BIG Data, **BIG** responsibility

Maneage: *Man*aging data lin*eage* for long-term and archivable reproducibility

(Published in CiSE 23 (3), pp 82-91: DOI:10.1109/MCSE.2021.3072860, arXiv:2006.03018)

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28th of November 2024

Most recent slides available in link below (this PDF is built from Git commit 125dd08):
https://maneage.org/pdf/slides-intro.pdf

Financiado por la Unión Europea-NextGenerationEU

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Unión Europea
Fondo Europeo de Desarrollo Regional
"Una manera de hacer Europa"

This project received financial support from the European Union's Horizon 2020 research and innovation grant agreement No. 777388 to the RDA EU 4.0 project.

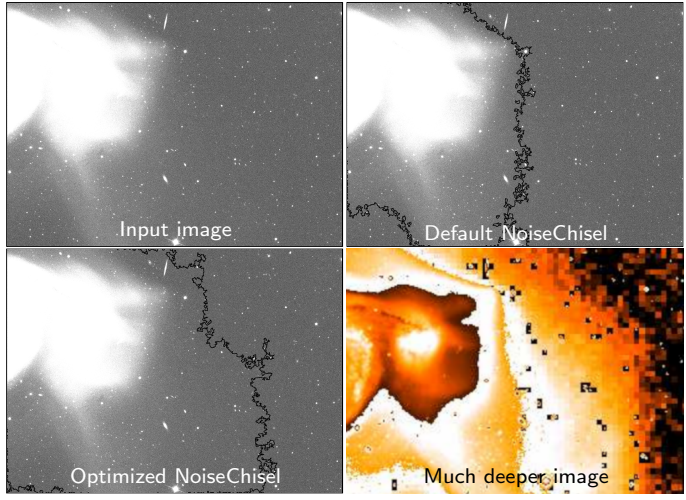
Let's start with this nice image of the Wirlpool galaxy (M51): https://i.redd.it/jfqgpqg0hfk11.jpg

Now, let's assume you want to study M51's outer structure, but you'll have to detect it first.

Example: Using a single exposure SDSS image with NoiseChisel (a program that is part of 'GNU Astronomy Utilities').

- When optimized, outskirts detected down to $S/N = 1/4$, or 28.3 mag/arcsec^2. By default, it only reaches $S/N > 1/2$.
- Akhlaghi 2019 (arXiv:1909.11230) describes optimized result:
  - Run-time options/configuration.
  - Steps before/after NoiseChisel.
- Deep/orange image from Watkins+2015 (arXiv:1501.04599) shown for reference.
- Therefore:
  - Default settings not enough.
  - Final number not just from NoiseChisel (more software involved).

Simply reporting in your paper that "*we used NoiseChisel*" is not enough to reproduce, understand, or verify your result.



Reproducibility crisis in the sciences/astronomy

Snakes on a Spaceship – An Overview of Python in Heliophysics

"...inadequate analysis descriptions and loss of scientific data have made scientific studies difficult or impossible to replicate". From Burrell+2018, (arXiv:1901.00143).

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Perspectives on Reproducibility and Sustainability of Open-Source Scientific Software

"It is our interest that NASA adopt an open-code policy because without it, reproducibility in computational science is needlessly hampered". From Oishi+2018, (arXiv:1801.08200).

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Schroedinger's code: source code availability and link persistence in astrophysics

"We were unable to find source code online ... for 40.4% of the codes used in the research we looked at". From Allen+2018, (arXiv:1801.02094).

Original image from `https://www.redbubble.com`

This problem isn't just limited to astronomy

Repeatability of published microarray gene expression analyses

Ioannidis+2009 evaluated the replication of data analyses in 18 articles ... in Nature Genetics and reproduced only 2 in principle.". DOI:10.1038/ng.295.

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Is Economics Research Replicable? 60 papers from Thirteen Journals Say "Usually Not"

Chang&Li2015 were are able to replicate less than half of 67 papers in well-regarded journals. Even *with help* from the authors. They "assert that economics research is usually not replicable". DOI:10.17016/FEDS.2015.083

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An empirical analysis of journal policy effectiveness for computational reproducibility

Stodden+2018 studied a random sample of 204 scientific papers in *Science* and were able to obtain artifacts from 44% and reproduce the findings for 26%. DOI:10.1073/pnas.1708290115

"Reproducibility crisis" in the sciences? (Baker 2016, Nature 533, 452, DOI:10.1038/533452a)

1576 researchers participated in a survey by Nature, 90% believed in a crisis!

Status	% agreed
Yes, a significant crisis	52
Yes, a slight crisis	38
Don't know	7
No, there is no crisis	3

Full PDF available at https://www.nature.com/articles/533452a.pdf

Our solution: CiSE 23 (3), pp 82-91: DOI:10.1109/MCSE.2021.3072860, arXiv:2006.03018

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Sandra Gesing, sandra.gesing@nd.edu

SPECIAL TRACK: REPRODUCIBLE RESEARCH

Toward Long-Term and Archivable Reproducibility

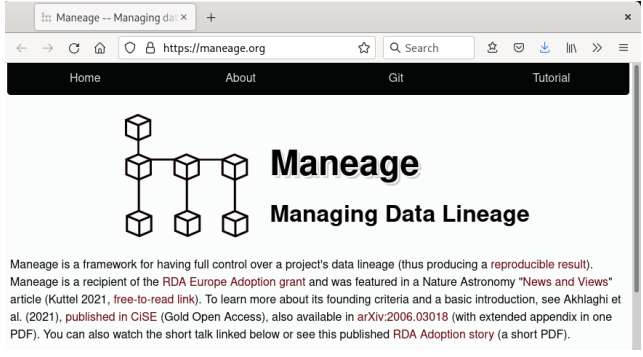
Mohammad Akhlaghi, *Instituto de Astrofísica de Canarias, La Laguna, Tenerife, 38205, Spain*
Raúl Infante-Sainz, *Universidad de La Laguna, La Laguna, Tenerife, 38205, Spain*
Boudewijn F. Roukema, *Nicolaus Copernicus University, Toruń 87-100, Poland*
Mohammadreza Khellat, *Ideal-Information, PC 133 Al Khuwair, Muscat, Oman*
David Valls-Gabaud, *Paris Observatory, Paris 75014, France*
Roberto Baena-Gallé, *Universidad Internacional de La Rioja, Logroño 26006, Spain*

Analysis pipelines commonly use high-level technologies that are popular when created, but are unlikely to be readable, executable, or sustainable in the long term. A set of criteria is introduced to address this problem: completeness (no execution requirement beyond a minimal Unix-like operating system, no administrator privileges, no network connection, and storage primarily in plain text); modular design; minimal complexity; scalability; verifiable inputs and outputs; version control; linking analysis with narrative; and free and open-source software. As a proof of concept, we introduce "Maneage" (managing data lineage), enabling cheap archiving, provenance extraction, and peer verification that has been tested in several research publications. We show that longevity is a realistic requirement that does not sacrifice immediate or short-term reproducibility. The caveats (with proposed solutions) are then discussed and we conclude with the benefits for the various stakeholders. This article is itself a Maneage'd project (project commit 313db0b). Appendices—Two comprehensive appendices that review the longevity of existing solutions are available as supplementary "Web extras," which are available in the IEEE Computer Society Digital Library at http://doi.ieeecomputersociety.org/10.1109/MCSE.2021.3072860. Reproducibility—All products available in zenodo. 4913277, the Git history of this paper's source is at git.maneage.org/project..git, which is also archived in Software Heritage: swh:1:dir:33fea8706bc1612daf011f161b9787b9a0df39f. Clicking on the SWHIDs in the digital format will provide more "context" for same content.

Reproducible research has been discussed in the sciences for at least 30 years.[1,2] Many reproducible workflow solutions (hereafter, "solutions") have been proposed, which mostly rely on the common technology of the day, starting with Make and Matlab libraries in the 1990s, Java in the 2000s, and mostly shifting to Python during the past decade.

However, these technologies develop fast, e.g., code written in Python 2 (which is no longer officially maintained) often cannot run with Python 3. The cost of staying up to date within this rapidly evolving landscape is high. Scientific projects, in particular, suffer the most: Scientists have to focus on their own research domain, but to some degree, they need to understand the technology of their tools because it determines their results

Digital Object Identifier 10.1109/MCSE.2021.3072860
Date of publication 13 April 2021; date of current version 15 June 2021.



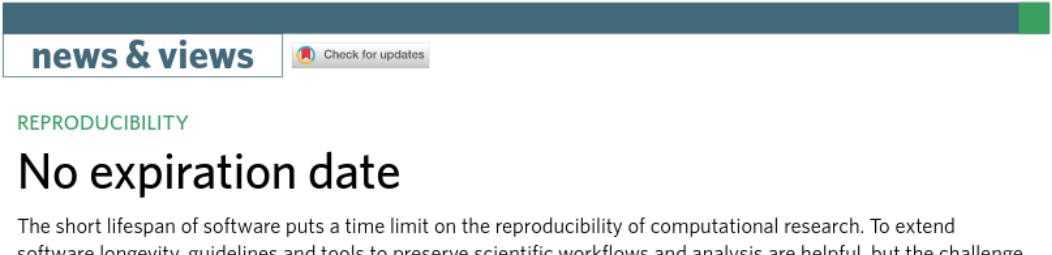
https://maneage.org

Recognition 1: RDA adoption grant (2019) to IAC for Maneage

For Maneage, the IAC is selected as a Top European organization funded to adopt RDA Recommendations and Outputs.

- Research Data Alliance was launched by the European Commission, NSF, National Institute of Standards and Technology, and the Australian Government's Department of Innovation.
- RDA Outputs are the technical and social infrastructure solutions developed by RDA Working Groups or Interest Groups that enable data sharing, exchange, and interoperability.

Recognition 2: “News and Views” in Nature Astronomy (2021NatAs...5..986K)



news & views

Check for updates

REPRODUCIBILITY

No expiration date

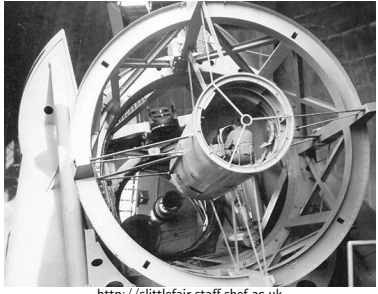
The short lifespan of software puts a time limit on the reproducibility of computational research. To extend software longevity, guidelines and tools to preserve scientific workflows and analysis are helpful, but the challenge is to get researchers to use them.

Michelle M. Kuttel

Free-to-read link: https://rdcu.be/cmYVx
DOI: 10.1038/s41550-021-01402-3

Replicability (hardware/statistical)

- Involves data collection.
- Inherently includes measurements errors (can never be exactly reproduced).
- Example: Raw telescope image/spectra.
- **NOT DISCUSSED HERE.**



http://slittlefair.staff.shef.ac.uk

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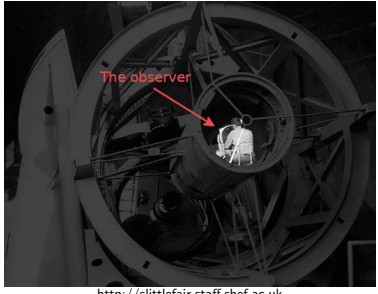

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Definitions & Clarification

(from the National Academies report in 2019, DOI:10.17226/25303)

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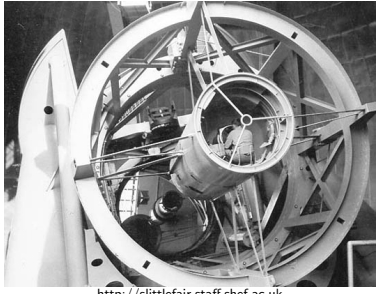

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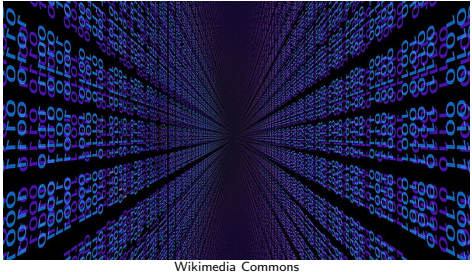
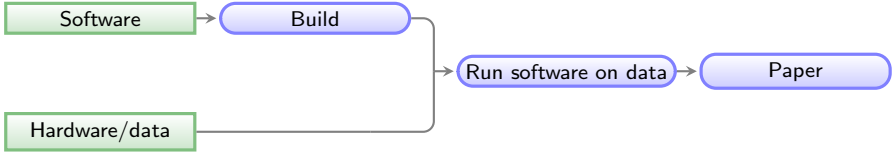
Reproducibility (Software/Deterministic)

- Involves data analysis, or simulations.
- Starts after data is collected/digitized.
- Example: $2 + 2 = 4$ (i.e., sum of datasets).
- **DISCUSSED HERE.**



Wikimedia Commons

General outline of a project (after data collection)



Green boxes with sharp corners: *source*/input components/files.
Blue boxes with rounded corners: *built* components.
Red boxes with dashed borders: questions that must be clarified for each phase.

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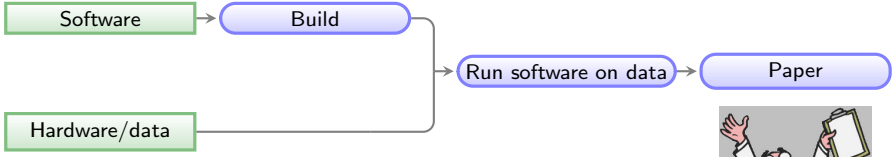

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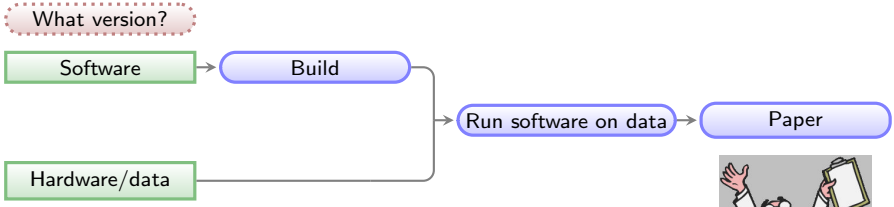

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Different package managers have different versions of software (repology.org, 2021/12/02)

Astropy

Packaging status	
Debian 10	3.1.2
Debian 11	4.2
Debian 12	4.3.1
Debian Unstable	5.0
Debian Experimental	5.0~rc2
Deepin	3.1.2
Devuan 3.0	3.1.2
Devuan 4.0	4.2
Devuan Unstable	5.0
Kali Linux Rolling	4.3.1
Pardus 19	3.1.2
Pardus 21	4.2
Parrot	4.2
PureOS Amber	3.1.2
PureOS landing	4.2
Raspbian Oldstable	3.1.2
Raspbian Stable	4.2
Raspbian Testing	4.3.1
Trisquel 9.0	3.0
Trisquel 10.0	4.0
Ubuntu 18.04	3.0
Ubuntu 20.04	4.0
Ubuntu 20.10	4.0.1+post1
Ubuntu 21.04	4.2
Ubuntu 21.10	4.2
Ubuntu 22.04	4.2
Ubuntu 22.04 Proposed	4.3.1

GNU Astronomy Utilities (Gnuastro)

Packaging status	
Debian 9	0.2.33
Debian 10	0.8
Debian 11	0.14
Debian 12	0.16.1
Debian Unstable	0.16.1
Deepin	0.8
Devuan 2.0	0.2.33
Devuan 3.0	0.8
Devuan 4.0	0.14
Devuan Unstable	0.16.1
DPorts	0.15
FreeBSD Ports	0.16
Funtoo 1.4	0.3
Gentoo	0.3
GNU Guix	0.16
Kali Linux Rolling	0.16.1
LiGurOS stable	0.3
LiGurOS develop	0.3
OpenBSD Ports	0.15
openSUSE Leap 15.1	0.8
openSUSE Leap 15.2	0.8
openSUSE Leap 15.3	0.8
openSUSE Tumbleweed	0.16
openSUSE Science Tumbleweed	0.16
Pardus 17	0.2.33
Pardus 19	0.8
Pardus 21	0.14
Parrot	0.14
PLD Linux	0.15
PureOS Amber	0.8
PureOS landing	0.14
Raspbian Oldstable	0.8
Raspbian Stable	0.14
Raspbian Testing	0.16.1
RPM Sphere	0.16.1
Trisquel 9.0	0.5
Trisquel 10.0	0.11
Ubuntu 18.04	0.5
Ubuntu 20.04	0.11
Ubuntu 20.10	0.12
Ubuntu 21.04	0.14
Ubuntu 21.10	0.14
Ubuntu 22.04	0.14
Ubuntu 22.04 Proposed	0.16.1

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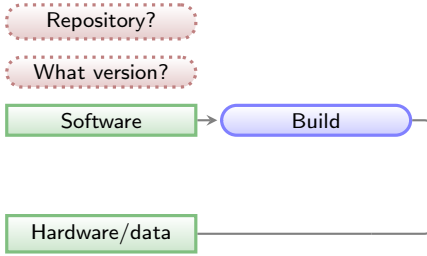

