Possible Directions for Improving Dependency Versioning in R

by Jeroen Ooms

Abstract One of the most powerful features of R is its infrastructure for contributed code. The built-in package manager and complementary repositories provide a great system for development and exchange of code, and have played an important role in the growth of the platform towards the de-facto standard in statistical computing that it is today. However, the number of packages on CRAN and other repositories has increased beyond what might have been foreseen, and is revealing some limitations of the current design. One such problem is the general lack of dependency versioning in the infrastructure. This paper explores this problem in greater detail, and suggests approaches taken by other open source communities that might work for R as well. Three use cases are defined that exemplify the issue, and illustrate how improving this aspect of package management could increase reliability while supporting further growth of the R community.

Package management in R

One of the most powerful features of R is its infrastructure for contributed code (Fox, 2009). The base R software suite that is released several times per year ships with the *base* and *recommended* packages and provides a solid foundation for statistical computing. However, most R users will quickly resort to the package manager and install packages contributed by other users. By default, these packages are installed from the "Comprehensive R Archive Network" (CRAN), featuring over 4300 contributed packages as of 2013. In addition, other repositories like BioConductor (Gentleman et al., 2004) and Github (Dabbish et al., 2012) are hosting a respectable number of packages as well.

The *R Core team* has done a tremendous job in coordinating the development of the base software along with providing, supporting, and maintaining an infrastructure for contributed code. The system for sharing and installing contributed packages is easily taken for granted, but could in fact not survive without the commitment and daily efforts from the repository maintainers. The process from submission to publication of a package involves several manual steps needed to ensure that all published packages meet standards and work as expected, on a variety of platforms, architectures and R versions. In spite of rapid growth and limited resources, CRAN has managed to maintain high standards on the quality of packages. Before continuing, we want to express appreciation for the countless hours invested by volunteers in organizing this unique forum for statistical software. They facilitate the innovation and collaboration in our field, and unite the community in creating software that is both of the highest quality and publicly available. We want to emphasize that suggestions made in this paper are in no way intended as criticism on the status quo. If anything, we hope that our ideas help address some challenges to support further growth without having to compromise on the open and dynamic nature of the infrastructure.

The dependency network

Most R packages depend on one or more other packages, resulting in a complex network of recursive dependencies. Each package includes a 'DESCRIPTION' file which allows for declaration of several types of dependencies, including Depends, Imports, Suggests and Enhances. Based on the type of dependency relationship, other packages are automatically installed, loaded and/or attached with the requested package. Package management is also related to the issue of *namespacing*, because different packages can use identical names for objects. The 'NAMESPACE' file allows the developer to explicitly define objects to be exported or imported from other packages. This prevents the need to attach all dependencies and lookup variables at runtime, and thereby decreases chances of masking and naming-conflicts. Unfortunately, many packages are not taking advantage of this feature, and thereby force R to attach all dependencies, unnecessarily filling the search path of a session with packages that the user hasn't asked for. However, this is not the primary focus of this paper.

Package versioning

Even though CRAN consistently archives older versions of every package when updates are published, the R software itself takes limited advantage of this archive. The package manager identifies packages by name only when installing or loading a package. The install.packages function downloads and

installs the *current* version of a CRAN package into a single global library. This library contains a single version of each package. If a previous version of the package is already installed on the system, it is overwritten without warning. Similarly, the `library` function will load the earliest found package with a matching name.

