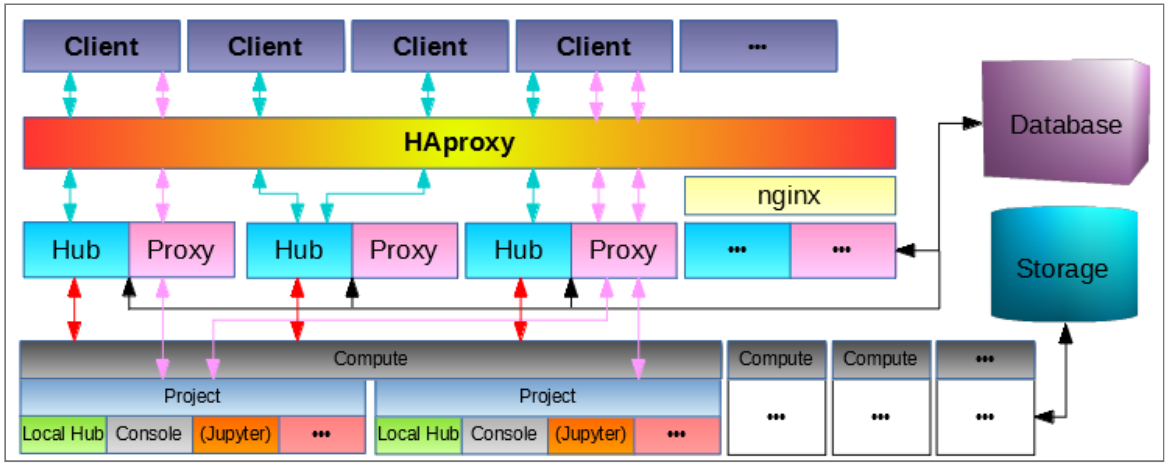
GitHub Gist

embray / architecture.png Secret

Last active 6 days ago

SageMathCloud Overview

architecture.png



overview.rst

SMC's README gives a very high level overview of its architecture. However, it doesn't really explain much about the implementation details--what technologies are used, how, and why. This is in part because a lot of it has been developed by the seat of their pants (understandably; this is not meant as a criticism) and a lot of the details have been in flux, and not worth documenting. After all, the details should only really be of interest of the SMC developers

themsevles. The details even of setting up a personal SMC server have mostly been squirreled away into install scripts and Dockerfiles such that it doesn't require one to have a deep understanding of how it all works.

Technologies used in SMC

This is a partial list of some of the major components that are used to make SMC--especially the parts that make up SMC's own source code (as opposed to external components such as the database and HAproxy, though those will be mentioned as well).

This will also attempt to give a brief overview of what those technologies are used for in general, and how they are used by SMC. The finer details of the architecture will be discussed further in later sections.

You can either read all these words first, or skip to the diagram where I've tried to show how everything fits together. But you won't understand the diagram unless you know what most of these terms are.

CoffeeScript

CoffeeScript is one of many languages that transcompile to JavaScript (a.k.a. compile-to-JavaScript), and one of the most popular. Wikipedia gives an easy to digest overview. It's basically just syntactic sugar for JavaScript with inspiration from other languages, like list comprehensions (my personal favorite). It's somewhat more Python-like (no braces or semicolons) with some syntax borrowed from functional languages like Haskell; some of it is also resembles YAML. Code written in CoffeeScript can be translated directly into equivalent, and not too hard to read JavaScript. Its use is not essential to SMC's design, but William prefers it over plain JS (and is in good company) so it's used virtually everywhere (along with a variant known as coffee-react or CJSX to be explained later).

Because of a number of factors, such as the prevalence of Node.js (see below), and also the differences across web browsers in what variants of JavaScript they support, as well as browser-specific quirks in their JavaScript implementations, it has become quite common in the web development community to use projects like Babel to write JavaScript in some meta-language, and then compile it to JavaScript that will actually work on different browsers (including "polyfills"--essentially backports--of features that are not available yet on all browser).

