Archiving, referencing and attributing research software

towards software as a first class citizen

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Software Heritage
THE GREAT LIBRARY OF SOURCE CODE

Outline

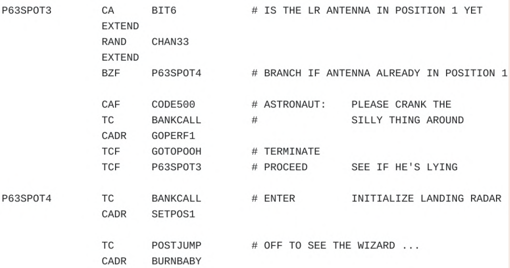
1. Software Source Code: a precious heritage
2. Software Source Code: a (forgotten) pillar of Science
3. Meet Software Heritage
4. Archive and reference *all* the source code
5. Describe and cite *research* source code
6. The road ahead

Software source code: a precious part of our heritage

Harold Abelson, Structure and Interpretation of Computer Programs (1st ed.) 1985

“Programs must be written for people to read, and only incidentally for machines to execute.”

Apollo 11 source code (excerpt)



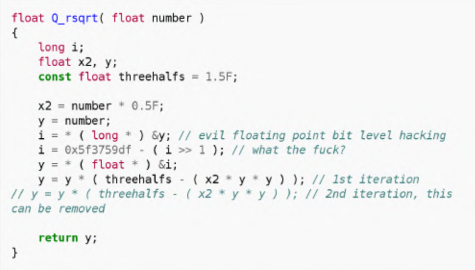
```
P63SPOT3        CA      BIT6            # IS THE LR ANTENNA IN POSITION 1 YET
                EXTEND
                RAND    CHAN33
                EXTEND
                BZF     P63SPOT4        # BRANCH IF ANTENNA ALREADY IN POSITION 1

                CAF     CODE500         # ASTRONAUT:     PLEASE CRANK THE
                TC      BANKCALL        #                SILLY THING AROUND
                CADR    GOPERF1
                TCF     GOTOPOOH        # TERMINATE
                TCF     P63SPOT3        # PROCEED        SEE IF HE'S LYING

P63SPOT4        TC      BANKCALL        # ENTER          INITIALIZE LANDING RADAR
                CADR    SETPOS1

                TC      POSTJUMP        # OFF TO SEE THE WIZARD ...
                CADR    BURNBABY
```

Quake III source code (excerpt)



```
float Q_rsqrt( float number )
{
    long i;
    float x2, y;
    const float threehalfs = 1.5F;

    x2 = number * 0.5F;
    y = number;
    i = * ( long * ) &y; // evil floating point bit level hacking
    i = 0x5f3759df - ( i >> 1 ); // what the fuck?
    y = * ( float * ) &i;
    y = y * ( threehalfs - ( x2 * y * y ) ); // 1st iteration
// y = y * ( threehalfs - ( x2 * y * y ) ); // 2nd iteration, this
can be removed

    return y;
}
```

Len Shustek, Computer History Museum

“Source code provides a view into the mind of the designer.”

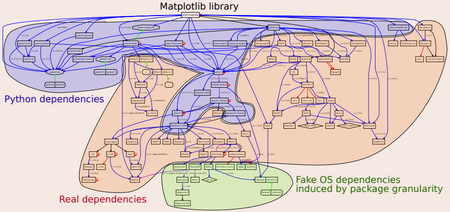
Source code is a *special* and endangered heritage

Software *evolves* over time

- projects may last decades
- the *development history* is key to its *understanding*

Complexity

- *millions* of lines of code
- large *web of dependencies*
  - easy to break, difficult to maintain
- sophisticated *developer communities*



Precious, endangered *Executable* and *human readable* knowledge

key people are passing away …

no organised effort to catalog and archive it

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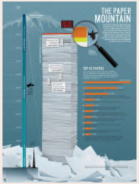
Software Source code: pillar of Open Science

Software is everywhere in modern research



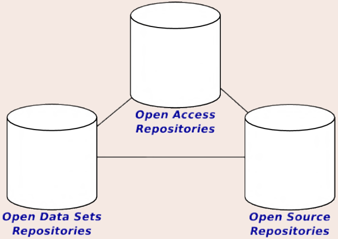
[. . .] software [. . .] essential in their fields.

Top 100 papers (Nature, 2014)

Sometimes, if you dont have the software, you dont have the data

Christine Borgman, Paris, 2018

Open Science: three pillars



Source code is needed to:

- *reproduce* and *verify*,
- *modify* and *evolve*, building new experiments from old ones

N.B.: the *links* in the picture are essential

The state of the art (in CS!) is far from ideal

ICSE (Zannier, Melrik, Maurer, 2006)

- complete absence of replication studies

ACM TOSEM 2001 to 2006 C. Ghezzi `http://bit.ly/tosemreprod`

- 60% of all papers have tools: only 20% *installable*

Collberg's 2015 study `http://reproducibility.cs.arizona.edu/`

- 601 mainstream papers: 508 with tools, only 40% *installable*

Main reasons

source code (*or the right version of it*) cannot be found

Where we stand

A wealth of initiatives!

- Policies: ACM Artifact Review and Badging, …
- Working groups: FORCE11, RDA, SPSO, …
- Metrics: Open Science Monitor (Elsevier!), …
- Journals: IPOL, ReScience, InsightJournal, eLife, ACM DL, …
- Repositories: FigShare, Zenodo, …

but …

Lack of recognition

not (yet) a first class citizen

- in the EOSC plan
- in the scholarly works

Lack of proper guidance on how to

- *archive* and *reference* software
- choose a license
- *cite* a software project

A plurality of needs

Researcher

- archive and reference sw used in articles
- get credit for the software they develop
- verify/reproduce/improve results

Laboratory/team

- track software contributions
- produce up-to date report / web page

University/Research Organization

- central view of research software assets
- tech transfer
- impact metrics

What is at stake in increasing order of difficulty

Archival

Research software artifacts must be properly archived

make it sure we can *retrieve* them (*reproducibility*)

Identification

Research software artifacts must be properly referenced

make it sure we can *identify* them (*reproducibility*)

Metadata

Research software artifacts must be properly described

make it easy to *discover* them (*visibility*)

Citation

Research software artifacts must be properly cited *(not the same as referenced!)*

to give *credit* to authors (*evaluation*!)

