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Abstract

This document is the third iteration of three reports on the state of FAIR in European scientific data by the FAIRsFAIR project. This report focuses on providing relevant current information about the implementation of the FAIR principles in the scientific community. It provides six notes in three brief chapters: prerequisites for FAIR implementation, best practices, and warnings.

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Abbreviations and Acronyms

API	Application Programming Interface
DMP	Data Management Plan

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EOSC	European Open Science Cloud
FAIR	Findable, Accessible, Interoperable, Reusable
FAIR4RS	FAIR for Research Software
FDO	FAIR Digital Object
FIP	FAIR Implementation Profile
GBIF	Global Biodiversity Information Facility
PID	Persistent Identifiers
RDA	Research Data Alliance

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Executive Summary

It is generally acknowledged that researchers require substantial support from research infrastructures, data stewards, service providers, funders, etc. in order to achieve reasonable levels of FAIRness. The European Open Science Cloud (EOSC) ecosystem also recognises the importance of FAIR data. As a final report, this deliverable aims to highlight and summarise the prerequisites, best practices and warnings that the EOSC association should take into account while driving forward the development, support and adoption of sustainable FAIR solutions.

The prerequisites outline the basic requirements for implementing robust technical FAIR solutions, namely multilingualism and readability for both machines and humans. The best practices highlight two key guidelines that can reliably lead to achieving more FAIRness. The warnings provide a couple of cautions regarding PIDs and research object types.

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Table of contents

FAIRsFAIR "Fostering FAIR Data Practices In Europe" has received funding from the European Union's Horizon 2020 project call H2020-INFRAEOSC-2018-2020 grant agreement 831558

1. Introduction

This report is the third deliverable by the FAIRsFAIR project on FAIR technologies and practices. The first report was a landscaping effort - to a general audience - that reviewed and documented commonalities and possible gaps regarding semantic interoperability, and the use of metadata and persistent identifiers across infrastructures. The second report further explored the developments to increase awareness on what good FAIR means, and provided an explanatory guide to researchers, data stewards and service providers on the use of PIDs, metadata and semantic interoperability.

This third report - to the EOSC association - focuses on six specific, possibly critical aspects on developing the open science community towards a FAIR supporting entirety. Not to repeat the effort done elsewhere, we base this report on previous work and additional material obtained from:

- Discussions with experts through different avenues
- Two webinars conducted in January[1] and February[2] 2021
- A workshop on 4 October 2021[3]
- The FAIRsFAIR Public Event on 27 January 2022[4]

1.1. PIDs and metadata are necessary for making FAIR a reality

Looking at the FAIR data principles, one can note that metadata are mentioned under each of the letters of FAIR, and two of the principles concern explicitly metadata. Metadata is thus a mandatory element of FAIR data as stated explicitly in F2. As explained in the I principles, metadata should be as interoperable as possible but it is still one of the challenges of FAIR implementation. There are always considerations that have to be made regarding costs and data quality when aiming at interoperability. Data mapping or harmonisation can lower the quality or distort a domain ontology. Metadata and mappings have to be curated and kept up-to-date. In addition, a lot of metadata could be automatically collected and kept, but this is not yet commonly part of the research work flow and hence it either is lost or takes a lot of effort. Thus, there is not one answer for all use cases. Still metadata creation is in fact not an integrated part of all research workflows today and the quality of data documentation varies. Prioritising and long-term lifecycle planning is necessary. Extensive competencies and skills on all levels are needed to manage and curate scientific content.

Identifiers, globally unique and persistent, are mentioned in the very first of the FAIR principles. But the principles do not say what kind of identifiers or technologies are recommended in which context, because they are principles, not standards. In practice, there are many use cases and possible solutions for creating identifiers. To build sustainable FAIR solutions we need not only better technical interoperability, but also even more specific policies and guidelines for when to mint and allocate PIDs and how different types of identifiers should be managed. Resilient FAIR service ecosystems and working data spaces need mindful PID usage and clear policies. User centricity and sustainability are key also regarding PID use. Besides different types of objects to identify, one must remember the dimension of the life cycle, for the data, metadata, PID and its metadata. Furthermore, technologies and research projects always have a lifecycle, too. If these aspects are ignored when planning, using and publishing identifiers, the FAIR data concept itself will be corrupted.

