Linkflows: Enabling a Web of Linked Semantic Publishing Workflows

Cristina-Iulia Bucur(✉)

Department of Computer Science, Vrije Universiteit Amsterdam,
Amsterdam, The Netherlands
c.i.bucur@vu.nl

Abstract. In recent decades, the prevalence of the Internet and Semantic Web technologies has shifted the traditional scientific journal publishing framework towards the digital environment. In support of this, ontologies on digital publishing and new forms of granular provenance modeling have been built to support digital publishing. These fine-grained technologies facilitate the decomposition of traditional science articles in constituent machine-readable parts that are linked not only with one another, but also to other related fine-grained parts of knowledge on the Web following the Linked Data principles. However, these resulting digital artifacts of fine-grained knowledge are static objects that do not take dynamic processes, or *scientific workflows*, into account. Additionally, *scientific workflows* are important because they directly produce and consume digital artifacts. In this project, we enable the decentralized execution of scientific workflows of digital artifacts across platforms such that individual steps of single workflows can be distributed. By considering these *scientific workflows*, we can further find new dimensions with respect to the quality and impact of digital artifacts. In our preliminary results we have developed a model that is able to support Linked Data Notifications to demonstrate the feasibility of our approach.

Keywords: Digital publishing workflows · Scientific workflows
Semantic publishing · Semantic web

1 Introduction

Publishing is an important practice, not only in the world of science, but also in everyday life. In the recent years, with the pervasiveness of technology and the Internet, we changed not only the way we do science, but also how we perform and disseminate science. As such, scientific publishing became a more versatile and multifaceted process, but the initial paradigm of publishing has stayed the same despite moving towards a digital environment with new methods of electronic publication including scientific workflows, research protocols and standard operating procedures [25]. Especially in the sciences, moving towards

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a more digital environment and generating digital content seems to be more the rule and challenges the classic ways of publishing.

In this rather new digital publishing context, Linked Data is a framework that supports scientific publications by enabling the exchange, reuse and linking of data on the Web [11]. While the Linked Data set of best practices to connect and publish structured data on the Web is not enough to enable the entire scientific publication process, it is an important layer that facilitates it. The Linked Data principles encourage using dereferenceable HTTP URIs for things like datasets, services, tools, etc. and including links to other URIs. Linked Data also supports provenance (meta-)information about the resources that are linked, thus giving a way to locate various versions of data and access information like ownership and copyright. In turn this would sustain reproducibility.

Reproducibility plays a crucial role in scientific research because it allows others to test, check and verify the validity of one's claims and methods [19] and it permits further collaboration and reuse of scientific discoveries. Unfortunately, according to a recent study published in Nature [23], over 70% of the 1500 interrogated scientists admitted to have failed to reproduce the work of other researchers at some point in time. The FAIR principles for scientific information [22] can be key factors in guiding towards reproducible research. According to these, data should be (i) findable both for humans and machines; (ii) accessible on the long term; (iii) interoperable by the use of shared vocabularies, for example; and (iv) reusable for both humans and machines. And, following these guidelines should, in turn, support reproducibility.

As Mons [10] notices, an important problem with traditional articles and another hurdle in the way of reproducibility is the process of "Knowledge Burying". That is all information is written and published in one bulk of text - the article - that contains the scientific hypotheses, arguments, methods and results. So, in order to extract knowledge from an article and have information in a structured form, additional methods like text mining need to be applied, thus resulting in a loss of knowledge.

In this project we want to investigate new approaches in the digital environment of scientific publishing by combining Linked Data principles to address problems like "Knowledge Burying" of traditional articles. Furthermore, we want to provide a framework that supports scientific workflows for digital artifacts. As such, we aim to link and connect the static products of dynamic processes - digital artifacts - to the processes that produce and consume them. The main innovative aspect of this research is the fact that scientific workflows are executed decentrally and linked across platforms, such that individual steps of a single workflow can be distributed. Moreover, these scientific workflows will be used to create new quality dimensions of digital artifacts that take into consideration the dynamic processes that produce and consume them. Thus, by using new and existing Semantic Web technologies we will support the reproducibility of scientific research, the exchange, reuse and linking of all digital artifacts involved in scientific workflows.