In the bad old days we used to clutter our JavaScript with browser and/or feature checks. But the movement in the web community has been toward writing JavaScript to some standard, and then using build tools (such as webpack

discussed later) to run Babel and other tools to prepare the "real" JavaScript that will run in specific browsers. It's basically just a repeat of high level languages like C superseding the need to write assembly language for different hardware platforms. But in this case the "assembly languages" are browser-specific JavaScript implementations. This has led to an explosion in "high-level" languages over native JavaScript, as well as associated compilers and build tools.

Node.js

Although SMC's source tree contains a smörgåsbord of (mostly small) Python scripts for various management tasks, most / all of SMC's backend is built not with Python, but with Node.js.

Most software developers are, at this point, at least passingly familiar Node.js (often referred to as just "Node"). But in short, it is a stand-alone JavaScript runtime that can run on a server. It includes an HTTP server and various I/O primitives that have been designed from the groud up for even-driven asynchronous I/O. Because it uses JavaScript it has been meteorically popular in the web development world because it allows developers to write both their front-end and back-end code in JavaScript, and even share library code between the front- and back-ends. This also made it easier for developers who otherwise specialize in web front-ends to cross into "full-stack" development.

None of the technologies SMC uses to drive its front-end necessarily require Node.js on the back-end--naturally; any server providing the same interfaces will work. But using Node.js makes sense due in part to the ecosystem around it--server and client technologies that were designed to work together--and because being able to write back- and front-end code in the same language reduces cognitive overhead as well.

Express

While Node.js has a decent standard library--mostly focused, as is its purpose, on network I/O--it is mostly relatively low-level and doesn't make too many impositions on how to build an application on top of it. So for example, while it includes a web server, it does not include a web *framework* for handling the kinds of things web frameworks typically do like URL routing and request handling.

Express is one such framework, built on top of Node.js. It is a fairly minimalistic and flexible framework, similar in concept to the popular Flask framework for Python.

SMC uses Express as the basic HTTP request handling framework for the majority of its web server components (particularly the Hub). That said, much of the communication that goes on between the SMC client side and the server happens (where available, which is most places these days) over WebSockets. But more on that later.

The main entry point to Express is an 'app'--an instance of its Application class. The app serves as a request handler for Node's HTTP server. Every time the server begins handling a request, it fires off a `'request'` event for which the app is a listener, and the app handles the request and returns a response to the client. The Express documentation on routing should give a basic idea of how it works. If you've used any web framework before it should be immediately familiar. If web development is new to you it might take a little more thinking, but the idea is basically simple: The app receives a request, looks at the URL and/or HTTP method of the request, and maps that information to a specific function registered to handle that request. The handler function is passed a request (represending the incoming request), and a response object that can be used for building up and sending an HTTP response to the client. Typical handlers will be the end-point for a request, and so will end with a call like `res.send(...)` which will send the response to the client and end the connection. However, there may also be middleware handlers that do something with the request (such as check authentication) before handing it off to other handlers.

Primus

Another important feature of modern web applications is real-time, bidirectional communication between the client (or clients) and the server. Because of the importance of this, and the many different ways to implement it all with different advantages and disadvantages, there has been an explosion of different real-time communication frameworks. As with other aspects of web development, the techniques to implment this functionality ("ajax", long-polling ("comet"), WebSockets, etc.) have changed over the years and have varying degrees of support on different clients. There are also higher-level connection features one needs such as multiplexing, heartbeats, automatic disconnects/reconnects, etc. and these are the kinds of features provided by these real-time frameworks.

As is typical, the plethora of frameworks has led to a meta-framework, and that's where Primus comes in. It abstracts out an API common to many / most real-time frameworks, and allows swapping out the underlying implementation. It's fair to say that different real-time frameworks have different advantages and disadvantages, and some are better than others for specific applications depending on their implementation details. Primus allows you to write your application once in its common API and then swap out the lower-level core implementation.

Engine.IO

Engine.IO is one such real-time communication framework, designed to be event-driven and asynchronous for integration into and compatability with Node.js. In fact, it attaches itself to Node.js's HTTP server, which it uses initially to negotiate connections with the client via traditional HTTP methods like long-polling. It then works with the client (with help of a client-side library) to discover support for other transport methods (like WebSockets) and transparently switches to those channels as they become available. The overall design and advantage of using Engine.IO is best explained by its documentation.