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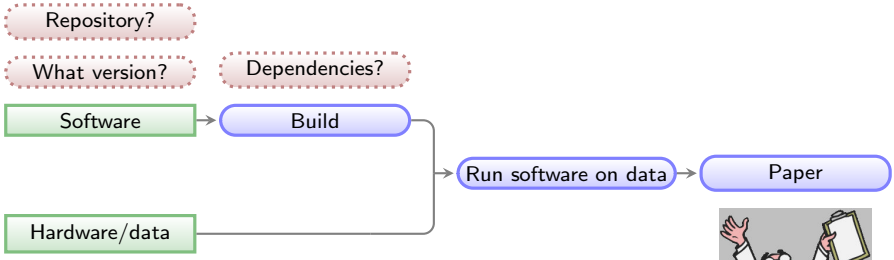

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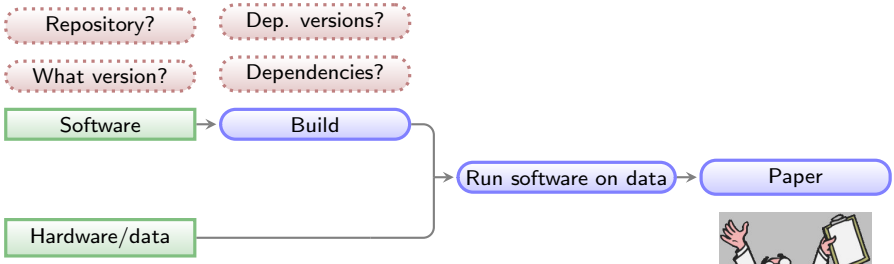

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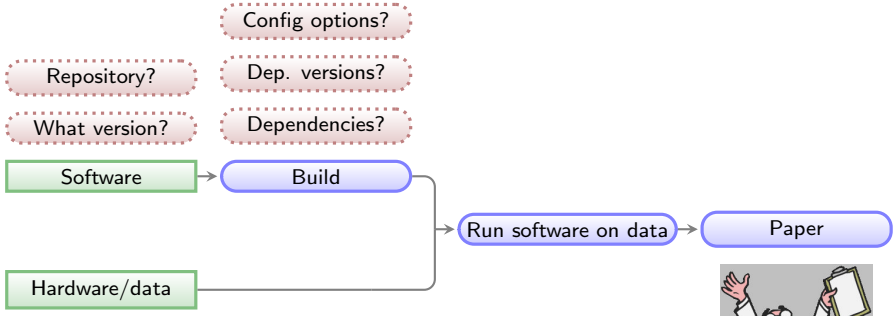

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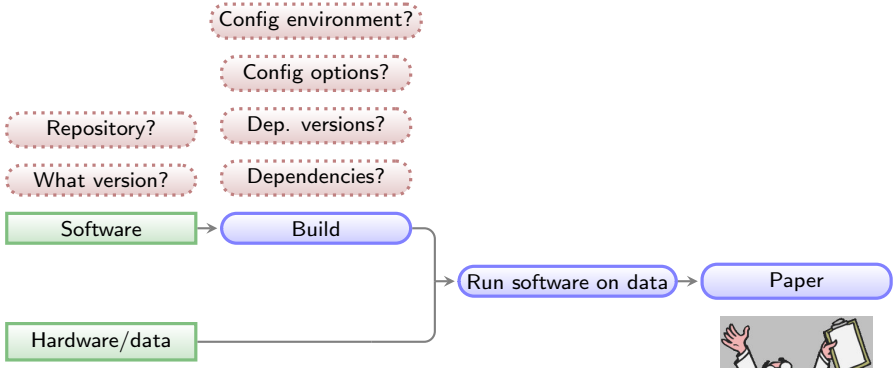

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Example: Matplotlib (a Python visualization library) build dependencies

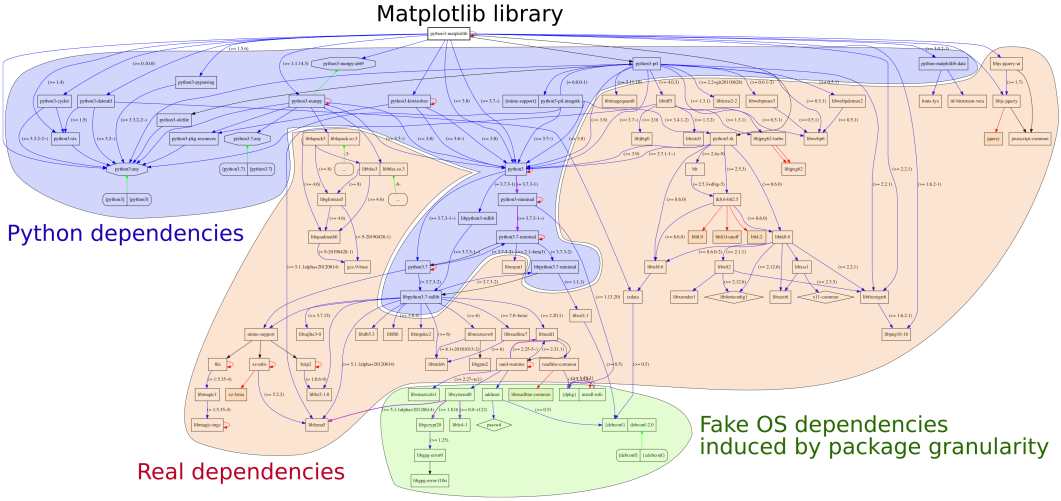
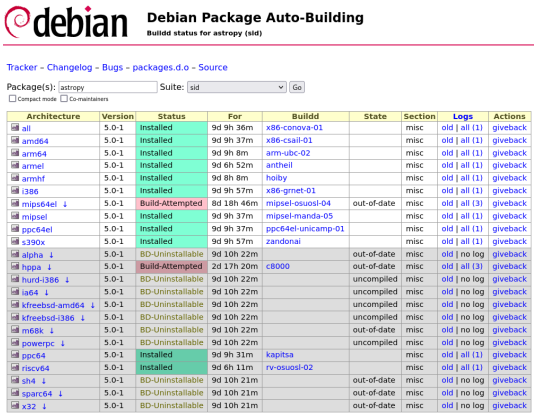


Fig. 1. Transitive dependencies of the software environment required by a simple "`import matplotlib`" command in the Python 3 interpreter.

From "Attributing and Referencing (Research) Software: Best Practices and Outlook from Inria" (Alliez et al. 2020, CiSE, DOI:10.1109/MCSE.2019.2949413).

Impact of "Dependency hell" on native building in various hardware (CPU architectures), retrieved from Debian on 2021/12/02



debian **Debian Package Auto-Building**

Buildd status for astropy (sid)

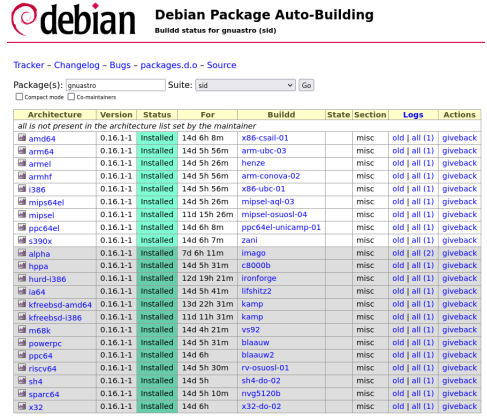
Tracker - Changelog - Bugs - packages.d.o - Source

Package(s): astropy Suite: sid Go

Compact mode Co-maintainers

Architecture	Version	Status	For	Buildd	State	Section	Logs	Actions
all	5.0-1	Installed	9d 9h 36m	x86-conova-01		misc	old | all (1)	giveback
amd64	5.0-1	Installed	9d 9h 37m	x86-csail-01		misc	old | all (1)	giveback
arm64	5.0-1	Installed	9d 9h 8m	arm-ubc-02		misc	old | all (1)	giveback
armel	5.0-1	Installed	9d 6h 52m	antheil		misc	old | all (1)	giveback
armhf	5.0-1	Installed	9d 8h 8m	hoiby		misc	old | all (1)	giveback
i386	5.0-1	Installed	9d 9h 57m	x86-grnet-01		misc	old | all (1)	giveback
mips64el	5.0-1	Build-Attempted	8d 18h 46m	mipsel-osuosl-04	out-of-date	misc	old | all (3)	giveback
mipsel	5.0-1	Installed	9d 9h 37m	mipsel-manda-05		misc	old | all (1)	giveback
ppc64el	5.0-1	Installed	9d 9h 37m	ppc64el-unicamp-01		misc	old | all (1)	giveback
s390x	5.0-1	Installed	9d 9h 57m	zandonai		misc	old | all (1)	giveback
alpha	5.0-1	BD-Uninstallable	9d 10h 22m		out-of-date	misc	old | no log	giveback
hppa	5.0-1	Build-Attempted	2d 17h 20m	c8000	out-of-date	misc	old | all (3)	giveback
hurd-i386	5.0-1	BD-Uninstallable	9d 10h 22m		uncompiled	misc	old | no log	giveback
ia64	5.0-1	BD-Uninstallable	9d 10h 22m		uncompiled	misc	old | no log	giveback
kfreebsd-amd64	5.0-1	BD-Uninstallable	9d 10h 22m		uncompiled	misc	old | no log	giveback
kfreebsd-i386	5.0-1	BD-Uninstallable	9d 10h 22m		uncompiled	misc	old | no log	giveback
m68k	5.0-1	BD-Uninstallable	9d 10h 22m		out-of-date	misc	old | no log	giveback
powerpc	5.0-1	BD-Uninstallable	9d 10h 22m		uncompiled	misc	old | no log	giveback
ppc64	5.0-1	Installed	9d 9h 31m	kapitsa		misc	old | all (1)	giveback
riscv64	5.0-1	Installed	9d 6h 11m	rv-osuosl-02		misc	old | all (1)	giveback
sh4	5.0-1	BD-Uninstallable	9d 10h 21m		out-of-date	misc	old | no log	giveback
sparc64	5.0-1	BD-Uninstallable	9d 10h 21m		out-of-date	misc	old | no log	giveback
x32	5.0-1	BD-Uninstallable	9d 10h 21m		out-of-date	misc	old | no log	giveback

Astropy depends on Matplotlib



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Compact mode Co-maintainers

Architecture	Version	Status	For	Buildd	State	Section	Logs	Actions
all is not present in the architecture list set by the maintainer								
amd64	0.16.1-1	Installed	14d 6h 8m	x86-csail-01		misc	old | all (1)	giveback
arm64	0.16.1-1	Installed	14d 5h 56m	arm-ubc-03		misc	old | all (1)	giveback
armel	0.16.1-1	Installed	14d 5h 26m	henze		misc	old | all (1)	giveback
armhf	0.16.1-1	Installed	14d 5h 56m	arm-conova-02		misc	old | all (1)	giveback
i386	0.16.1-1	Installed	14d 5h 56m	x86-ubc-01		misc	old | all (1)	giveback
mips64el	0.16.1-1	Installed	14d 5h 26m	mipsel-aql-03		misc	old | all (1)	giveback
mipsel	0.16.1-1	Installed	11d 15h 26m	mipsel-osuosl-04		misc	old | all (1)	giveback
ppc64el	0.16.1-1	Installed	14d 6h 8m	ppc64el-unicamp-01		misc	old | all (1)	giveback
s390x	0.16.1-1	Installed	14d 6h 7m	zani		misc	old | all (1)	giveback
alpha	0.16.1-1	Installed	7d 6h 11m	imago		misc	old | all (2)	giveback
hppa	0.16.1-1	Installed	14d 5h 31m	c8000b		misc	old | all (1)	giveback
hurd-i386	0.16.1-1	Installed	12d 19h 21m	ironforge		misc	old | all (1)	giveback
ia64	0.16.1-1	Installed	14d 5h 41m	lifshitz2		misc	old | all (1)	giveback
kfreebsd-amd64	0.16.1-1	Installed	13d 22h 31m	kamp		misc	old | all (1)	giveback
kfreebsd-i386	0.16.1-1	Installed	11d 11h 31m	kamp		misc	old | all (1)	giveback
m68k	0.16.1-1	Installed	14d 4h 21m	vs92		misc	old | all (1)	giveback
powerpc	0.16.1-1	Installed	14d 5h 31m	blaauw		misc	old | all (1)	giveback
ppc64	0.16.1-1	Installed	14d 6h	blaauw2		misc	old | all (1)	giveback
riscv64	0.16.1-1	Installed	14d 5h 30m	rv-osuosl-01		misc	old | all (1)	giveback
sh4	0.16.1-1	Installed	14d 5h	sh4-do-02		misc	old | all (1)	giveback
sparc64	0.16.1-1	Installed	14d 5h 10m	nvg5120b		misc	old | all (1)	giveback
x32	0.16.1-1	Installed	14d 6h	x32-do-02		misc	old | all (1)	giveback

GNU Astronomy Utilities doesn't.

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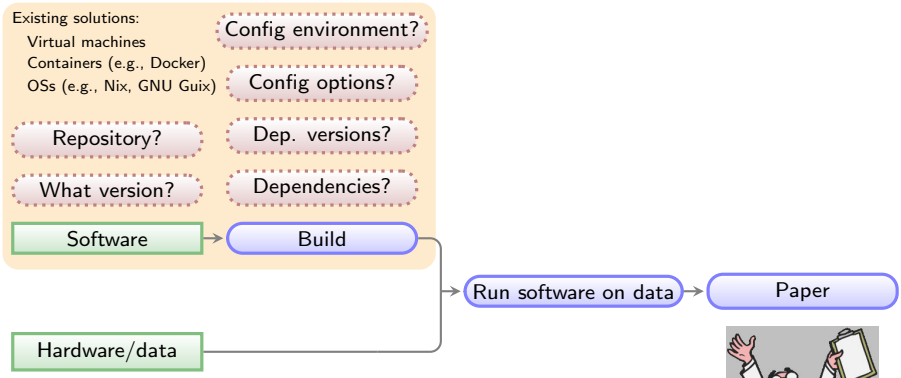

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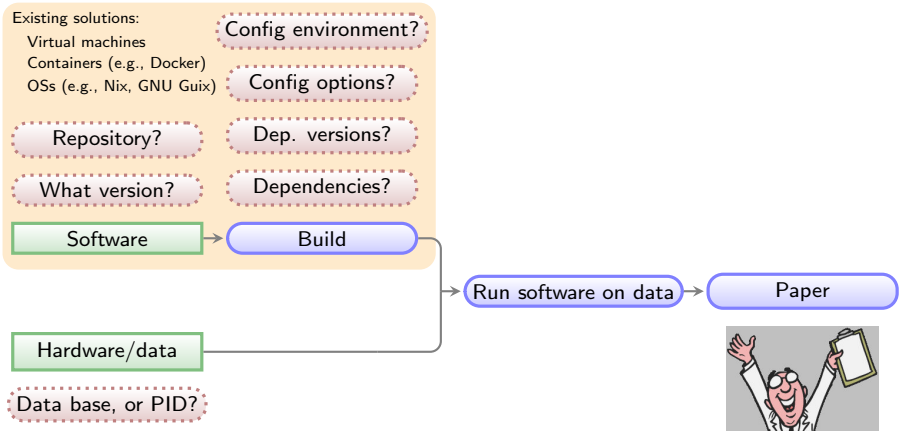

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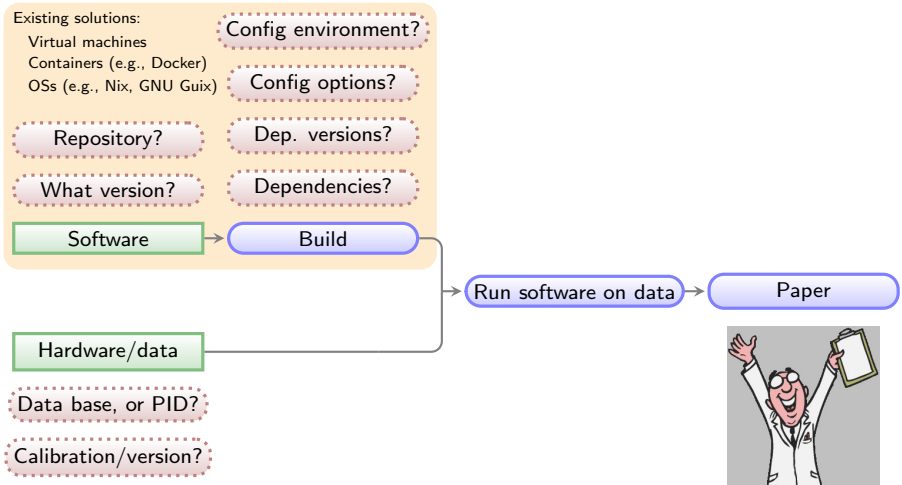

