Software (source code) and Open Science

Challenges and Opportunities

Roberto Di Cosmo

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Software Heritage

THE GREAT LIBRARY OF SOURCE CODE

Outline

1. Introductions
2. Software source code: a pillar of Open Science
3. An inconvenient truth
4. The way forward
5. Conclusion

Short Bio: Roberto Di Cosmo

Computer Science professor in Paris, now working at INRIA

- *30 years* of research (Theor. CS, Programming, Software Engineering, Erdos #: 3)
- *20 years* of Free and Open Source Software
- *10 years* building and directing structures for the common good

1999 *DemoLinux* – first live GNU/Linux distro

2007 *Free Software Thematic Group*
150 members 40 projects 200Me

2008 *Mancoosi project* `www.mancoosi.org`

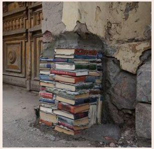
2010 *IRILL* `www.irill.org`

2015 *Software Heritage* at INRIA

2018 *National Committee for Open Science*, France

Software is knowledge

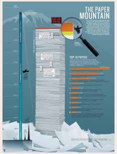
Key mediator for accessing *all* information (c) Banski



Information is a main pillar of our modern societies.

> *Absent an ability to correctly interpret digital information, we are left with [...] "rotting bits" [...] of no value.*
>
> *Vinton G. Cerf IEEE 2011*

Software is *an essential component* of modern scientific research



> *[...] the vast majority describe experimental methods or software that have become essential in their fields.*

Top 100 papers (Nature, October 2014)

Bottomline: Sofware embodies our *Knowledge* and *Cultural Heritage*

It *must* be *collected*, *referenced* and made *accessible*!

The knowledge is in the source code!

> *“The source code for a work means the preferred form of the work for making modifications to it."*
>
> *GPL Licence*

Hello World

Program (excerpt of binary)

```
4004e6: 55
4004e7: 48 89 e5
4004ea: bf 84 05 40 00
4004ef: b8 00 00 00 00
4004f4: e8 c7 fe ff ff
4004f9: 90
4004fa: 5d
4004fb: c3
```

Program (source code)

```
/* Hello World program */

#include<stdio.h>

void main()
{
    printf("Hello World");
}
```

Source code is *special*

Harold Abelson, Structure and Interpretation of Computer Programs

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

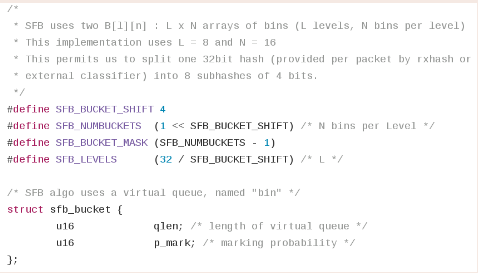
Quake III source code (excerpt)

```
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;
}
```

Net. queue in Linux (excerpt)



```
/*
 * SFB uses two B[l][n] : L x N arrays of bins (L levels, N bins per level)
 * This implementation uses L = 8 and N = 16
 * This permits us to split one 32bit hash (provided per packet by rxhash or
 * external classifier) into 8 subhashes of 4 bits.
 */
#define SFB_BUCKET_SHIFT 4
#define SFB_NUMBUCKETS  (1 << SFB_BUCKET_SHIFT) /* N bins per Level */
#define SFB_BUCKET_MASK (SFB_NUMBUCKETS - 1)
#define SFB_LEVELS      (32 / SFB_BUCKET_SHIFT) /* L */

/* SFB algo uses a virtual queue, named "bin" */
struct sfb_bucket {
        u16             qlen; /* length of virtual queue */
        u16             p_mark; /* marking probability */
};
```

Len Shustek, Computer History Museum

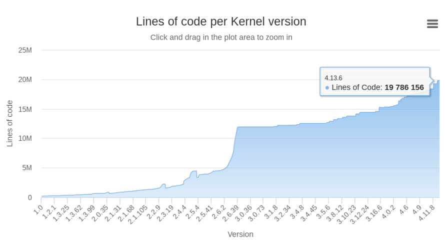
“Source code provides a view into the mind of the designer.”

~ 50 years, a lightning fast growth

Apollo 11 Guidance Computer (~60.000 lines), 1969

> "When I first got into it, nobody knew what it was that we were doing. It was like the Wild West."
>
> Margaret Hamilton

Linux Kernel



… now in your pockets!

