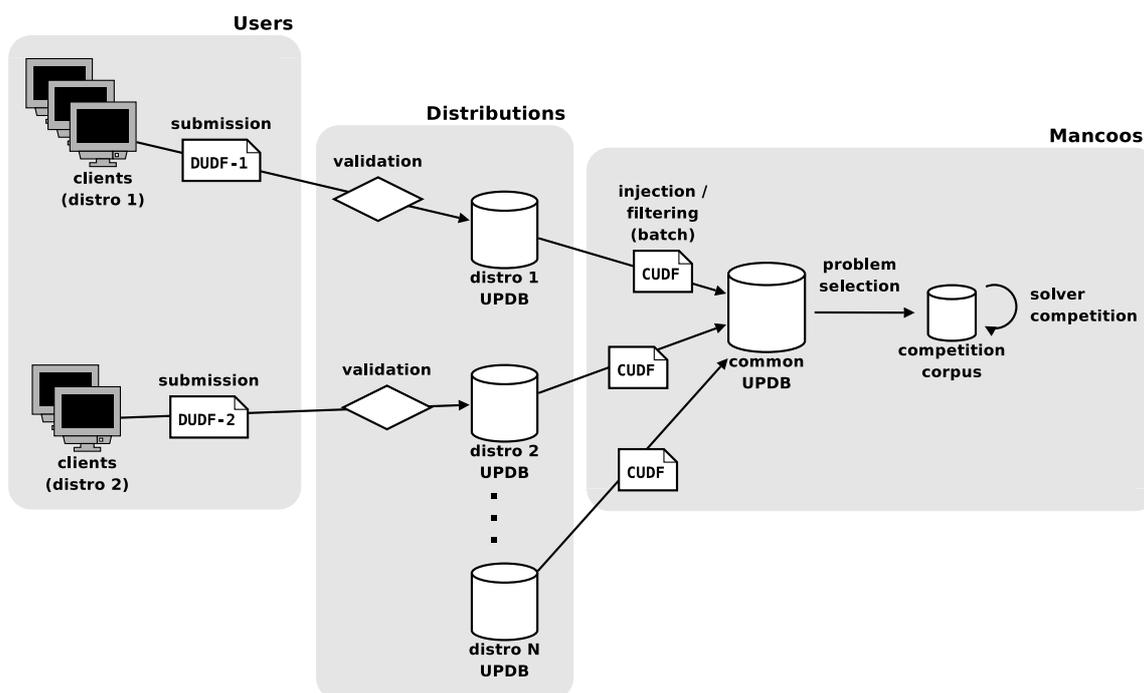


Figure 1.1: Data flow of UPDB submissions, from users to the corpus of problems for the competition

## 1.2 Problem data flow and submission architecture

Figure 1.1 gives an overview of the data flow of upgrade problems from user machines to the actual solver competition; several stages of transmission and filtering, as well as several different formats are involved.

Problems originate on user machines and are serialized in DUDF format (i.e. distribution-specific DUDF instances) using some client software. DUDF documents created that way will then be submitted to distribution-specific repositories using some other client software. All involved client software will be provided by distributions, such software will constitute implementations of the DUDF specification.

Distributions need to set up their own repositories to collect DUDF submissions coming from their users. Submissions that do not match the minimal quality requirements of DUDF will be rejected during a validation phase; this mainly boils down to rejecting problems that are not reproducible, see Chapter 2 for more details. All submissions that survive the validation phase are stored by the distribution editor in a distribution-specific UPDB.

Periodically, problems collected by distributions will be injected into a common (i.e. distribution-independent) UPDB, hosted on an infrastructure provided by Mancoosi as a project resource. The injection happens in CUDF format since distribution-specific details are not useful for the purpose of running the competition. Distributions are in charge of performing the conversion from DUDF to CUDF as they are the authoritative entities for the semantics of their proper DUDF instance and for resolving distribution-specific references. When exactly the conversion is performed is not relevant as long as CUDFs are ready to be injected when the periodic injections take place.

Among all the problems collected in the common UPDB, a subset of “interesting” problems will then be selected to form a corpus of problems on which the competition will be run. The act of selecting problems will not change the document format: the resulting corpus will still be a set of CUDF documents, chosen as a subset of the common UPDB.

## 1.3 Glossary

This section contains a glossary of essential terms which are used throughout this specification.

**Distribution** A collection of software packages that are designed to be installed on a common software platform. Distributions may come in different flavors, and the set of available software packages generally varies over time. Examples of distributions are Mandriva, Caixa Mágica, Pixart, Fedora or Debian, which all provide software packages for the the GNU/Linux platform (and probably others). The term *distribution* is used to denote both a collection of software packages, such as the *lenny* distribution of Debian, and the entity that produces and publishes such a collection, such as Mandriva, Caixa Mágica or Pixart. The latter are sometimes also referred to as *distribution editors*.

Still, the notion of distribution is not necessarily bound to FOSS package distributions, other platforms (e.g. Eclipse plugins, LaTeX packages, Perl packages, etc.) have similar distributions, similar problems, and can have their upgrade problems encoded in CUDF.

**Installer** The software tool actually responsible for physically installing (or de-installing) a package on a machine. This task particularly consists in unpacking files that come as an archive bundle, installing them on the user machine in persistent memory, probably executing configuration programs specific to that package, and updating the global system information on the user machine. Downloading packages and resolving dependencies between packages are in general beyond the scope of the installer. For instance, the installer of the Debian distribution is `dpkg`, while the installer used in the RPM family of distributions is `rpm`.

**Meta-installer** The software tool responsible for organizing a user request to modify the collection of installed packages. This particularly involves determining the secondary actions that are necessary to satisfy a user request to install or de-install packages. To this end, a package system allows to declare relations between packages such as dependencies or conflicts. The meta-installer is also responsible for downloading necessary packages. Examples of meta-installers are `apt-get`, `aptitude` and `URPMi`.

**Package** A bundle of software artifacts that may be installed on a machine as an atomic unit, i.e. packages define the granularity at which software can be added to or removed from machines. A package typically contains an archive of files to be installed on a machine, programs to be executed at various stages of the installation or de-installation of a package, and metadata.

**Package status** A set of metadata maintained by the installer about packages currently installed on a machine. The package status is used by the installer as a model of the software installed on a machine and kept up to date upon package installation and removal. The kind of metadata stored for each package varies from distribution to distribution, but typically comprises package identifiers (usually name and version), human-oriented information such as a description of what the package contains and a formal declaration of

the inter-package relationships of a package. Inter-package relationships can usually state package requirements (which packages are needed for a given one to work properly) and conflicts (which packages cannot coexist with a given one).

**Package universe** The collection of packages known to the meta-installer in addition to those already known to the installer, which are stored in the package status. Packages belonging to the package universe are not necessarily available on the local machine—while those belonging to the package status usually are—but are accessible in some way, for example via download from remote package repositories.

**Upgrade request** A request to alter the package status issued by a user (typically the system administrator) using a meta-installer. The expressiveness of the request language varies with the meta-installer, but typically enables requiring the installation of packages which were not previously installed, the removal of currently installed packages, and the upgrade to newer version of packages currently installed.

**Upgrade problem** The situation in which a user submits an upgrade request, or any abstract representation of such a situation. The representation includes all the information needed to recreate the situation elsewhere, at the very minimum they are: package status, package universe and upgrade request. Note that, in spite of its name, an upgrade problem is not necessarily related to a request to “upgrade” one or more packages to newer versions, but may also be a request to install or remove packages. Both DUDF and CUDF documents are meant to encode upgrade problems for different purposes.



## Chapter 2

# *Distribution* Upgradeability Description Formats

This chapter contains the specification of the Distribution Upgradeability Description Formats (DUDFs). Their purpose is to encode upgrade problems as faced by users, so that they can be submitted as candidate problems for the solver competition organized by the Mancoosi project.

Additionally, DUDF can also be used as a format to store information about the execution of a meta-installer on a user machine. A possible use case for this is to trace information for the purpose of composing problem reports against meta-installers. This is an added benefit for distribution editors which is, however, beyond the scope of the Mancoosi project itself.

Technically, the DUDF specification is not complete, in the sense that some parts of DUDF documents are under-specified and called “holes”. How to fill in those holes is a distribution-specific decision to be taken by each distribution implementing DUDF. The overall structure of DUDF documents is defined by the current document and is called the *DUDF skeleton*.

### 2.1 Upgrade problems

Upgrade problems manifest themselves at each attempt to change the package status of a given machine using a meta-installer. One of the aims of WP5 for the solver competition is to collect *upgrade problem descriptions* which faithfully describe the upgrade problems faced by users when invoking a meta-installer on their machine. Informally, “faithfully” means that the descriptions should contain all information needed to reproduce the problem reported by the user, and possibly to find better solutions if they exist.

As discussed in Chapter 1, problem descriptions will be encoded as DUDFs and submitted to distribution-specific repositories. Two kinds of submissions are supported by DUDF:

- (a) Sole problem descriptions.
- (b) Pairs  $\langle \textit{problem description}, \textit{problem outcome} \rangle$  where the outcome is a representation of the actual result of the originating meta-installer which has been used to generate the problem.

Pairs problem/outcome are the kind of submissions to be used for the competition. Their validity as submissions can be checked by attempting to reproduce them upon receipt (see

below), and the outcome of competing solvers can be compared not only among each other, but also with respect to the originating meta-installers in order to check whether they are doing better or worse than the contenders.

Sole problem descriptions cannot be checked for reproducibility. As such they are not interesting for the competition since they can not be “trusted”. Still they can be useful for purposes other than the competition. In particular they can be used—as well as pairs problem/outcome—by users to submit bug reports related to installers, meta-installers, and also incoherences in package repositories [EDO06]. This intended use is the main reason for supporting them in this specification.

## 2.2 Content

A DUDF document consists of a set of *information items*. Each item describes a part of the upgrade problem faced by the user. In this section we list the information items (or *sections*) that constitute the different kinds of DUDF submissions.

The actual format and content of each information item can either be fully described by this specification, or be specific to some of its instances (and hence not described here). In the latter case, we distinguish among parts which are specific to the *installer* and parts which are specific to the *meta-installer*. Installer-specific parts have content and format determined by the installer (e.g. rpm, dpkg, etc.) in use; similarly, parts specific to the meta-installer are determined by the meta-installer (e.g. apt-get, URPMi, etc.) in use.

Unless otherwise stated, all information items are required parts of DUDF documents.

The submission of a *sole upgrade problem description* consists of the following information items:

**Package status** (i.e. *installer status*) the status of packages currently installed on the user machine.

This item is installer-specific, but can also contain data specific to the meta-installer in case the meta-installers save some extended information about local packages. A concrete example of such extended information is the manual/automatic flag on package installation used by `aptitude` on Debian to implement “garbage collection” of removed packages.

**Package universe** the set of all packages which are known to the meta-installer, and are hence available for installation. This item is specific to the meta-installer.

The package universe is composed of one or more *package lists*; a number of well-known formats do exist to encode package lists. The package universe can generally be composed of several package lists, each encoded in a different format. Each package list must be annotated with a unique identifier describing which format has been used to encode the package list. A separate document will be published to list the set of well-known package list formats, as well as their unique identifiers.

**Requested action** the modification to the local package status requested by the user (e.g. “install X”, “upgrade Y”, “remove Z”). This item is specific to the meta-installer.

**Desiderata** user preferences to discriminate among possible alternative solutions (e.g. “minimize download side”, or “do not install experimental packages”). The exact list of possible user preferences depends on the distribution, and on the capabilities of the meta-installer (for instance, for Debian’s `apt` these may be defined in the file `/etc/apt/preferences`).

This information item is optional.

**Tool identifiers** two pairs  $\langle name, version \rangle$  uniquely identifying the installer and meta-installer which are in use, in the context of a given distribution. One pair identifies the *installer* used, the other the *meta-installer* used.

**Distribution identifier** a string uniquely identifying the distribution run by the user (e.g. *debian*, *mandriva*, *pixart*, ...), among all the implementations of DUDF.

