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Abstract. In open science, the expression "FAIRness assessment" refers to evaluating to which degree a digital object is Findable, Accessible, Interoperable, and Reusable. Standard vocabularies or ontologies are a key element to achieving a high level of FAIRness (FAIR Principle I2) but as any other data, ontologies have themselves to be FAIR. Despite the recent interest in the open science and semantic Web communities for this question, we have not seen yet a quantitative evaluation method to assess and score the level of FAIRness of ontologies or semantic resources in general (e.g., vocabularies, terminologies, and thesaurus). The main objective of this work is to provide such a method to guide semantic stakeholders for making their semantic resources FAIR. We present an integrated quantitative assessment grid for semantic resources and propose candidate metadata properties –taken from the MOD ontology metadata model– to be used to make a semantic resource FAIR. Aligned and nourished with relevant FAIRness assessment state-of-the-art initiatives, our grid distributes 478 credits to the 15 FAIR principles in a manner which integrates existing generic approaches for digital objects (i.e., FDMM, SHARC) and approaches dedicated to semantic resource or artefact (i.e., 5-stars V, MIRO, FAIRsFAIR, Poveda et al.). The credits of the grid can then be used for implementing FAIRness assessment methods and tools.

Keywords: FAIR data principles, FAIRness assessment, evaluation grid, semantic, ontologies, semantic resources / artefacts, metadata properties.

1 Introduction

In 2014, a group of researchers, research institutions, and publishers (called FORCE 11) defined fundamental guiding principles called FAIR (for Findable, Accessible, Interoperable, and Reusable) to make scientific data and their metadata interoperable, persistent, and understandable for both humans and machines [1], [2]. The FAIR principles emphasize the importance of semantic technologies in making data interoperable and reusable. However, ontologies[1] –the backbone of semantic technologies– have themselves to be FAIR. Until recently, not much attention has been made to quantitatively evaluating ontologies using FAIR principles; all related

[1] In this paper, we will consider the terms ontologies, terminologies, thesaurus and vocabularies as a type of knowledge organization systems [3] or knowledge artefacts [4] or semantic resources [5]. For simplicity, we will sometimes use "ontology" as an overarching word.

work or state-of-the-art methods regarding ontologies are qualitative i.e., proposing recommendations and best practices without providing a scoring mechanism. It is clear that the development of FAIRness assessment methods –i.e., ways to measure to which level a digital object implements FAIR principles– remains challenging [6], including for ontologies and semantic resources. In fact, the complexity of FAIRness assessment is due to the fact that the FAIR principles are expressed at a very generic level and need to be expanded and projected to specific digital objects to be more explicit. Furthermore, some criteria are very hard to evaluate by a program and require –sometimes-subjective– human expertise; for examples: *described with rich metadata* (F2), *meet domain-relevant community standards* (R1.3) or *associated with detailed provenance* (R1.2). Therefore, to enable FAIRness assessment and cover all the FAIR principles, it is preferable to clearly distinguish what relies on human decision (e.g., which license to assign, which good practices to follow) from how to capture or represent information in a way a machine can use to evaluate FAIRness.

For all these reasons, we believe it is essential to define a quantitative method i.e., a metric, for assessing and scoring to which degree a semantic resource is FAIR compliant –for example, determine if a resource is "not FAIR", "FAIR" or even "FAIRer" than a certain threshold or another resource. The objective of this work is to provide a *grid* dispatching different values of *credits* to each FAIR principle, depending on its importance when assessing FAIRness of ontologies. We talked about an *integrated grid*, to capture that our grid is aligned and nourished by existing generic approaches for digital objects in general (i.e., FDMM, SHARC) and approaches dedicated to semantic resource or artefact (i.e., 5-stars V, MIRO, FAIRsFAIR, Poveda et al.). As a result, the proposed grid totalizes *478 credits* that can be used for implementing FAIRness assessment tools. Such tools will then guide semantic stakeholders in (i) making their semantic resources FAIR and (ii) selecting relevant FAIR semantic resources for use.

The rest of this paper is organized as follows: Section 2 briefly introduces the FAIR principles and presents related work in FAIRness assessment or alike. Section 3 describes the methodology followed to integrate the most prominent existing works into one schema and details the proposed FAIRness assessment grid. Section 4 presents candidate metadata properties –taken from the MOD 1.4 ontology metadata model– to be used to enable FAIRness assessment. Section 5 presents our perspective of developing a methodology to automatize FAIRness assessment in the AgroPortal ontology repository. Finally, Section 6 concludes the paper.

