

# The concept of SciWIn as part of the reproducible science toolset in FAIRagro

HARALD VON WALDOW <sup>1</sup>, JENS KRUMSIECK <sup>1</sup>, ANTONIA LEIDEL <sup>2</sup> and PATRICK KÖNIG <sup>2</sup>

<sup>1</sup>Johann Heinrich von Thünen Institute, Braunschweig

<sup>2</sup>Leibniz Institute of Plant Genetics and Crop Plant Research (IPK), Gatersleben

## Thematic note

This text is deliverable D4.4.1 of Measure 4.4. in Task Area 4 of the NFDI consortium FAIRagro. “SciWIn” stands for **Scientific Workflow Infrastructure** and denotes the overall deliverable of Measure 4.4. This document concludes Action 1 of Measure 4.4. The title set forth in the proposal (Ewert et al., 2023) was “Joint concept of SciWIn as part of the RDC semantic toolset” Several assumptions made at the time of writing the proposal did not materialize. It was therefore necessary to adapt the direction of the project and consequently the thrust of its conceptualization.

## The missing Research Data Commons

The proposal foresaw the integration of SciWIn into a joint infrastructure involving in particular an “RDC mediation layer” (Ewert et al., 2023), where “RDC” stands for “Research Data Commons”. RDC was anticipated to become “an overarching virtual expandable infrastructure” (Glöckner et al., 2020) hosting “cross-cutting services for the NFDI” (Bierwirth et al., 2020). While Glöckner et al. (2020) and Bierwirth et al. (2020) are mere declarations of intent, the consortium NFDI4BioDiversity proposed to establish RDC as a cloud-based research infrastructure and provided a high-level architectural layered concept for RDC (Glöckner et al., 2019) into which SciWIn was supposed to be integrated.

In addition to “RDC” as infrastructure, the term “RDC” was also used in the FAIRagro proposal in the sense of a set of criteria that services should fulfil be be interoperable with the NFDI-wide infrastructure. It was proposed that “FAIRagro will comply with the NFDI-RDC” and that “Storage Instances [of M4.4] ... will hold RDC-compliant FAIR DOs ... ”

In June 2024 we organized a meeting with stakeholders from NFDI4Biodiversity, which were involved in the design and implementation of the NFDI4BioDiversity-specific RDC (Bio-RDC). It turned out that at that point in time, RDC existed as “a blueprint”, an “architectural model” and a collection of specific individual services, namely

- An image annotation software, BIIGLE
- The ontology directory BiodivPortal

- A search engine for biological data GFBio Search
- An object storage technology, Aruna
- An AAI-provider, Life Science Login by EOSC-Life
- A KPI monitoring service, Scorpion

The conceptual ideas had no actionable specification or reference implementation and also seemed to be still in flux. A move to a more domain-oriented decentralized architectural paradigm (“data mesh concept”) was considered. The six approved RDC services on the other hand did not bear direct touching points with SciWIn or FAIRagro. A list of criteria that services should fulfil in order to be “RDC compliant” was planned by TA4 of NFDI4Biodiversity but not yet published.

## Changed Directions

Under these circumstances we had to deal with the fact that there did not exist an “RDC” or an “RDC semantic toolset” into which SciWIn could have been meaningfully integrated. Also the realization of such a thing did not seem likely in a timeframe that would allow to take it into account in the planning and design of SciWIn. Another consequence of the lack of RDC or a clear path towards its realization was the lack of FAIRagro external cooperation partners to develop a “joint concept” with respect to “the RDC semantic toolset”.

