From Software Heritage to Code Commons

A vision for transparent and responsible AI in code-based model training

Roberto Di Cosmo
Director, Software Heritage
Inria and Université Paris Cité

March 2025

Software Heritage

THE GREAT LIBRARY OF SOURCE CODE

Outline

Short Bio: Roberto Di Cosmo

Computer Science professor in Paris, now working at INRIA

- *35+ years* of research (Theor. CS, Programming, Software Engineering, Erdos #: 3)
- *25+ years* of Free and Open Source Software
- *15+ 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

2021 *EOSC Task Force on Infrastructures for Software*, European Union

Software *Source Code* is Precious Knowledge

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 2006

"Source code provides a view into the mind of the designer."

Unveiled in 2016

Software Heritage

THE GREAT LIBRARY OF SOURCE CODE

Collect, preserve and share *all* software source code

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

Reference catalog

find and reference all software source code

Universal archive

preserve and share all software source code

Research infrastructure

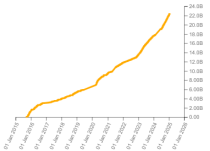
enable analysis of all software source code

A *universal* software archive, as a shared infrastructure

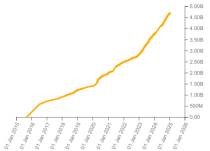
One infrastructure
open and shared

The largest archive ever built

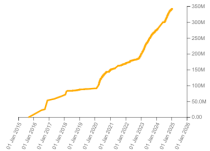
Source files
22,548,654,226



Commits
4,743,656,085



Projects
344,672,354



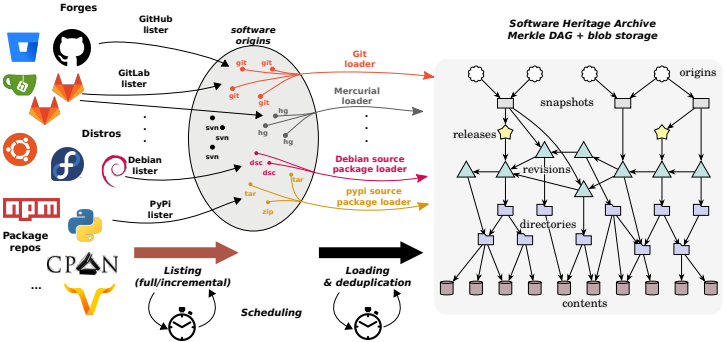
Directories
17,848,569,305

Authors
86,143,084

Releases
102,056,508

Diamond sponsors
Platinum sponsors
Gold sponsors
Silver sponsors
Bronze sponsors

The archive under the hood



Global development history permanently archived in a uniform data model

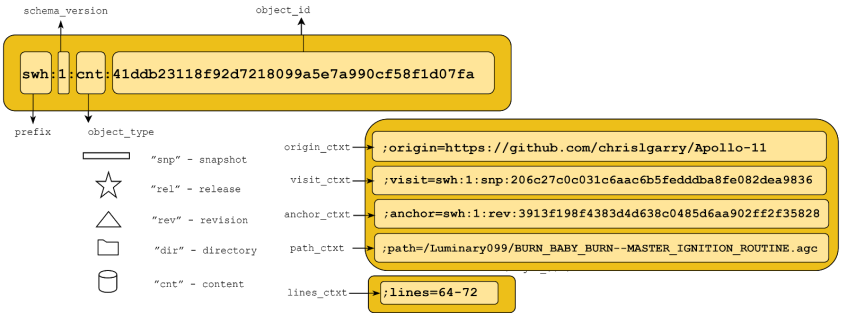
- over 22 billion unique source files from over 340 million software projects
- ~2PB (compressed) blobs, ~50 B nodes, ~800 B edges

The Software Hash persistent identifier (SWHID)

Software Hash Identifiers (SWHID)

see swhid.org

50+B intrinsic, decentralised, cryptographically strong identifiers, SWHIDs



In SPDX 2.2; IANA "swh:"; WikiData P6138; ISO standardization ongoing DIS 18670

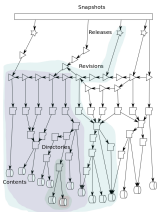
Full fledged *source code references* for traceability, integrity and reproducibility

Examples: Apollo 11 AGC, Quake III rsqrt; Guidelines available: HOWTO and ICMS 2020

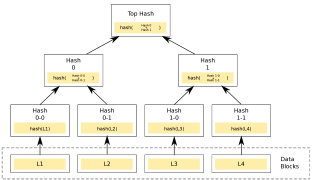
A revolutionary infrastructure

Modern "Library of Alexandria", *international, non profit, long term* initiative
addressing the needs of *industry, research, culture and society as a whole*

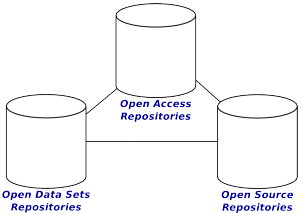
Software Graph



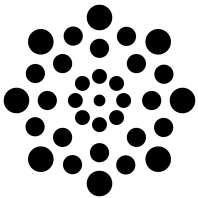
Software Blockchain



Open Science pillar



Big Code



One infrastructure, *shared*: more efficient, less waste …
… addressing a broad spectrum of needs!