2 Overview of the FAIR principles and related work

Hereafter, we briefly introduce the meaning of each F-A-I-R aspect: First, data are *findable* when they are sufficiently described with metadata and are registered or indexed in a searchable registry or repository. Data, metadata, and other associated resources should have a unique and persistent identifier that makes them findable and referenceable by humans and machines. Second, data are *accessible* when users can retrieve them using a universally implementable and open protocol. Nevertheless, this does not mean data have to be openly accessible without restrictions. Sometimes, data can be FAIR and not open. In other words, FAIR data should be associated with metadata that specifies conditions by which the data are accessible. Third, data are *interoperable* when other stakeholders can easily and in a standardized way, process them without need of specific software. The “I” principles might be considered as the harder to accomplish and still the most important key features for FAIR. They state data and metadata should be described in a formal, accessible, shared, and broadly applicable language for knowledge representation. In addition, that data must themselves reuse FAIR vocabularies or ontologies and include qualified references to other data and metadata. Early on, semantic Web and linked data technologies were identified as some best candidates to use for knowledge representation, machine-readability, and interoperability on the Web but the FAIR principles cannot be reduce to the Semantic Web [7]. Finally, data are *reusable* when they are provided with clear license and data usage information for humans and machines. They should be also associated with rich metadata and documentation that detail their provenance (data specifications, funding projects, use cases, versions, experimental processes, etc.).

Next, we briefly present related methods for assessing FAIRness. We distinguish between two FAIRness assessment approaches: the first category concerns general schemes or generic tools applicable for any kind of digital object; the second category is specific for the description and assessment of ontologies or semantic resources. We review both of them chronologically.

2.1 Generic FAIRness assessment approaches

The Research Data Alliance (RDA) *SHARing Rewards and Credit* (SHARC) Interest Group, created in 2017, proposed a FAIRness assessment grid to enable researchers and other data stakeholders to evaluate FAIR implementations and provide the appropriate means for crediting and rewarding to facilitate data sharing [8]. The SHARC grid defines a set of 45 generic criteria with importance levels (essential, recommended, or desirable) evaluated by answering one of four values (Never/NA, If mandatory, Sometimes, Always) to a question; questions are sometimes dependent on one another as in a decision tree.

In 2018, the RDA *FAIR Data Maturity Model* (FDMM) Working Group published a recommendation to normalize FAIRness assessment approaches and enable comparison of their results [9]. It describes a set of 47 generic criteria derived from each FAIR principle with priorities (essential, important, or useful). Both the SHARC grid and the FDMM recommendation assumed that some FAIR principles were more important than others. We have kept this philosophy in our methodology and kept the SHARC and FDMM outputs as influences on our FAIRness assessment score.

Some FAIRness assessment tools recently appeared such as FAIRdat tool, FAIR metrics, OzNome 5-star tool, FAIR self-assessment, FAIR-Aware. We describe some of them hereafter: Data Archiving and Networked Services (DANS) developed two prototypes: (i) *FAIRdat* tool [10], published in 2017, and addressed to data reviewers/curators, creates a badge scheme per principle called “FAIR profile” that evaluates on a 5-stars scale how much a dataset is compliant to each FAIR principle. For example, an evaluation result as “F4-A3-I2-R3" denotes that the dataset is easily findable, accessible under some conditions, has a low degree of interoperability, and is on average reusable. This tool has been influenced by the Open Data Certificate [11] and Tim Burners-lee’s 5-star scheme [12] by proposing star badges to represent the overall FAIRness of the dataset. (ii) *FAIR enough?* [13], addressed to users with less experience on data management, is a simple yes/no checklist to roughly assess the findability (3 questions), accessibility (1 question), interoperability (2 questions), and reusability (3 questions) of datasets. The prototype implements the GARDIAN FAIR metrics[2], it considers only 'F', 'A', and 'I'. 'R' is obtained with a simple average calculation, i.e. 'R'= 'F'+'A'+'I'/3.

In 2017, UPM-INIA, Oxford e-research center, and GO FAIR created the FAIR Metrics group and published the first "general, scalable, automatable FAIRness evaluation framework" [14] enabling any scientific community to define, implement and share metrics –called *Maturity Indicators* (MIs)– based on the community interpretation of the FAIR principles. The FAIR Metrics initiative answers several challenges related to FAIR assessment with a framework for a variety of data services and components –such as a community-based collection of open Maturity Indicators–, tests, metadata harvesting via automatic agents, recommendations on how to improve FAIRness, a simple report, and visualization of results.

In 2018, the *OzNome 5-star* tool [15] is published by CSIRO. An online survey (containing multiple-choice questions) generates a star chart representing the resultant degree of FAIR compliance of a dataset according to some specific metrics. In addition to the FAIR principles, the authors also considered Berners-Lee's 5-star Linked Open Data principles [16] and treated aspects that are not covered by some specific tool for producing their data rating system as for example the FAIR self-assessment tool (for more details see[3]). Similarly, our methodology was influenced by the Linked Open Data principles, because semantic resources and ontologies are frequently implemented by means of Semantic Web technologies.