Let's focus on the *first two!*

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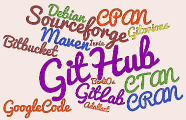
Software Heritage in a nutshell

Software Heritage
THE GREAT LIBRARY OF SOURCE CODE

Collect, preserve and share the *source code* of *all the software*

Preserving our heritage, enabling better software and better science for all

Reference catalog



find and reference all the source code

Universal archive

damage
storage
disaster
reference
deletion
media
malicious
obsolete
aging
attack
tear
dependencies
dangling
wear
corruption
encryption
format

preserve all the source code

Research infrastructure

enable analysis of all the source code

An international, non profit initiative built for the long term

Sharing the vision

UNESCO
United Nations
Educational, Scientific and
Cultural Organization

Software, GitLab, Engineering, eclipse, OW2, fsfe, nlnet foundation, SIGSOFT, Liberté • Égalité • Fraternité République Française, INAPI, The Linux Foundation, ADULLACT, Informatics Europe, Computer History Museum, software freedom conservancy, Software Freedom Law Center, AdaCore, gandi.net, IDF, Free Software Foundation, creative commons, SIF, open source initiative, openinventionnetwork

And many more ...
www.softwareheritage.org/support/testimonials

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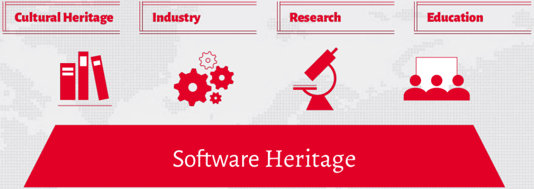
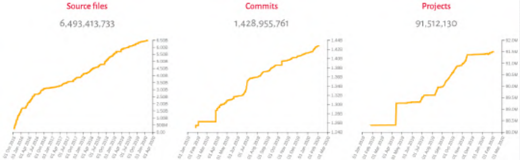
Largest software archive, principled http://bit.ly/swhpaper





Technology

- transparency and FOSS
- replicas all the way down

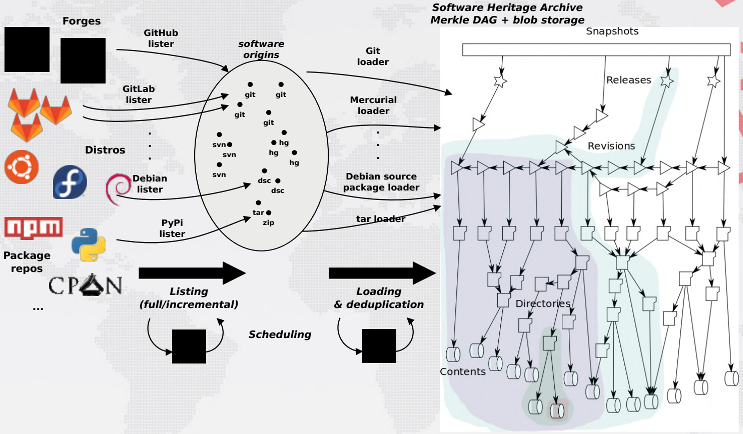
Content (billions!)

- intrinsic identifiers
- facts and provenance

Organization

- non-profit
- multi-stakeholder

A peek under the hood



Global development history permanently archived in a *unique* git-like Merkle DAG

- ~400 TB (uncompressed) blobs, ~20 B nodes, ~280 B edges

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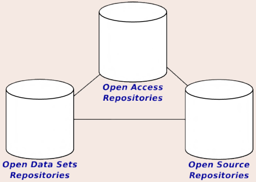
Archive and reference

Software Heritage: a revolutionary infrastructure



- universal archive of all source code
  - we archive *all* software: both research and non research
  - we *proactively collect software* in a systematic way
- intrinsic identifiers for reproducibility
  - identify software artefacts *without any third party*
  - cryptographically strong, compatible with git hashes

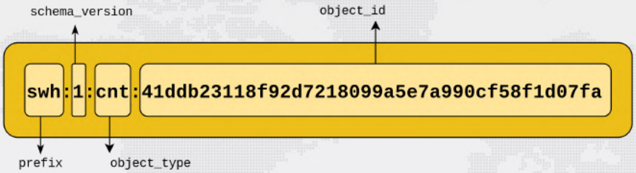
Demo

2012 Parmap paper before and after; OCamlP3l paper for the Ten year challenge

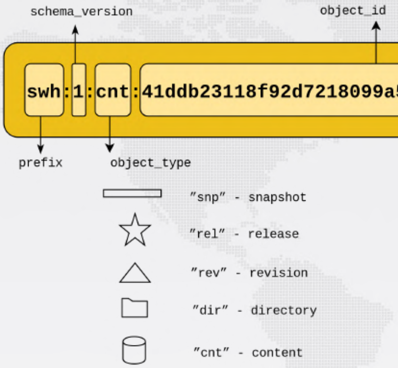
Full guidelines available! `https://www.softwareheritage.org/save-and-reference-research-software/`

