

The FAIR Principles

Erik Schultes, Barbara Magagna, Andrea Tarallo

29 November 2024

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-
Mission 4 “Education and Research” - Component 2: “From research to business” - Investment
3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”





Welcome - Recap

13:00-13:10
(Erik)



Agenda

13:00-13.10 (10 minutes)	Welcome - Recap (Erik)
13:10-13:30 (20 minutes)	FAIR Principles overview (Erik)
13:30-14:30 (60 minutes)	Interpretations: F and A Principles (Andrea, Erik)
14:30-14:45 (15 minutes)	Break
14:45-15:45 (60 minutes)	Interpretations: I and R Principles (Andrea, Erik)
15:45-16:00 (15 minutes)	Break
16:00-16:40 (40 minutes)	Breakout
16:40-17:00 (20 minutes)	Breakout presentations & discussion
17:00	Adjourn

Common Notes: https://bit.ly/FA-5-T-1_ITINERIS

Questions from last session?



History of the FAIR Guiding Principles

Erik Schultes, Barbara Magagna, Andrea Tarallo
27 November 2024

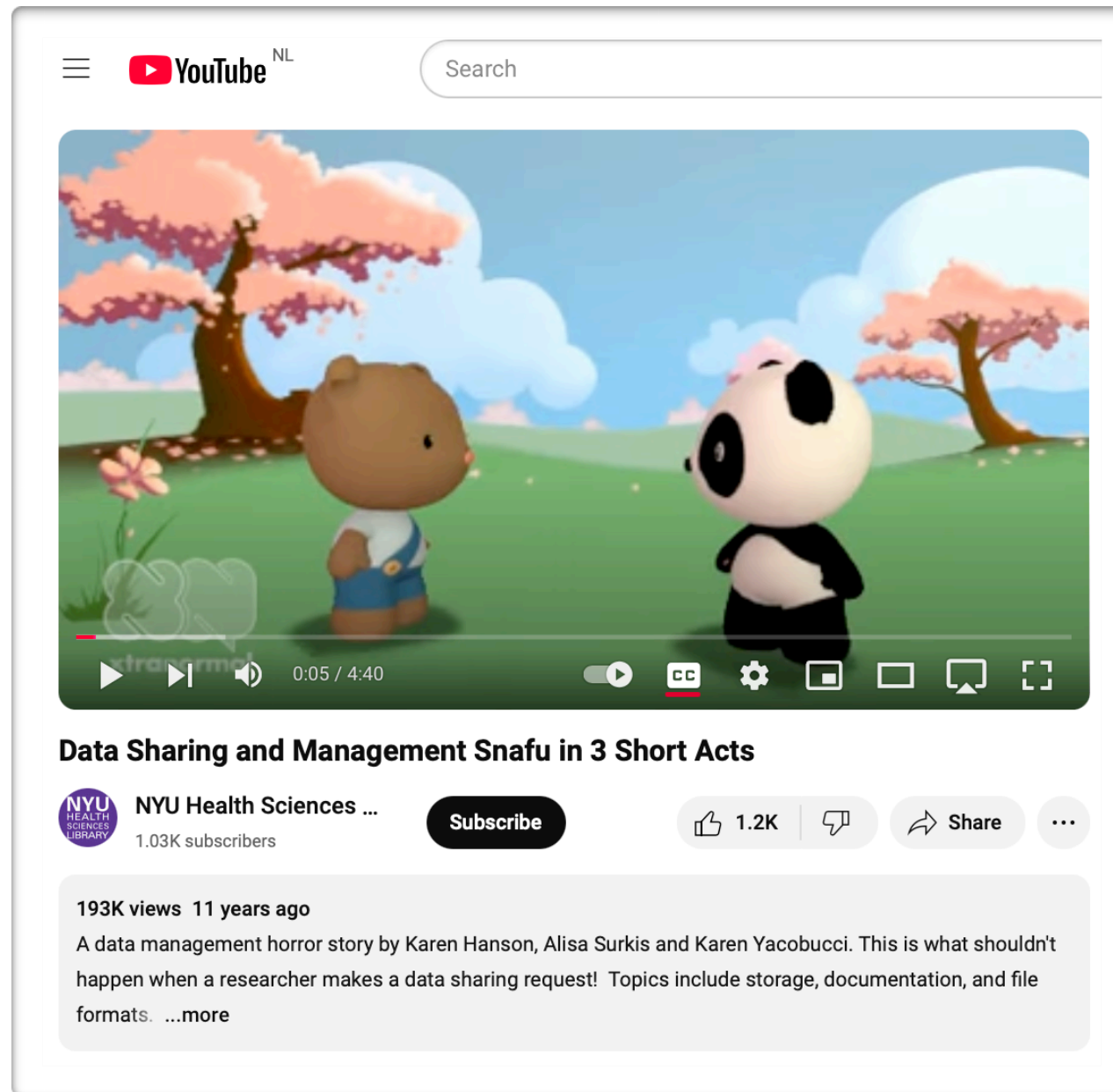
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Ministero
dell'Università
e della Ricerca



Homework



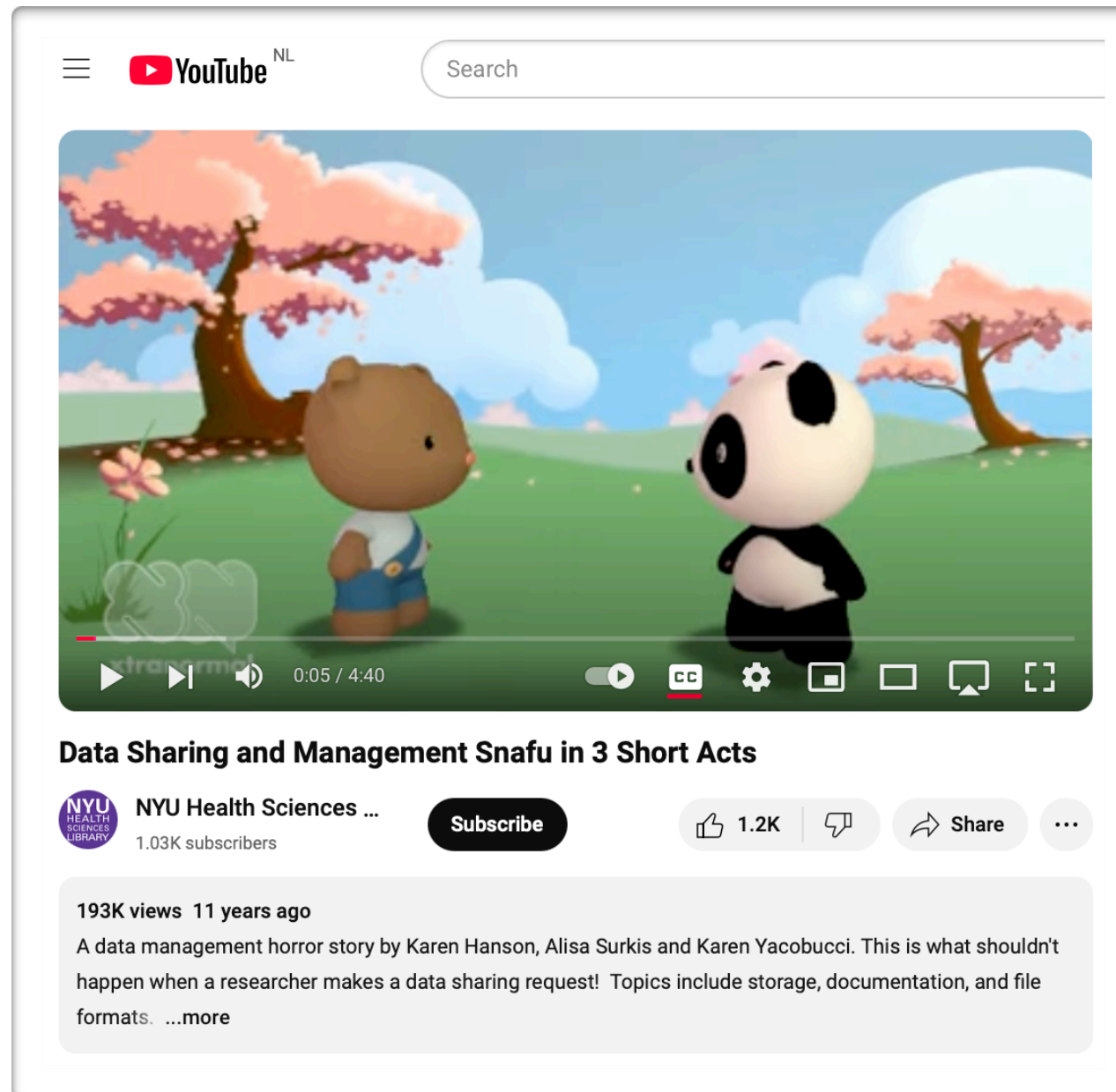
- **Panda Bear** reads about research in *Science*
- **PB** requests a copy of the data
- **BB** assumes (wishes) the data are already in the *Science* article
- **PB** indicates that the data are not there
- **BB** is not sure where the data are (a USB drive... in a box at home... so many boxes)
- **BB** 7 months to locate sends only copy to **PB**
- **BB** has 'complied' with the request for data but...
 - layers of idiosyncratic coding (specialized software is required to decode the hexadecimal notation)
 - software not supported since 2007
 - Semantically empty field names (SAM1, SAM2, ...) with no documentation (not even in the *Science* publication)
- Personnel point of failure: graduate student who moves back to China

Homework

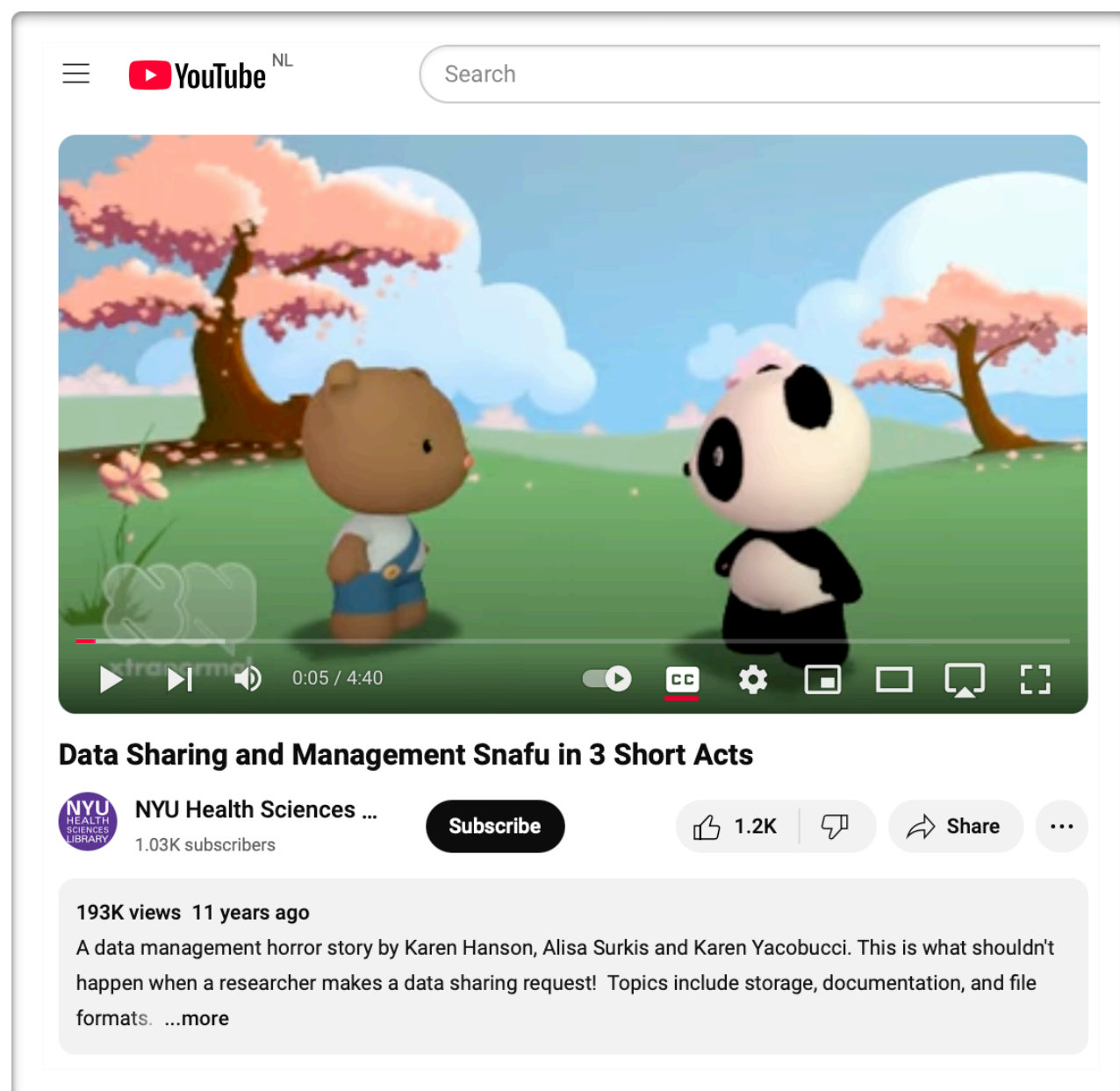


Brown Bear performed research that includes data on B Cell Function

- published in *Science*
- listed in PubMed Central
- funded by NIH



Homework



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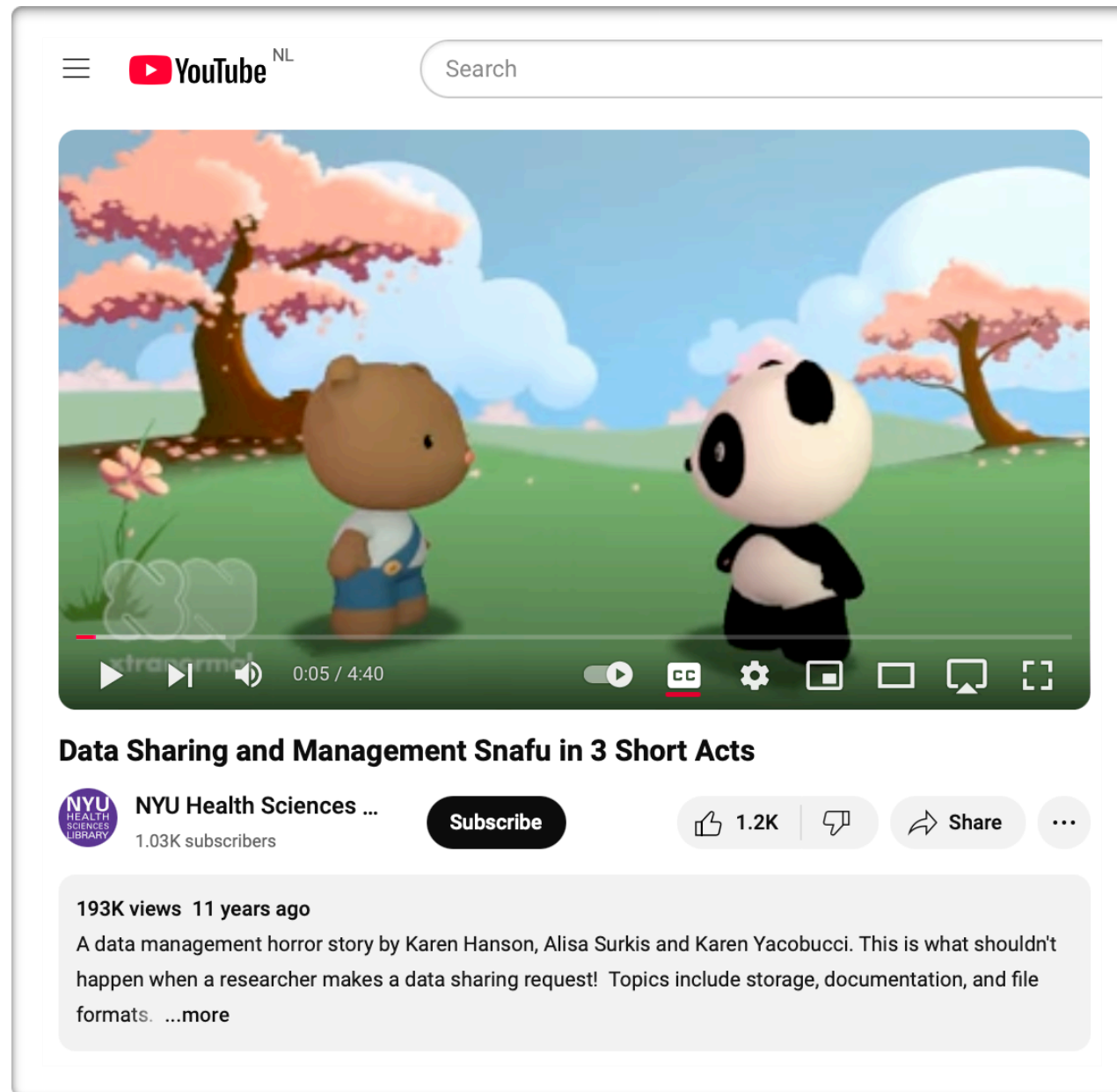
Data Sharing Policy at Science

<http://www.sciencemag.org/authors/science-editorial-policies>

Data and Materials Availability after Publication

After publication, **all data** and materials necessary to understand, assess, and extend the conclusions of the manuscript must be available to any reader of Science. **All computer codes** involved in the creation or analysis of data must also be available to any reader of Science. After publication, **all reasonable requests** for data or materials must be fulfilled.