In 2019, a FAIRness assessment tool for data librarians and information technology staff is proposed by ARDC, as a series of questions related to each FAIR principle [17]. It offers a green bar indicator that specifies the overall level of FAIRness of datasets. This prototype tool reflects ARDC'S interpretation of the FAIR principles but, as mentioned by its authors, part of the proposed questions has been inspired by the FAIRdat and 5-star data rating tool. Based on our knowledge, no specifications about the scoring scheme are publicly available.

Finally, in 2020, FAIR-Aware and F-UIJ tools were developed within the FAIRsFAIR H2020 project: (i) *FAIR-Aware* is an online self-assessment questionnaire composed of 10 yes/no questions (3 for F., 2 for A., 1 for I., and 4 for R). The experiences and feedback gathered on FAIRdat and FAIR enough? were used as inputs for the development of this tool (details are provided in [13]). Each question is associated with detailed information and links to assist users. FAIR-Aware still needs several improvements such as offering a synthesized score, being compliant with FAIR Metrics, providing recommendations to enhance FAIRness as a result of using the questionnaire. FAIRsFAIR has also a dedicated task on "FAIR semantics" detailed in the next section. (ii) *F-UJI*[4] supports an automated assessment of research data based on the FAIRsFAIR data object Assessment metrics [14]. The tool gets an object identifier and returns in JSON format a set of scores related to each FAIR principle.

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[2] https://gardian.bigdata.cgiar.org/files/GARDIAN_FAIR_metrics_guide.pdf

[3] https://confluence.csiro.au/display/OZNOME/Data+ratings

[4] https://seprojects.marum.de/fuji/api/v1/ui/

2.2 Specific FAIRness assessment approaches

Before the apparition of the FAIR principles, in 2011, Berners-Lee presented the foundational principles for Linked Open Data (LOD) [16] for making data available, shareable, and interconnected on the Web. The FAIR principles have been proposed for similar reasons with a stronger emphasis on data reusability (consideration of license agreement and provenance information). The 5-stars LOD principles were specialized in 2014 for Linked data vocabularies [18] as five rules to follow for creating and publishing "good" vocabularies. Under this scheme, stars denote the quality of data leading to better structure (i.e., use of W3C standards) and interoperability for reuse (i.e., metadata description, reuse of vocabularies and alignment). The proposed 5-star rating system (later called *5-stars V*) for vocabularies is simple however, no implementation tool was developed for making the assessment automatic and the principles are not largely referenced today. A study of the degree to which the FAIR principles align, and extend the 5-star LOD principles was proposed first in [19] and later in [20]; we have incorporated this alignment in our methodology.

In 2017, the *Minimum Information for Reporting an Ontology* initiative published the MIRO guidelines for ontology developers when reporting an ontology in scientific reports [21]. The MIRO guidelines aim to improve the quality and consistency of the information content descriptions; including development methodology, provenance and context of reuse information. They define 34 information items (such as "ontology name", "ontology license", "ontology URL") and specify the level of importance "must", "should', "optional" for each. This work was significant but, there existed, so far, no studies on how the MIRO properties align with or extend the FAIR principles. The MOD 1.4 metadata model (see hereafter) however provided an alignment between each MIRO guideline and the corresponding metadata properties in MOD. We therefore used this alignment in our methodology, to influence the FAIRness assessment score with the MIRO guidelines.

Dutta et al. [22] reviewed and harmonized existing metadata vocabularies and proposed a unified ontology metadata model called MOD (for *Metadata for Ontology Description*) to facilitate manual and automatic ontology descriptions, identification and selection. MOD is not another standard nor another metadata vocabulary, but more a set of catalogued and regrouped properties one can use to describe a semantic resource.[5] The MOD 1.2 model later extended in MOD1.4[6] was used in AgroPortal –a vocabulary and ontology repository for agronomy– to implement a richer, unified metadata model [19]. Now, AgroPortal recognizes 346 properties from 15 relevant metadata vocabularies (such as Dublin Core, Ontology Metadata Vocabulary, VoID, FOAF, Schema.org, PROV-O, DCAT, etc.) and map them to its unified model. In fact, this unified metadata model maybe consider as the first step for enabling FAIRness assessment (cf. Section 5). For example, an ontology developer can focus on his/her responsibility of determining the license to use an ontology, while MOD and AgroPortal offer means to encode such information in a way machines can use to

[5] For instance, MOD does not require the use of a specific authorship property but rather encode that `dc:creator`; `schema:author`, `foaf:maker`, or `pav:createdBy` can be used to say so.

[6] https://github.com/sifrproject/MOD-Ontology

assess the level of FAIRness. Based on the MOD model, we produce in this article guidelines on how FAIR principles might be met and evaluated. Section 4 provides a clear alignment between the MOD properties and the FAIR principles. For instance, to assess F1, we rely on the existing MOD properties to encode the identifiers of an ontology (`omv:uri`) and (`dct:identifier`).