In order to stay true to the spirit of this action as originally considered, we developed a set of goals to capture the essence of Action 1. Drawing from Bierwirth et al. (2020), Glöckner et al. (2020) and Diepenbroek et al. (2023), we defined characteristics that would 1) increase the chance for SciWIn to become a part of an NFDI-RDC if that concept were actually implemented, and 2) maximize cross-domain usage, usefulness and synergies in any case:

1. While primarily use-cases and requirement from the agrosystem science community drive SciWIn’s development in FAIRagro, it should nevertheless be domain-agnostic and potentially unleash its full potential also in other quantitative research domains.
2. SciWIn tools and services should be easily accessible for researchers from other NFDI consortia and other domains in general.
3. SciWIn should be based on data formats and protocols that are well established, domain-agnostic and future-proof, to maximize the chances for wide adoption and interoperability.
4. SciWIn should actively exploit existing services and services that are currently being developed
  - to avoid re-invention of the wheel,
  - to increase development efficiency and
  - to be exposed early on to the greater research ecosystem

## SciWIn components - Overview

The original idea of the SciWIn design, as laid out in an ecosystem map (Ewert et al., 2023, Figure 16) features five components:

1. An AAI provider,
2. The “Workflow Hub”,
3. Compute instances,

4. Storage instances, and
5. Workflow Objects

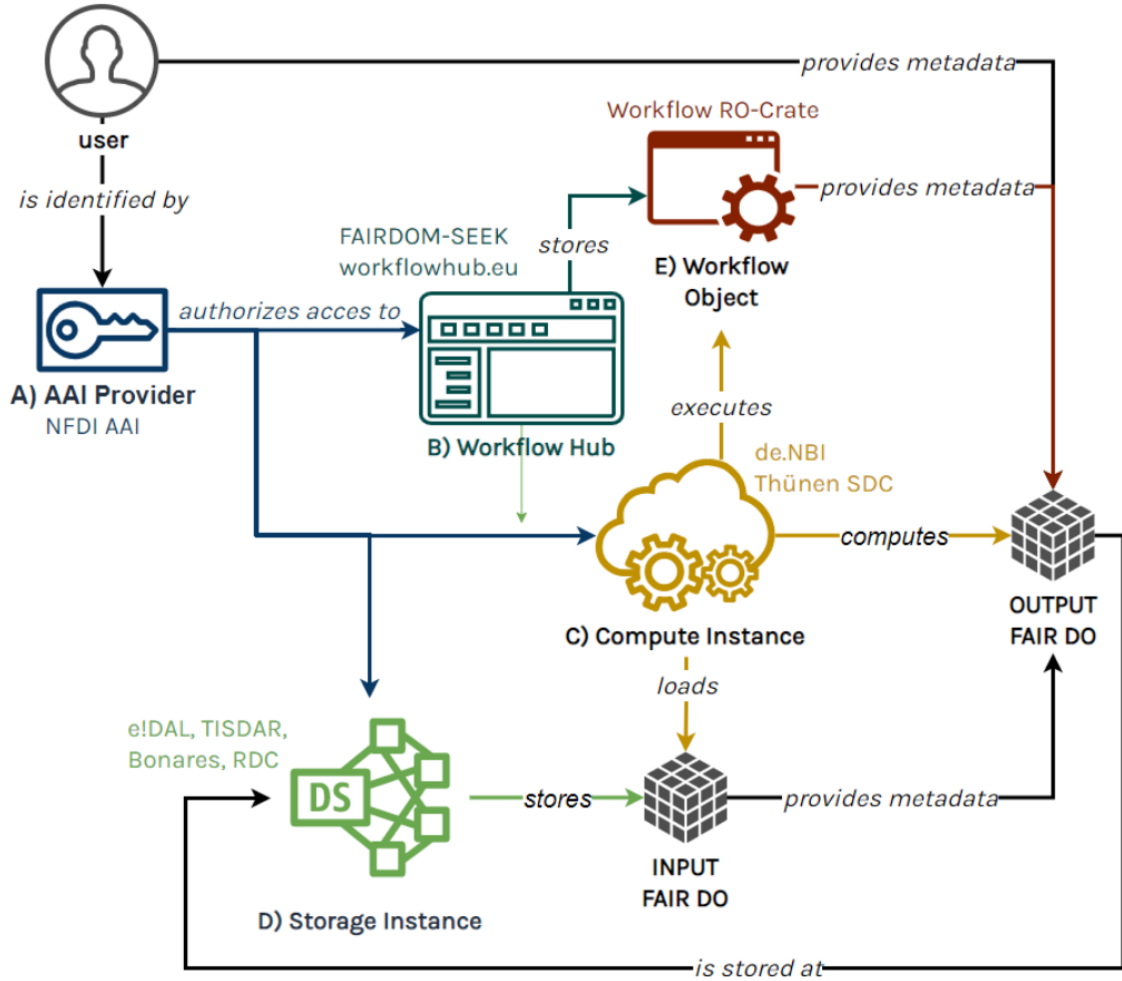


Figure 1: Original ecosystem idea for SciWIn (Figure 16 from Ewert et al., 2023)

### Nomenclature refinements

In that conceptualization, only the “Workflow Hub” was supposed to be developed as a dedicated infrastructure item by SciWIn, while the other components are existing services that communicate with the “Workflow Hub”. The main purpose of the “Workflow Hub” was the provision of “an easy-to-use interface to work on and create new FAIR DO outputs with automatically annotated provenance graphs”. “FAIR DO” stands for “FAIR Digital Objects”, which is used for a quite abstract concept in the current literature. Schultes & Wittenburg (2019) state that FAIR Digital Objects “represent data, software or other research resources” and “must be accompanied by persistent identifiers, metadata and contextual documentation to enable discovery, citation and reuse”. We slightly modify and sharpen the meaning of the terms “FAIR DO” and “Workflow Object” for use in SciWIn and at the same time adapt their semantics to better fit the current implementation strategy:

**FAIR DO** A serializable object that adheres to the definition of Schultes & Wittenburg (2019) above. This also implies that a FAIR Do resides in a suitable FAIR repository that provides discovery and citeability.

**Workflow Object:** A data structure that holds a definition of a computational workflow, associated data and software or pointers to them, along with provenance and version information for all these objects. The Workflow Object can be consumed by an execution engine, which then might return the Workflow Object amended with results of the execution of a computational workflow.

## Re-conceptualization of the “Workflow Hub”

Realizing that the main challenge to be solved lies in the provisioning of tooling for the easy creation of workflows, this task is now assigned to a stand-alone program that scientists use at their workstations in their habitual daily work without requiring internet-access, a central service, or authorization. This stand-alone program is called **SciWIn-Client**. The program supports not only the creation but also the management of all aspects of Workflow Objects containing computational workflows. In particular, it facilitates sharing of and collaboration on Workflow Objects by providing import and export functions to suitable platforms.

The second important function of SciWIn-Client is the communication with compute instances to enable scientists to submit computational workflows for remote execution and fetch the results. SciWIn-Client thus implements functionality that was assigned to “Workflow Hub” in the initial sketch in the proposal.

As a program that anybody can install on their computer, SciWIn-Client does not need an authentication service.

## Re-conceptualization of “Storage Instances”

The “Storage Instances” mentioned in the proposal that still exist are e!DAL-PGP and the BonaRes Repository. Those are established research repositories, just like OpenAgrar or Zenodo, that serve a wide range of research communities and users and have their own set of challenging requirements. “Storage Instances” in that sense are called “Repositories” from here on. They are run and operated by independent entities who in general have no interest to invest resources into fulfilling very specific requirements of FAIRagro. Therefore they are not suited to FAIRly realize the full potential of re-usable, re-combineable, modular computational workflows. The existing repositories are still useful in this context to publish workflows as citeable scientific output that is reliably preserved over long time-spans. However, a programmatically driven, non interactive submission of content is not possible with such repositories, and sometimes even reading data requires interactive operation.