Outline

A walkthrough

- Browse + Reference [DIS 18670] (Apollo 11 [excerpt], your work may be already there !)
- Trigger archival, use the updateswh browser extension, configure the webhooks
- Cite with biblatex-software (CTAN, Overleaf ACMART template)
- Describe with Codemeta (use codemeta generator)
- Curated deposit in SWH via HAL, see for example: LinBox, SLALOM, Givaro, NS2DDV, SumGra, Coq proof, ...
- Extracting all the software products for Inria, for CNRS, for CNES, for LIRMM or for Rémi Gribonval using HalTools
- Example with Parmap: devel on Github, archive in SWH, curated deposit in HAL
- Example research articles:
  - compare Fig. 1 and conclusions in the 2012 version and the updated version
  - SWHID in a replication experiment

Growing adoption of SWH in Academia (selection)

From Melissa Harrison's OSEC 2022 talk

What are they "referencing"?

source	n	percentage
Not available	2868	46.22
GitHub	1151	18.55
software heritage	387	6.24
zenodo	142	2.29
r package	70	1.13
cran	56	0.90
r package version	54	0.87
gitlab	35	0.56

- 6205 "software" references identified
- Top 8 listed, then long tail of 1055 other sites – 932 are unique "source"

Use on replicabilitystamp.org

Lightweight Curvature Estimation on Point Clouds with Randomized Corrected Curvature Measures

Jacques-Olivier Lachaud, David Coeurjolly, Céline Labart, Pascal Romon, Boris Thibert

Wiley Computer Graphics Forum (CGF)

doi Repository

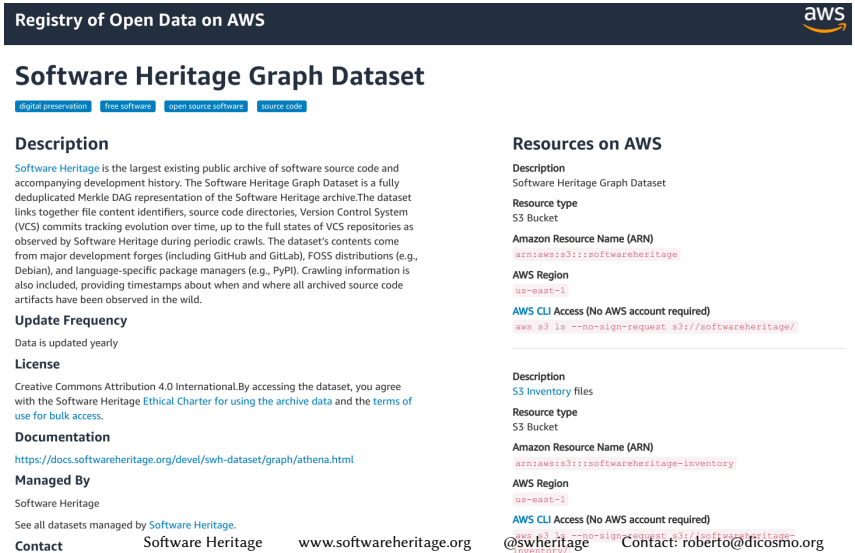
HAL+SWH in the Open Science software booklet

Funding agencies recommendations ANR 2023 guidelines (p. 17)

Enfin, conformément au 2ème Plan national pour la science ouverte, L'ANR recommande que les logiciels développés durant le projet soient mis à disposition sous une licence libre[30] et que les codes sources soient stockés dans l'archive Software Heritage[31] en indiquant la référence au financement ANR.

The full graph in the AWS Open Data collection

https://registry.opendata.aws/software-heritage/



Registry of Open Data on AWS

aws

Software Heritage Graph Dataset

digital preservation | free software | open source software | source code

Description

Software Heritage is the largest existing public archive of software source code and accompanying development history. The Software Heritage Graph Dataset is a fully deduplicated Merkle DAG representation of the Software Heritage archive.The dataset links together file content identifiers, source code directories, Version Control System (VCS) commits tracking evolution over time, up to the full states of VCS repositories as observed by Software Heritage during periodic crawls. The dataset's contents come from major development forges (including GitHub and GitLab), FOSS distributions (e.g., Debian), and language-specific package managers (e.g., PyPI). Crawling information is also included, providing timestamps about when and where all archived source code artifacts have been observed in the wild.

Update Frequency

Data is updated yearly

License

Creative Commons Attribution 4.0 International.By accessing the dataset, you agree with the Software Heritage Ethical Charter for using the archive data and the terms of use for bulk access.

Documentation

https://docs.softwareheritage.org/devel/swh-dataset/graph/athena.html

Managed By

Software Heritage

See all datasets managed by Software Heritage.

Contact

Resources on AWS

Description
Software Heritage Graph Dataset

Resource type
S3 Bucket

Amazon Resource Name (ARN)
`arn:aws:s3:::softwareheritage`

AWS Region
`us-east-1`

AWS CLI Access (No AWS account required)
`aws s3 ls --no-sign-request s3://softwareheritage/`

Description
S3 Inventory files

Resource type
S3 Bucket

Amazon Resource Name (ARN)
`arn:aws:s3:::softwareheritage-inventory`

AWS Region
`us-east-1`

AWS CLI Access (No AWS account required)
`aws s3 ls --no-sign-request s3://softwareheritage-inventory/`

Example: most popular commit verbs (stemmed)

Query using Amazon Athena

```
SELECT COUNT(*) AS C, word FROM (
   SELECT word_stem(lower(split_part(
    trim(from_utf8(message)),' ', 1)))
   AS word FROM revision
   WHERE length(message) < 1000000)
WHERE word != ''
GROUP BY word
ORDER BY C
DESC LIMIT 20;
```

Total cost: approximately .5 euros

Results

Completed — Time in queue: 272 ms — Run time: 33.545 sec — Data scanned: 94.51 GB

Results (20) — Copy — Download results

Search rows — 1

#	c	word
1	271573294	updat
2	163328012	merg
3	140044381	add
4	105800317	fix
5	103646653	ad
6	52891401	bump
7	50067041	initi
8	45609622	creat
9	42633225	remov
10	32230842	chang
11	23110410	delet
12	20734745	new
13	16644508	commit
14	15651821	test