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2. ✅Prerequisites

2.1. A shared digital space should be multilingual

The lingua franca of science is often considered to be English, but the content in many disciplines is in national or local languages. Accessibility for human users also means that they are able to understand content in a natural language. If we want to ensure societal engagement, uptake and impact of research, it is useful to consider that Europe is a truly multilingual area and the EU has 24 official languages and many more languages are spoken. Furthermore, research is of course global. FAIR data can also be multilingual and this brings an additional dimension to interoperability. When creating semantic interoperability with semantic artefacts we should not only see it as a normalisation within a language (linking synonyms) and creating clarity, but also use the same method to link different languages and thus enhance findability, access and reusability.

Europeana, a web portal created by the European Union containing digitised cultural heritage collections of more than 3,000 institutions across Europe has, since 2009, been aiming for multilingual services and has developed an approach to enhance access and discovery in different languages[5,6]. This has required significant effort, using manual work and developing technical solutions as well as using automated translations as the source data are diverse and complex. Offering enriched data via API[7] is also a valuable way of making this resource available. Generally using FAIR semantic artefacts is a good way to improve metadata quality.

Implementing the FAIR principles offers a good opportunity for making information more accessible and reusable for the end users like citizen scientists or researchers within humanities in different countries and language groups. Multilingual user interfaces enable citizen scientists to also contribute and use the data. The possibilities and tools to localise citizen science applications should be considered already from the beginning when designing the tools and creating data. The Europeana experience shows that using controlled vocabularies with translations is an efficient way to achieve these benefits[5]. Encouraging use of good quality semantic artefacts and developing tools that support their use is an important path towards more FAIR data spaces especially for the non-technical data stewards and researchers producing data and metadata. One example of the FAIR services and multilingualism is the iNaturalist website and application[8], where the translation effort has been crowdsourced via the Crowdin localization platform[9]. The application and website are used by hobbyists for collecting biodiversity data, i.e., observations of species occurrences at a location. The quality assurance also utilises vocabularies (i.e., species names and taxonomy) and is handled in the application by enabling other users to suggest (more accurate) identification or confirm the given one as a kind of peer review process. Species names and their common names in different languages can also be added by devoted users, but as it is considered to be reference data, maintaining the species names in the application requires more than basic level knowledge of the species group in question. For this reason, the taxonomy (including vernacular names) can't be tasked to citizen scientist translators, but they must be more strongly linked to official and referable check-lists maintained by official bodies (such as natural history museums). The Global Biodiversity Information Facility (GBIF) maintains the so-called taxonomy backbone[10] vocabulary which links together species names and hierarchies from 100 official sources.

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2.2. All research outputs should be understandable by both machines and humans

FAIR principles require human and machine readability from not only tabular data but also semantic artefacts and other data documentation, code, models, software, etc. - basically all research outputs. Machine readability and findability can be achieved, for example, in digital publications publicly available on the Web by using schema.org annotations for improving findability via search engines or automated aggregation.

Still, a lot of research outputs are geared mostly towards humans, and not machines. For example, most research data and their documentation that is published with the article are still published as appendix or as standalone publication, and even if publishing data in data repositories has increased since the FAIR principles were introduced, machine actionable citation, not to mention publishing other research outputs [than tabular data] as machine actionable data is still an exception.

Reproducibility is one of the inbuilt mechanisms in scientific methods. To this end, the novel "executable paper" format offers a transparent and reproducible way to communicate research. Executable papers are dynamic pieces of software that combine text, raw data, and the code used for the analysis, and that a reader can interact with[11].

The executable paper format enforces publishing data and analysis code in a clean and well-documented way alongside the article. Preparing such polished material takes time, but also gives an additional chance of catching mistakes, and leaves it ready-to-use and reuse for future research. Moreover, the additional transparency makes it hard to "hide" sloppiness in the analysis process or even fraudulent practices[11].

If we need to make a choice, machine readability is the way to go: it is easier to present it for a human later than it is to make human-directed output machine-understandable. For example: we should not rely on text mining to make a research article available to machines.

Software and code as digital objects can usually be read by humans, but understanding it usually is not easy, without documentation both as external materials like descriptive metadata and read-me files *and* good documentation within the code itself.

3. Best practices

3.1. FAIR is a journey, take it one step at a time - start with practical and user-friendly solutions

The FAIR principles have become a fundamental foundation for research data management within all research disciplines.

Someone stating that their data "are FAIR" or "have been FAIR for a long time" is a big red flag in data stewardship. Especially in the shifting landscape of interoperability, such a statement is an indicator that the data are exclusively interoperable with itself.

