Towards better tools for the analysis and quality assurance of FOSS distributions

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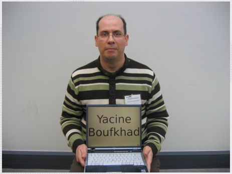

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Software Components

Proposed 1968 by Douglas McIlroy as a remedy to the "software crisis".

Some characteristics of components:

1. Multiple-use
2. Encapsulated i.e., non-investigable through its interfaces
3. A unit of independent deployment and versioning
4. Composable with other components

Problem: conflict between (3) and (4):

- Components evolve independently of each other, ...
- ... but they still have to work together.

The importance of components

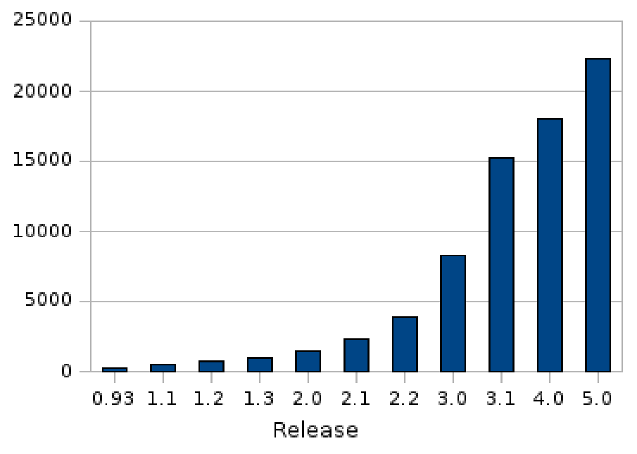
- Components can exist at different level: objects in the sense of an object oriented programming language, plugins for a specific platform, software packages in a GNU/Linux distribution, ...
- Main reason for bundling software items (programs, libraries, documentation, ...) into packages: ease of deployment and installation.
- Without Software packages we either would have
  - one single large system image
  - or compile and install every single program by hand
- Sharing of functionality between open components, instead of autonomous and closed software packages.

Free and Open Source Software (F/OSS)

The F/OSS infrastructure is particularly challenging:

- no central architect
- fast, distributed development
- strong interdependencies
- very large code base (Debian: $>$ 30.000 packages)
- provide packages for several compute architectures at a time (Debian: currently 11 architectures officially supported)
- possibly provide packages for several operating systems (Debian: 2 released OS, 1 experimental OS)

Number of binary packages in Debian



- Version 6.0 (Feb 2011): 28.000 packages

Players in the F/OSS universe

- "Upstream" authors : independent, develop software
- (sometimes) intermediate software assemblers: CPAN (perl), texlive (TEX)
- Distribution editors : create a coherent software distribution (Debian, Ubuntu, Mandriva, ...)
- Sysadmins: install distribution on machine; updates
- Users

Workflow for the Package Maintainer

- Get upstream program. Is it fit for release?
- Create/update a *source* package: format mostly useful for specific tools of the distribution (for instance: Debian) Compilation of source packages produces (in general several) binary packages.
- Testing, use automatic tools for assessing the quality (rare!)
- Publish both source package and binary packages.
- Automatic compilation for other architectures/OS
- Wait for bug reports . . .

Workflow for the Distribution Editor

- Source and binary packages are coming from individual maintainers
- Is the quality of individual packages OK?
- Is the quality of the *collection of packages* OK?
- From time to time: freeze the packages, throw out the bad ones, fix coherence problems, make an official release of a complete collection. (this is always a major pain!)

The current state of Quality Assurance in F/OSS

- Tests, sometimes automatic, for compilation and installation.
- No automatic generation of test cases
- No usage of automatic verification tools
- Urgent need of automatic tools for quality assurance both of individual packages, and of the distribution as a whole.

Workflow for the Sysadmin

- Initial installation of a complete distribution
- Add new packages to an existing installation
- Upgrade individual packages, or all packages (new functionalities, bug fixes, security updates)
- Probably: remove packages.

Why is FOSS interesting?

- Components, however components also exist elsewhere.
- A problem of scale: Large number of components, rapid evolution.
- All the data is freely available to everyone.
- We want to contribute to the advancement of FOSS.

The Mancoosi Project

mancoosi
managing software complexity

SEVENTH FRAMEWORK PROGRAMME

- Mancoosi: Managing the Complexity of the Open Source Infrastructure
- European Research Project in the 7th Framework
- Duration: Feb 2008 $\longrightarrow$ Mai 2011
- Successor of the EDOS European project (Jan 2004 $\longrightarrow$ Jun 2007)

edos
www.edos-project.org

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Concrete view of a package

A package consists of

- An archive of files that are to be placed on the target host (for instance a file $/usr/bin/ocaml$)
- Optionally some actions that are performed when installing, upgrading, or removing a package: create symbolic links, create or remove user and groups, (un)register documentation, update hashtables, restart or stop services, ...