As far as GNU/Linux distributions are concerned, a hint about what to use as a distribution identifier comes from the file `/etc/issue`. Its content should be used as distribution identifier where possible.

**Timestamp** a timestamp (containing the same information encoded by dates in RFC822 [Cro82] format, i.e. the same as used in emails) to record when the upgrade problem has been generated.

**Problem identifier** (i.e. *uid*) a string used to identify this problem submission *univocally*, among other submissions sent to the same distribution.

The intended usage of this information item is to let CUDF documents cross-reference the DUDF documents which were used to generate them.

In addition to what is stated above, the submission of a pair problem/outcome also contains the following information items:

**Outcome** either the new local package status as seen by the used meta-installers (in case of *success*) or an error message (in case of *failure*, i.e. the meta-installer was not able to fulfill the user request). The error message format is specific of the used meta-installer, it can range from a free-text error message to a structured error description (e.g. to point out that the requested action cannot be satisfied since a given package is not available in the package universe).

It is worth noting that Mancoosi is not interested in all kinds of errors, and that not all errors reported to the end user mean a failure that is interesting for the competition. Mancoosi is interested only in errors stemming from the resolution of package relations, which is the case when the meta-installer is not able to solve the various constraints expressed in the summary information *about* the packages. Mancoosi Workpackage 5 is not interested in runtime errors such as installation failures due to disks running out of space or execution errors of maintainer scripts. These errors, however, may still be relevant for submitting problem reports to a distribution vendor using the DUDF format.

Note that tool identifiers are part of the problem description since the requested action depends on the tools the user is using. Since available actions, as well as their semantics, can change from version to version, tool versions are also part of the problem description.

The distribution identifier is needed to avoid bloating the number of specified DUDFs too much. We observe that similar distributions (e.g. Debian and Ubuntu) can submit upgrade problems using the very same submission format (say Debian-DUDF). However, even though extensional data (see Section 2.3) are independent of which of the similar distributions were used, intensional data are not. Indeed, there is no guarantee that package *p* at version *v* is the same on Debian and Ubuntu; similarly there is no guarantee that an intensional package universe reference originated on Debian is resolvable using Ubuntu historical mirrors and vice-versa. Using the

- dudf:
  - version: 1.0
  - timestamp: *timestamp*
  - uid: *unique problem identifier*
  - distribution: *distribution identifier*
  - installer:
    - name: *installer name*
    - version: *installer version*
  - meta-installer:
    - name: *meta-installer name*
    - version: *meta-installer version*
  - problem:
    - package-status:
      - installer: *installer package status*
      - meta-installer: *meta-installer package status*
    - package-universe:
      - package-list<sub>1</sub> (format: *format identifier*; filename: *path*): *package list*
      - ...
      - package-list<sub>*n*</sub> (format: *format identifier*; filename: *path*): *package list*
    - action: *requested meta-installer action*
    - desiderata: *meta-installer desiderata*
  - outcome (result: *one of "success", "failure"*):
    - error: *error description* (only if result is "failure")
    - package-status: (only if result is "success")
      - installer: *new installer package status*
      - meta-installer: *new meta-installer package status*

Figure 2.1: The DUDF skeleton: information items and holes corresponding to problem/outcome submissions.

distribution identifier we can reuse the same DUDF instance for a set of similar distributions since the distribution identifier allows us to resolve the ambiguity.

A required property for each submission of problem/outcome pairs is *reproducibility*: an unreproducible submission is useless and a waste of user bandwidth. When submissions of problem/outcome pairs are received they have to be validated for reproducibility. This can be achieved by keeping (possibly stripped down) copies of commonly used tools on the server side and by running them on the received problem description to check that the outcome matches the reported one. Given that we are not taking into account runtime upgrade errors, an error should manifest itself on the server side if and only if it has manifested itself on the user machine.

Together, the information items supported for submissions of problem/outcome pairs denote an outline called *DUDF skeleton*. In the skeleton, the following information items are *holes*: package status, package universe, requested action, desiderata and outcome. Fully determined DUDF instances are made of this specification, together with distribution-specific documents

describing how those holes are filled. A sketch of the DUDF skeleton is reported in Figure 2.1.

Installer- or meta-installer-specific holes are denoted by framed text. Additional information (annotations or *attributes*) of information items are reported in parentheses. The names used for information items are for presentational purposes, yet actually normative (see Section 2.4).

Note that in the skeleton, the package universe is sketched in its full generality: it is made of several package lists, each of which is annotated with its package list format. It is possible, though not granted, that to each package list corresponds a single file on the filesystem; in that case it is possible to annotate package lists with a *filename* containing the absolute paths corresponding to them.

## 2.3 Extensional vs intensional sections

We have to minimize space consumption (in terms of bytes) in order not to discourage submissions by wasting the user's resources. In general, all the information items required for submissions are locally available on the user machine; in principle they are all to be sent as part of a submission. However, while some of the information items are *only* available on the user machine (e.g. current local package status and requested action) some other items can be grouped into parts stored elsewhere (e.g. package lists forming the current package universe) which have possibly been replicated on the user machine in a local cache.

We distinguish two alternative ways of sending submission information items (or sections): a section can either be sent intentionally or extensionally. An *extensional section* is a self-contained encoding of some information available on the user machine, for example a dump of the current local package database, or a dump of the current package universe.

An *intentional section* is a non self-contained encoding of some information available on the user machine, consisting of a *reference* pointing to some external resource. De-referencing the pointer, i.e. substituting the contents of the external resource for it, leads to the corresponding extensional section. For instance, several distributions have package repositories available on the Internet which are regularly updated. The current package universe for a given user machine may correspond to package indexes downloaded from one or several such repositories. A set of checksums of such indexes is an example of an intensional package universe section. Provided that a historical mirror of the distribution repositories is available somewhere, a corresponding extensional package universe can be built by looking up and then expanding the checksums in the historical mirror.

The use of intensional sections instead of extensional ones is the most straightforward space optimization we recommend to implement in collecting problem submissions. Here are some use cases for similar optimization:

- Most likely intentionality has to be used for the current package universe, though it will require setting up historical mirrors (the package metadata is sufficient for that, it will not be necessary to mirror the packages themselves).
- Even though the local package status appears to be a section that should forcibly be sent extensionally (as the information are not stored elsewhere), some partial intension can be designed for it.

For example, assuming that the pair  $\langle pkg\_name, pkg\_version \rangle$  is a key univocally deter-

mining a given package (*version uniqueness assumption*<sup>1</sup>), one can imagine sending as the local package status a set of entries  $\langle\langle pkg\_name, pkg\_version \rangle, pkg\_status \rangle$ , letting the server expand further package metadata (e.g. dependency information) on reception of the submission. In those rare cases where the version uniqueness assumption is not verified, the check for reproducibility is sufficient to spot non-reproducible submissions and discard them.

- The upgrade problem outcome has to be sent extensionally as to check for its reproducibility upon reception. Of course, the same optimizations as proposed in the previous point are applicable to outcomes in case of success.

Any section of a submission can be sent intentionally or extensionally, independently from the other sections; different choices can be applied to different submissions. In fact, the choices of how to submit the various sections are driven by the need of fulfilling the reproducibility requirement. For instance, if a given package universe is composed like the union of several remote package repositories, we will need to know all the involved packages, potentially coming from any repository in order to reproduce a submission. While a suitable intention might be available for some repositories, this may not be the case for some others (e.g. we might be lacking the needed historical mirror). In such a situation the proper solution is to send some repository reference intentionally, and the whole package listing of others extensionally.

It is up to the DUDF submission tool to know which parts of the package universe can be sent intentionally and which cannot.

## 2.4 Serialization

In this section we describe how to serialize any given instance of DUDF to a stream of bytes so that it can be serialized on disk (e.g. to create a local archive of problem descriptions to be submitted as a single batch) or over the network (for the actual submission to a distribution-specific problem repository).

The serialization of DUDF is achieved by describing a mapping from the DUDF skeleton to an XML [BPSM<sup>+</sup>06] tree. The actual serialization to bytes can then be done following the usual XML serialization rules.

To obtain the XML tree of a DUDF problem/outcome submission, one only needs to start from the corresponding outline (see Figure 2.1) and do the following:

1. Create a root element node called `dudf`, put it in the (default) namespace identified by `http://www.mancoosi.org/2008/cudf/dudf`.
2. Add an attribute `dudf:version`<sup>2</sup> to the root node, the value of which value is the value of the subsection `version` of the `dudf` section in the DUDF outline.
3. Starting from the DUDF outline root (and excluding the already processed `version` section), traverse the outline tree, adding child elements the general identifier of which is the section name used in the DUDF outline and the content of which is the result of recursively processing its content in the DUDF outline.

---

<sup>1</sup>This is assumption is not necessarily well-founded: users can rebuild packages locally, obtaining different dependency information, while retaining  $\langle pkg\_name, pkg\_version \rangle$

<sup>2</sup>The namespace prefix `dudf:` is bound to `http://www.mancoosi.org/2008/cudf/dudf`

4. For annotated outline elements (e.g. package lists composing the package universe, which are annotated with format identifiers), map annotations to XML attributes of the relevant XML elements (note that the attributes should be explicitly prefixed with `dudf:`, as in XML attributes do *not* inherit the default namespace).

The same procedure is applied to obtain the XML tree of a DUDF sole problem submission, except that the outcome section (which should be missing anyhow in the starting DUDF outline) has to be skipped.

A non-normative example of serialization from the DUDF skeleton of Figure 2.1 to XML can be found in Appendix A, Figure A.1.



## Chapter 3

# *Common Upgradeability* Description Format

This chapter contains the specification of the Common Upgradeability Description Format (CUDF). The purpose of such a format is to encode real upgrade problems, abstracting over details specific to a user distribution or a package manager, so that problems coming from different environments can be compared and treated uniformly. For the specific purposes of Mancoosi, upgrade problems encoded in CUDF format will be used to form a corpus of problems to be used in a solver competition.

The specification of CUDF is guided by the following general design principles:

**Be agnostic towards distribution details** The main purpose of CUDF, as reflected by its name, is to be a *common* format to be used to encode upgrade problems coming from heterogeneous environments. The main environments we are considering are FOSS distributions, but other software deployment platforms face similar upgrade needs. As a consequence, the key design principle of CUDF is to be agnostic with respect to distribution specific details such as the used package system, the used installer and meta-installer, etc. The final goal is to be able to compare problems coming from different platforms in a uniform settings upgrade, including at the very minimum all platforms for which a DUDF implementation (see Chapter 2) has been provided.

**Stay close to the original problem** There are several encodings that can be considered after removing all distribution-specific details [MBC<sup>+</sup>06]. Since CUDF aims to be as close as possible to the original problem we choose to avoid an encoding where the characteristic features of the original problem are abstracted away and are no longer distinguishable. There are various reasons backing this choice:

- Preserve the ability for humans to inspect problems encoded in CUDF.  
Ideally, users having submitted a problem (via submission of a DUDF document) should be able to look at their CUDF encoding and recognize the upgrade situation.
- Avoid bias towards specific upgrade planning techniques and implementations.  
Specific encodings (e.g. using a representation in propositional logic, or geared to constraint programming) bear the risk of giving an advantage or disadvantage to certain

resolution techniques. Since one of our goals is to provide a set of problems to stimulate the advancement in upgrade planning, CUDF strives to stay independent of specific techniques and implementation details.

- Make life easy to legacy tools (installers and meta-installers) to interact with CUDF.

Ideally, we want legacy tools to be able to take part in the solver competition we are organizing. That would be easy to achieve as long as the CUDF encoding still resembles something with which installers and meta-installers are familiar. Conversely, using an encoding that is too abstract would constitute an obstacle for the state-of-the-art tools.

**Extensibility** CUDF has no explicit support (yet) for specifying optimization criteria to the end of choosing the “best” possible solution among all possible solutions of a given upgrade problem. The reason is that until the end of the competition, criteria will not need to be specified as part of the submitted problems. It would be enough to have criteria fixed externally (e.g. the competition can have several “tracks”, each of which evaluates solution quality according to a single optimization criterion), *as long as* all the information needed to evaluate the quality of a solution are encoded in CUDF.