Instead of a *destination* that we should all achieve, it is a *journey* that we should all embark on. There is no (impossible) requirement that everyone achieves ultimate FAIRness; instead, everyone

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should be encouraged to analyse which steps can be taken to make data FAIR using reasonable steps that can be achieved with little effort and that have relatively large payoffs.

A consequence of this view is that FAIR measurements should not be compared between different data sets or with a norm ("your data can only become part of our system if it is at least 57% FAIR"). They should be seen as:

1. A revealing qualitative estimate of how far one is along the journey (i.e., especially how much further one can still go along each of the dimensions to achieve not only FAIR for humans but also for machines);
2. Ways to identify and implement possible improvements of FAIRness that are relatively easy to achieve (based on the fact that aspects of FAIRness are properly separated by the tests).

Important to note is that, at this moment, different FAIR evaluation tools can give wildly different results on testing the same resource, identified through the same URL: there is an example where Mark Wilkinson's FAIR evaluator Interoperability and Reusability tests come to 9 out of 9 and F-UJI's to 1 out of 14[12]. This is not to say that one tool is better than the other, it is only an indication that the tests and the guidance provided by different assessment tools are different, because there is not a categorical way to measure principles. This shows again that using the tools for their guidance towards more FAIRness is a better approach than taking the quantitative outcome at face value. In line with this, Mark Wilkinson has suggested[12] changing the name of the action from "FAIR assessment" to "FAIR assistance"; this philosophy is also represented in the name of the FAIRassist resource[13] that lists known FAIR assessment frameworks and tools.

The FAIR data landscape is diverse in many aspects: it is not productive to require the same level of FAIRness across different scientific domains and communities. For example, "findability" of health studies involving diabetes across the world is placing different demands than "findability" of high-energy physics data involving collisions between electrons and positrons: the physics data are collected in a limited set of experiments that are known to all field experts, so findability is relatively easy, whereas achieving sufficient findability of the health data, which can be collected in many different studies in different hospitals, requires a lot more effort. However, one common thing is the need for practical, easy-to-use implementations that are more valuable than precise and high flying, "correct", and hard-to-use solutions. Continuous adjustments can (and should) be expected as language, technology and science changes and evolves[14].

A good approach to optimising FAIRness is to make an analysis, and for each aspect that is found not to be met, make a judgement call: how much effort would it cost to make it compliant, and what would be the value for the project and for science. Only undertake the effort if it is worth it. However, we recognise that it is not always easy to estimate the value or relevance for other researchers/research fields. For instance, when researchers studied graphene in fundamental research, they could never have expected its current relevance and importance in for instance the mobile industry. If you would have asked those first researchers the relevance of their work to others and how much effort would be justifiable, they would probably have answered it differently than if you ask them now.

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Providers of tools that can help make data FAIR can learn from assembling such assessments: if one of the criteria fails the investment analysis frequently, it is in need of tools that make it easier: once the effort needed to pass the test is smaller, more projects will start seeing the benefit. Hence, these FAIR assessment tools are also a very nice way for service providers/research infrastructure providers to familiarise themselves with, possibly deploy them (and start to encourage researchers to use them) to understand how they can adjust their services accordingly.

Another example where differences between communities can be large, is how much focus should be put on FAIR for machines vs FAIR for human beings. The required depth of machine actionability depends on the maturity of a specific field. It is not always smart to implement machine actionability at a deep level because the cost-benefit balance is not always favourable. The most important thing is to have clear, coherent and unambiguous structures that can be maintained in a convenient manner over time.

Communities should work towards deepening the implementation of FAIR principles to cover the entire research process to secure reproducibility and transparency of scientific research. With that in mind, the view on interoperability should not only consider data, but also the many other research artefacts that may be used in the context of research activities, such as software code, scientific workflows, laboratory protocols, open hardware designs, etc. It should also consider the need to make services and e-infrastructures as interoperable as possible[15].

One important thing to remember in the journey towards FAIR, is the need of the designated community and specific domain should always be central. It is often about striking a balance that supports the achievement of findability, accessibility, interoperability and reproducibility in a valuable and maintainable manner. The solutions (tools, workflows, environments, etc.) should also be user-friendly. If researchers find them easy to use, they will be motivated and encouraged to apply them, hence supporting reproducible research[3].