The 'DESCRIPTION' file does allow the package author to specify a certain version of a dependency by postfixing the package name with >=, <= or == and a version string. However, using this feature is actually dangerous because R might not be able to satisfy these conditions, causing errors. This is again the result of R libraries, sessions and repositories being limited to a single current version of each package. When a package would require a version of a dependency that is not already installed or current on CRAN, it can not be resolved automatically. Furthermore, upgrading a package in the global library to the current CRAN version might break other packages that require the previously installed version. Experienced R users might try to avoid such problems by manually maintaining separate libraries for different tasks and projects. However, R can still not have multiple versions of a package loaded concurrently. This is perhaps the most fundamental problem because it is nearly impossible to work around. If package authors would actually declare specific versions of dependencies, any two packages requiring different versions of one and the same dependency will conflict and cannot be used together. In practice, this limitation discourages package authors to be explicit about dependency versions. The >= operator is used by some packages, but it only checks if an installed dependency is outdated and needs to be synchronized with CRAN. It still assumes that any current of future version will suffice, and does not protect packages from breaking when their dependency packages change. The <= and == operators are barely used at all.

When identifying a package by its name only, we implicitly make the assumption that different versions of the package are interchangeable. This basic assumption has far-reaching implications and consequences on the distributed development process and reliability of the software as a whole. In the context of the increasingly large pool of inter-dependent packages, violations of this assumption are becoming increasingly apparent and problematic. In this paper we explore this problem is greater detail, and try to make a case for moving away from this assumption, towards systematic versioning of dependency relationships. The term *dependency* in this context does not exclusively refer to formally defined relations between R packages. Our interpretation is a bit more general in the sense that any R script, Sweave document, or third party application *depends* on R and certain packages that are needed to make it function. The paper is largely motivated by personal experiences, as we have come to believe that limitations of the current dependency system are underlying multiple problems that R users and developers might experience. Properly addressing these concerns could resolve several lingering issues at once, and make R a more reliable and widely applicable analytical engine.

Use cases

A dependency defines a relationship wherein a certain piece of software requires some other software to run or compile. However, software constantly evolves, and in the open source world this happens largely unmanaged. Consequently, any software library might actually be something different today than it was yesterday. Hence, solely defining the dependency relationship in terms of the name of the software is often insufficient. We need to be more specific, and declare explicitly which version(s), branch(es) or release(s) of the other software package will make our program work. This is what we will refer to as *depencency versioning*.

This problem is not at all unique to R; in fact a large share of this paper consist of taking a closer look at how other open source communities are managing this process, and if some of their solutions could apply to R as well. But first we will elaborate a bit further on how this problem exactly appears in the context of R. This section describes three use cases that reveal some limitations of the current system. These use cases delineate the problem and lead towards suggestions for improvements in subsequent sections.

Case 1: Archive / repository maintenance

A medium to large sized repository with thousands of packages has a complicated network of dependencies between packages. CRAN is designed to consider the very latest version of every package as the only *current* version. This design relies on the assumption that at any given time, the latest versions of all packages are compatible. Therefore, R's built-in package manager can simply download and install the current versions of all dependencies along with the requested package, which seems convenient. However, to developers this means that every package *update* needs to maintain full backward compatibility with all previous versions. No version can introduce any breaking changes, because other packages in the repository might be relying on things in a certain way. Functions or objects may never be removed or modified; names, arguments, behavior, etc, must

remain the same. As the dependency network gets larger and more complex, this policy becomes increasingly vulnerable. It puts a heavy burden on contributing developers, especially the popular ones, and results in increasingly large packages that are never allowed to deprecate or clean up old code and functionality.

In practice, the assumption is easily violated. Every time a package update is pushed to CRAN, there is a real chance of some reverse dependencies failing due to a breaking change. In the case of the most popular packages, the probability of this happening is often closer to 1 than to 0, regardless of the author. Uwe Ligges has stated in his keynote presentation at useR that CRAN automatically detects some of these problems by rebuilding every package up in the dependency tree. However, only a small fraction of potential problems reveal themselves during the build of a package, and when found, there is no obvious solution. One recent example was the forced roll-back of the **ggplot2** (Wickham, 2009) update to version 0.9.0, because the introduced changes caused several other packages to break. The author of the **ggplot2** package has since been required to announce upcoming updates to authors of packages that depend on **ggplot2**, and provide a release candidate to test compatibility. The dependent packages are then required to synchronize their releases if any problems arise. However, such manual solutions are far from flawless and put even more work on the shoulders of contributing developers. It is doubtful that all package authors on CRAN have time and resources to engage in an extensive dialogue with other maintainers for each update of a package. We feel strongly that a more systematic solution is needed to guarantee that software published on CRAN keeps working over time; current as well as older versions.