This leads to the need of having an *extensible* format to encode upgrade problems and in particular package metadata. Indeed, since we cannot anticipate all possible interesting optimization criteria we can neither anticipate all the metadata that shall be stored in CUDF documents. Hence the CUDF specification establishes a type system to be used for typing package metadata (see Section 3.2.2) and a set of core set of package metadata (see Section 3.2.3). Additional metadata can be added in the future by providing their schemata, in terms of the available types.

For example, to run a competition track in which the installed size of all packages on the system should be minimized, the track organizers can state that, in addition to the core package metadata, each package must be equipped with an `Installed-Size` property, the type of which is `posint`. The track rules will then describe how to determine the best solution, on top of the semantics of positive integers.

**Transactional semantics** Problems are encoded in CUDF according to the *point of view of the meta-installer*, rather than to the point of view of an installer. This means that our notion of solution correctness (see Section 3.3) considers the resulting package status and not *how* that status is obtained on the target machine. In particular, the order of package installations and removals or even the various phases of package deployment and installation (downloading, unpacking, etc.) are beyond the scope of the CUDF encoding.

In a sense, CUDF assumes that it is possible to pass from the package status as described in a CUDF document to any (correct) status found by a meta-installer in a *transactional* way. As an example of a practical implication of this design principle, CUDF does not distinguish between Debian’s `Depends` and `Pre-Depends`; note that this is coherent with the semantic encoding of [MBC<sup>+</sup>06], from which the CUDF semantics takes its inspiration.

**Use plain text format** On a more technical side, CUDF aims to be a *simple to parse* (read) and *simple to generate* (write) format. The reason is as simple as our interest in providing a tool to reason about future better upgrade planners, ignoring distracting details such as parsing or pretty printing. Plain text is the universal encoding for information interchange formats in

the Free Software community [Ray03], using a plain text format makes it easy for contenders to adapt tools to our format. Moreover, it is an implicit need if we want users to be able to “look” at CUDF problems and understand them, without the need of specific tools. Similarly, this principle also implies that standard serialization formats should be preferred for CUDF. In fact, the CUDF specification describes the informative content of a CUDF document and its semantics on one hand, and how to serialize that content to disk (using already existing standards and technologies) on the other hand.

### 3.1 Overview of CUDF (non-normative)

This section gives an overview of the syntax and semantics of CUDF. A precise definition of the CUDF format will be given in Section 3.2, while a mathematical definition of its semantics will be given in Section 3.3. The current section is not normative, please refer to Sections 3.2 and 3.3 for precise definitions.

A CUDF document consists of a list of package description items, and a user request. It is recommended that the user request be listed at the end of the CUDF document. In the concrete representation (see Section 3.5) each item is a stanza consisting of one or several lines of text. It is recommended that successive stanzas be separated by empty lines even though this is not mandatory.

Every line in a stanza starts with the word denoting the first property of that stanza, followed by the ":" separator and then the value of the property, the only exception to this rule is the line “Problem:” which starts the stanza describing the query, and which does not necessarily have a meaningful value. Other properties of the same stanza come next, following the same serialization conventions.

A package description stanza starts with the property **Package** the value of which is the name of the package. Package names are strings of length at least two, starting on a lowercase ASCII letter, and containing only lower or uppercase ASCII letters (case is significant), numerals, dashes “-” and dots “.”. The order of all other properties in a package description stanza is not specified.

The only other mandatory property, besides **Package**, in a package description stanza is **Version**, the value of which is a positive (non-null) integer value. There may be at most one package description stanza for any given pair of package name and version.

Then there are a number of properties that are relevant for the formal semantics but that are only optional:

- The **Installed** property (the values of which are of type `bool`, with default value `false`) indicates whether a package is installed or not. It is a priori allowed to have several versions of the same package installed. The setting of this field in the stanzas of a CUDF document describe the “initial” configuration of a machine, i.e., the configuration in which the user request is evaluated.
- The **Keep** property has as possible values `version`, `package`, `feature` (being optional, it can also be omitted, in that case its value is `None`, a value shared by all omitted optional properties). This value is only relevant in case the **Installed** property is `true`. Package installations may evolve by changing the **Installed** property associated to pairs of package name and package version. The **Keep** property defines constraints on possible evolutions of the installation:

**version** means that this particular version of a package must not be removed,  
**package** means that at least one version of that package must remained installed,  
**feature** means that all features (see below) provided by this version of the package must continue to be provided,  
**None** puts no constraint on possible evolutions of the installation.

Then there are three properties which define relations between packages:

- The **Provides** property is a possibly empty list of names of so-called features, also called *virtual packages*. In this list, features may be declared either by giving an exact version, or without mentioning a version. Features are frequently used in RPM-like packaging system to declare the fact that a package installs a particular file on disk, and also both in RPM and Debian-like packaging systems to declare that a package provides a certain abstract functionality, like for instance *mail-transport-agent* or *postscript-reader*. A list of several features is interpreted as that package realizing all the features in the list, with the version as given in the list, or of *all possible versions* when no particular version is mentioned in the list.

The default value of that property is the empty list (that is, no feature is provided).

- The **Depends** property has a complex dependency on the existence of packages or on features for value. Simple dependencies are given as the name of the package or feature, and may carry in addition a constraint on the version number. Version constraints can be of any of the form  $= v$ ,  $!= v$ ,  $> v$ ,  $< v$ ,  $\leq v$  or  $\geq v$  where  $v$  is a version number. Complex dependencies are obtained by combining dependencies with conjunctions (denoted by  $" , "$ ) and disjunctions (denoted  $" | "$ ). However, dependencies are limited to so-called conjunctive normal forms, that is conjunctions of disjunctions.

The default value of this property is the formula **True** (that is no particular dependency constraint).

- The **Conflicts** property has a list of packages (or features), possibly equipped with package-specific version constraints for value; version constraints are the same as for the **Depends** property. Such a conflict list describes a list of packages that *must not* be installed. For instance, if package  $p$  of version 5 conflicts with package  $q \geq 7$  then we are not allowed to install version 5 of  $p$  together with any of the versions 7 or greater of  $q$ . However, it would be allowed to install version 5 of  $p$  together with version 6 of  $q$ .

There is a special treatment for so-called *self-conflicts*: any conflicts stemming from a pair of package  $p$  and version  $v$  are ignored when checking the conflicts of this pair  $(p, v)$ . For instance, when package  $p$  of version 5 indicates that it conflicts with package  $p$  (without version constraint) this means that version 5 of package  $p$  cannot be installed together with any other version of  $p$ . A conflict of package  $p$  in version 5 with package  $p$  in version 5 is allowed as a special case but does not have any effect.

Self-conflicts of this kind are often used by packaging systems in order to express that only one (version of a) package implementing a certain feature may be installed at any given time. For instance, both the package *sendmail* and the package *postfix* (of any version) may provide the feature *mail-transport-agent* and also conflict with *mail-transport-agent*. The effect of this is that it is not possible to install *sendmail* and *postfix* together (or any of them together with any other package providing *mail-transport-agent*), but it does

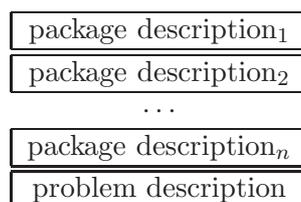


Figure 3.1: Overall structure of a CUDF document; information items are represented according to the canonical CUDF ordering.

allow to install *sendmail* or *postfix* since the conflict stemming from the package itself is ignored.

The default value of this property is the empty list (that is, no conflict declared here).

Finally, the CUDF document contains a stanza representing the user request. This stanza starts with the line **Problem:**, and it may contain an **Install** property, a **Remove** property, and a **Upgrade** property. Each of these properties is optional, their value is a list of packages (or features) possibly equipped with version constraints; the default value of these three properties is the empty list. The **Install** property gives packages that are demanded to be installed, while the **Remove** gives packages that must be removed. The **Upgrade** property has a similar meaning as **Install**, the difference being that the former requires that for every package in that list only one version be installed, and that this version be greater or equal to any version of that package previously installed.

## 3.2 Content

A CUDF document (or simply “CUDF”) is composed of a set of *information items*. Each item represents a part of the original upgrade problem.

Each information item belongs exactly to one of the following two classes:

**Package description items** specify packages that have a role in the upgrade problem described by a given CUDF.

A CUDF document contains several package description information items. In a typical scenario there is one such item for each package known to the package manager, including both locally installed packages (as part of the local status) and packages available from remote repositories known to the meta-installer (as part of the package universe).

**Problem description items** describe other information items that contribute to create the upgrade problem, but which are not specific to any particular package. A CUDF document must contain exactly one problem description item.

Intuitively, the item contains global information about the upgrade problem. At the very minimum, that information contains the request submitted by the user to the package manager.

CUDF documents consist of a single problem description item and several package description

items.<sup>1</sup> While there is no strict imposition on the relative order of information items in actual CUDFs, this specification assumes the *canonical ordering* of having first all package descriptions and then the single problem description, for uniformity of presentation. A schematic representation of a typical CUDF and its canonical ordering is given in Figure 3.1. A similar, yet more detailed, pictorial representation of CUDFs is given later on in Figure 3.3.

CUDF implementations should implement the canonical ordering whenever possible.

### 3.2.1 Generalities

Each information item consists of a set of *properties*. Each property has a name and a value (i.e. each property consists of a name-value pair).

A *property name* is a string of Unicode [Con06] characters matching the additional constraint of being an identifier. An *identifier* is a non-empty string composed only of characters belonging to the following character classes:

**Lowercase Latin letters** from “a” (Unicode code point U+0061) to “z” (U+007A), in the ordering induced by Unicode code points.

**Uppercase Latin letters** from “A” (U+0041) to “Z” (U+005A).

**Arabic numeral digits** from “0” (U+0030) to “9” (U+0039).

**Separators** the character “-” (U+002D)

Additionally, identifiers must start with one of the lowercase or uppercase Latin letters defined above.

A *property value* is a typed value, belonging to some set. We call this set the *set of values* or the *type domain* of the type associated to a property. The type is fixed for each property: any given property can only assume values having the very same type and coming from the very same set of values; the description of each supported property in this specification states what is the type of its values.

A property can be either optional or required. A property is optional if its value is indicated as optional in the property description, otherwise it is required. Required properties must always be present as part of the information items they belongs to, while optional properties may not be present. Optional properties that are present in CUDFs must assume a value belonging to its type domain. Optional properties can have a default value; it must be a value belonging to its type domain.

Optional properties that are not present in CUDFs and have a default value  $v$  are treated as properties assuming value  $v$ . It is indistinguishable whether the value was actually specified in the CUDF serialization or not. Optional properties that are not present in CUDFs and do not have an optional value are treated as properties assuming the distinguished value **None**. The value **None** does not belong to any set of values which can be written in CUDF serializations; this feature allows us to distinguish whether an optional property has been specified in actual CUDFs or not.

---

<sup>1</sup>There is no constraint on the number of package description items, but problems represented as CUDFs with no package description items are uninteresting. CUDFs are expected to include at least one package description item, and usually many more than just one.

Each property supported by CUDF can be fully specified using a *property schema*. Such a schema consists of:

- the name of the property;
- the type of property values;
- the information item the property belongs to;
- the optionality of the property (i.e. whether the described property is required in each instances of the information item it belongs to), optionality is either “required” or “optional”;
- for optional properties only, an optional default value. It is possible to give a default value for an optional property, but is not mandatory to do so.

Actual CUDF documents must contain all required properties for each information item. For both required and optional properties, the type of property values must match the type prescribed by property schemata.

Section 3.2.3 gives the schemata of the *core property set* supported by CUDF. Nevertheless the set of properties which can be given to build information items is open-ended (open-world assumption), and not restricted to the core set. Information items can contain extra properties *not* prescribed by this specification as long as their names do not clash with names of properties in the core set. It is up to implementations to make use of such extra properties, to define their names and the type of their values. Of course all extra properties are optional as far as conformance to this specification is concerned.