In March 2020, the FAIRsFAIR H2020 project delivered the first version of a list of 17 recommendations and 10 best practices recommendations for making semantic artefacts FAIR [4] (later revised in Dec. 2020 in a new deliverable). For each recommendation, the authors provided a detailed description, list its related semantic Web technologies, and in some cases point potential technical solutions. Similarly, best practices are introduced as recommendations that are not directly related to a FAIR principle but are contributing to the overall evaluation of a semantic resource. This proposal is currently being discussed, in the context of the RDA Vocabulary and Semantic Services Interest Group (VSSIG). The recommendations are also publicly available for comments on GitHub.[7] Our group is strongly involved in the revision and commenting of the second and third iteration of the FAIRsFAIR recommendations.

Later, in Septembre 2020, Poveda et al. considered some of the previous works and produced “guidelines and best practices for creating accessible, understandable and reusable ontologies on the Web” [20]. In another position paper [23], they complete their work with a qualitative analysis of how four ontology publication initiatives cover the foundational FAIR principles. They propose some recommendations on how to make ontologies FAIR and list some open issues that might be addressed by the semantic Web community in the future. These two publications are very relevant for our methodology; our work is a step further as it completes this work and proposes a concrete metric necessary for further work on automatic FAIRness assessment.

Other recent related work on FAIR principles for semantic resources include: A list of functional metrics and recommendations for Linked Open Data Knowledge Organization Systems (LOD KOS) products proposed in 2020 [24]. This work proposes a set of metrics for assessing the functionality of LOD KOS against FIT (Functional, Impactful, Transformable) metrics and four recommendations (one recommendation per FAIR principle) for enhancing their FAIRness level. This initiative is interesting but the proposed preliminary LOD KOS FAIR recommendations are very limited (do not cover all FAIR situations), and are also missing the consideration of existing research works. Finaly, DBPedia Archivo [25] is an ontology archive also released at the end of 2020 that aims to help developers and consumers in “implementing FAIR ontologies on the Web”. At this moment, Archivo contains about 1032 ontologies. The prototype[8] automatically discovers, downloads, archives and rates new ontologies. Once an ontology is saved, Archivo determines its 4-stars FAIR rating, tracks its changes and updates its scores. This work puts the spot on the role that ontology libraries and repositories play in the FAIRification process. Currently, Archivo is proposing an automatic assessment service and not guidelines or practical metrics for the semantic Web community. Unfortunately, this work is not inspired by existing research methodologies/tools. We think that it needs to be

[7] https://github.com/FAIRsFAIR-Project/FAIRSemantics/issues/
[8] https://archivo.dbpedia.org/

improved in order to make its 4-star rating system clearer for the community. We have not reused this much recent work in our methodology yet.
To design our FAIRness assessment methodology, we analyzed and merged relevant related approaches namely FDMM version v0.04, SHARC version v1.1, LOD 5-stars V, MIRO, FAIRsFAIR recommendations, and Poveda et al.'s guidelines. We consider both generic and specific approaches in order to provide a solution specialized for ontologies but still influenced by more general concerns, as ontologies are a kind of digital object. The integration was not straightforward, because none of the approaches used is simply and strictly aligned with the 15 sub-principles (e.g., FDMM provides 47 criteria) and two of them (i.e., MIRO and 5-stars V) were totally disconnected from the FAIR prism. Table 1 gives a summary about our selection. We classify approaches into three groups: (A) for generic approaches which set priorities for each FAIR principle or sub-principle; for specific approaches for semantic resources which: (B) includes FAIRsFAIR and Poveda et al. as these guidelines do not set priorities; (C) includes LOD 5-stars and MIRO as they are not aligned to the FAIR principles because pre-exist. Next section, we explain how we proceeded to integrate all these methodologies into the proposed grid.

Table 1. Summary of related works on FAIRness assessment or alike integrated in our approach.

Category	Generic (A)		Specific (B, C)			
Format	grid		principles	scheme	recommendations	
Approach	SHARC	FDMM	5-stars V	MIRO	FAIRsFAIR	Poveda et al.
Reference	[8]	[9]	[18]	[21]	[4]	[23]
Year	2017	2018	2011	2017	2020	2020
FAIR movement	after	after	before	before	after	after
FAIR priorities	yes	yes	n/a	n/a	no	no

3 Integrated quantitative FAIRness assessment grid for ontologies

The design considerations of our grid are:

1. Any semantic stakeholder should be able to assess any semantic resource;
2. It should be as objective as possible and reflect as much as possible existing approaches;
3. It should provide users with a clear metric enabling FAIRness qualification (e.g., not FAIR, FAIR or FAIRer) and resource comparison;
4. It should be easily implementable by FAIRness assessment tools, extensible and maintainable over time.

3.1 Methodology

In what follows, we explain how we quantify each approach against the FAIR principles, then for each category (A) and (B-C), and finally determine a set of final FAIR credits that could be used in evaluating any semantic resource.