2 State of the Art

In the last 25 years, scientific publishing has evolved from the form of a traditional, paper-printed article, to electronic publishing of scholarly journals. Accessing research publications without the restriction of subscriptions is the idea behind Open Access journals. These journals have been growing in number faster than traditional subscription journals [1]. Consequently, debates were raised whether the Open Access system is damaging the peer-review system and puts the quality of scientific journal publishing at risk [24]. In [13] the authors mention that semantic publishing is inevitable and that it will happen in incremental steps as it is already possible to publish data as RDF statements in the Linked Open Data Cloud [21]. Semantic Web technologies have launched a revolution in the field of scientific publishing and the idea is to create and facilitate an open access ecosystem where both content and metadata of scientific articles is accessible, together with formalized internal structures of the documents and components, enriched and with semantic connections to other related or similar documents.

In the view of the prevalence of the Semantic Web, considerable research has been done in enriching the meaning of a traditional article in the digital publishing environment, facilitating its automatic discovery, having access in a semantic way to and within the article and also being able to link to other related articles or other related parts of articles. Especially notable in this sense are the SPAR ontologies [27], the ontologies central to the task of semantic publishing. All these techniques, methods and approaches can facilitate the scientific publishing domain and our research.

As datasets, documents and, in general, knowledge is spread in the web of the Internet, where everything can be shared and reused and linked, decentralization is a key concept. Decentralization implies that there is no control of a central authority anymore, e.g. a publishing house, over the open content that exists on the Web. There is a lot of research in this area of computer science, but we will focus especially on technologies related to the field of digital scientific publishing. In the past, techniques to ensure the functioning of a secure and decentralized global file system over the Internet to entice collaborations have been described in [12]. Then, the BitTorrent communication peer-to-peer file sharing protocol over the Internet to distribute and access data in the digital publishing environment was studied in [20], while peer-to peer networks for RDF data were developed in [17] and a decentralized architecture to support nanopublications, scientific RDF snippets, was built in [30].

In terms of assessing the quality of scientific publications, the most widely used indicator is the Journal Impact Factor (JIF) [15], but this metric has been the subject of multiple debates in the past as it was shown that it can be favourably manipulated [28]. For example, the JIF can be biased towards journals that publish high number of non-research items (e.g. research notes, comments) and have higher publishing numbers [14]. So, new ways of rating the quality of scientific publications is needed. Semantic Web technologies with ontologies like the Dataset Quality Information (daQ) [18] can support better

and unbiased measures of quality, while new dimensions of quality that consider these technologies need to be taken into account.

In order to support provenance and reproducibility in scientific publications, we consider the notion of scientific workflows. While *scientific computational workflows* are mechanisms to specify and automate repetitive tasks for computational science or in silico science [16], we take into account not only these fully automated and computational workflows, but a more general concept of scientific workflows. Mainly, a *scientific workflow* as a set of inter-connected steps that produce and consume objects or digital artifacts that together combine for a certain result goal. This provides concrete specifications of workflows involved in scientific publishing that can be digitally stored themselves and allow for their automated execution. Additionally, we allow for abstract definitions or templates of scientific workflows or scientific workflow steps that can be executed by users.

3 Problem Statement and Contributions

This research PhD project will be guided by a main research question:

How can scientific workflows that produce and consume digital artifacts be assessed, linked and decentrally executed across platforms, such that individual steps of a single workflow can be distributed?