3.2. Become interoperable by avoiding misunderstandings

Interoperability can only be achieved if the data is so well described that even if someone tries their best, they cannot misunderstand it. Barend Mons often uses the phrase “The machine knows what I mean”[16] as a success measure of interoperability. Although this is an excellent description of the requirements for true interoperability, it is very difficult to measure in practice. This difficulty is overcome by changing the definition to the above: being so well described that it cannot be misunderstood by a human being.

It is the experience of FAIR experts making evaluation tools[17] that achieving machine interoperability is very hard to judge for humans. Somehow when we look at data, it is hard to imagine the difficulties a machine will encounter to understand it. In addition, when we look at *our own* data, we are not even capable of seeing how other humans could misunderstand it. If we don’t want to make these mistakes, we could write a computer program to encode machine interoperability. However, this is very tedious and it is frustrating to see how many different *standard* ways can be used to describe data.

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We suggest here to take a middle ground: we will not require that the machine understands the data, but at least we want to establish that the documentation helps the data to be unambiguously understood by someone else without requiring tacit "common" knowledge that is always less common than you think. As we have described in FAIRsFAIR D2.4[18], there are several concentric circles of interoperability, each successive one shares less tacit knowledge with you: (a) yourself in your next project, (b) a direct colleague, (c) someone in the same field elsewhere, and (d) someone doing other research with your data. Contrary to what is sometimes believed, interoperability is not only playing at the interdisciplinary level. It is also important to be interoperable with your own research in successive projects, and that is where interoperability should start. The further along we set our target on this list, the more challenging it will be to describe our data unambiguously.

To achieve a good level of unambiguousness we suggest the practical exercise described in the table below.

Invite your colleagues, in a brainstorming-style session, to try and come up with misinterpretations of your data. Let them build upon each other, just like in a normal brainstorm, and come up with the most outrageous ideas. Take good notes: Any possible misinterpretation points out an ambiguity in the description of the data that is worth fixing.

The result of this process is not that a machine will be able to flawlessly understand the data. But if this is done well, it will be so well described that somebody *could* program a computer to use the data. Of course, your colleagues are not clueless about your data, so they could miss ambiguities. The brainstorming format can help to uncover these.

Examples of how to play this game:

- Are any objects, processes, people not identified with a persistent identifier? How can someone be sure they have 'the right one', even in 10 years?
- Is anything indicated in two different ways? Can a clueless user find out unambiguously that they are the same?
- Is anything that is versioned lacking a version indicator?
- Are there any data fields that are not linked to a FAIR ontology? Missing units? Missing context (e.g., a gene missing the biological species)? Something that is listed as a "variation" missing a persistent link to the "reference"?
- Are any missing values or "exception values" not explained properly?
- Are any relationships between data values ("columns") left to the interpretation of the user? Can you think of another way to connect them? E.g., turn around cause and effect, or reverse any relationship that is not clearly directional (is it over, or under the "threshold"?)

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This is not a complete checklist. It is actually a way to try and misinterpret (meta)data. You can make it even more interesting trying to be more cynical. When this is done well, removing the uncovered ambiguities *will* reduce the number of requests for clarification by re-users.

Table 1: Practical exercise to help in reducing ambiguities in data

Related to this is the development by GO-FAIR[19] of the FAIR Implementation Profile (FIP[20]), which documents each of the choices you make, to make your data as FAIR as possible: which standards and methods you choose. An FIP itself can be stored as FAIR data, in form of statements as in nanopublications[21].

4. ⚠Warnings

4.1. Beware that translation of FAIR principles per research object type may be different

A digital object is simply defined as being "represented by a bitstream, referenced and identified by a persistent identifier and having properties that are described by metadata"[22]. In the context of FAIR, a FAIR digital object is "a sequence of bits that represents an informational unit and is presented according to the FAIR principles"[23]. It "must be accompanied by persistent identifiers, metadata and contextual documentation to enable discovery, citation and reuse"[24]. FAIR digital objects represent data, software or other research outputs such as publications, organisations, people, samples, equipment, repositories, etc[25].

The FAIR principles were meant for DATA. Data is defined differently in different communities, domains and disciplines. Furthermore, there was an important recommendation in the Turning FAIR into Reality report[24] to "Apply FAIR broadly" (rec 16) stating that "FAIR should be applied to metadata, identifiers, software and DMPs that are essential to the practice of research, and should inform metrics relating directly to these objects". FAIRsFAIR WP2 has looked at how the FAIR principles could be interpreted for different object types. In particular, deliverable D2.4[18] has addressed this for both software[26] and services[27] and task 2.2 D2.5 highlighted semantic artefacts as a specific type of digital object[28].