Concrete view of packages (2)

A package has prerequisites:

- System resources (disk space, ...)
- A certain version of a certain operating system
- File system structure (existence of, and access rights to certain directories)
- Availability of software libraries in a specific version
- Executability of other stand-alone tools

Abstract view of packages

A package contains *metadata*:

- A package provides a certain functionality that is denoted by the name of the package, probably refined by the version number.
- A package may also provide a even more abstract functionality (*feature*, *virtual package*), i.e. `web-browser`
- All prerequisites are expressed through relations to other packages (or virtual packages), or possibly other meta-data i.e. space consumption of the package.

A concrete example of metadata

```
Package: hevea
Installed-Size: 2112
Maintainer: Debian OCaml Maintainers
  <debian-ocaml-maint@lists.debian.org>
Architecture: all
Version: 1.10-5
Depends: gs, netpbm (>= 2:9.10-1), ocaml-base-nox-3.10.2,
  tetex-bin | texlive-base, tex-common (>= 1.10)
Suggests: hevea-doc
Description: translates from LaTeX to HTML, info, or text .
Homepage: http://hevea.inria.fr/
Tag: implemented-in::ocaml, interface::commandline, ...
```

An more complex example

```
Package: myspell-hu
Architecture: all
Source: magyarispell
Version: 0.99.4-1.1
Provides: myspell-dictionary, myspell-dictionary-hu,
   myhungarian
Depends: dictionaries-common (>= 0.10) | openoffice.org-upd
Suggests: openoffice.org
Conflicts: openoffice.org (<= 1.0.3-2), myhungarian
```

Model (simplified)

Names, Versions and Constraints

- Set N of names
- Set V of versions: total and dense order
- Set $\textsc{Con}$ of constraints : $= v, > v, < v, \ldots$ where $v \in \mathrm{V}$

A *package* (c, v, D, C) consists of

- a package name n,
- a *version* v,
- a set of dependencies $D \in \mathcal{P}(\mathcal{P}(\mathrm{N} \times \textsc{Con}))$,
- a set of conflicts $C \in \mathcal{P}(\mathrm{N} \times \textsc{Con})$,

A repository

is a set of packages, such that no two different packages carry the same name.

An R-installation

is a set $I \subseteq R$ with:

abundance For each element $d \in p.D$ there exists $(n, c) \in d$ and a package $q \in I$ such that $q.n = n$ and $p.v \in [[c]]$.

peace For each $(n, c) \in p.C$ and package $q \in I$, if $q.n = n$ then $q.v \notin [[c]]$.

flatness For all $p, q \in I$: if $p \neq q$ then $p.n \neq q.n$

Installability

$p \in R$ is R-installable if there exists an R-installation I with $p \in I$.

Is a installable in R?

Repository R

```
Package: a
Version: 1
Depends: b, c, d

Package: b
Version: 17

Package: c
Version: 42
Conflicts: b
```

Is a installable in R?

Repository R

```
Package: a
Version: 1
Depends: b, c

Package: b
Version: 17

Package: c
Version: 42
Conflicts: b > 15
```

Is a installable in R?

Is *a* installable in *R*?

Repository *R*

```
Package: a
Version: 1
Depends: b >= 18, c

Package: b
Version: 17

Package: b
Version: 18

Package: c
Version: 42
Depends: b <= 17
```

Is *a* installable in *R*?

Repository *R*

```
Package: a
Version: 1
Depends: b, c|d

Package: b
Version: 17

Package: c
Version: 42
Conflicts: b > 15

Package: d
Version: 87
Depends: b < 20
```

Modeling packages and dependencies

- (Package,version) = Propositional variable
  (package installed = value true)
- Complete installation = propositional model
- Modeling dependencies: $p \to \phi$ where ϕ is a positive formula
- Package p is not available: $\neg p$.
- Dependency theory D: *dual Horn theory*:
  Models are closed under union
- p is installable w.r.t. D : $D \wedge p$ satisfiable.
- Since D is dual Horn: p, q co-installable iff p installable and q installable (so far).

Modeling conflict relations

conflicts

- A package p may be in conflict with several other packages $q_1, q_2, \ldots$.
- Conflict theory C: $\{\neg(p \wedge q_1), \neg(p \wedge q_2), \ldots\}$ (neither Horn nor dual Horn)
- p is installable: $p \wedge P \wedge C$ is satisfiable.

A result from EDOS [ASE 2006]

Installability of packages (measured in the number of packages) is NP-complete.