Homework



Brown Bear performed research that includes data on B Cell Function

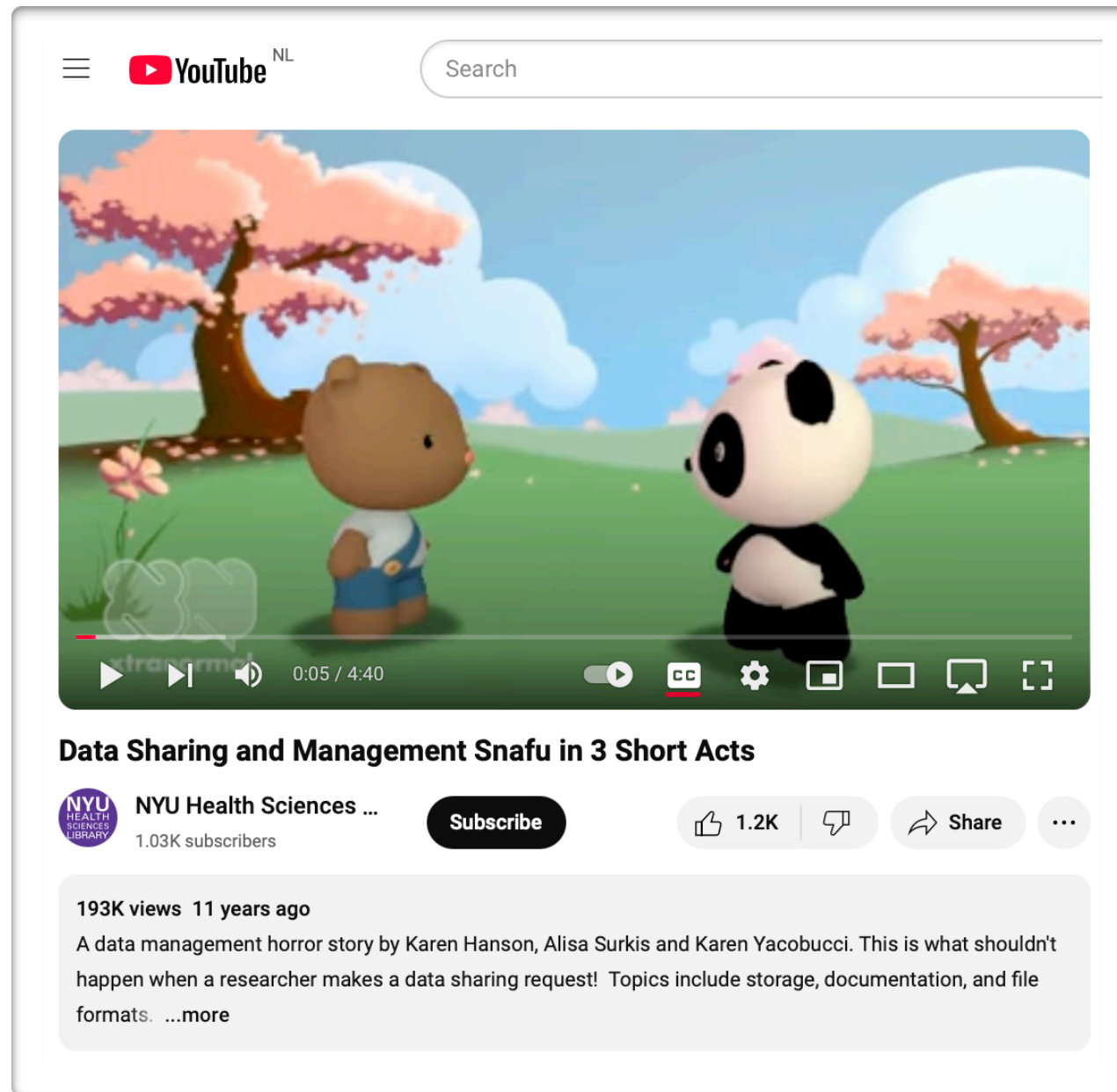
- published in *Science*
- listed in PubMed Central
- funded by NIH

Data Sharing Policy at PubMed Central <https://www.ncbi.nlm.nih.gov/pmc/about/guidelines/>

Supplementary Data

Any supplementary data (images, tables, video, or other documents / files) that are associated with an article **must be deposited in PMC** with the article. This applies to supplementary data that are available at the journal's site as well as those that may be stored in a public repository. **An exception** may be made for data sets that require **custom software** to read/use, or are very large (over 2 GB).

Homework



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- published in *Science*
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Data Sharing Policy at NIH

<https://www.ncbi.nlm.nih.gov/pmc/about/guidelines/>

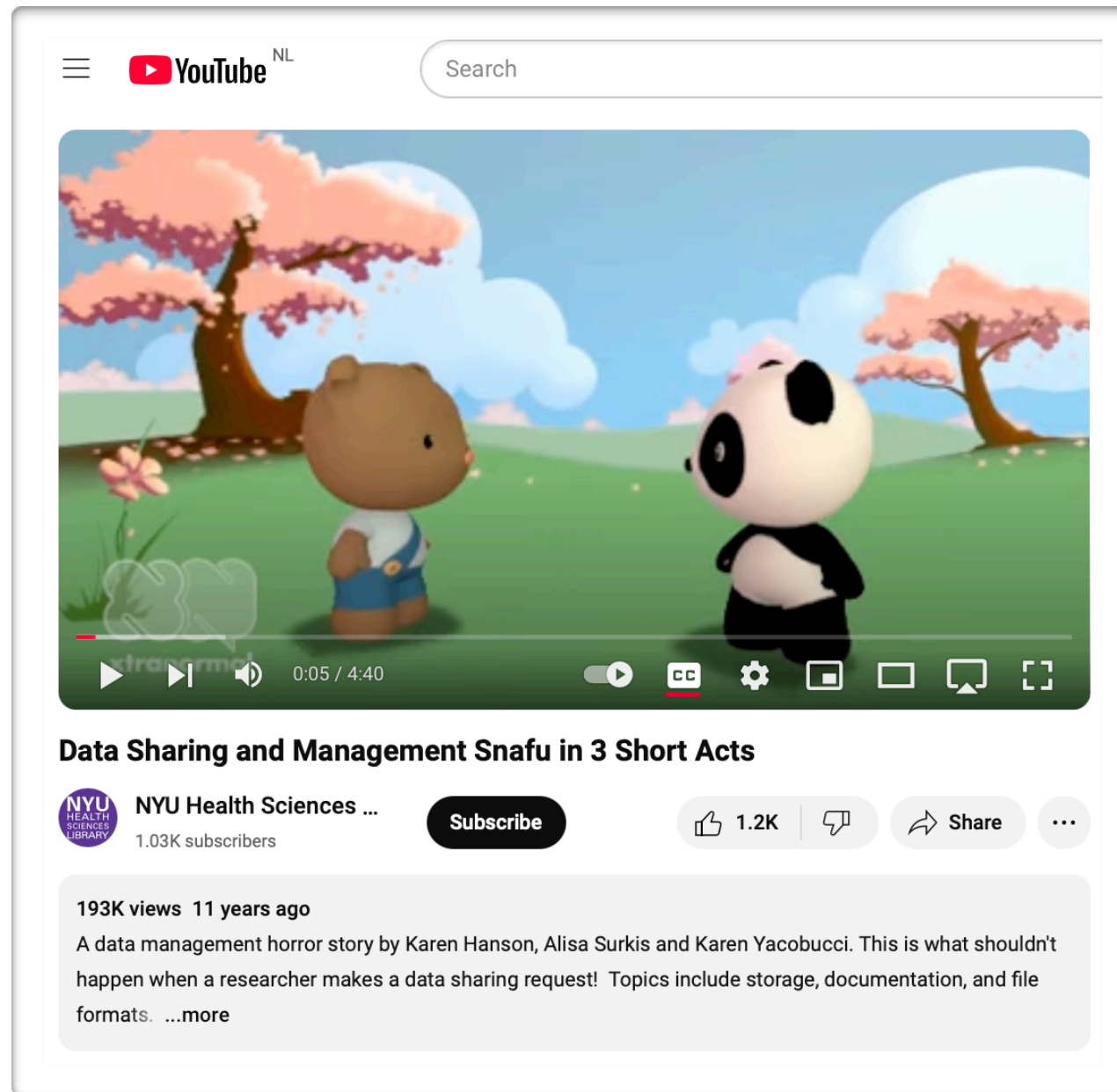
NIH Data Sharing Policy and Implementation Guidance

In NIH's view, all data should be considered for data sharing.

Data should be made as widely and freely available as possible while safeguarding the privacy of participants, and protecting confidential and proprietary data. To facilitate data sharing, investigators submitting a research application requesting \$500,000 or more of direct costs in any single year to NIH on or after October 1, 2003 are expected to include **a plan for sharing** final research data for research purposes, or state why data sharing is not possible.



Homework



Conclusion:

Despite the Data Policies of *Science*, PubMed Central and NIH, after 7 months of frustration and uncertainties, Panda Bear still can not reuse Brown Bear's data.

FAIR Principles - Overview

13:10-13:30

(Erik)



2014



Lorentz center

Jointly Designing a Data FAIRPORT

Workshop: 13 - 16 January 2014, Leiden, the Netherlands

Scientific Organizers

- Scott Lusher, NLeSC Amsterdam
- Barend Mons, Leiden UMC

Topics

- Towards a Modular Blueprint 'Floor-plan' of a Safe and Fair Data Stewardship, Trading and Routing Environment
- A Public Private Partnership to Ensure Long Term Solutions for Data in the eScience Era.

The Lorentz Center is an international center in the sciences. Its aim is to organize workshops for scientists in an atmosphere that fosters collaborative work, discussions and interactions. For registration see: www.lorentzcenter.nl

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Lorentz center

www.lorentzcenter.nl



2016

scientific data

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[Open Access](#) | [Published: 15 March 2016](#)

The FAIR Guiding Principles for scientific data management and stewardship

[Mark D. Wilkinson](#), [Michel Dumontier](#), [IJsbrand Jan Aalbersberg](#), [Gabrielle Appleton](#), [Myles Axton](#), [Arie Baak](#), [Niklas Blomberg](#), [Jan-Willem Boiten](#), [Luiz Bonino da Silva Santos](#), [Philip E. Bourne](#), [Jildau Bouwman](#), [Anthony J. Brookes](#), [Tim Clark](#), [Mercè Crosas](#), [Ingrid Dillo](#), [Olivier Dumon](#), [Scott Edmunds](#), [Chris T. Evelo](#), [Richard Finkers](#), [Alejandra Gonzalez-Beltran](#), [Alasdair J.G. Gray](#), [Paul Groth](#), [Carole Goble](#), [Jeffrey S. Grethe](#), [Jaap Heringa](#), [Peter A.C 't Hoen](#), [Rob Hooft](#), [Tobias Kuhn](#), [Ruben Kok](#), [Joost Kok](#), [Scott J. Lusher](#), [Maryann E. Martone](#), [Albert Mons](#), [Abel L. Packer](#), [Bengt Persson](#), [Philippe Rocca-Serra](#), [Marco Roos](#), [Rene van Schaik](#), [Susanna-Assunta Sansone](#), [Erik Schultes](#), [Thierry Sengstag](#), [Ted Slater](#), [George Strawn](#), [Morris A. Swertz](#), [Mark Thompson](#), [Johan van der Lei](#), [Erik van Mulligen](#), [Jan Velterop](#), [Andra Waagmeester](#), [Peter Wittenburg](#), [Katherine Wolstencroft](#), [Jun Zhao](#) & [Barend Mons](#)  [— Show fewer authors](#)

[Scientific Data](#) **3**, Article number: 160018 (2016) | [Cite this article](#)

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...the FAIR Principles put specific emphasis on **enhancing the ability of machines** to automatically find and use the data, in addition to supporting its reuse by individuals.



Box 2 | The FAIR Guiding Principles

<https://www.nature.com/articles/sdata201618>



To be Findable:

- F1. (meta)data are assigned a globally unique and persistent identifier
- F2. data are described with rich metadata (defined by R1 below)
- F3. metadata clearly and explicitly include the identifier of the data it describes
- F4. (meta)data are registered or indexed in a searchable resource

To be Accessible:

- A1. (meta)data are retrievable by their identifier using a standardized communications protocol
 - A1.1 the protocol is open, free, and universally implementable
 - A1.2 the protocol allows for an authentication and authorization procedure, where necessary
- A2. metadata are accessible, even when the data are no longer available

To be Interoperable:

- I1. (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation.
- I2. (meta)data use vocabularies that follow FAIR principles
- I3. (meta)data include qualified references to other (meta)data

To be Reusable:

- R1. meta(data) are richly described with a plurality of accurate and relevant attributes
 - R1.1. (meta)data are released with a clear and accessible data usage license
 - R1.2. (meta)data are associated with detailed provenance
 - R1.3. (meta)data meet domain-relevant community standards



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Machine-actionable metadata



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Technical infrastructure (accepted generic services)



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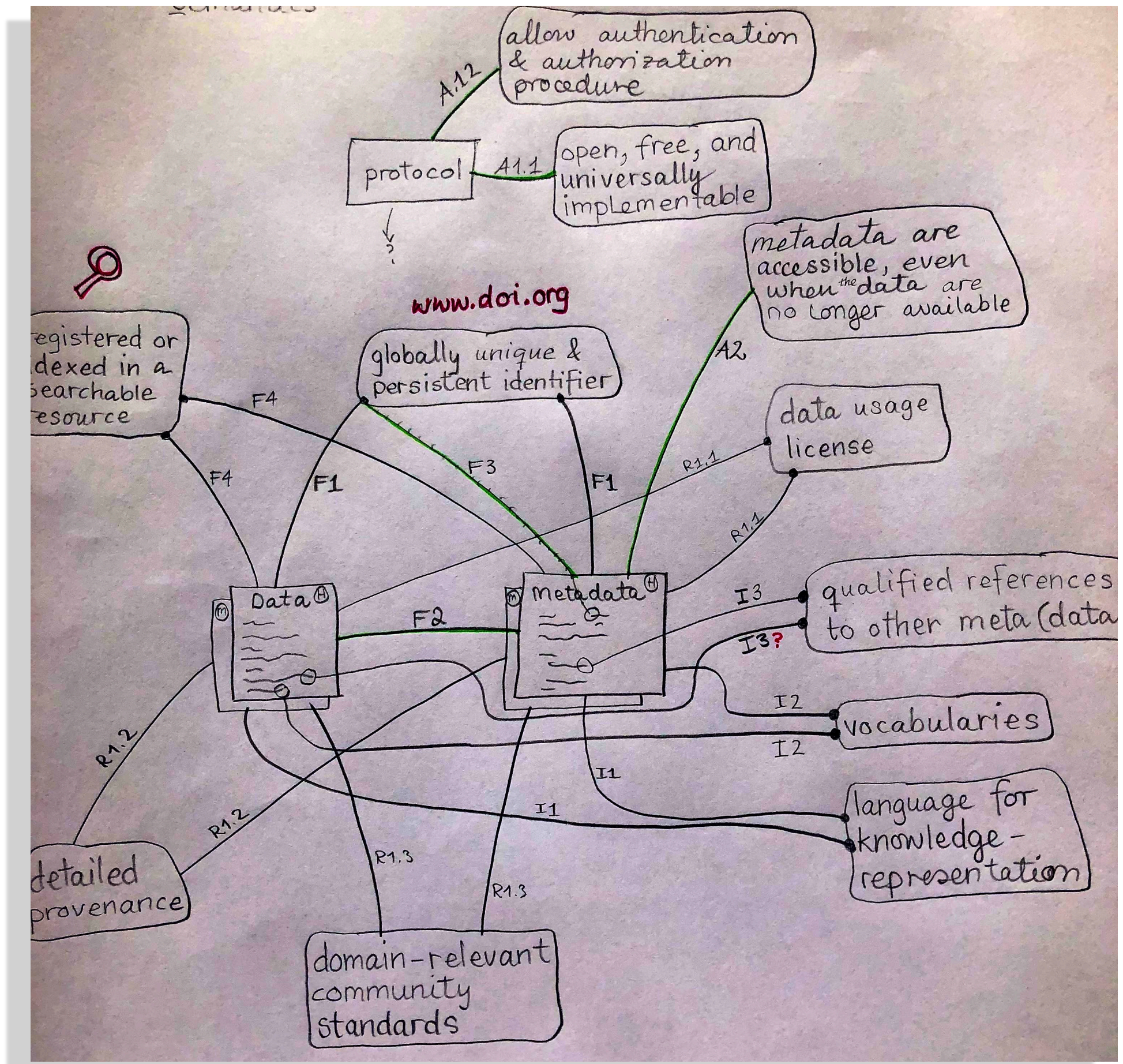
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Social decisions (domain specific agreements)



Box 2 | The FAIR Guiding Principles

<https://www.nature.com/articles/sdata201618>



Credits to Annika Jacobsen, LUMC



Computability

- *FAIR data* use knowledge representation languages and controlled vocabularies that reduce/eliminate ambiguity.

Trustworthiness

- *FAIR data* have (rich) provenance which provides evidence for the source of data. Provenance can include uncertainties and error estimation. Trust also requires large amounts of metadata.

Equitability

- *FAIR data* make explicit the conditions for reuse. Equitability can be technologically ensured, when data and metadata are FAIR

What FAIR is not...