See also: Apollo 11 (and the blog post!), Quake III Arena

The SWH-ID schema



The SWH-ID schema



▭ "snp" - snapshot

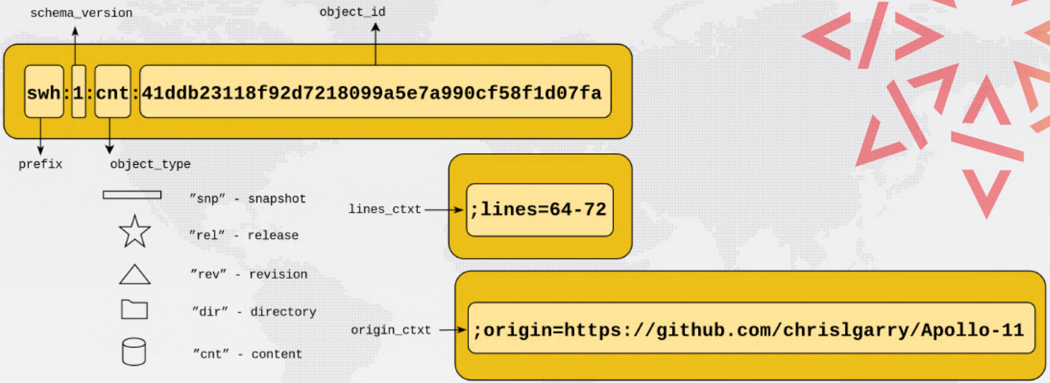
☆ "rel" - release

△ "rev" - revision

🗀 "dir" - directory

⛁ "cnt" - content

The SWH-ID schema



schema_version

object_id

swh:1:cnt:41ddb23118f92d7218099a5e7a990cf58f1d07fa

prefix

object_type

"snp" - snapshot

☆ "rel" - release

△ "rev" - revision

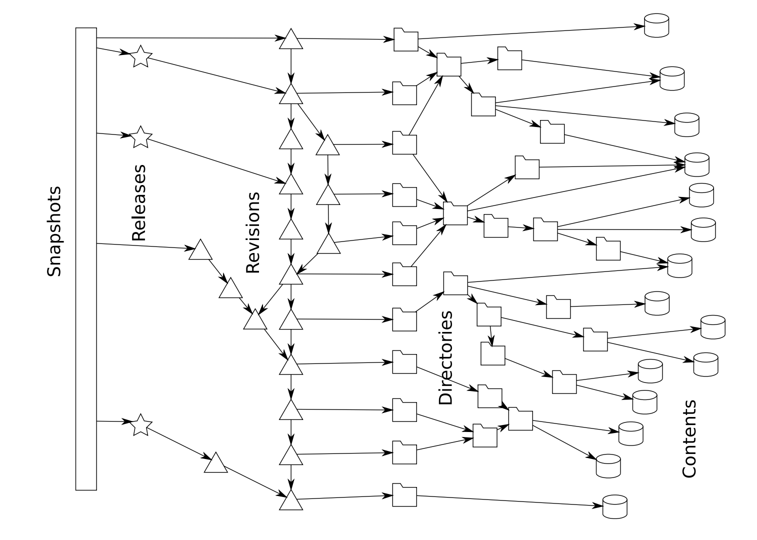
"dir" - directory

"cnt" - content

lines_ctxt → ;lines=64-72

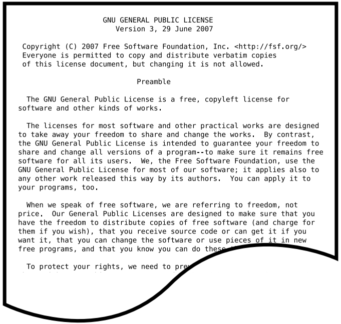
origin_ctxt → ;origin=https://github.com/chrislgarry/Apollo-11

A worked example



A worked example

Contents



```
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free programs, and that you know you can do these

  To protect your rights, we need to pre
```
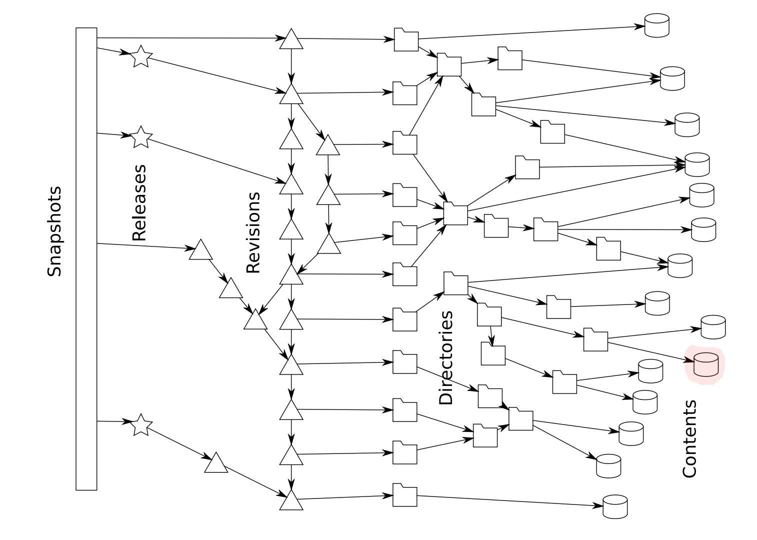
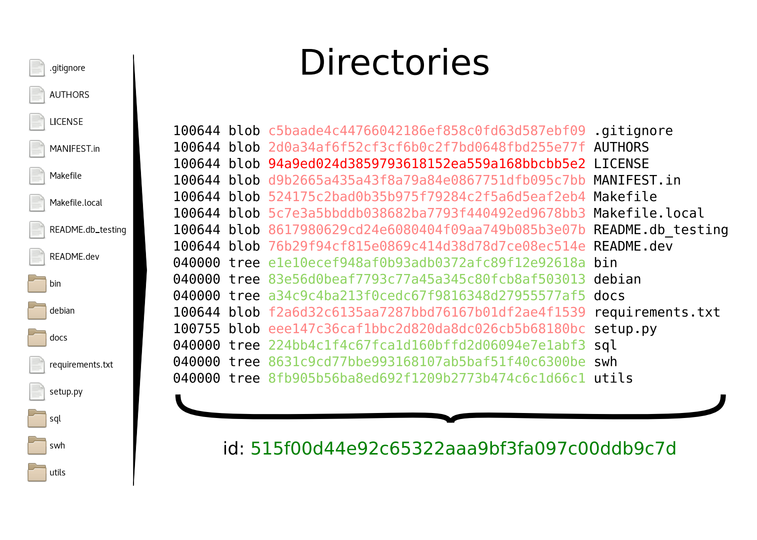

sha1: 8624bcdae55baeef...
sha256: 8ceb4b9ee5aded...
sha1_git: 94a9ed024d385...
length: 35147