Digital artifacts can be considered all objects or resources that belong to a scientific publication, such as text, datasets, code, multimedia objects, spreadsheets, reviews, figures, methods, protocols, and results. The *scientific workflows* refer to processes, actions or operations that produce or consume these *digital artifacts* like authoring, revising, editing, reviewing, commenting and annotating. A single scientific workflow can be composed of multiple steps and we argue that these various steps can be spread on various platforms like repositories, code bases and collaboration platforms. The innovative aspect of the project is that one platform would not be in full control of the complete workflow, but would provide the means to link to a workflow step as it is produced. Thus, a complete scientific workflow of a digital artifact would then be composed of these workflow steps that are distributed on different platforms. As such, the static digital objects will be linked to the dynamic processes that contain them. Another innovative aspect lies in the fact that new quality and impact measures of digital artifacts can be derived by considering the workflows that consume and produce them.

Different aspects of the main research question are captured by four sub-research questions:

1. *How can we model the decentralized execution of workflows by using Linked Data principles and tools?*
   First, we would like to be able to model scientific workflows. For this, we will provide and build the necessary framework based on PROV-Pings [3] and Linked Data Notifications (LDN) [4], to enable notifications across platforms and tracking of provenance of various scientific workflows. We will use Linked Data principles like dereferenceable URIs using open standards like RDF to

publish and link workflows. When workflows are modelled using the Linked Data principles and tools, we call them linkflows, the Linked Data version of workflows. To evaluate the model we will use a case study of at least 20 scientific articles together with their scientific workflows including reviewing and authoring. The innovative aspect is that workflow steps that are produced on various platforms are linked and then they are reused and consumed on other platforms.

2. *How can we execute workflows that produce and consume digital artifacts?* This research question allows the creation and execution of the workflow steps modelled previously. Through a software prototype, users will be able to create workflows for a selected corpora of digital artifacts, for example to generate a review. This software prototype will connect and enable linked workflows to flow across platforms and as such involve resources without involving the platform that contains a certain workflow step. This means, for example that the review that was created can be accessed by various interested parties, like online journal editors, who can consume it further by including the review in their own submission system. The innovative aspect that this sub-research question addresses is the same as in the first sub-research question, producing and linking workflows across platforms and consuming them on other platforms. The difference here is that the scientific workflows will be created in an automated manner with a focus on workflow decentralization and the small granularity of digital artifacts.
3. *How can we automatically analyze digital artifacts and assess their quality and impact based on the linked workflows that produce and consume them?* In this research question we want to analyze the workflows in which digital artifacts were produced and consumed. The goal is to evaluate the quality and impact that these digital artifacts have based on the workflows they are part of. For this, we will build a prototype of a user interface that makes visible the connection between the digital artifact and the workflow that generated it. Next, we will develop metrics to measure the quality of a digital artifact based on the linked workflows that produced it. Moreover, analyzing the workflows that consume the digital artifact, we would be able to measure the impact of the artifact. The innovative aspects here are two-fold: first, tracking and visualizing the workflow steps and the digital artifacts that contain them and second, enabling new ways of measuring quality and impact of digital artifacts that do not rely only on the analysis of their provenance, but how they participate in the flow of dynamic processes, thus in linked workflows across platforms.
4. *Can we use digital artifacts and the linked workflows that contain them to support inquires from users?* This last sub-research question will bridge and blend all previous aspects together. An inquiry consists of searches of digital artifacts. The search results will contain not only the static object, the digital artifact, that is relevant for the inquiry, but also the workflow(s) that produce and consume that digital artifact, together with metrics like quality and impact. Moreover, users would be able to generate workflows for digital artifacts at the same time.

So, a comment or a review could be added for a digital artifact, opening the execution of workflow steps for users. The innovative aspect would be two-fold: first, the inquiry responses will contain not only the corresponding digital artifact(s) of interest, but also the linked workflows that contain them and second, users would be able to produce, consume and execute workflows for digital artifacts on the fly.

