# Towards a Model Driven Approach to Upgrade Complex Software Systems*

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**Abstract.** Complex software systems are more and more based on the abstraction of *package*, brought to popularity by Free and Open Source Software (FOSS) *distributions*. While helpful as an encapsulation layer, packages do not solve all problems of deployment and management of large software collections. In particular *upgrades*, which often affect several packages at once due to inter-package dependencies, often fail and do not hold good transactional properties. This paper shows how to apply *model driven* techniques to describe and manage software upgrades of FOSS distributions. It is discussed how to model static and dynamic aspects of package upgrades - the latter being the most challenging aspect to deal with - in order to be able to *predict* common causes of upgrade failures and *undo* residual effects of failed or undesired upgrades.

## 1 Introduction

Increasingly, software systems are designed to routinely accommodate new features before and after the deployment stage. The deriving evolutionary pressure requires the system design and architecture to have enhanced quality factors: in particular, they have to retain the (user perceived as well as system-intrinsic) dependability at a satisfactory level and make component installation/removal operations less haphazard [1]. Free and Open Source Software (FOSS) distributions are among the most complex software systems known, being made of tens of thousands components evolving rapidly without centralized coordination. Similarly to other software distribution infrastructures, FOSS components are provided in "packaged" form by distribution editors. Packages define the granularity at which components are managed (installed, removed, upgraded to newer version, etc.) using *package manager* applications, *APT* [2], Smart [3], Apache Maven [4]. Furthermore, the system openness affords an (apparently) anarchic array of dependency modalities among the adopted packages. These usually contain *maintainer scripts*, which are executed during the upgrade process to finalize component configuration. The adopted scripting languages have rarely been formally investigated, thus posing additional difficulties in understanding their side-effects which can spread

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throughout the system.
In other words, even though a package might be viewed as a software unit, it lives without a proper component model which usually defines standards (e.g., how a component interface has to be specified and how components communicate) [5, 6] that facilitate integration assuring that components can be upgraded in isolation.

The problem of maintaining FOSS installations, or similarly structured software distributions, is intrinsecally difficult and a satisfactory solution is missing. State of the art package managers lack several important features such as complete dependency resolution and roll-back of failed upgrades [7]. Moreover, there is no support to simulate upgrades taking the behavior of maintainer scripts into account. In fact, current tools consider only inter-package relationships which are not enough to predict side-effects and system inconsistencies which can be encountered during upgrades.

This work is part of the MANCOOSI[3] project which aims at improving the management of complex software systems built of composable units which evolve independently. In particular, the paper describes a model-driven approach to specify system configurations and available FOSS packages.[4] Maintainer scripts are described in terms of models which abstract from the real system, but are expressive enough to predict several of their effects on package upgrades. Intuitively, we provide a more abstract interpretation of scripts, in the spirit of [8], which focuses on the relevant aspects to predict the operation effects on the software distribution. To this end, models can be used to drive roll-back operations to recover previous configurations according to user decisions or after upgrade failures.

**Paper Structure:** Section 2 describes the upgrade process of FOSS packages and summarizes the MANCOOSI project. Section 3 describes a model driven approach to (i) specify system configurations and packages, (ii) simulate the installation of software packages, and (iii) assist roll-backs. Section 4 analyzes the FOSS domain and introduces the required modeling constructs which are captured in different metamodels. Finally, Section 5 and 6 present related and future work, respectively.

## 2 Packages, Upgrades, and Failures

Overall, the architectures of FOSS distributions are similar. Each installation has a local *package status* recording which packages are currently installed and which are available from remote repositories. Package managers are used to manipulate the package status and can be classified in two categories [10]: *installers*, which deploy individual packages on the filesystem (possibly aborting the operation if problems are encountered) and *meta-installers*, which act at the inter-package level, solving dependencies and conflicts, and retrieving packages from remote repositories as needed. The term *upgrade problem* is used to refer generically to any request (install, remove, upgrade to a newer version,

[3] http://www.mancoosi.org

[4] While FOSS is the motivating scenario for this work, the presented model-driven techniques are not FOSS-specific. In fact, previous work on FOSS package management [9] has been easily ported to non-FOSS packages (e.g., in Apache Maven). The same can be done with the presented approach which—given the addressed upgradeability concerns—has been designed for the general case of installation side-effects embodied by maintainer scripts.

etc.) to change the system configuration status. Such problems are usually solved by meta-installers whose aim is to find a suitable *upgrade plan*, where one exists. This section gives an overview of packages as they can be found in current distributions, their role in the upgrade process, and the failures that can impact on upgrade deployment.

