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Sources of Inter-package Conflicts in Debian

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Inter-package conflicts require the presence of two or more packages in a particular configuration, and thus tend to be harder to detect and localize than conventional (intra-package) defects. Hundreds of such inter-package conflicts go undetected by the normal testing and distribution process until they are later reported by a user. The reason for this is that current meta-data is not fine-grained and accurate enough to cover all common types of conflicts. A case study of inter-package conflicts in Debian has shown that with more detailed package meta-data, at least one third of all package conflicts could be prevented relatively easily, while another one third could be found by targeted testing of packages that share common resources or characteristics. This paper reports the case study and proposes ideas to detect inter-package conflicts in the future.

1 Introduction

1.1 Package-based software distributions

Modern software distributions are organized into packages. A software package is a self-contained unit that can be installed or removed independently of other packages, as long as dependencies are met. A package manager controls such administrative tasks; compared to unmanaged installations, the benefits of a package-based approach are the ability to automatically install, upgrade, and remove packages without the need to remember installation locations or which files are affected by a change.

In real software, this ideal state is not easy to achieve, due to dependencies between software packages, and interactions between software belonging to different packages. Dependencies arise because some packages provide lower-level functionality used by others. Interactions occur on shared resources, such as files, and because packages may provide components that can be combined into a larger system (such as client and server packages communicating together).

Dependencies restrict the ability to freely install, remove, or upgrade packages. If a package *a* depends on another package *b*, a package manager automatically requires *b* to be installed when *a* is requested to be installed. Furthermore, package *b* cannot be removed as long as *a* is still in use. Finally, upgrades of one package often require a simultaneous upgrade of related packages. In addition to this, there is a notion of *conflicting* packages: two packages may use the same resource or provide the same service in a way that is incompatible with each other, so only one of these two packages may reside on a system at any given time.

In package-based software distributions, so-called *package meta-data* describes dependencies and relations between packages. Most Free Open Source Software (FOSS) systems are managed in that way. Meta-data contains information about dependencies of packages, and conflicts between them. At the time

of writing, meta-data covers relations between packages on a package level; dependencies and conflicts are indicated by package, not by the actual resources a package provides or depends on. So-called *virtual packages* are sometimes used as place-holders for actual resources or services provided by a package, but they do not constitute an accurate, fine-grained description of those resources, which may be files, network ports, or system services.

1.2 Inter-package conflicts

Inter-package conflicts occur if the combination of multiple packages results in a defect that is absent otherwise. Package meta-data may indicate such conflicts, which prevents conflicting combinations of packages from being installed. However, inter-package conflicts may still arise in practice. The reasons for such conflicts are manifold: Packages are not simply bundles of files, but include pre-installation and post-installation scripts. These scripts are unrestricted, Turing-complete programs running with full system (root) access. It is therefore impossible in general to capture the full side effects of these scripts with a formal description. The same problem arises of course as well for executing the software provided by these packages. Therefore, a complete logical analysis of package behavior is not possible; however, as this paper shows, steps can be taken towards covering certain types of common conflicts that are not automatically verifiable with current tools.

Another problem arises from the fact that meta-data is provided manually, by package maintainers. It is therefore a challenge to keep such meta-data up to date and accurate. This challenge becomes especially daunting in the presence of a huge number of software packages in distributions such as Debian GNU/Linux, where the number of packages available currently exceeds 30,000 [12].

As a consequence of this, bug reports referring to conflicts between packages are becoming frequent. This paper investigates the sources of the conflicts and tries to answer the following questions:

- What are the reasons why inter-package conflicts arise?
- Are there common categories of inter-package conflicts?
- Can these problems be addressed by using existing tools, or is there a need to augment existing tools, or create new ones?
- Is the package meta-data currently being used, accurate and sufficient? Is there a need to automatically verify such meta-data for accuracy, or is there a need to use additional meta-data for a more accurate notion of package conflicts? In other words, are most or all possible package conflicts covered by meta-data?

This paper is organized as follows: Section 2 describes related work. Section 3 shows a case study on inter-package conflicts in Debian, with a detailed evaluation of different kinds of package conflicts. Section 4 discusses the results and proposes possible strategies for remedying problems found, and Section 5 concludes and outlines future work.