A worked example



A worked example

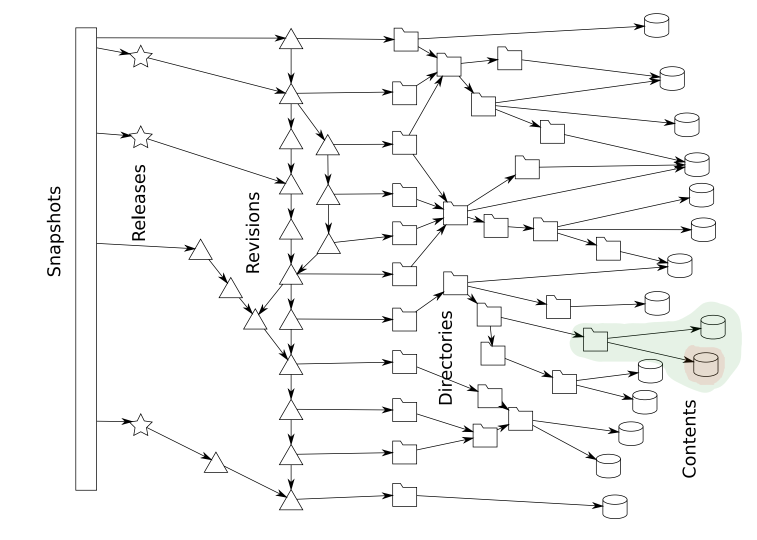


Directories

```
100644 blob c5baade4c44766042186ef858c0fd63d587ebf09 .gitignore
100644 blob 2d0a34af6f52cf3cf6b0c2f7bd0648fbd255e77f AUTHORS
100644 blob 94a9ed024d3859793618152ea559a168bbcbb5e2 LICENSE
100644 blob d9b2665a435a43f8a79a84e0867751dfb095c7bb MANIFEST.in
100644 blob 524175c2bad0b35b975f79284c2f5a6d5eaf2eb4 Makefile
100644 blob 5c7e3a5bbddb038682ba7793f440492ed9678bb3 Makefile.local
100644 blob 8617980629cd24e6080404f09aa749b085b3e07b README.db_testing
100644 blob 76b29f94cf815e0869c414d38d78d7ce08ec514e README.dev
040000 tree e1e10ecef948af0b93adb0372afc89f12e92618a bin
040000 tree 83e56d0beaf7793c77a45a345c80fcb8af503013 debian
040000 tree a34c9c4ba213f0cedc67f9816348d27955577af5 docs
100644 blob f2a6d32c6135aa7287bbd76167b01df2ae4f1539 requirements.txt
100755 blob eee147c36caf1bbc2d820da8dc026cb5b68180bc setup.py
040000 tree 224bb4c1f4c67fca1d160bffd2d06094e7e1abf3 sql
040000 tree 8631c9cd77bbe993168107ab5baf51f40c6300be swh
040000 tree 8fb905b56ba8ed692f1209b2773b474c6c1d66c1 utils
```

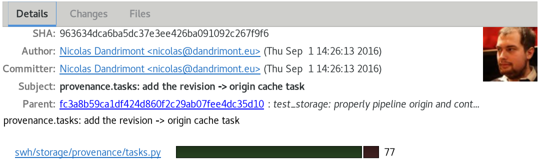
id: 515f00d44e92c65322aaa9bf3fa097c00ddb9c7d

A worked example



A worked example

Revisions



SHA: 963634dca6ba5dc37e3ee426ba091092c267f9f6
Author: Nicolas Dandrimont <nicolas@dandrimont.eu> (Thu Sep 1 14:26:13 2016)
Committer: Nicolas Dandrimont <nicolas@dandrimont.eu> (Thu Sep 1 14:26:13 2016)
Subject: **provenance.tasks: add the revision -> origin cache task**
Parent: fc3a8b59ca1df424d860f2c29ab07fee4dc35d10 : *test_storage: properly pipeline origin and cont...*

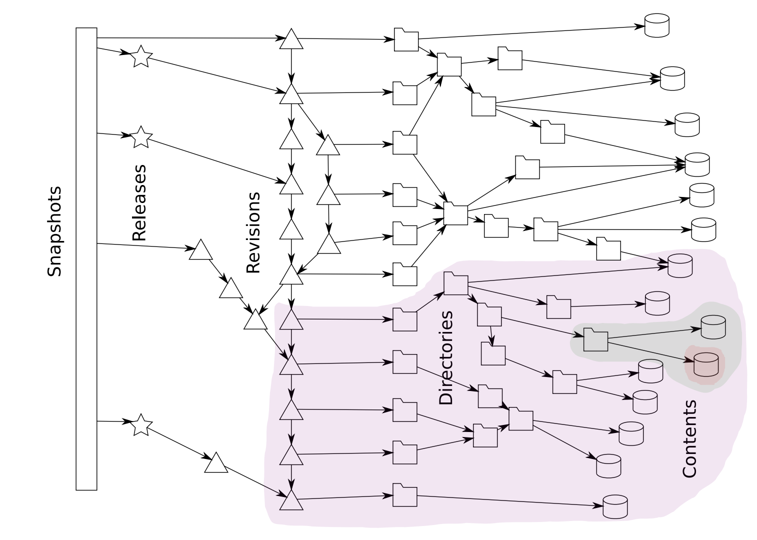
provenance.tasks: add the revision -> origin cache task

swh/storage/provenance/tasks.py 77

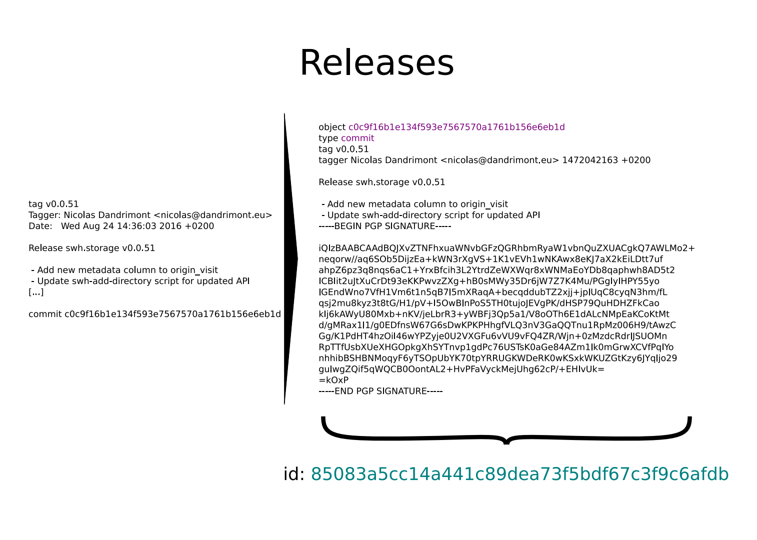
```
tree 515f00d44e92c65322aaa9bf3fa097c00ddb9c7d
parent fc3a8b59ca1df424d860f2c29ab07fee4dc35d10
author Nicolas Dandrimont <nicolas@dandrimont.eu> 1472732773 +0200
committer Nicolas Dandrimont <nicolas@dandrimont.eu> 1472732773 +0200

provenance.tasks: add the revision -> origin cache task
```