**Packages.** Abstracting over format-specific details, a *package* is a bundle of three main parts: (1) set of files, (2) meta-information, (3) maintainer scripts.

The core of a package is the set of *files* (1) that it ships: executable binaries, data, documentation, etc. *Configuration Files* are a distinguished subset of shipped files, which are tagged as affecting the runtime behavior of the package and meant to be customized by local administrators. Configuration files need to be present in the bundle (e.g., to provide sane defaults or documentation), but also need special treatment: during upgrades they cannot be simply overwritten by newer versions, as they may contain local changes which should not be thrown away.

Package *Meta-information* (2) is used by meta-installers to design upgrade plans. Details change from distribution to distribution, but a common core of meta-information consists of: a unique identifier (the package name), software version, maintainer and package description, *inter-package relationships*. These relationships represent the most valuable information for dependency resolution and usually include: dependencies (the need of other packages to work properly), conflicts (the inability of being co-installed with other packages), feature provisions (the ability to declare named *features* as provided by a given package, so that other packages can depend on them), and boolean combinations of them [10].

Packages come with a set of executable *maintainer scripts* (also known as "configuration scripts") (3). Their purpose is to attach actions to hooks invoked by the installer. The most common use case for maintainer scripts is to update some cache, blending together data shipped by the package, with data installed on the system, possibly by other packages. Three facets of maintainer scripts are noteworthy:

**(a)** maintainer scripts are full-fledged programs, written in Turing-complete programming languages. They can do anything permitted to the installer, which is usually run with system administrator rights;

**(b)** the functionality of maintainer scripts can not be substituted by just shipping extra files: the scripts often rely on data which is available only in the target installation machine, and not in the package itself;

**(c)** maintainer scripts are required to work "properly": upgrade runs, in which they fail, trigger upgrade failures and are usually detected via inspection of script exit code.

**Upgrades.** Table 1 summarizes the different phases of the so called *upgrade process*, using as an example the popular `APT` meta-installer. The process starts in phase (1) with the user requesting to alter the local package status. The expressiveness of the requests varies with the meta-installer, but the aforementioned actions (install, remove, etc.) are ubiquitously supported, possibly with different semantics [11].

Phase (2) checks whether a package satisfying dependencies and conflicts exists (the problem is at least NP-complete [10]). If this is the case one is chosen in this phase. Deploying the new status consists of package retrieval, phase (3), and unpacking, phase (4). Unpacking is the first phase actually changing both the package status (to keep track of installed packages) and the filesystem (to add or remove the involved files).

**Table 1.** The package upgrade process.

```
# apt-get install libapache2-mod-php5                                   (1) request
-------------------------------------------------------------------------
Reading package lists... Done
Building dependency tree... Done
The following NEW packages will be installed: libapache2-mod-php5      (2) dep. resolution
0 upgraded, 1 newly installed, 0 to remove and 0 not upgraded.
Need to get 2543kB  of archives. After this operation, 5743kB of
additional disk space will be used.
-------------------------------------------------------------------------
Get:1 http://va.archive.ubuntu.com hardy-updates/main libapache2-mod-php5  (3) package retrieval
5.2.4-2ubuntu5.3 [2543kB]
Fetched 2543kB in 2s(999kB)
-------------------------------------------------------------------------  (5a) pre-configuration
-------------------------------------------------------------------------
Selecting package libapache2-mod-php5.
(Reading database ... 162440  files and dirs installed.)                (4) unpacking
Unpacking libapache2-mod-php5
(from .../libapache2-mod-php5_5.2.4-2ubuntu5.3_i386.deb)
-------------------------------------------------------------------------  (5b) post-configuration
Setting up libapache2-mod-php5 (5.2.4-2ubuntu5.3)
```

Intertwined with package retrieval and unpacking, there can be several configuration phases, (exemplified by phases (5a) and (5b) in Table 1), where maintainer scripts get executed. The details depend on the available hooks; `dpkg` offers: pre/post-installation, pre/post-removal, and upgrade to some version [12].