We therefore refrain from a tight technical integration of such repositories into SciWIn. We do expect that users search and find data and code in such repositories, ideally even packaged as a FAIR DO that can be consumed directly by SciWIn. Search of and access to some of those repositories, covering specific needs of FAIRagro and the agrosystem research community is provided by the products of M4.2 and M4.3, the “Middleware” and the “Search Service”, respectively. We consider features for SciWIn-Client that ease the publication of Workflow Objects to such repositories by providing prompting for required metadata and specific formatting of such metadata for selected repositories.

In that context we also consider more domain and/or workflow specific repositories such as Workflow Hub or ARChive.

In addition to SciWIn-Client we are planning to realize a second software-project within Measure 4.4, the **SciWIn-Hub**. The need for SciWIn-Hub stems from the realization that the data repositories (“Storage Instances” such as *e!DAL-PGP*, *Bonares*, *TISDAR*<sup>1</sup> in the proposal)

**Access** to SciWIn-Hub and other services, such as the *FAIRagro Searchable Inventory of Services and Data* (Ewert et al., 2023, pp. 94–96) and compute instances, will be managed by the NFDI-wide Base4NFDI project IAM4NFDI, that is supported by the Working Group Identity and Access Management (Pempe & Politze, 2022). Integration of this AAI solution into FAIRagro is performed by FAIRagro Measure 4.2. **SciWIn-Client** will implement the respective authorization protocol.

**Workflow objects** in the SciWIn-context are data structures that encapsulate the definition of workflows with associated code and data or references to code and data. Since a close collaboration between FAIRagro and NFDI Consortium DataPLANT is established on different levels, we have taken into account their version of a FAIR Digital Object, the **Annotated Research Context (ARC)**, and the established standards on which it is based. These are the **Common Workflow Language** (Crusoe et al., 2022) to specify computational workflows and the **Research Object Crate** (RO-Crate, Soiland-Reyes et al., 2022) as a data structure to package data (which here also includes code and workflow descriptions). While compatibility with the advanced tooling and infrastructure of DataPLANT is an important piece to achieve synergies with this consortium covering a neighboring research domain, CWL and RO-Crate represent the state-of-the art for workflow descriptions and semantically annotated metadata formats. Therefore, they are also used or considered by other NFDI consortial, e.g. NFDI4Ing (Bronger et al., 2022) and NFDI4Health (Löbe & Turner, 2024). Furthermore, the semantic annotation of metadata allows for the integration of such FAIR Digital Objects into knowledge graphs that interconnect different domains.

While we consider the adoption of CWL and the RO-Crate as serialization formats to produce FAIR Digital Objects (De Smedt et al., 2020) as future-proof and highly interoperable choice, true, actionable interoperability doesn’t seem to be feasible with exactly one universal format. We therefore do not consider anymore a single specification of a “workflow object” as a deliverable of Measure 4.4. We rather expect to accept and produce a variety of formats to interact with the external infrastructures and services that turn out to be useful for SciWIn users.

The choice of CWL as workflow description language ensures that workflows created by SciWIn can be executed on a broad range of platforms (CWL community, 2025). However, many of these platforms require significant resources for setup and operation. Different platforms have different sets of compute backends, such as HTCondor, AWS, Azure, SLURM and Kubernetes. Additionally, the interaction with remote **compute instances** differs from platform to platform. Therefore, in order to experiment with remote execution of workflows and be able to pilot the whole range of SciWIn functionality, we have settled on **Reana** (Šimko et al., 2019) as primary execution platform. Originating from CERN, Reana is widely used and under active development since 8 years. Our main reason to settle on Reana however was the fact that NFDI4PUNCH provided us simple access to an instance at the Leibniz-Institute for Astrophysics Potsdam through an informal collaboration. Furthermore, the BASE4NFDI project MC4NFDI (*A Multicloud Infrastructure for the NFDI*) would

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<sup>1</sup>TISDAR is now called “Thünen-Atlas” and refers to the public repository of geospatial data at the Thünen Institute: atlas.thuenen.de.

have ensured robust, well-integrated access to Reana clusters for users of SciWIn. Unfortunately, the MC4NFDI proposal was rejected in the 7th submission round.