id: 963634dca6ba5dc37e3ee426ba091092c267f9f6

A worked example



A worked example



Releases

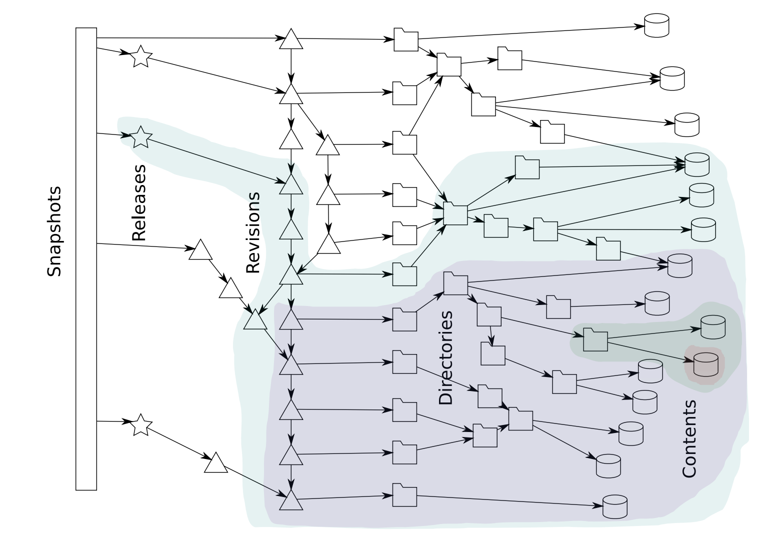
```
tag v0.0.51
Tagger: Nicolas Dandrimont <nicolas@dandrimont.eu>
Date:   Wed Aug 24 14:36:03 2016 +0200

Release swh.storage v0.0.51

 - Add new metadata column to origin_visit
 - Update swh-add-directory script for updated API
[...]

commit c0c9f16b1e134f593e7567570a1761b156e6eb1d
```

```
object c0c9f16b1e134f593e7567570a1761b156e6eb1d
type commit
tag v0.0.51
tagger Nicolas Dandrimont <nicolas@dandrimont.eu> 1472042163 +0200

Release swh.storage v0.0.51

 - Add new metadata column to origin_visit
 - Update swh-add-directory script for updated API
-----BEGIN PGP SIGNATURE-----

iQIzBAABCAAdBQJXvZTNFhxuaWNvbGFzQGRhbmRyaW1vbnQuZXUACgkQ7AWLMo2+
neqorw//aq6SOb5DijzEa+kWN3rXgVS+1K1vEVh1wNKAwx8eKJ7aX2kEiLDtt7uf
ahpZ6pz3q8nqs6aC1+YrxBfcih3L2YtrdZeWXWqr8xWNMaEoYDb8qaphwh8AD5t2
lCBlit2uJtXuCrDt93eKKPwvzZXg+hB0sMWy35Dr6jW7Z7K4Mu/PGgIyIHPY55yo
lGEndWno7VfH1Vm6t1n5qB7I5mXRaqA+becqddubTZ2xjj+jpIUqC8cyqN3hm/fL
qsj2mu8kyz3t8tG/H1/pV+I5OwBInPoS5TH0tujoJEVgPK/dHSP79QuHDHZFkCao
klj6kAWyU80Mxb+nKV/jeLbrR3+yWBFj3Qp5a1/V8oOTh6E1dALcNMpEaKCoKtMt
d/gMRax1I1/g0EDfnsW67G6sDwKPKPHhgfVLQ3nV3GaQQTnu1RpMz006H9/tAwzC
Gg/K1PdHT4hzOiI46wYPZyje0U2VXGFu6vVU9vFQ4ZR/Wjn+0zMzdcRdrIJSUOMn
RpTTfUsbXUeXHGOpkgXhSYTnvp1gdPc76USTsK0aGe84AZm1Ik0mGrwXCVfPqIYo
nhhibBSHBNMoqyF6yTSOpUbYK70tpYRRUGKWDeRK0wKSxkWKUZGtKzy6JYqIjo29
guIwgZQif5qWQCB0OontAL2+HvPFaVyckMejUhg62cP/+EHIvUk=
=kOxP
-----END PGP SIGNATURE-----
```

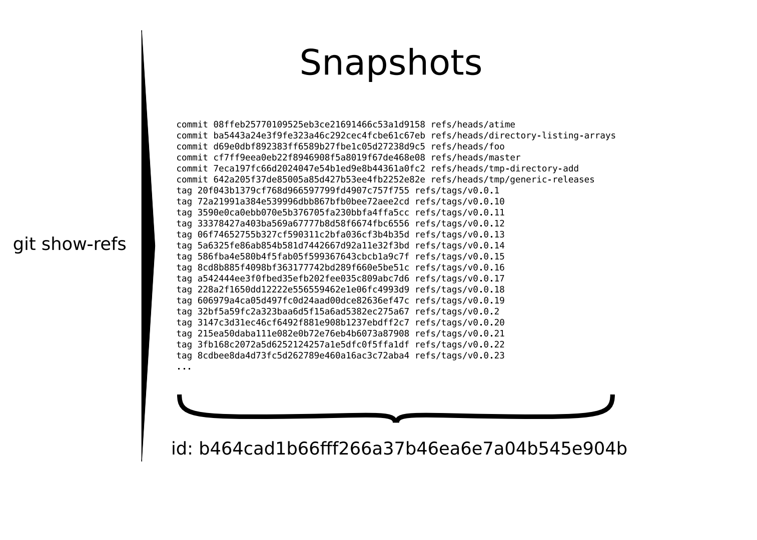
$$\underbrace{\hphantom{xxxxxxxxxxxxxxxxxxxx}}_{}$$

id: 85083a5cc14a441c89dea73f5bdf67c3f9c6afdb

A worked example



A worked example



Snapshots

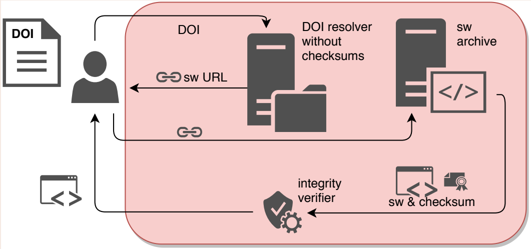
git show-refs

```
commit 08ffeb25770109525eb3ce21691466c53a1d9158 refs/heads/atime
commit ba5443a24e3f9fe323a46c292cec4fcbe61c67eb refs/heads/directory-listing-arrays
commit d69e0dbf892383ff6589b27fbe1c05d27238d9c5 refs/heads/foo
commit cf7ff9eea0eb22f8946908f5a8019f67de468e08 refs/heads/master
commit 7eca197fc66d2024047e54b1ed9e8b44361a0fc2 refs/heads/tmp-directory-add
commit 642a205f37de85005a85d427b53ee4fb2252e82e refs/heads/tmp/generic-releases
tag 20f043b1379cf768d966597799fd4907c757f755 refs/tags/v0.0.1
tag 72a21991a384e539996dbb867bfb0bee72aee2cd refs/tags/v0.0.10
tag 3590e0ca0ebb070e5b376705fa230bbfa4ffa5cc refs/tags/v0.0.11
tag 33378427a403ba569a67777b8d58f6674fbc6556 refs/tags/v0.0.12
tag 06f74652755b327cf590311c2bfa036cf3b4b35d refs/tags/v0.0.13
tag 5a6325fe86ab854b581d7442667d92a11e32f3bd refs/tags/v0.0.14
tag 586fba4e580b4f5fab05f599367643cbcb1a9c7f refs/tags/v0.0.15
tag 8cd8b885f4098bf363177742bd289f660e5be51c refs/tags/v0.0.16
tag a542444ee3f0fbed35efb202fee035c809abc7d6 refs/tags/v0.0.17
tag 228a2f1650dd12222e556559462e1e06fc4993d9 refs/tags/v0.0.18
tag 606979a4ca05d497fc0d24aad00dce82636ef47c refs/tags/v0.0.19
tag 32bf5a59fc2a323baa6d5f15a6ad5382ec275a67 refs/tags/v0.0.2
tag 3147c3d31ec46cf6492f881e908b1237ebdff2c7 refs/tags/v0.0.20
tag 215ea50daba111e082e0b72e76eb4b6073a87908 refs/tags/v0.0.21
tag 3fb168c2072a5d6252124257a1e5dfc0f5ffa1df refs/tags/v0.0.22
tag 8cdbee8da4d73fc5d262789e460a16ac3c72aba4 refs/tags/v0.0.23
...
```