*Example 1.* PHP5 (a scripting language integrated with the Apache web server) executes as its `postinst` (post-installation) script the following snippet, on the left hand-side:

```
1 #!/bin/sh
2 if [-e /etc/apache2/apache2.conf]; then
3     a2enmod php5 >/dev/null || true
4     reload_apache
5 fi
```

```
1 #!/bin/sh
2 if [-e /etc/apache2/apache2.conf]; then
3     a2dismod php5 || true
4 fi
```

The Apache module `php5`, installed during the unpacking phase, gets enabled invoking the `a2enmod` command on line 3; the Apache service is then reloaded (line 4) to make the change effective. Upon PHP5 removal the reverse will happen, as implemented by PHP5 `prerm` (pre-removal) script snippet above, on the right hand-side.

Note that `prerm` is executed *before* removing files from disk, which is necessary to avoid reaching an inconsistent configuration where the Apache server is configured to rely on no longer existing files. The expressiveness of inter-package dependencies is not enough to encode this kind of dependencies: Apache does not depend on `php5` (and should not, because it is useful also without it), but while `php5` is installed, Apache needs specific configuration to work in harmony with it; at the same time, such configuration would inhibit Apache to work properly once `php5` gets removed. The bookkeeping of such configuration intricacies is delegated to maintainer scripts.

**Failures.** Each phase of the upgrade process can fail. Dependency resolution can fail either because the user request is unsatisfiable (e.g., user error or inconsistent distributions [9]) or because the meta-installer is unable to find a solution. Completeness—the guarantee that a solution will be found whenever one exists—is a desirable meta-installer property unfortunately missing in most meta-installers, with too few claimed exceptions [13]. Package deployment can fail as well. Trivial failures, e.g., network or disk failures, can be easily dealt with when considered in isolation from the other

upgrade phases: the whole upgrade process can be aborted and unpack undone, since all the involved files are known. Maintainer script failures can not be as easily undone or prevented, since all non-trivial properties about scripts are undecidable, including determining *a priori* which parts of file-system they affect to revert them *a posteriori*.

**The MANCOOSI Project.** MANCOOSI is working to improve upgrade support in complex software systems such as FOSS distributions. On one hand the project is working on algorithms for finding optimal upgrade paths addressing complex preferences, on the other is working on models and tools to *(i)* simulate the execution of maintainer scripts, *(ii)* predict side-effects and system inconsistences which might be raised by package upgrades, and *(iii)* instruct roll-back operations to recover previous configurations according to user decisions or after upgrade failures. In the rest of this paper we introduce the approach we are using, in the context of MANCOOSI, to attack the problems of package upgrades, namely: modeling of the involved entities and upgrade simulation.

## 3 Proposed Approach

As discussed, the problem of maintaining FOSS installations is far from trivial and has not yet been addressed properly [7]. In particular, current package managers are neither able to *predict* nor to *counter* vast classes of upgrade failures. The reason is that package managers rely on package meta-information only (in particular on inter-package relationships), which are not expressive enough to detect upgrade failures. Our proposal consists in maintaining a model-based description of the system and simulate upgrades in advance on top of it, to detect predictable upgrade failures and notify the user before the system is affected. More generally, the models are expressive enough to isolate *inconsistent configurations* (as in the case of Example 1, where installed components rely on the presence of disappearing sub-components), which are currently not expressible as inter-package relationships.

The adoption of model-driven techniques presents several advantages: *(a)* models can be given at any level of abstraction depending on the analysis and operations one would like to perform as opposed to package dependency information whose granularity is fixed and currently too coarse; *(b)* complex and powerful analysis techniques are already available to detect model conflicts and inconsistencies [14, 15]. In particular, contradictory patterns can be specified in a structural way by referring to the underlying domain semantics in contrast with text-based tools like version control systems where conflicts are defined at a much lower level of abstraction as diverging modifications of the same lexical element.

Figure 1 depicts the proposed approach. Basically, to simulate an upgrade run, two models are taken into account: the *System Model* and the *Package Model* (see the arrow ⓐ). The former describes the state of a given system in terms of installed packages, running services, configuration files, etc. The latter provides information about the packages involved in the upgrade, in terms of inter-package relationships. Moreover, since a trustworthy simulation has to consider the behavior of the maintainer scripts which are executed during the package upgrades, the package model specifies also an abstraction of the behaviors of such scripts. There are two possible simulation out-

comes: *not valid* and *valid* (see the arrows ⓒ and ⓓ, respectively). In the former case it is granted that the upgrade on the real system will fail. Thus, before proceeding with it the problem spotted by the simulation should be fixed. In the latter case—*valid*—the upgrade on the real system can be operated (see the arrow ⓘ). However, since the models are an abstraction of the reality, upgrades failures might still occur.