2 Related Work

2.1 Software packaging

Software packages are a well-known example of the component models that have originated from the field of component-based software engineering (CBSE) [15, 3]. Packages fit very well within common component definitions, but the raise in their popularity—started with the advent of FOSS package

managers such as the FreeBSD porting system [13], APT [9], Yum, etc.—has highlighted very specific challenges related to their deployment [6]. Some of those challenges are being addressed relying on package meta-data and their formalization.

Seminal work by Mancinelli et. al [8] has shown how to encode the installability problem for software packages as a SAT problem, established the (NP-Hard) complexity of the problem, and shown applications of the encoding to improve the quality of package repositories by avoiding non installable packages. Based on the same formalization, various quality metrics have been established, such as strong dependency and sensitivity [1] (to evaluate the “importance” of a package in a given repository) and strong conflicts [5] (to pinpoint packages which might hinder the installation of several other packages). In the same vein, package meta-data have also been used to predict future (non) installability of software packages [2]. The abundance of studies that rely on package meta-data testifies the importance of the correctness of those meta-data.

On the other hand, studies on package meta-data correctness like this one, seem to be scarce. At the same time, a few testing can be found in the realm of Quality Assurance (QA) of FOSS distributions to discover *symptoms* that might then lead, a human, to discover errors in package meta-data. To name one, the “file overwrite” [16] initiative by Treinen helps in discovering undeclared conflicts among packages in the Debian distribution.

2.2 Alternatives to globally managed software packaging

As an alternative to globally managed software packages that are organized in a fine-grained hierarchy, self-contained packages including all sub-components, sometimes called *bundles*, are sometimes used. Such bundles include the application and all libraries it depends on, linked statically [11]. This contrasts to FOSS distributions where libraries are shared, and generally required to be shipped as separate packages—see for instance [7], “convenience copies of code”—in order to ease the deployment of (security) upgrades. In a system using bundled software, all applications using the library in question need to be updated separately. This usually entails a longer period during which a system is vulnerable, because some software bundles may be provided by third parties.

An advantage of self-contained software bundles is the ease of testing and deployment, as system-specific configurations and libraries have only limited impact on the software bundle. However, statically linking all libraries used by a bundle requires much disk space. If many applications include the same statically-linked libraries, these libraries are duplicated within the same system. Deduplication addresses this problem [4, 14]. Memory and storage deduplication merge same-contents chunks on block level, and reduce the consumptions of physical memory. By sharing identical chunks of storage, logical-level redundancies caused by static linking are resolved on the physical level.

3 Evaluation of Inter-package Conflicts

3.1 Methodology

The evaluation of existing inter-package conflicts in Debian was carried out on a snapshot of the Ultimate Debian Database (UDD) [10]. This database contains key data of all active (open) bugs at that time, such as bug ID, title, and the package involved. The snapshot used was taken on January 23 2011, and contained 79936 bugs.

This database is too large to be analyzed manually, so the selection of bugs was first narrowed down by a keyword search. We chose three keywords to search for: “break”, “conflict”, “overwrite”. The first

Keyword	Matches	Refined matches
break	575	161
conflict	252	85
overwrite	102	44

Table 1: Number of matches per keyword in Debian database.

two words are generic descriptions of inter-package conflicts and often appear in the form “*a* breaks *b*” or “*a* conflicts with “*b*”. The last keyword describes one of the most common inter-package problems, where one package overwrite a resource needed by another package.

Table 1 gives an overview of all the matches in the search. A total of 929 bugs match the initial search; some of the matches contain more than one keyword and therefore are duplicates. Our aim is not to get an exact number of how many inter-package conflicts there are in total; rather, we want to know what types of conflicts occur more often than others, relative to the total number.

We therefore narrow down the search to eliminate bug reports that describe problems that relate to one package alone, rather than a conflict between two packages. For example, “overwrite” could appear in a bug report on a text editor in a bug report related to overwriting text (or a file, on saving). In fact, an initial manual evaluation showed that about half of all bug reports found in the initial search were not related to inter-package conflicts. The search is refined to include only bug reports out of the initial selection, where the title contains the name of another package. This may filter out more bug reports than necessary (decreasing recall, in search terms), but makes the results much more precise. To avoid excluding too many packages, (version) numbers of packages are not included in this filter, even if the package name itself contains a version number. A manual check showed that this filter was actually a good approximation of a manual selection of true inter-package conflicts.