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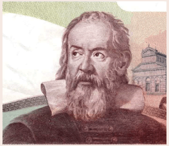
The scientific method…

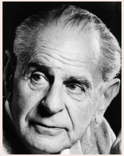
The experimental method



- make an *observation*
- formulate an *hypothesis*
- set up an experiment
- elaborate a *theory*

And then we reproduce and verify.

Reproducibility is the key



non-reproducible single occurrences are of no significance to science

Karl Popper, The Logic of Scientific Discovery, 1934

… evolves in the digital age!

For an experiment involving software, we need

open access to the scientific article describing it

open data sets used in the experiment

source code of all the components

environment of execution

stable references between all this

Remark

The first two items are already widely discussed!

… what about *software*?

An example from my research field, Computer Science

Analysis of 613 papers

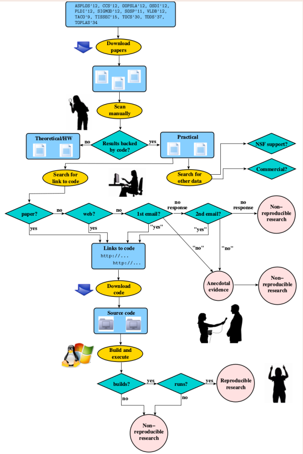
- 8 ACM conferences: ASPLOS’12, CCS’12, OOPSLA’12, OSDI’12, PLDI’12, SIGMOD’12, SOSP’11, VLDB’12
- 5 journals: TACO’9, TISSEC’15, TOCS’30, TODS’37, TOPLAS’34

all very practical oriented

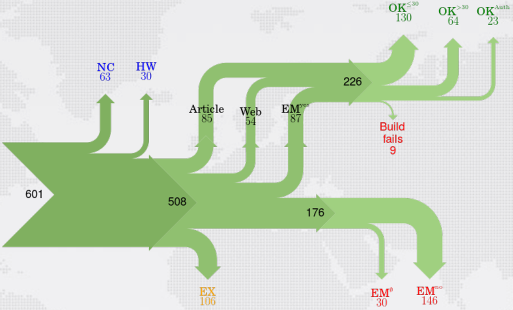
The basic question

can we get the code to build and run?

The workflow



… cont’d



…

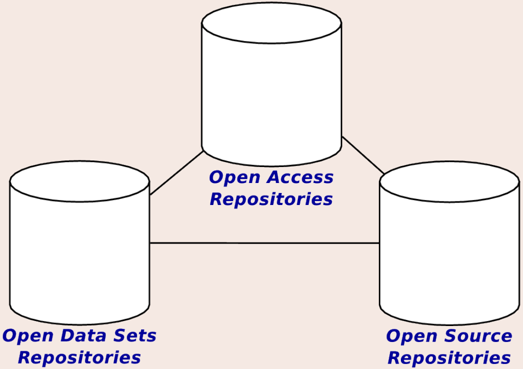
… that’s a whopping 40% of non reproducible works!

The main reasons

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

Software Source code is an important pillar

The Magic Triangle of Scientific Knowledge



Nota bene

The links in the picture are essential

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A *forgotten* pillar of Open Science

No reference catalog

Sourceforge
Debian
CPAN
Gitorious
Bitbucket
Maven
Inria
GitHub
BerliOS
CTAN
GitLab
CRAN
GoogleCode
Adullact

to find and reference all the source code

No universal archive

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

to preserve all the source code

No research infrastructure

to enable analysis of all the source code

Lack of recognition

not (yet) a first class citizen

- in the EOSC plan
- in the EU copyright reform
- in the scholarly works

Lack of guidance on how to

- choose a license
- cite a software project
- relate to industry best practices
- make source code FAIR(*)

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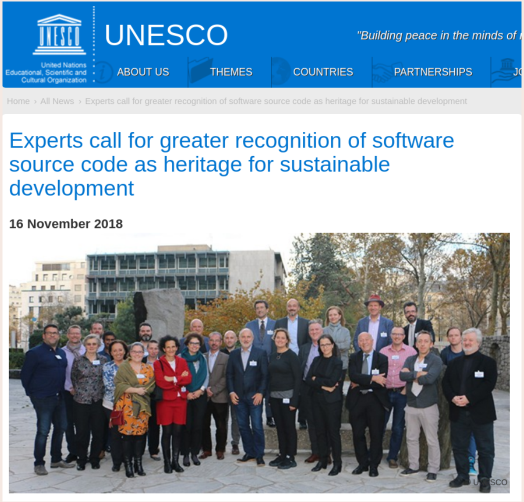
Raising Awareness

Inria Unesco agreement, April 3rd, 2017

Unesco Inria expert group, November 2018


UNESCO
United Nations Educational, Scientific and Cultural Organization
"Building peace in the minds of
ABOUT US
THEMES
COUNTRIES
PARTNERSHIPS
JO