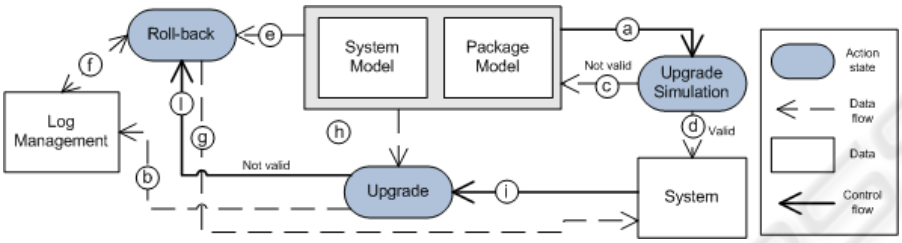



**Fig. 1.** Overall approach.

During package upgrades *Log models* are produced to store all the transitions between configurations (see arrow ⓑ). The information contained in the system, package, and log models (arrows ⓔ and ⓕ) are used in case of failures (arrow ⓛ) when the performed changes have to be undone to bring the system back to the previous valid configuration (arrow ⓖ).

Since it is not possible to specify in detail every single part of systems and packages, trade-offs between model completeness and usefulness have been evaluated; the result of such a study has been formalized in terms of metamodels (see next section) which can be considered one of the constituting concepts of Model Driven Engineering (MDE) [16]. They are the formal definition of well-formed models, constituting the languages by which a given reality can be described in some abstract sense [17] defining an abstract interpretation of the system.

Even though the proposed approach is expressed in terms of simulations, the entailed metamodels do not mandate a simulator. Hybrid architectures composed by a package manager and metamodel implementations can be more lightweight than the simulator, yet being helpful to spot inconsistent configurations not detectable without metamodel guidance.

## 4 Modeling System and Packages

The simulation approach outlined in the previous section is based on a set of coordinated metamodels which have been defined by analyzing the domain of package-based FOSS distributions. In general, a metamodel specifies the modeling constructs that can be used to define models which are said to conform to a given metamodel like a program conforms to the grammar of the programming language in which it is written [17].

In this work, we have considered two complex FOSS distributions (the Debian and RPM-based distributions, such as Mandriva.
Their analysis has induced the definition of three metamodels (see Figure 2) which describe the concepts making up a system configuration and a software package, and how

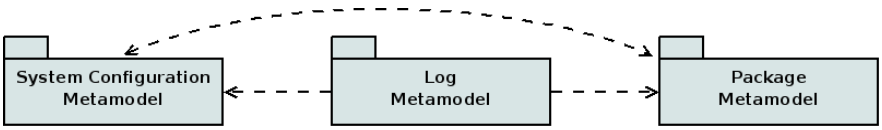



**Fig. 2.** Metamodels and their inter-dependencies.

to maintain the log of all upgrades. The metamodels have been defined according to an iterative process concisting of two main steps *(1)* elicitation of new concepts from the domain to the metamodel *(2)* validation of the formalization of the concepts by describing part of the real systems. In particular, the analysis has been performed considering the official packages released by the distributions with the aim of identifying elements that must be considered as part of the metamodels. The defined and used analysis strategy, due to the large amount of scripts, in general tries to collect scripts in clusters with the aim to concentrate the analysis only on representative scripts of the equivalence classes identified. Due to space constraints we cannot report the detailed analysis, but the interested reader can refer to [18]. We report here only the results of the analysis, i.e., the metamodels themselves:

The *System Configuration Metamodel* contains the modeling constructs to specify the configuration of a given FOSS system in terms of installed packages, configuration files, services, filesystem state, etc.;