As shown in Table 1, the refined selection contains 290 matches, 241 of which are distinct bug reports. Further manual post-processing of that list removes another 51 items, where the title indicates clearly that those are not inter-package conflicts. This leaves 190 bug reports where, judging from the title of the report, a possible inter-package conflict is reported.

A subset of these bug reports was evaluated in a first sample, to come up with a categorization of bug reports that would not be too coarse (giving only a few rough classes of bugs) and not be overly precise either (putting most bugs into a category of their own). After that, all bug reports are classified according to these criteria, or eliminated as not being inter-package conflicts, although the title would suggest so (in the list of 190 reports).

3.2 Results

The 190 cases of which the bug report titles suggested an inter-package conflict, were analyzed manually. This requires the full information available on each bug, which is not contained in the summary database (UDD) used in the first step. The 190 bug reports in question were downloaded from the web page at <http://www.debian.org/Bugs/>. 51 bug reports out of 190 contain no inter-package conflict, but rather a conflict that is not reproducible, or a conflict within a single package which is either misclassified or contains a misleading title. This leaves 139 genuine inter-package conflicts, which are classified into five broad categories:

1. Conflicts on files and similar shared resources (such as devices or C library function names). Whenever a conflict occurs directly on a file (or device), the conflict is caught at installation time

by `apt-get`, the package manager for Debian. This handling is safe, but unsatisfactory: if a list of files used was provided beforehand, then an enhanced package manager could prevent an installation attempt that is bound to fail. On the other hand, other types of conflicts, such as name clashes in libraries, may not be detected until an application is used at run-time.

2. Conflicts on shared data, configuration information, or the information flow between programs. Configuration information is often found in `/etc`, while shared data may be located elsewhere. Information flow refers to function calls or communication via pipes or a network. There are two basic cases where conflicts occur on data or communication: (1) An installation action of a package changes the configuration such that either the syntax of a configuration file is broken (made unreadable for the parser used by another tool), or the semantics create a conflict. (2) A change in the data format between versions of an application, which requires updating other components; the lack of an appropriate newer version of other components, or the lack of a declaration of such, causes a conflict. In both cases (1) and (2), the conflict only becomes evident at run-time.
3. Uncommon, previously untested combinations of packages, cause a conflict. In some cases, a package *a* using another package *b* makes a previously undetected fault in *b* evident; it is possible that other use cases for *b* could produce the same problem, so the failure can (at least in theory) be reproduced using *b* alone. In other cases, the combination of *a* and *b* is necessary for those packages to fail, and either package would work fine without the conflicting package being present. Nine cases fit this description, where the reason of a conflict could not be attributed to cases listed above.
4. Package evolution issues. When a software distribution evolves, packages may be renamed or split up into multiple packages, or several packages may be merged into one. This may require updating meta-data in other packages for the distribution to remain consistent. Furthermore, version changes with a package may also require meta-data changes due to possible incompatibilities mentioned above. Unfortunately, meta-data changes are not automated, and are primarily the responsibility of the maintainer of a given package. This causes a potential for meta-data to be outdated and not reflect a correct state anymore.
5. The last category represents cases where two packages are incorrectly classified as conflicting, although there is no conflict, at least not for the current version of these packages.

Table 2 and Figure 1 show an overview of the classification into these five categories. Larger categories were split up into smaller groups to get a more detailed picture. While human error in the classification is possible, the results are overall quite clear for larger categories. Some trends are evident:

1. Resource conflicts are common, representing more than one third of all conflicts. 22 out of 48 such conflicts are on files and caught by the package manager at installation time; other similar conflicts may not be caught until a package is actually used.
2. Conflicts on configuration, and to a lesser degree, the format of shared data, are equally common. 17 cases were found where syntactic problems caused a conflict between packages; the most common reason is the automatic modification of configuration files by installation scripts. These installation scripts are likely tested for common configurations, but may not behave as expected for less common settings. Unintended semantic changes in configuration files occurred 14 times during installation, and 4 times after installation, so this is also a significant problem. It is compounded by the fact that many files have to be customized by the user before a package can be used, and the formatting of a configuration file may see subtle changes that are correctly dealt with by the packaged software itself, but not by the installation scripts that manage the package.