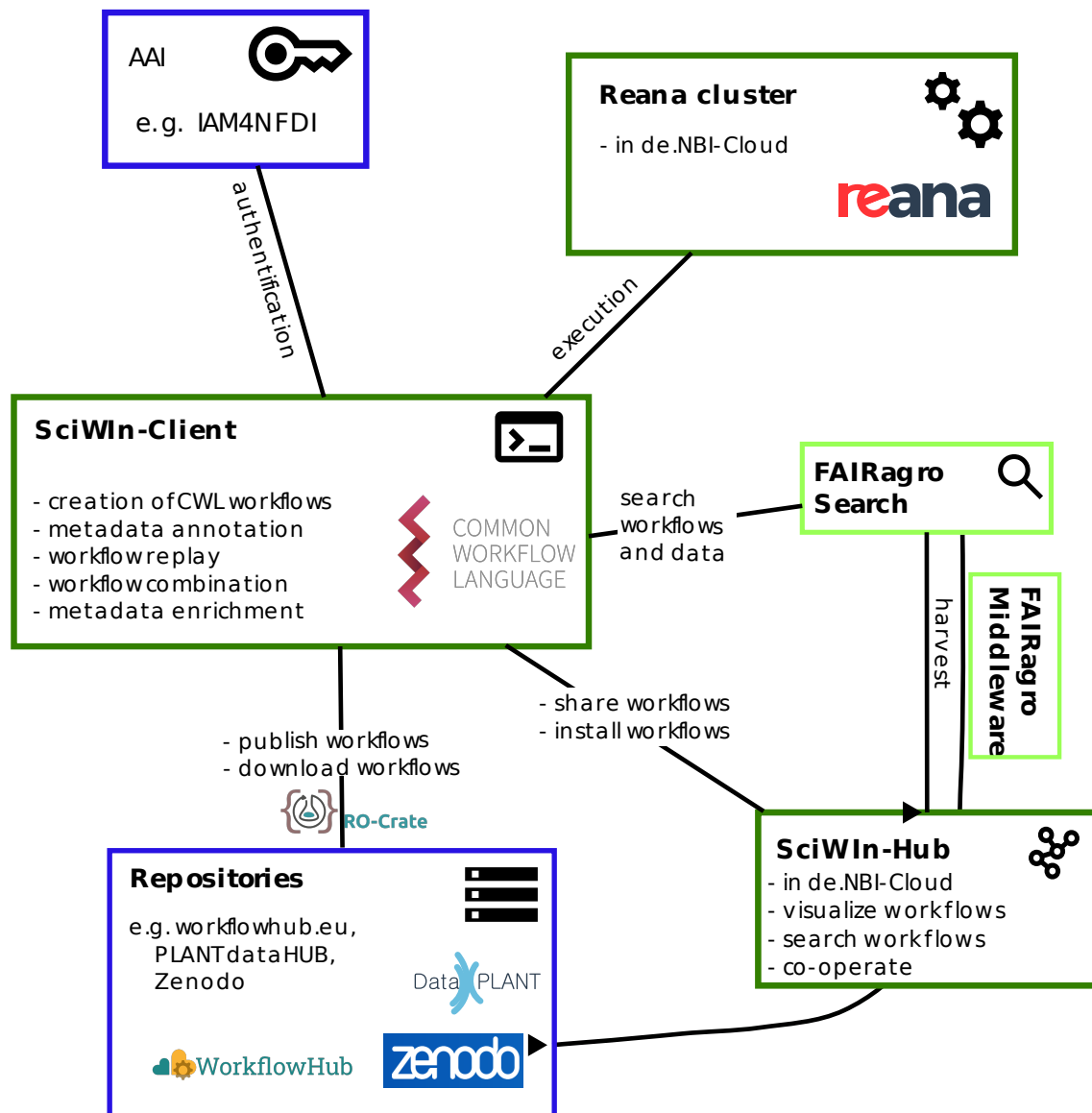


Figure 2: New ecosystem sketch

The main areas of activity of Measure 4.4 / SciWIn can therefore be listed as follows:

### 1. The SciWIn-Client

- effortless recording of computational workflows in CWL
- local and remote execution of computational workflows
- local management of multiple workflows
- import of workflows from remote sources
- export of workflows to remote targets

## 2. SciWIn-Hub

- sharing of computational workflows (up- and download)
- authorization against an AAI
- make workflows available for harvesting by FAIRagro-Search / Middleware
- stage workflows for publication on platforms such as workflowhub.eu, <https://workflow.earth/>, zenodo.org.
- visualization of workflow-graphs
- graphical selection and manipulation

## 3. Reana cluster

- Remote execution of computational workloads
- Capturing of output to produce complete Workflow Run RO-Crates (WRROC, Leo et al., 2024)
- Access management for computational resources

## SciWIn components - details

### Requirements

In proposal driven software development, the textbook recipes for requirements engineering do not work out of the box, since the usual stakeholder-structure is not present. In particular, a priori there are no “users” or “customers” that could be queried for requirements. Consequently, the acquisition of users has to be part of the project.

**The overarching goal or business case** of SciWIn as specified by the FAIRagro-proposal (Ewert et al., 2023) is it to “promote FAIR RDM” by facilitating the reproducibility, the deployment and the publication of data analysis workflows and simulation models.

### FAIRagro-intrinsic requirements

Sources for intrinsic requirements are: - Measure-internal brainstorming regarding personal goals of the developers - regular meetings with colleagues in Task Area 4 - meetings with colleagues from other Task Areas - feedback from the Community Advisory Board

While these requirements are not elicited in a systematic fashion, are expressed subjectively by various individuals and might change over time or assume changing priorities, at the time of writing we identify the following non-functional requirements for the software-output of Measure 4.4:

1. demonstration of a PoC
2. attract real use cases
3. create synergies with other consortia and other external projects
4. generate publications
5. adoption of the software in multiple domains
6. demonstration of research output that was made possible by use of SciWIn
- 7.

## User requirements

In lieu of collecting requirements from the future users that can be found through a customer relationship as in traditional software engineering [see e.g. robertson2024], we initially rely on requirements that we devise ourselves, based on our personal and consulting experience with regard to scientific computing and research data mangement. User requirements might be summarized as

1. create machine readable workflow descriptions
2. integrate naturally into a common comman-line interface oriented style of interactive work
3. have a low threshold of learning before scintific work efficiency increases
4. provide an easy overview of numerous versions, runs, inputs, outputs
5. provide an easy way to annotate worflows for re-used
6. allow to annotate workflows for publication
7. provide a way to publish workflows
8. provide a frictionless way to access remote (powerful) computing ressources
9. provide a tool to

easy-to-use interface to work on and create new FAIR DO outputs with automatically annotated provenance graphs

## SciWIn client

- 
- stakeholders
  - target group
- functional requirements
- non-functional requirements
- tech stack
- use cases
- A client-part that works de-centralized, independent of any central infrastructure as part of the scientists' daily toolset.
- Serves to capture computational workflows with minimal effort in a standards compliant way.

**conceptual challenges**   remote execution Reana wegen Multicloud workflow & data remote reference  
dockerization



## Selection of CWL

### SciWIn-Hub

In progress + requirements + target group + tech stack + use cases

- “CWL package manager”
- Visualisierung von Workflows
- cordra ...

## Development Strategy

The development strategy for SciWIn follows a pragmatic, research-oriented approach that prioritizes reproducibility, interoperability, and ease of adoption by the scientific community. Based on the implementation of the SciWIn-Client as evidenced in the `fairagro/m4.4_sciwin_client` repository, several key strategic decisions have shaped the project’s development trajectory.

