The FAIR for Research Software Principles after two years: An adoption update

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The FAIR for Research Software (FAIR4RS) Principles aim to promote and encourage the findability, accessibility, interoperability, and reusability (FAIR) of research software. The FAIR4RS Principles were released in 2022, with a number of organisations already planning adoption at that time. Adoption and implementation of the FAIR4RS Principles can increase the transparency, reproducibility, and reusability of research by providing research software that can be executed, replicated, built-upon, combined, reinterpreted, reimplemented, and/or used in different settings and by third-parties.

This blog post provides an update on initiatives that are working to implement the principles across five areas of cultural change: policies, incentives, communities, training and infrastructure. It is noted that while many activities are increasing aspects of the FAIRness of research software, more work is still needed to make it easier to embrace the FAIR4RS Principles in their entirety.

A framework for tracking adoption

The release of the FAIR4RS Principles succeeded in raising the profile of research software in FAIR initiatives, which have mostly been focused on FAIR data. Examples can be found across a range of initiatives, using a slightly adapted version of the five elements of Brian Nosek's strategy for culture change:

- Policy - make it required
- Incentives - make it rewarding
- Communities - make it normative
- Training - make it easy (this replaces user interface/experience in Nosek's version)
- Infrastructure - make it possible

To achieve culture change, initiatives are needed across all of the five elements. Whilst in the early stages, some elements can progress more quickly than others. For example, it's difficult to implement policy requirements if infrastructure and training (and preferably incentives) aren't already in place. Similarly, for tools evaluating FAIRness to be useful, changes in major infrastructures such as code hosting repositories are first required so that researchers can create the metadata files that evaluations may depend upon.

It should be noted that while the many activities listed here support increasing FAIRness of research software, most of them do not address aspects of all four of the FAIRness of research software foundational principles:

Findable (F): Software, and its associated metadata, is easy for both humans and machines to find.
Accessible (A): Software, and its metadata, is retrievable via standardised protocols.
Interoperable (I): Software interoperates with other software by exchanging data and/or metadata, and/or through interaction via application programming interfaces (APIs), described through standards.
Reusable (R): Software is both usable (can be executed) and reusable (can be understood, modified, built upon, or incorporated into other software).

This reflects that the FAIR4RS Principles are aspirational and high-level, and do not contain detailed guidance on how to achieve them. This is because specific technologies and tools are always changing, while the principles are intended to be long-lasting. Consequently, additional work is needed to make it simpler for people wanting to follow the FAIR4RS Principles to know how to practically do so. The following initiatives are assisting in achieving this, with some of these initiatives specifically addressing the range of opportunities for future work identified in 2022 by the FAIR4RS Working Group, which developed the FAIR4RS Principles. These opportunities include “metadata and identifier authority, metadata vocabularies and metadata properties, software identifiers, domain-relevant community standards for software and identification targets”. Whilst some of the initiatives identified in the infrastructure section below are contributing to this, more work still needs to be done.

1. Policies that encourage implementation:

- The Netherlands eScience Center and the Dutch Research Council (NWO) formed a working group that developed national guidelines for software management plans. Research institutions such as the University of Groningen’s Digital Competence Center link to this resource in its guidance for its researchers on research software management plans.
- The Software Management Plan Template of the Netherlands eScience Center has been updated to align and address the FAIR4RS Principles, and emphasises that open science, software quality, and software sustainability are key elements in eScience Center projects. A total of 13 eScience Center projects (11 under the Open eScience call 2023 (OEC2023) and 2 under the Software Sustainability call 2023 (SS2023)) are now using this template.
- Maastricht University in the Netherlands has an Open Science @UM policy, which includes FAIR software as one of its seven areas. Maastricht University proposes to inventory current practices in storage, sharing and reuse of software; and then identify gaps in awareness, knowledge and/or support on FAIR software. Actions likely to be taken include promotion of the creation of software management plans to ensure responsible use of research software.
- Enabling FAIR Workflows - Key actors and actions by the Open Research Funders Group outlines steps for different actors in the research community to take to embed sharing practices, persistent identifiers, and metadata throughout the research lifecycle.

This report references the FAIR4RS Principles in its recommendations on depositing research software.
- The German Research Council (DFG) published guidelines for reviewing grant proposals for Collaborative Research Centers (CRC/SFB) and suggested compliance with the FAIR4RS Principles for archiving and reuse.
- The Digital Research Alliance of Canada (the Alliance) published the National Research Software Strategy 2023. This proposes a set of strategic goals for advancing research software capability, community, and coordination in Canada for 2025-2030, with the FAIR4RS Principles providing a cross-cutting theme. The Alliance is developing a Software Management Plan (SMP) template to promote, cultivate and implement best practices, with an emphasis on the FAIR4RS Principles, for Canadian researchers. The goal is to implement the SMP template in future grant applications.