Modeling virtual packages

virtual package

If packages $p_1, \ldots, p_n$ provide a virtual package q:

$$q \rightarrow p_1 \vee \ldots \vee p_n$$

Exclusivity constraint

- Package p both provides q and conflicts with q.
- For every package $p' \neq p$ that provides q: $\neg(p \wedge p')$.
- Use case: allow only one package that provides a functionality, for instance `mail-transport-agent`.

EDOS-debcheck

- Written by Jérôme Vouillon in 2005, using SAT-solver technology
- Computes, for a complete distribution, *all* non-installable packages with explanation.
- And it does this in *a few seconds*.
- Integration into `pkglab`, an interactive system to explore package repositories of package-based software distributions.

Usage in Debian

Web service `edos.debian.net`

Uninstallable packages in testing/main 17–23 June 2008:

Date	alpha	amd64	arm	armel	hppa	i386	ia64	mips	mipsel	power
23/06	367(7)	14(2)	217(4)	348(21)	369(9)	12(4)	48(3)	267(3)	269(3)	21(3)
∆	+0/−0	+0/−0	+0/−1	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−3
22/06	367(7)	14(2)	218(4)	348(21)	369(9)	12(4)	48(3)	267(3)	269(3)	24(4)
∆	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−3	+0/−3	+0/−0
21/06	367(7)	14(2)	218(4)	348(21)	369(9)	12(4)	48(3)	270(4)	272(4)	24(4)
∆	+0/−0	+0/−3	+0/−3	+0/−9	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0
20/06	367(7)	17(3)	221(5)	357(24)	369(9)	12(4)	48(3)	270(4)	272(4)	24(4)
∆	+7/−0	+3/−0	+4/−3	+3/−27	+4/−0	+3/−0	+3/−0	+5/−11	+5/−0	+5/−0
19/06	360(5)	14(2)	220(6)	381(31)	365(8)	9(3)	45(2)	276(2)	267(2)	19(2)
∆	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0
18/06	360(5)	14(2)	220(6)	381(31)	365(8)	9(3)	45(2)	276(2)	267(2)	19(2)
∆	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0	+0/−0
17/06	360(5)	14(2)	220(6)	381(31)	365(8)	9(3)	45(2)	276(2)	267(2)	19(2)

Use in Debian (done by us)

- Release Team is using this information when finalising an official release.
- Detect *file conflicts* between packages: find pairs of packages that contain the same file and that can be installed together.

Use in Debian (not done by us)

- Verify installability of packages before uploading them to the archive, currently done by the *embedian* sub-project (debian for embedded systems).
- Used by debian autobuilders to avoid useless attempts to create build environments.

Putting results into practice

- The FOSS world is to a large extend influenced by a culture of volunteer communities (despite the fact that there are also players with important commercial interests).
- *Do-ocracy* : if you want to change the way things are done you have to implement it yourself and demonstrate that it works.
- Putting results into practice:
  - Identify a real problem in your community
  - Solve the problem with your technology
  - Integrate your solution into your community's infrastructure and workflow
  - Convince people that it is useful.

The problem

distcheck

Given a repository R and a package $(p, n) \in R$, is (p, n) uninstallable w.r.t R?

Our question

Given a repository R and a package $(p, n) \in R$, is (p, n) uninstallable w.r.t *all possible futures of* R?

To be made more precise

Define "possible futures of R"

Example 1: Is (*foo*,1) installable?

```
Package: foo
Version: 1
Depends: baz (= 2.5) | bar (= 2.3),
  bar (> 2.6) | baz (< 2.3)

Package: bar
Version: 2

Package: baz
Version: 2
Conflicts: bar (< 3)
```

Example 2: Will (*foo*,1) ever be installable?

```
Package: foo
Version: 1
Depends: baz (= 2.5) | bar (= 2.3),
  bar (> 2.6) | baz (< 2.3)

Package: bar
Version: 2.6

Package: baz
Version: 2.5
Conflicts: bar (> 2.6)
```

Is this useful?

- One asks for installability of the *current version* of package p in all futures of R.
- If a future F of R contains (p, m) with $m > n$ then (p, n) is (vacuously) not installable in F.
- The question is in reality about all futures of R *that contain the original version of* p.
- Interesting for QA: such a package definitely needs action, since noone else can fix it!

Is the problem difficult?

- Not-installability of a package w.r.t. a current repository: co-NP complete.
  - For installability one guesses an installation (coherence is trivial to verify)
  - Allows to encode 3-SAT
- Not-installability of a package w.r.t. all possible futures:
  - co-NP hard, since it allows to encode the original non-installability problem.
  - however, there are infinitely many possible futures of a repository!

What are possible futures of R?

First approximation:

- Packages can move to newer versions (there is a total and dense ordering on version numbers)
- Newer versions of packages my change their relations in any way (quite pessimistic approximation)
- Packages may be removed.
- New packages may pop up.
- There are infinitely many possible futures.