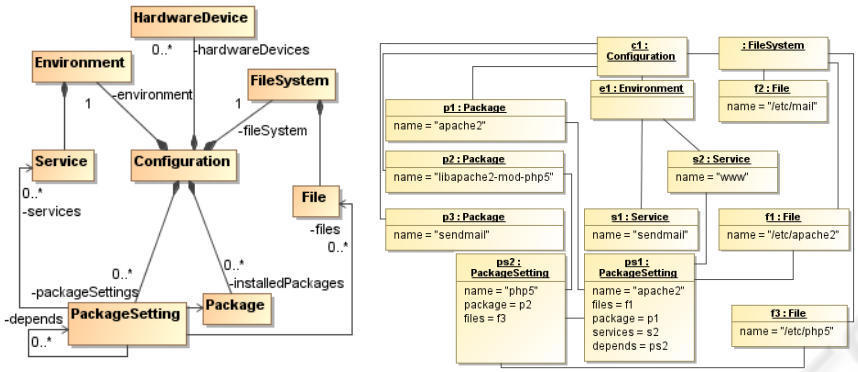
The *Package Metamodel* describes the relevant elements making up a package. The metamodel gives also the possibility to specify the maintainer script behaviors which are currently ignored—beside mere execution—by existing package managers;

The *Log Metamodel* is based on the notion of transaction which represents a set of statements which change the system configuration. Transitions can be viewed as model transformations [17] which let a configuration $C_1$ evolve into a configuration $C_2$.
As depicted in Figure 2, *System Configuration* and *Package* metamodels have mutual dependencies, whereas the *Log* metamodel has only direct relations with both the *System* and *Package* metamodels. In the rest of the section, such metamodels are described in more details and some explanatory models conforming to them are also provided.

### 4.1 Configuration Metamodel

A system configuration is the composition of artifacts necessary to make computer systems perform their intended functions [19]. In this respect, the metamodel depicted in Figure 3.a specifies the main concepts which make up the configuration of a FOSS system. In particular, the `Environment` metaclass enables the specification of loaded modules, shared libraries, and running process as in the sample configuration reported in Figure 3.b. In such a model the reported environment is composed of the services `www`, and `sendmail` (see the instances `s1` and `s2`) corresponding to the running web and mail servers, respectively.

All the services provided by a system can be used once the corresponding packages have been installed (see the association between the `Configuration` and `Package` metaclasses in Figure 3.a) and properly configured (`PackageSetting`). Moreover, the configuration of an installed package might depend on other package configurations.




(a) (b)

**Fig. 3.** a) (part of) configuration metamodel, and b) sample configuration model.

*Example 2.* Considering the PHP5 upgrade described in Example 1, the instances `ps1` and `ps2` of the `PackageSetting` metaclass in Figure 3.b represents the settings of the installed packages `apache2`, and `libapache-mod-php5`, respectively. The former depends on the latter (see the value of the attribute `depends` of `ps1` in Figure 3.b) and both are also associated with the corresponding files which store their configurations.

Note that at the level of inter-package relationships such a dependency should not be expressed, in spite of actually occurring on real systems. The ability to express such fine-grained and installation-specific dependencies is a significant advantage offered by the proposed metamodels which embody domain concepts which are not taken into account by current package manager tools.

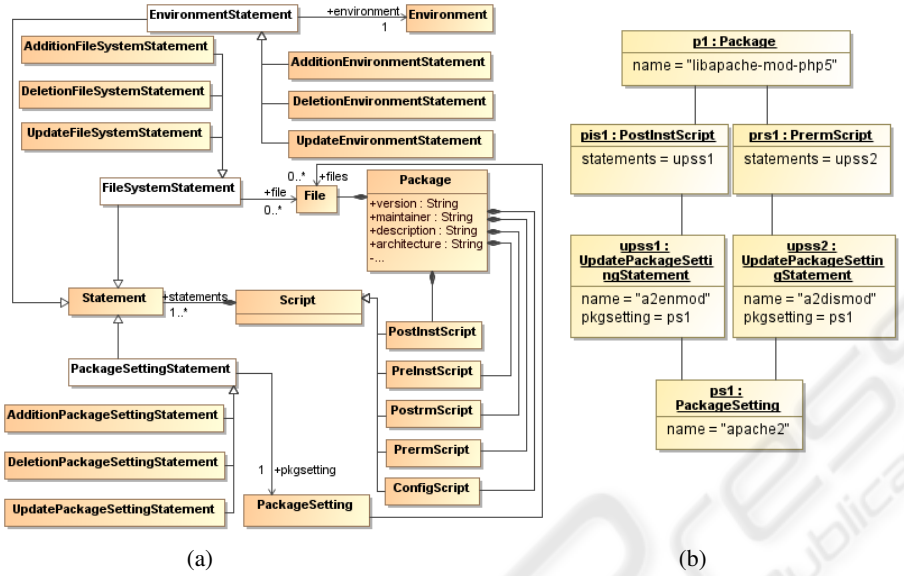
The configuration metamodel gives also the possibility to specify the hardware devices of a system by means of the `HardwareDevice` metaclass. Due to space constraint the usage of such a metaclass is omitted; for more information the interested reader can found the complete metamodels on the Web.[5]

The packages which are installed on a given system are specified by means of the modeling constructs provided by the *Package Metamodel* described in the next section.