When the repository reaches a critical size, and some packages collect hundreds of reverse dependencies, we have little choice but to acknowledge the fact that every package has only been developed for, and tested with certain versions of its dependencies. A policy of assuming that any current or future version of a dependency should suffice is dangerous and sets the wrong incentives for package authors. It discourages change, refactoring or cleanup, and results in packages accumulating an increasingly heavy body of legacy code. And as the repository grows, it is inevitable that packages will nevertheless eventually break as part of the process. What is needed is a redesign that supports the continuous decentralized change of software and helps facilitate more reliable package development. This is not impossible: there are numerous open source communities managing repositories with more complex dependency structures than CRAN. Although specifics vary, they form interesting role models to our community. As we will see later on, a properly archived repository can actually come to be a great asset rather than a liability to the developer.

Case 2: Reproducibility

Replication is the ultimate standard by which scientific claims are judged. However, complexity of data and methods can make this difficult to achieve computational science (Peng, 2011). As a leader in scientific computing, R takes a pioneering role in providing a system that encourages researchers to strive towards the gold standard. The CRAN Task View on Reproducible Research states that:

> The goal of reproducible research is to tie specific instructions to data analysis and experimental data so that scholarship can be recreated, better understood and verified.

In R, reproducible research is largely facilitated using literate programming techniques implemented in packages like **Sweave** that mix (weave) R code with LaTeX-markup to create a "reproducible document" (Leisch, 2002). However, those ever faced with the task of actually reproducing such a document might have experienced that the Sweave file does not always compile out of the box. Especially if it was written several years ago and loads some contributed packages, chances are that essential things have changed in the software since the document was created. When we find ourselves in such a situation, recovering the packages needed to reproduce the document might turn out to be non-trivial.

An example: suppose we would like to reproduce a Sweave document which was created with R 2.13 and loads the **caret** package (Kuhn, 2013). If no further instructions are provided, this means that any of the approximately 25 releases of **caret** in the life cycle of R 2.13 (April 2011 to February 2012) could have been used, making reproducibility unlikely. Sometimes authors add comments in the code where the package is loaded, stating that e.g. **caret 4.78** was used. However, this information might also turn out to be insufficient: **caret** depends on 4 packages, and suggests another 59 packages, almost all of which have had numerous releases in R 2.13 time frame. Consequently, **caret 4.78** might not work anymore because of changes in these dependencies. We then need to do further investigation to figure out which versions of the dependency packages were current at the time of the **caret 4.78** release. Instead, lets assume that the prescient researcher anticipated all of this, and saved the full output of `sessionInfo()` along with the Sweave document, directly after it was compiled. This output lists the version of each loaded package in the active R session. We could then proceed by manually downloading and installing R 2.13 along with all of the required packages from the archive. However,

users on a commercial operating systems might be up for another surprise: unlike source packages, binary packages are not fully archived. For example, the only binary builds available for R 2.13 are respectively **caret 5.13** on Windows, and **caret 5.14** on OSX. Most likely, they will face the task of rebuilding each of the required packages from source in an attempt to reconstruct the environment of the author.

Needless to say, this situation is suboptimal. For manually compiling a single Sweave document we might be willing to make this effort, but it does not provide a solid foundation for systematic or automated reproducible software practices. To make results generated by R more reproducible, we need better conventions and/or native support that is both explicit and specific about contributed code. For an R script or Sweave document to stand the test of time, it should work at least on the same version of R that was used by the author. In this respect, R has higher requirements on versioning than other software. Reproducible research does not just require a version that will make things work, but one that generates exactly the same output. In order to systematically reproduce results R, package versions either need to be standardized, or become a natural part of the language. We realize this will not archive perfect reproducibility, as problems can still arise due to OS or compiler specific behavior. However, it will be a major step forward that has the potential of turning reproducibility into a natural feature of the software, rather than a tedious exercise.