Home › All News › Experts call for greater recognition of software source code as heritage for sustainable development

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

16 November 2018

Actions in the research landscape

In the Research Data Alliance

Collaboration with a variety of international partners

- Source Code Interest Group
- Source Code Identification Working Group

In the French Open Science Plan

- the GPLO group
  - software citation, reference, archival
  - software licensing
  - best practices
- support for Software Heritage

Software Heritage

Mission

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

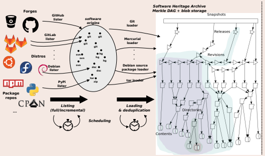
Partners

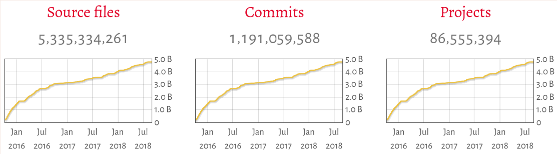
Initiator	Inria
Industry	Microsoft, Intel, Société Générale, *Google*, GitHub, FOSSID
Public sector	UNESCO, DINSIC, DANS, UQAM, Bologna University

In a nutshell

bit.ly/swhpaper

The largest software source code archive *ever*





Over *10 billions intrinsic* identifiers (IDOs) for reproducibility

Must read: conceptual framework for DIOs and IDOs `bit.ly/swhpidpaper`

Research software deposit

- moderated via HAL

open since 9/2018

Reference archive

- See for example

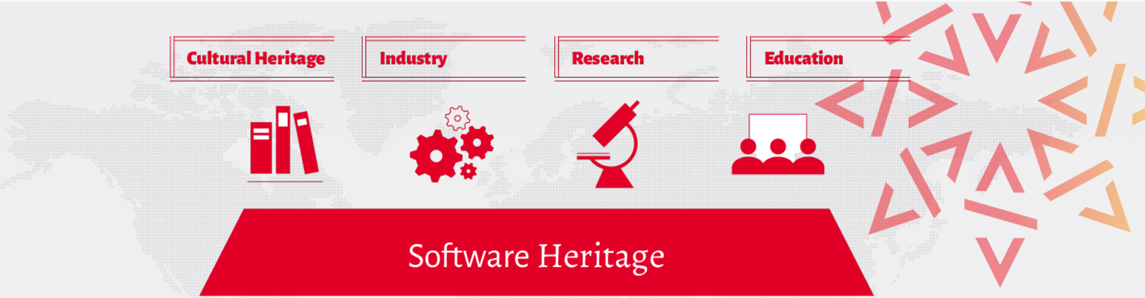
swmath.org

Collaboration HUB

- industry, research
- digital preservation

Now part of the *French National Plan for Open Science*

Reduce risk, avoid fragmentation



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.

A *common* infrastructure

- mutualisation for sustainability
- open source, non for profit
- mirror network open to all
- may prevent a useless diaspora

A word on FAIR

Research Source Code … is just Source Code!

FAIR for Research Software Source Code is *different*

For Software Source Code, FAIR has a *different meaning*:

reFerenced with intrinsic, verifiable identifiers

- see the iPres 2018 article `bit.ly/swhpidpaper`
- example: swh:1:cnt:41ddb23118f92d7218099a5e7a990cf58f1d07fa;lines=53-82

Accessible in an archive that holds it for the long term

cIted to credit authors, like all other scientific outputs

Reusable equipped with a proper Open Source license

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Conclusion

Challenges

Software Source code:

- (forgotten) pillar of Open Science
- (undervalued) key to reproducibility
- (underrated) scholarly production

Opportunities

Shared with Open Source communities

- learn from software development
- adopt proven approaches
- avoid dispersion of efforts

Jean-François Abramatic, Roberto Di Cosmo, Stefano Zacchiroli
Building the Universal Archive of Source Code
Communication of the ACM, October 2018

Roberto Di Cosmo, Morane Gruenpeter, Stefano Zacchiroli
Identifiers for Digital Objects: the Case of Software Source Code Preservation
iPRES 2018: Intl. Conf. on Digital Preservation

Roberto Di Cosmo, Publication scientifique: le rôle des États dans l'ère des TIC.
Upgrade, Vol. VII, No. 3, June 2006,
`http://www.dicosmo.org/FreeAccessToScience.pdf`