### 3.2.2 Types

As discussed above, each property value has a type which is fixed for any given property. A *type* is a set of values, which is also called *value space* or *domain* of a given type. Let  $t$  be a type, we denote with  $\mathcal{V}(t)$  its value space. Moreover, a *lexical space*  $\mathcal{L}(t)$  is associated to each type, and it denotes the set of possible representations of all values belonging to the value space as strings of Unicode characters. The relationships between the value spaces and lexical spaces are as follows:

- For each  $l \in \mathcal{L}(t)$  there is a unique corresponding value  $parse_t(l) \in \mathcal{V}(t)$ . The function  $parse_t(\cdot)$  is the *parsing* (partial) function used to parse syntactic values into semantic values.
- For each  $v \in \mathcal{V}(t)$  there can be several  $l \in \mathcal{L}(t)$  such that  $v = parse_t(l)$ , i.e. the parsing function is not necessarily one-to-one.

**Subtyping** Interesting relationships also exist between types, in particular *subtyping*. A type  $t_2$  is said to be a subtype of a *supertype*  $t_1$  (written  $t_2 <: t_1$ ) if  $\mathcal{V}(t_2) \subseteq \mathcal{V}(t_1)$ , that is, when the domain of the subtype is contained in the domain of its supertype. Given  $t_2 <: t_1$ , the lexical space of  $t_2$  can be obtained by restricting the lexical space of  $t_1$  to all elements which can be parsed to elements of the value space of  $t_2$ , i.e.  $\mathcal{L}(t_2) = \{l \in \mathcal{L}(t_1) \mid parse_{t_1}(l) \in \mathcal{V}(t_2)\}$ . Therefore the parsing function for a given subtype can be obtained by simply reusing the parsing

function of the supertype treating as parsing errors all values not belonging to the domain of the subtype.

As a consequence of the above definitions and properties, each type can be defined by describing its value and lexical spaces, as well as the semantics of its parsing functions. Subtypes can be defined by simply giving restrictions on the value space of supertypes. The section further gives the definitions for all types used by CUDF.

**Conventions** In this specification abstract values belonging to the value space are denoted using mathematical notation.

Lexical values are denoted by double-quoted strings typeset in `monospace font` and encoded in UTF-8. The double-quotes are used for presentational purposes of this specification and are not part of the actual lexical value. Such a value can be found by considering the Unicode string corresponding to the given UTF-8 string, after having removed double quotes. For example, the lexical value "foo" denotes the Unicode string of length 3, composed of the three lowercase letters "f" (Unicode code point U+0066), "o" (U+006F), and "o" again.

Functions can either be described intentionally or extensionally. In the former case, types are specified via natural language explanation of their semantics, or reference to functions described elsewhere. In the latter case they are defined by enumerating argument/result pairs using the following notation:  $\{input_1 \rightarrow output_1, \dots, input_n \rightarrow output_n\}$ .

For the sake of brevity, several details about lexical values and parsing functions are deferred to external specifications, most notably to "XML Schema Part 2: Datatypes" [BM04], which specify a set of simple datatypes, providing for each of them notions similar to the one introduced above: value space, lexical space and parsing functions. When deferring a definition to the definition of the corresponding XML Schema datatype, we will write  $xs : foo^{XML\ Schema}$ , where "xs:foo" is the XML Schema datatype name.

Complex lexical spaces are sometimes described by the means of EBNF grammars [EBN96] which use SMALLCAPS for non terminal symbols and double-quoted string as described above for terminals. Grammars are always given with the productions of their start symbol first. In order to avoid duplications, grammars appearing later on in this specification can reuse symbols defined in previous grammars. When EBNF grammars are used, the definition of parsing functions can be omitted and delegated to parsers built using the given grammar. For the completeness of this specification it is enough to state how the values associated to non terminals have to be translated to elements in the value space (i.e. to give the "semantic actions" associated to grammar productions).

## CUDF type library

In the presentation of the available CUDF types that follows, we first introduce all *primitive types*, i.e. all those types that are not obtained via subtyping; then we describe *derived types*, i.e. those that are obtained as subtypes of other (primitive or derived) types. As discussed above, each derived type can be described by simply giving a restriction of the value space of its supertype.

Figure 3.2 shows a diagram giving an overview of CUDF types and their relationships. In the figure, directed straight arrows denote subtyping relationships, with the type pointed at being the supertype; directed dashed arrows denote acquaintance, i.e. the fact that the values of one type contain values of other types, the latter being pointed at by the arrow. Transitive

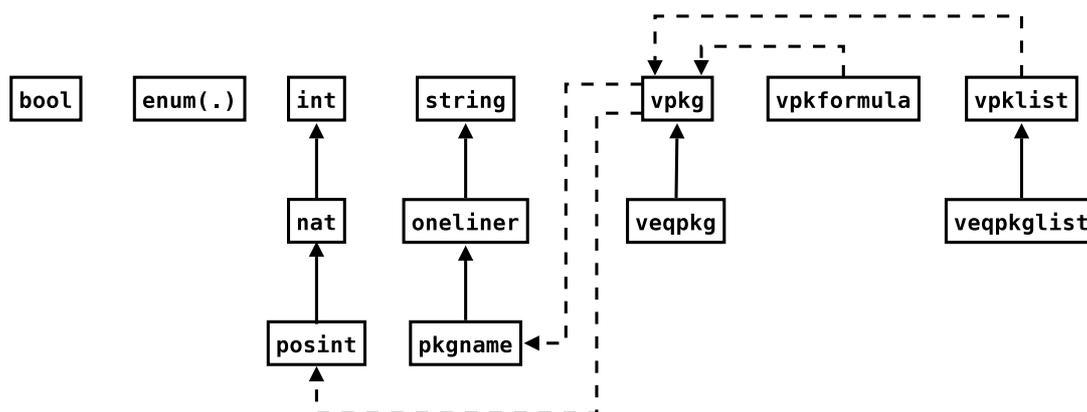


Figure 3.2: CUDF types and their relationships.

relationships are omitted from the figure.

NAME	<code>bool</code>
DESCRIPTION	Boolean values
VALUE SPACE	The set of distinguished values <code>{true, false}</code>
LEXICAL SPACE	The set of strings <code>{"true", "false", }</code>
PARSING	<code>{"true" → true, "false" → false}</code>

NAME	<code>int</code>
DESCRIPTION	Integer numbers
VALUE SPACE	The set of integer numbers $\mathbb{Z} = \{\dots, -2, -1, 0, 1, 2, \dots\}$ (Note that this set is infinite, unlike legacy integers available in most programming languages.)
LEXICAL SPACE	The same lexical representation as the one used by the <code>xs:integer<sup>XML Schema</sup></code> , i.e. finite-length sequences of decimal digits (U+0030–U+0039) with an optional leading sign (defaulting to "+"). For example: <code>"-1"</code> , <code>"0"</code> , <code>"12678967543233"</code> , <code>"+100000"</code> .
PARSING	The same parsing function as the one used for <code>xs:integer<sup>XML Schema</sup></code>

NAME	<code>string</code>
DESCRIPTION	Unicode strings
VALUE SPACE	The set of—possibly empty—strings of arbitrary Unicode characters.
LEXICAL SPACE	Some (specified) character encoding supported by Unicode. For the purpose of CUDF serialization the character encoding of choice is UTF-8 (see Section 3.5).
PARSING	The same parsing functions as the ones used for <code>xs:string<sup>XML Schema</sup></code> , i.e. simply decoding from the used character encoding to Unicode character strings.

We assume the notion of the function *length* for Unicode strings, which is defined by counting the number of Unicode characters (not bytes) forming a Unicode string in a given encoding. As a consequence, the empty string `""` has length 0.

---

NAME	<code>vpkg</code>
DESCRIPTION	Versioned package names
VALUE SPACE	The set of pairs $\langle vpred, p \rangle$ where $p$ is a value of type <code>pkgname</code> (see below) and $vpred$ is either $\top$ (denoting that no version constraint has been imposed on package name $p$ ) or a pair $\langle relop, v \rangle$ (denoting that a specific version constraint is in effect on package name $p$ ). In the latter case $relop$ is one of $\{=, \neq, \geq, >, \leq, <\}$ and $v$ is a value of type <code>posint</code> (see below).
LEXICAL SPACE	The set of strings matching the grammar: <div style="text-align: center; margin: 10px 0;"> <math display="block">\begin{aligned} \text{VPKG} &amp;::= \text{PKGNAME SP} + \text{VCONSTR?} \\ \text{VCONSTR} &amp;::= \text{SP} * \text{RELOP SP} + \text{VER SP*} \\ \text{RELOP} &amp;::= "="   "!="   "&gt;="   "&gt;"   "&lt;="   "&lt;" \\ \text{SP} &amp;::= " " \quad (\text{i.e. U+0020}) \\ \text{VER} &amp;::= \text{POSINT} \end{aligned}</math> </div>
PARSING	Induced by the grammar. RELOP is parsed by the function: $\{ "=" \rightarrow =, "!=" \rightarrow \neq, ">=" \rightarrow \geq, ">" \rightarrow >, "<=" \rightarrow \leq, "<" \rightarrow < \}$ .

---

The semantics of versioned package names depend on the context where they appear. Generally, package names without version constraints are to be intended as package predicates matching all packages with a given name. Package names with a version constraint will additionally satisfy the given version requirement.

---

NAME	<code>vpkgformula</code>
DESCRIPTION	Formulae over versioned package names
VALUE SPACE	The smallest set $F$ such that: <div style="text-align: center; margin: 10px 0;"> <math display="block">\begin{aligned} \text{true} &amp;\in F &amp;&amp; (\text{truth}) \\ \mathcal{V}(\text{vpkg}) &amp;\subseteq F &amp;&amp; (\text{atoms}) \\ \bigvee_{i=1, \dots, n} a_i \in F &amp; \quad a_1, \dots, a_n \text{ atoms} \in F &amp;&amp; (\text{disjunctions}) \\ \bigwedge_{i=1, \dots, n} d_i \in F &amp; \quad d_1, \dots, d_n \text{ disjunctions} \in F &amp;&amp; (\text{conjunctions}) \end{aligned}</math> </div>
LEXICAL SPACE	The set of strings matching the following grammar: <div style="text-align: center; margin: 10px 0;"> <math display="block">\begin{aligned} \text{FLA} &amp;::= \text{ANDFLA} \\ \text{ANDFLA} &amp;::= \text{ORFLA} (\text{SP} * " " \text{SP} * \text{ORFLA})^* \\ \text{ORFLA} &amp;::= \text{ATOMFLA} (\text{SP} * "   " \text{SP} * \text{ATOMFLA}) \\ \text{ATOMFLA} &amp;::= \text{VPKG} \end{aligned}</math> </div>
PARSING	Induced by the grammar. ATOMFLA nonterminals are parsed as atoms, ORFLA as disjunctions of the atoms returned by their ATOMFLAS, ANDFLA as conjunctions of the disjunctions returned by their ORFLAS.

---

Note that formulae over versioned package names are always in conjunctive normal form (CNF), i.e. they always have the shape of “conjunctions of disjunctions of atomic formulae”.