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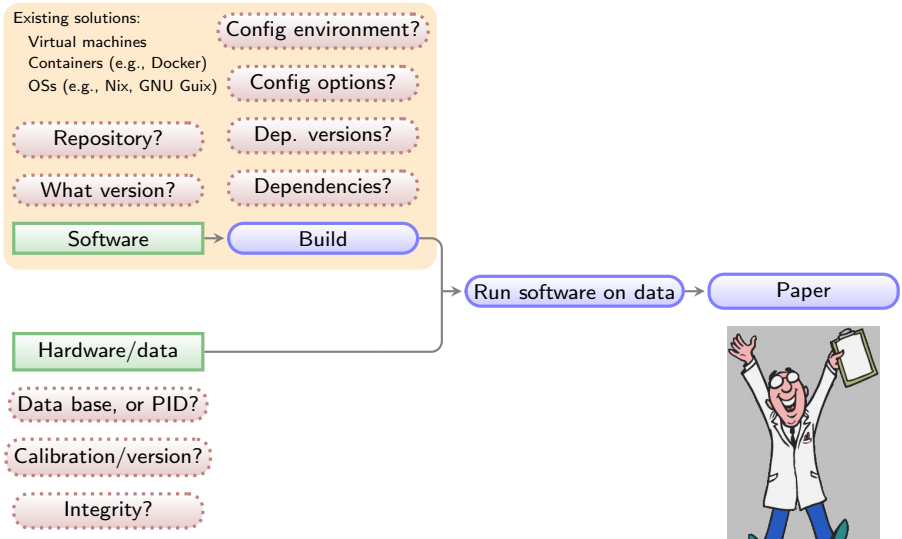

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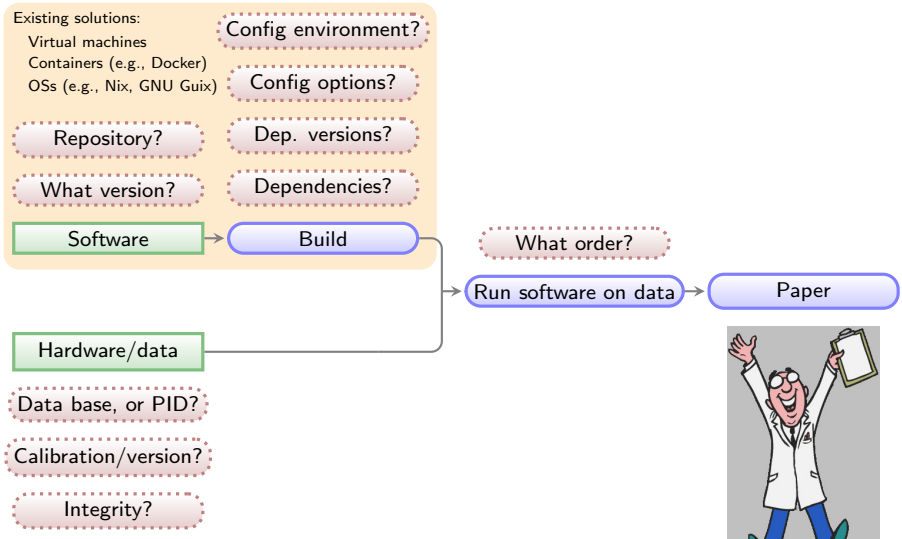

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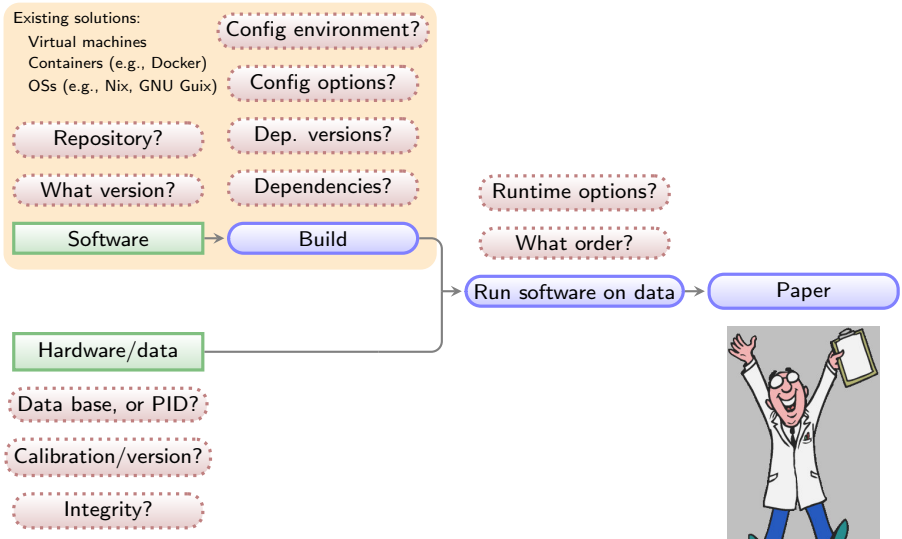

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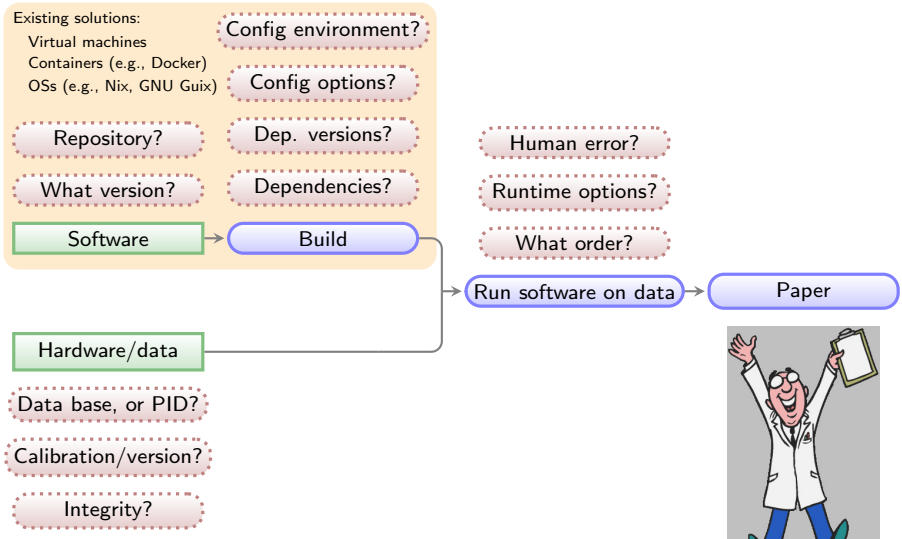

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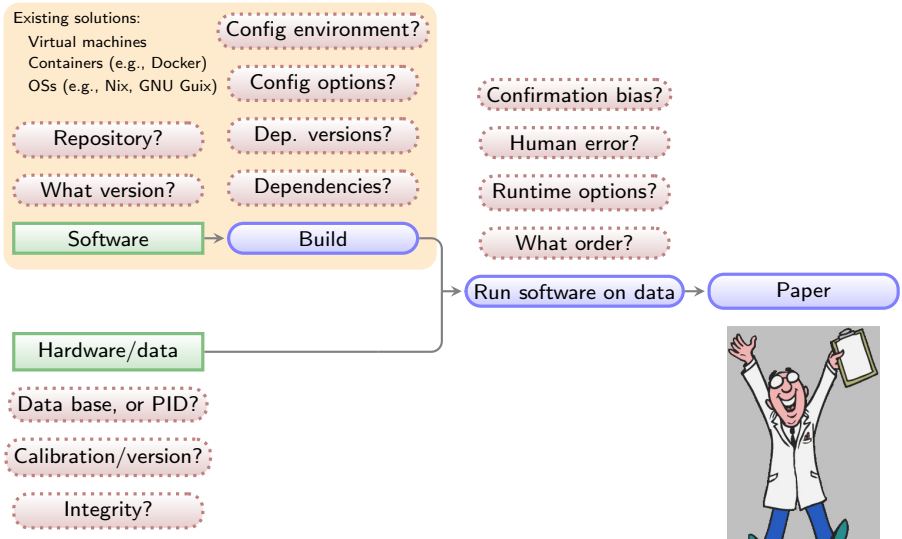

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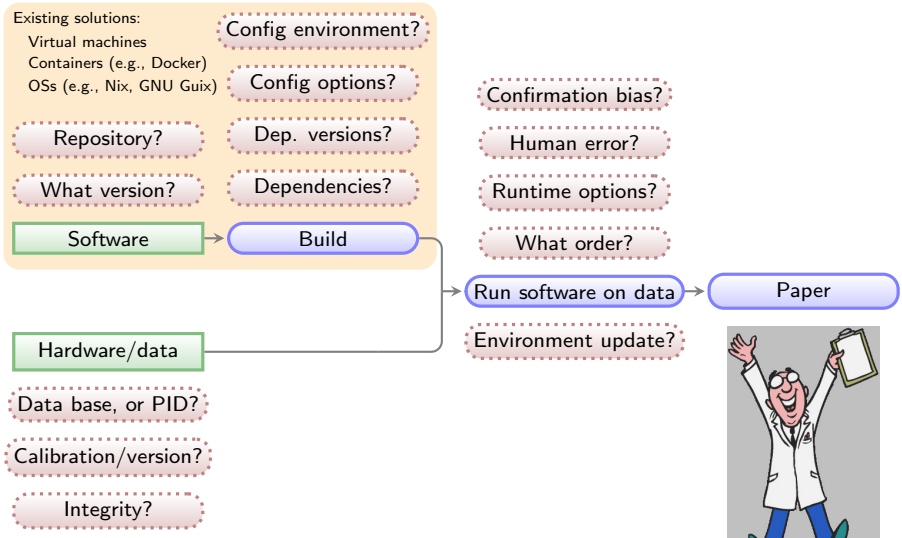

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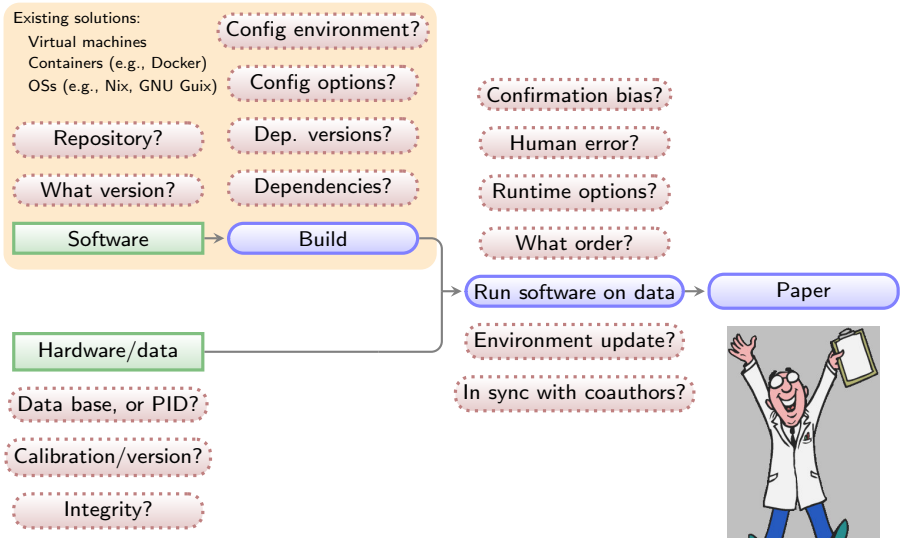

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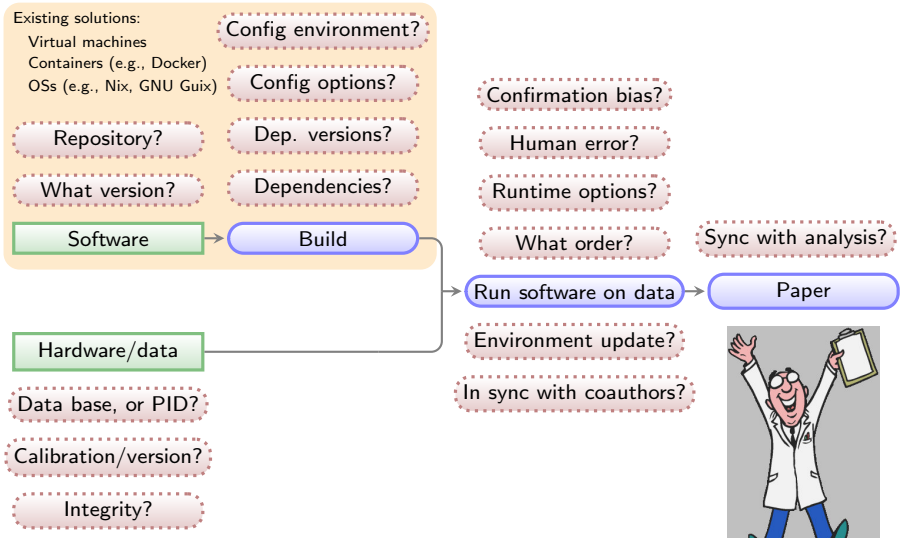

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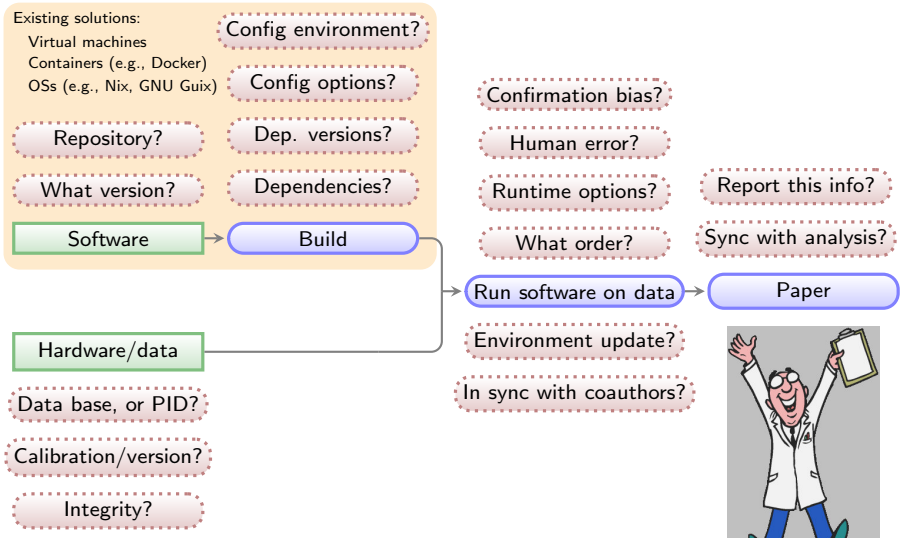

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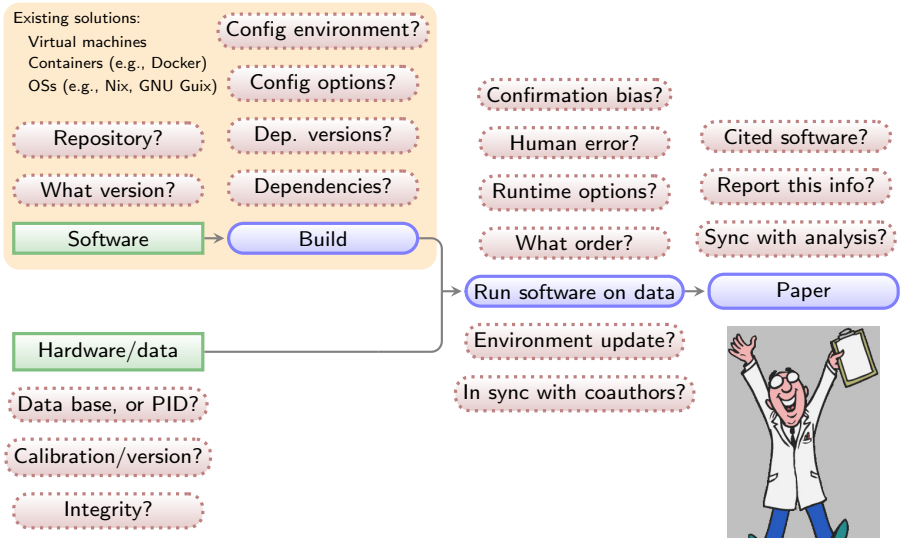

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Di Cosmo & Pellegrini (2019) Encouraging a wider usage of software derived from research

"**Software is a hybrid** object in the world research as it is equally a driving force (as a tool), a result (as proof of the existence of a solution) and an object of study (as an artefact)".

