

FAIROs: Towards FAIR assessment in Research Objects

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Abstract. The FAIR principles have become a popular means to guide researchers when publishing their research outputs (i.e., data, software, etc.) in a Findable, Accessible, Interoperable and Reusable manner. In order to ease compliance with FAIR, different frameworks have been developed by the scientific community, offering guidance and suggestions to researchers. However, scientific outputs are rarely published in isolation. Research Objects have been proposed as a framework to capture the relationships and context of all constituents of an investigation. In this paper we present FAIROs, a framework for assessing the compliance of a Research Object (and its constituents) against the FAIR principles. FAIROs reuses existing FAIR validators for individual resources and proposes i) two scoring methods for assessing the fairness of Research Objects, ii) an initial implementation of the scoring methods in the FAIROs framework, and iii) an explanation-based approach designed to visualize the obtained scores. We validate FAIROs against 165 Research Objects, and discuss the advantages and limitations of different scoring systems.

Keywords: FAIR assessment · Research object · Aggregation methods.

1 Introduction

The Findable, Accessible, Interoperable and Reusable principles (FAIR) introduce a set of best practices to share data, make data more reusable and support the reproducibility of results in research [22]. FAIR addresses using persistent identifiers for resources, rich metadata to favour discovery, explicit licenses to understand usage terms and using well established vocabularies to facilitate interoperability.

Although FAIR was originally proposed for datasets, additional initiatives are appearing to apply these principles to other research outputs, such as

software [15] [16], ontologies [19], virtual research environments¹ or digital objects [4] among others.

Since research outputs are rarely produced in isolation, the scientific community has proposed Research Objects [2] [20] to capture the context around a scientific investigation. Research Objects also provide the means to pack all the resources within some research, easing its understandability and facilitating its dissemination. However, assessing the compliance of a Research Object against the FAIR principles (i.e., their FAIRness) is challenging, as Research Objects aggregate multiple resources which may be prompt to individual assessment.

In this work we describe FAIROs, a framework for assessing the FAIRness of a research investigation, modeled as Research Object. Our contributions include i) an approach to integrate the FAIRness scores of all resources in a Research Object, ii) an implementation of our approach in an executable tool, and iii) a visualization of the scoring system for helping users understand how to improve the FAIRness of their resources.

FAIROs integrates existing efforts developed to assess the FAIRness of individual datasets, software projects and ontologies. We have tested our framework by calculating the FAIRness scores of over 160 Research Objects available in public repositories, comparing two different aggregation metrics. Based on our results, we discuss the advantages and disadvantages of different scoring methods for Research Object FAIRness. Our results show that the score is severely affected by i) the number of tests associated to each category and ii) the number of resources of each RO.

The rest of the paper is structured as follows. Section 2 describes existing efforts for assessing FAIR in different domains. Section 3 describes our approach, while Section 4 compares differences when using two scoring methods. Section 5 discusses our results, and Section 6 concludes the paper.

2 Related work

There are two main areas of related work: community efforts for guiding users when adopting FAIR, and quality assessment in Research Objects.

2.1 Adopting the FAIR principles

Checking whether a resource follows the FAIR principles has been a subject of discussion in the last years. For instance, in [23], the authors propose a community-driven framework to assess the FAIRness of digital objects. This framework is based on: i) a collection of maturity indicators, ii) principle compliance tests, and iii) a module to apply those tests to digital resources.

¹ <https://rd-alliance.org/group/fair-virtual-research-environments-wg/case-statement/fair-virtual-research-environments-vres>

The proposed indicators are a starting point to define which tests are needed for each type of resource [18].

Community groups like FAIRassist.org² have compiled lists of guidelines and tools for assessing the FAIRness of digital resources. These range from self-assessment tools like questionnaires and checklists to semi-automated validators [8]. Examples of automated validation tools include the F-UJI Automated FAIR Data Assessment Tool³ [7], FAIR Evaluator⁴ and FAIR Checker⁵ for datasets or digital objects; HowFairIs⁶ [21] for code repositories; and FOOPS [11] to assess ontologies. In our work, we build and incorporate some of these validators when calculating the FAIRness of all resources contained within a Research Object.