NAME	<code>vpkglist</code>
DESCRIPTION	Lists of versioned package names
VALUE SPACE	The smallest set $L$ such that: $\begin{aligned} \square &\in L && \text{(empty lists)} \\ p::l \in L \quad p \in \mathcal{V}(\text{vpkg}), l \in L && \text{(package concatenations)} \end{aligned}$
LEXICAL SPACE	The set of strings matching the grammar: $\text{VPKGS} ::= \text{"} \mid \text{VPKG (SP * " , " SP * VPKG)*}$
PARSING	Induced by the grammar. " is parsed as $\square$ , while an instance of <code>VPKG</code> followed by a list of versioned package names is parsed as package concatenation.
NAME	<code>enum(<math>s_1, \dots, s_n</math>)</code>
DESCRIPTION	Enumerations
VALUE SPACE	Rather than a single type, <code>enum</code> is a type scheme defining infinite possible actual types. All those types are indexed by the set of symbols $\{s_1, \dots, s_n\}$ , for any such set a single type (an <i>enumeration</i> ) is defined. Each enumeration is a type, its values can be one of the symbols $s_1, \dots, s_n$ . Symbols must match the constraints of identifiers. For convenience, in this specification symbols are written as strings, but without the external double quotes, and prefixed by a single quote <code>'</code> .
LEXICAL SPACE	$\{s \in \mathcal{L}(\text{string}) \mid s \text{ is an identifier}\}$
PARSING	$\{ "s" \rightarrow 's \mid s \text{ is an identifier}\}$ The parsing function is defined point-wise on each Unicode string matching the constraints of identifiers. For each of them, the parsing function returns a symbol, the name of which is that very same identifier.

For example, given the enumeration  $E = \text{enum}(\text{'foo'}, \text{'bar'}, \text{'baz'})$ , we have the following:  $\text{'foo} \in \mathcal{V}(E)$ ,  $\text{'bar} \in \mathcal{V}(E)$ , and  $\text{'baz} \in \mathcal{V}(E)$ . Note that `None` is not part of any enumeration, but optional properties having enumeration types can assume the `None` value as usual.

NAME	<code>oneliner</code>
DESCRIPTION	One-liner Unicode strings
VALUE SPACE	<code>oneliner</code> is a subtype of <code>string</code> . The set of, possibly empty, strings of Unicode characters not containing any of the following “newline” characters: line feed (U+000A), carriage return (U+000D). Note that, in spite of $\text{xs} : \text{string}^{\text{XML Schema}}$ not being a type available for use in CUDF, CUDF <code>oneliner</code> is conceptually a subtype also of $\text{xs} : \text{string}^{\text{XML Schema}}$ obtained by removing newline characters from its value space.
LEXICAL SPACE	As per subtyping.
PARSING	As per subtyping.

---

NAME	<b>pkgname</b>
DESCRIPTION	Package names
VALUE SPACE	<b>pkgname</b> is a subtype of <b>oneliner</b> . It is obtained allowing only strings that satisfy the following condition in the value space: <ul style="list-style-type: none"> <li>• the string starts with a lowercase Latin letter</li> <li>• the string only consists of: lowercase Latin letters, Arabic numeral digits, dashes (U+002D), dots (U+002E)</li> <li>• the string has length 2 or greater</li> </ul>
LEXICAL SPACE	As per subtyping.
PARSING	As per subtyping.

---



---

NAME	<b>nat</b>
DESCRIPTION	Natural numbers
VALUE SPACE	<b>nat</b> is a subtype of <b>int</b> . It is obtained by allowing only non-negative integers in the value space.
LEXICAL SPACE	As per subtyping.
PARSING	As per subtyping.

---



---

NAME	<b>posint</b>
DESCRIPTION	Positive natural numbers
VALUE SPACE	<b>posint</b> is a subtype of <b>nat</b> . It is obtained by removing the number 0 from the value space of <b>nat</b> .
LEXICAL SPACE	As per subtyping.
PARSING	As per subtyping.

---



---

NAME	<b>vepkg</b>
DESCRIPTION	Version-specific package names
VALUE SPACE	<b>vepkg</b> is a subtype of <b>vpkg</b> . It is obtained by removing all packages with version constraints other than =, more formally: $\mathcal{V}(\mathbf{vepkg}) = \{\langle vpred, p \rangle \mid \langle vpred, p \rangle \in \mathcal{V}(\mathbf{vpkg}), vpred = \top \vee vpred = \langle =, v \rangle \text{ for some } v\}$ from the value space of <b>vpkg</b> .
LEXICAL SPACE	As per subtyping.
PARSING	As per subtyping.

---

---

NAME	<code>veqpkglist</code>
DESCRIPTION	Lists of version-specific package names
VALUE SPACE	<code>veqpkglist</code> is a subtype of <code>vpkglist</code> . It is obtained by using as value space only the smallest set $L' \subseteq \mathcal{V}(\text{vpkglist})$ such that:
	$\begin{aligned} [] &\in L' && \text{(empty lists)} \\ p::l \in L' & \quad p \in \mathcal{V}(\text{veqpkg}), l \in L' && \text{(package concatenations)} \end{aligned}$
LEXICAL SPACE	As per subtyping.
PARSING	As per subtyping.

---

### 3.2.3 Property schemata

Each of the information items supported by CUDF (either package or problem description items, see Section 3.2) is composed of several properties. In this section we give the schemata for all properties that can be part of package description items and problem description items.

#### Package description

A package description item describes several facets of a package.

---

NAME	Package
TYPE	<code>pkgname</code>
OPTIONALITY	required
DESCRIPTION	Name of the package being described.

---



---

NAME	Version
TYPE	<code>posint</code>
OPTIONALITY	required
DESCRIPTION	Version of the package being described.

---



---

NAME	Depends
TYPE	<code>vpkgformula</code>
OPTIONALITY	optional
DEFAULT	<code>true</code>
DESCRIPTION	Intentional representation of the dependencies of the package being described.

---

Dependencies indicate which packages need to be installed to make a given package installable. Dependencies are indicated as boolean CNF formulae over possibly versioned package names. Dependencies are the most expressive relationships which can be stated among packages using CUDF properties.

---

NAME	<b>Conflicts</b>
TYPE	<b>vpkglist</b>
OPTIONALITY	optional
DEFAULT	[]
DESCRIPTION	Intentional representation of packages which conflict with the package being described.

---

Conflicts indicate which packages cannot be co-installed, in any given installation, together with a given package. Note that the language to express conflicts is more limited than that used to express dependencies: it consists of plain lists of possibly versioned package names, rather than CNF formulae.

Also note that as far as CUDF is concerned there are no implicit conflicts assumed between different versions of the same package, if they are intended they need to be explicitly specified using the **Conflicts** property. According to the CUDF semantics this can be achieved by declaring, for a package  $p$ , a conflict with  $p$  itself; see Section 3.3 for more information.

---

NAME	<b>Provides</b>
TYPE	<b>vepkglist</b>
OPTIONALITY	optional
DEFAULT	[]
DESCRIPTION	Features provided by the package being described.

---

A package can declare zero or more *features* that it provides. To abstract over package names, other packages may declare relationships with such features. Packages can provide a specific version of a given feature, or provide a feature without mentioning a version (meaning that *all* possible versions of a given feature are provided by that package).

---

NAME	<b>Installed</b>
TYPE	<b>bool</b>
OPTIONALITY	optional
DEFAULT	<b>false</b>
DESCRIPTION	Flag stating whether or not the package being described is installed.

---

Two kinds of packages play a role in the upgrade process: currently installed packages constituting the local package status and (locally or remotely) available packages which are known to the meta-installer and constitute the package universe. **Installed** distinguishes among these two cases, it is **true** for packages which are part of the local status and **false** for those which are part of the package universe. Other kinds of packages that do not play a role in the package upgrade problem are not represented in CUDF.

---

NAME	Keep
TYPE	enum('version','package','feature')
OPTIONALITY	optional
DESCRIPTION	Indication of which aspects of the package being described the user wants to preserve across upgrades. <ul style="list-style-type: none"> <li>• 'version' means preserving the current version, as recorded in the package status.</li> <li>• 'package' means preserving at least one version of the package in the resulting package status.</li> <li>• 'feature' means preserving all the provided features.</li> </ul>

---

Note that it is not specified *how* the requirements of the **Keep** feature have to be fulfilled; in the particular case of 'feature' it is possible that the requirement gets fulfilled by replacing a package by some other packages, which, together, provide the same features. See Section 3.3 for the formal specification of the meaning of the **Keep** property.

### Problem description

---

NAME	Install
TYPE	vpkglist
OPTIONALITY	optional
DEFAULT	[]
DESCRIPTION	List of packages the user wants to be installed.

---



---

NAME	Remove
TYPE	vpkglist
OPTIONALITY	optional
DEFAULT	[]
DESCRIPTION	List of packages the user wants to be removed.

---



---

NAME	Upgrade
TYPE	vpkglist
OPTIONALITY	optional
DEFAULT	[]
DESCRIPTION	List of packages the user wants to be upgraded to newer versions.

---

The properties **Install**, **Remove** and **Upgrade** provide the same mechanism for specifying the target packages: lists of package names with optional version specifications. A properly completed **Install** action ensures that the requested packages are installed in the resulting package status, on the contrary **Remove** ensures that they are not. Since CUDF supports multiple installed versions of the same package in principle there is no implicit need of removing other packages due to homonym upon **Install**. **Upgrade** is similar to **Install**, but additionally ensures that only one version of each of the target packages is preserved in the resulting packages status; it also ensures that newer versions of them get installed. See Section 3.3 for a formal specification of the semantics of actions.

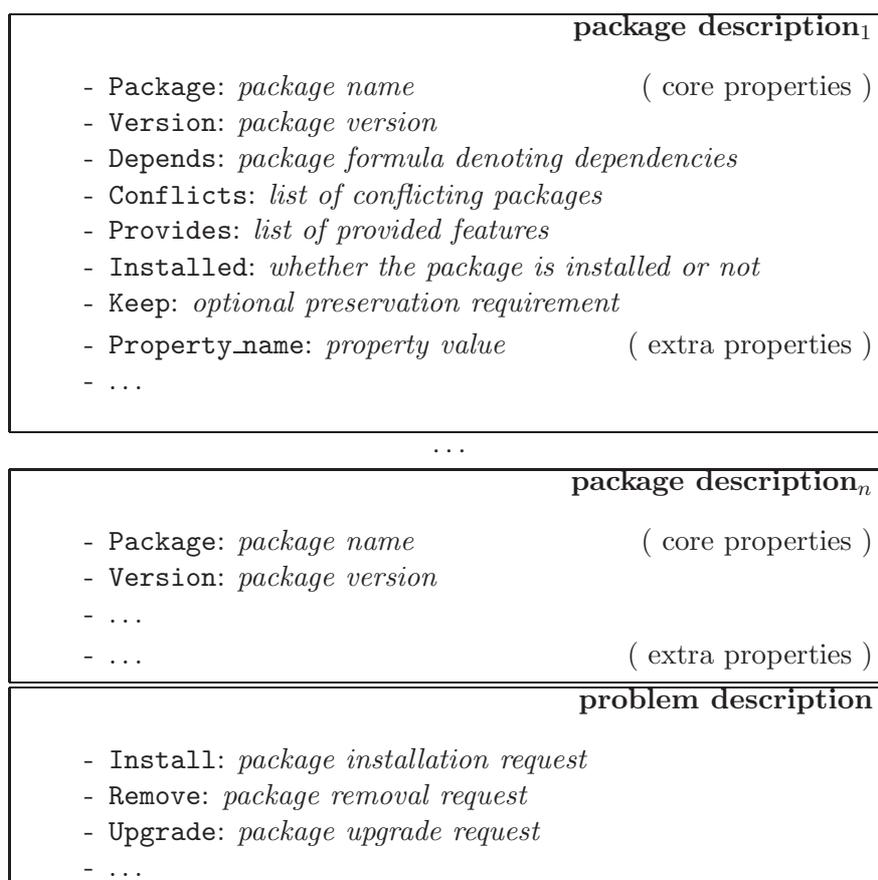


Figure 3.3: Detailed structure of a CUDF document with highlight of core properties.

### 3.2.4 Document structure

Putting it all together, the detailed structure of CUDF document is as depicted in Figure 3.3; the figure has to be interpreted as a refined version of Figure 3.1, which we are now able to fill with the properties described in the previous section. Note that all core properties are shown in the figure, in spite of their optionality.

#### Global constraints

In addition to the per-property constraints reported in the previous section, CUDF documents must respect extra constraints which are not specific to sole information items or properties.