Case 3: Production applications

R is no longer exclusively used by the local statistician through an interactive console. It is increasingly powering systems, stacks and applications with embedded analytics and graphics. When R is part of say, an application used in hospitals to create on-demand graphics from patient data, the underlying code needs to be stable, reliable, and redistributable. Within such an application, even a minor change in code or behavior can result in complete failure of the system and cannot easily be fixed or debugged. Therefore, when an application is put in production, software has to be completely frozen.

An application that builds on R has been developed and tested with certain versions of the base software and R packages used by the application. In order to put this application in production, exactly these versions need to be shipped, installed and loaded by the application on production servers. Managing, distributing and deploying production software with R is remarkably hard, due to limited native dependency versioning and the single global library design. Administrators might discover that an application that was working in one place doesn't work elsewhere, even though exactly the same operating system, version of R, and installation scripts were used. The problem of course is that the contributed packages constantly change. Problems become more complicated when a machine is hosting many applications that were developed by different people and depend on various packages and package versions.

The default behavior of loading packages from a global library with bleeding edge versions is unsuitable for building applications. Because the CRAN repository has no notion of stable branches, one manually needs to download and install the correct versions of packages in a separate library for each application to avoid conflicts. This is quite tricky and hard to scale when hosting many applications. In practice, application developers might not even be aware of these pitfalls, and design their applications to rely on the default behavior of the package manager. They then find out the hard way that applications start breaking down later on, because of upstream changes or library conflicts with other applications.

Solution 1: staged distributions

The problem of managing bottom-up decentralized software development is not new; rather it is a typical feature of the open source development process. The remainder of this paper will explore two solutions from other open source communities, and suggest how these might apply to R. The current section describes the more classic solution that relies on staged software *distributions*.

A *software distribution* (also referred to as a *distribution* or a *distro*) is a collection of software components built, assembled and configured so that it can be used essentially "as is" for its intended purpose. Maintainers of distributions do not develop software themselves; they collect software from various sources, package it up and redistribute it as a system. Distributions introduce a formal release cycle on the continuously changing upstream developments and maintainers of a distribution take responsibility for ensuring compatibility of different packages within a certain release of the distribution. Software distributions are most commonly known in the context of free operating systems (BSD, Linux, etc). Staging and shipping software in a distribution has proven to scale well to very large code bases. For example, the popular Debian GNU/Linux distribution (after which R's package description format was modeled) features over 29000 packages with a large and complex dependency

network. No single person is familiar with even a fraction of the code base that is hosted in this repository. Yet through well organized staging and testing, this distribution is known to be one of the most reliable operating systems today, and is the foundation for a large share of the global IT infrastructure.

The release cycle

In a nutshell, a staged distribution release can be organized as follows. At any time, package authors can upload new versions of packages to the *devel* pool, also known as the *unstable* branch. A release cycle starts with distribution maintainers announcing a *code freeze* date, several months in advance. At this point, package authors are notified to ensure that their packages in the unstable branch are up to date, fix bugs and resolve other problems. At the date of the code freeze, a copy (fork) of the unstable repository is made, named and versioned, which goes into the *testing* phase. Software in this branch will then be subject to several iterations of intensive testing and bug fixing, sometimes accompanied by *alpha* or *beta* releases of the distribution. However, software versions in the testing branch will no longer receive any major updates that could potentially have side effects or break other packages. The goal is to converge to increasingly stable set of software. When after several testing rounds the distribution maintainers are confident that all serious problems are fixed, the branch is tagged *stable* and released to the public. Software in a stable release will usually only receive minor non-breaking updates, like important compatibility fixes and security updates. For the next "major release" of any software, the user will have to wait for the next cycle of the distribution. As such, everyone using a certain release of the distribution is using exactly the same versions of all programs and libraries on the system. This is convenient for both users and developers and gives distributions a key role in bringing decentralized open source development efforts together.