Going beyond SQL

State-of-the-art graph compression from social networks

Paolo Boldi, Antoine Pietri, Sebastiano Vigna, Stefano Zacchiroli

Ultra-Large-Scale Repository Analysis via Graph Compression

SANER 2020, 27th Intl. Conf. on Software Analysis, Evolution and Reengineering. IEEE

Results

Full graph structure (50 B nodes, 700 B edges) in 300 GiB RAM

- traversal time is tens of ns per edge
- bidirectional traversals implemented
- beware: metadata access is still *off RAM*

Java, gRPC and Rust APIs available

docs.softwareheritage.org/devel/swh-graph/grpc-api.html

A word on long term reproducibility for HPC

(re)create fully reproducible binaries from source… https://guix.gnu.org/

- functional package manager
- bit by bit reproductibility
- *from the source code*

… with a focus on HPC https://hpc.guix.info/

- environment control
- support cluster deployment
- *from the source code*

connection with Software Heritage

- source code *archival and identification* for `guix` and `nix`
- automatic fallback for missing sources (see experience report)

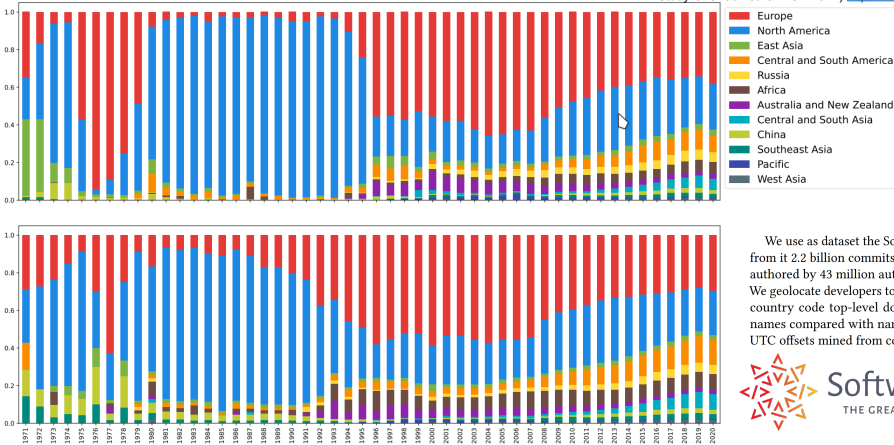
Outline

Because software is naturally international !

MSR '22, May 23–24, 2022, Pittsburgh, PA, USA

Davide Rossi and Stefano Zacchiroli

Geographic Diversity in Public Code Contributions: An Exploratory Large-Scale Study Over 50 Years. MSR 2022) https://doi.org/10.1145/3524842.3528471

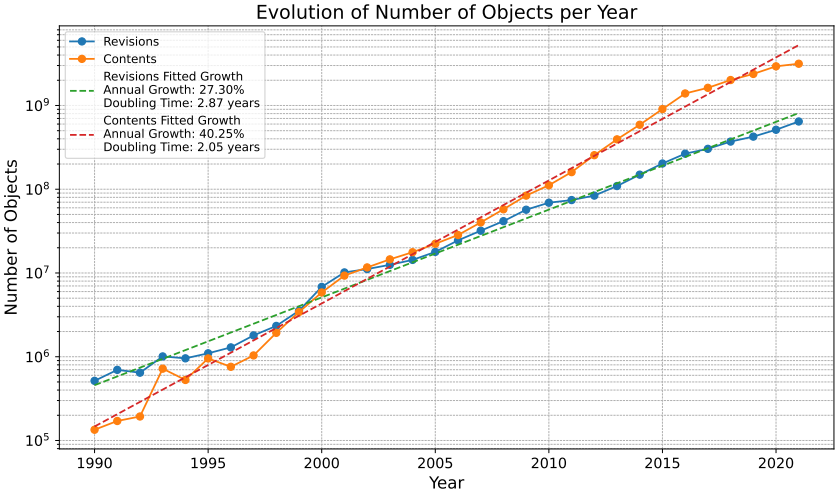


We use as dataset the Software Heritage archive [3] and analyze from it 2.2 billion commits archived from 160 million projects and authored by 43 million authors during the 1971–2021 time period. We geolocate developers to 12 world regions, using as signals email country code top-level domains (ccTLDs) and author (first/last) names compared with name distributions around the world, and UTC offsets mined from commit metadata.

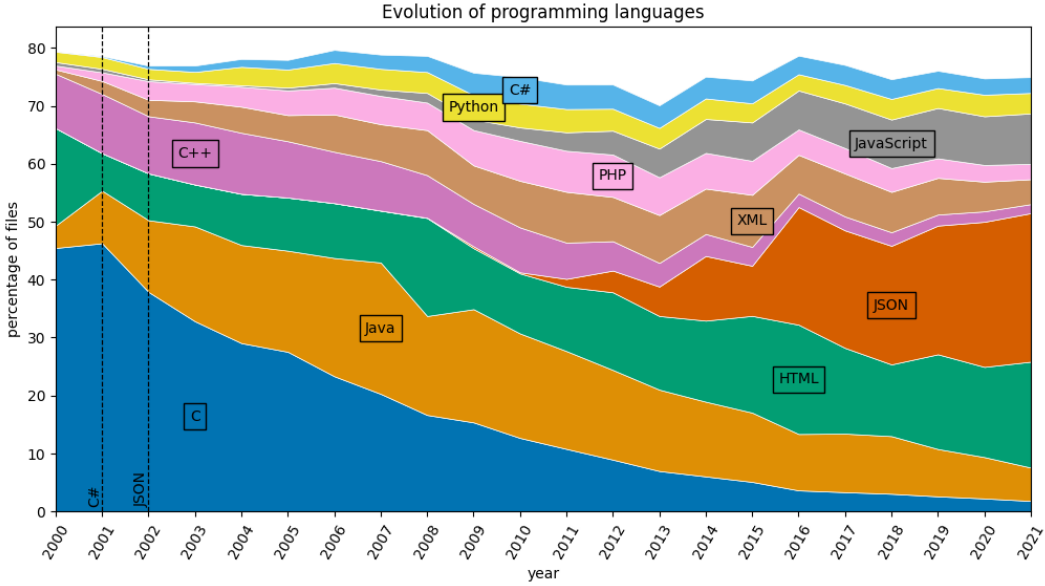
Software Heritage
THE GREAT LIBRARY OF SOURCE CODE