Cloudy, increasingly FAIR; revisiting the FAIR Data guiding principles for the European Open Science Cloud [Cite](#)

Article type: Research Article

Authors: [Mons, Barend](#)^{a; b; c; *} | [Neylon, Cameron](#)^d | [Velterop, Jan](#)^e | [Dumontier, Michel](#)^f | [da Silva Santos, Luiz Olavo Bonino](#)^{b; g} | [Wilkinson, Mark D.](#)^h

Affiliations: [a] Leiden University Medical Centre, Leiden, The Netherlands. E-mail: b.mons@lumc.nl | [b] Dutch Techcentre for Life Sciences, Utrecht, The Netherlands | [c] Netherlands eScience Centre, Amsterdam, The Netherlands | [d] Centre for Culture and Technology, Curtin University, Perth, Western Australia | [e] Independent Open Access Publishing Consultant, Guildford, United Kingdom | [f] Institute for Data Science, Maastricht University, Maastricht, The Netherlands | [g] Vrije Universiteit Amsterdam, Amsterdam, The Netherlands | [h] Centre for Plant Biotechnology and Genomics U.P.M. – I.N.I.A., Madrid, Spain

Correspondence: [*] Corresponding author: Barend Mons, Einthovenweg 20, 2333 ZC Leiden, P.O. Box 9600, 2300 RC Leiden, The Netherlands. Tel.: +31624879779; E-mail: b.mons@lumc.nl.

Keywords: FAIR Data, Open Science, interoperability, data integration, standards

DOI: 10.3233/ISU-170824

Journal: [Information Services & Use](#), vol. 37, no. 1, pp. 49-56, 2017

Published: 7 March 2017

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Abstract

The FAIR Data Principles propose that all scholarly output should be Findable, Accessible, Interoperable, and Reusable. As a set of guiding principles, expressing only the kinds of behaviours that researchers should expect from contemporary data resources, how the FAIR principles should manifest in reality was largely open to interpretation. As support for the Principles has spread, so has the breadth of these interpretations. In observing this creeping spread of interpretation, several of the original authors felt it was now appropriate to revisit the Principles, to clarify both what FAIRness is, and is not.

Common misconceptions about FAIR:

- FAIR is not a standard
- FAIR is not only semantic web / Linked Open Data
- FAIR is not equal to ‘Open’ or ‘Free’
 - Data are often Open (Access) but not FAIR
 - Some data can never be Open, yet be perfectly FAIR

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By design, FAIR is not explicit about:

- data quality
- trustworthiness
- fit to purpose for reuse
- responsibility
- ethics

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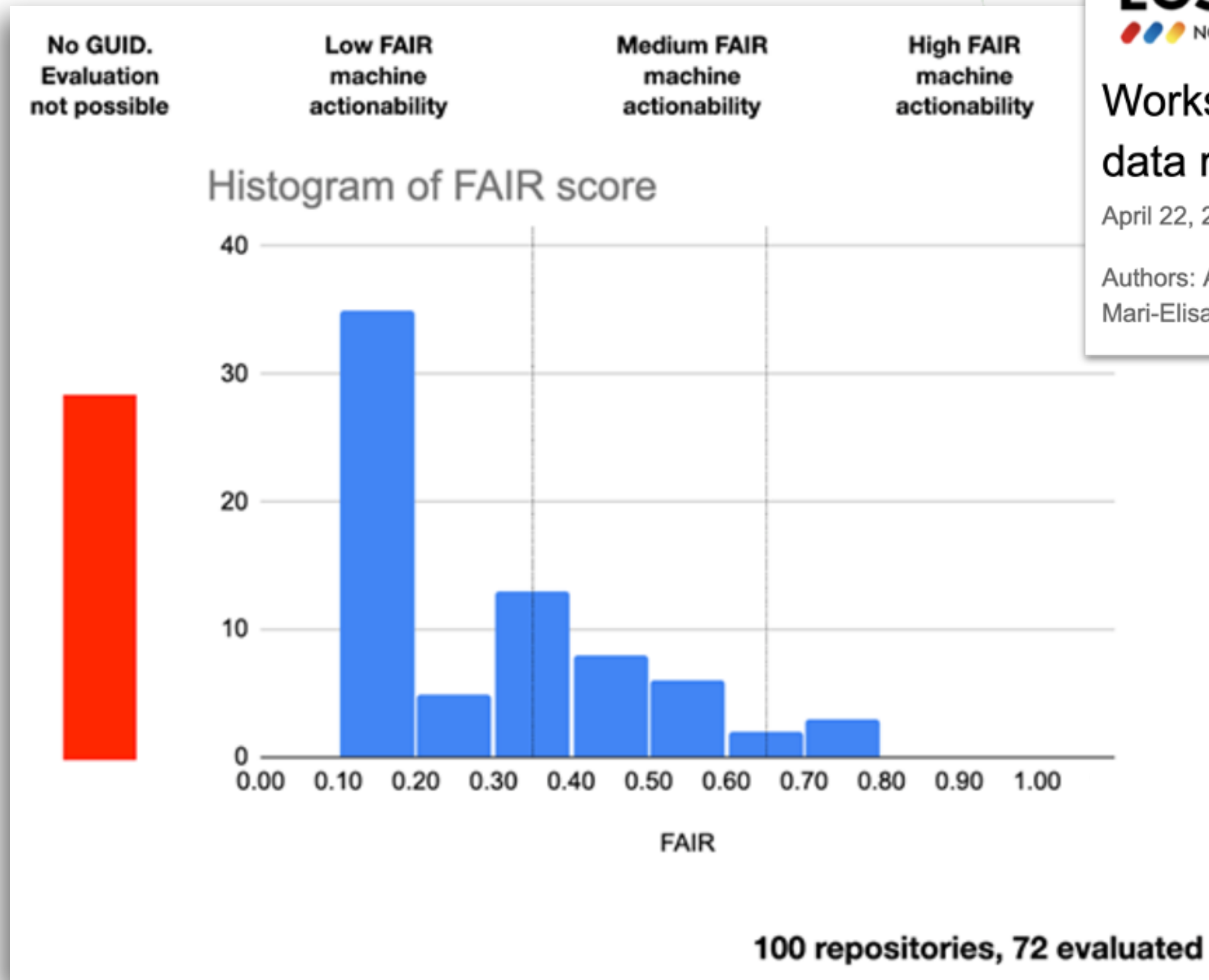
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+ doi ≠ FAIR

What FAIR is not...



<https://www.eosc-nordic.eu/kh-material/fair-uptake/>

Workshop 'FAIRification of Nordic+Baltic data repositories'

April 22, 2020

Authors: Andreas O Jaunsen, Tuomas Altera, Josefine Nordling, Mari-Elisa Kuusniemi, Bert Meerman, Erik Schultes

Follow-up report on FAIR uptake of repositories in the Nordics and Baltics <https://www.eosc-nordic.eu/kh-material/d4-3-report-on-nordic-and-baltic-repositories-and-their-uptake-of-fair/>



Assessing FAIR



FAIR Assessment Tools: Towards an “Apples to Apples” Comparisons

Authorship Community:

Mark D Wilkinson^{1,3*}, Susanna-Assunta Sansone^{2,4*}, Marjan Grootveld^{2,5}, Josefine Nordling^{2,6}, Richard Dennis^{2,7}, David Hecker^{2,8} on behalf of the EOSC FAIR Metrics subgroup

¹ Co-Chair, EOSC Task Force on FAIR Metrics and Data Quality

² Member, EOSC Task Force on FAIR Metrics and Data Quality

³ Departamento de Biotecnología-Biología Vegetal, Escuela Técnica Superior de Ingeniería Agronómica, Alimentaria y de Biosistemas, Centro de Biotecnología y Genómica de Plantas. Universidad Politécnica de Madrid (UPM) - Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria-CSIC (INIA-CSIC). Campus Montegancedo 28223 Pozuelo de Alarcón (Madrid), Spain. 0000-0001-6960-357X

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⁷ Novo Nordisk Foundation Center for Stem Cell Medicine - reNEW, University of Copenhagen, Denmark, 0000-0002-4472-7194

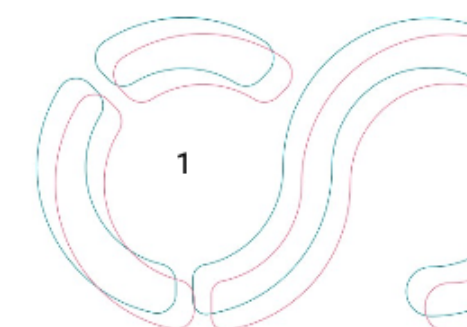
⁸ German Aerospace Center, Research Data Management, Germany, 0000-0003-3836-2800

* Corresponding authors: mark.wilkinson@upm.es, susanna-assunta.sansone@oerc.ox.ac.uk

** All TF members have had the opportunity to review and edit this document; invitations to be on the authorship list were open to all

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Reg. number: 0755 723 931 | VAT number: BE0755 723 931



ITINERIS FAIR Awareness training:
FAIR Assessment tools
December 11, 2024



2018

***FAIR
Principles***



***FAIR
Implementations***



2018

***FAIR
Principles***



We need a precise and explicit interpretation of the FAIR Principles

***FAIR
Implementations***

Interpreting the FAIR Principles:

F & A

13:30-14:30

(Erik & Andrea)

Interpreting the FAIR Principles

Volume 2, Issue 1-2
Winter-Spring 2020



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- 3. INTERPRETATIONS AND IMPLEMENTATION CONSIDERATIONS PER FAIR GUIDING PRINCIPLE
- 4. DISCUSSION
- ACKNOWLEDGEMENTS
- Notes
- REFERENCES

January 01 2020

FAIR Principles: Interpretations and Implementation Considerations

Annika Jacobsen, Ricardo de Miranda Azevedo, Nick Juty, Dominique Batista, Simon Coles, Ronald Cornet, Mélanie Courtot, Mercè Crosas, Michel Dumontier, Chris T. Evelo, Carole Goble, Giancarlo Guizzardi, Karsten Kryger Hansen, Ali Hasnain, Kristina Hettne, Jaap Heringa, Rob W.W. Hooft, Melanie Imming, Keith G. Jeffery, Rajaram Kaliyaperumal, Martijn G. Kersloot, Christine R. Kirkpatrick, Tobias Kuhn, Ignasi Labastida, Barbara Magagna, Peter McQuilton, Natalie Meyers, Annalisa Montesanti, Mirjam van Reisen, Philippe Rocca-Serra, Robert Pergl, Susanna-Assunta Sansone, Luiz Olavo Bonino da Silva Santos, Juliane Schneider, George Strawn, Mark Thompson, Andra Waagmeester, Tobias Weigel, Mark D. Wilkinson, Egon L. Willighagen, Peter Wittenburg, Marco Roos, Barend Mons  , Erik Schultes



> Author and Article Information

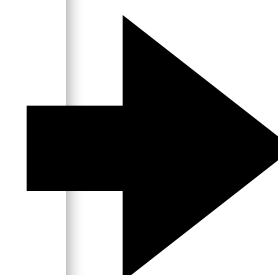
Data Intelligence (2020) 2 (1-2): 10–29.

https://doi.org/10.1162/dint_r_00024

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Abstract

The FAIR principles have been widely cited, endorsed and adopted by a broad range of stakeholders since their publication in 2016. By intention, the 15 FAIR guiding principles do not dictate specific technological implementations, but provide *guidance* for improving Findability, Accessibility, Interoperability and Reusability of digital resources. This has likely contributed to the broad adoption of the FAIR principles, because individual stakeholder communities can implement their own FAIR solutions. However, it has also resulted in inconsistent interpretations that carry the risk of leading to incompatible implementations. Thus, while the FAIR principles are formulated on a high level and may be interpreted and implemented in different ways, for true interoperability we need to support convergence in implementation choices that are widely accessible and (re)-usable. We introduce the concept of *FAIR implementation considerations* to assist accelerated global participation and convergence towards accessible, robust, widespread and consistent FAIR implementations. Any self-identified stakeholder community may either *choose* to reuse solutions from existing implementations, or when they spot a gap, accept the *challenge* to create the needed solution, which, ideally, can be used again by other communities in the future. Here, we provide interpretations and implementation considerations (choices and challenges) for each FAIR principle.



3.1.4 Principle F4: (meta)data are registered or indexed in a searchable resource

1) Interpretation

Principle F4 states that digital resources must be registered or indexed in a searchable resource. The searchable resource provides the infrastructure by which a metadata record (F1) can be discovered, using either the attributes in that metadata (F2) or the identifier of the data object itself (F3) [21].

2) Implementation considerations

Current *challenges* are numerous, significantly limiting, and largely outside of the control of the average data provider. First, there is no single-source for search that currently indexes all possible metadata fields in all domains. Second, there is no uniform way to execute a search, and thus every search tool must be accessed with tool-specific software. Finally, many search engines forbid automated searches, precluding their use by FAIR-enabled software. Various initiatives are emerging that attempt to address this, at least in part, by providing a well-defined, machine-accessible search interface over indexed metadata. Nevertheless, to our knowledge, none of these currently index all possible metadata properties, nor do they span all possible domains/communities; rather, they focus on specific metadata schemas such as schema.org, at the expense of other well-established metadata formats such as DCAT, and/or are limited to specific communities such as biotechnology, astronomy, law, or government/administration. Current *choices* are for each community to choose, and publicly declare, what search engine to use for their own purposes, general or field-specific, and should at a minimum provide metadata following the standard that is indexed by the search engine of choice. They should also provide a machine-readable interface definition that would allow an automated search without human intervention.

https://doi.org/doi:10.1162/dint_r_00024



Interpreting the FAIR Principles

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January 01 2020

FAIR Principles: Interpretations and Implementation Considerations

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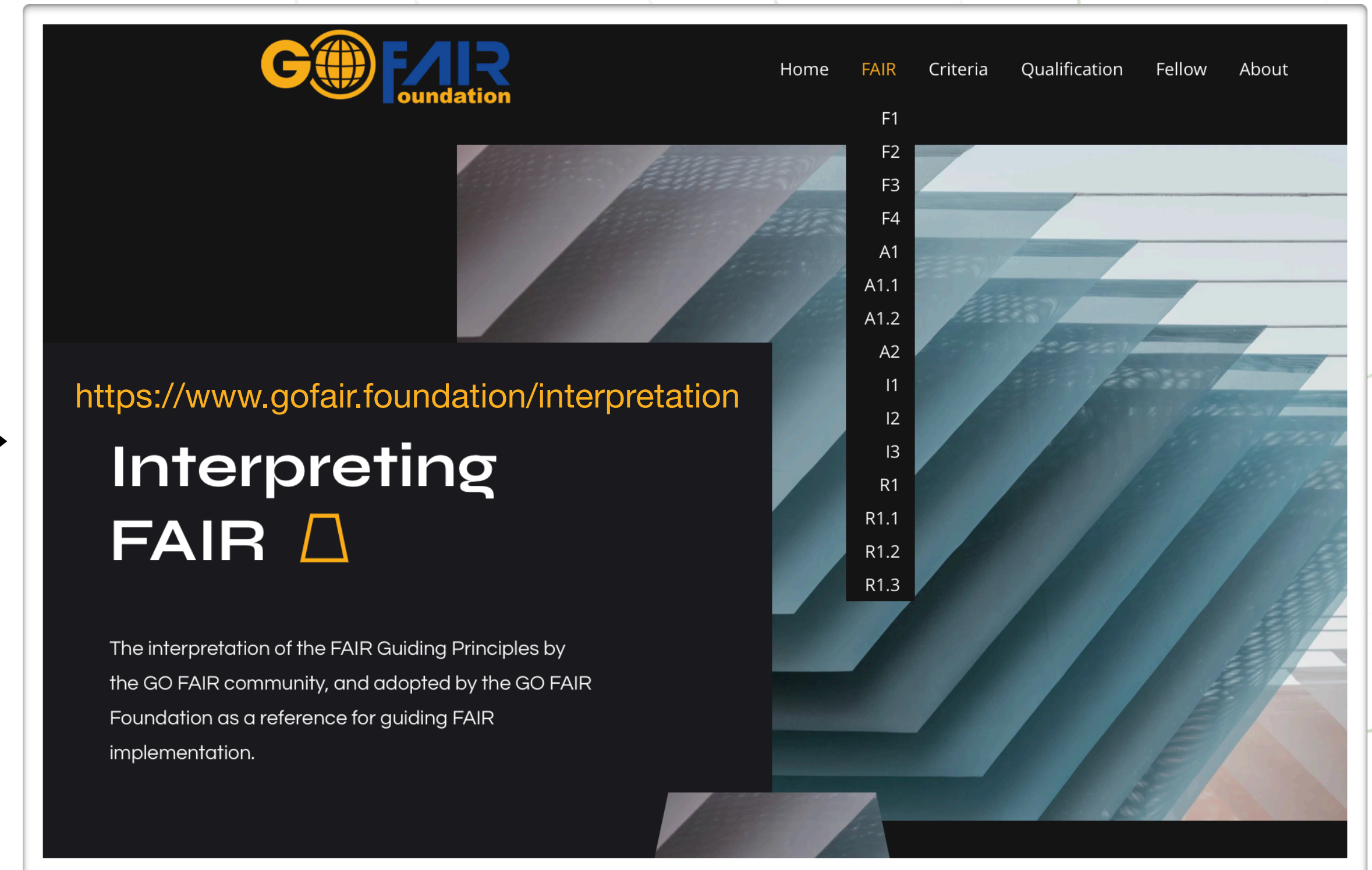
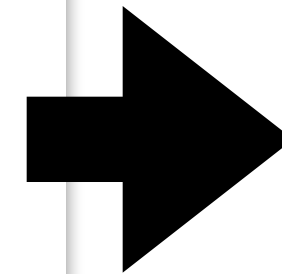
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Interpreting the FAIR Principles



FAIR Data Maturity Model Specification and Guidelines 2020



Proposed RDA Recommendation
Produced by: **FAIR Data Maturity Model WG, 2019-2020**
<https://www.rd-alliance.org/groups/fair-data-maturity-model-wg>