Engine.IO is actually the core to another higher-level real-time framework you will see reference to called Socket.IO. But SMC does not use Socket.IO directly, opting instead to use Primus as its "high-level" real-time framework, with Engine.IO being one of Primus's supported underlying transport layers (whereas Socket.IO is designed to work only with Engine.IO).

pug

pug (formerly named "Jade" but recently renamed for trademark reasons) is a template engine for templated HTML in particular, written for Node.js. Although it has its own particular syntax, the concept should be familiar to anyone who's written a web template before. Pug/Jade is the *default* template engine used by Express, though one can easily substitute it for any other template engine (after all, at the end of the day all a template engine is doing is returning an HTML string to be sent in the HTTP response). If you've used Flask, this is just like how Flask uses Jinja2 by default, but by no means enforces its use.

I won't go much more into pug as SMC barely uses it. In fact there is currently only one pug template in SMC (`webapp-lib/index.jade`) for the main index page to SMC. Mostly all this page does is provide some metadata and favicons, and disply the big "Loading" banner you see when you first load SMC. All the rest of the front-end is loaded in via React which we'll discuss next.

React

React, also often referred to as React.js, ReactJS, etc. is a powerful toolkit for web UIs, developed by Facebook. Although one still uses HTML+CSS to specifiy the look and feel of a UI component, React allows one to manipulate components of a UI in an object-oriented manner, not unlikely traditional desktop GUI toolkits.

The example on their front page gives a great introductory example of a little "TODO list" widget. It's implemented as a class, which has a `render()` method used to display the widget in its initial state, a few internal attributes for managing its state (such as the list items), and some methods for handling different events on the widget. There's also a very nice tutorial for building a tic-tac-toe game. If you can grok that then you'll have the hang of React.

If you've ever used a GUI toolkit like wx or Swing it shouldn't be too hard to pick up on what it's doing.

Using React is quite a bit different from the old-fashioned way of making reactive web UIs with JavaScript. What I'm calling the "old-fashioned" way is a couple things. For one, the server might render serve up a bunch of HTML containing all the elements in your page, many of which might by "hidden" using CSS, and the JavaScript would hide and unhide elements on the page. Or the JavaScript might generate some elements and insert them directly into the DOM and remove them as needed, either using the DOM API directly or, somewhat later, tools like jQuery (note: jQuery still has a role to play even in conjunction with React though).

In other words, gone are the days of servers rendering and returning HTML to the browser. All the rendering is pushed entirely to the client, with the client-server communication focused on as light-weight as possible message passing. This potentially frees up enormous resources for the server, while pushing much more work to the client (which is why so many of your browser tabs are using over 100 MB of memory, among other reasons).

The way React works, in short, is this: It maintains its own "virtual DOM" separate from the actual DOM of the browser document, with the same API as the real DOM. Whenever you show, hide, or otherwise update the contents of a UI element in the application, it uses a copy of its virtual DOM to figure out exactly what needs to change in order for that to happen, and generates (and subsequently applies) a stream of operations to perform on the actual DOM in order to enact those changes. The result is that there's nothing in the real DOM except for what's actually displayed on the page, which is convenient for debugging and inspection via your browser's development tools. There's a simple demonstration of this aspect in the docs.

Another nice aspect of React is its JSX domain-specific language which I'll discuss more next.

As I mentioned in the section on pug, essentially all of SMC's web frontend is built using React. Almost no HTML is ever sent from the server. Instead the frontend is built up by React. When user interactions with the UI need to be persisted, those are sent as event messages (typically over WebSockets) to the server, which may in turn respond with events that result in updating the UI in some appropriate way (the event messages are usually a JSON object of some kind). This is still an over-simplification (see for example the section on Redux later), but that's the basic idea.

JSX

JSX is a language that comes as part of React. It's a superset of JavaScript that allows embedding templated HTML. In some ways this resembles the bad-old-days of mixing code with HTML à la PHP. But it does have some advantages too, described in the linked docs. It's actually a very convenient way to use markup to describe how a UI element should be rendered. It's also a convenient way to nest UI components. For example, one might define some UI component as a class that extends `React.Component`:

```
class MyWidget extends React.Component { ... }
```

This now lets you use `MyWidget` in JSX as though it were any other HTML element like:

```
<div id="widgets">
  <MyWidget name="foo" />
  <MyWidget name="bar" />
  <MyWidget name="baz" />
</div>
```

and so on. [Note: Simple React components that are stateless can also be implemented as functions, which server as their `render()` method).]