### 4.2 Package Metamodel

The metamodel reported in Figure 4.a plays a key role in the overall simulation. In fact, in addition to the information already available in current package descriptions, the concepts captured by the metamodel enable the specification of the behavior of maintainer scripts. In this respect, the metaclass `Statement` in Figure 4.a represents an abstraction of the commands that can be executed by a given script to affect the environment, the file system or the package settings of a given configuration (`EnvironmentStatement`, `FileSystemStatement`, and `PackageSetting-Statement`, respectively).

[5] http://www.di.univaq.it/diruscio/mancoosi




(a) (b)

**Fig. 4.** a) (part of) package metamodel, and b) sample package model.

*Example 3.* For instance, the sample package model in Figure 4.b reports the scripts contained in the package `libapache-mod-php5` introduced in Section 2. Due to space constraints, Figure 4.b contains only the relevant elements of the `postinst`and `prerm` scripts which are represented by the elements `pis1` and `prs1`, respectively.

According to the model in Figure 4.b the represented scripts update the configuration of the package `apache2` (see the element `ps1`) which depends on `libapache-mod-php5`. In particular, the element `upss2` corresponds to the statement `a2dismod` which disables the PHP5 module in the Apache configuration before removing the package `libapache-mod-php5` from the filesystem. This statement is necessary, otherwise inconsistent configurations can be reached like the one shown in Figure 5. The figure reports the sample `Configuration2` which has been reached by removing `libapache-mod-php5` without changing the configuration of `apache2`. Such a configuration is broken since it contains a dependency between the `apache2` and `libapache-mod-php5` package settings, whereas only `apache2` is installed.

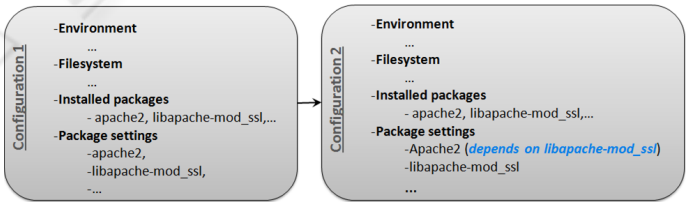
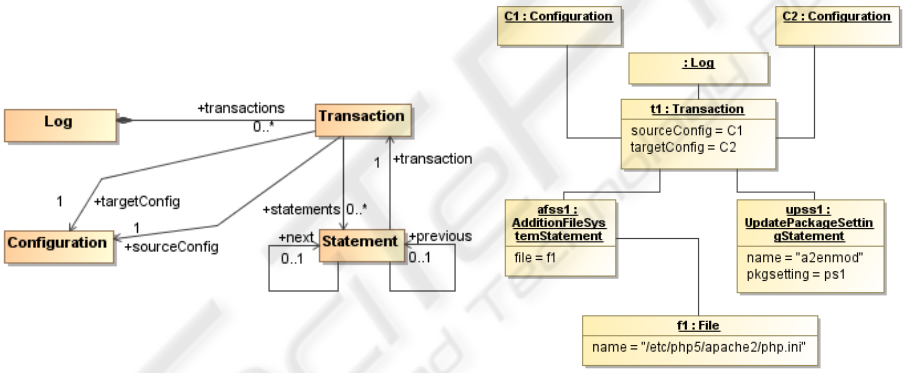



**Fig. 5.** Incorrect package removal.

Currently, the package managers are not able to predict inconsistencies like the one in Figure 5 since they take into account only information about package dependencies and conflicts. The metamodel reported in Figure 4 gives the possibility to specify an abstraction of the involved maintainer scripts which are executed during the package upgrades. This way, consistence checking possibilities are increased and trustworthy simulations of package upgrades can be operated.

### 4.3 Log Metamodel

The metamodel depicted in Figure 6.a underpin the development of a transactional model of upgradeability that will allow us to roll-back long upgrade history, restoring previous configurations. In particular, the metaclass `Transaction` in Figure 6.a refers to the set of statements which have been executed from a source configuration leading to a target one. For instance, according to the sample log model in Figure 6.b, the installation of the package `libapache-mod-php5` modifies the file system (see the statement `afss1` which represents the addition of the file `f1`) and updates the Apache configuration (see the element `upss1`).