What are possible futures of R?

A further complication (ignored for most of the rest of this talk):

- In a distribution, packages are upgraded by clusters of *source packages*. $\Rightarrow$ all packages with the same source are synchronized in their version.
- This ignores abnormal situations due to autobuilder failure.
- It also ignores the fact that packages may change their source (this happens!)
- Problem: a source package may generate binary packages with different versions $\Rightarrow$ it is not clear how future versions of binary packages relate.

Formalization of futures

Futures

A repository F is a *future* of a repository R, written $R \rightsquigarrow F$, if

monotonicity For all $p \in R$ and $q \in F$: if $p.n = q.n$ then $p.v \leq q.v$.

Upgrades

If $R \rightsquigarrow F$, we say that a package $p \in R$ is *upgraded* when there is a $q \in F$ with $p.n = q.n$ and $p.v < q.v$.

Admissible properties (1)

$names(R)$: names of packages defined in R.

Focus of package sets

Let R, P be two sets of packages The R-*focus* of P is

$$\pi_R(P) := \{(p.n, p.v)) \mid p \in P, p.n \in names(R)\}$$

Focused properties

A property ϕ of installations is called R-*focused* if for all installations I_1 and I_2 (not necessarily subsets of R)

$$\pi_R(I_1) = \pi_R(I_2) \text{ implies } \phi(I_1) = \phi(I_2)$$

Admissible properties (2)

Admissible properties of futures

Let R be a repository. A property ψ of futures of R is called *admissible* if there is an R-focused property ϕ of installations such that for all futures F of R:

$$\psi(F) \Leftrightarrow \text{ for all } F\text{-installations } I\text{: } \phi(I)$$

Outdated packages

Let R be a repository. A package $p \in R$ is *outdated* in R if p is not installable in any future F of R.

Outdated is admissible

p is *outdated* in R iff $\forall F.\forall I \in \mathit{Inst}(F), \phi_{out}(I)$ where

$$\phi_{out}(I) = (p.n, p.v) \notin \pi_R(I)$$

Optimistic Futures

Definition

A repository F is an *optimistic future* of a repository R if any package in $F - R$ has empty dependency and conflicts.

Lemma

Let R be a repository, and ψ an *admissible* property of repositories. The following two assertions are equivalent:

- All futures F of R satisfy ψ.
- All optimistic futures F of R satisfy ψ.

Conservative Futures

depnames(R): names of packages used in dependencies in R.

Definition

Let $R \rightsquigarrow F$. F is a *conservative* future of R if

$$names(F) = names(R) \cup depnames(R)$$

Lemma

Let R be a repository, and ψ an *admissible* property of repositories. The following two assertions are equivalent:

- All futures F of R satisfy ψ.
- All optimistic and conservative futures F of R satisfy ψ.

What remains to solve

- We have only a finite set of new package names.
- We may ignore package removals.
- New versions of packages have no relations (but conflict implicitly with different versions of packages with the same name, due to Debian semantics).
- Remaining problem : infinitely many future versions of packages, hence infinitely many future repositories.

Finitely many versions

- It is sufficient to consider, for package name p, version numbers that are explicitly mentioned, plus one intermediate, plus one that is beyond.
- Example : $(p, 5) \in R$
  Dependencies and conflicts in R on $(p, \diamond 9)$, $(p, \diamond 12)$, where $\diamond$ is any comparison.
- Representatives of future versions of p :

$$5, 6(\in]5, 9[), 9, 10(\in [9, 12[), 12, 13(> 12)$$

Further reduction: observational equivalence

- Consider all unary predicates on versions of p occurring in R
- Build quotient under observational equivalence: identifying versions that behave the same on all these unary predicates.

Still, that's a huge number of repositories

- So far we have a finite set (but huge) set F of repositories.
- Packages (p, n) in any repository in F are unique (same metadata).
- We can build a new repository : $\bigcup F$, containing representatives of the complete future of all relevant packages.
- ☺Any $R \in F$-installation is a $\bigcup F$-installation.
- ☹There are $\bigcup F$ installations that aren't in any future repository because ...

The problem when lumping together all futures

- Binary packages coming from the same source are synchronized !
- When considering $\bigcup F$: we have to exclude installations that mix binary packages coming from the same source but different version.
- Solution: add (versioned!) provides and conflicts:
- If (p, n) has source s: Add
  Provides: src:s $(= n)$
  Conflicts: src:s $(\neq n)$
- Finally : One single `distcheck` run on a large repository .

Conclusion

- Class of admissible properties of futures.
- Finite set of futures to consider.
- Another instance of this class: "In any future in which p is upgraded (now matter how) and without touching any other packages, it is no longer possible to install q".
- To do: define a logic for package repositories!