React can be used without JSX, but it saves a lot of verbosity and is probably a bit clearer, especially to anyone with HTML template experience.

CJSX

If JSX is the preferred way to write React components, this presents a challenge for integrating JSX with codebases that otherwise use CoffeeScript. One could write everything in CoffeeScript *except* for the code for React components (which would have to go in separate JSX files), but that introduces another difficult cognitive overhead.

To solve that, the CJSX language is just a simple superset of CoffeeScript to support JSX-like syntax. In other words, CJSX is to CoffeeScript as JSX is to vanilla JavaScript.

So this is what all the `.cjsx` sources (something I had not seen before) are in SMC. If you see a file in SMC with the `.cjsx` extension you can bet there's probably a React component defined in there somewhere.

[Note: In the process of researching this I learned that the original developer of CJSX has abandoned the project and there isn't really anything to take its place yet. William insists that SMC will continue to use it, and with good reason!, but it leaves me not without doubts...]

Redux

It's a little tricky to explain exactly what Redux 'is' without specific examples. According to its docs:

> Redux is a predictable state container for JavaScript apps.

It's really little more than a simple protocol for application state updates by way of immutable state containers and pure functions that return an updated state based on some action performed on it (where the action can be any abstract operation that results in an updated application state). These functions are called reducers.

There's very little else in Redux--it's mostly convenience functions for managing a state object, and combining reducers to produce new states from state changing actions.

The purpose, all in all, is to provide a sane, predictable, reproducible way to manage and track (using middleware that logs actions) the live state of a complex application. We'll come back to this later with some specific examples. SMC wraps most of its use of Redux into its own abstractions that are implemented in `smc-webapp/smc-react.coffee`.

React-Redux

SMC's `smc-react.coffee` modules also makes use of the React Redux JavaScript module to tie Redux state objects to React containers (i.e. update displays when the state changes--abstracting the state itself from any given view of the state). This is just a package for making it convenient to implement model / view separation in React components. The web developers describe this as "container components" but really they're just reinventing MVC abstraction. The idea is to design React components that are stateless and just display a "snapshot" of some data that might be in the state, and then wrap the stateless views in "container components" that handle updating the view upon state changes.

React Redux makes it easy to auto-generate these "container components" that connecting a React container to a Redux state and its reducers, to re-render the underlying view every time the state changes. This includes defining a function called `mapStateToProps` which, given any application state, specifies which "props" (variable data) of the view are associated with the given state. So when the application state changes, it can check which "props" in the view have changed, and determine whether or not the view needs to be re-rendered.

If this is unclear, probably the best way to understand quickly is to read the example in the Redux docs. I will go more into exactly how SMC uses React-Redux later.

webpack

Preparing a large, multiple-file web application consisting of specialized JavaScript dialects like CoffeeScript and JSX with many interdependencies, as well as external dependencies, and getting everything to load in the correct order is tricky.

For one, the modern ECMAScript supports features not supported by the JavaScript on browsers, such as the `import` statement for loading variables, classes, and functions into other files (without polluting the global namespace, as was necessary to share between JavaScript files in the bad old days). Unfortunately, most (in fact no) browsers support this feature. One also needs ways to find static resources relative to JavaScript modules, transform the development dialect into JavaScript that can run in the browser, minify and uglify the code, and put it all together in a big bundle that loads everything in the correct order.

webpack is one of a number of popular build tools that serve this purpose. The entry-point to a webpack project is a file called `webpack.config.js` (or in SMC's case `webpack.config.coffee` since it uses CoffeeScript just about everywhere). You can think of `webpack.config` a little bit like the `setup.py` in a Python project, but don't take the analogy too far--it doesn't work the same way (a larger part of this purpose is also served by the `package.json` file that defines npm packages).