Table 1 FAIR data maturity model indicators

FAIR	ID	Indicator	Priority
F1	RDA-F1-01M	Metadata is identified by a persistent identifier	●●● Essential
F1	RDA-F1-01D	Data is identified by a persistent identifier	●●● Essential
F1	RDA-F1-02M	Metadata is identified by a globally unique identifier	●●● Essential
F1	RDA-F1-02D	Data is identified by a globally unique identifier	●●● Essential
F2	RDA-F2-01M	Rich metadata is provided to allow discovery	●●● Essential
F3	RDA-F3-01M	Metadata includes the identifier for the data	●●● Essential
F4	RDA-F4-01M	Metadata is offered in such a way that it can be harvested and indexed	●●● Essential
A1	RDA-A1-01M	Metadata contains information to enable the user to get access to the data	●● Important
A1	RDA-A1-02M	Metadata can be accessed manually (i.e. with human intervention)	●●● Essential
A1	RDA-A1-02D	Data can be accessed manually (i.e. with human intervention)	●●● Essential
A1	RDA-A1-03M	Metadata identifier resolves to a metadata record	●●● Essential
A1	RDA-A1-03D	Data identifier resolves to a digital object	●●● Essential
A1	RDA-A1-04M	Metadata is accessed through standardised protocol	●●● Essential
A1	RDA-A1-04D	Data is accessible through standardised protocol	●●● Essential
A1	RDA-A1-05D	Data can be accessed automatically (i.e. by a computer program)	●● Important
A1.1	RDA-A1.1-01M	Metadata is accessible through a free access protocol	●●● Essential
A1.1	RDA-A1.1-01D	Data is accessible through a free access protocol	●● Important
A1.2	RDA-A1.2-01D	Data is accessible through an access protocol that supports authentication and authorisation	● Useful
A2	RDA-A2-01M	Metadata is guaranteed to remain available after data is no longer available	●●● Essential
I1	RDA-I1-01M	Metadata uses knowledge representation expressed in standardised format	●● Important
I1	RDA-I1-01D	Data uses knowledge representation expressed in standardised format	●● Important
I1	RDA-I1-02M	Metadata uses machine-understandable knowledge representation	●● Important
I1	RDA-I1-02D	Data uses machine-understandable knowledge representation	●● Important
I2	RDA-I2-01M	Metadata uses FAIR-compliant vocabularies	●● Important
I2	RDA-I2-01D	Data uses FAIR-compliant vocabularies	● Useful
I3	RDA-I3-01M	Metadata includes references to other metadata	●● Important
I3	RDA-I3-01D	Data includes references to other data	● Useful
I3	RDA-I3-02M	Metadata includes references to other data	● Useful

<https://zenodo.org/records/3909563#.YGRNnq8za70>



Interpreting the FAIR Principles

FAIR Data Maturity Model Specification and Guidelines 2020

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F1	RDA-F1-01D	Data is identified by a persistent identifier	●●● Essential
F1	RDA-F1-02M	Metadata is identified by a globally unique identifier	●●● Essential
F1	RDA-F1-02D	Data is identified by a globally unique identifier	●●● Essential
F2	RDA-F2-01M	Rich metadata is provided to allow discovery	●●● Essential

●● Important

RDA-I2-01M Metadata uses [FAIR-compliant](#) vocabularies

Principle to which the indicator relates	This indicator is linked to the following principle: <i>I2: (Meta)data use vocabularies that follow the FAIR principles.</i>
Description of the indicator RDA-I2-01M	The indicator requires the vocabulary used for the metadata to conform to the FAIR principles, and at least be documented and resolvable using globally unique and persistent identifiers. The documentation needs to be easily findable and accessible.
Assessment details	The indicator can be evaluated by verifying that each of the vocabularies used in the metadata is documented and resolvable using globally unique and persistent identifiers, with the documentation being easily findable and accessible. Typically, the reference to the specification of the vocabularies used will be included in the documentation of the digital object or the repository where it is kept.

I1	RDA-I1-02M	Metadata uses machine-understandable knowledge representation	●● Important
I1	RDA-I1-02D	Data uses machine-understandable knowledge representation	●● Important
I2	RDA-I2-01M	Metadata uses FAIR-compliant vocabularies	●● Important
I2	RDA-I2-01D	Data uses FAIR-compliant vocabularies	● Useful
I3	RDA-I3-01M	Metadata includes references to other metadata	●● Important
I3	RDA-I3-01D	Data includes references to other data	● Useful
I3	RDA-I3-02M	Metadata includes references to other data	● Useful

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F1: (meta)data are assigned a globally unique and persistent identifier

3.1.1 Principle F1: (meta)data are assigned a globally unique and persistent identifier

1) Interpretation

Principle F1 states that digital resources, i.e., data and metadata, must be assigned a globally unique and persistent identifier in order to be found and resolved by computers. This is the **most fundamental** of the FAIR principles, as globally unique and persistent identifiers are essential elements found in all of the other FAIR principles. **Globally unique** means that the identifier is guaranteed to unambiguously refer to exactly one resource in the world (please note that *global* should be interpreted as *universal* as there are digital assets outside the world). Therefore, it is **insufficient** for it to be unique only locally (e.g. unique within a single, local database). **Persistence** refers to the requirement that this globally unique identifier is never reused in another context, and continues to identify the same resource, even if that resource no longer exists, or moves. In practice, this often involves using a third-party to generate an identifier that has guaranteed longevity and is project/organization-independent.

2) Implementation considerations

Current **challenges** relate to ensuring the longevity of identifiers – in particular, that identifiers created by a project/community should **survive the termination of the project or the dissolution of the community**. Obtaining a persistent identifier, therefore, may require reliance on a **third-party organization** that promises longevity, and maintains these identifiers independently of the project/community. Current **choices** are for each community to choose, for all appropriate digital resources (i.e., data and metadata), identifier registration service(s) such as these that ensure global uniqueness and that also comply with the community-defined criteria for identifier persistence and resolvability.

A common example of a useful identifier is the Digital Object Identifier (DOI) which is guaranteed by the DOI specification to be globally unique and persistent. DOIs provide an additional service, under principle A1, of being able to direct calls to the source data to the location of that data, even if the identified data moves. This ensures that identifiers are stable and valid beyond the project that generated them. In some circumstances, again with DOIs being an example, third-party persistent identifiers may also provide support for principle A2 (that metadata exists beyond the lifespan of the data) since these identifiers may still be responsive to Web calls, and be capable of providing metadata, even if the source resource is no longer active. For a discussion on identifiers see [16][17].

F1	RDA-F1-01M	Metadata is identified by a persistent identifier	●●●	Essential
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https://en.wikipedia.org/wiki/Link_rot

three major open access publishers and found a half-life of about 11 years, generally confirming a 2000 study that found that half of the **URLs** cited in *D-Lib Magazine* articles were active 10 years after publication.^[7] Other studies have found higher rates of link rot in academic literature but typically suggest a half-life of four years or greater.^{[8][9]} A 2013 study in *BMC Bioinformatics* analyzed nearly 15,000 links in abstracts from Thomson Reuters's *Web of Science* citation index and found that the median lifespan of web pages was 9.3 years, and just 62% were archived.^[10] A 2021 study of external links in *New York Times* articles published between 1996 and 2019 found a half-life of about 15 years (with significant variance among content topics) but noted that 13% of functional links no longer lead to the original content—a phenomenon called *content drift*.^[11]

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Examples?

F2: data are described with rich metadata

3.1.2 Principle F2: data are described with rich metadata

1) Interpretation

Whereas principle F1 enables unambiguous identification of resources of interest, principle F2 speaks to the ability to discover a resource of interest through, for example, search or filtering. Digital resources must be described with rich metadata – descriptors of the content of the resource referred to by that identifier. It is hard to generally define the minimally required “richness” of this metadata, except that the more generous it is, both for humans and computers, the more specifically findable it becomes in refined searches. While other principles speak to the specific kinds of metadata that should be included, principle F2 simply says that a digital resource that is not well-described cannot be accurately discovered. Thus, this principle encourages data providers to consider the various facets of search that might be employed by a user of their data, and to support those users in their discovery of the resource. To enable both global and local search engines to locate a resource, generic and domain-specific descriptors should be provided.

2) Implementation considerations

It is a *challenge* for each domain-specific community to define their own metadata descriptors necessary for optimizing findability. The minimal “richness” of the metadata should be defined so that it serves its intended purpose and should also be guided by the requirements of the other FAIR principles. This then poses a *challenge* to each community to create machine-actionable templates that facilitate capturing uniform and harmonized metadata about similar data resources among all community stakeholders, and to provide a means to ensure that this metadata is updated and curated [17].

Examples of metadata schemata can be found in FAIRsharing^⑤ [18][19] and include for instance the Data Documentation Initiative (DDI)^⑥, the HCLS Dataset Descriptors^⑦, and many domain-specific “minimal information” models that have been invented.

F2

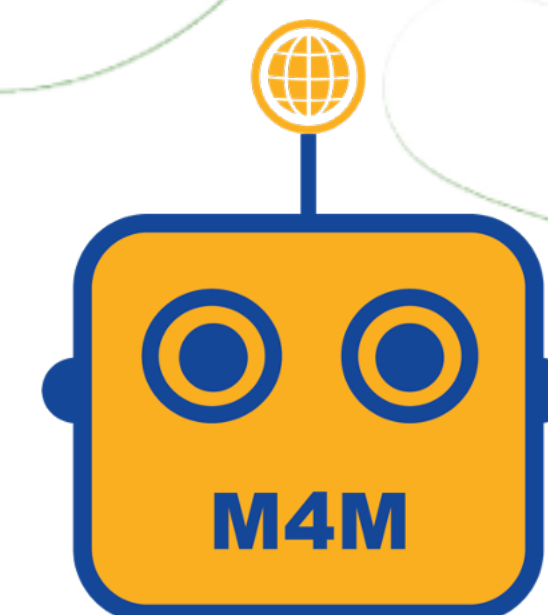
[RDA-F2-01M](#)

Rich metadata is provided to allow discovery



Essential

CEDAR Workbench
<https://metadatacenter.org>



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F2

[RDA-F2-01M](#)

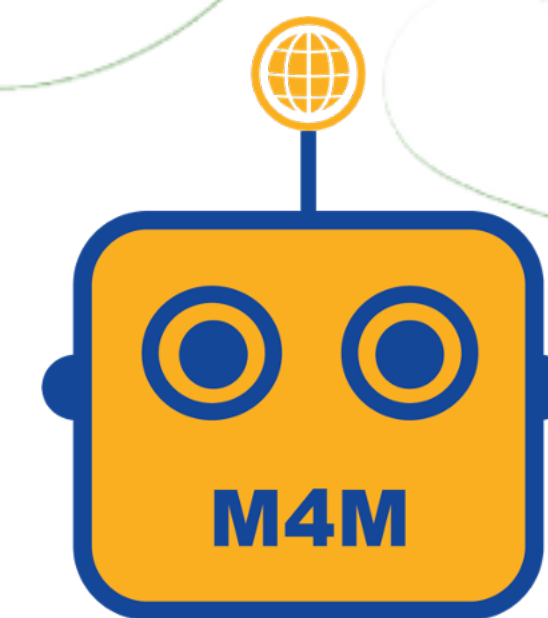
Rich metadata is provided to allow discovery



Essential

Examples?

CEDAR Workbench
<https://metadatacenter.org>



F3: metadata clearly and explicitly include the identifier of the data it describes

3.1.3 Principle F3: metadata clearly and explicitly include the identifier of the data it describes

1) Interpretation

Principle F3 states that any description of a digital resource must contain the identifier of that resource being described. For instance, the description of a computational workflow, should explicitly contain the identifier for that workflow in a manner that is unambiguous.

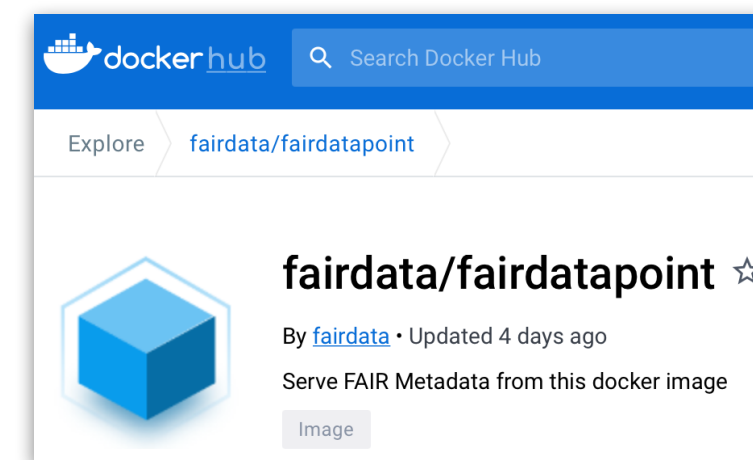
This is especially important where the resource and its metadata are stored independently, but persistently linked, which is generally considered good practice in FAIR. The purpose of this principle is twofold. First, it is perhaps trivial to say that a descriptor should explicitly say what object it is describing; however, there is a second, less-obvious reason for this principle. Many digital objects (such as workflows, as mentioned above) have well-defined structures that may disallow the addition of new fields, including fields that could point to the metadata about that digital object. Therefore, if you have one of these digital objects in-hand, the only way to discover its metadata is through a search using the identifier of that digital object. Thus, by requiring that a metadata descriptor contains the identifier of the thing being described, that identifier may then successfully be used as the search term to discover its metadata record.

2) Implementation considerations

It is a *challenge* to each community to choose a machine-actionable metadata model that explicitly links a resource and its metadata.

An example of a technology that provides this link is FAIR Data Point [20], which is based on the Data Catalogue model (DCAT) [®] that provides not only unique identifiers for potentially multiple layers of metadata, but also provides a single, predictable, and searchable path through these layers of descriptors, down to the data object itself.

F3 [RDA-F3-01M](#) Metadata includes the identifier for the data Essential



Ousamma Mohammed Benhamed, Kees Burger, Rajaram Kaliyaperumal, Luiz Olavo Bonino da Silva Santos, Marek Suchánek, Jan Slifka, Mark D Wilkinson; The FAIR Data Point: Interfaces and Tooling. Data Intelligence 2022; doi: https://doi.org/10.1162/dint_a_00161

FAIR DIGITAL OBJECTS  FORUM

<https://fairdo.org>



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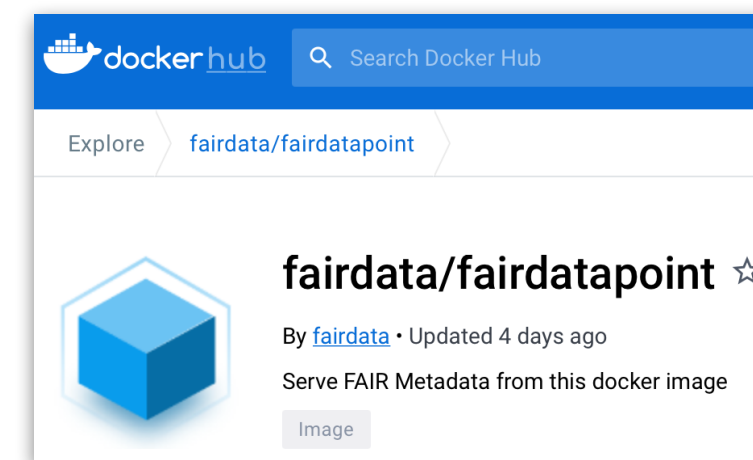
F3

[RDA-F3-01M](#)

Metadata includes the identifier for the data

●●● Essential

What about most data repositories?



Ousamma Mohammed Benhamed, Kees Burger, Rajaram Kaliyaperumal, Luiz Olavo Bonino da Silva Santos, Marek Suchánek, Jan Slifka, Mark D Wilkinson; The FAIR Data Point: Interfaces and Tooling. Data Intelligence 2022; doi: https://doi.org/10.1162/dint_a_00161

FAIR DIGITAL OBJECTS  FORUM

<https://fairdo.org>



F4: (meta)data are registered or indexed in a searchable resource

3.1.4 Principle F4: (meta)data are registered or indexed in a searchable resource

1) Interpretation

Principle F4 states that digital resources must be registered or indexed in a searchable resource. The searchable resource provides the **infrastructure** by which a metadata record (F1) can be discovered, using either the attributes in that metadata (F2) or the identifier of the data object itself (F3) [21].

2) Implementation considerations

Current *challenges* are numerous, significantly limiting, and largely outside of the control of the average data provider. First, there is **no single-source for search that currently indexes all possible metadata fields in all domains**. Second, there is no uniform way to execute a search, and thus every search tool must be accessed with tool-specific software. Finally, many search engines forbid automated searches, precluding their use by FAIR-enabled software. Various initiatives are emerging that attempt to address this, at least in part, by providing a well-defined, machine-accessible search interface over indexed metadata. Nevertheless, to our knowledge, none of these currently index all possible metadata properties, nor do they span all possible domains/communities; rather, they focus on specific metadata schemas such as schema.org, at the expense of other well-established metadata formats such as DCAT, and/or are limited to specific communities such as biotechnology, astronomy, law, or government/administration. Current *choices* are for each community to choose, and publicly declare, what search engine to **use for their own purposes, general or field-specific, and should at a minimum provide metadata following the standard that is indexed by the search engine of choice**. They should also provide a machine-readable interface definition that would allow an automated search without human intervention.

An example of a generic searchable resource that supports manual exploration is Google Dataset Search⁹; however, this suffers from several of the problems mentioned above, in particular, that it indexes only certain types of metadata (schema.org) and the search cannot be automated under the Google Terms of Service, and therefore cannot be implemented within FAIR software.