Figure 3: Ratio of commits (above) and active authors (below) by world zone over the 1971–2020 period.

30 years of growth of public source code



Programming language evolution over 50 years



Outline

Software Heritage and Generative AI, first contacts

October 19, 2023

Software Heritage Statement on Large Language Models for Code

Principles

1. Knowledge derived from the Software Heritage archive must be given back to humanity, rather than monopolized for private gain. The resulting *machine learning models* must be made available under a suitable open license, together with the documentation and toolings needed to use them.
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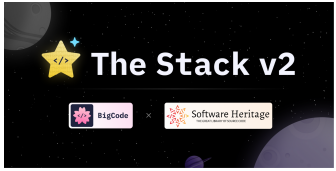
February 2024

Yes, it's possible!



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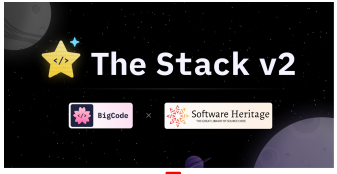
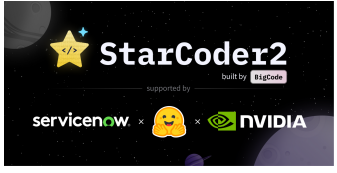
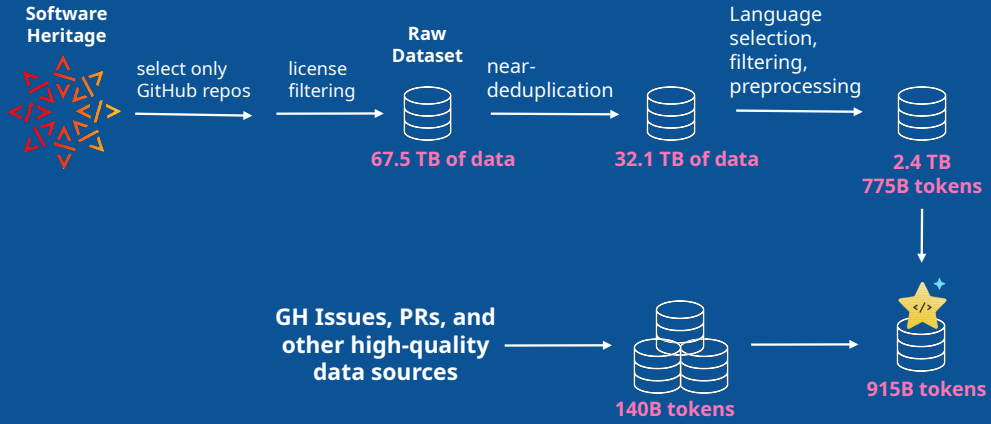




But it's hard…

The Stack v2

Data collection pipeline fully open and transparent built by BigCode



This slide is courtesy of Leandro Von Werra and Harm de Vries

Lessons learned

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N.B. : may be mandated by regulations!

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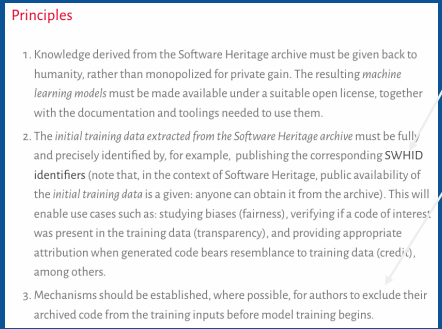

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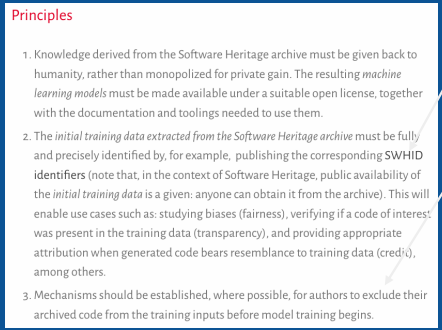
Opt out is complex: who is *the real right owner*?
(similar issues to license compliance)

Lessons learned



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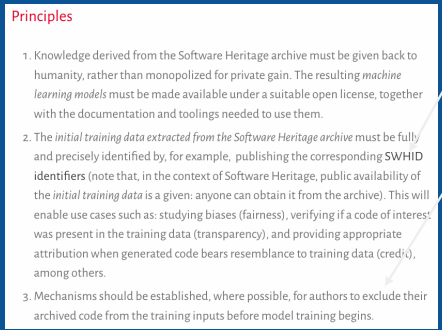

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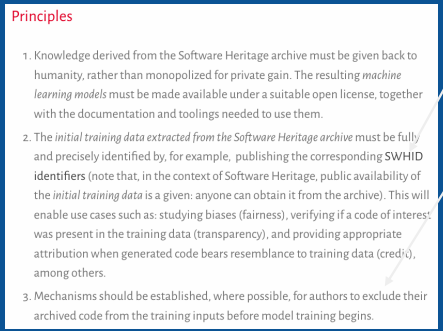
+