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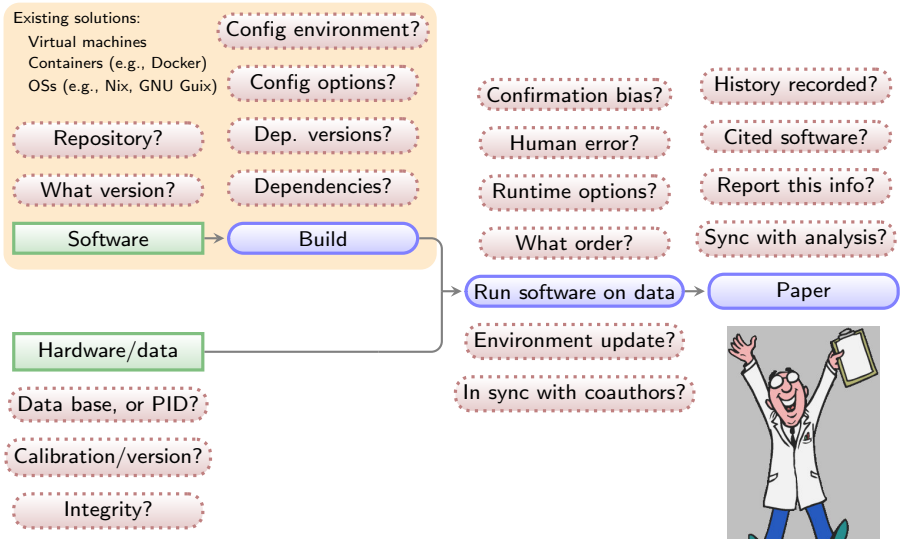

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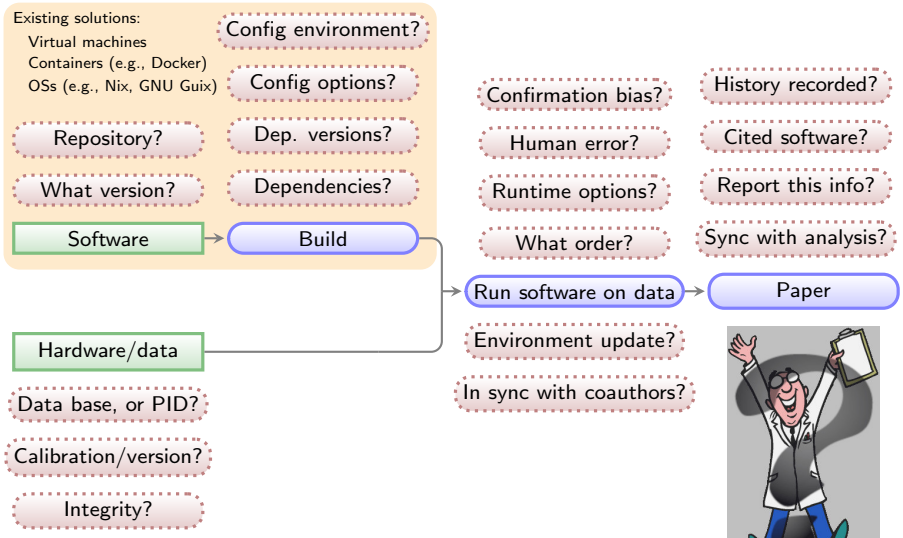

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http://pngimages.net

Science is a tricky business

> Data analysis [...] is a human behavior. Researchers who hunt hard enough will turn up a result that fits statistical criteria, but their discovery will probably be a false positive.
>
> Five ways to fix statistics (Nature, 551, Nov 2017; DOI:10.1038/d41586-017-07522-z).

Buckheit & Donoho (1996) Lecture Notes in Statistics (vol 103, DOI:10.1007/978-1-4612-2544-7_5)

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Basic/simple principle:

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- **Free and open source software:** Free software is essential: non-free software is not configurable, not distributable, and dependent on non-free provider (which may discontinue it in N years).

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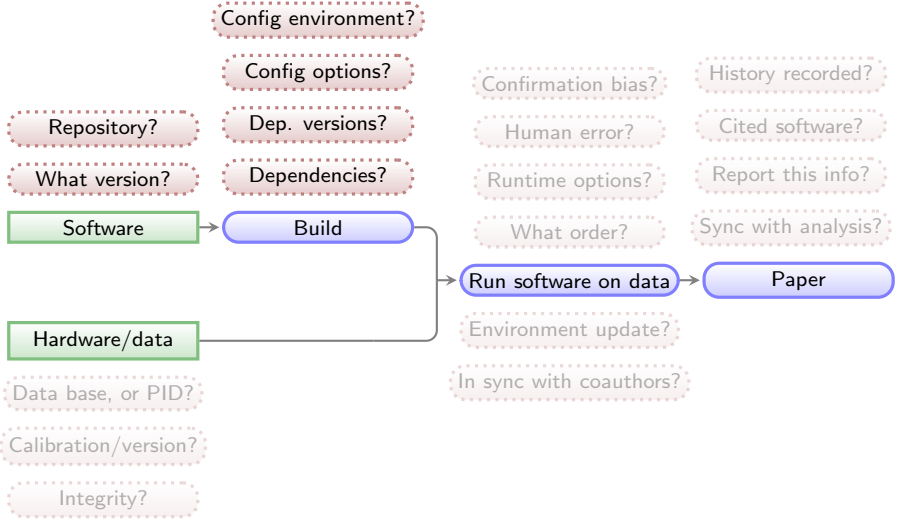

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Predefined/exact software tools

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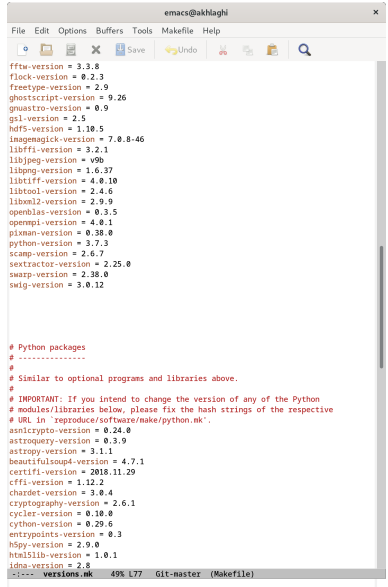

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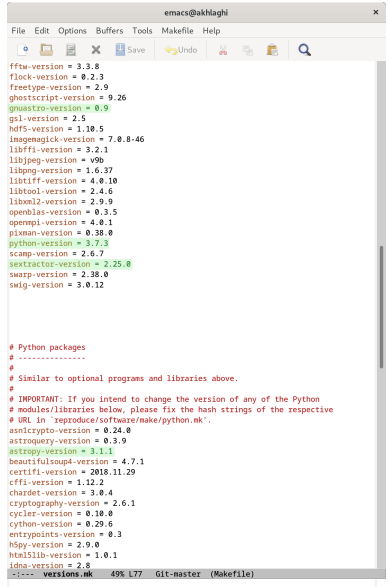
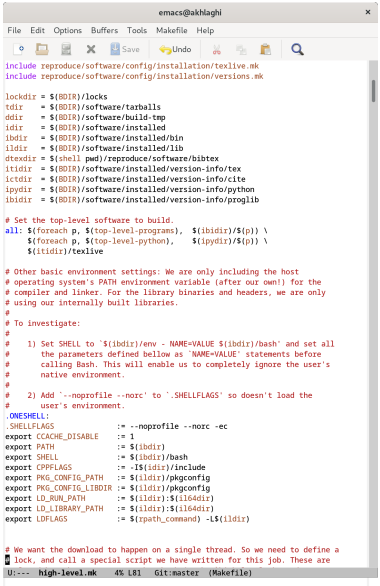
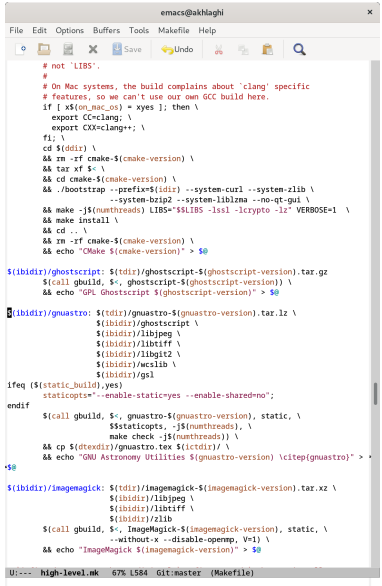


Controlled environment and build instructions





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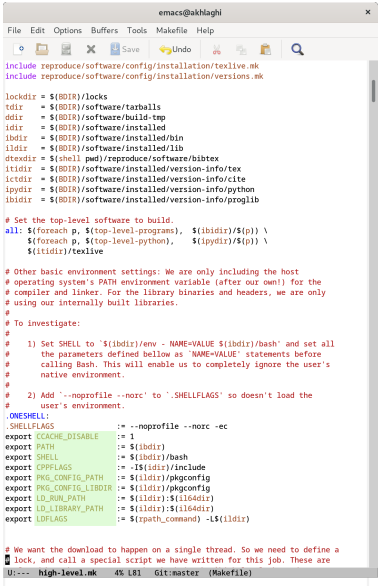

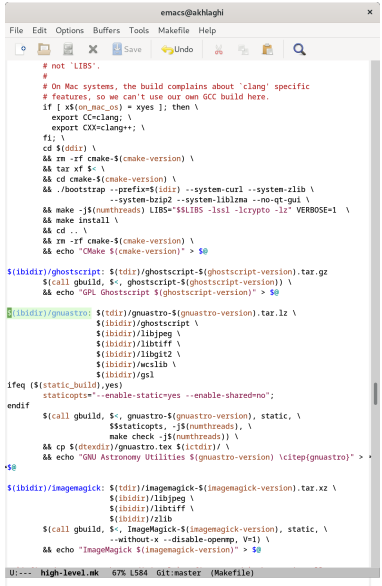

Example: Matplotlib (a Python visualization library) build dependencies

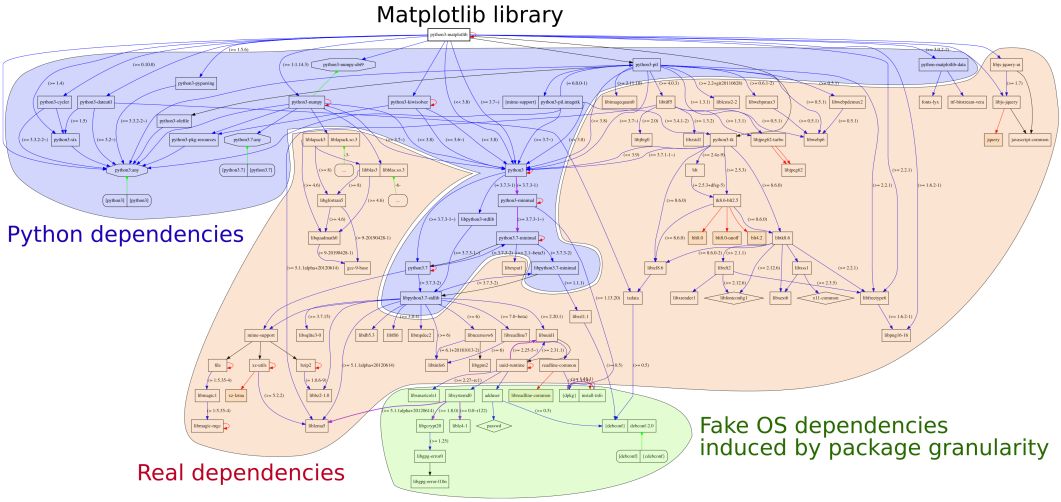

Fig. 1. Transitive dependencies of the software environment required by a simple "`import matplotlib`" command in the Python 3 interpreter.

From "Attributing and Referencing (Research) Software: Best Practices and Outlook from Inria" (Alliez et al. 2019, hal-02135891)

All high-level dependencies are under control (e.g., NoiseChisel's dependencies)

GNU/Linux distribution

```
$ ldd .local/bin/astnoisechisel
    libgnuastro.so.7 => /PROJECT/libgnuastro.so.7 (0x00007f6745f39000)
    libgit2.so.26 => /PROJECT/libgit2.so.26 (0x00007f6745df1000)
    libtiff.so.5 => /PROJECT/libtiff.so.5 (0x00007f6745d77000)
    liblzma.so.5 => /PROJECT/liblzma.so.5 (0x00007f6745d4f000)
    libjpeg.so.9 => /PROJECT/libjpeg.so.9 (0x00007f6745d12000)
    libwcs.so.6 => /PROJECT/libwcs.so.6 (0x00007f6745ba8000)
    libcfitsio.so.8 => /PROJECT/libcfitsio.so.8 (0x00007f674588b000)
    libcurl.so.4 => /PROJECT/libcurl.so.4 (0x00007f6745811000)
    libssl.so.1.1 => /PROJECT/libssl.so.1.1 (0x00007f6745777000)
    libcrypto.so.1.1 => /PROJECT/libcrypto.so.1.1 (0x00007f6745491000)
    libz.so.1 => /PROJECT/libz.so.1 (0x00007f6745474000)
    libgsl.so.23 => /PROJECT/libgsl.so.23 (0x00007f67451e3000)
    libgslcblas.so.0 => /PROJECT/libgslcblas.so.0 (0x00007f67451a1000)
    linux-vdso.so.1 (0x00007fffdcbf7000)
    libpthread.so.0 => /usr/lib/libpthread.so.0 (0x00007f6745006000)
    libm.so.6 => /usr/lib/libm.so.6 (0x00007f6745027000)
    libc.so.6 => /usr/lib/libc.so.6 (0x00007f6744e43000)
    libdl.so.2 => /usr/lib/libdl.so.2 (0x00007f6744e1e000)
    /lib64/ld-linux-x86-64.so.2 => /usr/lib64/ld-linux-x86-64.so.2
```

macOS

```
$ otool -L .local/bin/astnoisechisel
    /PROJECT/libgnuastro.7.dylib (comp ver 8.0.0, cur ver 8.0.0)
    /PROJECT/libgit2.26.dylib (comp ver 26.0.0, cur ver 0.26.0)
    /PROJECT/libtiff.5.dylib (comp ver 10.0.0, cur ver 10.0.0)
    /PROJECT/liblzma.5.dylib (comp ver 8.0.0, cur ver 8.4.0)
    /PROJECT/libjpeg.9.dylib (comp ver 12.0.0, cur ver 12.0.0)
    /PROJECT/libwcs.6.2.dylib (comp ver 6.0.0, cur ver 6.2.0)
    /PROJECT/libcfitsio.8.dylib (comp ver 8.0.0, cur ver 8.3.47)
    /PROJECT/libcurl.4.dylib (comp ver 10.0.0, cur ver 10.0.0)
    /PROJECT/libssl.1.1.dylib (comp ver 1.1.0, cur ver 1.1.0)
    /PROJECT/libcrypto.1.1.dylib (comp ver 1.1.0, cur ver 1.1.0)
    /PROJECT/libz.1.dylib (comp ver 1.0.0, cur ver 1.2.11)
    /PROJECT/libgsl.23.dylib (comp ver 25.0.0, cur ver 25.0.0)
    /PROJECT/libgslcblas.0.dylib (comp ver 1.0.0, cur ver 1.0.0)
    /usr/lib/libSystem.B.dylib (comp ver 1.0.0, cur ver 1252.50.4)
```

Project libraries: High-level libraries built from source for each project (note the same version in both OSs).
GNU C Library: Project specific build is in progress (`http://savannah.nongnu.org/task/?15390`).
Closed operating system files: We have no control on low-level non-free operating systems components.

Advantages of this build system

- Project runs in fixed/controlled environment: custom build of Bash, Make, GNU Coreutils (`ls`, `cp`, `mkdir` and etc), AWK, or SED, LaTeX, etc.
- No need for root/administrator permissions (on servers or super computers).
- Whole system is built automatically on any Unix-like operating system (less 2 hours).
- Dependencies of different projects will not conflict.
- Everything in plain text (human & computer readable/archivable).

https://natemowry2.wordpress.com

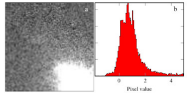

Figure 2: (a) An example image of the Wide-Field Planetary Camera 2, on board the Hubble Space Telescope from 1993 to 2009. This is one of the sample images from the FITS standard webpage, kept as examples for this file format. (b) Histogram of pixel values in (a).

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[3] http://mirrors.ctan.org/graphics/pgf/contrib/pgfplots/doc/pgfplots.pdf

3. ACKNOWLEDGEMENTS

Please include the following two paragraphs in the Acknowledgement section of your paper. This reproducible paper template was developed in parallel with Gnuastro, so it benefited from the same grants. If you don't use Gnuastro in your final/accepted project, please remove it from the paragraph below, only mentioning the reproducible paper template.