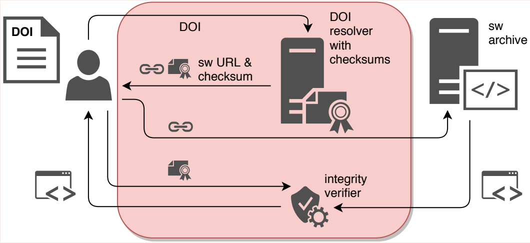
id: b464cad1b66fff266a37b46ea6e7a04b545e904b

Zoom on the trust model for identifiers

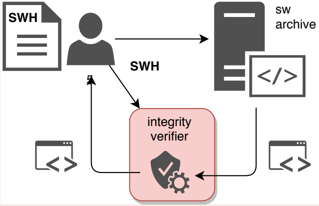
Trust model for usual DOIs



Trust model for DOIs with checksums



Trust model for SWH-IDs



Outline

1. Software Source Code: a precious heritage
2. Software Source Code: a (forgotten) pillar of Science
3. Meet Software Heritage
4. Archive and reference *all* the source code
5. Describe and cite *research* source code
6. The road ahead

Context

Many articles/guidelines

- reproducibility
- archival
- credit and evaluation

Most common limitations

- software is 'just data'
- citation = reference = DOIs
- citation produced by automated tools

A few remarkable exceptions

- ASCL (since 1999): metadata only, carefully curated
- geodynamics.org : source, documentation, metadata
- swmath.org : software catalog via articles

Software Citation WG at Inria (since 10/2018)

- leverage a 50 year experience, make recommendations
- read more https://hal.archives-ouvertes.fr/hal-02135891

Why it is not simple

Software is complex

Structure monolithic/composite; self-contained/external dependencies

Lifetime one-shot/long term

Community one man/one team/distributed community

Authorship complex set of roles *(more later)*

Authority institutions/organizations/communities/single person

Various granularities

Exact status of the source code for reproducibility, e.g.

“you can find at swh:1:cnt:cdf19c4487c43c76f3612557d4dc61f9131790a4;lines=146-187 the core algorithm used in this article”

(Major) release *“This functionality is available in OCaml version 4”*

Project *“Inria has created OCaml and Scikit-Learn”.*

Proposals for the scholarly world

Refined ontology for contributors

- Design, Architecture,
- Coding, Testing, Debugging,
- Documentation, Maintenance, Support,
- Management

see also CRediT, Geodynamics

Reference is distinct from citation

- Reference is for *reproducibility*
- Citation is for *credit*

They must not be conflated

Beware of the numbers game:

… do we really want an *s-index* ?

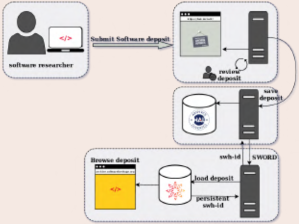
Keep the human in the loop

When *credit* is at stake, automation/crowdsourcing is not enough!

Humans *are needed* to get *quality information*

First steps with HAL / Software Heritage

How it works, what is special



Generic mechanism:

- SWORD based
- review process
- versioning

Today: deposit .zip or .tar.gz file (*guide*)

Tomorrow: just provide the *SWH id*

Deposit/describe research software in HAL

- author: `https://hal.archives-ouvertes.fr/hal-01872189`
- moderator: `https://hal.archives-ouvertes.fr/hal-01876705`

Examples

LinBox, SLALOM, Givaro, NS2DDV, SumGra, Coq proof, ...

The swmath.org approach

Article based citation

See for example:

- SemiPar on swmath.org

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We need to care more about research software

You can help make a change

- leverage Software Heritage in conferences, journals, AEC for *archival* and *reference*
  https://www.softwareheritage.org/save-and-reference-research-software/
- join the conversation on *software citation* and *software evaluation* criteria
- tackle the scientific problems : big code, classification, infrastructure, etc.

Thank you!

Jean-François Abramatic, Roberto Di Cosmo, Stefano Zacchiroli
Building the Universal Archive of Source Code, CACM, October 2018 (10.1145/3183558)

Roberto Di Cosmo, Morane Gruenpeter, Stefano Zacchiroli
Referencing Source Code Artifacts: a Separate Concern in Software Citation,
CiSE 2020 (10.1109/MCSE.2019.2963148) (hal-02446202)

Pierre Alliez, Roberto Di Cosmo, Benjamin Guedj, Alain Girault, Mohand-Said Hacid, Arnaud Legrand and Nicolas Rougier
Attributing and referencing (research) software: Best practices and outlook from Inria,
CiSE 2020 (10.1109/MCSE.2019.2949413) (hal-02135891)

Appendix

Software Heritage for Research and Innovation

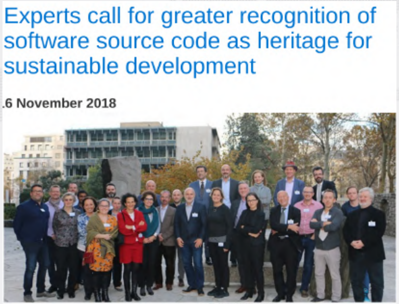
Reference platform for *Big Code*

- unique observatory of all software development
- big data, machine learning paradise: classification, trends, coding patterns, code completion...

First datasets are available!