R: downstream staging and repackaging

The semi annual releases of the r-base software suite can already be considered as a distribution of the 29 base and recommended packages. However in the case of R, this collection is limited to software that has been centrally developed and released by the same group of people; it does not include contributed code. Due to the lack of native support for dependency versioning in R, several projects have introduced some form of downstream staging in order to create stable, redistributable collections R software. This section lists some examples and explains why this is suboptimal. In the next section we will discuss what would be involved with extending the R release cycle to contributed packages.

One way of staging R packages downstream is by including them in existing software distributions. For example, Eddelbuettel and Blundell (2009) have wrapped some popular CRAN packages into deb packages for the Debian and Ubuntu systems. Thereby, pre-compiled binaries are shipped in the distribution along with the R base software, putting version compatibility in the hands of the maintainers (among other benefits). This works well, but requires a lot of effort and commitment from the package maintainer, which is why this has only been done for a small subset of the CRAN packages. Most distributions expect high standards on the quality of the software and package maintenance, which makes this approach hard to scale up to many more packages. Furthermore, we are tied to the release cycle of the distribution, resulting in a somewhat arbitrary and perhaps unfortunate snapshot of CRAN packages when the distribution freezes. Also, different distributions will have different policies on if, when and which packages they wish to ship with their system.

Another approach is illustrated by domain-specific projects like BioConductor (genomic data) and REvolution R Enterprise (big data). Both these systems combine a fixed version of R with a custom library of frozen R packages. In the case of REvolution, the full library is included with the installer; for BioConductor they are provided through a dedicated repository. In both cases, this effectively prevents installed software from being altered unexpectedly by upstream changes. However, this also leads to a split in the community between users of R, BioConductor, and REvolution Enterprise. Because of the differences in libraries, R code is not automatically portable between these systems, leading to fragmentation and duplication of efforts. E.g. BioConductor seems to host many packages that could be more generally useful; yet they are unknown to most users of R. Furthermore, both projects only target a limited set of packages; they still rely on CRAN for the majority of the contributed code.

The goal of staging is to tie a fixed set of contributed packages to a certain release of R. If these decisions are passed down to distributions or organizations, a multitude of local conventions and repositories arises, and different groups of users will still be using different package versions. This leads to unnecessary fragmentation of the community by system, organization, or distribution channel. Moreover, it is often hard to assess compatibility of third party packages, resulting in somewhat arbitrary local decision making. It seems that the people who are in the best position to manage and control compatibility are the package authors themselves. This leads us to conclude that a more

appropriate place to organize staging of R packages is further upstream.

Branching and staging in CRAN itself

Given that the community of R contributors evolves mainly around CRAN, the most desirable approach to organizing staging would be by integrating it with the publication process. Currently, CRAN is managed as what distributions would consider a *development* or *unstable* branch. It consists of the pool of *bleeding-edge* versions, straight from package authors. Consequently it is wise to assume that software in this branch might break on a regular basis. Usually, the main purpose of an *unstable* branch is for developers to exchange new versions and test compatibility of software. Regular users obtain software releases from *stable* branches instead. This does not sound unfamiliar: the r-base software also distinguishes between stable versions *r-release* and *r-release-old*, and an unstable development version, *r-devel*.