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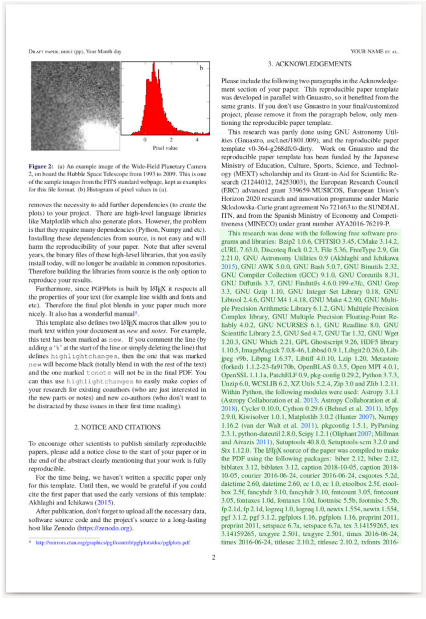
References

Akhlaghi, M. and T. Ichikawa (Sept. 2015). *ApJS*, 220, 1.
Astropy Collaboration et al. (Oct. 2013). *A&A*, 558, A33.
Astropy Collaboration et al. (Sept. 2018). *AJ*, 156, 123.
Bacon, R. et al. (Nov. 2017). *A&A*, 608, A1.
Behnel, S. et al. (Mar. 2011). *CiSE*, 13, 31.
Hunter, J. D. (2007). *CiSE*, 9, 90.
Millman, K. J. and M. Aivazis (Mar. 2011). *CiSE*, 13, 9.
Oliphant, T. E. (May 2007). *CiSE*, 9, 10.
van der Walt, S. et al. (Mar. 2011). *CiSE*, 13, 22.

Software citation automatically generated in paper (including Astropy)



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[4] http://mirrors.ctan.org/graphics/pgf/contrib/pgfplots/doc/pgfplots.pdf

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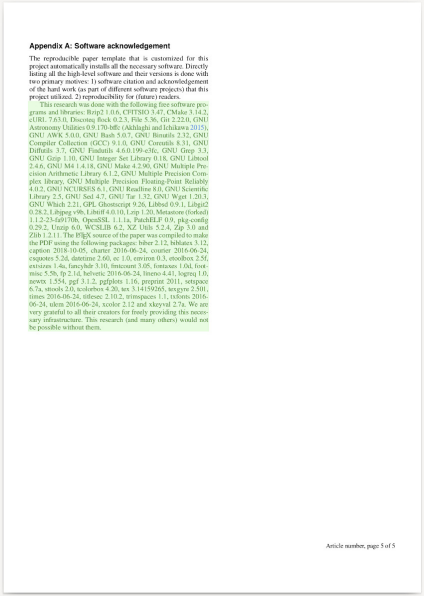

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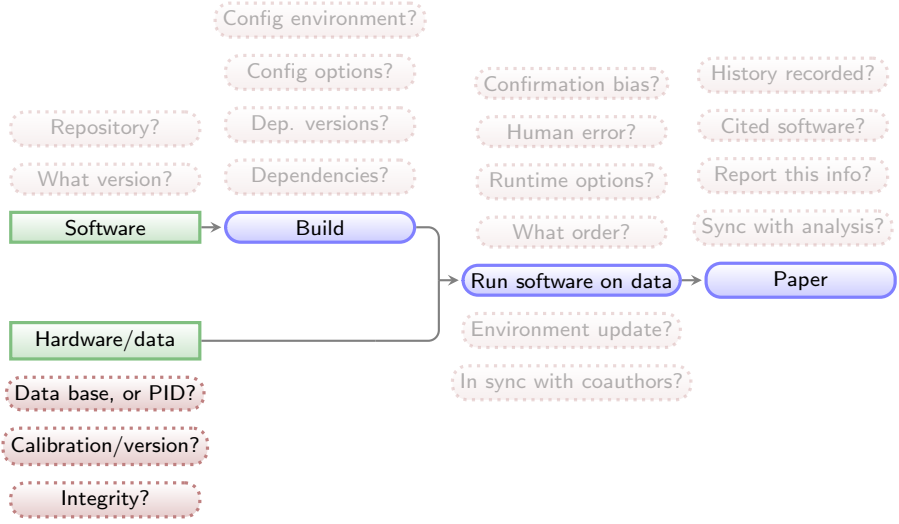
General outline of a project (after data collection)



Green boxes with sharp corners: *source*/input components/files.
Blue boxes with rounded corners: *built* components.
Red boxes with dashed borders: questions that must be clarified for each phase.

Input data source and integrity is documented and checked

Stored information about each input file:

- PID (where available).
- Download URL.
- MD5-sum to check integrity.

All inputs are downloaded from the given PID/URL when necessary (during the analysis).

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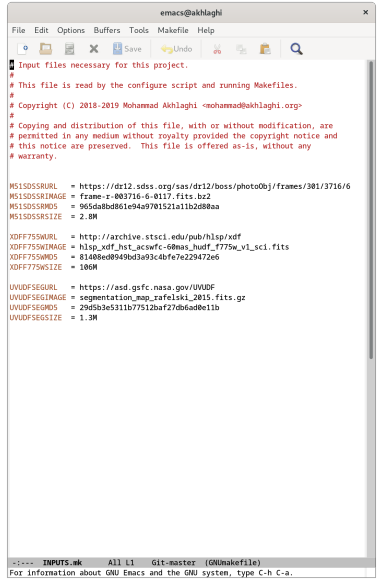
Example from the reproducible paper arXiv:1909.11230.
This paper needs three input files (two images, one catalog).



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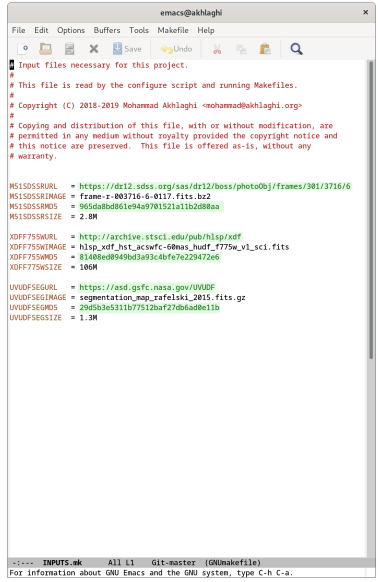

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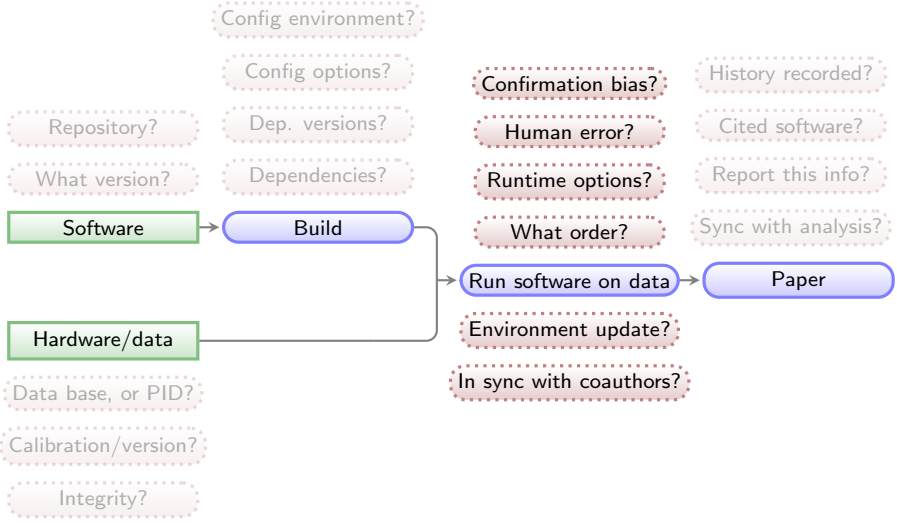

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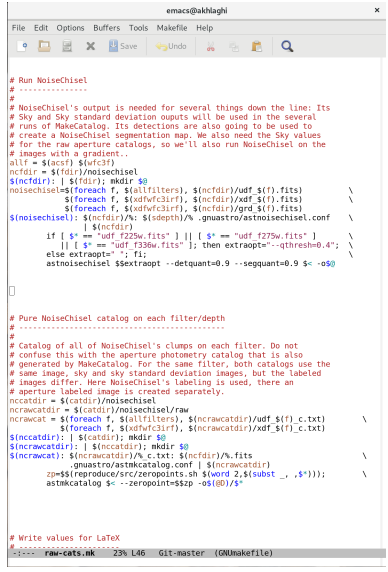
Reproducible science: Maneage is managed through a Makefile

All steps (downloading and analysis) are managed by Makefiles (example from zenodo.1164774):

- Unlike a script which always starts from the top, a Makefile starts from the end and steps that don't change will be left untouched (not remade).
- A single *rule* can manage any number of files.
- Make can identify independent steps internally and do them in parallel.
- Make was designed for complex projects with thousands of files (all major Unix-like components), so it is highly evolved and efficient.
- Make is a very simple and small language, thus easy to learn with great and free documentation (for example GNU Make's manual).



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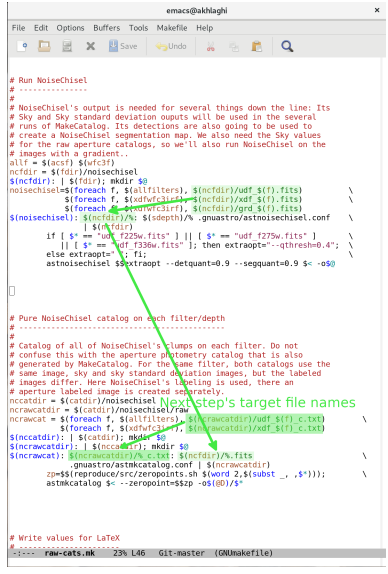

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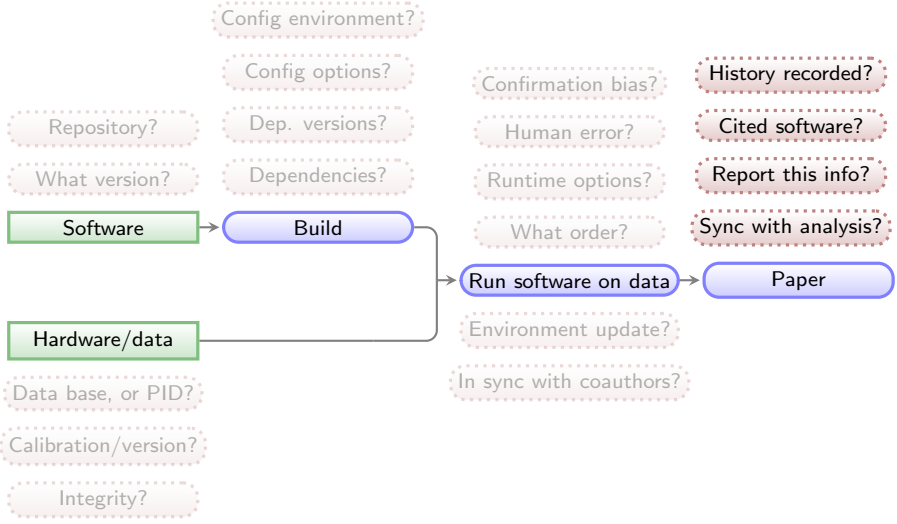

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Values in final report/paper

All analysis results (numbers, plots, tables) written in paper's PDF as LaTeX macros. They are thus updated automatically on any change.
Shown here is a portion of the NoiseChisel paper and its LaTeX source (arXiv:1505.01664).

```
\begin{equation}
  \label{tSNeq}
  \mathrm{S/N}_T=\frac{NF-NS_a}{\sqrt{NF+N\sigma_S^2}}
  =\frac{\sqrt{N}(F-S_a)}{\sqrt{F+\sigma_S^2}}.
\end{equation}

\noindent
See Section \ref{SNeqmodif} for the modifications required when
the input image is not in units of counts or has already been
Sky subtracted. The distribution of {\small S/N}$_T$ from the
objects in $R_s$ for the three examples in Figure \ref{dettf}
can be seen in column 5 (top) of that figure. Image processing
effects, mainly due to shifting, rotating, and re-sampling the
images for co-adding, on the real data further increase the size
and count, and hence, the {\small S/N} of false detections in
real, reduced/co-added images. A comparison of scales on the
{\small S/N} histograms between the mock ((a.5.1) and (b.5.1))
and real (c.5.1) examples in Figure \ref{dettf} shows the effect
quantitatively. In the histograms of Figure \ref{dettf}, the bin
with the largest number of false pseudo-detections respectively
has an {\small S/N} of $\onelargedettfmax$,
$\sensitivitycdettfmax$, and $\fourdettfmax$.
```

smaller than `--detsnminarea` are removed from the analysis in both R_s and R_d. In the examples in this section, it is set to 15. Note that since a threshold approximately equal to the Sky value is used, this is a very weak constraint. For each pseudo-detection, S/N_T can be written as,

$$S/N_T = \frac{NF - NS_a}{\sqrt{NF + N\sigma_S^2}} = \frac{\sqrt{N}(F - S_a)}{\sqrt{F + \sigma_S^2}}. \quad (3)$$

See Section 3.3 for the modifications required when the input image is not in units of counts or has already been Sky subtracted. The distribution of S/N_T from the objects in R_s for the three examples in Figure 7 can be seen in column 5 (top) of that figure. Image processing effects, mainly due to shifting, rotating, and re-sampling the images for co-adding, on the real data further increase the size and count, and hence, the S/N of false detections in real, reduced/co-added images. A comparison of scales on the S/N histograms between the mock ((a.5.1) and (b.5.1)) and real (c.5.1) examples in Figure 7 shows the effect quantitatively. In the histograms of Figure 7, the bin with the largest number of false pseudo-detections respectively has an S/N of 1.89, 2.37, and 4.77.

The S/N_T distribution of detections in R_s provides a very ro-

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{\small S/N} histograms between the mock ((a.5.1) and (b.5.1))
and real (c.5.1) examples in Figure \ref{dettf} shows the effect
quantitatively. In the histograms of Figure \ref{dettf}, the bin
with the largest number of false pseudo-detections respectively
has an {\small S/N} of $\onelargedettfmax$,
$\sensitivitycdettfmax$, and $\fourdettfmax$.
```

smaller than `--detsnminarea` are removed from the analysis in both R_s and R_d. In the examples in this section, it is set to 15. Note that since a threshold approximately equal to the Sky value is used, this is a very weak constraint. For each pseudo-detection, S/N_T can be written as,

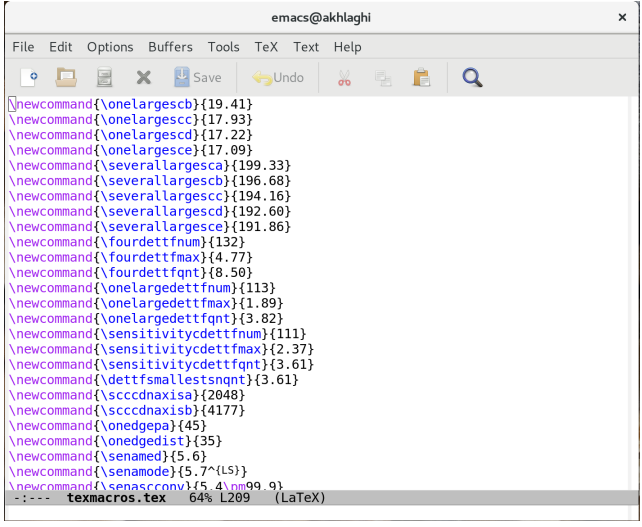
$$S/N_T = \frac{NF - NS_a}{\sqrt{NF + N\sigma_S^2}} = \frac{\sqrt{N}(F - S_a)}{\sqrt{F + \sigma_S^2}}. \quad (3)$$

See Section 3.3 for the modifications required when the input image is not in units of counts or has already been Sky subtracted. The distribution of S/N_T from the objects in R_s for the three examples in Figure 7 can be seen in column 5 (top) of that figure. Image processing effects, mainly due to shifting, rotating, and re-sampling the images for co-adding, on the real data further increase the size and count, and hence, the S/N of false detections in real, reduced/co-added images. A comparison of scales on the S/N histograms between the mock ((a.5.1) and (b.5.1)) and real (c.5.1) examples in Figure 7 shows the effect quantitatively. In the histograms of Figure 7, the bin with the largest number of false pseudo-detections respectively has an S/N of 1.89, 2.37, and 4.77.

The S/N_T distribution of detections in R_s provides a very ro-

Analysis step results/values concatenated into a single file.

All LaTeX macros come from a single file.



Analysis step results/values concatenated into a single file.

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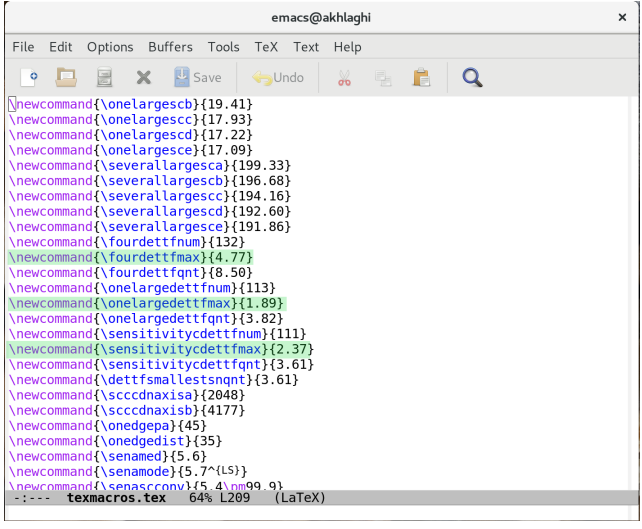

Analysis results stored as LaTeX macros

The analysis scripts write/update the LaTeX macro values automatically.