However, different assessment tools may have different interpretations for each principle. In [9] the authors compare different FAIRness evaluation tools (F-UJI, FAIR Evaluator and FAIR Checker), obtaining different scores and different level of detail when assessing resources. The study highlights the importance of transparency in the evaluation, making each metric and score explainable. Hence, we follow this principle in our work.

2.2 Quality assessment models for Research Objects

Research Object are semantically rich aggregations of research resources designed to facilitate the publication, sharing and reuse of such entities[1]. In order to evaluate Research Objects, [10] proposes ROHUB⁷, a platform with metadata checklists to assess Research Object *completeness*. This indicator is calculated by checking the inclusion of metadata such as title, description, creator, publisher information, etc.; as well as the inclusion of certain resources like datasets, software or publications. However, this approach only takes into account the presence of general metadata, implementing only a subset of the FAIR principles. Our work builds on this approach, taking into account every resource in a Research Object and assessing their compliance against all FAIR principles.

Lastly, FAIR Digital Objects (FDO) have been recently proposed as a self-contained, typed, machine-actionable data package [6]. FDOs should be FAIR by definition but, to the best of our knowledge, there are no existing works measuring the degree of compliance with FAIR in FDOs.

² <https://fairassist.org/>

³ <https://www.fairsfair.eu/f-uji-automated-fair-data-assessment-tool>

⁴ <https://fairsharing.github.io/FAIR-Evaluator-FrontEnd>

⁵ <https://github.com/IFB-ElixirFr/fair-checker>

⁶ <https://github.com/fair-software/howfairis/>

⁷ <https://www.rohub.org>

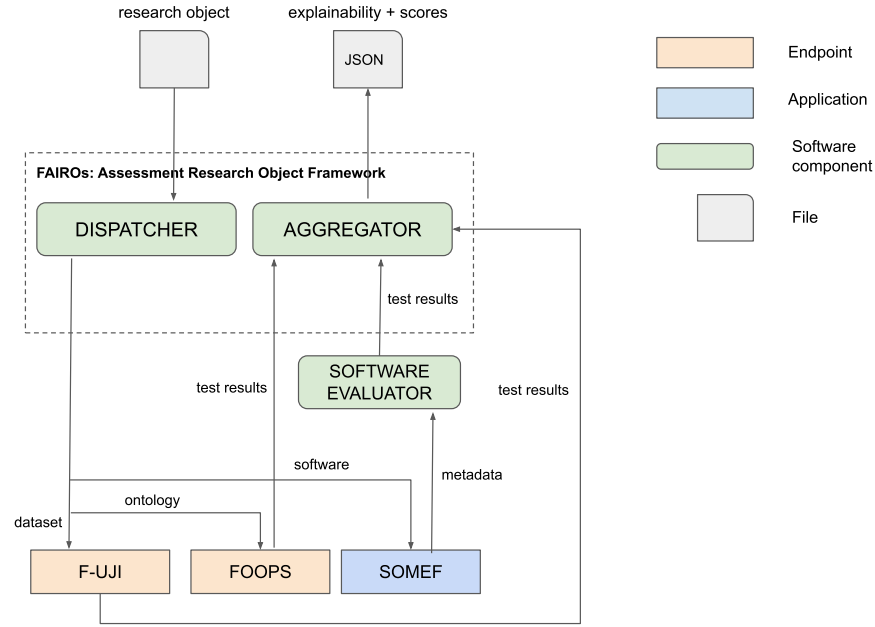


Fig. 1. FAIROs architecture

3 FAIROs: A Research Object FAIR assessment framework

Figure 1 shows an overview of the architecture of FAIROs. Our framework has two main components:

- **Dispatcher.** This component analyzes the Research Object metadata file and detects the different resources of the research object (datasets, software and ontologies). Once the resources are analyzed, the information is sent to the specific tool, as described in Section 3.1.
- **Aggregator.** This component collects the results from the tests executed and aggregates the information to calculate a FAIR score for the Research Object. Tests depend of resource's type and the FAIR principle, as described in Section 3.2.

FAIROs is open source and available on GitHub⁸. The source code of the version presented in this paper can be found in Zenodo [3].