Classification of inter-package conflicts

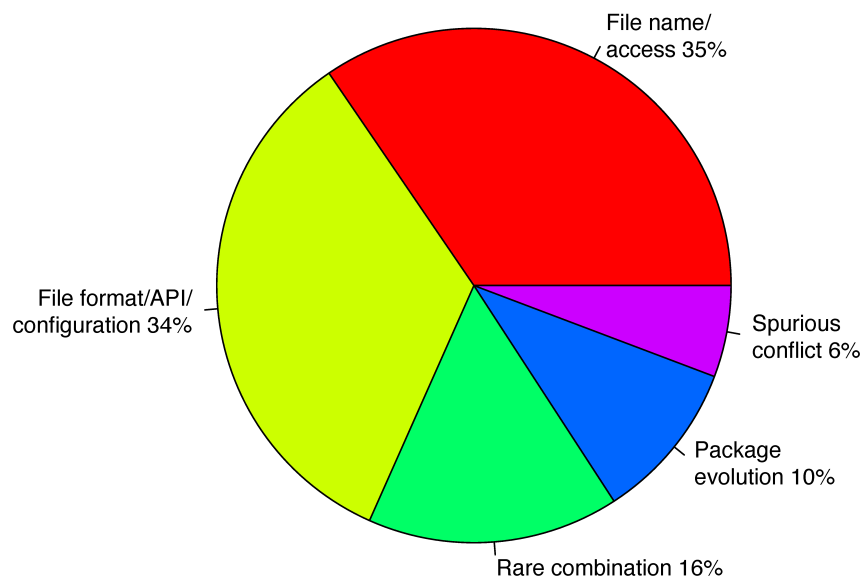


Figure 1: Overview of sources of inter-package conflicts.

# of conflicts	Conflict type
48	access to files and similar shared resources
22	package provides same file as other package
4	package installers modify or delete file used by other package
2	file missing that is supposed to be provided by other package
3	packages modify/disable same shared resource or package
3	file permission conflict on shared file
4	file/directory name conflict (for names including version number etc.)
9	clashing C library symbols/function names/device names
1	package removal script corrupts system
47	file/API/data/configuration format
17	update/installation breaks configuration or file format
14	package breaks on uncommon or user-defined configuration/setting
4	package use (post-install) overwrites/breaks configuration files
9	API change between different package version breaks other package
3	kernel package not compatible with given version of other package
22	rare (previously untested) combination of packages
13	defect in one package made visible by installation/use of other package
9	uncommon combination of packages makes one or more packages always fails
14	package evolution (split/merge/change) or faulty meta-data results in conflict
9	incorrect/outdated dependency meta-data (requires/conflicts)
5	package renaming/split/merge results in incorrect meta-data of other package
8	spurious “conflicts” declaration prevents compatible packages from being used

Table 2: Overview of all package conflicts found in the Debian bug database.

- Other problems between packages that are usually not installed together represent one out of six inter-package conflicts. The huge number of available packages makes it impossible to test all combinations (or even just all pairwise possible combinations) of packages together, so a conflict often goes undetected until reported by a user.
- Conflicts on meta-data level, often caused by package evolution, contribute about 10 %.
- Incorrect (or outdated) information on conflicting packages sometimes occurs as well, which does not create a package conflict per se, but instead prevents two packages from being used together.

4 Discussion

The previous section has given a categorization of inter-package conflicts based on empirical data. We now propose possible solutions that can potentially cover some or all instances of each class of conflicts.