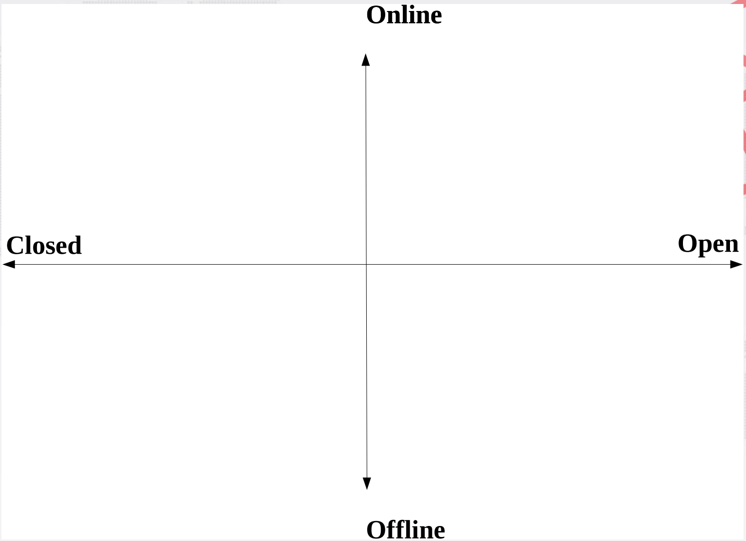
Outline

6 Strategy

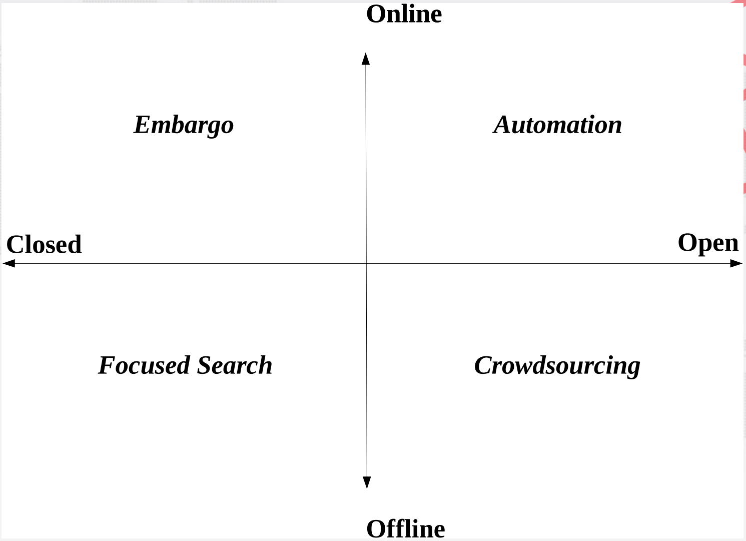
7 Identifiers are not easy

8 Looking for the right identifiers

All the source code



All the source code: strategy



Online

Embargo

Automation

Closed

Open

Focused Search

Crowdsourcing

Offline

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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.

404

URLs used in articles *decay*!

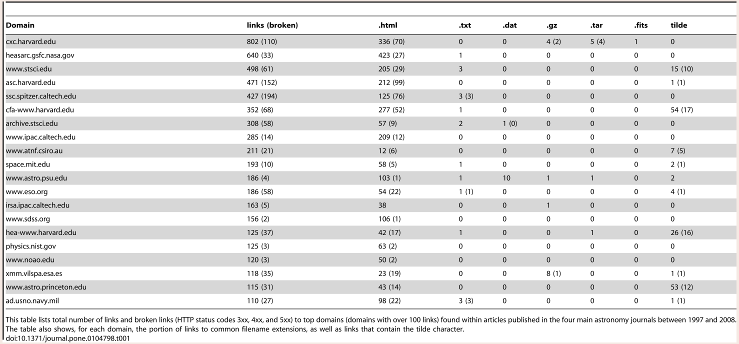
Analysis of *IEEE Computer* (Computer), and the *Communications of the ACM* (CACM): 1995-1999

- 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

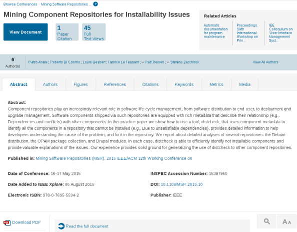
PLOS August 28, 2014

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

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 ...
?
Related Articles
Automatic documentation for program maintenance
Proceedings. Sixth International Workshop on Prin...
IEE Colloquium on 'User Interface Management Syst...
View Document
1 Paper Citation
45 Full Text Views
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Mining Component Repositories for Installability Issues

6 Author(s): 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

INSPEC Accession Number: 15397950

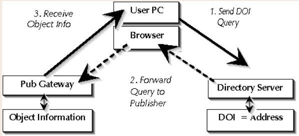
Date Added to IEEE *Xplore*: 06 August 2015