3.1 Modules for individual resource FAIR assessment

In order to measure the FAIRness of Research Objects, FAIROs integrates existing tools to assess individual datasets, software and ontologies. These

⁸ <https://github.com/oeg-upm/FAIR-Research-Object>

Table 1. FAIR principles coverage by the FAIR assessment tools used in FAIROs

Service	F1	F2	F3	F4	A1	A1.1	A1.2	A2	I1	I2	I3	R1	R1.1	R1.2	R1.3
F-UJI	X	X	X	X	X				X		X	X	X	X	X
SOMEF	X	X											X	X	
FOOPS	X	X	X	X	X	X		X	X	X		X	X	X	

tools have been selected for four main reasons: i) their ability to assess the analyzed resources automatically, without human intervention, ii) their accessibility, iii) ease of use and iv) they implement metrics described in scientific publications.

For **datasets**, we have deployed in our server an instance of F-UJI. This application provides a REST service to assess the FAIRness of datasets based on 16 of the 17 metrics defined in the FAIRsFAIR Data Objects Assessment Metrics.⁹ The results of these tests are sent to the aggregator module.

For **ontologies**, we use the service provided by the Ontology Pitfall Scanner for FAIR (FOOPS!). This tool analyzes an ontology with several tests based on [12] [19] and returns a FAIRness score with an explanation of the results, categorized by each FAIR principle. The dispatcher module prepares the request and the response from FOOPS! is sent to the aggregator module.

Regarding **software** assessment, we have created a prototype validator based on the principles identified in [16].

In order to extract metadata associated with a given code repository, we use the Software Metadata Extraction Framework (SOMEF) [17], which analyzes repository documentation to retrieve the license, description, installation instructions, requirements, versions, citation text or provenance information (authors, creation date). These metadata fields are particularly relevant for reusability and are checked by our tests.

As shown in Figure 1, an additional component has been developed to execute SOMEF, run a set of tests to validate the extracted metadata and send the results to the aggregator component. Table 1 summarizes the FAIR principles [22] covered by the different components of our framework.

The last component of the aggregator is in charge of evaluating the metadata of **Research Objects** themselves, by using the RO-Crate specification [20] and the ro-crate-py library[5]. We run the following tests:

- F1: We verify if the RO has a persistent identifier ['w3id.org', 'doi.org', 'purl.org', 'www.w3.org'].
- F2: We verify if the following minimum metadata ['author', 'license', 'description'] are present in the RO-crate.

⁹ <https://www.fairsfair.eu/fairsfair-data-object-assessment-metrics-request-comments>

- F3: We verify that the hasPart elements exists and are described in the RO, as ROs aggregate resources.
- R1.1: We verify if there is at least one author, a datePublished and a citation in the root element.
- R1.2: We verify that all elements of the RO have the following fields: ['author', 'datePublished', 'citation']

3.2 Scoring Aggregations of resources in Research Objects

A RO is composed by resources, including the metadata of the RO itself. Each resource is evaluated against the FAIR principles, and each principle is evaluated by a set of tests (which depend on the type of the resource and the FAIR assessment tool used). The final FAIRness score associated with a Research Object may vary depending on the percentage of tests passed by each resource and on the design decisions used to aggregate the FAIR scores.

To illustrate this difference, we have defined two aggregation metrics in our framework to calculate the final FAIRness score of a Research Object. Note that the metrics are based on the tests defined for each principle and resource. Metrics do not change the tests executed, only how test results are dealt with in the aggregation formula. Our proposed metrics are:

- **Global metric:** calculated by formula (1). It represents the percentage of total passed tests. It doesn't take into account the principle to which a test belongs.
- **FAIR average metric:** calculated by formula (2). It represents the average of the passed tests ratios for each principle plus the ratio of passed tests used to evaluate the Research Object itself.

Both metrics are agnostic to the kind of resource analyzed. The score they produce ranges from [0 - 100].

$$total_score_{global} = \frac{\#tests_passed}{\#tests} \quad (1)$$

$$total_score_{FAIR_average} = \frac{\sum_{i \in G} \frac{\#test_passed_i}{\#tests_i}}{\#G}, \quad (2)$$

where G represents the group of tests from the categories Findable (F), Accesible (A), Interoperable (I), Reusable (R) and Research Objects (RO).

