Contents

Abstract

Solid, for **So**cial **Li**nked **D**ata, is a new web standard that gives users control over their online data. Developed by the inventor of the World Wide Web, Sir Tim Berners-Lee, it aims to decouple web applications from data. In a Solid environment, users own a Personal Online Datastore (Pod) and consume solid-apps. A solid-app is a zero data web application that is connected to the user's Pod and reads or writes data on the user Pod instead of its database.

CERN, the birthplace of the Web, is interested in Solid and has defined a project to investigate how Solid could be used inside CERN's infrastructure. In particular, CERN shows interest in deploying its Solid server. A Solid server's goal is mainly to serve Pods and handle authentification through an Identity Provider (IDP). Community Solid Server (CSS), released in August 2021, is one of the first open-source Solid servers that implement the Solid specification [css readme]. The central goal of this thesis is to investigate CSS as a solution for CERN's Solid server needs by deploying a CSS instance inside CERN's infrastructure.

The investigation concludes that even if CSS, and mostly its ecosystem, lack maturity, CSS is a software of high quality, with remarkable plasticity and a viable long-term solution for CERN to a certain discussed extent.

1 Context and terminology

In this chapter, we will describe the principal elements needed to understand the context and motivation of this thesis. First, we will go through a quick recall of the history of the web and its current challenges. Then we will talk about the motivation behind Solid and describe its main components.

1.1 History and current state of the World Wide Web

In the 1980s, the European Organization for Nuclear Research, also known as CERN, was looking for a way to make physicists easily share their work and data around the globe. Internet was at its beginning, the TCP/IP protocol was freshly invented, but at this time, sharing data across multiple computers was laborious and inefficient[1]. A layer was lacking to write, transmit and store information easily through the network. In 1989, Sir Tim Bernes Lee submitted a proposal for an information management system to tackle the former issue with new concepts such as hypertext links, web browsers, the HTML language, and the HTTP protocol[2] [3].

On 1991 August 6, the first website available on the world wide web, "http://info.cern.ch" was born.

Today's web might be far from the decentralized digital utopia imagined by Sir Tim Berners Lee in the early 90s. Currently, most services, data, and patents related to web technologies belong to only a few companies, commonly referred to as GAFAM[4]. This oligopoly is in part due to a phenomenon called the "vendor lock-in": users tend to stay with the same platform since it is too hard to switch to another one . Furthermore, the centralization of web services and data has been a the heart of the latest internet scandal such as Cambridge Analytica or the worldwide NSA information gathering revealed by Edward Snowden[5].

1.2 Solid: Tim Berners-Lee proposal to Re-Decentralise the web

To tackle those problems, Tim Berners-Lee has started the Solid project in 2016 as a mean to re-decentralize the web[6]. Solid take advantage of the Semantic Web (also known as Web 3.0 but not to be confused with web3), a new set of standards extending the current World Wide Web to make the internet's data machine-readable. It is made machine-readable through Linked Data, a new

[1] https://eu.usatoday.com/story/tech/news/2019/03/12/world-wide-web-turns-30-berners-lee-contract-thoughts-internet/3137726002/

[2] https://www.vox.com/2019/3/12/18260709/30th-anniversary-world-wide-web-google-doodle-history

[3] https://www.w3.org/History/1989/proposal.html

[4] https://www.cairn.info/article.php?ID_ARTICLE=COMLA_188_0061#

[5] https://www.theguardian.com/technology/2018/sep/08/decentralisation-next-big-step-for-the-world-wide-web-dweb-data-internet-censorship-brewster-kahle

[6] https://en.wikipedia.org/wiki/Solid_(web_decentralization_project)

way of formatting structured data to ensure its integration, interpolation, and interpretation by machines in the Semantic Web. Solid - sometimes stylized SoLiD - stands for **So**cial **Li**nked **D**ata. It aims to give back data control to internet users and improve their privacy online. Solid is not a technology in itself, but rather a set of specifications that allows decoupling of web applications' authentification, data, and app logic[7] . The end goal is to give internet users complete control over their data[8] . However, the web needs a couple of new artifacts and vocabulary to allow this decoupling; the two most important are the Pod (decoupling data storage) and the Identity Provider (decoupling authentification).

A Pod (Personal Online Datastore) is where Solid users store their data online. Like a Unix filesystem, the WAC (Web Access Control) controls who can read, write or delete files stored in a Pod. Each of these permissions is defined in `.acl` "Access Control List" files, hosted on the Pod itself[9].

WebIDs are the standardization of a universal identifier used for authentification. More than replacing the traditional username, it is a full URI that, once dereferenced, can give more information on the end user. It usually has the form of:

`https://my-webid-host.net/my-username/profile/card#me`

The Identity Provider (IDP) permits the user to login into various applications with their WebID in the fashion of today's "Sign in with Google/Facebook". It uses The Solid-OIDC protocol - built on top of Open ID Connect - that manages authentification in a Solid environment.

Identity Provider and Pod Provider are two decoupled services, but a Solid Server usually serves both.

Let us illustrate all those new terms with an example: Alice has a pod hosted on `http://alice.pod.org` where she stores her data, including a holiday picture at `http://alice.pod.org/picture/holiday.png`. By associating the `READ` permission to Bob's WebID `https://bob.anotherpod.org/profile/card#me` in the ACL file `http://alice.pod.org/picture/holiday.acl`, now Bob, if authenticated with his WebID will be authorized to access the picture at `http://alice.pod.org/picture/holiday.png`.

Those specifications are developed by the World Wide Web Consortium (W3C), an organization of web standard founded by Tim Berners-Lee, which promote technologies compatibility around the web. Tim Berners-Lee has also created a startup called Inrupt that aims to build a Solid commercial solution. Inrupt is financing a team of researchers from Ghent University to develop the Community Solid Server.

[7] https://solid.github.io/specification/protocol
[8] https://en.wikipedia.org/wiki/Solid_(web_decentralization_project)
[9] https://en.wikipedia.org/wiki/Solid_(web_decentralization_project)

1.3 Solid Community Server, an implementation of the Solid specifications

The Community Solid Server is an open-source Solid Server - i.e. a Pod and Identity Provider - that implements Solid Specification. It can also deliver WebIDs. Currently, only two implementations fulfill the Solid-specification: CSS and NSS (Node Solid Server). CSS can be considered a new replacement for the legacy NSS that power `https://solidcommunity.net`, currently the most used solid server. CSS is a newborn software under active development: version 1.0 was released in the symbolic month of August 2021, exactly 30 years after the World Wide Web first webpage, and version 3.0 was released the 23 February 2022 [10]. Inrupt financially support IDLab from Gent University (Belgium) to build the software . It's copyrighted by Inrupt and IMEC research and development hub under the MIT license. Built in a modular fashion, it has been designed for researchers and developers who want to test Solid App and/or design new features and experience with Solid[11]. Such modularity is empowered using components.js, a dependency injection framework at the core of CSS.

1.4 Component.js: a dependency injection that powers CSS modularity

Component.js is a javascript dependency injection developed by CSS authors. A Dependency Injection (DI) implements a form of inversion of control, a programming principle where part of a program receives its execution flow from a framework. Dependency injection will dynamically create (inject) the dependencies between the different components of a computer program. Therefore, the program execution flow is expressed not only through static code but also dynamically assigned during execution. In particular, components.js lets us describe the dependencies between CSS components from a JSON configuration file. Even if the CSS authors have written components.js mainly to answer CSS needs, it has been built as a general-purpose dependency injection framework and can be used for other software.

The innovation of components.js, compared to other javascript DI frameworks such as `inversify` or `typedi`, is to be built around the concept of Linked Data. In other words, the configuration files leverage the power of the semantic web: each component can be uniquely and globally identified through a URI. Furthermore, having configuration files machine-readable and built under the same vocabulary and makes it easy to generate, parse, compare, or edit them in a script.

[10] https://github.com/solid/community-server/releases
[11] https://github.com/solid/community-server/

1.5 CERN's IT infrastructure

CERN is primarily a high-energy physics laboratory. Counting 12,400 users from instititution from more than 70 countries [12], strong computing infrastructure is of paramount importance. To facilitate the host and deployment of web applications inside its computing environment, CERN has deployed a Platform-as-a-Service (PaaS) to its users.

PaaS is a cloud computing service meant for developers. Its goal is to simplify workload by offering the developer to quickly initiate, run and manage one or more web applications without worrying about the computing infrastructure part such as networking, storage, OS and others. [13]

OKD4 or Openshift 4 is Red Hat's PaaS solution. The community version used at CERN is free and open source under the Apache 2 license [14]. It is powered by other popular open-source technologies such as Docker and Kubernetes.

CERN's Openshift allows its developers to quickly deploy web applications with strong DevOps tooling and provides them with a high-level integration to CERN's computing environment, such as user and access management[15].