DOI: 10.1109/MSR.2015.10

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

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*

Outline

6 Strategy

7 Identifiers are not easy

8 Looking for the right identifiers

Systems of identifiers

A *system of identifiers* is

- a set of labels (the identifiers)
- mechanisms to perform :

Generation (minting)	create a new label
Assignment	associate label to object
Retrieval	get object from a label

- optionally, mechanisms to perform:

Verification	check label and object
Reverse Lookup	get label from an object
Description	get metadata of an object

Mechanisms offered in some systems of identifiers

Mech. / System	Handle	DOI	Ark	PURL
Generation	Yes	Yes	Yes	Yes
Assignment	Yes	Yes	Yes	Yes
Retrieval	Yes	Yes	Yes	Yes
Verification	N.A.	N.A.	N.A.	N.A.
Reverse Lookup	N.A.	N.A.	N.A.	N.A.
Description	Yes	Yes	Yes	N.A.

Our challenges in the PID landscape

Typical properties of systems of identifiers

uniqueness, non ambiguity, persistence, abstraction (opacity)

Key needed properties from our use cases

gratis identifiers are free (billions of objects)

integrity the associated object cannot be changed (sw dev, *reproducibility*)

no middle man no central authority is needed (sw dev, *reproducibility*)

we could not find systems with both integrity and no middle man !

An important distinction: DIOs vs. IDOs

> *The term "Digital Object Identifier" is construed as "digital identifier of an object," rather than "identifier of a digital object"* — *Norman Paskin. 2010*

DIO (Digital Identifier of an Object)

digital identifiers for (potentially) non digital objects

- epistemic complexity (manifestations, versions, locations, etc.)
- need an authority to ensure persistence and uniqueness

IDO (Identifier of a Digital Object)

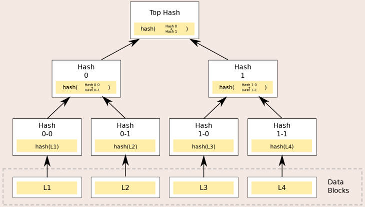
digital identifiers (only) for digital objects

- can provide both integrity and no middle man
- broadly used in modern software development (git, etc.)

for the core Software Heritage archive, IDOs are enough

IDOs in Software Development: the origins

Merkle tree (R. C. Merkle, Crypto 1979)



Combination of

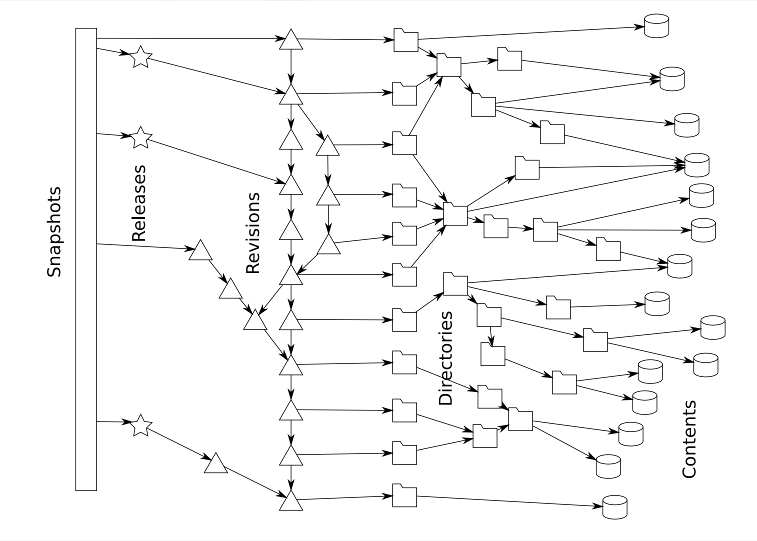
- tree
- hash function

Classical cryptographic construction

fast, parallel signature of large data structures, built-in deduplication

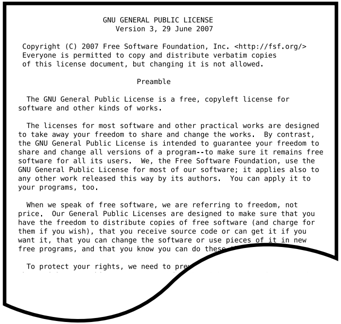
- satisfies all three criteria: gratis, integrity, no middle man!
- widely used in industry (e.g., Git, nix, blockchains, IPFS, ...)