The `webpack` CLI then reads in this `webpack.config` and outputs a single file containing all your Javascript. This is of course the most basic usage--SMC currently actually generates three JS files (from three separate "entry points" to the dependency graph webpack generates). It also generates the `index.html` file that is served at the root of the website (from the aforementioned `index.jade` template) into which webpack inserts `<script>` tags that load its

generated JS files. It also does some other tricks, such as appending a hash to the JS filenames so that they can replace cached versions whenever the source changes.

In practice it's less convenient to run `webpack` over and over again--instead one can run `webpack --watch` which watches all files for changes and rebuilds continuously.

Conclusion

As previously stated, this is only a partial list of the tools that go into building SMC--particularly the core backend and client code. It doesn't even discuss the many dependencies that go into its various features, such as Jupyter, browser-based editors and terminals, chat clients, etc. Later I may include an update to list more of those.

How it all works

High level view

The high level architecture diagram from the Readme in SMC's source is accurate:

```
   Client    Client    Client   Client  ...
     /|\
      |
   https://cloud.sagemath.com (primus)
      |
      |
     \|/
HAproxy (load balancing...)HAproxy                  Admin     (monitor and control system)
/|\       /|\      /|\      /|\
 |         |        |        |
 |http1.1  |        |        |
 |         |        |        |
\|/       \|/      \|/      \|/
Hub<----> Hub<---->Hub<---> Hub  <-----------> RethinkDB <--> RethinkDB  <--> RethinkDB ...
          /|\      /|\      /|\
           |        |        |
  ---------|        |        | (tcp)
```

```
    |                |        |
    |                |        |
   \|/              \|/      \|/
  Compute<-------->Compute<-->Compute <--- rsync replication  to Storage Server, which has BTRFS snapshots
```

(with the exception that William is in the process of replacing RethinkDB with PostgreSQL).

It may be helpful to explain some of the entities in this diagram a bit more.

Client

This is the SMC client interface, built primarily with React and bundled together webpack as described previously. When a user goes to the root of SMC in their web browser, the HAproxy configuration serves it the `index.html` from its default backend, which happens to be a simple nginx server dedicated to static files. It also gets images, and the client JavaScript from the static server. Once the JavaScript takes over everything else happens in the browser including setting up the appropriate view for the client (whether or not they're logged in, etc.) and communicating with the hub using Primus/Engine.IO (through the HAproxy--more on that next). The majority of the client is implemented in the code in `smc-webapp` and `webapp-lib`, with some bits from `smc-util`.

HAproxy

HAproxy serves as the front line to all connections from clients to SMC. It routes all connections to different backends depending, primarily, on the URL (and port). The main frontend is of course HTTPS over port 443. By default requests are sent to the static file server (nginx) as mentioned above. Most other requests are sent to the 'hub' backend, which may be running any number of the hub servers, one of which is selected using the currently configured load balancing scheme (it also uses a session cookie to keep individual clients connected to the same hub instance).

Hub

The "Hub" is the primary server backend for SMC, built on Node.js as described previously. It consists of an HTTP server with Primus + Engine.IO attached to handle real-time bidirectional client/hub communication. Most communication between the Client and the backend happens through the Hub, whose HTTP server uses Express to route requests to different services (account management, project management, payment, etc.). Each Hub also sets

up a `ComputeServerClient` which gives it access to all the running compute servers (discussed next). The names and URLs of all the available compute servers live in a system table in the database.

It also uses node-http-proxy to create an HTTP proxy server associated with each Hub (on port number one higher than the Hub's HTTP port). If I understand correctly, the proxy handles all requests that are to be forwarded to individual compute nodes (such as requesting files, or resources on web servers belonging to a specific project). HAproxy doesn't know anything about the compute nodes themseves--it just sees URLs that look like they belong to a project (they begin with a project UUID) and forwards those requests to the Hub's proxy, which in turn checks that the requester is authenticated and has permissions to access that project's resources. The proxy then forwards the request to the appropriate port on that project's compute node:

```
Client <--> HAProxy <--> Hub Proxy <--> Compute
```

Compute

Compute servers are where the real work gets done in SMC projects. Every project is associated with a specific compute server where all their data is stored (by way of storage servers mounted on the compute node) and where all process and computation tasks done by the project are performed. This includes running Sage. The Compute servers are Linux VMs with varying degrees of hardware capacity, depending on how much you're willing to pay. In most cases the servers are shared between projects (you don't have admin on the servers) though in principle one could pay for one's own compute server as well.