- full graph of software development (~20Bn nodes, ~200Bn edges) see Pietri, Spinellis, Zacchiroli, MSR 2019 `https://dx.doi.org/10.1109/MSR.2019.00030`
- MSR 2020 mining competition see `https://2020.msrconf.org/track/msr-2020-mining-challenge#Call-for-Papers`

Raising awareness about Software Source Code



Experts call for greater recognition of software source code as heritage for sustainable development

.6 November 2018

UNESCO, Inria, Software Heritage invite

40 international experts meet in Paris …

PARIS CALL

SOFTWARE SOURCE CODE

AS HERITAGE FOR SUSTAINABLE DEVELOPMENT

Their call is published on Feb 2019

It's an important *policy tool*, already referenced and used … *yes, you can sign it!*

https://en.unesco.org/foss/paris-call-software-source-code

Outline

7. Guidelines detailed and SWH-ID use cases
8. News
9. Inria’s committment
10. Identifiers are not easy

Prepare your software source code

complete guidelines

Prepare your public repository with:

- README, LICENSE, AUTHORS & codemeta.json files

What's a good README

extracted from Eric Steven Raymond and Make a README

MUST include:

- Name and a description of the software.

SHOULD include:

- how to run and use the source code
- build environment, installation, requirements

CAN include:

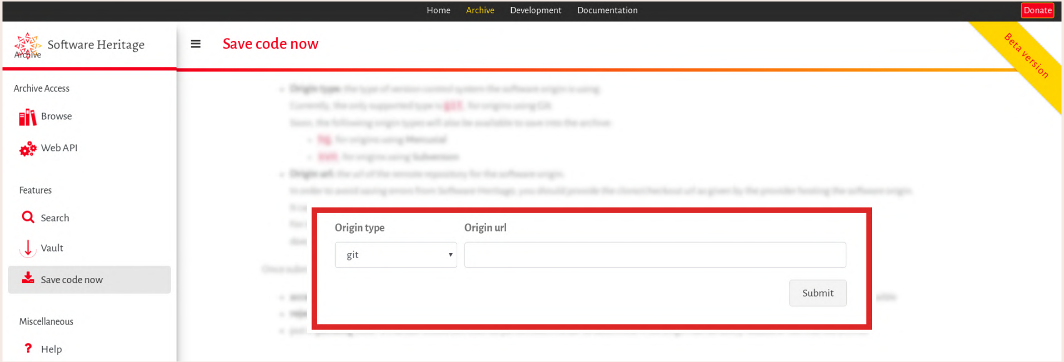
- project website or documentation pointer and recent news
- visuals

Submit save request on SWH

complete guidelines

Save code now on https://archive.softwareheritage.org/save/

- git, svn or mercurial
- intrinsic metadata files
- complete history



Save code now

Origin type: git

Origin url:

Reference software artifacts in your articles

complete guidelines

Choose the granularity level for the reference:

file (with code fragment)

swh:1:**cnt**:c60366bc03936eede6509b23307321faf1035e23;lines=473-537

... and add *;origin=https://github.com/sagemath/sage/*

James McCaffrey's **algorithm** in sageMath

directory

swh:1:**dir**:c6f07c2173a458d098de45d4c459a8f1916d900f

... and add *;origin=https://github.com/id-Software/Quake-III-Arena/*

source code of **Quake-III Arena** from id-Software

Reference software artifacts in your articles complete guidelines

specific release

swh:1:**rel**:22ece559cc7cc2364edc5e5593d63ae8bd229f9f

... and add *;origin=https://github.com/darktable-org/darktable/*

release 2.3.0 of Darktable, dated 24 December 2016

full snapshot (including all branches and all releases)

swh:1:**snp**:c7c108084bc0bf3d81436bf980b46e98bd338453

... and add *;origin=https://github.com/darktable-org/darktable/*

a **snapshot** of the entire Darktable repository (4 May 2017, GitHub)

Outline

7 Guidelines detailed and SWH-ID use cases

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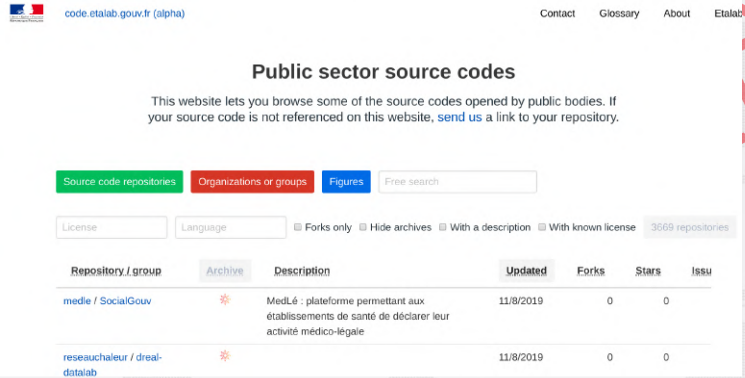
News : archiving *public* code



code.etalab.gouv.fr (alpha)

Contact Glossary About Etalab

Public sector source codes

This website lets you browse some of the source codes opened by public bodies. If your source code is not referenced on this website, send us a link to your repository.

Source code repositories | Organizations or groups | Figures | Free search

License | Language | □ Forks only □ Hide archives □ With a description □ With known license | 3669 repositories

Repository / group	Archive	Description	Updated	Forks	Stars	Issu
medle / SocialGouv	✻	MedLé : plateforme permettant aux établissements de santé de déclarer leur activité médico-légale	11/8/2019	0	0	
reseauchaleur / dreal-datalab	✻		11/8/2019	0	0	

https://code.etalab.gouv.fr

News : SWHAP

Paris Call on Software Source Code

“[We call to] support efforts to gather and preserve the artifacts and narratives of the history of computing, while the earlier creators are still alive”

SWHAP : an important step forward

- detailed guidelines to curate landmark legacy source code and archive it on Software Heritage
- intense cooperation with Università di Pisa and UNESCO
- open to all, we’ll promote it worldwide

https://www.softwareheritage.org/swhap

News : ENEA mirror

Thomas Jefferson, February 18, 1791

…let us save what remains: not by vaults and locks which fence them from the public eye and use in consigning them to the waste of time, but by such a multiplication of copies, as shall place them beyond the reach of accident.