F4

[RDA-F4-01M](#)

Metadata is offered in such a way that it can be harvested and indexed



Essential

https://www.doi.org/resources/2006_05_02_Kahn_Framework.pdf

A Framework for Distributed Digital Object Services

Robert Kahn
Corporation for National Research Initiatives

Robert Wilensky
University of California at Berkeley

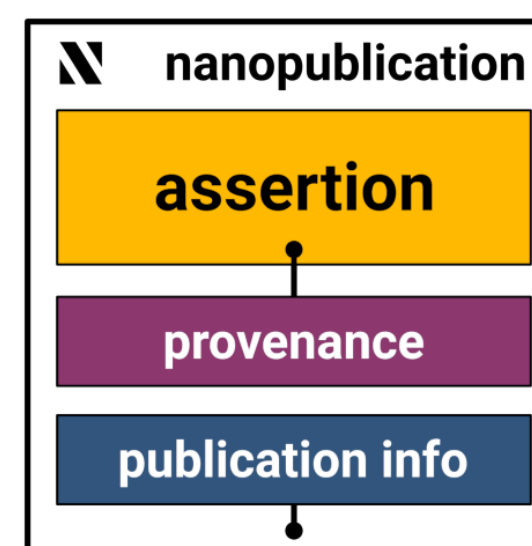
May 13, 1995
cnri.dlib/tn95-01

1. Introduction

This document describes fundamental aspects of an **infrastructure** that is open in its architecture and which supports a large and extensible class of **distributed digital information services**. Digital libraries are one example of such services; numerous other examples of such services may be found in emerging electronic commerce applications. Here we define basic entities to be found in such a system, in which information in the form of **digital objects** is stored, accessed, disseminated and managed. We provide naming conventions for identifying and locating digital objects, describe a service for using object names to locate and disseminate objects, and provide elements of an access protocol.

Note: these are not registries

FAIR DIGITAL OBJECTS FORUM



F4: (meta)data are registered or indexed in a searchable resource

3.1.4 Principle F4: (meta)data are registered or indexed in a searchable resource

1) Interpretation

Principle F4 states that digital resources must be registered or indexed in a searchable resource. The searchable resource provides the **infrastructure** by which a metadata record (F1) can be discovered, using either the attributes in that metadata (F2) or the identifier of the data object itself (F3) [21].

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https://www.doi.org/resources/2006_05_02_Kahn_Framework.pdf

A Framework for Distributed Digital Object Services

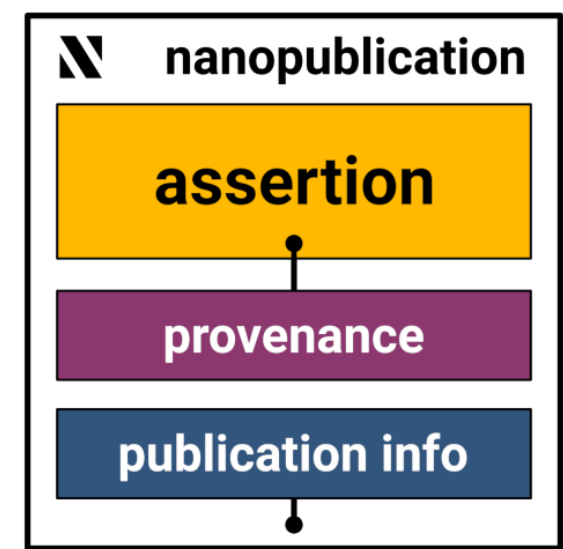
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Examples of search engines?



A1.1: the protocol is open, free, and universally implementable

3.2.2 Sub-Principle A1.1: the protocol is open, free and universally implementable

1). Interpretation

The protocol (mechanism) by which a digital resource is accessed (e.g. queried) should not pose any bottleneck. It describes an access process, hence does not directly pertain to restrictions that apply to using the resource. The protocols underlying the World-Wide Web, such as HTTP, are an archetype for an open, free, and universally implementable protocol. Such protocols reduce the cost of gaining access to digital resources, because they are well defined and open and allow any individual to create their own standards-compliant implementation. That the use of the protocols is free ensures that those lacking monetary means can equitably access the resource. That it is universally implementable ensures that the technology is available to all (and not restricted, for instance, by country or a sub-community), thus encompassing both the “gratis” and “libre” meaning of “free”¹¹.

2) Implementation considerations

Current *challenges* are to explicitly and fully document access protocols that are not open/free (for example, access only after personal contact) and make those protocols available as a clearly identified facet of the machine-readable metadata. Current *choices* are for communities to choose standardized communication protocols that are open, free and universally implementable.

The most common example of a compliant protocol is the HTTP protocol that underlies the majority of Web traffic. It has additional useful features, including the ability to request metadata in a preferred format, and/or to inquire as to the formats that are available. It is also widely supported by software and common programming languages.

A1	RDA-A1-01M	Metadata contains information to enable the user to get access to the data	●●	Important
A1	RDA-A1-02M	Metadata can be accessed manually (i.e. with human intervention)	●●●	Essential
A1	RDA-A1-02D	Data can be accessed manually (i.e. with human intervention)	●●●	Essential
A1	RDA-A1-03M	Metadata identifier resolves to a metadata record	●●●	Essential
A1	RDA-A1-03D	Data identifier resolves to a digital object	●●●	Essential
A1	RDA-A1-04M	Metadata is accessed through standardised protocol	●●●	Essential
A1	RDA-A1-04D	Data is accessible through standardised protocol	●●●	Essential
A1	RDA-A1-05D	Data can be accessed automatically (i.e. by a computer program)	●●	Important
A1.1	RDA-A1.1-01M	Metadata is accessible through a free access protocol	●●●	Essential
A1.1	RDA-A1.1-01D	Data is accessible through a free access protocol	●●	Important

https://en.wikipedia.org/wiki/World_Wide_Web



This [NeXT Computer](#) was used by [Sir Tim Berners-Lee](#) at [CERN](#) and became the world's first [Web server](#). [CC BY-SA 3.0](#)

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A1	RDA-A1-04D	Data is accessible through standardised protocol	●●●	Essential
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This [NeXT Computer](#) was used by [Sir Tim Berners-Lee](#) at [CERN](#) and became the world's first [Web server](#). [CC BY-SA 3.0](#)

Other protocols?

A1.2: the protocol allows for authentication & authorization procedure where necessary

3.2.3 Sub-Principle A1.2: the protocol allows for an authentication and authorization procedure, where necessary

1) Interpretation

This principle clearly demonstrates that FAIR is not equal to “open”. Some digital resources, such as data that have access restrictions based on ethical, legal or contractual constraints, require additional measures to be accessed. This often pertains to assuring that the access requester is indeed that requester (authentication), that the requester's profile and credentials match the access conditions of the resource (authorization), and that the intended use matches permitted use cases (e.g. non-commercial purposes only) (see also R1.1, where there are requirements to provide explicit documentation about who may use the data, and for what purposes). At the level of technical implementation, an additional authentication and authorization procedure must be specified, if it is not already defined by the protocol (see A1.1). A requester can be a human or a machine agent. In the latter case it is probably a proxy for a human or an organization to which the authentication and authorization protocol should be applied, in which case, the machine should be expected to present the appropriate credentials. The principle requires that a FAIR resource must provide such a protocol, but the protocol itself is not further specified. In practice, an Internet of FAIR Data and Services cannot function without implementing Authentication and Authorization Infrastructure (AAI, see also [22]).

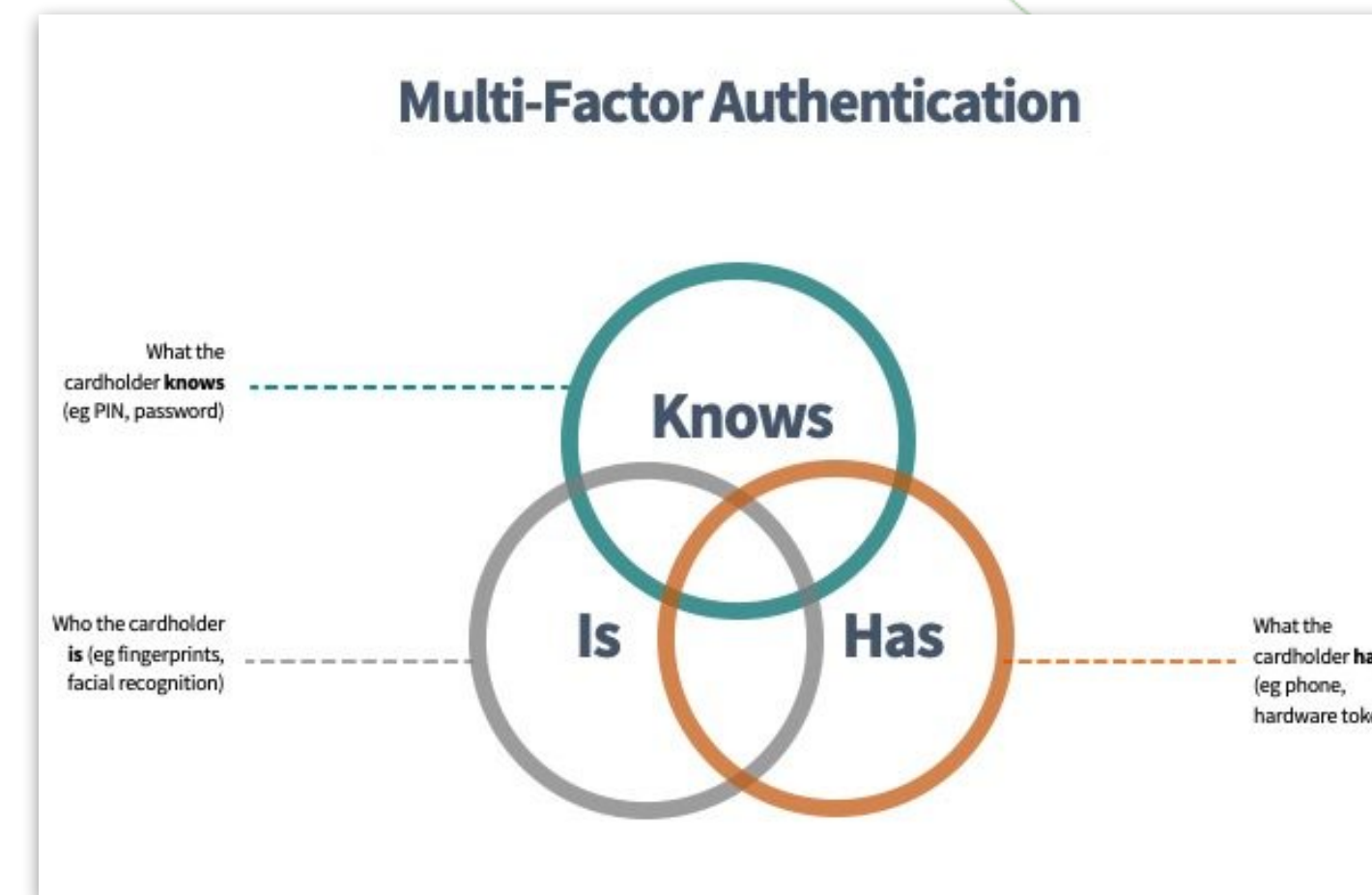
2) Implementation considerations

Current choices are for communities to choose protocols to use when controlling access of agents to meta(data). Preferably these should be as generic as possible and as domain specific as necessary. Attempts to harmonize AAI approaches are numerous, but not covered in this article.

Again, the most common example of a compliant protocol is the HTTP protocol. Another example is the life science AAI protocol. Brewster *et al.* [22] describe an early implementation of an ontology-based approach to this challenge.

A1	RDA-A1-01M	Metadata contains information to enable the user to get access to the data	●●	Important
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A1	RDA-A1-04D	Data is accessible through standardised protocol	●●●	Essential
A1	RDA-A1-05D	Data can be accessed automatically (i.e. by a computer program)	●●	Important

A1.2	RDA-A1.2-01D	Data is accessible through an access protocol that supports authentication and authorisation	●	Useful
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3.2.3 Sub-Principle A1.2: the protocol allows for an authentication and authorization procedure, where necessary

1) Interpretation

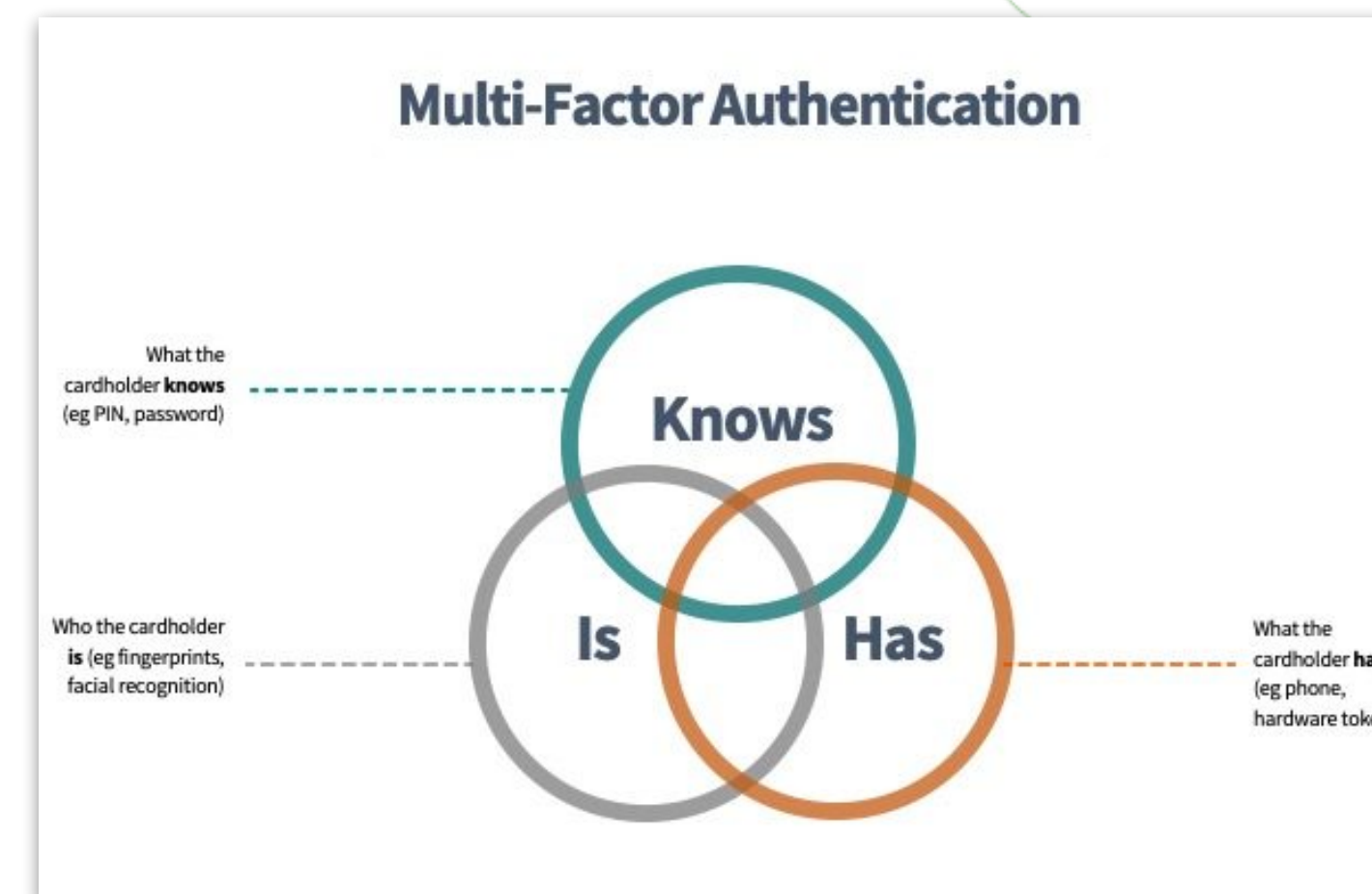
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A1.2	RDA-A1.2-01D	Data is accessible through an access protocol that supports authentication and authorisation	●	Useful



Consider the ITINERIS Platform?

A2: metadata are accessible, even when the data are no longer available



3.2.4 Principle A2: metadata are accessible, even when the data are no longer available

1) Interpretation

There is a continued focus on keeping relevant digital resources available in the future. Data may no longer be accessible either by design (e.g. a defined lifespan within limited financial resources or legal requirements to destroy sensitive data) or by accident. However, given that those data may have been used and are referenced by others, it is important that consumers have, at the very least, access to high quality metadata that describes those resources sufficiently to minimally understand their nature and their provenance, even when the relevant data are not available anymore. This principle relies heavily on the “second purpose” of principle F3 (the metadata record contains the identifier of the data), because in the case where the data record is no longer available, there must be a clear and precise way of discovering its historical metadata record. This aspect of accessibility is further elaborated in the Joint Declaration of Data Citation Principles [23].

2) Implementation considerations

Current choices/challenges are for communities to choose/define a persistence policy for metadata that describes data that may not always be available, choose/define machine-actionable templates for a persistence policy document for metadata, and in addition choose/define a machine-actionable scheme to reference the metadata persistence policy.

Examples of early attempts to address this critical principle relates closely to the principles of digital curation¹² including the concept of a FAIR compliant DMP (Data Management Plan)¹³ [24]. Many other efforts are underway to improve the long-term stewardship of reusable digital resources.

A2 RDA-A2-01M Metadata is guaranteed to remain available after data is no longer available ●●● Essential



nanobench | my channel | users | search | publish | Erik Schultes (0000-0001-8888-635X)

Publish a new Nanopublication

Assertion: Defining a metadata preservation policy ^

short name, used as URI is a Metadata preservation policy .

short name, used as URI is called "the name of the metadata preservation policy" .

short name, used as URI has the description "description of the metadata preservation policy" .

short name, used as URI is a FAIR Enabling Resource that is available on .

short name, used as URI declares minimum metadata preservation in years as number of years .

short name, used as URI has data policy document at link to data policy document (optional)

Provenance: [Attributed to myself] ^

The assertion above is attributed to me .

Publication info [add element...] ^

Creator: ^

This nanopublication is created by me .

With license: ^

This nanopublication is published under the license select the license here .