We chose to provide numerical credits {0;1;2;3} to respectively represent the degree of priorities/qualification of each *indicator* (other name for sub-principle e.g., F1, F2, F3 et F4 for F) within an approach {e.g., “none”, “may”, “should”, “must”}. A “must” represents an essential principle, a “should” means that a principle is important except under some particular circumstance, “may” is an optional requirement, and “none” a non-revealed/specified qualification of a principle. Table 2 lists the correspondences between the five approaches, their priorities and their attributed credits.

Table 2 Alignment between priorities in related work approaches and credits.

Group	**Approach**	**none (0 credit)**	**may (1 credit)**	**should (2 credits)**	**must (3 credits)**
A	**FDMM**	n/a	useful	important	essential
	SHARC	n/a	desirable	recommended	essential
B	**FAIRsFAIR**	n/a	1 Rec	2 Rec	3 Rec or >
	Poveda et al.	n/a	1 Rec	2 Rec	3 Rec or >
C	**MIRO**	n/a	optional	should	must
	5-stars V	n/a	1 star	2 stars	3 stars or >

To determine the FAIR principle credits for each group, we follow certain rules:

- Group A: we calculate the approximate average value of credits per indicator (FDMM) or principle (SHARC). For SHARC, we divide the obtained average value by the number of indicators associated with a principle.
- Group B: we count the number of recommendations to determine the credits.
- Group C: we count the number of properties for MIRO and stars for 5-stars V.

The final credits for each sub-principle is the sum of all obtained credits per methodology. An example is provided hereafter:

Example 1: We illustrate how we determine for each group (i.e., A, B and C) the credits of F1 (noted $Credits_{F1}$):

Group A:

- FDMM defines 4 “essential” indicators (F1-01M, F1-01D, F1-02M, and F1-02D). Thus, $Credits_{F1,FDMM} = 3 * 4 = 12$.
- SHARC defines 12 sub-indicators (8 essential, 4 recommended) for F. Thus the approximative $Credits_{F1,SHARC} = (8 * 3 + 4 * 2) \div 4 = 8$. The deduced priority is thus 3 (i.e., rounded value of 8÷3).

Group B:

- FAIRsFAIR defines 2 recommendations (P-Rec 1 and P-Rec 2) related to F1 thus, $Credits_{F1,FsF}$=2.
- Poveda et al. define 4 recommendations related to F1 (Rec 1, Rec 2, Rec 3 and Rec 5) thus $Credits_{F1,Poveda\ et\ al.} = 3$.

Group C:

- MIRO refers to 2 “must” properties (“A” category- basics) for F1 sub-principle: ontology version (A.4) and IRI version (A.4). Thus, $Credits_{F1,MIRO}$=2.

- LOD 5-stars V does not specially cover Findability thus, $Credits_{F1,5-starsV}=0$.

3.2 Results

From a semantic Web perspective, the results obtained emphasize the need for the establishment of agreement about a set of core metadata ontology description, a federation model for ontologies regarding repositories and search engines, clear ontology and metadata ontology perseveration strategies within endpoints, mechanisms for references qualification, and best practices to document and communicate ontologies. Fig. 1 (c) provides final integrated FAIR credits per indicator; it shows how both generic approaches and semantic resources specific approaches address FAIRness and score each FAIR indicator. For example, $Credits_F = 113$:

- $Credit_{F1} = 10\ (baseline) + 20 + 11 = 41$; as explained above.
- $Credits_{F2} = 10\ (baseline) + 10 + 7 = 27$
- $Credits_{F3} = 10\ (baseline) + 10 + 1 = 21$
- $Credits_{F4} = 10\ (baseline) + 11 + 3 = 24$

Fig. 1 (part c) illustrates the importance of each indicator in our integrated method. When doing the final sums, we have chosen a baseline value fixed to 10, to represent the fact that originally, as suggested by the FORCE 11 group, the FAIR principles were not ordered by importance; they were supposed to all contribute equally. The final credits are presented in our integrated FAIRness assessment grid (Table 3); the 478 credits of the grid, dispatched by each sub-principle, can be used for the assessment of any semantic resource or ontologies.

Table 3. Integrated FAIRness assessment grid for semantic resources and ontologies.

Principle		Base line	SHA RC	FDMM	5-stars V	MIRO	FAIRs FAIR	Poveda et al.	Credits	
F	**F1**	10	8	12	0	6	2	3	**41**	**113**
	F2	10	8	2	0	5	1	1	**27**	
	F3	10	8	2	0	0	1	0	**21**	
	F4	10	8	3	0	0	2	1	**24**	
A	**A1**	10	6	18	3	3	1	2	**43**	**113**
	A1.1	10	6	11	0	0	1	0	**28**	
	A1.2	10	6	5	0	0	1	0	**22**	
	A2	10	6	3	0	0	1	0	**20**	
I	**I1**	10	4	12	1	12	3	2	**44**	**109**
	I2	10	4	7	0	9	2	0	**32**	
	I3	10	4	12	1	3	2	1	**33**	
R	**R1**	10	9	3	1	6	0	3	**32**	**143**
	R1.1	10	9	12	0	3	2	1	**37**	
	R1.2	10	9	3	0	12	3	1	**38**	
	R1.3	10	9	12	0	0	3	2	**36**	