**Package/version uniqueness** among all package description items forming a given CUDF, there must not exist two package descriptions  $p_1$  and  $p_2$  such that they have the same value of the property **name** and the same value of the property **version**, i.e. the pair of property values  $\langle \text{name}, \text{version} \rangle$  can be used as a “key” to look up package descriptions in a given CUDF.

There is no strict imposition neither in specifying at least one of the **Install/Remove/Upgrade** properties, nor in specifying non empty-lists as their values. Nevertheless, CUDFs representing problems with empty queries are mostly uninteresting.

### 3.3 Formal semantics

The semantics is defined in a style similar to [MBC<sup>+</sup>06], however, we now have to deal with an abstract semantics that is closer to “real” problem descriptions, and that contains artifacts like *features*. This induces some complications for the definition of the semantics. In [MBC<sup>+</sup>06] this and similar problems were avoided by a pre-processing step that expands many of the notions that we wish to keep in the CUDF format.

#### 3.3.1 Abstract syntax and semantic domains

The abstract syntax and the semantics is defined using the value domains defined in Section 3.2.2. In addition, we give the following definitions:

- Definition 1** • *CONSTRAINTS* is the set of version constraints, consisting of the value  $\top$  and all pairs  $(relop, v)$  where  $relop$  is one of  $=, \neq, <, >, \leq, \geq$  and  $v \in \mathcal{V}(posint)$ .
- *KEEPVALUES* is the set of the possible values of the *Keep* property of package information items, that is:  $\{ 'version, 'package, 'feature, None \}$

The abstract syntax of a CUDF document is a pair consisting of a package description (as defined in Definition 2) and a request (see Definition 4).

**Definition 2 (Package description)** A package description is a partial function

$$\mathcal{V}(pkgname) \times \mathcal{V}(posint) \rightsquigarrow \mathcal{V}(bool) \times \text{KEEPVALUES} \times \mathcal{V}(vpkgformula) \times \mathcal{V}(vpkglist) \times \mathcal{V}(vepkglist)$$

The set of all package descriptions is noted *DESCR*. If  $\phi$  is a package description then we write  $Dom(\phi)$  for its domain. If  $\phi(p, n) = (i, k, d, c, p)$  then we also write

- $\phi(p, n).installed = i$
- $\phi(p, n).keep = k$
- $\phi(p, n).depends = d$
- $\phi(p, n).conflicts = c$
- $\phi(p, n).provides = p$

It is natural to define a package description as a function since we can have at most one package description for a given pair of package name and version in a CUDF document. The function is generally only partial since we clearly do not require to have a package description for any possible pair of package name and version.

We define the removal operation of a particular versioned package from a package description. This operation will be needed later in Definition 13 to define the semantics of *package conflicts* in case a package conflicts with itself or a feature provided by the same package.

**Definition 3 (Package removal)** Let  $\phi$  be a package description,  $p \in \mathcal{V}(\text{pkgname})$  and  $n \in \mathcal{V}(\text{posint})$ . The package description  $\phi - (p, n)$  is defined by

$$\begin{aligned} \text{Dom}(\phi - (p, n)) &= \text{Dom}(\phi) - \{(p, n)\} \\ (\phi - (p, n))(q, m) &= \phi(q, m) \quad \text{for all } (q, m) \in \text{Dom}(\phi - (p, n)) \end{aligned}$$

**Definition 4 (Request)** A request is a triple  $(l_i, l_u, l_d)$  with  $l_i, l_u, l_d \in \mathcal{V}(\text{vpkglist})$ .

In a triple  $(l_i, l_u, l_d)$ ,  $l_i$  is the list of packages to be installed,  $l_u$  the list of packages to be updated, and  $l_d$  the list of packages to be deleted.

### 3.3.2 Installations

**Definition 5 (Installation)** An installation is a function from  $\mathcal{V}(\text{pkgname})$  to  $P(\mathcal{V}(\text{posint}))$ .

The idea behind this definition is that the function describing an installation associates the set of versions that are installed to any possible package name. This set is empty when no version of the package is installed.

We can extract an installation from any package description as follows:

**Definition 6 (Current installation)** Let  $\phi$  be a package description, the current package installation of  $\phi$

$$i_\phi: \mathcal{V}(\text{pkgname}) \rightarrow P(\mathcal{V}(\text{posint}))$$

is defined by

$$i_\phi(p) := \{n \in \mathcal{V}(\text{posint}) \mid (p, n) \in \text{Dom}(\phi) \text{ and } \phi(p, n).\text{installed} = \text{true}\}$$

A package can declare zero or more *features* that it provides. We can also extract the *features* provided by a package description:

**Definition 7 (Current features)** Let  $\phi$  be a package description, the current features of  $\phi$

$$f_\phi: \mathcal{V}(\text{pkgname}) \rightarrow P(\mathcal{V}(\text{posint}))$$

is defined by

$$f_\phi(p) := \bigcup_{p \in \text{Dom}(i_\phi)} \left( \bigcup_{n \in i_\phi(p)} \text{expand-features}(\phi(p, n).\text{provides}) \right)$$

where we define

$$\begin{aligned} \text{expand-features}((=, n), f) &= \{(f, n)\} \\ \text{expand-features}(\top, f) &= \{(f, n) \mid n \in \mathcal{V}(\text{posint})\} \end{aligned}$$

The second clause in the definition of *expand-features* mentioned above expresses the fact that providing a feature without a version number means providing that feature at any possible version.

In order to define the semantics of a CUDF document, we will frequently need to merge two installations. This will mainly be used for merging an installation of packages with an installation of provided features. The merging operation is formalized as follows:

**Definition 8 (Merging)** Let  $f, g: \mathcal{V}(\text{pkgname}) \rightarrow P(\mathcal{V}(\text{posint}))$  be two installations. Their merge  $f \cup g: \mathcal{V}(\text{pkgname}) \rightarrow P(\mathcal{V}(\text{posint}))$  is defined as

$$(f \cup g)(p) = f(p) \cup g(p) \quad \text{for any } p \in \mathcal{V}(\text{pkgname})$$

### 3.3.3 Consistent package descriptions

We define what it means for an installation to satisfy a constraint:

**Definition 9 (Constraint satisfaction)** The satisfaction relation between a natural number  $n$  and a constraint  $c \in \text{CONSTRAINTS}$ , noted  $n \models c$ , is defined as follows:

$$\begin{array}{lll} n \models \top & \text{for any } n & n \models (<, v) \quad \text{iff } n < v \\ n \models (=, v) & \text{iff } n = v & n \models (>, v) \quad \text{iff } n > v \\ n \models (\neq, v) & \text{iff } n \neq v & n \models (\leq, v) \quad \text{iff } n \leq v \\ & & n \models (\geq, v) \quad \text{iff } n \geq v \end{array}$$

Now we can define what it implies for a package installation to satisfy some formula:

**Definition 10 (Formula satisfaction)** The satisfaction relation between an installation  $I$  and a formula  $p$ , noted  $I \models p$ , is defined by induction on the structure of  $p$ :

- $I \models (c, p)$  where,  $c \in \text{CONSTRAINTS}$  and  $p \in \mathcal{V}(\text{pkgname})$ , iff there exists an  $n \in I(p)$  such that  $n \models c$ .
- $I \models \phi_1 \wedge \dots \wedge \phi_n$  iff  $I \models \phi_i$  for all  $1 \leq i \leq n$ .
- $I \models \phi_1 \vee \dots \vee \phi_n$  iff there is an  $i$  with  $1 \leq i \leq n$  and  $I \models \phi_i$ .

We can now lift the satisfaction relation to sets of packages:

**Definition 11** Let  $I$  be an installation, and  $l \in \mathcal{V}(\text{vpkglist})$ . Then  $I \models l$  if for any  $(c, p) \in l$  there exists  $n \in I(p)$  with  $n \models c$ .

Note that, given that  $\mathcal{V}(\text{vepkglist}) \subseteq \mathcal{V}(\text{vpkglist})$ , this also defines the satisfaction relation for elements of  $\mathcal{V}(\text{vepkglist})$ . Also note that one could transform any  $l \in \mathcal{V}(\text{vpkglist})$  into a formula  $l_\wedge \in \mathcal{V}(\text{vpkgformula})$ , by constructing the conjunction of all the elements of  $l$ . The semantics of  $l$  is the same as the semantics of the formula  $l_\wedge$ .

**Definition 12 (Disjointness)** The disjointness relation between an installation  $I$  and a set  $l \in \mathcal{V}(\text{vpkglist})$  of packages possibly with version constraints, is defined as:  $I \parallel l$  if for any  $(c, p) \in l$  and all  $n \in I(p)$  we have that  $n \not\models c$ .

**Definition 13** A package description  $\phi$  is consistent if for every package  $p \in \mathcal{V}(\text{pkgname})$  and  $n \in i_\phi(p)$  we have that

1.  $i_\phi \cup f_\phi \models \phi(p, n).depends$
2.  $i_{\phi-(p,n)} \cup f_{\phi-(p,n)} \parallel \phi(p, n).conflicts$

In the above definition, the first clause corresponds to the *Abundance* property of [MBC<sup>+</sup>06]: all the dependency relations of all installed packages must be satisfied. The second clause corresponds to the *Peace* property of [MBC<sup>+</sup>06]. In addition, we now have to take special care of packages that conflict with themselves, or that provide a feature and at the same time conflict with that feature: we only require that there be no conflict with any *other* installed package and with any feature provided by some *other* package (see also Section 3.3.5).

### 3.3.4 Semantics of requests

The semantics of a request is defined as a relation between package descriptions. The idea is that two package descriptions  $\phi_1$  and  $\phi_2$  are in the relation defined by the request  $r$  if there exists a transformation from  $\phi_1$  to  $\phi_2$  that satisfies  $r$ . Integration of optimization criteria is discussed in Section 3.4 and is outside the scope of the current section.

First we define the notion of a successor of a package description:

**Definition 14 (Successor relation)** *A package description  $\phi_2$  is called a successor of a package description  $\phi_1$ , noted  $\phi_1 \mapsto \phi_2$ , if*

1.  $Dom(\phi_1) = Dom(\phi_2)$
2. For all  $p \in \mathcal{V}(pkgrname)$  and  $n \in \mathcal{V}(posint)$ : if  $\phi_1(p, n) = (i_1, k_1, d_1, c_1, p_1)$  and  $\phi_2(p, n) = (i_2, k_2, d_2, c_2, p_2)$  then  $k_1 = k_2$ ,  $d_1 = d_2$ ,  $c_1 = c_2$ , and  $p_1 = p_2$ .
3. For all  $p \in \mathcal{V}(pkgrname)$ 
  - for all  $n \in i_{\phi_1}(p)$ : if  $\phi_1(p, n).keep = 'version$  then  $n \in i_{\phi_2}(p)$ .
  - if there is an  $n \in i_{\phi_1}(p)$  with  $\phi_1(p, n).keep = 'package$  then  $i_{\phi_2}(p) \neq \emptyset$
  - for all  $n \in i_{\phi_1}(p)$ : if  $\phi_1(p, n).keep = 'feature$  then  $i_{\phi_2} \cup f_{\phi_2} \models \phi_1(p, n).provides$

The first and the second item of the above definitions indicate that a successor of a package description  $\phi$  may differ from  $\phi$  only in the status of packages. The third item refines this even further depending on keep values:

- If we have a keep status of **version** for an installed package  $p$  and version  $n$  then we have to keep that package and version.
- If we have a keep status of **package** for some installed version of a package  $p$  then the successor must have at least one version of that package installed.
- If we have a keep status of **feature** for some installed version  $n$  of a package  $p$  then the successor must provide all the features that were provided by version  $n$  of package  $p$ .

**Definition 15 (Request semantics)** *Let  $r = (l_i, l_u, l_d)$  be a request. The semantics of  $r$  is a relation  $\overset{r}{\sim} \subseteq DESCR \times DESCR$  defined by  $\phi_1 \overset{r}{\sim} \phi_2$  if*

1.  $\phi_1 \mapsto \phi_2$
2.  $\phi_2$  is consistent
3.  $i_{\phi_2} \cup f_{\phi_2} \models l_i$

4.  $i_{\phi_2} \cup f_{\phi_2} \parallel l_d$

5.  $i_{\phi_2} \cup f_{\phi_2} \models l_u$ , and for all  $p \in l_u$  and all  $(p, n) \in l_u$  we have that  $i_{\phi_2}(p) = \{n\}$  is a singleton set with  $n \geq n'$  for all  $n' \in i_{\phi_1}(p)$ .