IDOs in Software Heritage: a worked example



IDOs in Software Heritage: a worked example

Contents



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Version 3, 29 June 2007

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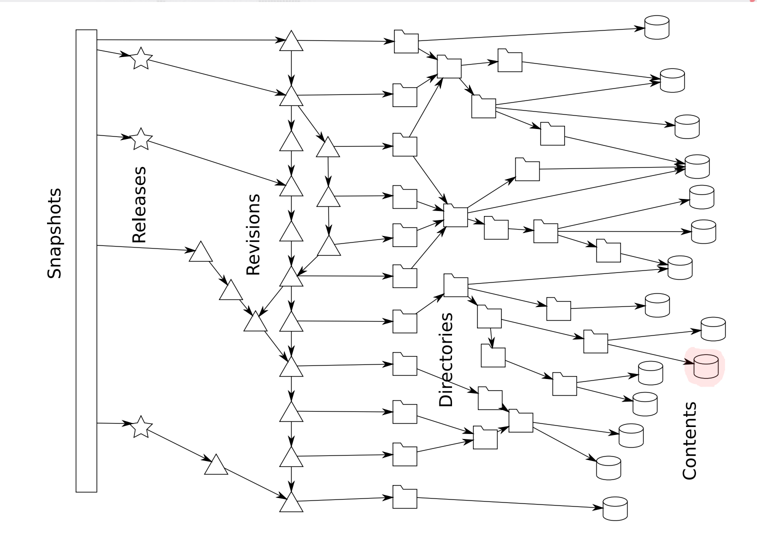
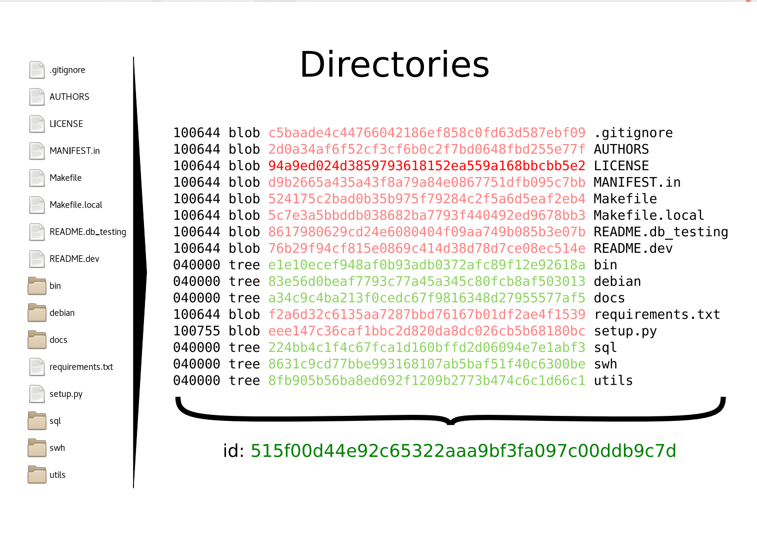
To protect your rights, we need to pre

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

IDOs in Software Heritage: a worked example



IDOs in Software Heritage: a worked example

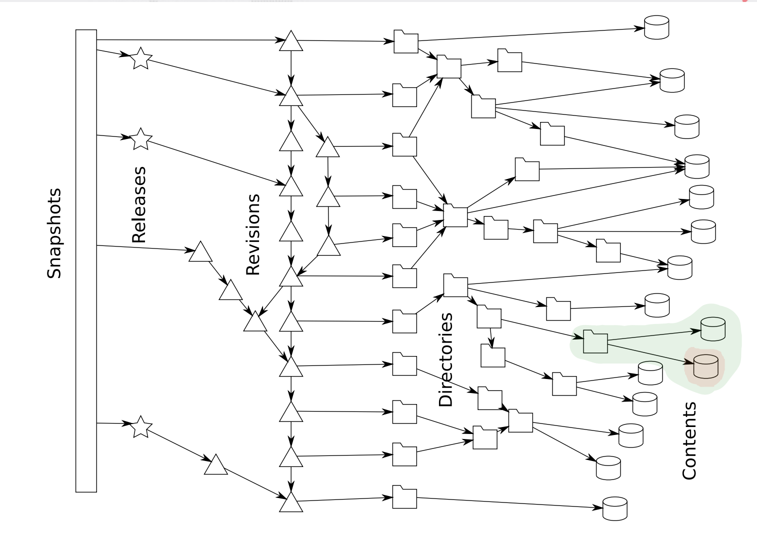


Directories

```
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
```

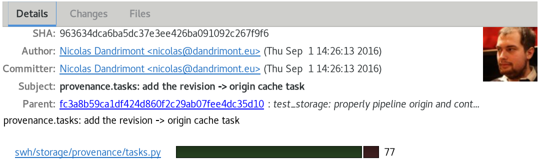
id: 515f00d44e92c65322aaa9bf3fa097c00ddb9c7d