- Conflicts on files are not directly covered by existing meta-data, although they may be implied by package-level conflicts. Work is in progress to systematically test package installations against overwriting files provided by another package [16]. As an alternative to this, *file diversions* enable a package to install files at a different location; work is in progress to automate this.¹

This case study shows that while the majority of such conflicts occurs at file level, file *permissions* (and ownership) rather than just file names, and possible file/directory renaming actions during

¹<http://wiki.debian.org/SummerOfCode2011/DeclarativeDiversions>, retrieved June 2011

package upgrades, should also be considered. Finally, coverage of similar resources such as network ports and C function names would further augment the ability of such tools to detect conflicts proactively.

More detailed meta-data will require much more space than existing (rather compact) package meta-data. We propose that such extra meta-data is generated and used only by developers and package maintainers. As it covers possible conflicts proactively, at development time, extra meta-data does not have to be included in the final distribution. We think that most or all of such resource-related meta-data can be extracted automatically from test runs, therefore requiring no extra effort from package maintainers.

2. Conflicts on configuration files, file formats and API versions are also common, and clearly demonstrate the need of systematic testing against such conflicts. In the light of testing against overwriting files [16], inter-package tests should also be automatically run against conflicts on shared data. This is much more difficult to automate, and only feasible for packages that include automatic regression tests.

The problem is that regression tests are used by developers and package maintainers, but not by end users who install and use these packages. Because of this, regression tests are currently not covered by package meta-data. This makes them inaccessible to today's package management tools, and pretty much precludes the automated discovery of such intricate conflicts. However, at a lower level, many source-level distributions have a "make test" or "make check" build target that automatically performs such tests. In the future, such information could be provided in package meta-data, for package maintainers. Furthermore, on a basic level, certain problems may be found just by executing a program and checking whether its return value indicates an error, or by attempting to start and stop a system service cleanly.

3. The fact that rare combinations of packages may cause problems is not surprising, given the large number of packages available. An exhaustive testing of package combinations is not feasible, but heuristic-based testing of sets of packages may be. A possible approach may be to install larger subsets of packages, and to narrow down the set of conflicting packages by a systematic search such as delta debugging [17].
4. Package evolution often brings with it an invalidation of package meta-data. The fact that about one tenth of inter-package conflicts occurred directly due to invalid meta-data after larger package modifications (such as splitting a package into two packages), shows that meta-data needs to be verified for consistency and accuracy. Especially when given a situation with "known good" meta-data (before the modification), automatic verification of the new meta-data is feasible if packages can be tested automatically.

As with other issues described above, meta-data does not cover the requirements of packages in enough detail. For example, take a package a that is split up into a' and a'' , because some parts of a are not used by many packages. If a package b depended on a in the old configuration, it is possible that it will depend on a' , a'' , or both packages in the new configuration. If some of the resources provided by these packages are loaded dynamically by b (at run-time), then verification of the actual software is required to determine the correct new dependency.

5. Spurious (or outdated) declarations of inter-package conflicts can be responded to, by automated testing of packages that supposedly conflict. As mentioned above, work is in progress to detect file-level conflicts, but other types of conflicts require more detailed meta-data, or mechanisms to better support the automatic testing of the execution of the software that packages provide.

5 Conclusions and Future Work

Conflicts between software packages occur due to a variety of reasons. Conflicts on shared resources and configuration files are particularly common. The underlying problem is that package behavior at installation, use, and de-installation time is unrestricted, so a complete formal description of package behavior cannot be achieved. However, steps can be taken towards increasing the expressiveness and accuracy of package meta-data, by adding meta-data that is intended for package developers and maintainers.

In our case study, we categorize a large number of inter-package conflicts, and propose possible solutions to common categories of conflicts. Our study uses a single snapshot of bugs between packages reported in Debian GNU/Linux. Future work includes studying the evolution of packages, and bugs reported, in more depth by investigating multiple snapshots over time. Furthermore, other software distributions such as Fedora may also be considered.

As a conclusion from our initial case study, we found that ongoing and future projects can reduce inter-package conflicts most efficiently by (a) identifying and testing combinations of packages that may conflict, (b) generating and using extra meta-data, and (c) checking the validity of (manually provided) meta-data. Such meta-data should cover files including file meta-data in particular, and as a next step, other system resources such as network ports, shared (global) configuration data, and communication between components. Another aspect currently omitted in meta-data is information about regression tests that already exist in many packages, but are inaccessible on a package level because they are not declared or available in a uniform way.

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