### 3.3.5 Comments on the semantics

(non-normative)

**Installing multiple versions of the same package** The semantics allows a priori to install multiple versions of the same package. This coincides with the semantics found in RPM-like F/OSS distributions (which a priori do not forbid to install multiple versions of the same package), but is in opposition to the semantics found in Debian-like F/OSS distributions (which allow for one version of any package to be installed at most).

In many practical cases the distinction between a priori allowing or not for multiple versions of a package makes little difference. In the RPM world multiple versions of the same package are very often in a conflict by their features or shipped files. If both versions of the same package provide the same feature and also conflict with that feature then the RPM semantics, as the CUDF semantics, does not allow to install both at the same time. Only packages that have been designed to have distinct versions provide distinct features (in particular, files with distinct paths) can in practice be installed in the RPM world in several different versions at a time. This typically applies to operating system packages. In order to have a meta-installer with Debian semantics work correctly on such a package description, it is sufficient to rename the packages, and to create a new package, say  $p - n$ , for a package  $p$  and version  $n$  when  $p$  can be installed in several versions.

On the other hand, a meta-installer with RPM semantics will produce solutions on a package description that would not be found by a meta-installer with Debian semantics since it is free to install several version of the same package. The uniqueness restriction of Debian can easily be made explicit in the package description by adding say a serialized property “**Conflicts:**  $p$ ” to any stanza in the package description, say of package  $p$ .

## 3.4 Integrating optimization criteria

The semantics given in Section 3.3 is designed to define when passing from one installation to another installation satisfies a user request. It does not discriminate among different resulting installations, which is in most cases too coarse to express the requirements a good meta-installer should satisfy. For instance, one might expect from a meta-installer that it does not call for the installation of unnecessary packages, or that it installs the latest version of packages when possible.

All single criteria of this kind can easily be expressed as optimization criteria that are in fact orthogonal to the semantics defined in Section 3.3. In order to express optimization criteria we use an optional property of package descriptions, called **Cost**, for instance, with value space **int** and default 0. Using this new property we can extend the definition of a package description to also yield the value of the **Cost** property in addition to the five properties already required in Definition 2. We will write  $\phi(p, v).cost$  for the value of the property **Cost** of the package description with package name  $p$  and version  $n$ .

**Definition 16 (Installation cost)** The cost  $cost(\phi)$  of a package description  $\phi$  is defined as

$$cost(\phi) = \sum_{p \in \mathcal{V}(\text{pkgname})} \left( \sum_{v \in i_\phi(p)} \phi(p, v).cost \right)$$

We say that  $\phi_1$  is as most as expensive as  $\phi_2$ , written  $\phi_1 \lesssim \phi_2$ , if  $cost(\phi_1) \leq cost(\phi_2)$ .

In other words, the cost of a package description is simply the sum of the `Cost` values of all installed versions of packages. Mathematically, the relation  $\lesssim$  is a so-called quasi-order, that is we have that  $\lesssim$  is reflexive ( $\phi \lesssim \phi$  for all  $\phi$ ) and transitive ( $\phi_1 \lesssim \phi_2$  and  $\phi_2 \lesssim \phi_3$  imply  $\phi_1 \lesssim \phi_3$ ), but not necessarily anti-symmetric (it may be the case that  $\phi \lesssim \psi$  and also  $\psi \lesssim \phi$  for different package descriptions  $\phi$  and  $\psi$ ).

**Lemma 1** Let  $\phi$  be a package description such that  $Dom(\phi)$  is finite, and  $r$  a request. If there exists an  $\psi$  such that  $\phi \overset{r}{\sim} \psi$  then there exists an installation  $\psi_0$  such that  $\psi_0 \lesssim \psi$  for all  $\psi$  with  $\phi \overset{r}{\sim} \psi$ .

This means that if a request has a solution at all then an optimal solution exists, even though this optimal solution may not be unique.

The proof of Lemma 1 is obvious from the fact that the smallest possible value of  $cost(\psi)$  is limited by

$$\sum_{(p,n) \in Dom(\phi)} \min\{0, \phi(p, n).cost\}$$

Alternatively, one might argue that for any given finite package installation there is only a finite number of possible successors.

Let us now see how various frequent optimization criteria can be translated into appropriate choices of the `Cost` property.

- Optimization of the disk space occupied by the installation may be indicated by putting the size taken by the installation of a package as value of the `Cost` property in the package description.
- Optimization of the download size required to pass to the new installation may be indicated by putting the download size of the package as the value of the `Cost` property if that version of the package is not installed, and 0 if that version of the package is already installed. Note that this amounts to expressing an optimization criterion for all *newly* installed packages even though the general optimization mechanism is defined on the set of *all* packages that are installed in the end.
- Preference of installation of most recent available versions of packages can be expressed by putting the value 0 as the value of the `Cost` property of package  $p$  and version  $v$  if  $n$  is the latest version of  $p$ , and 1 otherwise. This can easily be extended to taking into account “how outdated” a package is, either by putting the value of `Cost` of package  $p$  and version  $v$  to be the number of versions of  $p$  that are greater or equal to  $v$  and strictly smaller than the latest version of  $p$ , or by using some other metric.
- The requirement of installing a minimal number of auxiliary packages (i.e. packages that are not mentioned in the request) can be implemented by putting the value of `Cost` property to 0 if version  $v$  of package  $p$  is already installed or if its installation is explicitly required, and 1 otherwise.

- The requirement that a minimal number of packages should be removed is implemented by putting the value of the `Cost` property to `-1` if a package is installed, and to `0` otherwise.

Note that all these optimization criteria are *single* criteria. A user might have a vague notion of wanting to optimize several of these criteria at the same time (such as “upgrade as many packages as possible to their latest version, and at the same time remove as few packages as possible”). However, it is at the moment absolutely not clear what the exact semantics of this might be. In order to define the semantics of such a request one would have to define, for any two solutions, which of the two is the preferred solution.

Also note that while we have used a single `Cost` property throughout this section to discuss optimization possibilities, implementations are not required to do so. In fact, it is recommended that implementations define meaningful properties (e.g. `Installed-Size`, `Download-Size`, etc.) and that cost functions to be optimized get defined over the semantic values assumed by those extra properties.

## 3.5 Serialization

This section describes how to serialize CUDF documents as stream of bytes and, symmetrically, how to parse streams of bytes as CUDF documents. We refer generically to one or the other action as *CUDF serialization*.

Serialization is meant to make the storage of CUDF documents as files possible and to transfer them over the network. A stream of bytes which can be parsed as a CUDF document respecting this specification is called a *CUDF file*.

### 3.5.1 Overall CUDF file syntax

A CUDF file is a plain-text file containing several *file stanzas*. The bytes composing the file should be interpreted as Unicode characters encoded in UTF-8.

The overall organization of a CUDF file in stanzas reflects the schematic structure of CUDF content (see Section 3.2). Each file stanza is the serialization of a CUDF information item. Blank lines (i.e. empty lines, or lines composed only by white space characters: `U+0020`, `U+000D`, `U+000A`, `U+0009`) occurring between file stanzas are ignored.

Serialization should—where possible—follow the canonical ordering of information items given in Section 3.2, that is first contain the list of stanzas corresponding to package descriptions (*package description stanzas*) and then the sole stanza corresponding to problem description (*problem description stanza*).

To recognize the beginning of file stanzas, each of them starts with a *postmark*, which is specific to information item classes. Postmarks denote the beginning of a new file stanza only *when occurring either at the beginning of the file or just after a newline* (Unicode code point `U+000A`).

- For package description items, the postmark is the string `"Package: "`.
- For problem description items, the postmark is the string `"Problem: "`.

In both cases, the postmark can be followed by some characters other than a newline, and end with a single newline.

### 3.5.2 Information item serialization

Each information item, whatever its class, is serialized as a stream of bytes serializing all of its properties in an arbitrary order. A single property is serialized as a stream of bytes performing the following steps in order:

1. serialize the property name as the string corresponding to the NAME given in its property schema;
2. output the string " : " , i.e. a double colon followed by a space (U+0020);
3. serialize the property value;
4. output a single newline.

Let  $t$  be the type of a property whose value  $v$  has to be serialized as a stream of bytes. The value is serialized by choosing a value from  $v' \in \mathcal{L}(t)$  such that  $parse_t(v') = v$ . That is, all possible values that will be parsed back as the value to be serialized are valid serializations of it.

Since parsing is not one-to-one in general for CUDF types, it is possible that different implementations of this specifications make different choices in terms of how to serialize a given value. Hence it should not be taken for granted that two serializations of CUDF values which are not byte-to-byte identical do not denote the same CUDF value.

An important distinction exists between the serialization of different classes of information items. For package descriptions, the postmark is part of the serialization of properties, i.e. the line starting with "Package: " is the serialization of the Package property (i.e. the package name). As a consequence, and in amendment of the general rule above on the property serialization order, the *Package must be the first property serialized in each file stanza*, because it is used to recognize the beginning of package description file stanzas.

On the contrary, for problem descriptions the postmark is used to recognize the beginning of the corresponding file stanza, but does not represent the serialization of any particular property. Instead of leaving an empty line after the problem description postmark, implementations should output a problem identifier, possibly cross-referencing the source from which a given CUDF is being generated from (e.g. a DUDF unique identifier).

An example of CUDF file is given in Appendix C.

### 3.5.3 CUDF file parsing

How to parse CUDF files to obtain CUDF documents is almost straightforward and follows from an analysis of the serialization rules given above.

*Parsing errors* can be encountered while parsing CUDF serializations which do not match the rules provided by this specification. Parsing errors can be localized at specific positions of the CUDF serialization. When the position of a parsing error belongs to a specific file stanza (i.e. it is in between two postmarks, or between a postmark and the end of file), that error is said to be recoverable. The recovery strategy is to ignore the file stanza the error belongs to and act as if that stanza was not there.

The actual parsing procedure is as follows:

1. Given a CUDF file, split it at occurrences of postmarks. The result of this operation is a list of file stanzas. Each of them can be recognized as the serialization of either a package description (if the postmark is "Package: ") or a problem description (if the postmark is "Problem: ").

Afterwards, problem description postmarks are useless and can be ignored for further processing. On the contrary, problem description postmarks should be integrated again as part of the following package description file stanza.

2. Parse each file stanza as a list of property serializations by splitting at occurrences of newlines.
3. Parse each property serialization as a pair of property name and value serializations by splitting when the string ": " occurs.
4. Turn each property name serialization into a property name in a straightforward way, as long as it matches the constraints on property names. Otherwise raise a parsing error; the error must be located in the file stanza owning the affected property.

For each property name check whether that property is supported by the information item serialization in which it appears. If this is the case then this specification permits to assign all the information coming from its schema to that property, in particular a type and possibly an optional value. If the property is not supported by this specification for a given information item, it is either known, via some unspecified external mechanism, how to associate a schema to that property or that property cannot be processed any further and will be disregarded.

After this step all properties have an associated schema and a (yet to be parsed) value serialization.

5. For each value serialization parse it using the parsing function of the associated property type. If the function is not defined for the given serialization then a parsing error is raised; the error is located in the file stanza owning the affected value.

After this step, each file stanza has been parsed into a list of properties as supported by CUDF. That list can be turned into a set. If the same property name appears twice or more in the set, a parsing error is raised; the error is located in the file stanza containing the properties.

Once sets are formed, the CUDF file has been fully parsed into a list of information items; together they already form a CUDF document.

6. The only missing step is handling of default values. For each information item check whether some of the optional properties are missing according to the information item kind (package or problem description). For each such missing optional property, add a property of that name to the information item where it was missing. The corresponding value is either `None` (for properties which do not specify a default value) or the default value defined in the property schema.