IDOs in Software Heritage: a worked example



IDOs in Software Heritage: 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...*

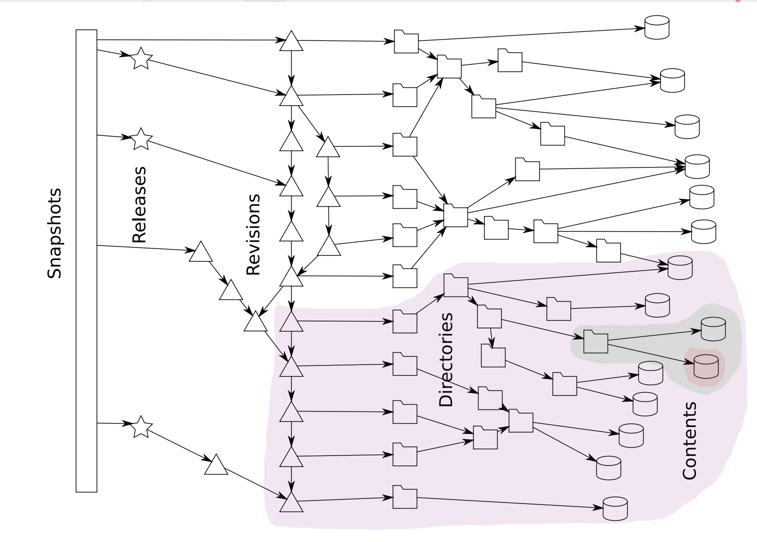
provenance.tasks: add the revision -> origin cache task

swh/storage/provenance/tasks.py 77

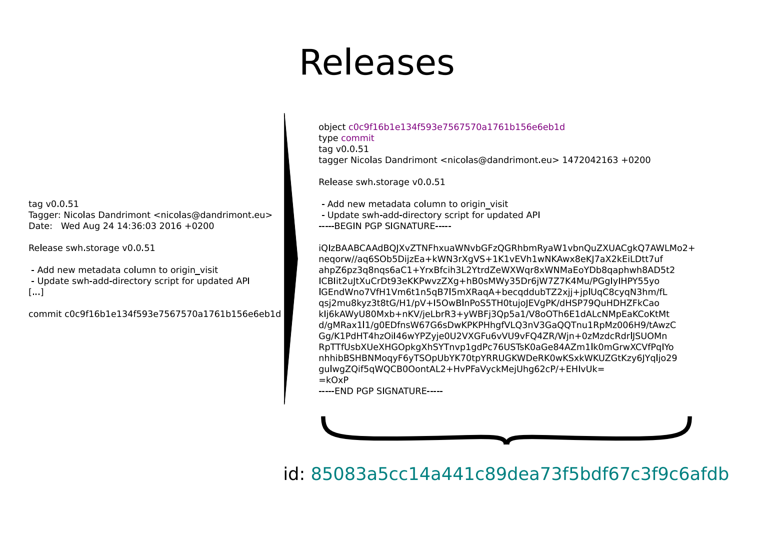
```
tree 515f00d44e92c65322aaa9bf3fa097c00ddb9c7d
parent fc3a8b59ca1df424d860f2c29ab07fee4dc35d10
author Nicolas Dandrimont <nicolas@dandrimont.eu> 1472732773 +0200
committer Nicolas Dandrimont <nicolas@dandrimont.eu> 1472732773 +0200

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

id: 963634dca6ba5dc37e3ee426ba091092c267f9f6

IDOs in Software Heritage: a worked example



IDOs in Software Heritage: a worked example



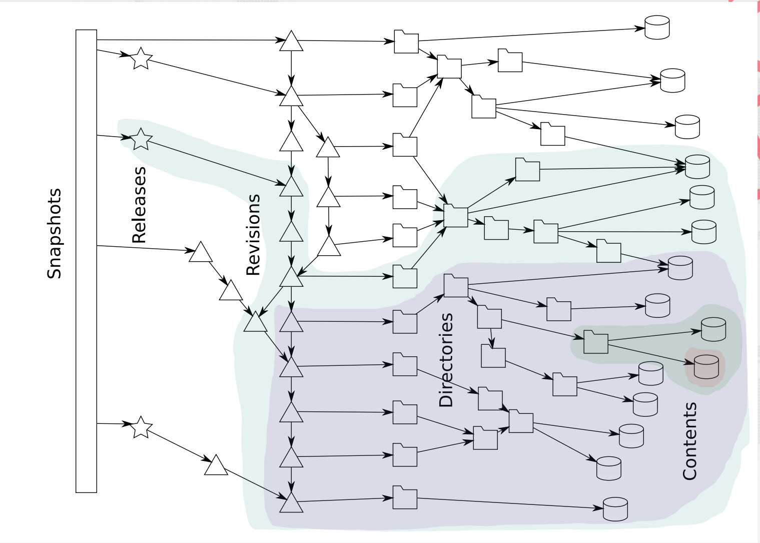
Releases