Total credits	**478**

A quick analysis of Table 3 and Fig. 1 reveals interesting points:

- The most important principles for generic and specific approaches are not the same. Generic approaches tend to emphasize principles F1 (identifier), A1 (access protocol), R1.1 (license) and R1.3 (community standards) while specific approaches emphasize principles I1 (knowledge representation), R1.2 (provenance) and I2 (use of vocabularies). This confirms our hypothesis that being FAIR is strongly dependent on the type of digital object considered and therefore FAIRness assessment methods must be customized for each type.
- In the integrated grid, the three sub-principles that are assigned the higher number of credits are F1, A1 and I1. These aspects being "generally" well addressed by ontologies, it will contribute to an overall good level of FAIRness.
- Four sub-principles, important aspects for FAIR, were completely ignored/avoided by specific approaches, except the FAIRsFAIR recommendations: F3 (link data-metadata), A1.1 (protocol openness), A1.2 (protocol security) and A2 (long term metadata). Consequently, three of this four keep the minimum number of credits in the integrated grid.
- None of the specific approaches covered all of the FAIR sub-principles. This is not surprising for MIRO and 5-stars V which preexist the FAIR movement, but more surprising for FAIRsFAIR and Poveda et al. which recommendations were done specifically for ontologies or semantic resources to be FAIR. Only A1, I1 and I3 were found in the four approaches studied. This point backups our methodology which mixes both generic and specific approaches.
- Despites differences in credits assigned to the sub-principles, the sums by principles are relatively close with a mean of 119,5. Only the R group is significantly above the mean. The group I is slightly under, mostly because it is made of only three sub-principles instead of four.
- R being the most important may reveal the concern that ontologies and semantic resources, often developed by means of semantic Web technologies (RDFS, OWL, SKOS) are naturally equipped with good findability, accessibility and interoperability features (e.g., URIs for identifiers, HTTP for accessibility, W3C standards for knowledge representation, enclain to use vocabularies, etc.) whereas they lack reusability.

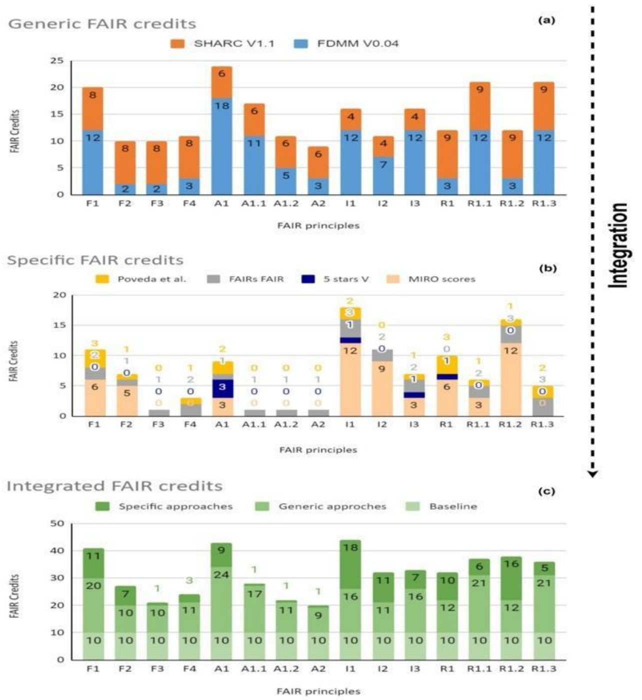

Fig. 1. Credits assigned to each FAIR principle by generic approaches (a), specific approaches (b) and sums with a common baseline in our integrated grid (c).

4 Candidate metadata properties for FAIR ontologies

Working on FAIR ontologies [23] and metadata vocabularies for ontologies [18], [19] since 2016, we elicited candidate metadata properties that can be used for each FAIR sub-principles. Indeed, most sub-principles (about 93%) might be partially or totally implemented and assessed with a series of metadata properties. In this section, we review candidate metadata properties that could be used by anyone developing (i) an ontology or semantic resource or (ii) a FAIRness assessment tool, to obtain associated credits as listed in the previous section.

4.1 Candidate metadata properties to support FAIRness

Here, we reuse the MOD ontology metadata model[9] (v1.4) [19] as reference to pickup metadata properties. MOD1.4 reviewed 346 metadata properties from 23 standard metadata vocabularies (such as Dublin Core, DCAT, VoID, ADMS, VOAF, Schema.org, etc.) to provide a list of 128 "aligned" properties that can be used to describe an ontology or a semantic resource. MOD allows us to unambiguously identify which property may be used; however, our grid could be implemented with any other metadata standard or combination of standard which cover all the sub-principles.