## Compatibility with RFC822

(non-normative)

Conforming implementation of CUDF serialization produces CUDF files which are blank-separated sequences of messages conforming to RFC822 [Cro82].

This aspect hints an alternative—yet correct—way of parsing CUDF files via exploitation of existing RFC822 implementations. On top of them it is enough to perform the parsing steps given above from 4 to 6, skipping steps 1–3 which are subsumed by RFC822 parsing.

## 3.6 Generating CUDF (non-normative)

While it is possible to generate CUDF documents directly, it is expected that the largest fraction of the CUDF corpus to be used for the competition will be generated via conversion from DUDF documents provided by users of F/OSS distributions.

Each distribution interested in providing upgrade problems for the UPDB (see Chapter 1) is then required to provide specification and tools that implement the conversion. Ideally, the description of how to convert from a specific DUDF instance and CUDF should be described together with the specification of the specific DUDF instance. It is expected that each partner interested in contributing problems to the UPDB publishes a document describing both aspects.

During the conversion, we expect three main tasks to be implemented.

**Translation: package information** → **package information items** Each DUDF instance is expected to encode the information about all packages known to the meta-installer in some way. The first required task to create the resulting CUDF is to convert such (meta-installer-/distribution-specific) information to package information items as described in this specification.

The implementation of this task should account not only for data conversions imposed by the CUDF type system (e.g. translating from legacy versioning schemata—*x.y.z*—to positive integers), but also for semantic differences between the origin distribution and CUDF. Likely, the most common cause of semantic incompatibilities will be the translation from Debian-like packaging systems to CUDF (see Section 3.3.5 for advice on how to address this problem).

**Translation: user request** → **problem description item** Similarly, the request that the user posed to its meta-installer needs to be translated to a problem description item.

The request language supported by CUDF is expected to be expressive enough to encode the vast majority of user requests nowadays expressible in state of the art meta-installers. Exceptions are of course possible, in which case no translation from DUDF to CUDF is possible. Specifications of DUDF instances must clearly state such limitations.

**Expansion of intentional sections** DUDF encodings are expected to be more compact than the corresponding CUDF encoding (see Section 2.3). To that end DUDF documents can refer to external resources whereas CUDF documents are expected to be entirely self-contained. Therefore, all references to external entities occurring in DUDF documents must be expanded before being able to create the corresponding CUDF encoding.

Since in general only distributions are expected to be able to perform the expansions (e.g. because the referred repositories are mirrors or databases hosted by them), the actual translation from DUDF instances to CUDF should be performed by distributions *before* injecting problems into the central UPDB.

**Serialization** Once all information items translated from DUDF to the CUDF model, they need to be serialized to files (see Section 3.5).

## Chapter 4

# Conclusion

The Mancoosi project will run a solver competition [DC08], in which each participant will try to find the best possible solutions to upgrade problems as those faced by users of F/OSS software distributions. This specification has defined two (classes of) document formats which play important roles in the work-flow of the competition.

The first class of document formats is DUDF (Distribution Upgrade Description Format), described in Chapter 2. Specific instances of DUDF will be used as document formats to encode real life problems encountered by users of F/OSS software distributions. DUDF is meant to be a compact representation of upgrade problems, suitable to be transferred over the network. In addition to the purposes of the competition, DUDF documents might be useful to store and transfer the state of package managers, for example for reporting bugs concerning package management tools.

Distributions that are interested in providing problems on which the competition will possibly be run should have an interest in implementing DUDF for their own distributions. The current document only describes the outline (or skeleton) of DUDF. Implementing DUDF actually means standardizing a specific instance of it, by describing in a separate document how the holes left open by this specification have to be filled in the context of a specific software distribution. Equipped with this specification and the specification of a DUDF instance, implementors will be able to produce and interpret DUDF corresponding to upgrade problems faced on final user machines.

The second document format introduced by this specification is CUDF (Common Upgrade Description Format), described in Chapter 3. The purpose of CUDF is to provide a model in which upgrade problems can be encoded, by abstracting over distribution-specific details. In the context of the competition, the interest of CUDF is to encode problems on which the actual competition will be run. This way, participating solvers will not need to implement distribution-specific semantics, and will only have to reason about a self-contained problem.

As far as CUDF is concerned, this specification has provided a formal model in which constraints coming from popular packaging “worlds” (e.g. Debian and RPM) can be expressed. On top of that model the semantics of typical upgrade action requests (e.g. install, remove, upgrade) has been described; using that semantics it is possible to check whether a solution provided by a solver properly implements a given user request.

In addition to the formal model, this specification has also provided a document structure in which both the user request and the universe of all packages known to a package manager can be encoded. Parsing and serialization rules for the document structure have been given as well,

so that CUDF documents can be dealt with in file form. Solvers taking part in the competition are meant to parse CUDF files in order to obtain the upgrade problem they are asked to solve.

To complete the competition scenario two important aspects are missing, but have been left beyond the scope of this document on purpose:

**Optimization criteria** It is expected that solvers taking part into the competition will not simply be asked to solve a given upgrade problem. At least for some competition “tracks”, there will be extra requirements to find the best possible solution among several alternative solutions which are correct according to the CUDF model.

How to specify optimization criteria is beyond the scope of this document and, is also outside the purpose of CUDF files. Each competition track will advertise the optimization criteria to be implemented by participating solvers. Optimization criteria can be defined on top of package properties which are already expressible in the present version of CUDF. To this end, CUDF is extensible: additional properties not prescribed by this specification can be added to package descriptions, by exploiting existing CUDF types.

**Solver output format** The output format of solvers taking part in the competition is beyond the scope of this specification. Nevertheless it will be needed in order to have a common way to understand the solutions found by solvers and to determine their quality according to the optimization criteria.

Naively, the solver output can be encoded by serializing the new local package status as if it were a CUDF document missing the problem description item. Practically though, such a representation would encode a lot of information which is a duplication of the CUDF input initially fed into the solver. Hence, a format which is more likely to be used for solver output is a “patch” with respect to the initial local package status as encoded in the CUDF input.

A separate document will be published, well in time for the competition, to describe the required output format and how to interpret it to obtain the package status meant by the solver.

## Part A

# DUDF skeleton serialization example

This non-normative section contains an example of DUDF serialization to XML. The example is given in Figure A.1, which is the serialization of the DUDF skeleton given in Figure A.1. In the example, XML comments have been put in place of outline holes and other missing information.

```

<dudf version="1.0"
  xmlns="http://www.mancoosi.org/2008/cudf/dudf"
  xmlns:dudf="http://www.mancoosi.org/2008/cudf/dudf">
  <timestamp><!-- timestamp in RFC822 format --></timestamp>
  <uid><!-- unique problem identifier --></uid>
  <distribution><!-- distribution identifier --></distribution>
  <installer>
    <name><!-- installer name --></name>
    <version><!-- installer version --></version>
  </installer>
  <meta-installer>
    <name><!-- meta-installer name --></name>
    <version><!-- meta-installer version --></version>
  </meta-installer>
  <problem>
    <package-status>
      <installer><!-- installer status --></installer>
      <meta-installer>
        <!-- meta-installer status -->
      </meta-installer>
    </package-status>
    <package-universe>
      <package-list
        dudf:format=<!-- package list format identifier -->
        dudf:filename=<!-- package list absolute path --> >
        <!-- package list -->
      </package-list>
      <!-- ... other package lists ... -->
      <package-list
        dudf:format=<!-- package list format identifier -->
        dudf:filename=<!-- package list absolute path --> >
        <!-- package list -->
      </package-list>
    </package-universe>
    <action><!-- requested meta-installer action --></action>
    <desiderata><!-- meta-installer desiderata --></desiderata>
  </problem>
  <outcome dudf:result=<!-- one of: "success", "failure"--> >
    <error><!-- error description (result: "failure")--></error>
    <package-status> <!-- result: "success" -->
      <installer><!-- new installer status --></installer>
      <meta-installer>
        <!-- new meta-installer status -->
      </meta-installer>
    </package-status>
  </outcome>
</dudf>

```

Figure A.1: XML serialization skeleton of a DUDF problem/outcome submission

## Part B

# RELAX NG schema for DUDF

This non-normative section contains a RELAX NG [CM01] schema which can be used to check whether a given XML document represents a valid DUDF skeleton serialization. The schema only ensures that the skeleton part of the XML document is valid with respect to this specification, since the details about how holes are filled are distribution-specific.

Additional comments in the schema denote “side conditions”—e.g. the fact that dates should be in RFC882 format—which are not expressed by the schema itself, and which should be checked to ensure proper implementation of DUDF.

The RELAX NG schema is reported in Figure B.1.

```
default namespace dudf = "http://www.mancoosi.org/2008/cudf/dudf"

any = ( element * { any* } | attribute * { text }* | text )

tool_id = (
  element name { text },          # must be a package name
  element version { text }       # must be a version number
)

package_status =
  element package-status {
    element installer { any* },    # installer-specific
    element meta-installer { any* }? # meta-installer-specific
  }

start = element dudf {
  attribute dudf:version { "1.0" },
  element timestamp { text }, # must be a date in RFC822 format
  element uid { text },
  element distribution { text },
  element installer { tool_id },
  element meta-installer { tool_id },
  element problem {
    package_status,
    element package-universe {
      element package-list {
        attribute dudf:format { text },
        attribute dudf:filename { text }?, # must be an
                                           # absolute path
      }
      any*
    }+
  },
  element action { text },
  element desiderata { text }?
},
(element outcome {
  attribute dudf:result { "success" },
  package_status
}
| element outcome {
  attribute dudf:result { "failure" },
  element error { text }
})
}
```

Figure B.1: RELAX NG schema for the DUDF skeleton

## Part C

# CUDF serialization example

This non-normative section contains an example of CUDF serialization to file. The example below has been inspired by the EDOS car/glass example [EDO06].

Some remarks about the example follow.

- The example does not rely on any extended properties.
- Intuitively, the example comes from a packaging world where different versions of the same package are implicitly conflicting with each other. To grasp this, all packages for which multiple versions are available declare a non-versioned conflicts with themselves.
- The `engine` feature is mutually exclusive, only one (installed) package can provide it. This is encoded using conflicts with the feature from each package providing it.

```
Package: car
Version: 1
Depends: engine, wheel, door, battery
Installed: true
```

```
Package: bicycle
Version: 7
```

```
Package: gasoline-engine
Version: 1
Depends: turbo
Provides: engine
Conflicts: engine, gasoline-engine
Installed: true
```

```
Package: gasoline-engine
Version: 2
Provides: engine
Conflicts: engine, gasoline-engine
```

```
Package: electric-engine
Version: 1
Depends: solar-collector | huge-battery
Provides: engine
Conflicts: engine, electric-engine
```

Package: electric-engine  
Version: 2  
Depends: solar-collector | huge-battery  
Provides: engine  
Conflicts: engine, electric-engine

Package: solar-collector  
Version: 1

Package: battery  
Version: 3  
Provides: huge-battery  
Installed: true

Package: wheel  
Version: 2  
Conflicts: wheel  
Installed: true

Package: wheel  
Version: 3  
Conflicts: wheel

Package: door  
Version: 1  
Conflicts: door  
Installed: true

Package: door  
Version: 2  
Depends: window  
Conflicts: door

Package: turbo  
Version: 1  
Installed: true

Package: tire  
Version: 1  
Conflicts: tire

Package: tire  
Version: 2  
Conflicts: tire

Package: window  
Version: 1  
Conflicts: window

Package: window  
Version: 2  
Depends: glass = 1  
Conflicts: window

Package: window

Version: 3  
Depends: glass = 2  
Conflicts: window

Package: glass  
Version: 1  
Conflicts: glass

Package: glass  
Version: 2  
Conflicts: glass, tire = 2

Problem: source: Debian/DUFD 733963bab9fe1f78fd551ad20485b217  
Install: bicycle, electric-engine = 1  
Upgrade: door, wheel > 2



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