```
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
```

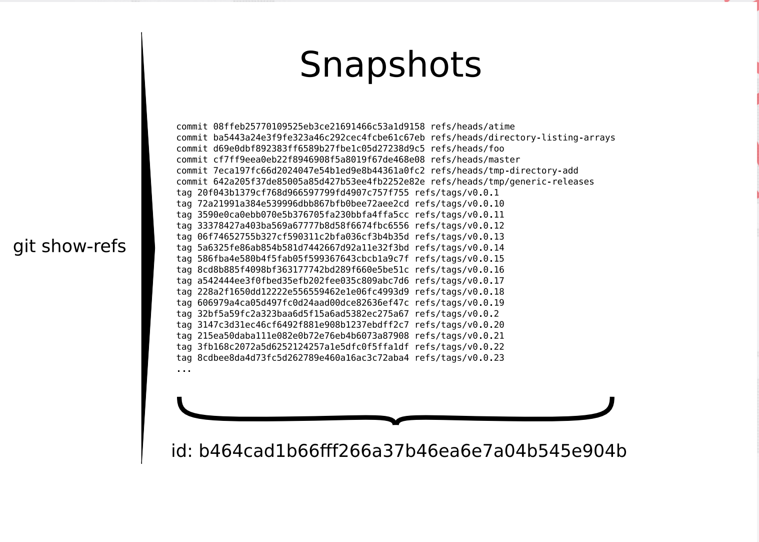
```
object c0c9f16b1e134f593e7567570a1761b156e6eb1d
type commit
tag v0.0.51
tagger Nicolas Dandrimont <nicolas@dandrimont.eu> 1472042163 +0200

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
lCBIit2uJtXuCrDt93eKKPwvzZXg+hB0sMWy35Dr6jW7Z7K4Mu/PGgIyIHPY55yo
lGEndWno7VfH1Vm6t1n5qB7l5mXRaqA+becqddubTZ2xjj+jplUqC8cyqN3hm/fL
qsj2mu8kyz3t8tG/H1/pV+I5OwBlnPoS5TH0tujoJEVgPK/dHSP79QuHDHZFkCao
kIj6kAWyU80Mxb+nKV/jeLbrR3+yWBFj3Qp5a1/V8oOTh6E1dALcNMpEaKCoKtMt
d/gMRax1l1/g0EDfnsW67G6sDwKPKPHhgfVLQ3nV3GaQQTnu1RpMz006H9/tAwzC
Gg/K1PdHT4hzOiI46wYPZyje0U2VXGFu6vVU9vFQ4ZR/Wjn+0zMzdcRdrlJSUOMn
RpTTfUsbXUeXHGOpkgXhSYTnvp1gdPc76USTsK0aGe84AZm1lk0mGrwXCVfPqIYo
nhhibBSHBNMoqyF6yTSOpUbYK70tpYRRUGKWDeRK0wKSxkWKUZGtKzy6JYqIjo29
gulwgZQif5qWQCB0OontAL2+HvPFaVyckMejUhg62cP/+EHIvUk=
=kOxP
-----END PGP SIGNATURE-----
```

id: 85083a5cc14a441c89dea73f5bdf67c3f9c6afdb

IDOs in Software Heritage: a worked example



IDOs in Software Heritage: 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

The Software Heritage IDO schema (see `http://bit.ly/swhpids`)

swh:1:**cnt**:94a9ed024d3859793618152ea559a168bbcbb5e2 full text of the GPL3 license

swh:1:**dir**:d198bc9d7a6bcf6db04f476d29314f157507d505 Darktable source code

swh:1:**rev**:309cf2674ee7a0749978cf8265ab91a60aea0f7d

a **revision** in the development history of Darktable

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

release 2.3.0 of Darktable, dated 24 December 2016

swh:1:**snp**:c7c108084bc0bf3d81436bf980b46e98bd338453

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

Current resolvers: `archive.softwareheritage.org` and `n2t.org`