3.3 Result format and visualization

FAIROs generates two outputs:

- A JSON file with the executed tests and the final/intermediate scores generated by a specific metric. The final score is calculated based on the selected metric. Each resource is analyzed based on the tests defined for each FAIR principle. Also, the different tests executed for each principle are described.
- A visual diagram explaining the scores and each test. The diagram is generated in the Graphviz format.¹⁰ An example can be seen in Figure 2. In this diagram, the first-level boxes represent the different digital objects that make up the research object. We can find information such as identifier, type, tool used and the score. In a second level box, the partial scores for each FAIR principle (Findable, Accesible, Interoperable, Reusable) can be found. Finally, we can find the final aggregation score calculated according with the metrics selected.

The output JSON file format is composed by a list of components (resources of the RO), which describes the executed tests and includes an explanation of the obtained scores. Listing 1.1 shows an example, showing some of the tests run for the Findable principle.

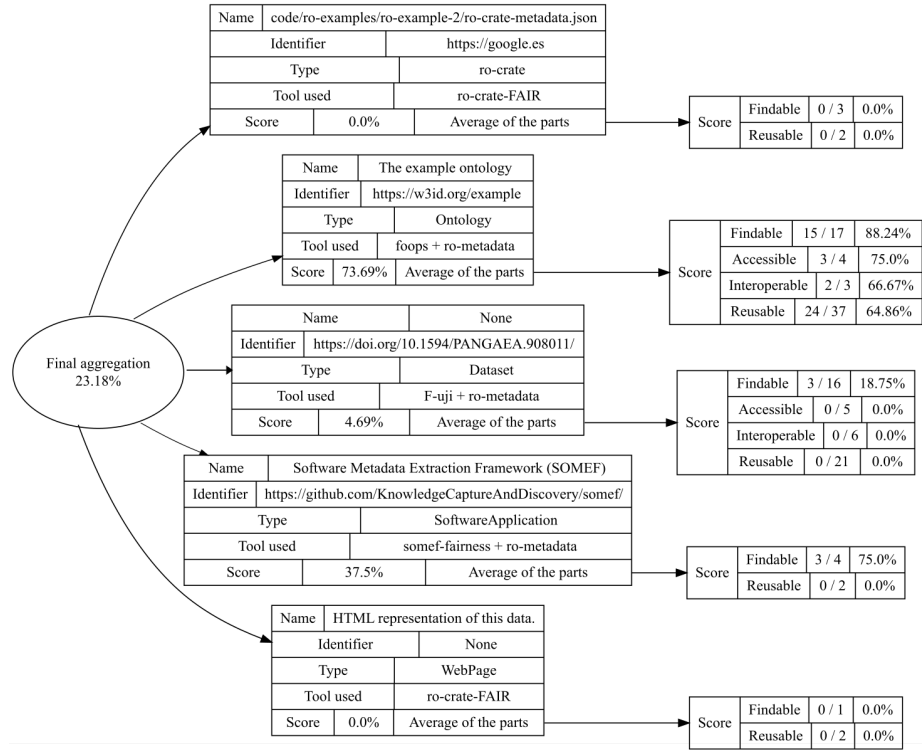
```

1 {"principle_id": "F3",
2   "category_id": "Findable",
3   "title": "Metadata_clearly_and_explicitly_include_the_identifier_
      ↪ of_the_data_they_describe",
4   "description": "This_check_verifies_that_the_hasPart_elements_
      ↪ exists_and_are_describe_in_the_ro",
5   "total_passed_tests": 1,
6   "total_tests_run": 1,
7   "status": "ok",
8   "explanation": "All_element_identifiers_exists"
9 }
```

Listing 1.1. Test execution with explanation

For each component, we include a summary of the tests categorized by principle. The final score calculated by the formula defined by the selected metric is included under the key *overall_score*, as shown in Listing 1.2.

¹⁰ <https://graphviz.org/doc/info/lang.html>

**Fig. 2.** Scores visualization diagram

```

1 "overall_score": {
2   "description": "The_score_is_calculated_by_adding_all_the_
   ↳ scores_of_the_different_components_together._All_passed_
   ↳ tests_and_all_total_tests_are_added_together_and_then_
   ↳ the_percentage_is_calculated",
3   "score": 37.5,
4   "total_sum": {
5     "total_passed_tests": 3,
6     "total_run_tests": 8
7   }
8 }

```

Listing 1.2. Total score obtained for a sample Research Object

The output file format is the same for both of our proposed metrics.