Welcoming ENEA

ENEA

Italian National Agency for New Technologies, Energy and Sustainable Economic Development

- first institutional mirror
- increased resilience
- AI infrastructure for researchers
- stepping stone to
  an European joint effort

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Inria's ongoing contributions

Software Heritage

universal archive (research) software source code archived and referenced

Reproducibility

tools Guix (now with Software Heritage)

training/research RR workshops, MOOC

Research software curation

HAL - SWH bridge curation of metadata, and deposit in Software Heritage

Outline

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URL decay disrupts the *web of reference*

Web links *are not* permanent (even *permalinks*)

there is no general guarantee that a URL… which at one time points to a given object continues to do so

T. Berners-Lee et al. Uniform Resource Locators. RFC 1738.

URLs used in articles *decay*!

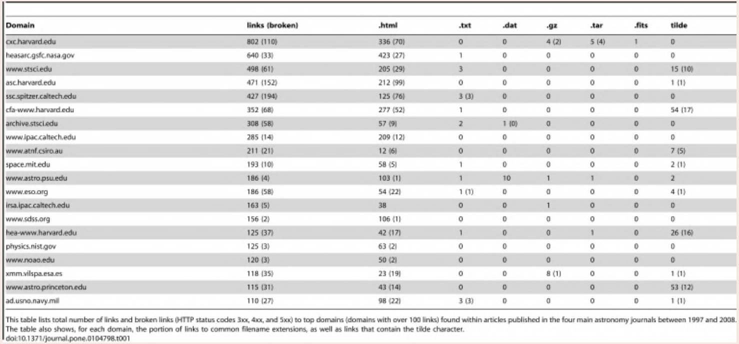
Analysis of *IEEE Computer* (Computer), and the *Communications of the ACM* (CACM): 1995-1999

- the *half-life* of a referenced URL *is approximately 4 years* from its publication date
  D. Spinellis. The Decay and Failures of URL References.
  Communications of the ACM, 46(1):71-77, January 2003.

Similar findings in Lawrence, S. et al. *Persistence of Web References in Scientific Research*, IEEE Computer, 34(2), pp. 26–31, 2001.

Scholar roster of broken links

An example from Astronomy



Domain	links (broken)	.html	.txt	.dat	.gz	.tar	.fits	tilde
cxc.harvard.edu	802 (110)	336 (70)	0	0	4 (2)	5 (4)	1	0
heasarc.gsfc.nasa.gov	640 (33)	423 (27)	1	0	0	0	0	0
www.stsci.edu	498 (61)	205 (29)	3	0	0	0	0	15 (10)
asc.harvard.edu	471 (152)	212 (99)	0	0	0	0	0	1 (1)
ssc.spitzer.caltech.edu	427 (194)	125 (76)	3 (3)	0	0	0	0	0
cfa-www.harvard.edu	352 (68)	277 (52)	1	0	0	0	0	54 (17)
archive.stsci.edu	308 (58)	57 (9)	2	1 (0)	0	0	0	0
www.ipac.caltech.edu	285 (14)	209 (12)	0	0	0	0	0	0
www.atnf.csiro.au	211 (21)	12 (6)	0	0	0	0	0	7 (5)
space.mit.edu	193 (10)	58 (5)	1	0	0	0	0	2 (1)
www.astro.psu.edu	186 (4)	103 (1)	1	10	1	1	0	2
www.eso.org	186 (58)	54 (22)	1 (1)	0	0	0	0	4 (1)
irsa.ipac.caltech.edu	163 (5)	38	0	0	1	0	0	0
www.sdss.org	156 (2)	106 (1)	0	0	0	0	0	0
hea-www.harvard.edu	125 (37)	42 (17)	1	0	0	1	0	26 (16)
physics.nist.gov	125 (3)	63 (2)	0	0	0	0	0	0
www.noao.edu	120 (3)	50 (2)	0	0	0	0	0	0
xmm.vilspa.esa.es	118 (35)	23 (19)	0	0	8 (1)	0	0	1 (1)
www.astro.princeton.edu	115 (31)	43 (14)	0	0	0	0	0	53 (12)
ad.usno.navy.mil	110 (27)	98 (22)	3 (3)	0	0	0	0	1 (1)

This table lists total number of links and broken links (HTTP status codes 3xx, 4xx, and 5xx) to top domains (domains with over 100 links) found within articles published in the four main astronomy journals between 1997 and 2008. The table also shows, for each domain, the portion of links to common filename extensions, as well as links that contain the tilde character.
doi:10.1371/journal.pone.0104798.t001

How Do Astronomers Share Data?

Pepe, Goodman, Muench, Crosas, Erdmann

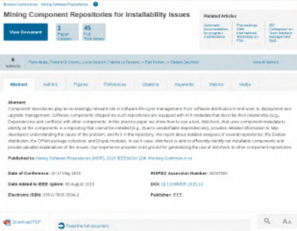
dx.doi.org/10.1371/journal.pone.0104798

PLOS August 28, 2014

DOI limitations

Example: doi:10.1109/MSR.2015.10

- to find what 10.1109/MSR.2015.10 is, go to a *resolver* (e.g. doi.org)
- this returns http://ieeexplore.ieee.org/document/7180064/
- at this URL we find ...



Browse Conferences › Mining Software Repositories ...

Mining Component Repositories for Installability Issues

Pietro Abate ; Roberto Di Cosmo ; Louis Gesbert ; Fabrice Le Fessant ; Ralf Treinen ; Stefano Zacchiroli

Abstract:
Component repositories play an increasingly relevant role in software life-cycle management, from software distribution to end-user, to deployment and upgrade management. Software components shipped via such repositories are equipped with rich metadata that describe their relationship (e.g., Dependencies and conflicts) with other components. In this practice paper we show how to use a tool, distcheck, that uses component metadata to identify all the components in a repository that cannot be installed (e.g., Due to unsatisfiable dependencies), provides detailed information to help developers understanding the cause of the problem, and fix it in the repository. We report about detailed analyses of several repositories: the Debian distribution, the OPAM package collection, and Drupal modules. In each case, distcheck is able to efficiently identify not installable components and provide valuable explanations of the issues. Our experience provides solid ground for generalizing the use of distcheck to other component repositories.

Published in: Mining Software Repositories (MSR), 2015 IEEE/ACM 12th Working Conference on

Date of Conference: 16-17 May 2015

Date Added to IEEE Xplore: 06 August 2015

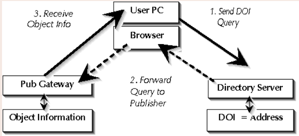
Electronic ISBN: 978-0-7695-5594-2

INSPEC Accession Number: 15337380

DOI: 10.1109/MSR.2015.10

Publisher: IEEE

Architecture of the DOI infrastructure



- DOI resolution *can change*
- content at URL *can change*
- no *intrinsic* way of noticing
- persistence based on *good will* of *multiple parties*