- **Building the training set** is complex: e.g. includes **license compliance** alike work **at massive scale**

Lessons learned



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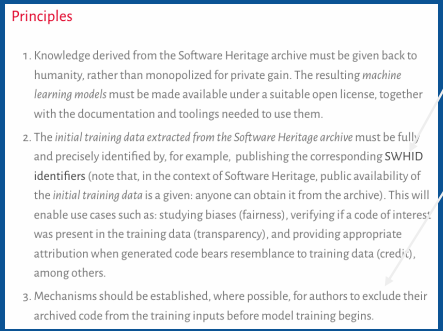
- Generating **attribution information** on model output **is more complex** than license compliance

Lessons learned



Principles

1. Knowledge derived from the Software Heritage archive must be given back to humanity, rather than monopolized for private gain. The resulting *machine learning models* must be made available under a suitable open license, together with the documentation and toolings needed to use them.
2. The *initial training data extracted from the Software Heritage archive* must be fully and precisely identified by, for example, publishing the corresponding SWHID identifiers (note that, in the context of Software Heritage, public availability of the *initial training data* is a given: anyone can obtain it from the archive). This will enable use cases such as: studying biases (fairness), verifying if a code of interest was present in the training data (transparency), and providing appropriate attribution when generated code bears resemblance to training data (credit), among others.
3. Mechanisms should be established, where possible, for authors to exclude their archived code from the training inputs before model training begins.

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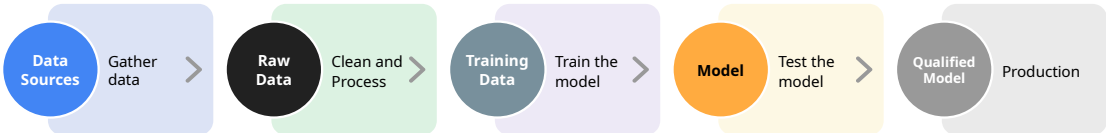
We need **a coordinated effort** to ensure fully open models will succeed!

GENERATIVE AI FOR CODE : OPEN ISSUES



Issues

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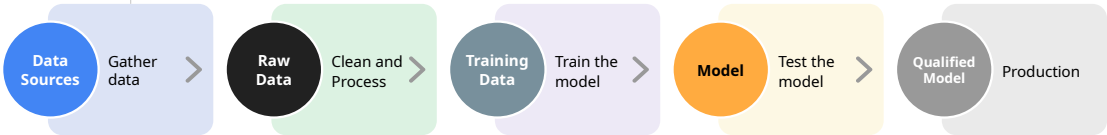
Gousios et al. GHTorrent
: GitHub's data from a firehose, MSR 2012

Collect source code, issues, PR, discussions, etc. **is very expensive**. **Redoing** it over and over again **is an anti-ecological waste**.



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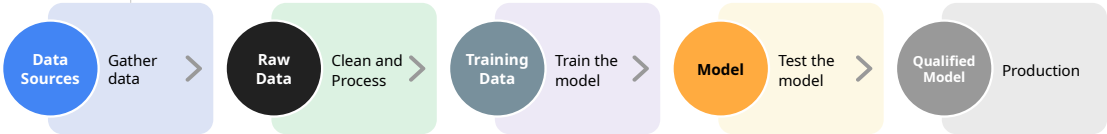

Building a quality training set is a **very complex task**, redoing it over and over again behind closed doors is a waste of energy and human resources

Gunasekar et al. « Textbooks Are All You Need » 2023
https://arxiv.org/abs/2306.11644

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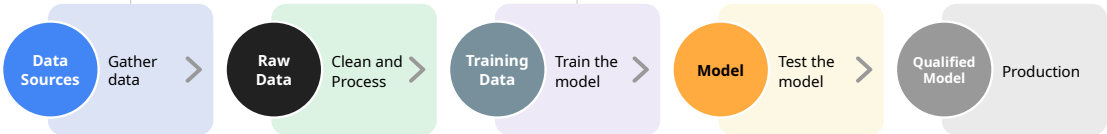

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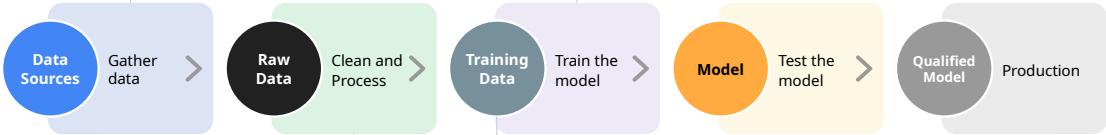

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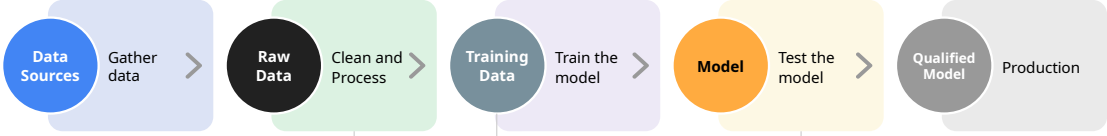

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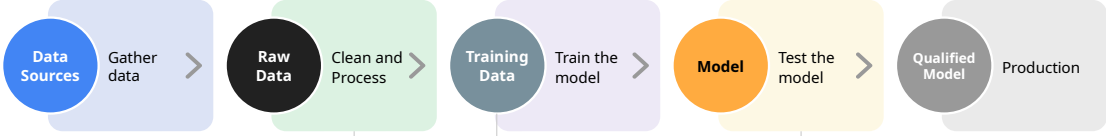
Sallam et al.
ChatGPT utility in healthcare education, research, and practice: systematic review on the promising perspectives and valid concerns
2023