1.6 Thesis' plan

The main goal of this thesis is to investigate CSS by deploying a CSS instance inside CERN's infrastructure. First, we will explore the current solution for CSS regarding Single-Sign-On and User Interface integration. Next, we will describe a particular recipe we build for CERN and argue on our design choices. Subsequently, we will show the DevOps pipeline used to deploy our recipe to CERN's infrastructure. Finally, after explaining a potential security risk with Pods-hosted webpage, we will finish reviewing the software quality and open source dynamics.

2 CSS current status

In this section, we will discuss the current status of CSS toward UI and Single-Sign-On (SSO) compatibility. First, we will investigate CSS compatibility with CERN's SSO provider Keycloak, particularly a proxy solution developed by Digita. Then we will analyse, compare and test potential UI for CSS, as CSS comes default without (or a very minimalistic) UI. We will draw conclusion on the available UIs.

2.1 Single-Sign On Investigation TODO??

- tests with Digita proxy

[12] https://en.wikipedia.org/wiki/CERN
[13] https://en.wikipedia.org/wiki/Platform_as_a_service
[14] https://okd.io/about/
[15] https://paas.docs.cern.ch/]

  - successfull on localhost with custom made app
  - not successfull with third party app such as penny because of difference in login interaction -> dropped
- General purpose MITMproxy setup to analyse Solid Server <-> Middleware <-> Keycloak

2.2 Pod UI comparison

This section compares different UI candidates for our CERN's CSS instance. If the UI is not compatible with CSS, we will investigate the root cause of the incompatibility. Finally, we will discuss the states of CSS compatibility with UIs and the options for CERN's CSS instance.

Definition

A *Pod UI* (also called an *UI* in this paper) is a particular type of solid application strongly related to a Pod or a WebID hosted on a solid server. We expect most of its features to be related to the agent (user or organization) represented by the WebID or interacting with the Pod content. Examples of standard features of a solid server UI can be:

- a Pod file browser: allow users to explore and manage all the content of a Pod: add, edit or delete files, manage ACL authorization.
- a profile page: create and manage information about the Pod's owner's personal information and WebID (as name, profile picture among others)
- contact or friends list related to the WebID
- chat and messaging: communicate with the agent represented by the WebID

Where to host a solid server UI

As seen in figure 1 , the Pod UI can be hosted in three different locations.

- As an **external app**: hosted on a different server, the UI will still be able to interact with the solid server if the user provides the correct permission upon login. Compared to the two others options, it differs strongly by being hosted on a different URL than the Pod's URL and the WebID URL.
- As an **internal app**: by creating a recipe with a particular components.js configuration, it is possible to host a Pod UI alongside CSS . In order to do so, a new node in the dependency injection graph needs to be added to create a `DefaultUiConverter` class that shall point to the UI entry point (usually an `index.html` file). Currently, two recipes exist, one using Mashlib and another using Penny as a Pod UI (those two are also available as an external app).
- As a **Pod-based app**. It is possible to host HTML files on a Pod and serve them with the correct content type, so they get interpreted as client-side web applications by the browser. Using Inrupt Solid client-side library, one

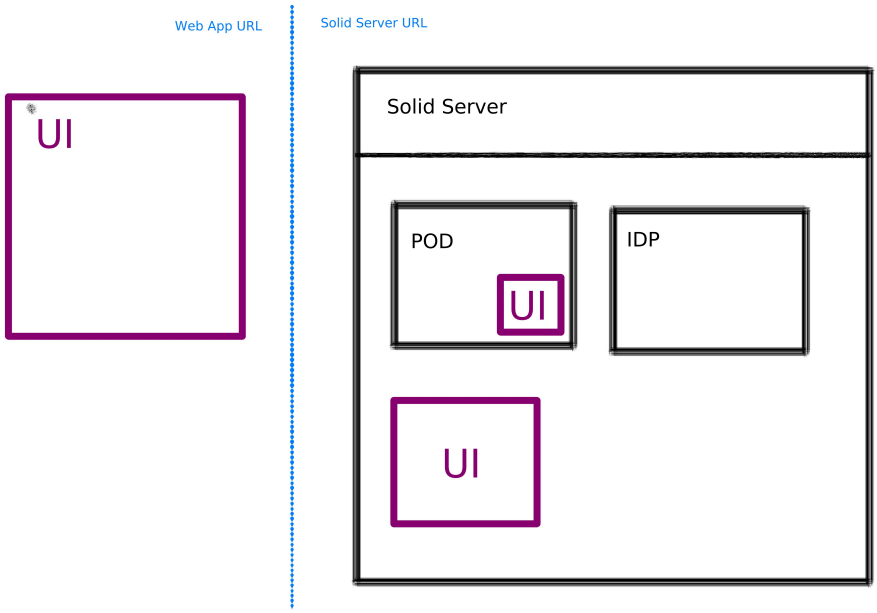


Figure 1: Different locations of a Pod UI

can build a solid application and, therefore, a Pod UI. Pod-homepage is an example of such Pod UI.

2.2.1 UI comparison

In the following, we will experiment and test different Pod UI solutions against our CERN's CSS instance. Then, we will discuss the main differences between each solution and argue which solution we choose for CERN's use.

After researcheses, we could find the following candidates:

- oh-my-pod
- Inrupt's PodBrowser
- Penny
- Pod-homepage

For each of the candidates, we tested:

- CSS integration: can the UI be integrated into a CSS instance
- Pod Browsing features: How does the UI help the user manage the content of their Pod, which includes:
  - Browse Pod's content
  - Add a document to the Pod
  - Delete a document hosted on the Pod

  - Edit a document hosted on the Pod
  - Edit `.acl`: from the UI edit `.acl` files to manage access right

- Profile's features: How does the UI can represent the owner of the Pod, which includes:
  - Display profile: when accessing the WebID URL, the UI display a profile page with the user's information
  - Edit profile: a particular page is available in the UI to modify the user's profile information. Of course, if the UI offers the possibility to edit pod content, it should also be able to create and edit profile documents. However, in this test, we would like to see a dedicated interface where the user should not directly modify the source turtle file.

2.2.1.1 testing external app In the following, we tested the 3 UIs available as external UI: Vincent Tunru's Penny UI, Inrupt's PodBrowser and Empathy's oh-my-pod. For the "Display profile" criteria, the None Applicable value is given by default, as this is only relevant when the UI and the Solid Server are delivered under the same URL (which is not the case for external UI).

2.2.1.1.1 Penny https://penny.vincenttunru.com/

- CSS integration: OK
- Browse Pod's content: OK
- Add a document: OK
- Delete a document: OK
- Edit a document: OK
- Edit `.acl`: OK
- Display profile: NA
- Edit profile: NO

2.2.1.1.2 oh-my-pod https://ohmypod.netlify.app/

We could not log in using our WebID hosted in CERN's CSS instance. The error "WebID is not valid" is returned by oh-my-pod login page during the sign-in process, and an error `POST https://css.app.cern.ch/idp/reg 400 (Bad Request)` is prompted in the console. We found out that the issue comes from the library used for the sign-in. The library uses a depreciated username/password login only supported on NSS. More recent solid servers such as CSS and ESS use the safer sign-in based on JWT web token. Therefore, the oh-my-pod sign-in procedure needs to be updated to support JWT web-token-based authentification to be compatible with CSS. https://github.com/solid/solid-node-client/issues/15

We decided to bypass the error by signing in with our NSS account hosted on `solidcommunity.net` to be able to test oh-my-pod features.

- CSS integration: NO

- Browse Pod's content: OK
- Add a document: Not Working ERR: 403 forbiden
- Delete a document: Not available
- Edit a document: OK
- Edit `.acl`: NO
- Display profile: NA
- Edit profile: OK

2.2.1.1.3 Inrupt's PodBrowser https://podbrowser.inrupt.com/

Similar to oh-my-pod, we could not log in from our CSS instance. Inrupt's PodBrowser is mainly developed to work with Inrupt's Enterprise Solid Server. According to Pod Browser developers, the UI is having trouble upgrading to the latest version of the authentification library, which causes compatibility issue with CSS [https://github.com/inrupt/pod-browser/issues/449#issuecomment-1074175962] Nevertheless, PodBrowser is compatible with NSS, so we tried the UI with our `solidcommunity.net` account to test its features.

- CSS integration: NO
- Browse Pod's content: OK
- Add a document: OK
- Delete a document: OK
- Edit a document: OK
- Edit `.acl`: OK
- Display profile: NA
- Edit profile: OK

In fine, we can see that only Penny shows compatibility with our CSS instance. However, an important note is that it will split the UI and CSS-related functionality into two URLs. For example, The registration and password reset page will live under the solid server URL, whereas all the UI functionality (Pod browsing, profile page, contact ...) will live under the external Pod UI URL. We will debate the potential consequences of this split in the discussion section.