### Technology Stack and Language Choice

The selection of Rust as the primary programming language for SciWIn-Client represents a strategic decision to balance performance, safety, and cross-platform compatibility. Rust’s memory safety guarantees eliminate entire classes of runtime errors that are common in scientific computing environments, while its zero-cost abstractions ensure optimal performance for computationally intensive workflow operations. The language’s robust package management system (Cargo) facilitates modular development and dependency management, crucial for a tool that must integrate with diverse scientific computing environments. ### Modular Architecture Strategy

The SciWIn-Client employs a modular workspace architecture that separates concerns into distinct crates, enabling independent development and testing of different functionalities. This architectural decision supports:

- **Maintainability:** Individual components can be updated and tested in isolation
- **Extensibility:** New workflow formats and execution backends can be added without affecting core functionality
- **Reusability:** Core components can be leveraged by other projects within the FAIRagro ecosystem

### Standards-Based Interoperability

A cornerstone of the development strategy is the adoption of established, domain-agnostic standards rather than proprietary formats. The implementation of Common Workflow Language (CWL) as the primary workflow description format ensures broad compatibility with existing workflow execution platforms. This standards-based approach addresses the project’s goal of cross-domain applicability and reduces the risk of vendor lock-in or format obsolescence.

## Developer Experience and Accessibility

The development strategy emphasizes lowering barriers to adoption through intuitive command-line interfaces and comprehensive tooling. The SciWIn-Client provides researchers with familiar Git-like workflow tracking capabilities, allowing them to leverage existing version control knowledge. The tool's design philosophy prioritizes:

- **Minimal learning curve:** Familiar command patterns and clear documentation
- **Offline capability:** Core functionality works without internet connectivity
- **Platform independence:** Cross-platform support through Rust's compilation targets

## Quality Assurance and Testing Strategy

The project implements a comprehensive testing strategy using Cargo's built-in testing framework, with both unit and integration tests ensuring reliability across different operating systems and workflow configurations. The dual-licensing approach (Apache 2.0 and MIT) reflects a commitment to open science principles while providing flexibility for different institutional requirements.

## Incremental Development and Community Engagement

The development follows an incremental approach, with early releases focusing on core functionality and subsequent versions adding advanced features based on user feedback. The GitHub-based development workflow enables transparent community involvement and contribution, supporting the broader NFDI goal of collaborative infrastructure development.

## Integration Strategy

Rather than developing isolated tools, the SciWIn development strategy emphasizes integration with existing scientific computing infrastructure. This includes compatibility with container technologies, support for various execution backends, and design considerations for future integration with Base4NFDI services such as IAM4NFDI for authentication and authorization.

The overall development strategy positions SciWIn as a bridge between researchers' local development environments and distributed computing resources, supporting both current scientific workflows and future infrastructure developments within the NFDI ecosystem.

## Interaction within FAIRagro

SciWIn's integration within the FAIRagro ecosystem is designed to create synergies across multiple measures and task areas while supporting the consortium's overarching goals of FAIR data management and reproducible science. The interaction strategy encompasses technical integration, user support, and collaborative development approaches.

## Technical Integration with FAIRagro Infrastructure

**Search and Discovery Integration:** SciWIn workflows are designed to be discoverable through the FAIRagro Searchable Inventory of Services and Data (Ewert et al., 2023, pp. 94–96). The standardized metadata format based on RO-Crate enables automated harvesting and indexing of workflow descriptions, making computational processes findable alongside datasets. This integration ensures that researchers can discover not only relevant data but also the computational methods used to process and analyze it.

**Middleware Connectivity:** Through Measure 4.2’s service middleware components, SciWIn-Client interfaces with FAIRagro’s broader service ecosystem. This includes authentication and authorization services that will be provided by Base4NFDI’s IAM4NFDI, enabling seamless access to protected computational resources and data repositories within the consortium.

**Data Repository Integration:** While existing FAIRagro data repositories (e!DAL-PGP, BonaRes, Thünen-Atlas) serve as long-term preservation systems for workflow outputs, SciWIn-Hub provides the complementary functionality of active workflow sharing and collaboration. This dual approach ensures both the permanence required for scientific reproducibility and the agility needed for active research collaboration.