(a) (b)

**Fig. 6.** a) (part of) Log metamodel, and b) Sample Log model.

The usefulness of log models like the one in Figure 6.b is manyfold and accounts for several roll-back needs:

**(a)** *Preference Roll-back:* the user wants to recover a previous configuration, for whatever reason. For instance, the user is not in need of PHP5 anymore and wants to remove the installed package `libapache-mod-php5`. In this case, the configuration `C1` can be recovered by executing the dual operation of each statement in the transaction between `C1` and `C2`. Note that the log models have all the information necessary to roll-back to any previous valid configuration not necessary a contiguous one;

**(b)** *Compensate Model Incompleteness:* as already discussed, upgrade simulation is not complete with respect to upgrades, and undetected failures can be encountered while deploying upgrades on the real system. For instance, the addition of the file `php.ini` during the installation of the package `libapache-mod-php5` can raise faults because of disk errors. In this case we can exploit the information stored in the log model

to retrieve the fallacious statements and to roll-back to the configuration from which the broken transaction has started.

**(c)** *"Live" failures:* the proposed approach does not mandate to pre-simulate upgrades. In fact, it is possible as well to avoid simulation and have metamodeling supervise upgrades to detect invalid configurations as soon as they are reached. At that point, if any, log models comes into play and enable rolling back deployed changes to bring the system back to a previous valid configuration.

The log metamodel will play a key role in the definition of tools and algorithms to keep track of the evolution of the system and to revert the system to previous (working) states and retrieve it in an efficient way.

## 5 Related Works

The main difficulties related to the management of upgrades in FOSS distributions depend on the existence of maintainer scripts which can have system-wide side-effects, and hence can not be narrowed to the involved packages only. In this respect, proposals like [20, 21] represent a first step toward roll-back management. Both proposals exploit re-creation of removed packages on-the-fly, so that they can be re-installed to undo an upgrade. However, such approaches can track only files which are under package manager control, therefore they cannot undo maintainer script side effects.

An interesting proposal to support the upgrade of a system, called NixOS, is presented in [22]. NixOS is a purely functional distribution meaning that all static parts of a system (such as software packages, configuration files and system boot scripts) are expressed as pure functions. Among the main limitations of NixOS there is the fact that some actions related to upgrade deployment can not be made purely functional (e.g., user database management). Moreover, NixOS solution poses security concerns due to the fact that "garbage collection" of shared library (implemented to ensure no dangling library references can exist) makes hard ensuring that no security flawed versions of a library which is being fixed stay around.

[23] proposes an attempt to monitor the upgrade process with the aim to discover what is actually being touched by an upgrade. Unfortunately, it is not sufficient to know which files have been involved in the maintainer scripts execution but we have also to consider system configuration, running services etc., as taken into account by our metamodels. Even focusing only on touched files, it is not always possible to undo an upgrade by simply recopying the old file[6].

Finally, this work can be related with techniques for static analysis of scripting languages. Some previous work [24] deals with SQL injection detection for PHP scripts, but it did not consider the most dynamic parts of the PHP language, which are quite common in shell script languages. Whereas, [25] presents a mechanism to detect argument arity bugs in shell scripts, but once more only considers a tiny fragment of the shell language. Both works hence are far even from the minimal requirement of determining a priori the set of files touched by script execution, letting aside how restricted

[6] This argument goes far beyond the scope of this work, see [7] for a more in-depth discussion of the topic.

were the considered shell language subsets. Given these premises, we are skeptical that static analysis can fully solve the problems illustrated in this work.

## 6 Conclusions and Future Works

In this paper we presented a model-driven approach to manage the upgrade of FOSS distributions. This approach represents an important advance with respect to the state of the art in the following directions: it provides the base on which developing features to(*i*) support the roll-back of failed or unwanted upgrades, and (*ii*) simulate the execution of upgrade runs (including maintainer script behaviors) that we described in terms of models. A running example showed how the proposed models allow a reasonable description of the state of the system and representation of its evolution over time.

As future work we plan to implement these results and to develop a transactional update engine in the real context of Debian and Mandriva distributions. Moreover, the metamodels proposed in this paper will be the foundation to define a new Domain Specific Language (DSL) for maintainer script specifications.

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