```
# Numbers for dettf.tex:
sqnt=9999999
function dettfhist
{
    # Set the file name.
    if [ $2 == 4 ]; then                obase=four;
    elif [ $2 = sensitivity3 ]; then    obase=sensitivityc;
    else                                obase=$2;
    fi
    if [ $2 == onelarge ]; then ind="_7"; else ind="_12"; fi
    name=$1$2$ind"_detsn"$txt

    dettfnum=$(awk '/points binned in/{print $4; exit(0)}' $name)
    dettfqnt=$(awk '/quantile has a value of/{
                    printf("%.2f", $9); exit(0);}' $name)
    dettfmax=$(awk 'BEGIN { max=-999999 }
                    !/^#/ { if($2>max){max=$2; mv=$1} }
                    END { printf("%.2f", mv) }' $name)
    addtexmacro $obase"dettfnum" $dettfnum
    addtexmacro $obase"dettfmax" $dettfmax
    addtexmacro $obase"dettfqnt" $dettfqnt

    # Find the smallest S/N quantile:
    sqnt=$(echo " " | awk '{if('$dettfqnt'<'$sqnt') print '$dettfqnt'}')
}
for base in 4 onelarge sensitivity3
do dettfhist $texdir/dettf/ $base;  done
addtexmacro dettfsmallestsnqnt $sqnt
```

Analysis results stored as LaTeX macros

The analysis scripts write/update the LaTeX macro values automatically.

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# Numbers for dettf.tex:
sqnt=9999999
function dettfhist
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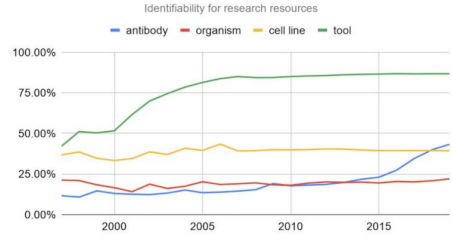
    # Find the smallest S/N quantile:
    sqnt=$(echo " " | awk '{if('$dettfqnt'<'$sqnt') print '$dettfqnt'}')
}
for base in 4 onelarge sensitivity3
do dettfhist $texdir/dettf/ $base;  done
addtexmacro dettfsmallestsnqnt $sqnt
```

Let's look at the data lineage to replicate Figure 1C (green/tool) of Menke+2020 (DOI:10.1101/2020.01.15.908111)

C.

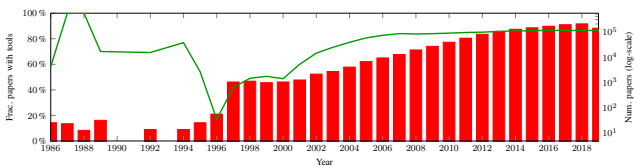


ORIGINAL PLOT

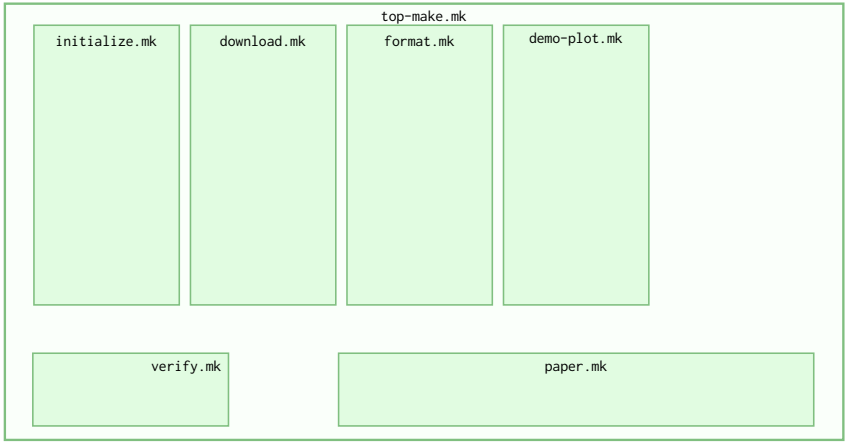
The Green plot shows the fraction of papers mentioning software tools from 1997 to 2019.

OUR enhanced REPLICATION

The green line is same as above but over their full historical range.
Red histogram is the number of papers studied in each year

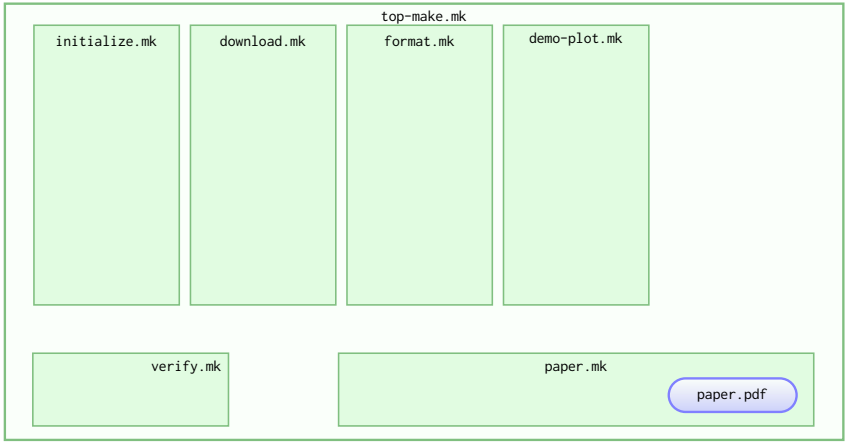


Makefiles (`.mk`) keep contextually separate parts of the project, all imported into `top-make.mk`



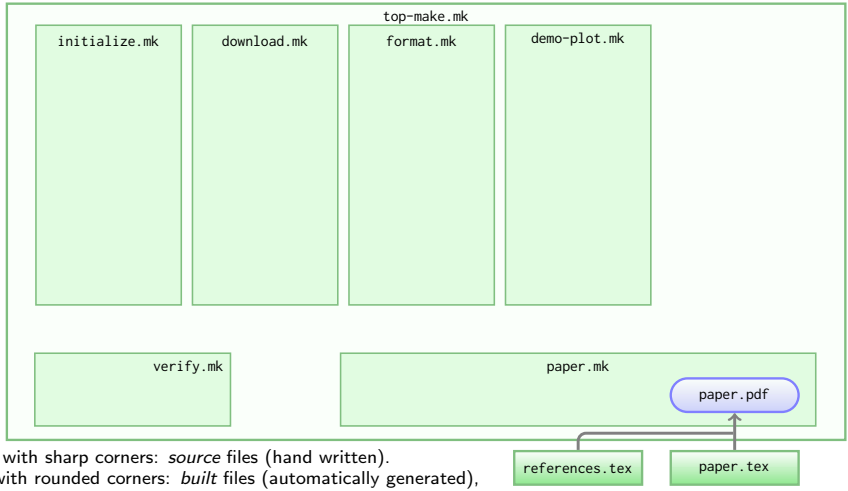
Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

The ultimate purpose of the project is to produce a paper/report (in PDF).



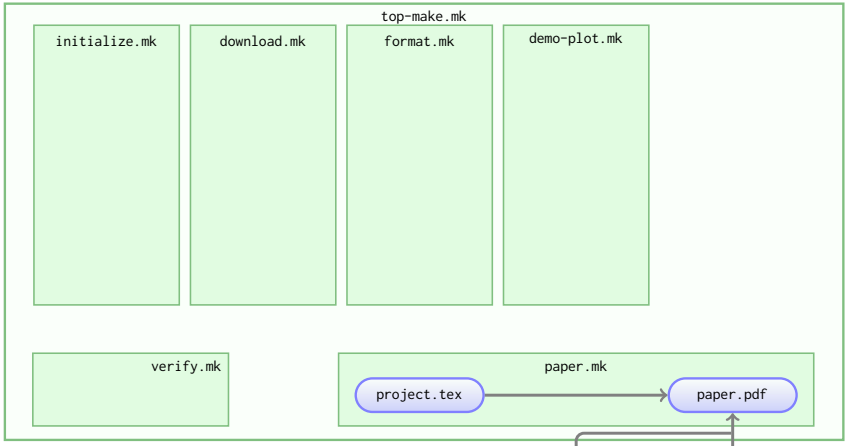
Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

The narrative description, typography and references are in `paper.tex` & `references.tex`.



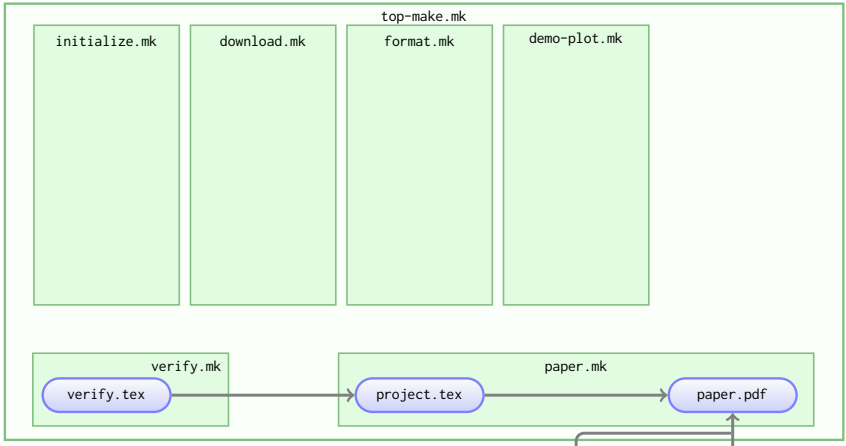
Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

Analysis outputs (blended into the PDF as LaTeX macros) come from `project.tex`.



Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

But analysis outputs must first be *verified* (with checksums) before entering the report/paper.



Green boxes with sharp corners: *source* files (hand written).
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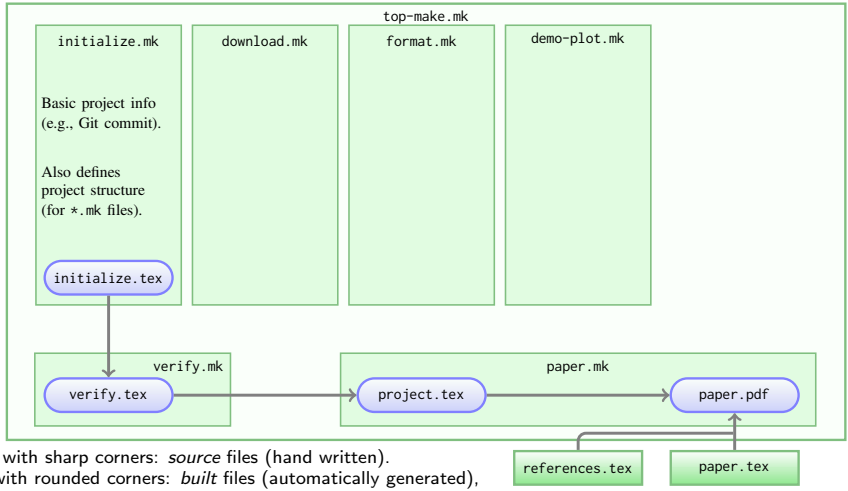
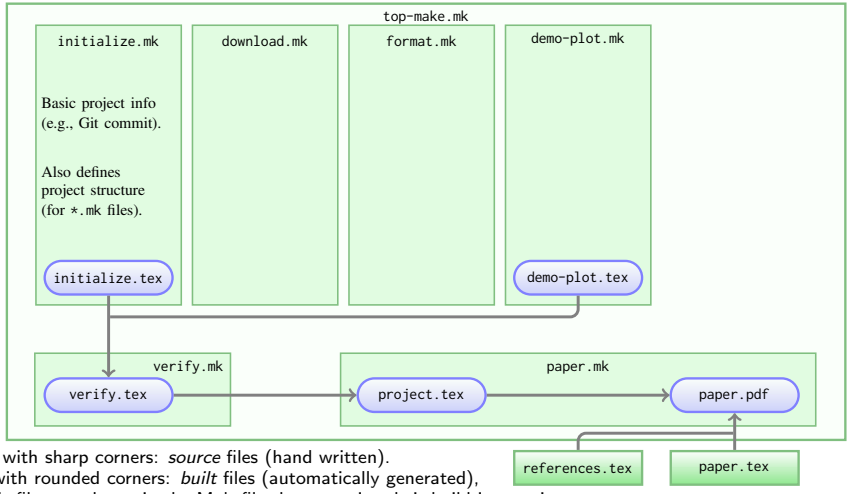
built files are shown in the Makefile that contains their build instructions.

Basic project info comes from `initialize.tex`.



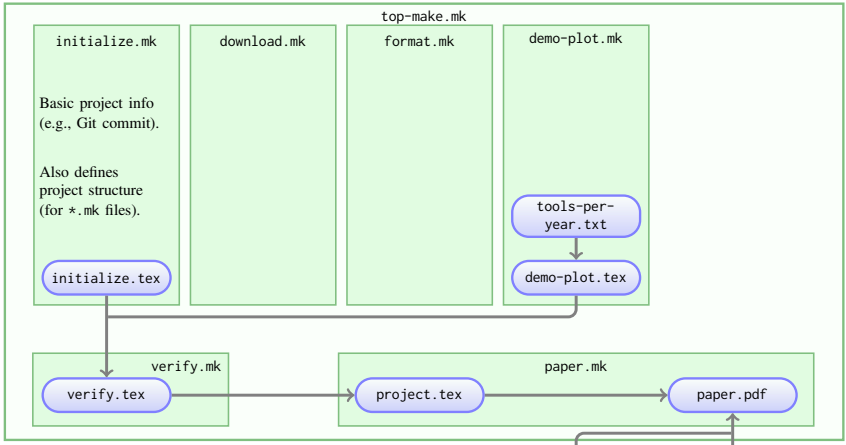
Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

The paper includes some information about the plot.



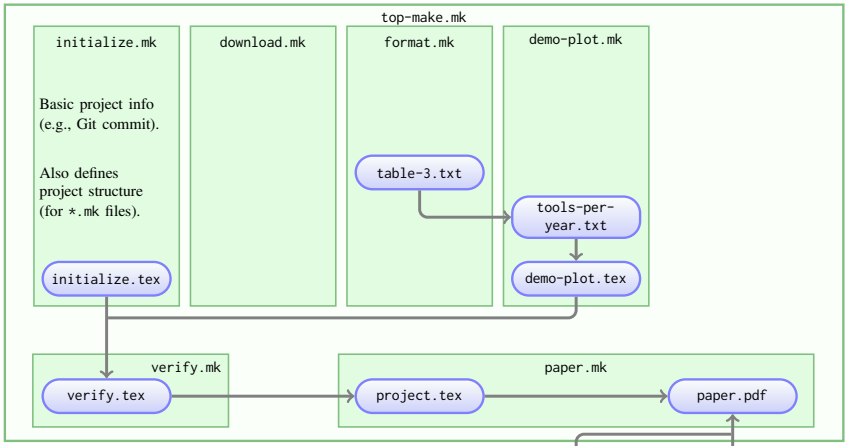
Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

The final plotted data are calculated and stored in `tools-per-year.txt`.



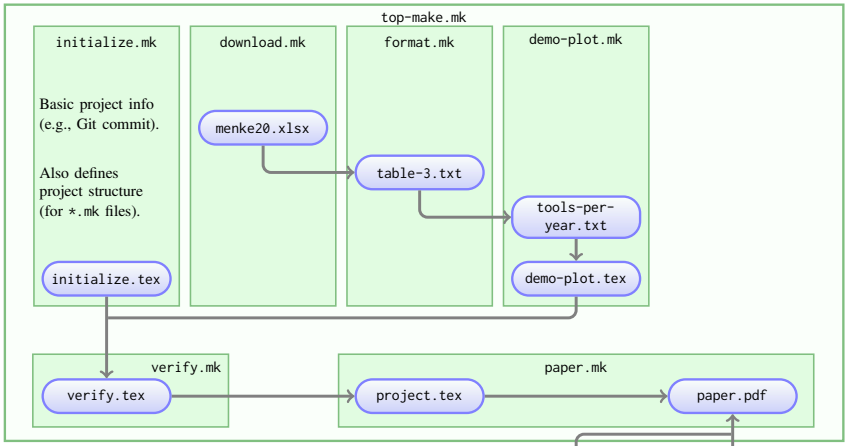
Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

The plot's calculation is done on a formatted sub-set of the raw input data.