4 Comparing FAIR Research Object Assessment Metrics

We have run a small experiment comparing the effect of our proposed metrics when assessing the FAIRness of more than 160 workflow-centric Research Objects (i.e., ROs containing at least a scientific workflow).

In all runs, we have used the release v0.0.1 of our framework [3].

The objective of our experiment was to analyze the behaviour and the impact of the two metrics defined in our framework on workflow-centric ROs. Therefore, we downloaded 168 ROs [13] from the workflowhub¹¹ platform. These Research Objects are composed by a workflow and other resources such as datasets and other files (images of sketches in many cases). In total, 74 Research Objects contain one resource, 75 contain 2 resources, and 16 contain 3 or more resources. As an important note, 92% of the resources were evaluated as Datasets, but only 17% were CSV and JSON files (i.e., typically considered data inputs or outputs). The rest of the files range from images to configuration files, but are consistent with our analysis, as they can be described with metadata. Note that many times, images are deposited in data repositories.

As a result, each RO produces two JSON files, one for the global metric and another one for the FAIR_{average} metric.

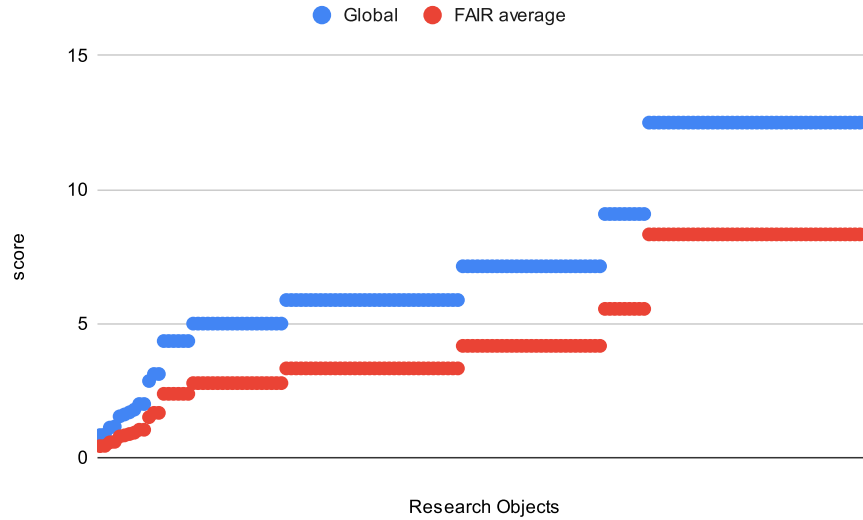


Fig. 3. Distribution of FAIR RO scores in over 160 Research Objects

¹¹ <https://www.workflowhub.eu>

The distribution of scores is depicted in Figure 3. The x-axis, shows the different Research Objects ordered by score. Both scores are different, but consistent, i.e., when the score of a metric is increased, the scores of the other metric increase too. We also detect regular patterns in the results, influenced by the number of resources and the publication of the Research Objects in the same platform.

Figure 4 shows a histogram with the distribution and frequency of the scores obtained by each metric on the corpus of analyzed ROs. In summary:

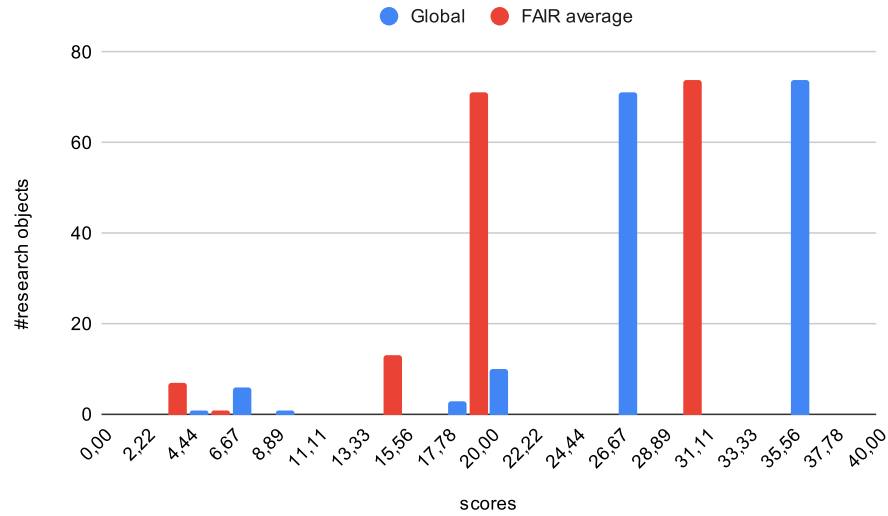


Fig. 4. Distribution of the number of ROs with a given score.