The outcome of this process is a list of 55 candidate metadata properties that may be used to support FAIRness assessment and assign some credits of our grid. These metadata properties might allow to assign a part of 320 credits over the total of 478 (67%). We have separated the metadata properties for any principles from the ones for F2 which has to be treated apart. Indeed, F2 ("Data are described with rich metadata") will be assigned all the properties that MOD1.4 has reviewed as relevant for ontologies that have not been assigned to another sub-principle. We refer to the first group as *core metadata properties* (Table 4) and to the second group as *extra metadata properties* (Table 5). The idea is that any ontologies using some of the 73 extra metadata properties in addition to the core 55 ones, will be "FAIRer".

Table 4. List of core metadata properties from MOD1.4 to help make an ontology FAIR.

Principle		Credits	Metadata properties
F	F1	35	`owl:ontologyIRI, owl:versionIRI, dct:identifier`
	F4	20	`schema:includedInDataCatalog`
A	A1	12	`owl:ontologyIRI, dct:identifier, sd:endpoint`
	A1.2	18	`schema:includedInDataCatalog`
	A2	10	`dct:hasVersion, omv:status`
I	I1	44	`omv:hasOntologyLanguage, omv:hasFormalityLevel, omv:hasOntologySyntax, dct:hasFormat, dct:isFormatOf`
	I2	32	`owl:imports, voaf:hasEquivalenceWith, owl:priorVersion, voaf:similar, voaf:metadataVoc, dct:relation, dct:isPartOf, voaf:specializes, schema:translationOfWork, voaf:generalizes`
	I3	6	`mod:ontologyInUse, omv:endorsedBy`
R	R1	32	`mod:prefLabelProperty, mod:synonymProperty, mod:definitionProperty, mod:authorProperty, bpm:obsoleteProperty, mod:hierarchyProperty, mod:obsoleteParent, mod:maxDepth, mod:maxChildCount, mod:averageChildCount, mod:classesWithOneChild, mod:classesWithNoDefinition`

[9] https://github.com/sifrproject/MOD-Ontology

	R1.1	37	dct:license, dct:rightsHolder, dct:accessRights, cc:morePermissions, cc:useGuidelines
	R1.2	38	dct:source, prov:wasGeneratedBy, prov:wasInvalidatedBy, dct:accuralMethod, dct:accrualPeriodicity, dct:accrualPolicy, omv:versionInfo, vann:changes, dct:hasVersion, omv:usedOntologyEngineeringTool, omv:usedOntologyEngineeringMethodology, omv:conformsToKnowledgeRepresentationParadigm, omv:designedForOntologyTask, mod:competencyQuestion, dct:fundedBy
	R1.3	36	mod:group
Total		**320**	**55 metadata properties**

We identified that 60% of the FAIR principles (i.e., F2, F3, I1, I2, I3, R1, R1.1, R1.2 and R1.3) are totally evaluable with metadata properties, 33% are partially evaluable (i.e., F1, F4, A1, A1.2 and A2). The only principle for which we have not found any metadata property is A1.1 ("*(Meta)data are retrievable by their identifier using a standardized communications protocol*") because it is completely related to the evaluation of the communication protocol. A sub-principle is not totally evaluable with metadata properties when it is about an aspect independent of the ontology itself but related to the access protocol or library/repository hosting the ontology. For instances: (i) F4 ("*(Meta)data are registered or indexed in a searchable resource.*") concerned also ontology repositories; (ii) A1.2 ("*The protocol allows for an authentication and authorization where necessary*") is related to the protocol but can be in part assessed by verifying if the ontology repositories support authentication/authorization.

F3 ("*Metadata clearly and explicitly include the identifier of the data they describe.*") is excluded from the Table 4 as MOD1.4 do not yet offer a property to establish the link between an ontology and its metadata (necessary when metadata are not explicitly included in the same file than the ontology itself). Such a property is currently being discussed in the FAIR Digital Object working group of GO FAIR that shall soon release a new metadata vocabulary including `fdo:hasMetadata` and `fdo:metadataOf` properties. Even if I3 is totally evaluable with metadata, the current proposed list for I3 is not sufficient for its evaluation. Here again, we need some extension to MOD to enable encoding all information needed for this principle (especially alignment qualification). MOD is currently being extended as a new model compliant with DCAT2 within the RDA VSSIG and H2020 FAIRsFAIR.

Table 5. List of extra metadata properties from MOD1.4 to make an ontology FAIRer.