2.2.1.2 testing internal Pod UI

2.2.1.2.1 Penny

- CSS integration: OK
- Browse Pod's content: OK
- Add a document: OK
- Delete a document: OK
- Edit a document: OK
- Edit `.acl`: OK
- Display profile: NO
- Edit profile: NO

Pod Browser and oh-my-pod would not work as an internal Pod UI for the reasons mentioned in the previous section. Yet, this compatibility gap might be closed in the future. For that reason, we still tried to create recipe to see if the UI could be integrated into CSS even without working.

For Inrupt's solution, we could not build and run the standalone client-side app. The easiest way to integrate a UI to CSS is to have the UI in the form of a standalone client-side web application; this is how the Mashlib and Penny recipe are built. Then, we can use componentsjs to create a `DefaultUiConverter` class that will point to our UI web application entry point. However, PodBrowser needs to be run as a server-side application [https://github.com/inrupt/pod-browser/issues/449#issuecomment-1075678127]. With compentsjs it is possible to use a server-side UI application, but such a configuration needs to be built from scratch. Of course, this work would only be worth it once the authentification compatibility issue is solved. Therefore, we did not investigate this solution further.

Similarly, we could not run oh-my-pod as a standalone client-side app, but we were able to connect to an NSS account when run as a server-side app.

2.2.1.3 Testing Pod-based UI Finally, we tested Pod-homepage, the only Pod-based UI we have found. Unfortunately, Pod-homepage uses a depreciated solid authentification library that does not support JWT web-token-based sign-in. Therefore, we could not test the UI as it needs to be upgraded from solid-node-client[https://github.com/solid/solid-node-client] to Inrupt's solid-client-authn-js [https://github.com/inrupt/solid-client-authn-js] to be compatible with CSS.

2.2.1.3.1 Pod-homepage

- CSS integration: NO
- Browse Pod's content: Partially: only shows root's files
- Add a document: NO
- Delete a document: NO
- Edit a document: NO
- Edit `.acl`: NO
- Display profile: YES
- Edit profile: NO

2.2.2 Discussion

From our tests, we can see that the majority of the UI candidates, Penny exepted, are incompatible with CSS, primarily for authentification compatibility reasons. Solid specifications are still in a magmatic state and evolving fast [https://github.com/solid/specification]. Therefore, it is not always easy for solid applications to keep up with the specification. Unlike the legacy NSS, CSS uses stronger authentification based on web token rather than username/password . Unfortunately, most of the UIs are built and tested toward NSS. Penny seems to

be the most suited UI candidate for CSS, even if it only provides Pod managing features.

Contrary to external UI, Pod-based and internal UI is reachable from the same URL as the Pod URL or the WebID. Since the user will not have to remember a second URL for the UI of their Pod, we can argue that they both offer a better user experience. For example, two URLs are presented to the user after a CSS registration, the Pod URL and the WebID. We can easily assume that one of the first actions taken by the user after the registration will be to click those URLs. Therefore, we believe that it makes more sense if those URLs dereferences to a Pod UI instead of raw data.

Pod-based and internal UIs, even if they both live under the solid server URL, still have their differences. A Pod-based UI will be accessible from the path where it is stored on the Pod. For example, if the CSS user Alice uploads a UI on her `ui` folder, the UI will only be accessible from `http://my-css-instance.net/alice/ui/index.html`, assuming that the UI is contained in an `index.html` file. Therefore it is also directly accessible from `http://my-css-instance.net/alice/ui/`. The UI will not be accessible from, for example, `http://my-css-instance.net/alice/otherfolder/` unless we copy the UI to this folder.

A new Pod template can be created to avoid the fastidious task of uploading the UI to each new Pod. CSS's `TemplateResourcesGenerator` class is responsible for creating the minimum required files to include in a Pod after its creation. The default behavior includes a `profile` folder containing the `card` holding the WebID and two `.acl` files in the `root` and `profile` folder. CSS also adds an unnecessary but helpful `README` file. It is possible with componentsjs to rewrite this class to point to a new template that includes our Pod-based UI. Then, each newly created Pod will, by default, include the UI.

2.2.3 Decision

Penny is arguably the most suited candidate for UI integration to CERN's CSS instance, even if it only offers Pod management features. The last question remains whether it should be integrated to CSS as an internal UI or an external UI. We choose not to integrate it as an internal UI for our CSS instance. Using a UI as an external app has the substantial inconvenience of splitting the usage of the Solid Server into two different URLs; therefore, it might not be the optimal solution in terms of User Experience. However, we thought that UIs are not yet well developed for CSS, and it would be too soon to settle with one. Therefore, it seems most valuable to leave the space empty if new UIs get developed that suit CERN's needs or the current incompatible ones get upgraded or if CERN decides to develop its own UI.

3 Building a CSS instance for CERN

As we explained earlier, CSS is built with a dependency injection called components.js. It allows CSS to take a different shape regarding a chosen configuration. We will call *recipe* a particular components.js configuration. This chapter is about the recipe we built for CERN's CSS instance. First, we will showcase a component we built to improve the CSS registration page; then, after a few tests on CSS storage options, we will argue on our storage configuration. Finally, we will showcase another component we coded for our recipe: a minimalistic profile viewer.

3.1 Easy-token: a improved registration page component

In this chapter, we will talk about the easy-token component. Easy-token is a component we build to facilitate the registration of new users already in possession of a WebID.

3.1.1 Problem description:

As we stated previously, SCS is a recent software, and some of its parts - even if functioning - still lack some user-friendliness. One clear example of this statement has been experienced early in the thesis when testing the registration process.

Data storage and identities are decoupled in the solid specification; hence when a user wants to create a pod on SCS, SCS registration will offer two options:

- create a Pod and create a new WebID as the Pod owner
- create a Pod and set the owner to an already existing WebID

Since CERN has done previous experimental work with Solid[16][17] some of CERN's users already have a WebID, mainly hosted on `https://solidcommunity.net`. Therefore, it was essential to allow those users to create an account with their existing WebID.

For legitimate security reasons, the user wanting to create a Pod with an existing external WebID needs to prove that they are the owner of the given external WebID. Otherwise, an attacker would be able to create a Pod usurping someone else identity and un-allowing the actual owner of the WebID to create a Pod . The purpose is similar to the verification email we receive when we sign-up on a platform with our email address.

To prove that the user is the owner of the claimed external WebID, SCS asks to add a verification token to the user's WebID document. By proving that they have modification rights to the WebID document, they prove that the document belongs to them.

[16] TODO
[17] TODO

When creating a Pod with an external WebID, SCS will return a `400 - BadRequestHttpError` asking the user to add a given verification token, see figure 2 . The error message is the following:

> Error: Verification token not found. Please add the RDF triple `<https://cacao.solidcommunity.net/profile/card#me> <http://www.w3.org/ns/solid/terms#oidcIssuerRegistrationToken> "276c3e90-1af4-437d-b46f-a5240933ce99".` to the WebID document at https://cacao.solidcommunity.net/profile/card to prove it belongs to you. You can remove this triple again after validation.

As we can see, the error message refers to technical terms that are probably unfamiliar to newcomers.

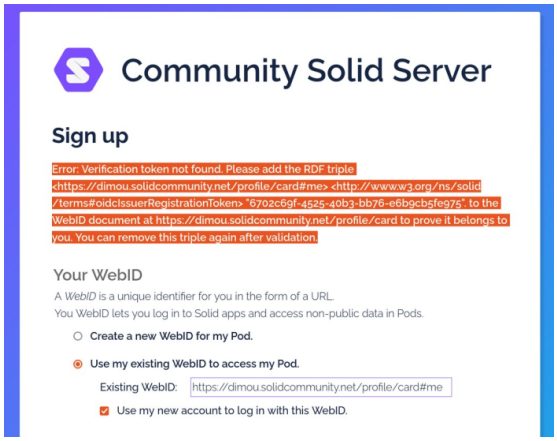


Figure 2: The error message showed by SCS highlighted in red. SCS does not give the user further help on how to achieve that task.

Currently, the fastest way to add a token to a WebID document is by doing the following tasks:

- Copy the triple with the random token given in the SCS sign-up page
- open a new page,
- use an external pod browser such as Penny
- connect to their Pod through the pod browser
- navigate their Pod to the WebID document, typically `/profile/card`
- add given token verification triple
- return to the sign-up page and finish the login

The former flow also makes strong assumptions that the user knows a pod browser solid app and knows how to add a triple to its WebID document As shown in the figure 2, besides being a tedious process, one needs to be well aware of concepts such as RDF tripe and pod architecture to understand the error message, which might not be the case for users with low experience with Solid.