4 Research Methodology and Approach

In order to answer the research questions from Sect. 3, we will move away from the idea of a traditional scientific article. We will consider digital artifacts as "universal entities" or objects that can be in the form of text, figures, datasets, code, presentation slides, multimedia objects, etc. as represented in Fig. 1. Each of these digital artifacts can be represented in the form of a node in a network. As such, a classical scientific PDF article is comprised of various digital artifacts like text, figures, datasets, code, etc. that are inter-connected. These digital artifacts are considered first class citizens and all bear the same importance. Connections between the nodes of this network of digital artifacts are links, as in Web links.

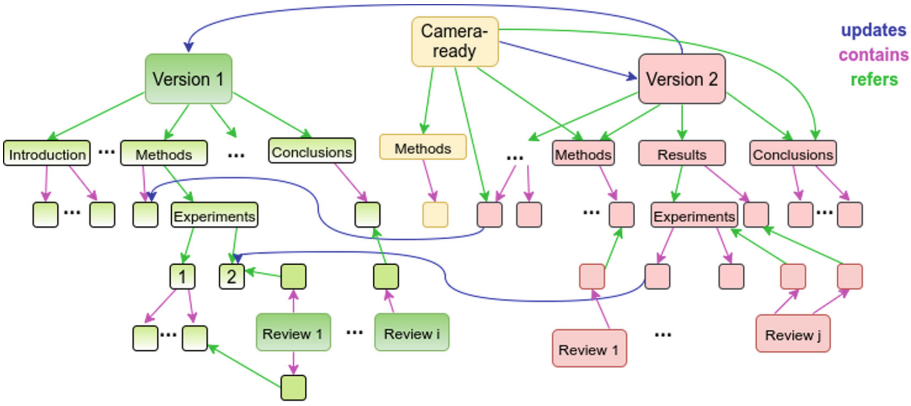

Fig. 1. Traditional scientific article represented as interconnected digital artifacts.

The digital artifacts that connect together to form a scientific contribution are involved in specific scientific workflows for their production and even when they are consumed by various systems, platforms and users. A scientific workflow involving a digital artifact is the collection of processes and actions that the digital artifacts undergo in science, like reviewing, commenting, annotating, etc. The linked workflows of a digital artifact are called linkflows. As such, either small steps of these workflows or entire workflows on a digital artifact are open

and distributed in the sense that they can be produced on one platform and consumed on another, thus allowing the smooth flow of a workflow across platforms. This means, for example, that a review of a digital artifact can be produced on platform A, but platforms B and C can get notified of this review and consume or use it on these platforms. In the same way, a scientific workflow can contain multiple steps and these steps can be executed on different platforms, but linked together to form a coherent flow.

Considering this networked structure, when modifications are made in the network of a scientific contribution, notifications can be sent around about the changes as these propagate through the network. Here PROV-Pings [3] and Linked Data Notifications [4] technologies will help in sending notifications to the interested parties. But, every node in the network, thus each digital artifact, can be considered a fixed and immutable entity making provenance and versioning possible. Using Trusty URIs [29] and the use of hashes can help in establishing and tracking the changes that a digital artifact goes through.

In this project we will collaborate closely with two organizations:
Use case 1: The Netherlands Institute of Sound and Vision[1] - the biggest audio-visual cultural archive in the Netherlands having almost 70% of the Dutch audio-visual heritage under its tutelage. For this project, we will work closely with two open access media historical e-journals: VIEW Journal of European Television History and Culture and Tijdschrift voor Mediageschiedenis.
Use case 2: IOS Press[2] - an independent publishing house that has about 100 journals (mainly focused on medicine, but also from scientific and technical domains) and around 130 books published annually. For this project we will consider two of the open access journals that are printed by IOS Press: one in the computer science domain, the Data Science Journal, and a journal from the medical domain, the Journal of Alzheimer's Disease Reports (JAD Reports).

Throughout this project, we will implement, test and evaluate the linked workflows (linkflows) on the journals or datasets described in the use cases above. The diversity of the domains, ranging from audio-visual and multimedia to computer science and medicine will ensure a complex coverage of our project.