## User Support and Community Engagement

**Helpdesk and Support Services:** SciWIn benefits from and contributes to FAIRagro’s distributed support model. Domain experts within the consortium provide specialized guidance on workflow development for specific agricultural and environmental research contexts, while the SciWIn development team offers technical support for tool usage and integration challenges.

**Training and Capacity Building:** The SciWIn team actively participates in FAIRagro’s training and outreach activities, developing educational materials and conducting workshops that demonstrate the integration of workflow management with FAIR data principles. These activities target different user groups, from individual researchers to institutional data managers, ensuring broad adoption across the agrosystem science community.

**Use Case Development:** Collaboration with FAIRagro’s domain working groups has yielded concrete use cases that drive SciWIn’s development priorities. These include scenarios such as multi-site agricultural modeling, environmental monitoring data processing, and cross-scale analysis workflows that combine field observations with satellite data. Each use case informs both technical requirements and user experience design decisions.

## Collaborative Development and Governance

**Cross-Measure Collaboration:** SciWIn development involves close coordination with other FAIRagro measures, particularly Measure 3.5 (FAIR Digital Objects) for metadata standards, Measure 4.2 (service middleware) for infrastructure integration, and various domain-specific measures for use case validation and requirements gathering.

**Community Feedback Integration:** The open development model of SciWIn incorporates feedback from the broader FAIRagro community through regular demonstration sessions, user testing programs,

and participation in consortium-wide technical discussions. This collaborative approach ensures that development priorities align with actual research needs across the diverse FAIRagro partner institutions.

**Standards Harmonization:** SciWIn actively participates in FAIRagro’s efforts to harmonize metadata standards and interoperability protocols across the consortium. The adoption of CWL and RO-Crate supports this harmonization while enabling integration with tools and services developed by other measures.

The interaction model positions SciWIn not as an isolated tool but as an integral component of FAIRagro’s research infrastructure, supporting the consortium’s mission of enabling FAIR and reproducible agrosystem science through enhanced computational workflow capabilities.

## **Interaction within NFDI and beyond**

- BASE4NFDI (KG4NFDI, MC (Reana), IAM4NFDI)

## **Towards the establishment of SciWIn as a common tool for computational workflows**

Use cases, Outreach Workshop, Identify other consortia to co-operate reach out to other communities

## **Quotes to be mined**

Develop the concept of SciWIn (Measure 4.4) jointly together under the umbrella of the NFDI-RDC and collaborate with NFDI4BioDiversity and DataPLANT as well as the prototypic container deployment to the de.NBI cloud node at BLU;

A SciWIn pilot will be rolled out at de.NBI operated by Bielefeld University (BLU).

The concept of data integration is partly described in the RDC mediation layer and covered by semantic tools (Glöckner et al., 2020), and a concept for integrated data and process storage is part of the DataPLANTs ARC model (Krantz et al., 2021), but a fully integrated infrastructure is provided by neither of those consortia. Therefore, Measure 4.4 will extend the two architectural designs and provide a workflow infrastructure that applies the FAIR DO concepts (Measure 3.5), the service middleware components (Measure 4.2) and its own workflow hub as an easy-to-use interface to work on and create new FAIR DO outputs with automatically annotated provenance graphs.

SciWIn will be part of the NFDI cross-cutting topic “RDC implementations”, and therefore, its concept will be developed as a joint effort between FAIRagro, FAIR-DS, Dataplant and the NFDI section, RDC [as part of cross-cutting topics (Ebert et al., 2021)]. Coordinated in Measure 5.3, the SciWIn working group brings these stakeholders together and will be initiated by a kickoff meeting (M4.4.1). Thus, the fundamental principles, architectures and interfaces are described, and a coordinated concept will be created and published (D4.4.1), which will incorporate the RDC ideas and DataPLANTs ARC model.

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