Principle		**Credits**	**Metadata properties**
F	F2	27	omv:acronym, dct:title, dct:alternative, skos:hiddenLabel, dct:description, foaf:page, omv:resourceLocator, omv:keywords, dct:coverage, foaf:homepage, vann:example, vann:preferredNamespaceUri, void:uriRegexPattern, idot:exampleIdentifier, dct:creator, dct:contributor, dct:publisher, pav:curatedBy, schema:translator, dct:subject, mod:group, owl:backwardCompatibleWith, door:comesFromTheSameDomain, mod:sampleQueries, void:uriLookuPEndpoint, omv:knownUsage, dct:audience, doap:repository, doap:bugDatabase, doap:mailing-list, mod:hasEvaluation, mod:metrics, omv:numberOfClasses, omv:numberOfIndividuals, omv:numberOfProperties, mod:numberOfDataProperties, mod:numberOfObjectProperties, omv:numberOfAxioms, mod:numberOfLabels, mod:byteSize,

			vann:preferredNamespacePrefix, dct:language, dct:abstract, mod:analytics, dct:bibliographicCitation, rdfs:comment, foaf:depiction, foaf:logo,voaf:toDoList, schema:award, schema:associatedMedia, owl:isIncompatibleWith, dct:hasPart, schema:workTranslation, door:hasDisparateModelling, voaf:usedBy, voaf:hasDisjunctionsWith, omv:keyClasses, void:rootResource, mod:browsingUI, mod:sampleQueries, void:propertyPartition, void;classPartition, void:dataDump, void:openSearchDescription, void:uriLookupEndpoint, schema:comments, dct:created, dct:modified, dct:valid, dct:dateSubmitted, pav:curatedOn, omv:IsOfType
Total		**27**	**73 metadata properties**

4.2 FAIR or FAIRer: How much is a semantic resource FAIR?

Qualifying the degree of FAIRness of a semantic resource or even comparing it with other semantic resources necessarily implies the use of a metric delimiting the range of values for each qualification (e.g., not FAIR, FAIR, or FAIRer). In that context, our proposed integrated quantitative grid allows defining *thresholds*. For instance, the median value of the resulting total credits can be considered a minimal threshold to be FAIR. A semantic resource with a degree/score under this threshold will not be considered FAIR. Similarly, a semantic resource might be considered as "FAIRer" if it is described with extra metadata properties. In other words, answering the question: *"how much is a semantic resource FAIR?"* becomes possible with such a metric. In our grid, the total credits is 478, so a first threshold could be at 240 (478/2+1) and the second one at 451 (478-27) as illustrated in Fig. 2.

Fig. 2. Not FAIR, FAIR or FAIRer: using the metric of the integrated quantitative grid.

Clearly, using a metric and thresholds is a first required step in making the FAIRness assessment task machine actionable and enable the development of automatic FAIRness assessment tools. We believe it will also be beneficial for researchers to themselves quantify the FAIRness degree of their semantic resources and compare their resources with other ones.

5 Perspective: a FAIRness assessment tool in AgroPortal

Our grid was in part developed in the context of designing a FAIRness assessment methodology for ontologies; it is essentially based on a list of 69 assessment questions that enable to assign a score to an ontology with respect to the credits available in our grid, Section 3. To answer these questions, we rely as much as possible on the candidate metadata properties listed Section 4. We are currently developing a prototype FAIRness assessment tool in AgroPortal (http://agroportal.lirmm.fr), a vocabulary and ontology repository dedicated to agri-food [24] and based on the generic and open source OntoPortal technology[10]. AgroPortal's ontology metadata model relies on MOD 1.4 to harmonize ontology descriptions, and facilitate identification and selection, as well as drawing the landscape of ontologies in the domain [26]. Such richness in ontology metadata description offers enough material to encode our grid. A further study will allow us to: (1) score and analyze the level of FAIRness of 135 semantic resources in AgroPortal; (2) offer ontology developers means to assess their resources and compare it to any other ontologies in the repository; (3) enable ontology users to identify and select Ms. Right ontology following the FAIR principles.

6 Conclusion

In this paper, we proposed an integrated quantitative grid for assessing the level of FAIRness of semantic resources and ontologies. Moreover, we provided a list of candidate metadata properties –from the MOD model v1.4– to enable FAIRness assessment and possibly implement systems based on our grid. Our grid was realized by analyzing existing related work (among others the semantic Web community work before and since the FAIR movement) and summarizing them into one coherent scheme. A distinct feature of our grid is to propose a metric –and thus possible thresholds– for the qualification of any semantic resource. The grid is conceived in a way that it can be customized, extended or improved by other semantic experts in further studies. We believe that this work is a starting point for developing machine actionable FAIRness assessment tools in the context of semantic Web.

The motivation of this work was to go beyond the current recommendations to guide semantic stakeholders for making their semantic resources FAIR: We actually consider these recommendations, harmonize and integrate them to build a grid of 478 credits to assess the 15 FAIR principles.

Currently, we are using the grid to implement a FAIRness assessment tool in AgroPortal. However, in the future, this work will need to be further tested in other FAIRness assessment approaches and discussed within some international FAIR initiatives for instance, RDA, GO FAIR or projects such as FAIRsFAIR.

[10] https://github.com/ontoportal-lirmm

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