3.1.2 Design

To tackle the problem formerly defined, we designed a new login interaction. We stated the following principle to base our new user interaction:

- the user should not leave the sign-up page during the sign-up process
- the user should be able to sign-up without knowledge of RDF triple
- the token should be added "under the hood" and the user should be able to sign-up seamlessly
- WebID verification should not imply interactions unfamiliar to newcomers with no Solid experience.

To achieve the former goals, we made the following design proposal:

- A button is added to the sign-up page
- The button redirects to the user ID Provider and ask them to login
- Once logged in, they are automatically redirected to the SCS sign-up page; even if the user has left SCS sign-up page, the automatic redirection gives a seamless experience
- Now that we have authenticated the user, the script has the necessary authorization to write to the user's WebID document and add the verification token
- The script adds the verification token to the user's WebID document.

In final, the user's only interaction is to click the "Verify my WebID" button and log in to their IDP.

All the rest is taken care of in the background by the script. In parallel, the user can finish with their registration process. Timing-wise, by the time the user finishes the registration process, the script should be done adding the token to the WebID document.

3.1.3 Implementation

3.1.3.1 Description of the javascript logic To implement the former design, we used Inrupt's solid client browser authentification library[18] and Solid client library[19]. Both are client-side javascript libraries. The first one handles the authentification to a solid pod, and the second performs basic CRUD action to a Pod once authenticated with the first library.

Our implementation consists of 3 main functions:

1. the login function
2. fetch token function
3. the add_token function

1. the `login` function

[18] TODO
[19] TODO

The login function relies mainly on the Inrupt authentication library. Once called, it will redirect the user to their IDP. Once the user has been authenticated on its IDP (usually using an email/password credential, but other methods can be used), the IDP redirects the user back to the sign-up page, which now benefits from a token stored in the browser local storage. The token can be used by Inrupt's client library to edit the user WebID document with authenticated CRUD action.

2. the `fetch_token` function

The fetch function's primary goal is to get the verification token. With the current state of SCS, the only way to get the verification token is to make a failed login attempt. After verifying that all the field of the sign-up form has been duly completed, the registration page will then check if an "oidcIssuerRegistrationToken" exist on the user WebID document. If not, and this is the case for each first sign-up attempt, SCS will return an error stipulating that a triple needs to be added to the WebID document with the token's value.

In other words, at the current stage of SCS, the only way to get the verification token is to fail a sign-up attempt. Therefore, two registration attempts are needed to register with a external verified WebID: a first one to get the token and a second one after the token has been added to the WebID document.

3. the `add_token` function

After successfully logging in and getting the verification token, the `add_token` function has everything it needs to add the verification token to the user's WebID document.

3.1.3.2 Description of the HTML user interface In the HTML part, we used the agile software development methodology. Therefore we went through a few iterations before achieving its final form. We first delivered a minimalistic prototype, producing short and incremental iterations. For each one, we would get face-to-face feedback with the "client" (here, the client was represented by Maria Dimou, CERN-Solid collaboration manager at CERN). We asked the user to test the new feature on each iteration by creating an account with an external WebID. We will describe the first and final iteration of this agile process.

The first iteration consisted of two parts:

1. A text input where the user can enter the host of their WebID. The default value is solidcommunity.net, as it is a popular WebID host, see figure 3.
2. A "Verify my WebID" button: once the user clicks the button and successfully logs in to their WebID's IDP, the WebID appears above the button, see figure 4.

Testing this implementation with a CERN user has raised a few tickets:

1. The user would click the "Verify my WebID" button again after the WebID appears above the button. The arrival of a new item on the page (see

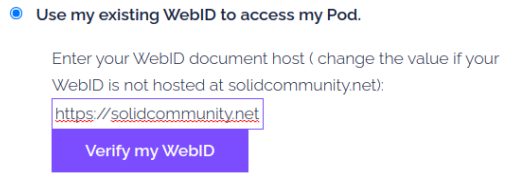


Figure 3: The first iteration, before the clicking the verification button

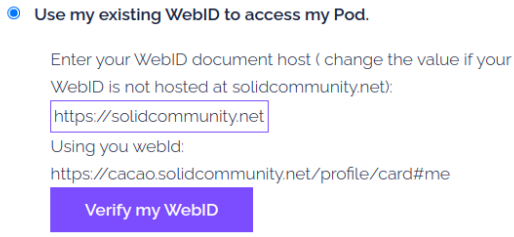


Figure 4: The first iteration, after the clicking the verification button

figure 3) seems to create a new call for action for the user. More than being unnecessary to click the button twice, the script requests the verification token a second time and breaks the registration process. Therefore, a fix for this issue was critical.
2. The user would click the wrong permission when asked for the permission scope - also marked as a critical issue.
3. This ticket does not come from user feedback, but it seems inconvenient for users not to have their WebID hosted on solidcommunity.net to type their WebID host manually. Since this would be highly improbable for CERN users, this issue was marked with low priority.

In the latest and current iteration, we addressed all the three issues with the following patches respectively:

1. After the successful login to the ID Provider, the button turns green, its text change to “Verified” to signify to the user that our script did add the verification token to their WebID document, see figure 6 . The change in color and text should indicate that there is no more call for action. Furthermore, the button also becomes unclickable to prevent the user from clicking it twice, preventing the app from malfunctioning..
2. We added a picture indicating which permission to give when the IDP asks for permission scope, see figure 6 .
3. We change the input text for an editable dropdown: it allows to select from a list of options or enter another one in a text field to let the users choose the host of their WebID, see figure 7 .

We still display an input text field with the value of the WebID for convenience

reasons, so the user can double-check that the WebID they are submitting to the form is indeed the correct one, see figure 6.

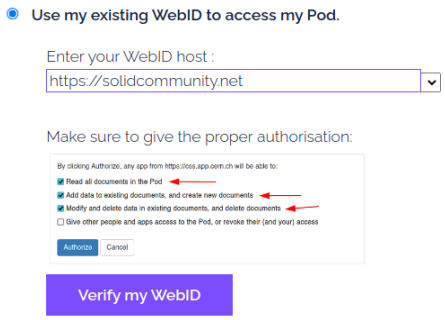


Figure 5: The final iteration before clicking the verification button

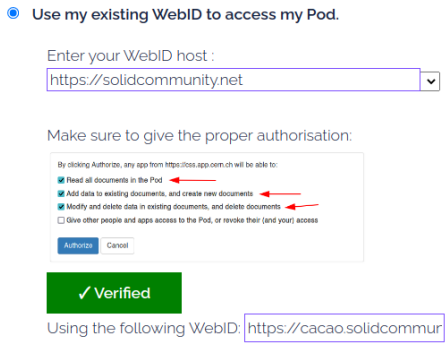


Figure 6: The final iteration after clicking the verification button

3.1.3.3 Component.js configuration If we first build this new registration page by directly editing SCS' source code, we quickly decided to take advantage of components.js' dependency injection library and refactor it as an independent component. Doing so, anyone who wants to add our new sign-up page to their SCS instance has to change a few lines in their SCS config file instead of merging two code bases. We will explain how the component has been designed.

First, we extracted all our editing files into a new folder. This folder contains five sub-folders:

1. `components/` containing a necessary `context.jsonld` file to make our component importable to components.js library.
2. `src/` where we store our javascript source code. Using Webpack, all those source files will be compiled to:

Figure 7: A convienent editable dropdown was also added

3. `scripts/` which includes a minimized single javascript file that we will import into our HTML page.
4. `templates/` with the alternative registration HTML page
5. `config/` holds the `components.js` required config files that we will import from the main SCS' config file. It essentially has two things:
   1. The first creates a `StaticAssetHandler` class that points to our `scripts/` folder. It will make the script accessible through an URL and therefore importable from our HTML file.
   2. The second creates a `BasicInteractionRoute` that will point the `/idp/register/` endpoint to our sign-up HTML page in the `template/` folder.

Then we need to edit the root config file to import the two former defined files instead of the ones from the default configuration.

3.2 File storage

In this part, we will discuss the possible option to store data with CSS, and after a few tests, we will explain why we choose to store data as files.

Currently, CSS allows two options from user data storage:

- RAM-based
- file-based

Two aspects of storage are particularly relevant for us: how do the different options affect performance, and how sensitive information, such as passwords, are stored.