Lack of **traceability** of generative AI outputs make it **irrespective of authors**



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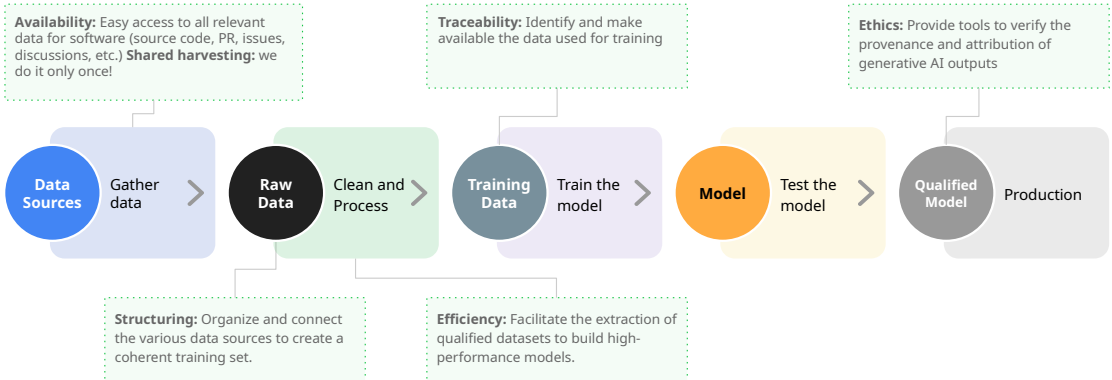
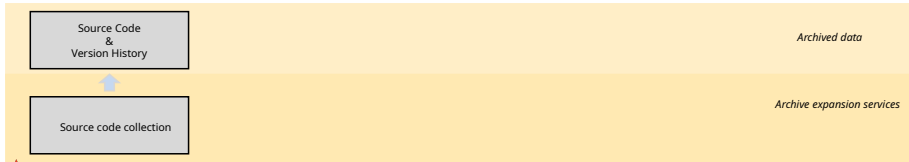
A STEP FORWARD: CodeCommons



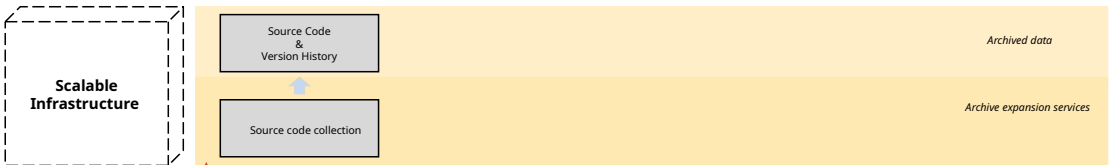
Solutions

CodeCommons: bird’s eye view (technical focus)



Software Heritage
THE GREAT LIBRARY OF SOURCE CODE

CodeCommons: bird’s eye view (technical focus)



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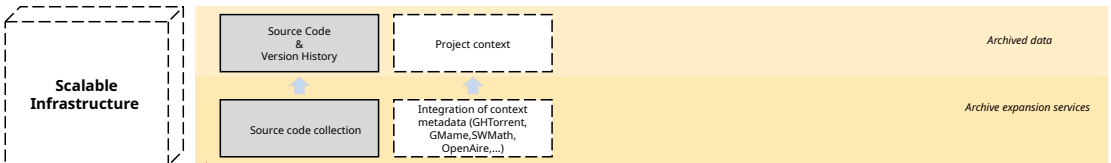

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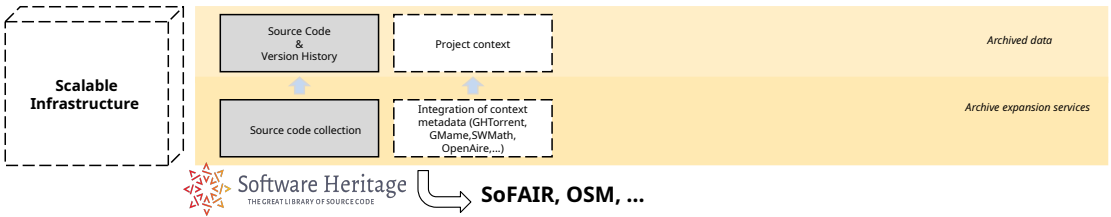

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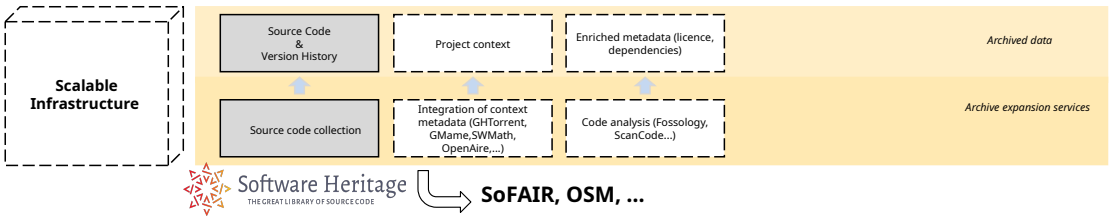