- There are four clusters of scores among the analyzed Research Objects, due to their common number of resources.
- When the value of the score is low, data from the global metric are more dispersed than the FAIR average metric. That is, the first metric generates scores with more variance. In general, the standard deviation of the global metric (6.31) is higher than the standard deviation of the FAIR average metric (5.59).

All the files used and produced in our experiment are available online [14].

5 Discussion

Based on our initial results, we discuss several points we consider key for addressing the compliance of Research Objects against the FAIR principles:

Research Object resource metadata. As shown in Figure 3, many of the FAIRness scores obtained for the Research Objects analyzed are not high (scores are below 40 out of 100 for the best metric). This is due, in part, to the lack of metadata for the resources included in a Research Object. However, additional work is needed to identify whether this behavior is commonplace in ROs belonging to other common platforms or not.

Research Object FAIRness as a proxy of RO quality? Figure 3 shows how by using different aggregation metrics, the FAIRness score of a RO can change significantly (even if scores are consistent with each other). This has two main implications: 1) scores may be used as a guideline to improve the quality of a Research Object, but should not act as a replacement for its quality; and 2) it is key to explain the aggregation method used to produce any Research Object FAIRness score. The objective of the scoring system should not be to produce a ranking, but become a mechanism to improve the FAIRness of ROs.

Resource tests in FAIR scores. Each type of resource (datasets, ontologies, etc.) has different number of tests, so the weight in the final score will depend on the proportion of resources defined in the Research Object. For example, imagine two ROs; one with 4 datasets and another with 6 datasets and 5 software packages. Since the number of tests to assess the FAIRness of software is lower than the number of tests for datasets, the score of the first Research Object will likely be better than the second one, even when the second Research Object may comply with more FAIR principles, in percentage.

FAIROs limitations. While our framework provides a first step towards assessing Research Object FAIRness, it also present some limitations. For example, FAIROs makes some assumptions about concrete resources for which there is no FAIR validator (e.g., instance images and sketches may be considered datasets, which may miss metadata embedded in the files). This approach may introduce bias, but the tests defined for each resource category/principle are quite similar. For example, the process of testing the presence of a persistent identifier is the same, independently the type of the resource. Our study focused on workflow-centric ROs present in one platform, so it does not represent a total overview of the ROs domain. Nevertheless, these results can be used as a starting point and extended when applied to other categories of ROs.

6 Conclusions and Future Work

In this work we have presented FAIROs, a framework for assessing the compliance of Research Objects against the FAIR principles. FAIROs integrates existing tools for assessing the FAIRness of datasets, software and

ontologies; and provides two different aggregation metrics for calculating Research Object FAIRness scores.

Our results show a potential imbalance in the FAIRness score obtained depending on the number of tests run by each principle and resource. For example, if a dataset assessment runs more tests than software, or if more tests are run for the findable principle than for interoperability. Transforming our platform in a plug-in architecture where new assessment tools can be easily incorporated would make it easier to reduce this imbalance.

As for future work, we plan to increment the number of tests run in the Research Object to get a more detailed impression of the Research Object FAIRness. These tests will be accompanied with a collection of recommendations to improve the FAIRness of the target resource. In addition, we plan include partial results from each FAIR principle (Findable, Accesible, Interoperable and Reusable) into our final reports.

Also, we aim to open the aggregation metrics to users. This way, users may define their own metrics based on their preferences. For example, assigning more weight to some resources/principles than others, according to their use cases.

From the architecture point of view, we are in the process of transforming our framework into a service, providing support to the community. We are integrating FAIROs in the RELIANCE Research Object platform,¹² in order to test our work against hundreds of Research Objects in the Geosciences domain.

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¹² <https://reliance.rohub.org/>

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