If the CSS instance's machine shuts down, all user data will be lost with RAM storage configuration. Naturally, file storage was the preferred choice as it permits saving user data in a persistent external volume that can be mounted to CSS's host machine. Other benefits, such as the use of an external persistent volume are explained in the DevOps chapter. With file-based data storage, CSS will store authentification data as a file, but sensitive data such as passwords will be hashed with the bcrypt algorithm [ref code]. Bcrypt is a robust hashing algorithm

derived from Bruce Schneier's Blowfish, built to resist brute-forcing and rainbow tables attacks; the two primary attacks again hashed password[^bcryptWeb] . Other files are stored unencrypted. Therefore, anyone having access to the server (either the official sysadmin or a potential hacker) will have clear access to file content, even if the ACL permission file restricted the access to specific authorized users. Options to encrypt all user data files have been evoked but are not yet implemented. [ref github issue]

Amazon has realized that reducing its loading page by 100ms would result in a 1% sales increase[^amazon]. This example shows how speed performance is of paramount importance for users' engagement in web applications. Therefore, measuring any performance differences between RAM and files-based storage seems relevant. Therefore, we ran a test to compare performances between both options to verify if one of them would represent a considerable disadvantage.

Our first hypothesis is that RAM storage should be faster than file-based storage. We would also like to measure how much each option impacts speed performance.

To test our hypothesis, we created different recipes. The first one stores user data in RAM, and a second one stores user data on the hard drive filesystem. To protect the test from internet connection fluctuations, we decided to run the test on a local machine.

To see if the size of the file would impact performance, we generate a set of text files of randomly generated characters, ranging from approximately 1 kB to 1 GB. We generate them with the following bash script:

```
# Example generating a ~ 1 kB files of random character
tr -dc "A-Za-z0-9\n\r" < /dev/urandom | head -c 1000 > 1K.txt
```

Then we store those files in a `data` directory. We create a new Pod on each of our recipes and upload the files folder in each. For that purpose, we used Penny for our RAM-based recipe, and we copy-pasted the `data` folder inside the Pod for the files-based recipe.

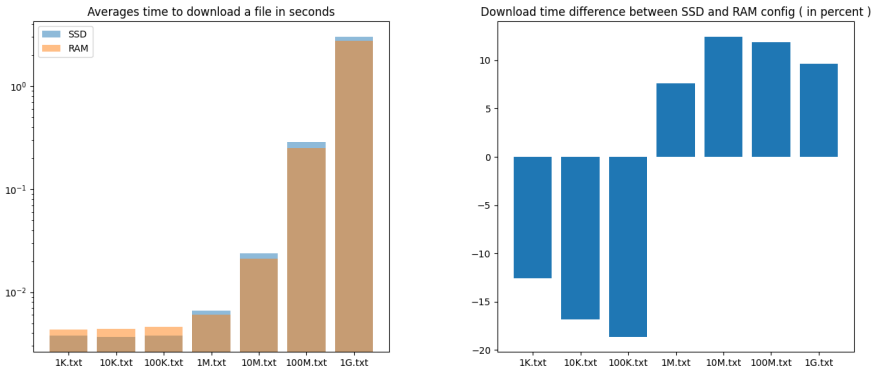
In order to not get an authorization error when trying to reach the file from our script, we need to change the `.acl` file in the root of each Pod to permit the public (therefore our script) to access all Pod contained files. We must change the Pod's root `.acl` file for that purpose. More precisely, the `public` subject needs to use the `acl:default` predicate (which gives access to the subject to the predicate folder and subfolder) instead of the `acl:accessTo` (which only give the subject access to the object file). The object remains the same (`<./>`), which represents the current folder (in our case, the root folder). Therefore, The `public` subject should be defined like so in the Pod's root folder:

```
<#public>
    a acl:Authorization;
    acl:agentClass foaf:Agent;
    acl:default <./>;
    acl:mode acl:Read.
```

We changed on line 4 `acl:accessTo <./>;` *to* `acl:default <./>;`

Finally, we use a python script to fetch each file for each recipe. The python script will iterate through each Pod configuration, and for each config, the script will try to download all files ranging from 1kB to 1G. To get a more robust result, we repeat each download an undread time and take the average download time.

Results



As we can see, files under 1mB have more or less the same average download speed. We believe those results are biased by the constant time taken by CSS to process the file, and at that point, the size of the file is nugatory compared to the processing time. Interestingly, we can see that RAM-based storage gives poorer results with files under 1mB; we could not find the root cause of the phenomenon. Otherwise, RAM-based storage confirmed our hypothesis and showed better performance for files above 1mB. RAM seems to be 13% faster on average than file-based storage (with a standard deviation of 2 points of percentage). The downloading speed difference does not increase or decrease as the files grow in size.

Discussion

For current CERN's use case, performance is not yet a priority. Therefore, using file-based storage seems more advantageous than the performance gained with RAM-based storage. Nevertheless, it is valuable to know that downloading speed can be improved on this level. In such a case, it would be essential to consider regular backups of the memory state to avoid any data loss if the host machine shuts down.

Furthermore, even if CSS author stated that it is developed for experimental purposes only[^cssReadme], is it important to notice that their use up to date, secure hashing algorithm for passwords, which will provide state of the art protection in case of data leak (2nd rec-

ommended hashing algorithm by the web security OWASP organization [https://cheatsheetseries.owasp.org/cheatsheets/Password_Storage_Cheat_Sheet.html])

3.3 Profile viewer component TODO

3.3.1 motivation:

3.3.2 design:

3.3.3 implementation

3.3.4 discution

3.4 DevOps

Setup description

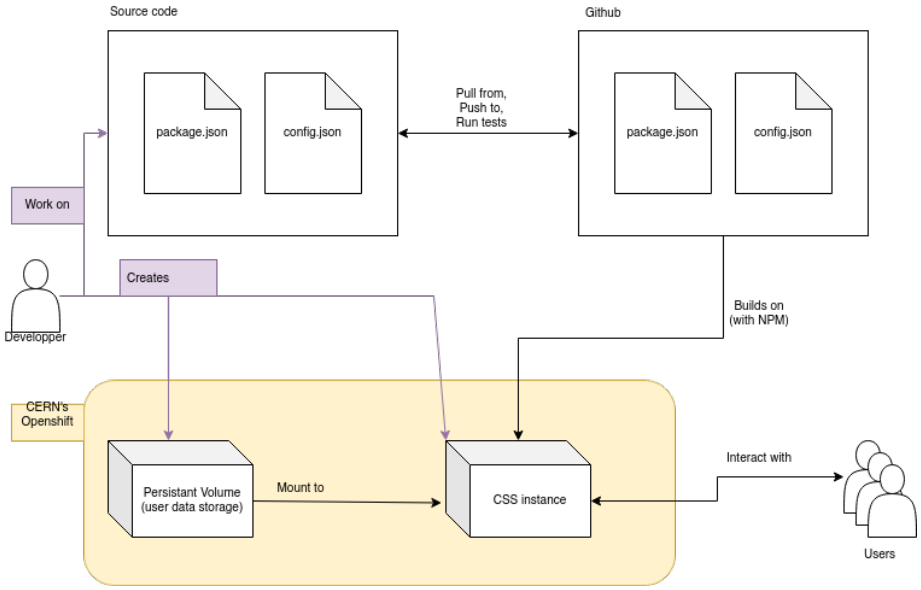


Figure 8: DevOps architecture diagram

As see in the figure 8, the global architecture for the development operations consists of 3 main entities:

- the source code, where the developer(s) can edit CERN's CSS recipe
- the remote repository, where the source code is published, reviewed and edited by other coders
- the server in itself, hosted inside CERN's Openshift infrastructure, is built of two virtual machines (VM):

- The App VM: serving the CSS instance, this VM leverage OpenShift CI/CD to automatically build our CSS recipe from a git repository. If the repository contains a `package.json` file, OpenShift is smart enough to understand that it has to build an NPM package. Therefore, it will first try to build the package with the default command `npm build`. Once the package is built, it will try to run the package with the default command `npm run`. The former can be edited through the global variable `NPM_RUN`, which we can set when starting the VM build. In our case, we do need to modify use `NPM_RUN` to set the server correctly:
  * we set up the running port 8080 to match OpenShift configuration:
  * we set up the path where CSS should store users' data which is the path where we mount the persistent volume for user data (see next section)
  * we set up the basename. For Cross-Origin Resource Sharing reasons and to display links with the server's full URL correctly, CSS needs to know on what is the base name of our server URL (i.e. it's domain name)
- Persistent Volume (PV): this VM acts as a simple file system that can be mounted to other VMs; it is where our CSS recipe stores users' data. Such a VM should be built only once, as rebuilding it would erase users data. A good improvement would be to apply backup regularly to prevent any data loss . Since the goal of this thesis is mainly experimental, it has not been judged necessary to deploy any backup process.

The choice of separating data and application has a few benefices. The main one is that it allows the creation and experimentation of different recipes hosted on different VM. Then, the persistent volume can be attached to a new application from the Openshift interface. It allows to test the application in the hosted environment (instead of locally) before publishing it to end-users. Secondly, we were not able to create a script to update a recipe within an App VM; whereas rebuilding the whole application can be done with a few lines of bash script . In addition, it permits to roll back to a previous build from the Openshift platform.