Resources that support inclusion of FAIR into institutional policies are also relevant. The list of research institutional policies that support research software, curated by the Research Software Alliance (ReSA), is part of ongoing work by the joint ReSA and Research Data Alliance (RDA) Policies in Research Organisations for Research Software (PRO4RS) Working Group to create a community of stakeholders involved in promoting and/or implementing policy that supports research software at the research institution level (such as universities, national laboratories). This includes curation of resources on how to influence policy change, such as Health Research Performing Organisations (HRPOs) FAIR Guidelines by Celia Alvarez Romero et al. This provides principles, steps, and resources to support the complex change needed to implement a data policy, which could also be applied to research software policy change.

2. Incentives that motivate change:

- FAIR-IMPACT launched open calls for cascading grants that provide financial support ranging from 4,000-10,000 euros. Focus areas on research software include:
    - Path 1: Assessment and improvement of existing research software using a new extension of F-UJI (a web service to assess FAIRness of research objects).
    - Path 2: Implementation of the Research Software MetaData Guidelines for better archiving, referencing, describing, and citing research software artefacts.
- The German Research Council (DFG) issued a Call for Proposals to Increase the Usability of Existing Research Software that refers to the FAIR4RS Principles in terms of availability and reproducibility.
- The German Ministry of Education and Research (BMBF) issued funding guidelines (in German) for developing data custodian models that refer to standards based on the FAIR4RS Principles for reusable and well-documented open source software developed under this program.

3. Communities that are normalising adoption:

- The RDA Software Source Code Interest Group provides a forum to discuss issues on management, sharing, discovery, archival and provenance of software source code. In

October 2023 the group session at the RDA Plenary included a focus on the FAIR-IMPACT Metrics for Assessing Research Software FAIRness (recording). In addition, this group is the maintenance home for the FAIR4RS Principles.
- The Research Software Funders Forum included a working group focused on implementation of the FAIR4RS Principles, which review the FAIR4RS Principles per the interests of research software funders, to identify gaps.
- Ten simple rules for starting FAIR discussions in your community presents guidance and recommendations on how to start up discussions around the implementation of the FAIR Principles and creation of standardised ways of working. Whilst not specific to FAIR4RS Principles, these recommendations can assist in providing understanding of the benefits and barriers of standardisation are, and will support a more effective way of engaging the community.

4. Training to develop relevant skills:

- The Netherlands X-omics Initiative has created Ten quick tips for building FAIR workflows, which provides practical recommendations for implementation of the FAIR4RS Principles when creating computational workflows.
- Making Biomedical Research Software FAIR: Actionable Step-by-step Guidelines with a User-support Tool assists biomedical researchers to make their research software compliant with the FAIR4RS Principles. The FAIR Biomedical Research Software (FAIR-BioRS) guidelines are based on the FAIR4RS Principles and a workflow that streamlines the process of implementing these guidelines is also provided.
- The Netherlands eScience Center is developing and piloting the Research Software Support course which covers the FAIR4RS Principles and provides guidance for research personnel.
- The Digital Competence Centre of the Delft University of Technology (TU Delft) in the Netherlands is offering a 13-week FAIR for Research Software Program, which includes resources from the Code Refinery, a project within the Nordic e-Infrastructure Collaboration (NeIC). TU Delft's program aims to teach the essential tools for creating scientific software following the FAIR4RS Principles and how to apply them.
- The Data Competence Center at the Leiden University Medical Center (LUMC) aims to help researchers implement the FAIR4RS Principles by increasing software stewardship capacity.
- The European Infrastructure for Translational Medicine (EATRIS) promotes adoption of the FAIR4RS Principles by sharing practical implementation examples from and with the community via its Multi-omics Toolbox (MOTBX).
- The Alliance's National Research Software Strategy 2023 recommends FAIR4RS as a key element underlying training & support initiatives for research software, which will be included in the forthcoming national training framework and resourced appropriately.