I understand that publishing cannot be fully undone and that the provided information will be publicly visible and openly connected to my ORCID Identifier (but nanopublications can be retracted, which makes them invisible in most situations).



A2: metadata are accessible, even when the data are no longer available

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A2 [RDA-A2-01M](#) Metadata is guaranteed to remain available after data is no longer available ●●● Essential



Consider the DiSSCo Metadata Preservation Policy

[nanobench](#) | [my channel](#) | [users](#) | [search](#) | [publish](#) | Erik Schultes (0000-0001-8888-635X)

Publish a new Nanopublication

Assertion: Defining a metadata preservation policy ^

short name, used as URI	is a	Metadata preservation policy
short name, used as URI	is called	"the name of the metadata preservation policy"
short name, used as URI	has the description	"description of the metadata preservation policy"
short name, used as URI	is a	FAIR Enabling Resource that is available o...
short name, used as URI	declares minimum metadata preservation in years as	"number of years"
short name, used as URI	has data policy document at	link to data policy document (optional)

Provenance: Attributed to myself ^

The assertion above is attributed to me



Resume 15:00 CET

Interpreting the FAIR Principles:

I & R

14:45-15:45

(Erik & Andrea)

I1: (meta)data use a formal... language for knowledge representation

3.3.1 Principle I1: (meta)data use a formal, accessible, shared, and broadly applicable language for knowledge representation

1) Interpretation

Consumers spend a disproportionate amount of time trying to make sense of the digital resources they need and designing accurate ways to combine them. This is most often due to a **lack of suitably unambiguous content descriptors**, or a lack of such descriptors entirely with respect to non-machine-interpretable data formats such as tables or “generic” XML. Community-defined data exchange formats work reasonably well within their original scope of a few types of data and a relatively homogeneous community, but not well beyond that. This makes interoperation and integration an expensive, often impossible task (even for humans), but also means that machines cannot easily make use of digital resources, which is the primary goal of FAIR. For example, when a machine visits two data files in which a field “temperature” is present, then it will need more contextual descriptions to distinguish between weather data in one file and body temperature measurements in another. **Achieving a “common understanding” of digital resources** through a globally understood “language” for machines is the purpose of principle I1, with an emphasis on “knowledge” and “knowledge representation”. This becomes critical when many differently formatted resources need to be visited or combined across organizations and countries and is especially challenging for interdisciplinary studies or for meta-analyses, where results from independent organizations, pertaining to the same topic, must be combined. In this context, the principle says that producers of digital resources are required to use a language (i.e., a representation of data/knowledge) that has a defined mechanism for mechanized interpretation – a machine-readable “grammar” – where, for example, the difference between an entity, as well as any relevant relationship between entities, is defined in the structure of the language itself. This allows machines to consume the information with at least a basic “understanding” of its content. It is a step towards a common understanding of digital resources by machines, which is a prerequisite for a functional Internet of FAIR Data and Services. Several technologies can be chosen for principle I1.

I1	RDA-I1-01M	Metadata uses knowledge representation expressed in standardised format	●●	Important
I1	RDA-I1-01D	Data uses knowledge representation expressed in standardised format	●●	Important
I1	RDA-I1-02M	Metadata uses machine-understandable knowledge representation	●●	Important
I1	RDA-I1-02D	Data uses machine-understandable knowledge representation	●●	Important

2) Implementation considerations

Communities will have to choose an available technology or decide how they will otherwise deal with multiple representations and languages. In any case, they will have to make sure that each data item that is the same in multiple resources is interpreted in *exactly* the same way by every agent (human and computer), and that how items across resources relate to one another can be unambiguously understood by all agents [25]. The key consideration in this regard is that **FAIR speaks to the ability of data to be reused by a generic agent, rather than a community-specific agent**. This is most easily accomplished by making the knowledge available in the most widely used format(s), even if this means duplication of the information in the community-specific format.

The most widely-accepted choice to adhere to this principle, at the present time, is the **Resource Description Framework (RDF)** which is the W3C's recommendation for how to represent knowledge on the Web in a machine-accessible format⁽¹⁴⁾. Other choices may also be acceptable, for instance when they are already in widespread use within a given community. In that case, it would be helpful for the community to also provide a “translator” between their preferred format, and a more widely used format such as RDF.

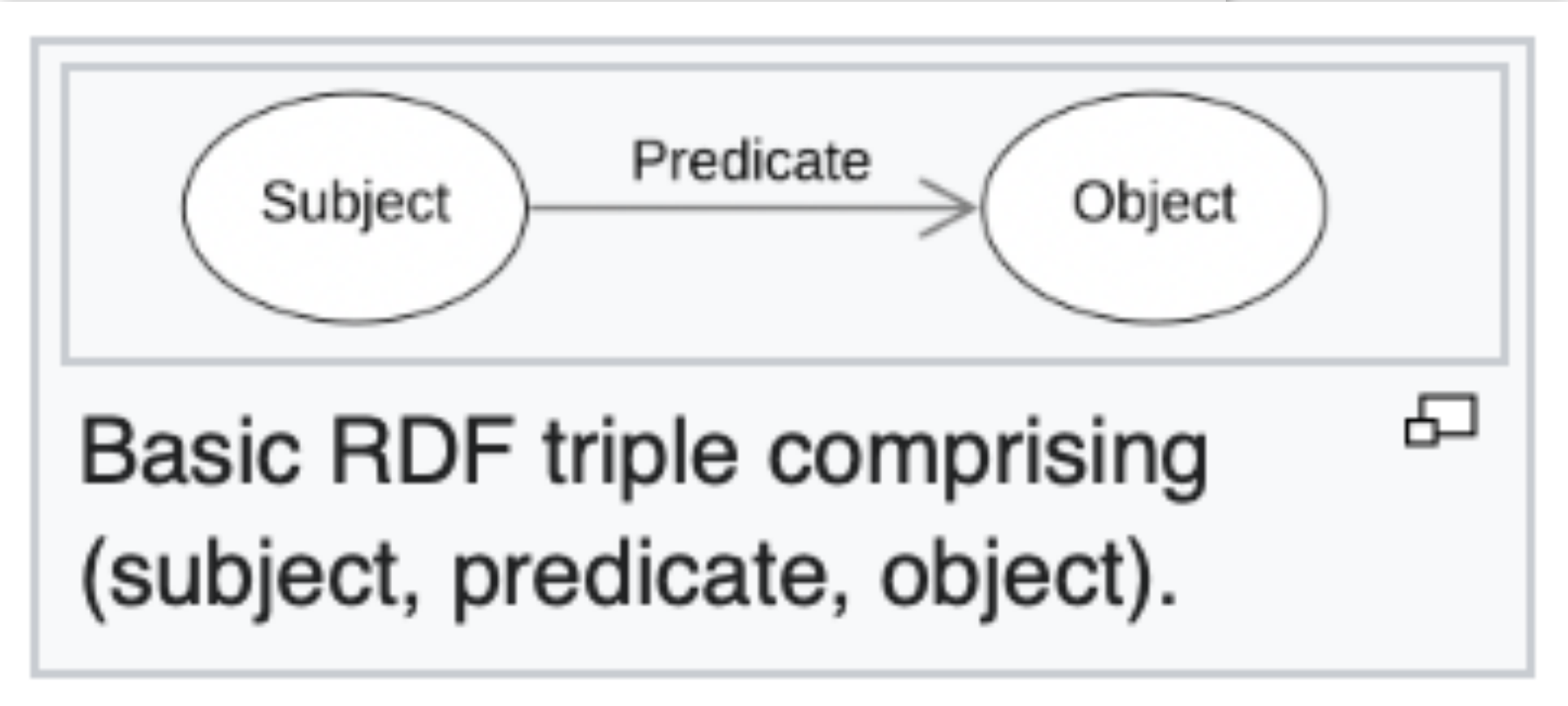
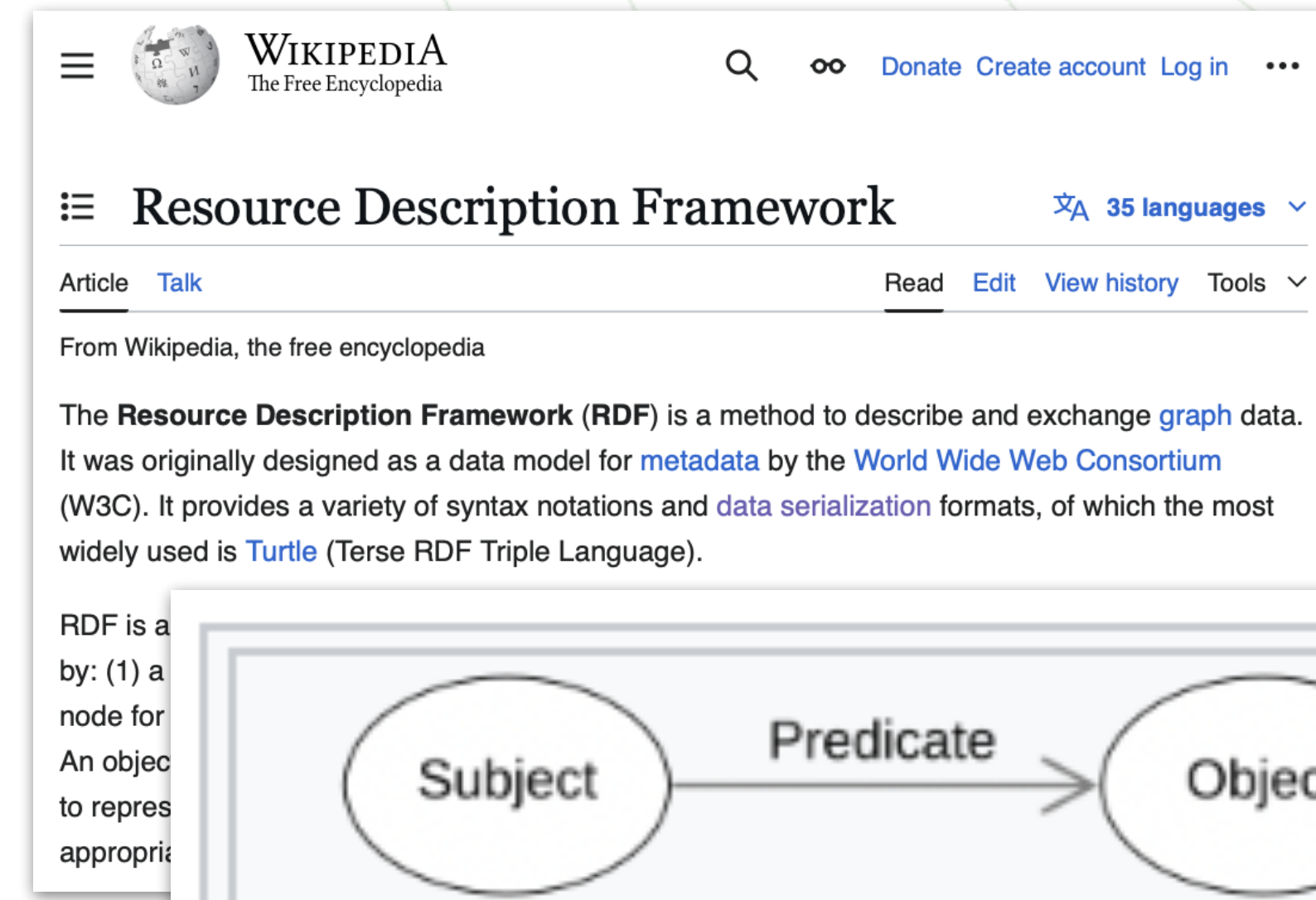
I1: (meta)data use a formal... language for knowledge representation

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I1	RDA-I1-02M	Metadata uses machine-understandable knowledge representation	●●	Important
I1	RDA-I1-02D	Data uses machine-understandable knowledge representation	●●	Important



I2: (meta)data use vocabularies that follow FAIR principles

3.3.2 Principle I2: (meta)data use vocabularies that follow FAIR principles

1) Interpretation

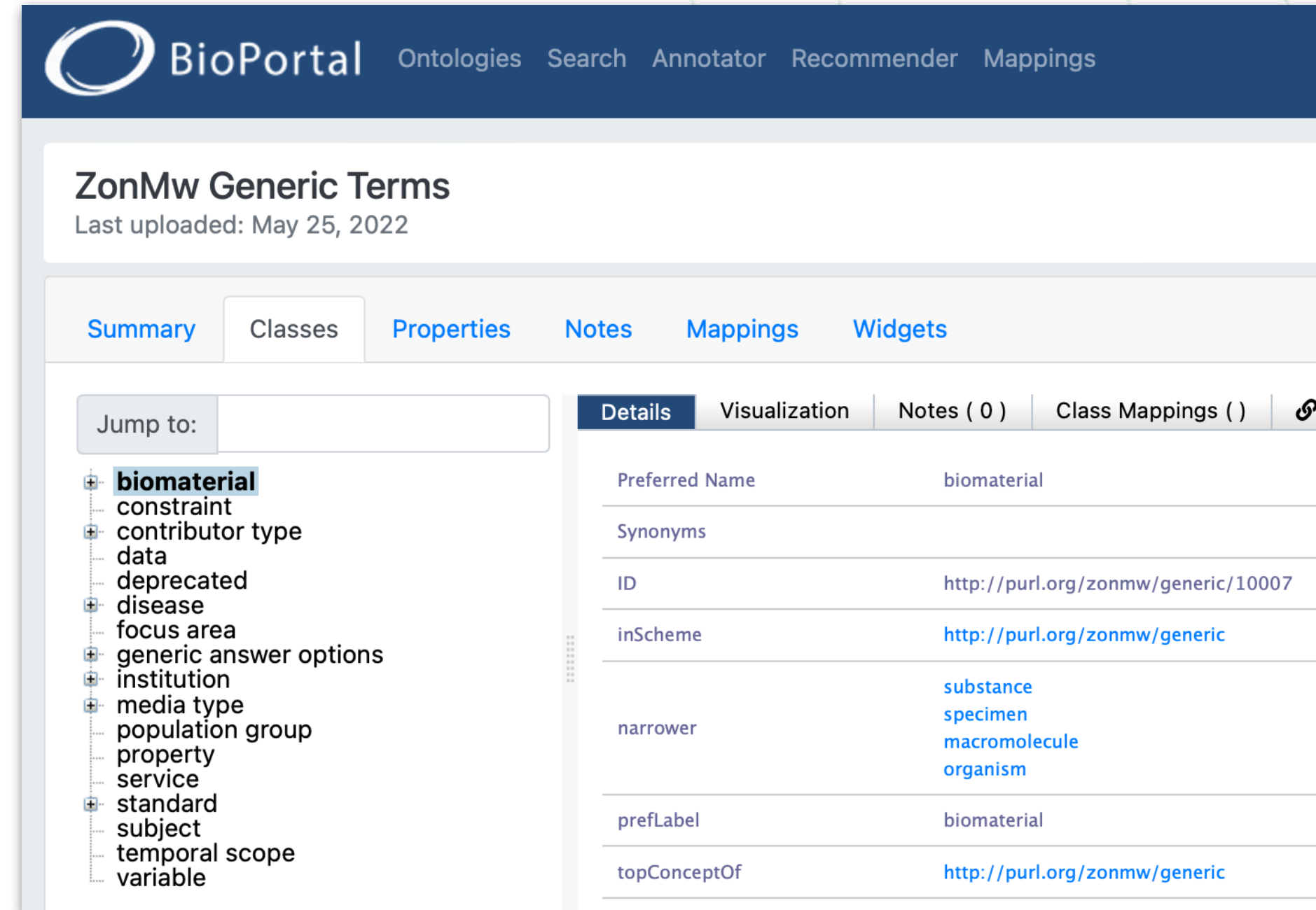
Principle I2 uses “vocabularies” to refer to the methods that unambiguously represent concepts that exist in a given domain. The use of shared, and formally structured (I1), sets of terms is an essential part of FAIR. Terminology systems, including flat “vocabularies”, hierarchical “thesauri” and more granular specifications of knowledge such as data models and ontologies, play an important role in community standards. However, the vocabularies used for metadata or data also need to be findable, accessible, interoperable, and reusable in their own right so that users (including machines) can fully understand the meaning of the terms used in the metadata. This principle has been criticized as “circular” but as has been made clear earlier in this article, the simple use of a “label” (e.g. “temperature”) is insufficient to enable a machine to understand both the intent of that label (Body temperature? Melting temperature?) and the contexts within which it can be properly linked – same-with-same – to other similarly-labelled data. I2, therefore, requires that the vocabulary terms used in the knowledge representation language (principle I1) can be sufficiently distinguished, by a machine, to ensure detection of “false agreements” as well as “false disagreements”.

2) Implementation considerations

Current considerations are for communities to ensure that terminology systems and, for instance, the units of measure, classifications, and relationship definitions are themselves FAIR. Thesauri that are proprietary and not universally accessible should be avoided wherever possible, because machines (and indeed particular countries, regions or communities as a whole) may not have the authority to access their definitions, such that even data that is accessible after authentication via A1.2 may not be useful to an agent that has no authority to access the concept definitions used within that data.