Bash script to deploy a CSS recipe to openshift from a git repository

```
# Fill the following variables

APP_NAME=""
PROJECT_NAME=""
GIT_REPO=""
# path where the PV is mounted on openshift
DATA_STORAGE_PATH=""
# required but doesnt need to be meaningfull
PROJECT_DESC="$PROJECT_NAME"
```

```
# default openshift URL
BASE_NAME="https://${APP_NAME}-${PROJECT_NAME}.app.cern.ch"

echo "remember to run sshuttle and login with oc"

# comment/uncomment the desired options:
# Create an app in a new project...
oc new-project "$PROJECT_NAME" \
  --description "$PROJECT_DESC"

# ... or form an existing one
# oc project $PROJECT_NAME

oc new-app "$GIT_REPO" \
  --name "$APP_NAME"

oc create route edge \
  --service=$APP_NAME \
  --insecure-policy='Redirect' \
  --port=8080

oc annotate route $APP_NAME \
  --overwrite haproxy.router.openshift.io/ip_whitelist=''

oc start-build $APP_NAME \
  --env=NPM_RUN="start -- -p 8080 -b $BASE_NAME \
    -f $DATA_STORAGE_PATH"
```

3.5 Terra Incognita user test

3.5.1 Context

CERN holds the *Terra Incognita* meetings once a month, where CERN's IT department members share ideas and ongoing work with their peers [https://indico.cern.ch/category/11108/]. We presented on the 31st of January the CSS recipe to CERN's IT team. We took this occasion to run a simple, informal user test. After presenting Solid and CSS, we asked CERN's members to create their Pod on CERN's CSS instance and use an external Solid application.

Most attendees did not have a Pod or a WebID, but some were already in possession of a WebID from `solidcommunity.net`, due to the previous CERN-Solid master thesis made by Jan Schill [https://it-student-projects.web.cern.ch/projects/cern-solid-code-investigation]. For that reason, the group was well suited to test the CERN's CSS instance, as some of them would need to create a Pod and link it to an already existing WebID, which was an excellent opportunity to test the *easy-token* component developed during

this thesis.

3.5.2 Method

Alongside the presentation, the crowd, through a simple user manual [https://github.com/joeitu/cern-css/blob/main/manual/readme.md], was invited to go through the following steps:

1. Create a Pod on CERN's CSS instance with or without an existing WebID
2. Inspect the content of their Pod using an external UI such as Penny
3. Consume Media Kraken Solid App. Media Kraken [https://noeldemartin.github.io/media-kraken/login] is a simple solid app built by Noel De Martin that lets users search movies through IMDb API and adds them to a watchlist.
4. Go back to the UI to see the changes on the Pod

3.5.3 Result

All users creating both a Pod and a WebID could follow the experiment until the end without difficulty. However, a user using his already existing WebID, could not finish the procedure. On the good side, the `easy-token` component did not raise any issue and seemed to work well, probably due to all the tests already done, as explained in the `easy-token` chapter. The issue came when using Media Kraken solid-app. First, the user was confused during the login to Media Kraken, if their would have to enter the `solidcommunity.net` WebID or the CERN's CSS instance URL. Entering the `solidcommunity.net` WebID would have stored their data to the `solidcommunity.net` Pod. Once entered the correct input - CERN's instance URL - the solid-app still returned an error. We were able to reproduce the error with a test account; Kraken prompted the following error:

> Couldn't determine if document at https://testkraken.solidcommunity.net/movies/ exists, got 500 response

The error (code 500 means internal server error) shows that the app is trying to save the movie into the storage of the WebID (hosted on `solidcommunity.net`) instead of our CSS instance. The app assumes that the WebID and the storage are in the same server, and under the same URL.

We could not find the root cause of the issue in the Media Kraken source code. However, it is not the first time we encountered an issue when signing in with an account that has a Pod and WebID hosted on different servers. For example, in the app `hello` - a simple hello world solid-app - we can see that in the login logic the app will assume that the Pod and the WebID are on the same URL [https://github.com/0dataapp/hello/blob/main/solid/solid-rest-api/solid.js#L262].

According to CSS core-developer, the usual flow when using a solid app should be: [https://github.com/CommunitySolidServer/CommunitySolidServer/issues/1138#issuecomment-1028707133]

1. Client asks the user what the WebID or OIDC provider is.
2. Client uses authn library to connect to the provider and authenticate the user WebID.
3. Client asks the user where their want to store their data.
4. Client uses that URL to read/write the user's data.

However, step number 3 is often omitted by the solid-app, as it will assume the storage location should be the same as the WebID.

A solution to the issue would be to register the different storage (Pod) linked to the WebID directly in the WebID document. But the solution has not reached a consensus. Since the WebID is a public document, this would expose a user's different storage location and imply security and privacy issues. [https://github.com/CommunitySolidServer/CommunitySolidServer/issues/910]

In conclusion, our CSS instance and, in particular, our `easy-token` components performed well during the user test, even if rudimentary. However, this test has shown us that if the decoupling of the identity and the storage should work in theory, it is far from being a solved issue in practice. Currently, having the WebID and the Pod under the same URL shows stronger stability.

4 Phishing risk of Pod hosting HTML files

The main goal of this thesis has never been to make an exhaustive security audit of the Community Solid Server. Nevertheless, our close work on CSS mechanisms has naturally led us to investigate the security aspect of some of its interactions. In particular, we tested how CSS could be prone to phishing attacks by using a fake look-alike login and registration webpage hosted on a trustable URL.

Context

A CSS Pod allows users to store files, particularly HTML files. If these files are publicly available through the ACL, CSS will serve them with the appropriate `content-type` header, making the browser interpret them not as text files but as client-side web applications, see figure 9. Unfortunately, if this feature allows users to host their website on their Pod, it can also have a negative counterpart if used with evil intention.

Method

As with any classic phishing attack, the following scenario does not require any advanced technical skills, apart from being able to clone a webpage. In the following scenario, Eve will try to steal Alice's credentials. First, Eve will clone our CSS instance's original and legitimate login or registration web page. Then, edit its source code to change the behavior of the form: instead of submitting the form's data to CSS's API endpoint, the form will send them to a malicious server that will log and steal the credentials. Optionally, the phishing page can redirect the user to the original web page after submitting the form to make the

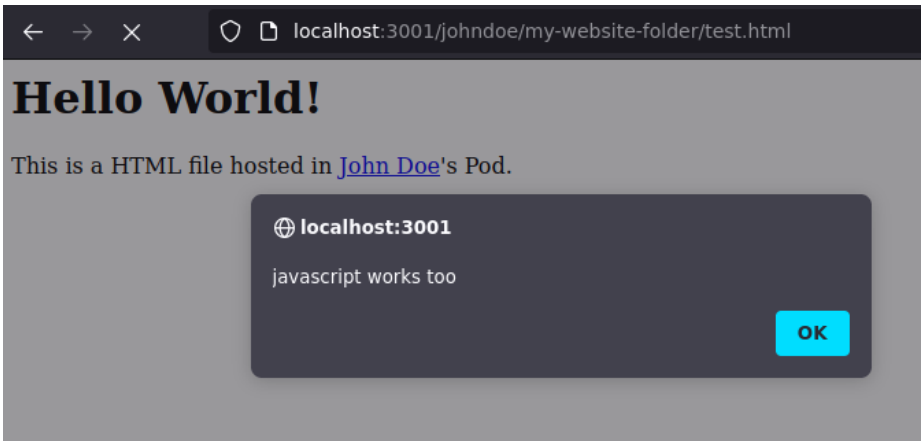


Figure 9: An example of a user webpage hosted in a Pod on a local CSS instance

attack more credible.

In a second time, Eve will create a new account and carefully choose the Pod name of that new account, as it will appear in the URL of the hosted webpage. In our case, we choose to call the pod `password`. Then, Eve will host the fake registration page on the root of here Pod and change the ACL to make the page accessible to the public. Now, Eve should have hosted a login form at: `https://css.app.cern.ch/password`

Finally, assuming that Eve has access to a chat or users' email addresses, it would be possible to send a highly credible phishing message that brings users to the un-legitimate page.

Tests

Testing this attack with CSS gives us good results. CSS does not have a banlist for username. Therefore, we could create accounts with any arbitrary string such as `password`, `account` and others.

Moreover, we were able to create accounts close to the `idp` keyword. `idp` is in front of the URL path of the login and the registration page (`/idp/registration/` and `/idp/login/`). We used different variation techniques such as homoglyph (replacing a letter with a similar one: `idp` to `ldp`) and transposition (swaps two letters: `idp` to `ipd`). By creating a `register` and `login` folder in the Pod named `ipd`; and then hosting an evil registration page on an `index.html` file, we were able to host a webpage under the URL `http://my-css-instance.net/ipd/register/` instead of the official `http://my-css-instance.net/idp/register/` (the only difference is the permutation of the `p` and `d` in the `idp` part of the URL).