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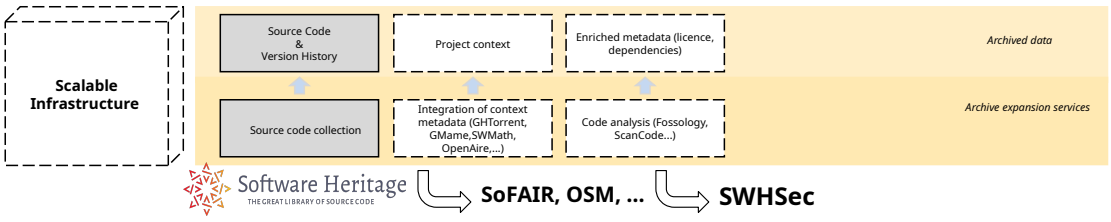

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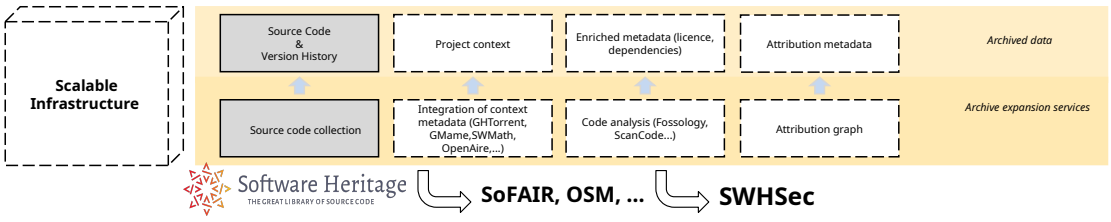

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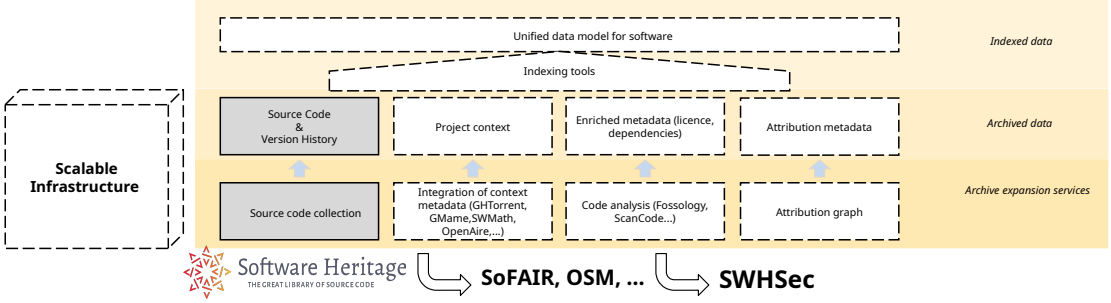

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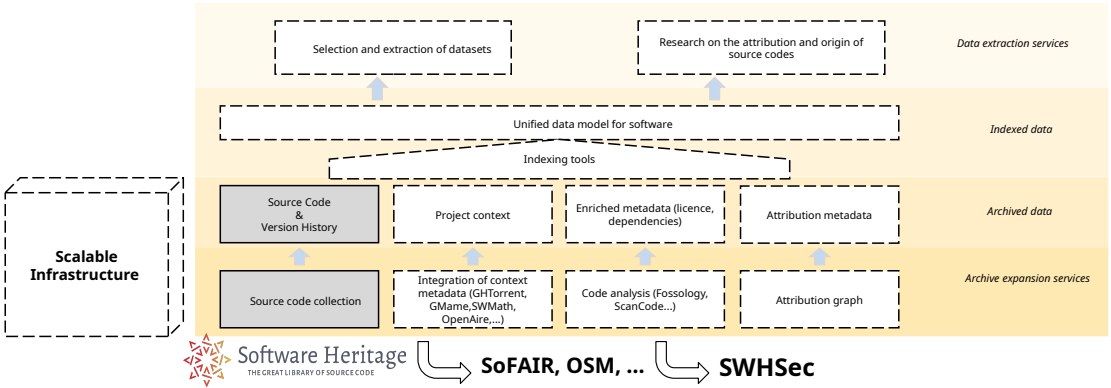

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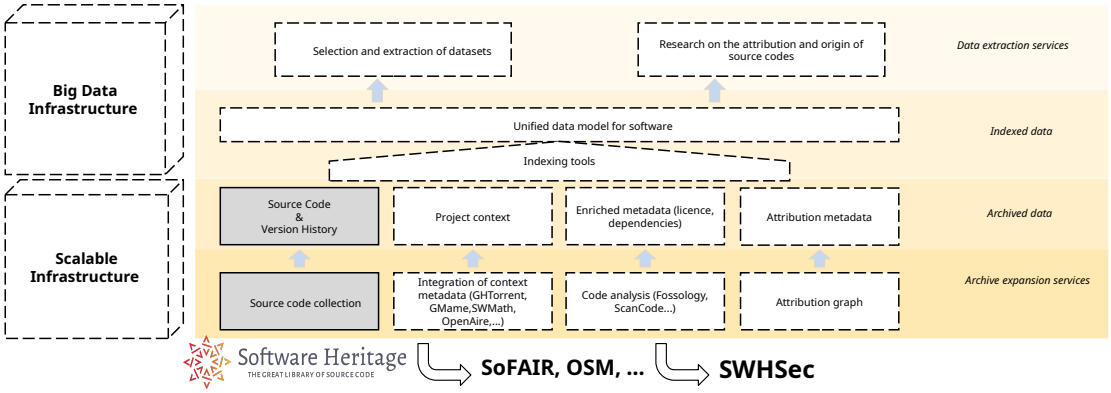