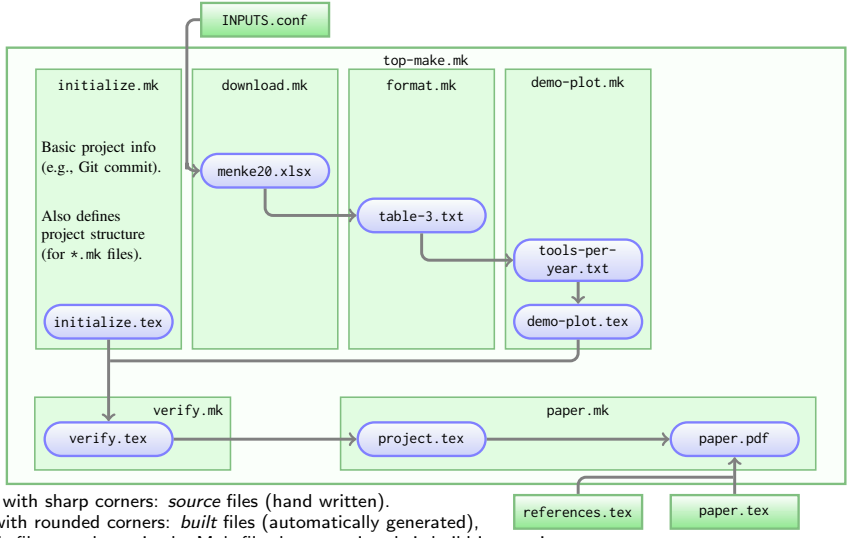
Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

The raw data that were downloaded are stored in XLSX format.



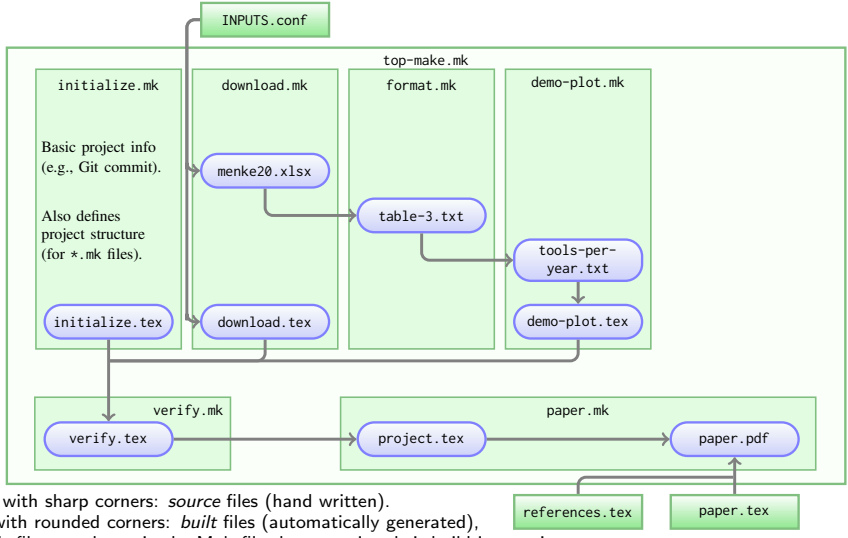
Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

The download URL *and* a checksum to validate the raw inputs, are stored in `INPUTS.conf`.



Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

We also need to report the URL in the paper...



Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
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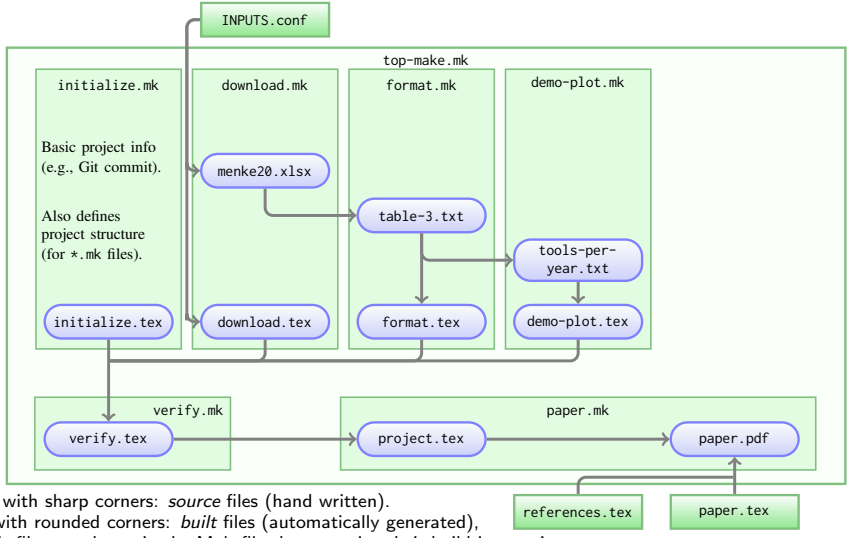
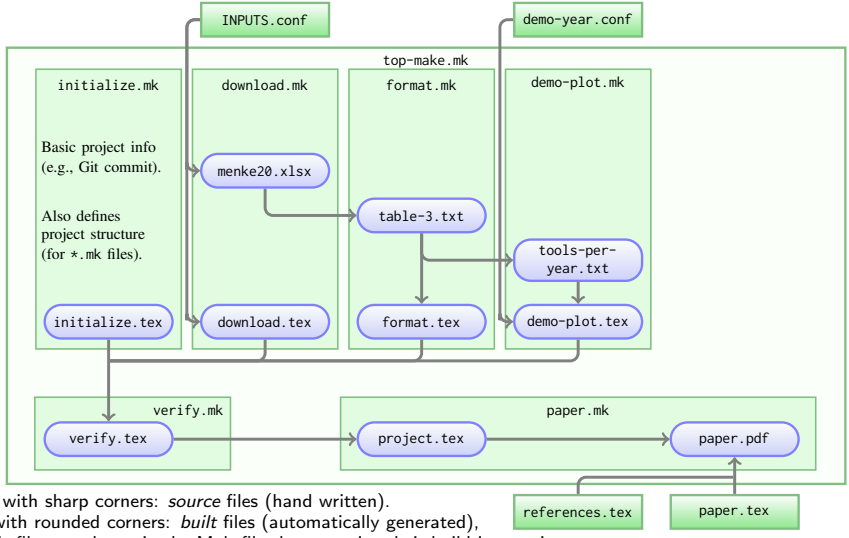
Some general info about the full dataset may also be reported.



Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
built files are shown in the Makefile that contains their build instructions.

We report the number of papers studied in a special year, desired year is stored in `.conf` file.



Green boxes with sharp corners: *source* files (hand written).
Blue boxes with rounded corners: *built* files (automatically generated),
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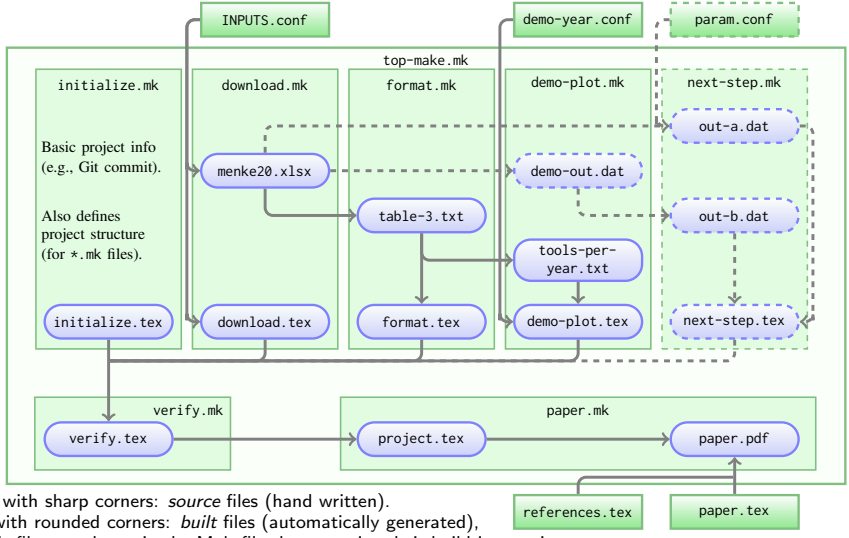
It is very easy to expand the project and add new analysis steps (this solution is scalable)



Green boxes with sharp corners: *source* files (hand written).
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built files are shown in the Makefile that contains their build instructions.

The whole project is a directed graph (codifying the data's lineage).

- Every file (source or built) is a node in the graph (connected to others).
  (The links/connections/dependencies between the nodes, defined by the Makefiles: `*.mk`)

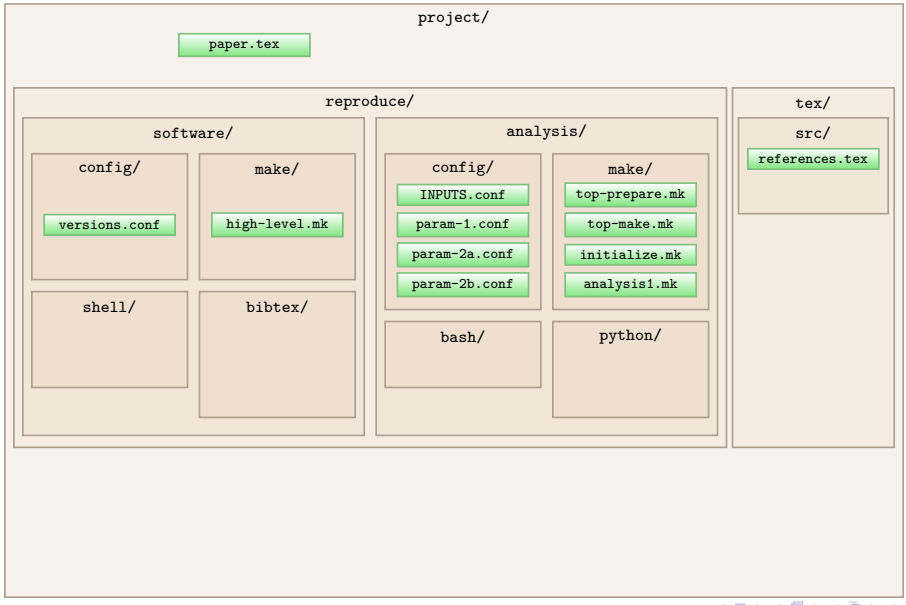
- There are two types of nodes/files:
  - Source nodes (`*.conf` and `paper.tex`) only have an outward link.
  - Built files always have inward *and* (except `paper.pdf`) outward link(s).

- All built files ultimately originate from a `*.conf` file,
  ... and ultimately conclude in `paper.pdf`.

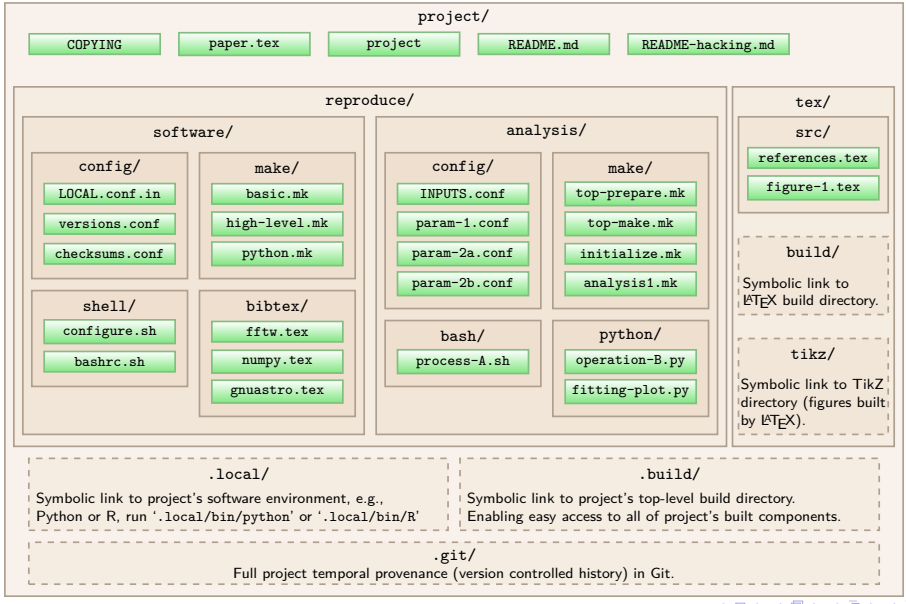
Benefits of using Make

- Make can parallelize the analysis:
  Make knows which steps are indepenent and will run them at the same time.
- Make can automatically detect a change and will re-do *only* the affected steps.
  (for example to change the multiple of sigma in a configuration file to see its effect)
- Easily backtrace any step (without needing to remember!).
  (very useful to find problems/improvements)
- The above will speed up your work, and encourage experimentation on methods.
- Make is available on any system: many people are already familiar with it.
- And again: its all in plain text!
  (doesn't take much space, easy to read, distribute, parse automatically, or archive)
- Recall that the project's software installation was also managed in Make.

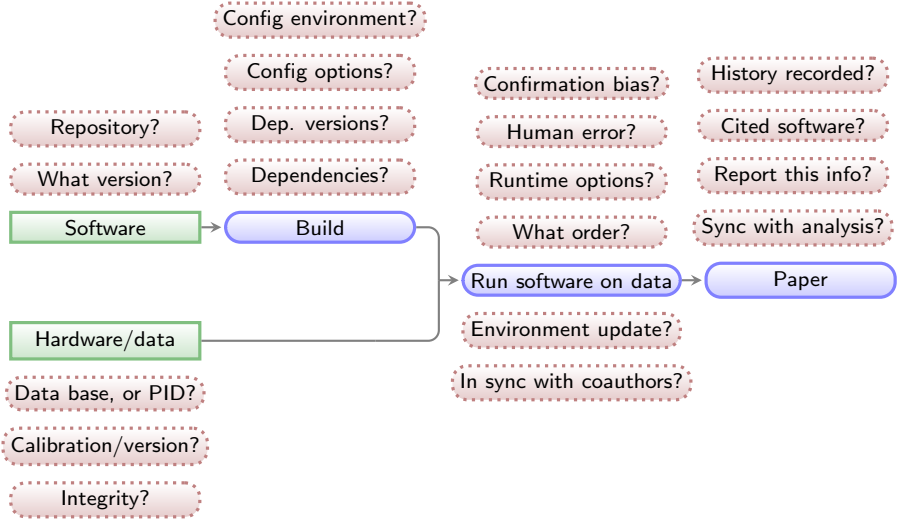
Files organized in directories by context (here are some of the files discussed before)



Files organized in directories by context (now with other project files and symbolic links)

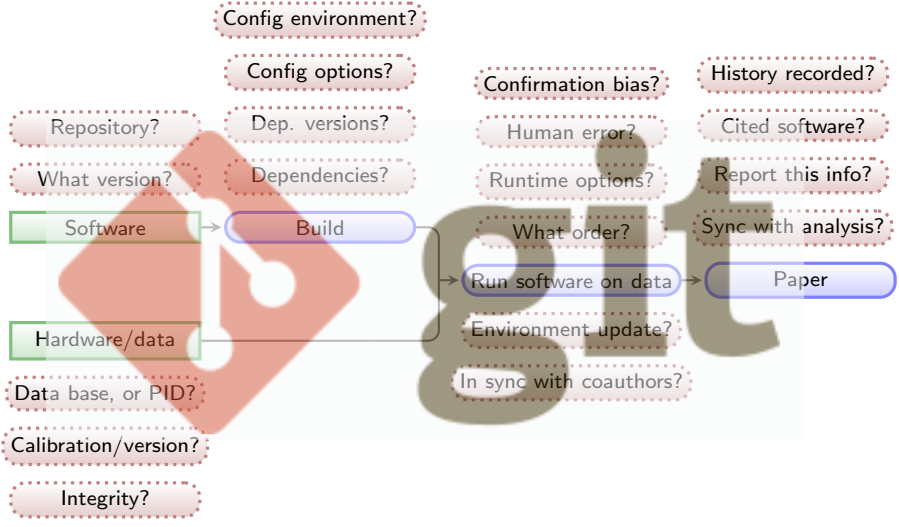


All questions have an answer now (in plain text: human & computer readable/archivable).



Green boxes with sharp corners: *source*/input components/files.
Blue boxes with rounded corners: *built* components.
Red boxes with dashed borders: questions that must be clarified for each phase.

All questions have an answer now (in plain text: so we can use Git to keep its history).



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New projects branch from Maneage

- The project (answers to questions above) will evolve.

New projects branch from Maneage

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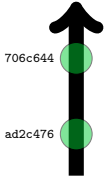
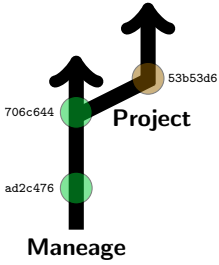
New projects branch from Maneage

- Each point of project's history is recorded with Git.