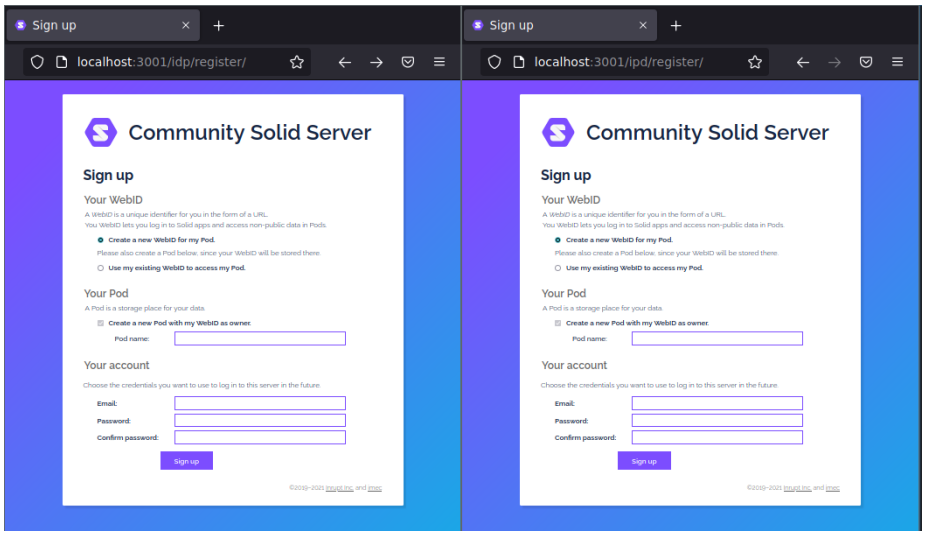


Figure 10: One the right side the original registration page. On the left, an evil registration page in a `index.html` file, contained in the `register` folder of a Pod named `ipd`

For comparison purposes, we tried the same attack on the `solidcommunity.net` NSS server. We realized the NSS is using a banlist, and we could not create a Pod named `password`. However, due to the open-source nature of `solidcommunity.net`, we could find the original banlist [20]. Therefore it was easier for us to find a Pod name that would pass the banlist verification, and we ended up creating a Pod named `password-recovery`.

We also confronted CSS to homograph attack - a kind of homoglyph attack known as Visual Spoofing Attack. Homographs appeared after switching from ASCII to the utf-8 character set. The goal is to replace a string of Latin characters by using a similar letter from a non-Latin alphabet. For example, the Cyrillic letter `е` looks identical to the Latin letter `e`[21]. However, CSS replaces non-Latin characters with a minus character (`-`). Consequently, CSS is not prone to visual spoofing attacks.

Discution

The consequent security impact is highly relative to whom the app is exposed. If the CERN's CSS instance is only available inside CERN's network and accessible to users who have VPN access to the network, it will not be as high as if the application is exposed to the whole world. When deploying an application to CERN's openshift platform, it will - by default - restrict its access to CERN's network. Assuming that all CERN's users can be considered trusted used,

[20] https://github.com/marteinn/The-Big-Username-Blocklist/blob/main/list_raw.txt
[21] https://www.researchgate.net/publication/220420915_The_Homograph_Attack

deploying a CSS instance on CERN's openshift platform should not compromise CERN's security.

However, CERN's openshift platform also allows exposing the instance publicly. It can be done by replacing the application router's `ip_whitelist` with an empty string. An easy way of doing so is by adding the following line in our script in the DevOps chapter , before the `oc start-build` command.

oc annotate route $APP_NAME
–overwrite haproxy.router.openshift.io/ip_whitelist='' ~~~

Then, we allow anyone to host a web page, therefore to spoof the CSS web page and any of CERN's registration/login page under the `cern.ch` domain name and TLS certificate. In that case, the security risk should be taken seriously. In the following, we will discuss three potential solutions. From the most secure solution to the less secure:

1. Do not allow CSS to serve webpage.

The most radical solution is to disable the rendering of web pages from CSS. Is it possible with componentsjs to create a `ContentTypeReplacer` class that replace all response with the `text/html` content-type to `text/plain`. However, this would break the rendering of potential internal UIs and Pod-based UI, as they would be returned as plain text. According to CSS developers, making the content-type converter work alongside an internal UI is possible, but it would require advanced configuration (by creating a `WaterfallHandler` class which can contain the original UI converter and the content type replacer). [22]

2. Do not allow users to choose their pod name

A less restrictive solution would be to create all users with defined username, podname and a temporari password. It can be automated using CSS' API with the following request.

Create a new user from CSS' API

```
curl -i  -H "Accept: application/json"
         -H "Content-Type: application/json"
         -X POST
         -d `{"email": "johndoe@mail.net",
              "password": "s3cr3t",
              "confirmPassword": "s3cr3t",
              "podName": "johndoe",
              "register": "on",
              "createWebId": "on",
              "createPod": "on"}`
         http://my-css-instance.net/idp/register/
```

[22] https://github.com/CommunitySolidServer/CommunitySolidServer/issues/1226

This solution still allows users to host their webpage but it allows the sysadmin to control the creation of new accounts. Plus, it will not allow them to create misleading URLs.

3. Create a banlist for Pod names

A strong banlist can prevent - but not avoid - creating a misleading Pod name. Nonetheless, as we have seen with the `solidcommunity.net` example, banlist have their limit. As mentioned above, users will still be able to host their webpage.

Conclusion

This section confirms the intention of CSS authors[^CSSReadme]: CSS is built in priority for experimental purposes. However, this investigation also shows that thanks to componentsjs and CSS high modular capability, a solution can be easily implemented to tackle security issues. Finding one security issue in CSS default configuration does not imply that CSS is insecure by essence but only by its default configuration. Work still needs to be done to build a hardened-secure configuration. It does not seem unlikely that a secure-hardened CSS recipe will appear in the future. Until then, it is recommended for CERN to use CSS for its current purpose: experimentation; and the future Solid developer at CERN should consider particular attention regarding whom the application is exposed to and what data is hosted on the Pods.

5 CSS quality review

With the understanding gained from the former investigation, we will review CSS software quality to the extent of our knowledge and experimentations. First, we will review the software, with criteria taken from the ISO25010 software quality standards. Then, we will analyze and review its open source community dynamics.

5.1 CSS software quality review

Based on our experience in creating a CSS instance into CERN's infrastructure, we will go to a review of the software quality of CSS. We will base our review on the ISO25010.

The ISO25000s are a series of software and data quality standards defined by the International Organization for Standardization, developing and publishing worldwide technical standards. In particular, the ISO25010 defines a framework to measure software quality. All ISO25010 criteria might not be relevant depending on the reviewed software. Also, in our case, criteria might apply CSS as standalone software or at our particular CERN's CSS recipe implementation.

The review is limited by the understanding and technical knowledge acquired in the process of this thesis. Therefore, it is by any means a complete and exhaustive

ISO25010 review. We will, for each criterion, advance factual arguments in favor or disfavor based on our experience.

Each criterion will be stylized in *italic* and refer to the official ISO25010 definition. Therefore, we recommend the user either read the definition before or alongside the following section.

5.1.1 Functional Suitability

The *functional completeness* and *functional correctness* are clearly defined by the solid specification and the solid test suit, respectively. The solid test suit provides an independent test suite to confront software to the solid specification. Currently CSS passes all tests of solid 0.9 specification . Therefore we can say that CSS has strong *functional completeness and correctness*.

In practice, we have during the *Terra Incogigna* user test, experienced a user not being able to delete his account, and the intervention of the sys-admin was required to perform this action. The former shows that CSS v2 lacks at least this point of *functional appropriateness*. We precise v2, because the issue has been reported and should be fixed in the later CSS iteration

As a final word, CSS addresses well the *functional suitability* for developers' needs. However, some tasks could be facilitated for the end-user in practice.

5.1.2 Performance efficiency

Did not run performance efficiency on CSS, as we didn't judge it of critical importance for CERN CSS needs.

However, regarding *capacity*, which only applies to our CERN's recipe, capacity can be effortlessly extended on the persistent volume with openshift infrastructure. Moreover, the DevOps setup splits the application and the storage; hence, the persistent volume can be switched to another hard drive with low maintenance. To achieve the former, one would need to copy an existing file to the other hard drive and mount the new hard drive to the application machine, for example, to switch from an SSH to an HHD storage.