5. Infrastructure that provide supporting tools:

- FAIR-IMPACT's release of Metrics for automated FAIR software assessment in a disciplinary context defines 17 metrics that can be used to automate the assessment of research software against the FAIR4RS Principles, and provides examples of how these might be implemented in one exemplar disciplinary context of the social sciences. The FAIR-IMPACT project will work to implement the metrics as practical tests by extending existing assessment tools such as F-UJI.
- Horizon Europe's European Virtual Institute for Research Software Excellence (EVERSE) aims to create a framework for research software and code excellence, that are collaboratively designed and championed by the research communities. EVERSE will also continue the work of FAIR-IMPACT by developing and implementing processes and tools that support the assessment and verification of code quality, based on established best practices and standards across scientific communities.
- FAIRsoft is a practical implementation of the FAIR4RS Principles, and the FAIRsoft evaluator is a tool for developers and users to assess how specific software complies with FAIR for software indicators. It is part of the ELIXIR's OpenEbench Software Observatory, an instrument for the systematic observation and diagnosis of the quality of research software in the life sciences.
- FAIR-Impact's Guidelines for recommended metadata standard for research software within EOSC acknowledges the rising need for establishing software metadata guidelines to effectively collect and curate metadata. A comprehensive set of Research Software MetaData (RSMD) Guidelines are provided that offer flexible and adaptable recommendations for end-users that can be used in different disciplines and different software development contexts. The guidelines are directly relevant to end users, including software creators and curators in their quest to improve the FAIRness of their software.
- The ELIXIR Software Best Practices group, NFDI4DataScience and Bioschemas are collaborating together to support machine-actionable SMPs which are aligned to the ELIXIR Software Management Plan for Life Sciences published by ELIXIR; and also aligned to other initiatives but also to others, such as the practical guide to SMPs by the Dutch Research Council (NWO) and the Netherlands eScience Center, and the SMP template by the Max Planck Digital Library.
- A new version of the machine-actionable Software Management Plan Ontology (maSMP Ontology) metadata schema, vr2.1.0, was released in January 2024, together with usage guidance about the properties (profiles, guides on minimum, recommended and optional properties with cardinalities). The metadata schema includes entities involved in software management planning, such as an SMP itself, software source code, software release, documentation, authors and their relations. Integration into Bioschemas is still pending.
- A metadata enrichment cycle aligned to the maSMP metadata schema has been proposed by ELIXIR thanks to the Software Management Wizard, a tool to make completion of SMPs easier. A similar effort is within the scope of NFDI4DataScience and the Research Data Management Organiser (RDMO) SMP. This approach reuses a command-based tool to extract metadata from GitHub repositories, SOMEF, which is currently being extended to cover the maSMP metadata schema case.

- The Research Software APIs and Connectors project within the FAIRCORE4EOSC project is working on developing tools and services for archival, reference, description, and citation of research software artefacts. This implements the key recommendations of the Scholarly Infrastructures of Research Software report to interconnect scholarly repositories, publishers, and aggregators. Interconnections are possible with the Software Heritage universal source code archive, using the CodeMeta standard, and the Software Heritage intrinsic identifiers (SWHID). Instructions on how to archive your software to Software Heritage is one outcome.
- FAIRSECO: An Extensible Framework for Impact Measurement of Research Software aims to enable research software engineers to rapidly find and extract relevant software fragments from the worldwide research software ecosystem.
- Towards a Quality Indicator for Research Data publications and Research Software publications -- A vision from the Helmholtz Association develops indicators to be used within the Association. It presents a quality assessment spanning six dimensions of research software quality that augments the four FAIR principles with two additional indicators: Scientific basis and Technical basis, resulting in the FAIR-ST framework.
- A self-assessment tool to promote FAIR research software has been developed by the Netherlands eScience Center and Australian Research Data Commons, to encourage the uptake of the FAIR4RS Principles (and see the 2022 Survey on Adoption Guidelines for the FAIR4RS Principles for more resources).
- openCARP-CI provides Python scripts that allow developers to automatically derive CFF and DataCite files from a CodeMeta file. These pipelines can easily be integrated in continuous integration and deployment environments. They also provide tools for software publication via tagged releases, creation of BagIt and BagPack files, and publication on the research data repository RADAR.
- CodeMeta-3.0: The minimal metadata schema for science software and code, in JSON-LD, provides a possibility to developers and researchers to insert metadata in their code and increase FAIRness.
- FAIR-USE4OS: From open source to Open Source by Raphael Sonabend et al., extends the FAIR4RS Principles to provide criteria for assessing if software is Open Source. By adding 'USE' (User-Centred, Sustainable, Equitable), software development can adhere to open source best practice by incorporating user-input early on, ensuring front-end designs are accessible to all possible stakeholders, and planning long-term sustainability alongside software design.
- FAIR4RS has also been discussed within the scope of Open Science and software quality, for instance the EOSC Task Force Infrastructures for Quality Research Software compiled software quality metrics and identified those that can be aligned to the FAIR4RS Principles.

Other impacts

The publication of the FAIR4RS principles and introductory articles created awareness and raised interest in the research community, reflected in over 200 citations from across the disciplinary spectrum. Examples include the results of searches on Google Scholar for “FAIR

principles for research software (FAIR4RS principles)" or " Introducing the FAIR Principles for research software". In addition to work discussing trans-disciplinary application of the FAIR4RS Principles, there are research policy and software management publications referring to and implementing the FAIR4RS Principles.

The FAIR4RS Principles have also provided value to the broader research ecosystem by providing a base for other communities to adapt the FAIR Principles to different research objects. Examples include FAIR AI Models in High Energy Physics, which provides a practical definition of FAIR principles for machine learning and artificial intelligence models in experimental high energy physics, including a FAIR AI project template; and the Open Modeling Foundation's work to identify, develop, and promote common standards and best practices for FAIR modelling, by working with model organisations and individuals active within the social, ecological, environmental, and geophysical sciences.