While services cannot be classified as more or less FAIR, they can either support or reduce the FAIRness of the content they hold. Regarding software, it was discovered that *accessibility* creates the largest challenges and sometimes is not even applicable. Even more importantly, there are still differences in the interpretation of the principles regarding software. Especially *reusability* and *interoperability* might have different meanings when it comes to software, and the interpretation was not perceived to be directly captured in the FAIR guiding principles. A significant development has happened since building on this work, as the FAIR4RS working group in RDA, published the FAIR Principles for Research Software[29]. These clarifying specifications now help in creating FAIR research software. Similar specifications and explanations are made regarding the semantic artefacts in the Recommendations for FAIR Semantics [28].

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Although identifiers may differ across the various research objects, it should be understood that the most important thing is their ability to be interoperable and reusable. Interoperability and reusability can both be achieved through machine-actionable metadata that provides rich information on how an object type should be handled. As recommended by the FAIRsFAIR Synchronisation Force, interoperability frameworks should be developed in order to support a ‘FAIR by design’ EOSC ecosystem[30].

4.2. Similar to zombies: beware of zombie PIDs

For the concept of persistent identifiers to work, there is a substantial element of trust. If trust is lost by unmet promises of persistence, the system will be corrupt and lose its *raison d’être* and the FAIR data ecosystem might crumble. Therefore, it is important that PIDs should be owned and maintained by trustworthy organisations, not individual people or research projects. In practice, services for persistent identifiers provide links between an identifier and the item they represent. These links should not be broken and they should be interoperable. This always comes with a cost.

Objects represented by PIDs can either be digital data in one form or another or digital representations of real-world objects or concepts. The metadata as well as the PID should be considered integrated parts of the FAIR digital object. Creating new PIDs for metadata only should be done mindfully and preferably only in the latter case, when real world objects, like organisations, collections, researchers or services are implicitly included in the represented object. Other solutions might cause confusion if clear and transparent guidelines are not provided for both humans and machines. Another challenge with PIDs and registries is that they should promote reuse rather than bulk creation of PIDs. To support interoperability, they could be considered semantic artefacts and be used mindfully. And above all a PID should be reused to refer to the same object whenever possible.

On the other hand, as a PID never should be reused to represent some other content, its uniqueness over time has to be ensured by technical as well as organisational means. Following the premise that a PID is a promise, it means that a user can always anticipate to find the object linked to a particular PID. If the object no longer exists, the owner should offer a ‘tomb page’ stating the object’s unavailability[3].

Master data management and ownership must be unambiguous and sustainable. The principle that only kernel metadata in a PID service is master data should be kept in order to avoid conflicts and confusion. The FDO metadata should lie with the digital object itself, not in a resolver or similar service.

5. Final reflections

The adoption of FAIR principles is gaining momentum across different scientific domains and communities. There are ongoing efforts to encourage data sharing in user-friendly ways, but there are still many challenges. As the ocean of data and information continues to grow, the potential for improving data management cannot be ignored. Researchers should be trained and supported as they make use of available tools to produce FAIR data and research outputs.

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FAIR Digital Objects (FDOs) are central to the realisation of FAIR data principles. These objects need to be identified by persistent identifiers (PIDs) and rich metadata. The details of the FAIR principles for data, the implementation and implications for services are still neither clearly defined nor settled yet. Implications of the FAIR data principles for services, repositories and software have been investigated within the FAIRsFAIR project. The development of FAIR tools and implementation of the FAIR data principles should be driven by researcher needs to achieve wide adoption and the potentially significant benefits of FAIR data. Community adoption and trust are decisive factors. It is now time for user-centred solutions focusing on the communities and their needs when promoting FAIR principles.

As EOSC develops into a web of FAIR solutions, it is important to think of the long-term sustainability of these solutions. A strong sense of ownership and responsibility should be encouraged amongst the stakeholders of the current research landscape (funders, research performing organisations, service providers etc) so that they can contribute to the development of a FAIR data culture within their particular roles.

The prerequisites, best practices and warnings presented in this document can only be observed widely within EOSC and across different communities with support from current research policies that strongly encourage and enable Open Science practices.

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