5 Preliminary Results

For answering the first sub-research question, we model the workflow steps of a journal submission using the Linked Data Notifications (LDNs) protocol [4]. To support this, we use the LDN protocol, but we might also consider OWL-S ontology [5] in the future to describe in more detail the semantic web services that are used.

First, we chose a PDF article from the Data Science journal from IOS Press [26]. This article has two versions, three reviews for each version and a final, camera-ready, version. Next, in order to analyze the publishing workflow of this

[1] https://beeldengeluid.nl/en.
[2] https://www.iospress.nl/.

article at a more granular level, we decomposed it into more fine-grained interconnected parts or digital artifacts and represented them as nodes in a network. For this we mainly used the SPAR ontology suite [8] to decompose the bulk of PDF text into separate paragraphs with semantic meaning, used PROV-O [7] to model the provenance of these digital artifacts, the FAIR* reviews ontology [2] for modeling the reviews and the Web Annotation Data Model [9] for modeling information or connections between certain nodes in this network. The online repository of the model can be found online [6]. In total we had 284 nodes and 685 links. In the future we will use the LDNs protocol to model all the workflow steps in which the digital artifacts that comprise this article are involved.

6 Evaluation Plan

Throughout the various stages of our research methodology we will perform various evaluations to assess the validity of our results. For this we will mostly consider the use cases provided by the Netherlands Sound and Vision and IOS Press.

For the first sub-research question, where we want to model the decentralized execution of workflows, for a more complex evaluation we will use two different use cases: (i) we will manually model around 20 published scientific articles together with their scientific workflows; (ii) we will use the automated extraction of information from a bioinformatics repository already curated by experts, e.g. DisGeNET, "one of the largest and comprehensive repositories of human gene-disease associations currently available". For the evaluation we will conduct a qualitative analysis on the corpus of selected scientific papers and on the bioinformatics repository. We will consider reviews content, comments and annotations and how these relate to the structured parts of the article or of the bioinformatics repository.

For the second sub-research of how we can execute workflows that produce and consume digital artifacts, we will use the manually created model from the first step. The prototype that we will build will provide the software means to create a fully decentralized reviewing workflow. For evaluation purposes, we will conduct a controlled user experiment where we will ask participants to evaluate both the user interfaces, as well as the new way the reviews are conducted and how these reviewing workflows are generated by comparing it with how this process was carried on previously.

The third sub-research question addresses new ways of evaluating the quality and impact of a digital artifact based on the analysis of the workflows that produced and consumed the respective artifact. Here, we will develop new metrics for quality assessment of digital artifacts based on the scientific workflows that produce them, like reviewing. We will also develop a metrics for the impact that a digital artifact has based on the workflows that consume it. To evaluate these two metrics, we will first use nichesourcing (crowdsourcing with experts). At the same time, we will use existing data to import workflows and use it as a ground truth for generating the workflows.

For the fourth sub-research question, where we want to be able to provide answers to inquiries made by users, we will develop a prototype that can return digital artifacts in response to user queries, together with the linked workflows that contain them. Furthermore, users would be able to create on the fly workflows for digital artifacts. For evaluation, we will use crowdsourcing to evaluate the software prototype in terms of the relevancy and the results that are returned as answers to user inquiries and also for rating the creation and execution of workflows on digital artifacts.

7 Conclusions

This project address issues like provenance and reproducibility in scientific publications and the support for a descentralized system of publishing in which scientific workflows can be modeled using Semantic Web technologies. We also define alternative ways of assessing the quality of scientific publications based on the more granular representation of digital artifacts involved in scientific workflows. This fine-grained representation of digital artifacts in the form of a continuously-expanding network of digital artifacts supports in turn the more granular execution of scientific workflows and workflow steps, allowing for greater transparency and descentralization of scientific workflows like the peer review process. This new way of publishing digital artifacts by considering the *scientific wokflows* that produce and consume them will improve the dissemination, transparency and reproducibility of science in the future.

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