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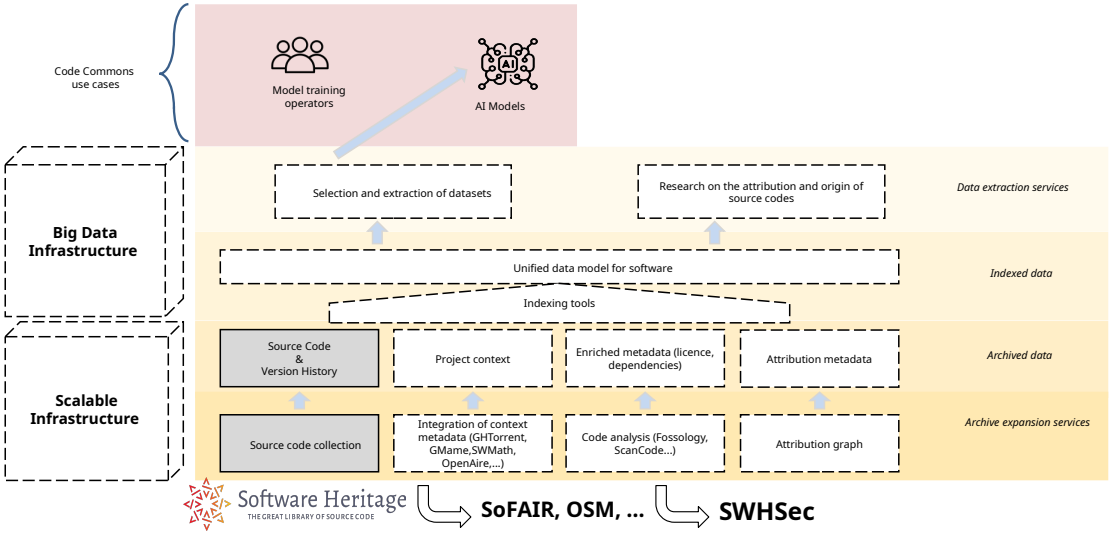

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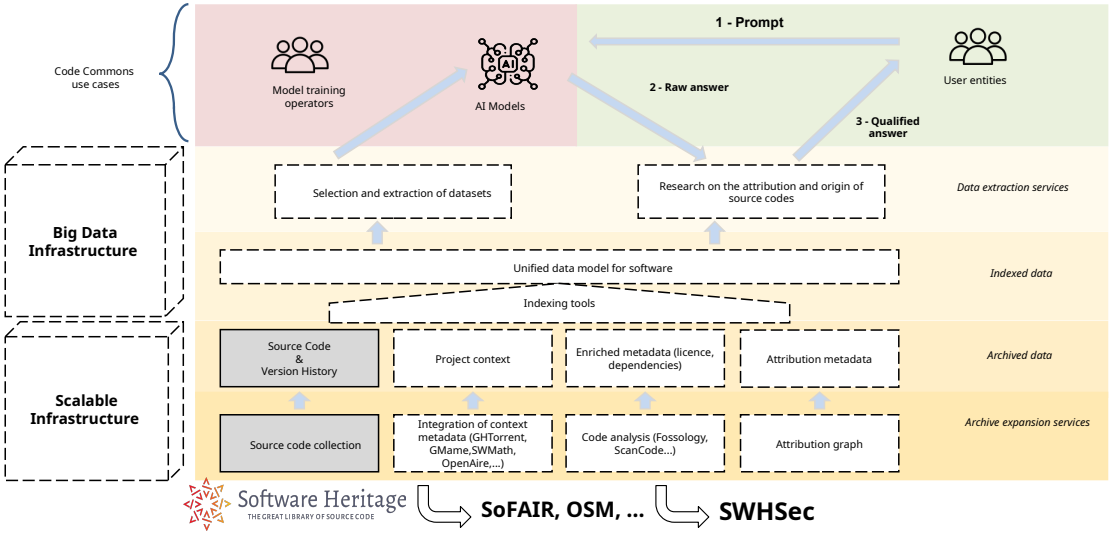

COMMONS CODE: THE ACTORS

Team	Entity / Referent	Expertise	
Funded partners			
Software Heritage		Universal Archive of Software Source Code	
DiverSE	Inria	Software engineering, code, programming, languages, Software variability management Large-scale software evolution Generative AI for software development	
Almanac		Automatic linguistic modeling and analysis and computational humanities	
CEDAR	cea	Analysis and processing of complex, large-scale data	
DIASI	TWEAG by Modus Create	Automatic language processing Generative AI	
DILS		Engineering, Software and Systems	
AboutCode		Machine learning, Modeling, Natural language processing Distributed computing	
Subcontracting (budget < 200k€)			
Sant'Anna School of Advanced Studies – Pisa	Philippe Ombredanne	The global benchmark for license detection	
Unfunded partners			
Emeritus Inria	Patrick Valduriez	Cutting-edge expertise in big data management	
Alma Mater Studiorum Università di Bologna	Paolo Ferragina	Data compression and text algorithms (ACM Paris Kanellakis award 2022)	
Università degli Studi di Torino	Marco Danelutto	Massively parallel HPC programming expertise	

CodeCommons

Open, responsible, and transparent AI: Our shared goal

CodeCommons is an ambitious project to create the world's most comprehensive digital commons for code

Building on the existing foundation of Software Heritage, the largest publicly available source code archive, CodeCommons aims to bring into one place all the **critical** and **qualified** information needed to create **smaller**, **better** datasets for the next generation of AI tools.

At its core, the project prioritizes transparency and traceability, enabling model builders and users to **respect creators' rights** while promoting **sovereign** and **sustainable** AI.

Learn more

Meet the teams

Outline

Come in, we're open! https://softwareheritage.org

Software Heritage is

- vendor neutral, open source
- worldwide, long term

Software Heritage enables

- archival, reference, integrity
- traceability, global knowledge base

Call to action

- support a shared open infrastructure to support your use cases
- develop new applications, tackle new scientific challenges
- positions open for CodeCommons

Join us

Annual report 2024