The fact that R already has an semi-annual release cycle for the 29 base and `recommended` packages, would make it relatively straightforward to extend this cycle to CRAN packages. A snapshot of CRAN could be frozen along with every version of *r-release*, and new package updates would only be published to the *r-devel* branch. In practice, this could perhaps quite easily be implemented by creating a directory on CRAN for each release of R, containing symbolic links to the versions of the packages considered *stable* for this release. In the case of binary packages for OSX and Windows, CRAN actually already has separate directories with builds for each release of R. However currently these are not frozen and continuously updated. In a staged repository, newly submitted packages are only build for the current *devel* and *testing* branches; they should not affect *stable* releases. Exceptions to this process could still be granted to authors that need to push an important update or bugfix within a stable branch, commonly referred to as *backporting*, but this should only happen incidentally.

To fully make the transition to a staged CRAN, the default behavior of the package manager must be modified to download packages from the stable branch of the current version of R, rather than the latest development release. As such, all users on a given version of R will be using the same version of each CRAN package, regardless on when it was installed. The user could still be given an option to try and install the development version from the unstable branch, for example by adding an additional parameter to `install.packages` named `devel=TRUE`. However when installing an unstable package, it must be flagged, and the user must be warned that this version is not properly tested and might not be working as expected. Furthermore, when loading this package a warning could be shown with the version number so that it is also obvious from the output that results were produced using a non-standard version of the contributed package. Finally, users that would always like to use the very latest versions of all packages, e.g. developers, could install the `r-devel` release of R. This version contains the latest commits by R Core and downloads packages from the devel branch on CRAN, but should not be used or in production or reproducible research settings.

Organizational change

Appropriate default behavior of the software is a key element to encourage adoption of conventions and standards in the community. But just as important is communication and coordination between repository maintainers and package authors. To make staging work, package authors must be notified of upcoming deadlines, code freezes or currently broken packages. Everyone must realize that the package version that is current at the time of code freeze, will be used by the majority of users of the upcoming version of R. Updates to already released *stable* branches can only be granted in exceptional circumstances, and must guarantee to maintain full backward compatibility. The policies of the BioConductor project provide a good starting point and could be adapted to work for CRAN.

Transitioning to a system of "stable" and "development" branches in CRAN, where the stable branch is conventional for regular users, could tremendously improve the reliability of the software. The version of the R software itself would automatically imply certain versions of contributed packages. Hence, all that is required to reproduce a Sweave document created several years ago, is which version of R was used to create the document. When deploying an application that depends on R 2.15.2 and various contributed packages, we can be sure that a year later the application can be deployed just as easily, even though the authors of contributed packages used by the application might have decided to implement some breaking changes. And package updates that deprecate old functionality or might break other packages that depend on it, can be uploaded to the *unstable* branch without worries, as the stable branches will remain unchanged and users won't be affected. The authors of the dependent packages that broke due to the update can be warned and will have sufficient time to fix problems before the next *stable* release.

Solution 2: versioned package management

The previous section described the "classical" solution of creating distributable sets of compatible, stable software. This is a proven approach and has been adopted in some way or another by many open-source communities. However, one drawback of this approach might be that some additional coordination is needed for every release. Another drawback is that it makes the software a bit more conservative, in the sense that regular users will generally be using versions of packages that are at least a couple of months old. The current section describes a different approach to the problem that is used by for example the Javascript community. This method is both reliable and flexible, however would require some more fundamental changes to be implemented in R.

Node.js and NPM

One of the most recent and fastest growing open source communities is that of the node.js software (for short: *node*), a Javascript server system based on the open source engine *V8* from Google. One of the reasons that the community has been able to grow rapidly is because of the excellent package manager and identically named repository, *NPM*. Even though this package manager is only 3 years old, it is currently hosting over 30000 packages with more than a million downloads daily, and has quickly become the standard way of distributing Javascript code. The NPM package manager is a powerful tool for development, publication and deployment of both libraries and applications. NPM addresses some problems that Javascript and R actually have in common, and makes an interesting role model for a modern solution to the problem.