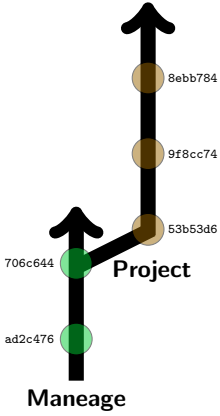


New projects branch from Maneage

- Each point of project's history is recorded with Git.
- New project: a branch from the template.
  Recall that every commit contains the following:
  - Instructions to download, verify and build software.
  - Instructions to download and verify input data.
  - Instructions to run software on data (do the analysis).
  - Narrative description of project's purpose/context.



New projects branch from Maneage



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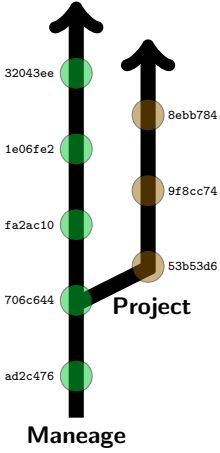
  - Instructions to run software on data (do the analysis).
  - Narrative description of project's purpose/context.
- Research progresses in the project branch.

New projects branch from Maneage



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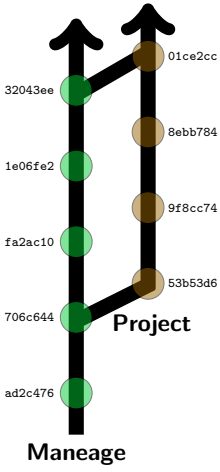
  - Narrative description of project's purpose/context.
- Research progresses in the project branch.
- Template will evolve (improved infrastructure).

New projects branch from Maneage



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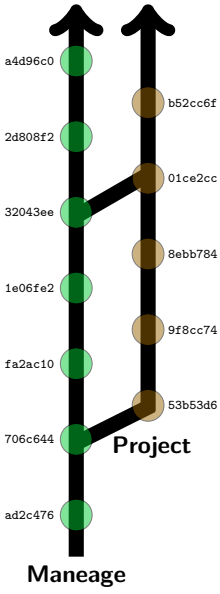
- Template will evolve (improved infrastructure).
- Template can be imported/merged back into project.

New projects branch from Maneage



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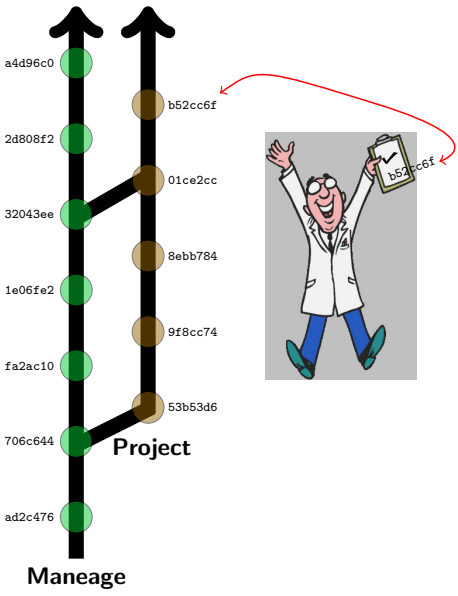
- Template will evolve (improved infrastructure).
- Template can be imported/merged back into project.
- The template and project will evolve.
- During research this encourages creative tests
  (previous research states can easily be retrieved).
- Coauthors can work on same project in parallel
  (separate project branches).

New projects branch from Maneage



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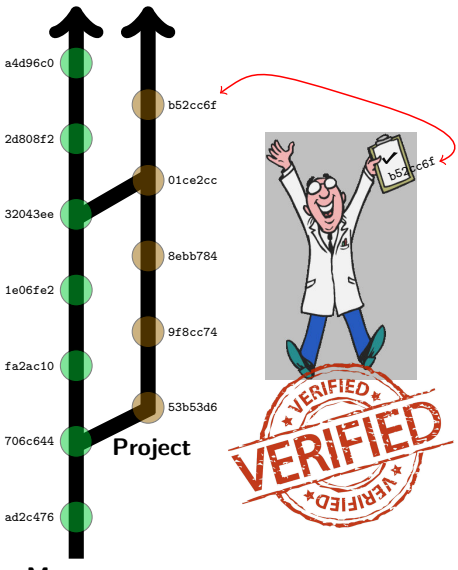
- Template can be imported/merged back into project.
- The template and project will evolve.
- During research this encourages creative tests (previous research states can easily be retrieved).
- Coauthors can work on same project in parallel (separate project branches).
- Upon publication, the Git checksum is enough to verify the integrity of the result.

New projects branch from Maneage



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- Template will evolve (improved infrastructure).
- Template can be imported/merged back into project.
- The template and project will evolve.
- During research this encourages creative tests (previous research states can easily be retrieved).
- Coauthors can work on same project in parallel (separate project branches).
- Upon publication, the Git checksum is enough to verify the integrity of the result.

"Verified" image from vectorstock.com

Two recent examples (publishing Git checksum in abstract)

The Realm of the Low-Surface-Brightness Universe
Proceedings IAU Symposium No. 355, 2019
D. Valls-Gabaud, J. Trujillo & S. Okamoto, eds.

DOI: 00.0000/X0000000000000000X

Carving out the low surface brightness universe with NoiseChisel

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Abstract. NoiseChisel is a program to detect very low signal-to-noise ratio (S/N) features with minimal assumptions on their morphology. It was introduced in 2015 and released within a collection of data analysis programs and libraries known as GNU Astronomy Utilities (Gnuastro). Over the last ten stable releases of Gnuastro, NoiseChisel has significantly improved: detecting even fainter signal, enabling better user control over its inner workings, and many bug fixes. The most important change may be that NoiseChisel's segmentation features have been moved into a new program called Segment. Another major change is the final growth strategy of its true detections, for example NoiseChisel is able to detect the outer wings of M51 down to S/N of 0.25, or 28.27 mag/arcsec^2 on a single-exposure SDSS image (r-band). Segment is also able to detect the localized IHI regions as "clumps" much more successfully. Finally, to orchestrate a controlled analysis, the concept of a "reproducible paper" is discussed: this paper itself is exactly reproducible (snapshot v4-0-g8505fcd).

Keywords. galaxies: halos, galaxies: photometry, galaxies: structure, methods: data analysis, methods: reproducible, techniques: image processing, techniques: photometric

1. Introduction

Signal from the low surface brightness universe is buried deep in the datasets noise and thus requires accurate detection methods. In Akhlaghi and Ichikawa (2015) (henceforth AI15) a new method was introduced to detect such very low signal-to-noise ratio (S/N) signal from the images in a non-parametric manner. It allows accurate detection of the diffuse outer features of galaxies (that often have a different morphology from the centers). The software implementation of this method (NoiseChisel) is released as part of a larger collection of data analysis software known as GNU Astronomy Utilities[†] (Gnuastro). It was the first professional astronomical software to be independently refereed by an independent panel (GNU Evaluation committee) and fully conforms with the GNU Coding Standards[‡].

Since its release, NoiseChisel has been used in many studies. For example Bacon et al. (2017) used it to identify objects that were missed by Rafelski et al. (2015) (henceforth R15), who used a combination of six SExtractor (Bertin and Arnouts 1996) runs with different configurations to avoid deblending problems, but still missed many sources with significant signal, see Figure 1. Borlaff et al. (2019), Miller et al. (2019), and Trujillo et al. (2019) used it for accurate flat field and Sky subtraction to create deeper co-added images in galaxy fields for optimal detection of the low surface brightness features. Calvi et al. (2019) used it to find Lyman-α emitters in spectra. For future studies, Laine et al.

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The Sloan Digital Sky Survey extended point spread functions

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ABSTRACT

A robust and extended characterization of the point spread function (PSF) is crucial to extract the photometric information produced by deep imaging surveys. Here, we present the extended PSFs of the Sloan Digital Sky Survey (SDSS), one of the most productive astronomical surveys of all time. By stacking ∼1000 images of individual stars with different brightness, we obtain the bidimensional SDSS PSFs extending over 8 arcmin in radius for all the SDSS filters (*u*, *g*, *r*, *i*, *z*). This new characterization of the SDSS PSFs is near a factor of 10 larger in extension than previous PSFs characterizations of the same survey. We found asymmetries in the shape of the PSFs caused by the drift scanning observing mode. The flux of the PSFs is larger along the drift scanning direction. Finally, we illustrate with an example how the PSF models can be used to remove the scattered light field produced by the brightest stars in the central region of the Coma cluster field. This particular example shows the huge importance of PSFs in the study of the low-surface brightness Universe, especially with the upcoming of ultradeep surveys, such as the Large Synoptic Survey Telescope (LSST). Following a reproducible science philosophy, we make all the PSF models and the scripts used to do the analysis of this paper publicly available (snapshot v0.4-0-gf906ad0).

Key words: instrumentation: detectors – methods: data analysis – techniques: image processing – techniques: photometric – galaxies: haloes.

1 INTRODUCTION

The point spread function (PSF) describes the response of an imaging system to the light produced by a point source. Real PSFs have complex structures as their shapes depend on the optical path that light takes as it travels through the atmosphere and multiple optical elements, mirrors, lenses, detectors, etc. For the vast majority of astronomical works, only a tiny portion of the PSF (i.e. normally a few inner arcseconds; see e.g. Trujillo et al. 2001a, b) is characterized. In practice, however, the light of both point and extended sources are spread over the entire detector due to the effect of the PSF at large radii. Therefore, it is necessary to have a good understanding of its structure along the entire detector (typically extending over arcminutes or more).

Extended PSFs have become a vital tool to obtain precise photometric information in modern astronomical surveys. For instance, Slater, Harding & Mihos (2009) modelled the extended PSF and the internal reflections produced by the stars of the Burrell Schmidt telescope and showed that virtually all the pixels of the image are dominated by the scattered light by both stars and galaxies at 29.5 mag arcsec^{-2} (*V*-band). Trujillo & Fliri (2016) also characterized and used the extended PSF of the 10.4 m Gran Telescopio Canarias (GTC) telescope to model and remove the scattered light in ultradeep observations of the UGC 00180 galaxy. Even more troublesome for low-surface brightness studies is the finding (see e.g. Trujillo & Bakos 2013; Sandin 2014, 2015) that the outer regions of astronomical objects are severely affected by their own scattered light produced by the convolution with the PSF. In order to correct this effect, Karabal et al. (2017) generated the PSF and models of the internal reflections from images of the Canada–France–Hawaii Telescope (CFHT) to de-convolve a sample of three galaxies and correct them from instrumental scattered light. More recently, Román, Trujillo & Montes (2019) characterized the PSFs of the Stripe 82 survey and used them to model and correct the scattered light field produced by stars to study the optical properties of the Galactic cirri. All the above works have shown that having an extended PSF is crucial when accurate photometric and structure properties of astronomical objects at low-surface brightness levels are required.

One of the most commonly used surveys for measuring photometric properties of astronomical objects is the Sloan Sky Digital Survey (SDSS; York et al. 2000), covering 14 555 deg^2 on the sky (just over 35 per cent of the full sky) in five photometric bands (*u*, *g*, *r*, *i*, and *z*). Although SDSS is a relatively shallow survey compared

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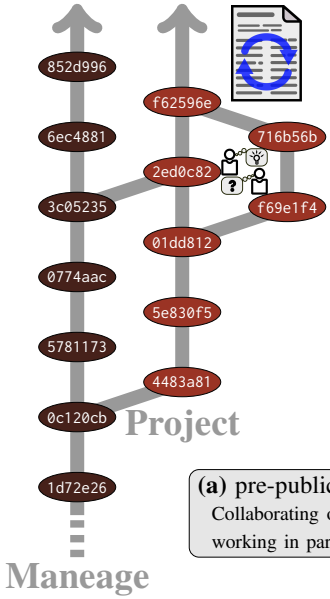
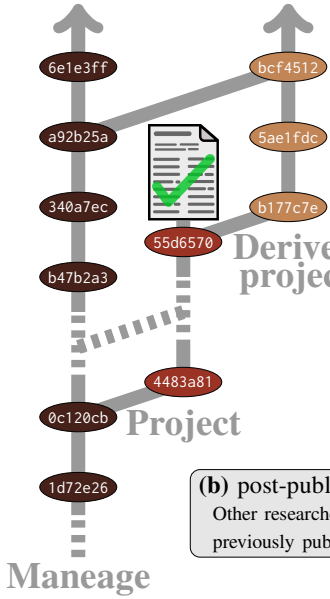
Any Git-based workflow is possible.



(a) pre-publication:
Collaborating on a project while working in parallel, then merging.



(b) post-publication:
Other researchers building upon previously published work.

Publication of the project

A reproducible project using Maneage will have the following (plain text) components:

- Makefiles.
- LaTeX source files.
- Configuration files for software used in analysis.
- Scripts/programming files (e.g., Python, Shell, AWK, C).

The volume of the project's source will thus be negligible compared to a single figure in a paper (usually $\sim$ 100 kilo-bytes).

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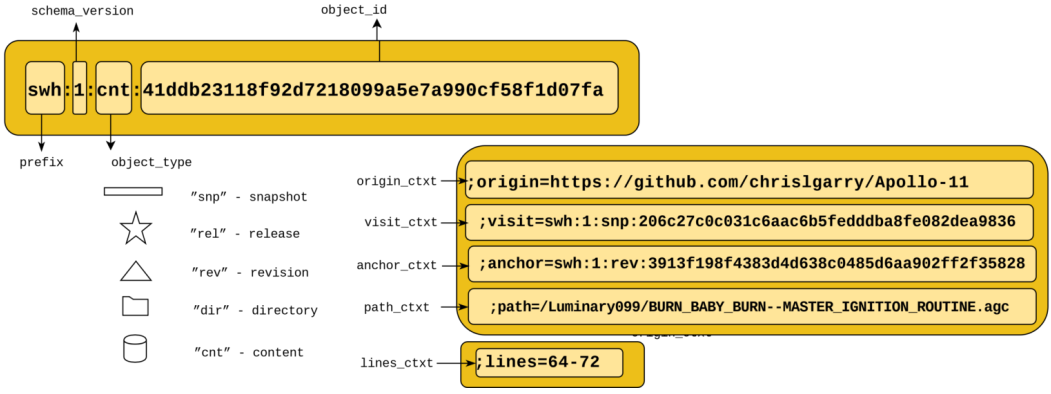
The project's pipeline (customized Maneage) can be published in

- arXiv: uploaded with the LaTeX source to always stay with the paper (for example arXiv:1505.01664 or arXiv:2006.03018).
- Zenodo: Along with all the input datasets (many Gigabytes) and software (for example zenodo.3872247) and given a unique DOI.
  - ... and put links to data in paper! See ending of caption of Figure 1 in the Maneage paper.
- Software Heritage: to archive the full version-controlled history of the project. (for example swh:1:dir:33fea87068c1612daf011f161b97787b9a0df39fk)
  - ... and put links to exact parts of the code! See caption of Listing 1 in the Maneage paper or Table 1 of arXiv:1909.11230.

Software Heritage IDs (SWHID); persistent identifier for source code (or any text!)



For more details, see SoftwareHeritage FAQ (at https://www.softwareheritage.org/faq)

Project source and its execution

> Programs [here: Scientific projects] must be written for people to read...
> ...and only *incidentally* for machines to *execute*.
>
> Harold Abelson, Structure and Interpretation of Computer Programs

General outline of using this system (for example arXiv:1909.11230)

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$ git clone http://gitlab.com/makhlaghi/iau-symposium-355    # Import the project.
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$ ./project make               # Does all the analysis and makes final PDF.
```

Future prospects...

Adoption of reproducibility by many researchers will enable the following:

- A repository for education/training (PhD students, or researchers in other fields).
- Easy verification/understanding of other research projects (when necessary).
- Trivially test different steps of others' work (different configurations, software and etc).
- Science can progress incrementally (shorter papers actually building on each other!).
- Extract meta-data after the publication of a dataset (for future ontologies or vocabularies).
- Applying machine learning on reproducible research projects will allow us to solve some Big Data Challenges:
  - *Extract the relevant parameters automatically.*
  - *Translate the science to enormous samples.*
  - *Believe the results when no one will have time to reproduce.*
  - *Have confidence in results derived using machine learning or AI.*

Summary:

Maneage is introduced as a customizable template that will do the following steps/instructions (all in simple plain text files).

- Automatically downloads the necessary *software* and *data*.
- Builds the software in a closed environment.
- Runs the software on data to generate the final research results.
- Only parts affected by a modifcation are re-done.
- Using LaTeX macros, paper's figures, tables and numbers will be Automatically updated.
- The whole project is under version control (Git) encouraging tests/experimentation.
- The Git commit hash of the project source, is printed in the paper and on output data products.
- These slides are available at `https://maneage.org/pdf/slides-intro.pdf`.

For a technical description of Maneage's implementation, as well as a checklist to customize it, and tips on good practices, please see this page:
`https://gitlab.com/maneage/project/-/blob/maneage/README-hacking.md`

Feel free to contact me: `mohammad@akhlaghi.org`