5.1.3 Compatibility

Highly relying on linked data and W3C standard CSS show robust *interoperability* features. A confirmation of this *interoperability* is its decoupling of the UI. Surely, we have experienced issues with some UI build for NSS, but these issues come from differences in authentification implementation between the two servers, and the authentification specification of Solid is still evolving . Another example of good *interoperability* is that we could create pods with external WebIDs hosted on an NSS server.

Co-existent is not relevant to us, as CSS runs in its environment without other software.

Finally, we can say that CSS has strong *compatibility* quality, as it is built upon W3C standards, a client/server API design and a dependency injection framework.

5.1.4 Usability TODO

TODO

5.1.5 Reliability

Concerning CSS *maturity*, even if CSS does most of the essential functions of a Solid Server, it would be hard to say that CSS is a mature software when we confront it in real-life practice. An example can be taken from our user test where a user could not delete their accounts. CSS comes by default with a minimum set of components . Therefore, from an end-user perspective, CSS relies strongly on its ecosystem. As we could witness from the limited amount of available UI and the SSO integration, the ecosystem is still a work in progress and lacks maturity, affecting CSS end-experience and maturity.

Regarding *fault tolerance*, standalone CSS shows good features. Explicit errors are shown on its HTML form if fields are not fulfilled correctly. The same goes for the API, which shows clear error messages in case of a faulty request. We did not experience the server crashing, even under the stress of the speed test experiment. The registration form was also handling correctly non-Latin character set, as shown in the security chapter.

The setup described in the DevOps section should show good *recoverability* capacity. Indeed, decoupling the application and user data in a persistent volume should allow plugging another recipe (for example, a previous version in case of a rollback) while keeping the same routing and user data.

CSS shows overall good *reliability* feature to a certain extent. Undoubtedly, CSS is a young software that relies on third-party components and the fact that the ecosystem is not entirely mature yet affects CSS maturity.

5.1.6 Security

CSS *authenticity* relies on Solid-OIDC, a more secure flavor of the standard and widely used Open ID Connect protocol. In that matter, CSS uses state-of-the-art authentication protocol.

About *integrity* and *confidentiality*, CSS uses the Web of Access Control, defined by the Solid specification and common to all Solid servers. No resource has been found to measure the security implication of the Web Access Control mechanism.

On a general note, it is essential to know that no security audit has been done on CSS yet. In our experience, we show that passwords were hashed using the OWASP recommended bcrypt algorithm. We also show in the security

chapter that CSS could be an opportunity for phishing attacks under default configuration.

To conclude, we believe the security of CSS is uncertain. Unfortunately, not enough resources are available to give an enlighted judgment on that matter.

5.1.7 Maintainability

Maintainability plays a vital role in software quality because bad maintainability forces radical decisions, such as switching to another software solution.

Divided into small independent components with componentsjs and build with a client-server API design, CSS shows great *modularity* and *modifiability* features. In this thesis, we show of few examples of this modularity. We have been able to create our custom-made registration page with the easy-token implementation and integrate it to CSS without modifying the source code. We have been able to build our UI or plug existing UI into CSS. Developers can easily replace most CSS building blocks with other ones through its dependency injection.

Componentsjs also provide great *reusability* characteristics, as components can be imported and exported from one recipe to another. Moreover, general-purpose components can be exported from one software (even non-CSS software) to another as long as they are built with componentsjs.

Globally, we can say that CSS shows excellent *maintainability* attributes that will allow it to evolve in time. Therefore, CSS can be considered a good long-term bet.

5.1.8 Portability

As for *portability*, CSS has good *installability* and *adaptability* characteristics, as it can be deployed as an NPM package or through a Docker image. Therefore it is installable on any machine that can run the required NPM or Docker version. NPM and Docker are popular enough to be robust in the long-term evolution of infrastructure environment. In term of *replaceability*, our recipe should be seamlessly replaced with another CSS recipe, thanks to the user storage and application decoupling. However, replacing it with another Solid Server would be more complicated. Even if the file-based storage should ease the switch to another software, user credentials might be compicated to transfer, depending on the implementation of the other Solid server.

CSS shows substantial *portability* characteristic, as it can be easily installed and transferred to various environments.

5.2 Open source community dynamics review

CSS is a free and open-source software under MIT license, which means anyone with the necessary skills can contribute to the original project source code. Therefore, the community dynamics around the software greatly influence the

software itself and the experience of developers working with it. This chapter will review the open-source quality of this software and, in particular, its community dynamics. After quickly talking about its licensing, we will analyze its community dynamics.

5.2.1 MIT licensing

The MIT license is one of the most popular permissive licenses. A permissive licensing means little restrictions on how the software can be used, modified, and redistributed. In addition, it allows the software to have high license compatibility, meaning that it can easily be distributed with software under other licensing, including proprietary licenses.

5.2.2 CSS open source community

Hypothesis

During the experience of this thesis, we had to interact daily with CSS' community. Those would include submitting issues and starting discussions on CSS' source code repository, chatting with the community on the Gitter channel, or Zoom meetings. Through personal experience interacting with CSS' community, we had good support from the community, but mainly from the core developers. Ergo, we will make the following hypothesis and try to gather metrics to validate them.

- For the moment, CSS is built mainly by core developers, and there is not so much contribution from the community
- Most of the tickets answer comes from core developers
- The core developers are dynamically working on the repo
- The developers are quickly answering Pull Requests (PR) and tickets

Method

To verify the former hypothesis, we build a series of scripts specially crafted for this chapter . Those scripts take advantage of `mergestat`, an open-source tool to make SQL queries to a git repository that we mainly used to get data from CSS' Github repository in a JSON format. We also query Github API directly when needed.

Results

To interpret the gathered data correctly, we first need to define a few groups of Github users:

- **bots**: Github's bot such as renovate, dependabot and gitter-badger are always removed from the gathered data, as we are only interested in human community dynamics.

- **core-developers**: which consists of the following users: joachimvh, Ruben-Verborgh rubenswork and matthieubosquet[23].

Since Digita (a European based company promoting Solid and working with CSS) were highly influencing the results, we decided to create the two following groups:

- **non-core developers**: are defined by all Github users that do not belong to the core developers, including Digita's team.
- **newcomers**: are a subset of the non-core groups, excluding Digita's team.

From the data gathered, we extracted the following information:

- 74% of the Pull Requests (PR) are made from the core-developers
- 27 PR made by different non-core developers, totaling 128 new PR (1/5 of total PRs)
- 25% of the issues are left unanswered and in particular:
  - 10% of non-core developers left unanswered
  - 2% of newcomers left unanswered
- non-core developers raise 40% of issues
- 73% of the raised issue get a first attention (a first attention is the first answer in an issue threat)
- core developers wrote 90% of the first attention

Discussion

With the former information, we can validate our hypothesis related to the involvement of the core developers in the community: they answer to most of the issues of newcomers . However, surprisingly, we can see that 20% of the PR comes from non-core developers, which shows a genuine enthusiasm for the software from the community. In conclusion, we can say that the core developers are strongly involved in the community, as they consistently answer issues and questions raised by newcomers. Of course, a community around the software is far from non-existent, but it seems that they are more active in creating issues and submitting PRs rather than solving issues raised by others. It might be because the community lacks expertise since CSS is still a young software.

6 Conclustion

By creating a CSS recipe and, in particular, the development of two components, we have demonstrated the excellent modularity feature of SCS and how developers can extend it to one's particular need. The former is the result of two factors: excellent code quality and modularity with dependency injection and API design, plus strong support from the core developers, as we showed in the review chapter . Contrary to SolidOs - the UI used on `solidcommunity.net`, which comes with a wide range of built-in features, SCS comes with a bare minimum to run a solid

[23]https://github.com/solid/community-server#-license

server and a very minimalistic UI. However, it provides the building block to create one's own tailor-made Solid server solution. For that reason, CSS depends strongly on the community and the surrounding ecosystem.

We have shown that this ecosystem lacks maturity. Nevertheless, as community and enthusiasm grow around Solid and its community server, more components and UIs should be available for CSS, from which CERN could benefice. SCS is still a young software made for experimental purposes, but it has all the potential to mature from experimental software to a production-ready solution.

Currently, a UI still needs to be found for CERN's CSS instance. Two options are presented to the CERN, either use already existing UI, even if it needs some work to fix compatibility issues. For each UIs, we found the root cause of the issue in the UI chapter). The option to build its own UI is also available, and we have built a simple UI to ease the bootstrapping of such an initiative.

As the most prominent international scientific organization and the birthplace of the Web, CERN's notoriety in new technologies is not to be proven. By adopting qualitative software such as CSS as a Solid server, CERN will hold to its reputation.

Even if one can argue that the web is facing a crisis on data and user privacy, it is good knowing that robust solutions are developed to build a more prolific and ethical world wide web.