The Javascript community can be described as decentralized, unorganized and highly fragmented development without any quality control authority. Similar to CRAN, NPM basically allows anyone to claim a "package name" and start publishing packages and updates to the repositories. The repository has no notion of branches and simply stores every version of a package indefinitely in its archives. However, a major difference with R is how the package manager handles installation, loading and namespacing of packages.

Dependencies in NPM

Every *NPM* package ships with a file named 'package.json', which is the equivalent of the 'DESCRIPTION' in R packages, yet a bit more advanced. An overview of the full feature set of the package manager is beyond the scope of this paper, but the interested reader is highly encouraged to take a look over the fence at this well designed system: https://npmjs.org/doc/json.html. The most relevant feature in the context CRAN is how NPM declares and resolves dependencies.

Package dependencies are defined using a combination of the package *name* and *version range descriptor*. This descriptor is specified with a simple dedicated syntax, that extends some of the standard versioning notation. Below a snippet taken from the 'package.json' file in the NPM manual:

```
"dependencies" : {
   "foo" : "1.0.0 - 2.9999.9999",
   "bar" : ">=1.0.2 <2.1.2",
   "baz" : ">1.0.2 <=2.3.4",
   "boo" : "2.0.1",
   "qux" : "<1.0.0 || >=2.3.1 <2.4.5",
   "asd" : "http://asdf.com/asdf.tar.gz",
   "til" : "~1.2",
   "elf" : "~1.2.3",
   "two" : "2.x",
   "thr" : "3.3.x",
}
```

The version range descriptor syntax is a powerful tool to specify which version(s) or version range(s) of dependencies are required. It provides the exact information needed to build, install and/or load

the software. In contrast to R, NPM takes full advantage of this information. In R, all packages are installed in one or more global libraries, and at any given time a subset of these packages is loaded in memory. This is where NPM takes a very different approach. During installation of a package, NPM creates a *subdirectory* for dependencies inside the installation directory of the package. It compares the list of dependency declarations from the 'package.json' with an index of the repository archive, and then constructs a private library containing the full dependency tree and precise versions as specified by the author. Hence, every installed package has its own library of dependencies. This works recursively, i.e. every dependency package inside the library again has its own dependency library.

```
jeroen@ubuntu:~/Desktop$ npm install d3
jeroen@ubuntu:~/Desktop$ npm list
/home/jeroen/Desktop
└── d3@2.10.3
    ├── jsdom@0.2.14
    │   ├─┬ contextify@0.1.3
    │   │ └── bindings@1.0.0
    │   ├── cssom@0.2.5
    │   ├── htmlparser@1.7.6
    │   ├─┬ request@2.12.0
    │   │ ├─┬ form-data@0.0.3
    │   │ │ ├── async@0.1.9
    │   │ │ └─┬ combined-stream@0.0.3
    │   │ │   └── delayed-stream@0.0.5
    │   └── mime@1.2.7
    └── sizzle@1.1.0
```

By default, a package loads dependencies from its private library, and the namespace of the dependency is imported explicitly in the code. This way, an installed NPM package is completely unaffected by other applications, packages, and package updates being installed on the machine. The private library of any package contains all required dependencies, with the exact versions that were used to develop the package. A package or application that has been tested to work with certain versions of its dependencies, can easily be installed years later on another machine, even though the latest versions of dependencies have had major changes in the mean time.

Back to R

A similar way of managing packages could be very beneficial to R as well. It would enable the same dynamic development and stable installation of packages that has resulted in a small revolution within the Javascript community. The only serious drawback of this design is that it requires more disk space and slightly more memory, due to multiple versions packages being installed and/or loaded. Yet the memory required to load an additional package is minor in comparison with loading and manipulating a medium sized dataset. Considering the wide availability of low cost disk space and memory these days, we expect that most users and developers will happily pay this small price for more reliable software and reduced debugging time.