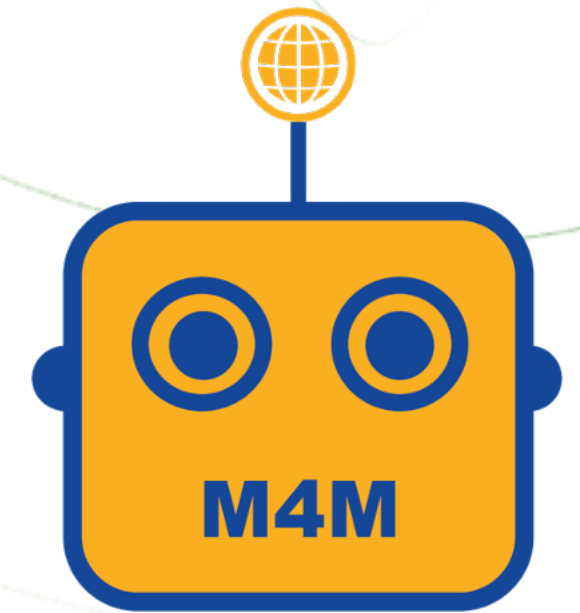
Ontologies defined in the “Web Ontology Language” (OWL) and shared via a publicly accessible registry (e.g. BioPortal for life science ontologies¹⁵) are examples of formally represented, accessible, mapped, and shared knowledge representations in a broadly applicable language for knowledge representation, that are also compliant with the Findability requirements of FAIR, since BioPortal provides a machine-accessible search interface.

I2	RDA-I2-01M	Metadata uses FAIR-compliant vocabularies	●●	Important
I2	RDA-I2-01D	Data uses FAIR-compliant vocabularies	●	Useful



The screenshot shows the BioPortal interface for the ZonMw Generic Terms ontology. The page includes a navigation bar with links for Ontologies, Search, Annotator, Recommender, and Mappings. The main content area is titled "ZonMw Generic Terms" and indicates it was last updated on May 25, 2022. Below the title are tabs for Summary, Classes, Properties, Notes, Mappings, and Widgets. The "Classes" tab is active, showing a list of terms including biomaterial, constraint, contributor type, data, deprecated, disease, focus area, generic answer options, institution, media type, population group, property, service, standard, subject, temporal scope, and variable. A "Jump to:" search box is present. To the right, a "Details" tab is active, displaying a table of properties for the selected term "biomaterial".

Property	Value
Preferred Name	biomaterial
Synonyms	
ID	http://purl.org/zonmw/generic/10007
inScheme	http://purl.org/zonmw/generic
narrower	substance , specimen , macromolecule , organism
prefLabel	biomaterial
topConceptOf	http://purl.org/zonmw/generic



I2: (meta)data use vocabularies that follow FAIR principles

3.3.2 Principle I2: (meta)data use vocabularies that follow FAIR principles

1) Interpretation

Principle I2 uses “vocabularies” to refer to the methods that **unambiguously represent concepts that exist in a given domain**. The use of shared, and formally structured (I1), sets of terms is an essential part of FAIR. Terminology systems, including flat “vocabularies”, hierarchical “thesauri” and more granular specifications of knowledge such as data models and ontologies, play an important role in community standards. However, the vocabularies used for metadata or data also need to be findable, accessible, interoperable, and reusable in their own right so that users (including machines) can fully understand the meaning of the terms used in the metadata. This principle has been criticized as “circular” but as has been made clear earlier in this article, the simple use of a “label” (e.g. “temperature”) is insufficient to enable a machine to understand both the intent of that label (Body temperature? Melting temperature?) and the contexts within which it can be properly linked – same-with-same – to other similarly-labelled data. I2, therefore, requires that the vocabulary terms used in the knowledge representation language (principle I1) can be sufficiently distinguished, by a machine, to ensure detection of “false agreements” as well as “false disagreements”.

2) Implementation considerations

Current considerations are for communities to ensure that terminology systems and, for instance, the units of measure, classifications, and relationship definitions are themselves FAIR. **Thesauri** that are proprietary and not universally accessible should be avoided wherever possible, because machines (and indeed particular countries, regions or communities as a whole) may not have the authority to access their definitions, such that even data that is accessible after authentication via A1.2 may not be useful to an agent that has no authority to access the concept definitions used within that data.

Ontologies defined in the “Web Ontology Language” (OWL) and shared via a publicly accessible registry (e.g. **BioPortal** for life science ontologies¹⁵) are examples of formally represented, accessible, mapped, and shared knowledge representations in a broadly applicable language for knowledge representation, that are also compliant with the Findability requirements of FAIR, since BioPortal provides a machine-accessible search interface.

I2	RDA-I2-01M	Metadata uses FAIR-compliant vocabularies	●●	Important
I2	RDA-I2-01D	Data uses FAIR-compliant vocabularies	●	Useful

RDA-I2-01M Metadata uses [FAIR-compliant](#) vocabularies ●● Important

Principle to which the indicator relates	This indicator is linked to the following principle: <i>I2: (Meta)data use vocabularies that follow the FAIR principles.</i>
Description of the indicator RDA-I2-01M	The indicator requires the vocabulary used for the metadata to conform to the FAIR principles, and at least be documented and resolvable using globally unique and persistent identifiers. The documentation needs to be easily findable and accessible.
Assessment details	The indicator can be evaluated by verifying that each of the vocabularies used in the metadata is documented and resolvable using globally unique and persistent identifiers, with the documentation being easily findable and accessible. Typically, the reference to the specification of the vocabularies used will be included in the documentation of the digital object or the repository where it is kept.



I2: (meta)data use vocabularies that follow FAIR principles

3.3.2 Principle I2: (meta)data use vocabularies that follow FAIR principles

1) Interpretation

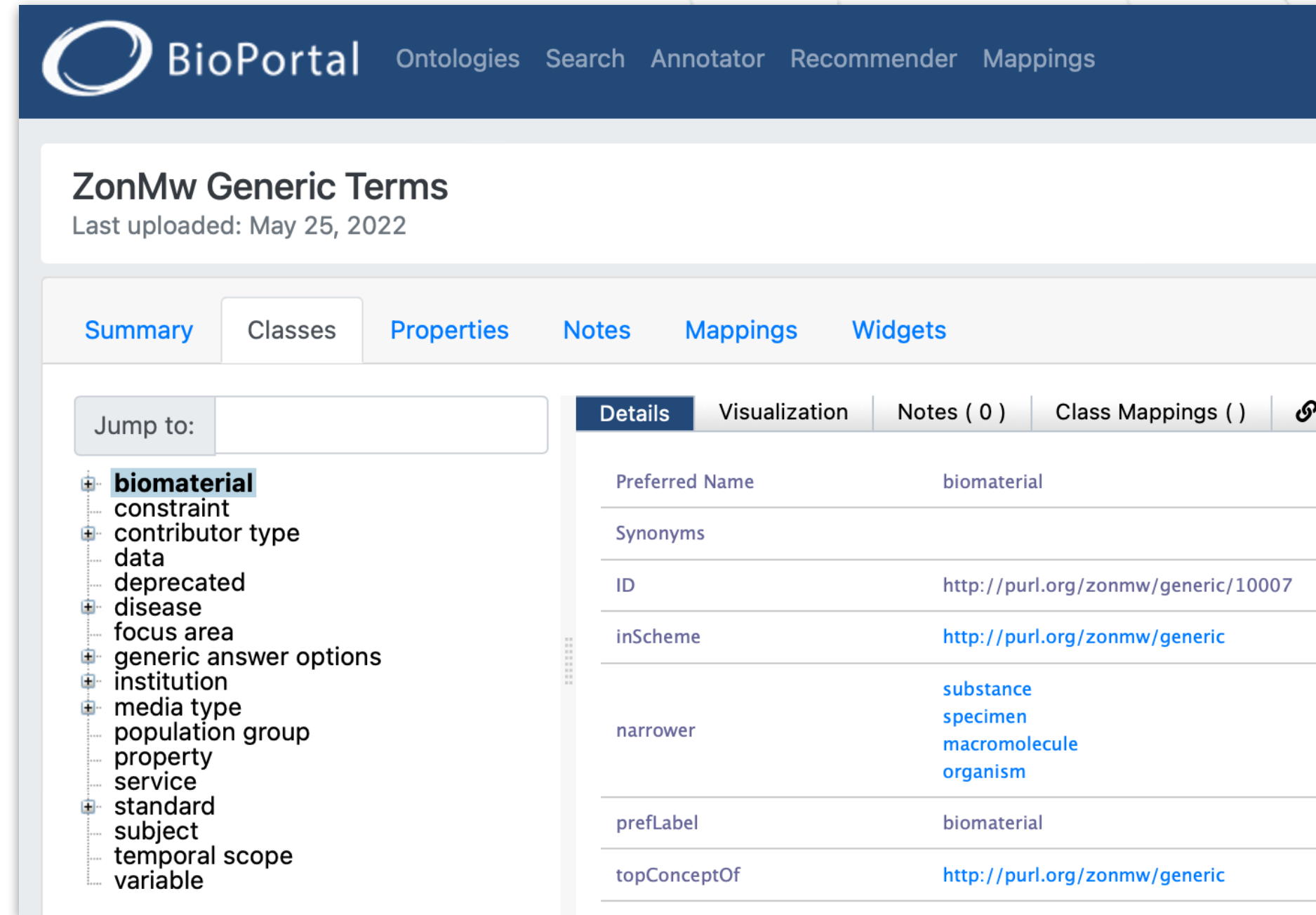
Principle I2 uses “vocabularies” to refer to the methods that unambiguously represent concepts that exist in a given domain. The use of shared, and formally structured (I1), sets of terms is an essential part of FAIR. Terminology systems, including flat “vocabularies”, hierarchical “thesauri” and more granular specifications of knowledge such as data models and ontologies, play an important role in community standards. However, the vocabularies used for metadata or data also need to be findable, accessible, interoperable, and reusable in their own right so that users (including machines) can fully understand the meaning of the terms used in the metadata. This principle has been criticized as “circular” but as has been made clear earlier in this article, the simple use of a “label” (e.g. “temperature”) is insufficient to enable a machine to understand both the intent of that label (Body temperature? Melting temperature?) and the contexts within which it can be properly linked – same-with-same – to other similarly-labelled data. I2, therefore, requires that the vocabulary terms used in the knowledge representation language (principle I1) can be sufficiently distinguished, by a machine, to ensure detection of “false agreements” as well as “false disagreements”.

2) Implementation considerations

Current considerations are for communities to ensure that terminology systems and, for instance, the units of measure, classifications, and relationship definitions are themselves FAIR. Thesauri that are proprietary and not universally accessible should be avoided wherever possible, because machines (and indeed particular countries, regions or communities as a whole) may not have the authority to access their definitions, such that even data that is accessible after authentication via A1.2 may not be useful to an agent that has no authority to access the concept definitions used within that data.

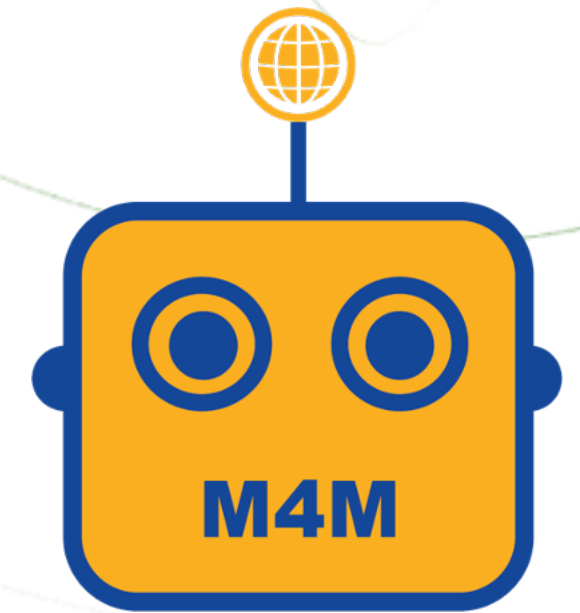
Ontologies defined in the “Web Ontology Language” (OWL) and shared via a publicly accessible registry (e.g. BioPortal for life science ontologies¹⁵) are examples of formally represented, accessible, mapped, and shared knowledge representations in a broadly applicable language for knowledge representation, that are also compliant with the Findability requirements of FAIR, since BioPortal provides a machine-accessible search interface.

I2	RDA-I2-01M	Metadata uses FAIR-compliant vocabularies	●●	Important
I2	RDA-I2-01D	Data uses FAIR-compliant vocabularies	●	Useful



The screenshot shows the BioPortal interface for the ZonMw Generic Terms ontology. The page title is "ZonMw Generic Terms" with a sub-header "Last updated: May 25, 2022". The navigation menu includes Summary, Classes, Properties, Notes, Mappings, and Widgets. The main content area is divided into a left sidebar with a "Jump to:" list and a right main panel. The sidebar list includes: biomaterial, constraint, contributor type, data, deprecated, disease, focus area, generic answer options, institution, media type, population group, property, service, standard, subject, temporal scope, and variable. The main panel shows a table of properties for the selected term:

Property	Value
Preferred Name	biomaterial
Synonyms	
ID	http://purl.org/zonmw/generic/10007
inScheme	http://purl.org/zonmw/generic
narrower	substance , specimen , macromolecule , organism
prefLabel	biomaterial
topConceptOf	http://purl.org/zonmw/generic



Example vocabularies?



I3: (meta)data include qualified references to other (meta)data

3.3.3 Principle I3: (meta)data include qualified references to other (meta)data

1) Interpretation

An important aspect of FAIR is that data or metadata, generally speaking, does not exist in a silo – we must do what is necessary to ensure that the knowledge representing a resource is **connected to that of other resources** to create a meaningfully interlinked network of data and services. A “qualified reference” is a reference to another resource (i.e., referencing that external resource's persistent identifier), in which **the nature of the relationship is also clearly specified**. For instance, when multiple versions of a metadata file are available, it may be useful to provide links to prior or next versions using a named relation such as “prior version” or “next version” (preferably using an appropriate community standard relationship that itself conforms to the FAIR principles). In the case of data, imagine a dataset that specifies the population of cities around the world. To be FAIR with respect to principle I3, the data could contain links to a resource containing city data (e.g., Wikidata ¹⁶ [26]), geographical and geospatial data, or other related domain resources that are generated by that city, so long as they are properly qualified references using meaningful, clearly-interpretable relationships. It is also important to note that many different metadata files (containers) being FAIR digital resources in themselves, can be pointing to the same “target” object (a data set or a workflow for instance). We can for instance have intrinsic metadata (“*what is this*”) and how was it created (provenance type metadata) as well as “secondary” metadata that are for instance created (separately and later in time) by reusers of a particular digital resource. These could all be **metadata containers essentially describing the same digital resource from different perspectives**. This principle therefore also relates to the good practice to clearly distinguish between metadata (files/containers) and the resources they describe.

I3	RDA-I3-01M	Metadata includes references to other metadata	●●	Important
I3	RDA-I3-01D	Data includes references to other data	●	Useful
I3	RDA-I3-02M	Metadata includes references to other data	●	Useful
I3	RDA-I3-02D	Data includes qualified references to other data	●	Useful
I3	RDA-I3-03M	Metadata includes qualified references to other metadata	●●	Important
I3	RDA-I3-04M	Metadata include qualified references to other data	●	Useful

2) Implementation considerations

The considerations and choices made here are based on the same reasoning as the decisions made for principle I2. Vocabularies (often formal ontologies) of both concepts and relationships exist, and an appropriate relationship should either be selected from one of these, or “coined” and properly published following the FAIR Principles.

It is worth noting as an example that several “upper ontologies” such as the SemanticScience Integrated Ontology ¹⁷ have a wide range of precisely-defined relationships that can be used as-is, or as a starting-point for a newly-minted relationship that is more specific than the one provided in the upper-ontology. The benefit of “inheriting” from higher-level relationships is that agents capable of understanding these higher level concepts, can infer at least a basic interpretation of the intent of the new relationship coined within the community, and therefore enhances interoperability.

<Malaria><is associated with><Mosquitoes>

<Malaria><is transmitted by><Mosquitoes>

R1.1: (meta)data are released with a clear and accessible data usage license

3.4.2 Sub-Principle R1.1: (meta)data are released with a clear and accessible data usage license

1) Interpretation

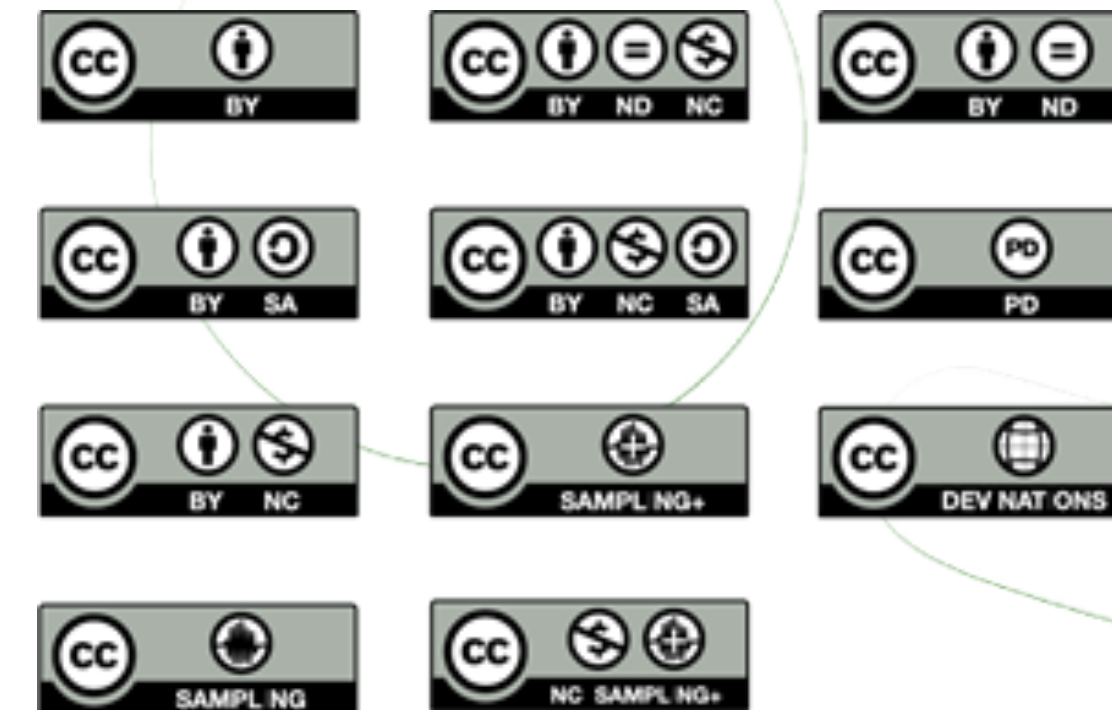
Digital resources and their metadata must always, **without exception**, include a license that describes under which conditions the resource can be used, even if that is **“unconditional”**. **By default, resources cannot be legally used without this clarity**. Note also that a license that **cannot be found by an agent**, is effectively the same as no license at all. Furthermore, the license may be **different for a data resource and the metadata** that describes it, which has implications for the indexing of metadata v.v. findability. This is a clear public domain statement, an equivalent such as terms of use or computer protocol to digitally facilitate an operation (for instance a smart contract). Thus, the absence of a license does not indicate “open”, but rather creates legal uncertainty that will deter (in fact, in many cases legally prevent) reuse. Note also that the combination of resources with restrictive license conditions may lead to adverse effects, and ultimately preclude the use of the combined resources. In order to facilitate reuse, the license chosen should be as open as possible.