Unfortunately, implementing a package manager like NPM for R would require some fundamental changes in the way R installs and loads packages and namespaces, which might break backward compatibility at this point. One change that would probably be required for this is to move away from the Depends relation definition, and require all packages to rely on Imports and a NAMESPACE file to explicitly import objects from other packages. A more challenging problem might be that R should be able to load multiple versions of a package simultaneously while keeping their namespaces separated. This is necessary for example when two packages are in use, which both depend on different versions of one and the same third package. In this case, the objects, methods and classes exported by the dependency package should affect only to the package that imported them.

Finally, it would be great if the package manager was capable of installing multiple versions of a package inside a library, for example by appending the package version to the name of the installation directory (e.g. MASS_7.3-22). The library and require functions could then be extended with an argument specifying the version to be loaded. This argument could use the same version range descriptor syntax that packages use to declare dependencies. Missing versions could automatically be installed, as nothing gets overwritten.

```
library(ggplot2, version="0.8.9")
library(MASS, version="7.3-x")
library(Matrix, version=">=1.0")
```

Code as above leaves little ambiguity and tremendously increases reliability and reproducibility of R code. When the author is explicit about which package versions are used, and packages are explicit about dependency versions, an R script or Sweave document that once worked on a certain version of R, will work for other users, on different systems, and keep working over time, regardless of upstream changes. For users not concerned with dependency versioning, the default value of the version argument could be set to "*". This value indicates that any version will do, in which case the package manager gives preference to the most recent available version of the package.

The benefits of a package manager capable of importing specific versions of packages would not just be limited to contributed code. Such a package manager would also reduce the necessity to include all of the standard library and more in the R releases. If implemented, the R Core team could consider moving some of the *base* and *recommended* packages out of the r-base distribution, and offer them exclusively through CRAN. This way, the R software could eventually become the minimal core containing only the language interpreter and package manager, similar to e.g. Node and NPM. More high-level functionality could be loaded on demand as versioning is controlled by the package manager. This would allow for less frequent releases of the R software itself, and further improve compatibility and reproducibility between versions of R.

Summary

The infrastructure for contributed code has supported the steady growth and adoption of the R software. For the majority of users, contributed code is just as essential in their daily work as the R base software suite. But the number of packages on CRAN has grown beyond what could have been foreseen, and practices and policies that used to work on a smaller scale are becoming unsustainable. At the same time there is an increasing demand for more reliable, stable software, that can be used as part of embedded systems, enterprise applications, or reproducible research. The design and policies of CRAN and the package manager shape the development process and play an important role in determining the future of the platform. The current practice of publishing package updates directly to end-users facilitates a highly versatile development, but comes at the cost of reliability. The default behavior of R to install packages in a single library with only the latest versions is perhaps more appropriate for developers than regular users. After nearly two decades of development, R has reached a maturity where a slightly more conservative approach could be beneficial.

This paper explained the problem of dependency versioning, and tried to make a case for transitioning to a system that does not assume that package versions are interchangeable. The most straightforward approach would be by extending the *r-release* and *r-devel* branches to the full CRAN repository, and only publish updates of contributed packages to the *r-devel* branch of R. This way, the *stable* versions of R are tied to a fixed version of each CRAN package, making the code base and behavior of a given release of R less ambiguous. Furthermore, a release cycle allows us to concentrate coordination and testing efforts for contributed packages along with releases of R, rather than continuously throughout the year.

In the long term, a more fundamental revision of the packaging system could be considered, in order to facilitate dynamic contributed development without sacrificing reliability. However, this would involve major changes in the way libraries and namespaces are managed. The most challenging problem will be support for concurrently loading multiple versions of a package. But when the time is ready to make the jump to the next major release of R, we hope that R Core will consider revising this important part of the software, adopting modern approaches and best practices of package management that are powering collaboration and uniting efforts within other open source communities.

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Jeroen Ooms
Department of Statistics
University of California
Los Angeles
jeroen.ooms@stat.ucla.edu
http://jeroenooms.github.io/