2) Implementation considerations

A current **challenge** is that there is currently no well-defined relationship(s) that can be used to distinguish a license that applies to the data being described, versus a license that applies to the metadata record itself, resulting in potential ambiguity in the interpretation of a license referred-to in the metadata record. Current **choices** are for communities to choose which usage license(s) or licensing requirements to reusable digital resources as well as to their metadata for its own purposes, but also consider broader reuse than originally anticipated or intended.

There are good reasons for choosing a CC0 license for data¹⁸ and these considerations should be assessed, alongside all other considerations, when a community decides on the license they wish to apply. It is critical, however, that a license is chosen. The community should then ensure that a qualified link to that license is contained in the metadata record.

R1.1	RDA-R1.1-01M	Metadata includes information about the license under which the data can be reused	●●●	Essential
R1.1	RDA-R1.1-02M	Metadata refers to a standard reuse licence	●●	Important
R1.1	RDA-R1.1-03M	Metadata refers to a machine-understandable reuse licence	●●	Important



R1.1: (meta)data are released with a clear and accessible data usage license

3.4.2 Sub-Principle R11: (meta)data are released with a clear and accessible data usage license

1) Interpretation

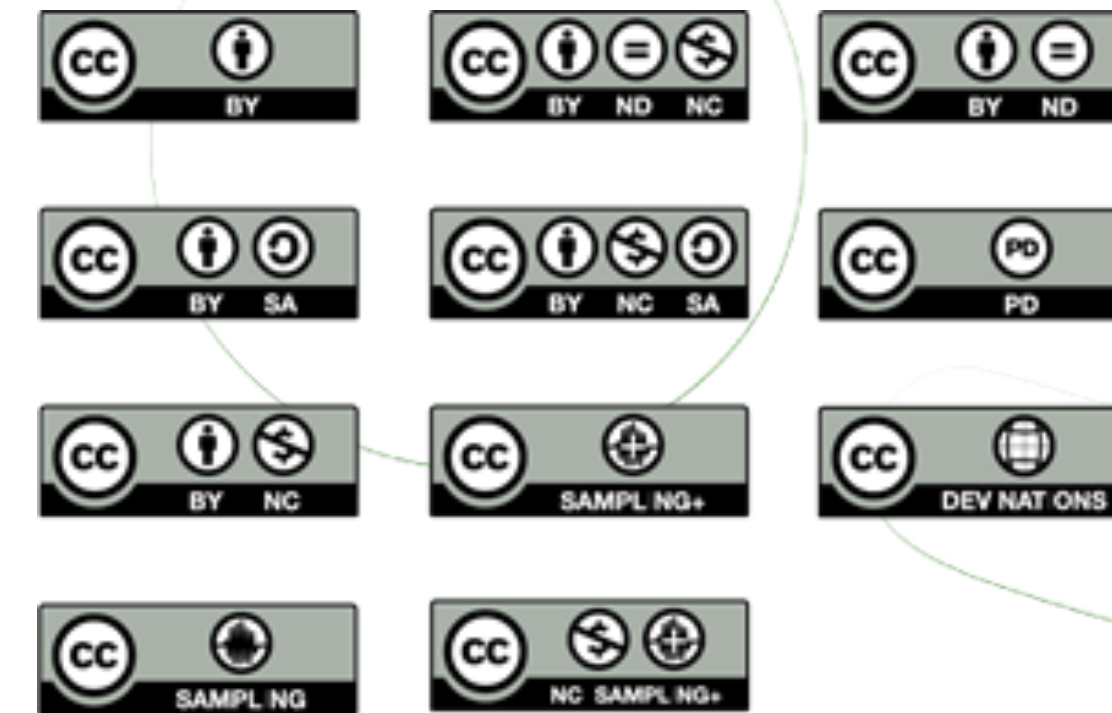
Digital resources and their metadata must always, **without exception**, include a license that describes under which conditions the resource can be used, even if that is **“unconditional”**. **By default, resources cannot be legally used without this clarity**. Note also that a license that **cannot be found by an agent**, is effectively the same as no license at all. Furthermore, the license may be **different for a data resource and the metadata** that describes it, which has implications for the indexing of metadata v.v. findability. This is a clear public domain statement, an equivalent such as terms of use or computer protocol to digitally facilitate an operation (for instance a smart contract). Thus, the absence of a license does not indicate “open”, but rather creates legal uncertainty that will deter (in fact, in many cases legally prevent) reuse. Note also that the combination of resources with restrictive license conditions may lead to adverse effects, and ultimately preclude the use of the combined resources. In order to facilitate reuse, the license chosen should be as open as possible.

2) Implementation considerations

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R1.1	RDA-R1.1-01M	Metadata includes information about the license under which the data can be reused	●●●	Essential
R1.1	RDA-R1.1-02M	Metadata refers to a standard reuse licence	●●	Important
R1.1	RDA-R1.1-03M	Metadata refers to a machine-understandable reuse licence	●●	Important



How would we make “machine-readable” licenses?



R1.2: (meta)data are associated with detailed provenance

3.4.3 Sub-Principle R1.2: (meta)data are associated with detailed provenance

1) Interpretation

Detailed provenance includes facets such as how the resource was generated, why it was generated, by whom, under what conditions, using what starting-data or source-resource, using what funding/resources, who owns the data, who should be given credit, and any filters or cleansing processes that have been applied post-generation. Provenance information helps people and machines assess whether a resource meets their criteria for their intended reuse, and what data manipulation procedures may be necessary in order to reuse it appropriately.

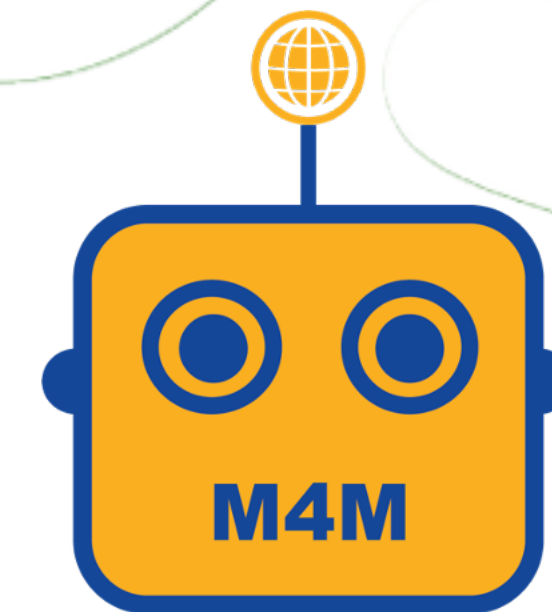
2) Implementation considerations

Current choices are for communities to choose a set of metadata descriptions to optimize provenance to optimally enable machine and human reusability for its own purposes. These choices, and, as argued before the richness of the provenance associated with a digital resource will strongly influence its actual reuse. Therefore, the implementation considerations for implementing according to this principle are inherently the same as described for principle F2, but now more focused on appropriateness for reuse than on findability *per se*.

Provenance descriptions can for instance be implemented following community specific templates according to the PROV-Template¹⁹ approach. These templates allow to predefine the structure of the intended collection of provenance information using variables which are later instantiated with appropriate data extracted from existing process output. Such templates also reduce the burden on community members to deeply understand the highly structured PROV ontology, and the well-defined data structures that emerge from its use – that is to say, PROV should not be treated as a simple vocabulary from which terms can be selected, but rather as a model that constrains how those terms must be used in relation to one another. Several early tools are under development to make the construction of FAIR metadata easier, including for instance CEDAR²⁰, CASTOR²¹ and the knowledge models in the Data Stewardship Wizard²² [24].

R1.2	RDA-R1.2-01M	Metadata includes provenance information according to community-specific standards	<input checked="" type="radio"/>	Important
R1.2	RDA-R1.2-02M	Metadata includes provenance information according to a cross-community language	<input type="radio"/>	Useful

CEDAR Workbench
<https://metadatacenter.org>



R1.2: (meta)data are associated with detailed provenance

3.4.3 Sub-Principle R1.2: (meta)data are associated with detailed provenance

1) Interpretation

Detailed provenance includes facets such as how the resource was generated, why it was generated, by whom, under what conditions, using what starting-data or source-resource, using what funding/resources, who owns the data, who should be given credit, and any filters or cleansing processes that have been applied post-generation. Provenance information helps people and machines assess whether a resource meets their criteria for their intended reuse, and what data manipulation procedures may be necessary in order to reuse it appropriately.

2) Implementation considerations

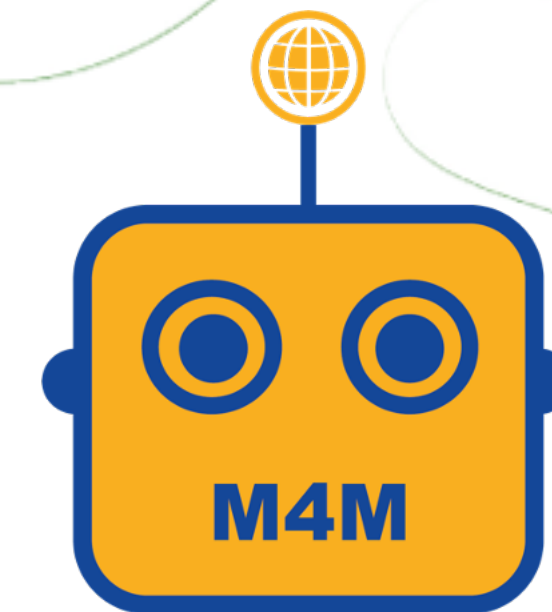
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R1.2	RDA-R1.2-01M	Metadata includes provenance information according to community-specific standards	<input checked="" type="checkbox"/>	Important
R1.2	RDA-R1.2-02M	Metadata includes provenance information according to a cross-community language	<input type="checkbox"/>	Useful

Examples of provenance information?

CEDAR Workbench
<https://metadatacenter.org>



R1.3: (meta)data meet domain-relevant community standards

3.4.4 Sub-Principle R1.3: (meta)data meet domain-relevant community standards

1) Interpretation

Where **community standards** or best practices for data archiving and sharing exist, they should be followed. Several disciplinary communities have defined *Minimal Information Standards* describing most often the minimal set of metadata items required to assess the quality of the data acquisition and processing and to facilitate reproducibility. Such standards are a good start, noting that true (interdisciplinary) reusability will generally require richer metadata. For a list of such standards, consult FAIRsharing ²³.

2) Implementation considerations

Current *choices* are for a community to choose which practices to use for data and metadata, taking into **full consideration the relevant inter-domain interoperability requirements**. Communities must then take-on the *challenge* of deciding which metadata elements, addressed within their community's "boutique" standard(s), should be additionally represented using a more global standard (principles F2 and R1.2), even if this results in duplication of metadata, such that it can be used for search and interpretation by more generic, third-party agents.

An example of minimal information standards is the MIAME standard [27], and various metadata profiles have been defined on top of specifications (e.g. various DCAT profiles).

R1.3 [RDA-R1.3-02D](#) Data is expressed in compliance with a machine-understandable community standard ●● Important

Home > [Advances in Conceptual Modeling](#) > Conference paper

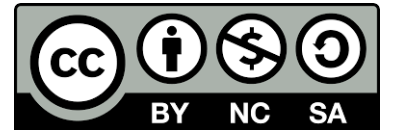
Reusable FAIR Implementation Profiles as Accelerators of FAIR Convergence

Conference paper | First Online: 22 December 2020
pp 138–147 | [Cite this conference paper](#)

Advances in Conceptual Modeling
(ER 2020)

FAIR Implementation Community

- FAIR Enabling Resource
- FAIR Enabling Resource
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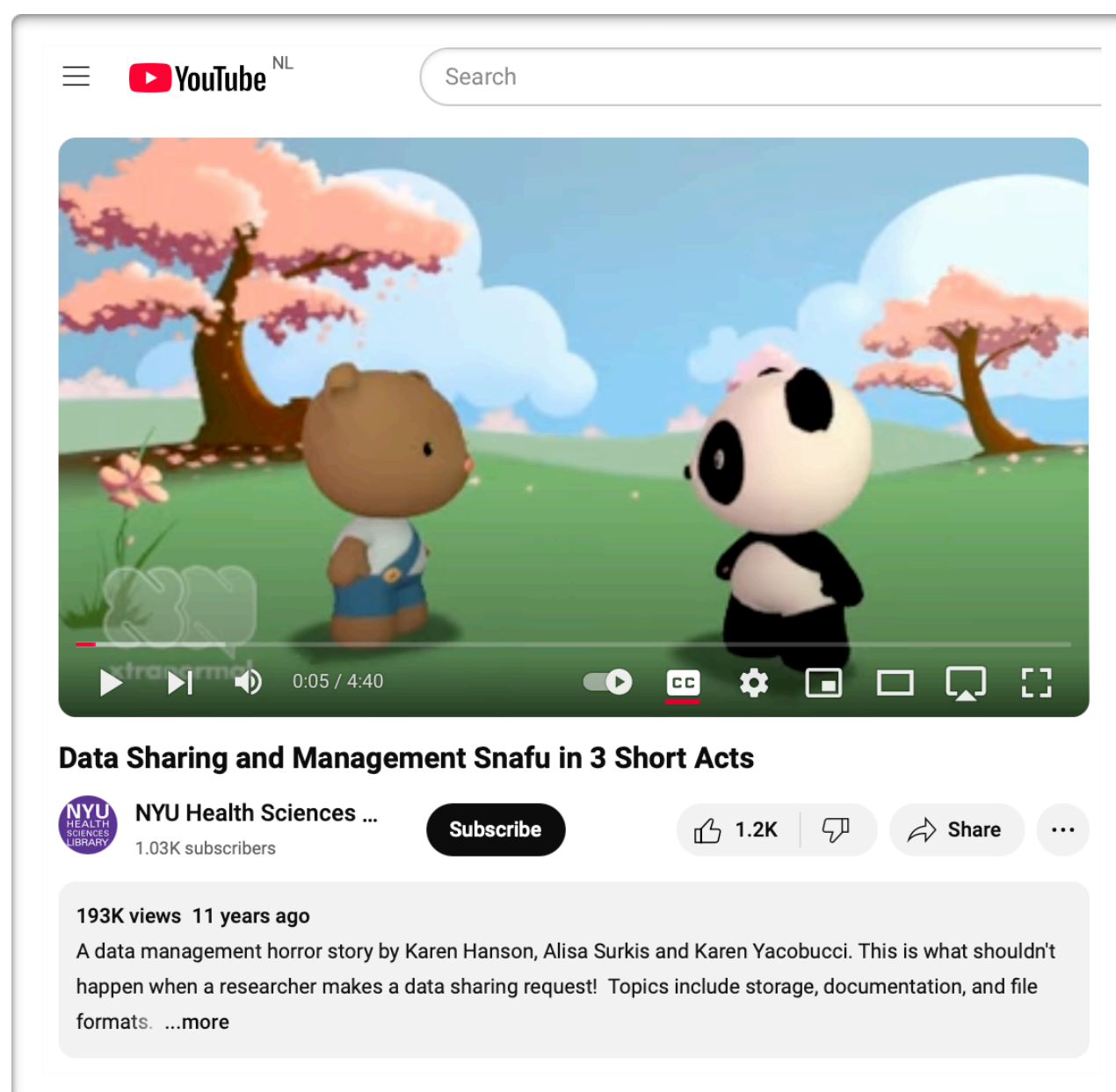




Resume 16:00 CET

Interpreting the FAIR Principles: Revisting the FigJam

16:00-16:40
(Breakout)



- **Panda Bear** reads about research in *Science* **(F)**
- **PB** requests a copy of the data **(A)**
- **BB** assumes (wishes) the data are already in the *Science* article **(assumes data are FAIR)**
- **PB** indicates that the data are not there **(they are not FAIR)**
- **BB** is not sure where the data are (a USB drive... in a box at home... so many boxes) **(F, A, I)**
- **BB** 7 months to locate **(F)** sends only copy to **PB (risking A)**
- **BB** has 'complied' with the request for data but...
 - layers of idiosyncratic coding (specialized software is required to decode the hexadecimal notation) **(I)**
 - software not supported since 2007 **(F, A, R)**
 - Semantically empty field names (SAM1, SAM2, ...) with no documentation (not even in the *Science* publication) **(I, R)**
- Personnel point of failure: graduate student who moves back to China **(I, R)**

Interpreting the FAIR Principles: Presentations & Discussion

16:40-17:00





FAIR
Well!

THANKS!

Erik Schultes, Barbara Magagna, Andrea Tarallo
29 November 2024

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-
Mission 4 "Education and Research" - Component 2: "From research to business" - Investment
3.1: "Fund for the realisation of an integrated system of research and innovation infrastructures"