Otherwise, one can do quite a bit of different things on their compute node, including log in to the shell directly (you log in as a user named after your project's UUID). This can be done either through the web terminal in SMC, or one can SSH in directly.

Each compute node also runs a simple socket server `smc-hub/compute-server.coffee` that is used by the Hub to communicate with the compute node (using simple JSON messages). For example, one can make status inquiries on the node, or send commands to run a command in a project.

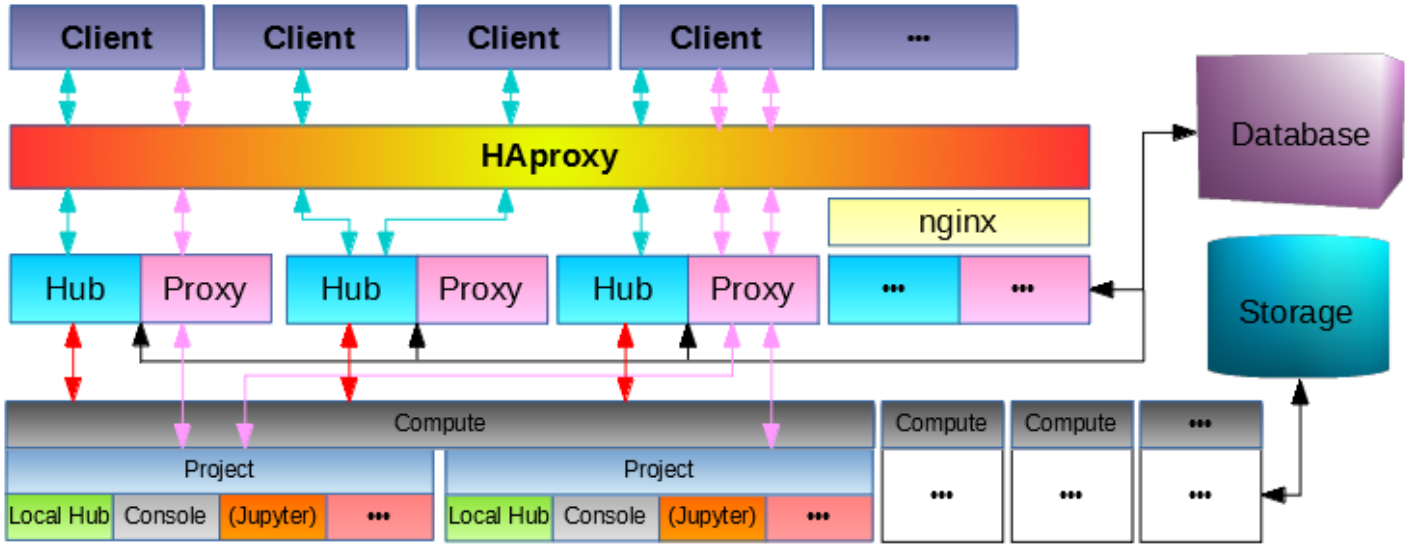
Additionally, each *project* runs a couple per-project daemons when the project is created and running. These include the the console server (`smc-project/console_server.coffee`) which provides the backend for the web terminal, and the

"local hub" (`smc-project/local_hub.coffee`). I don't yet know everything that the "local hub" does, but whereas the "compute-server" manages the entire compute node, the "local hub" runs per-project (as that project's user) and helps coordinate connections between software running in the project and the "global hub" (i.e. the Hub, through which the client is communicating).

As I understand it, whereas the compute server is used to issue commands to the compute node on behalf of a project, such as starting the project's local hub, the local hub then takes care of the rest. This all makes sense, but gets rather complicated as starting the actual local hub is buried under a pile of Python scripts. Some of this may still be legacy from earlier versions of SMC that were written primarily in Python, and is need of cleaning up.

Deeper view

With all that said, let's consider a more complete picture of the current architecture (which still leaves a lot out, but incorporates some of the additional elements discussed above:



A few explanations about this diagram:

- The cyan arrows represent communication between the client and the hub. All client communication goes first through HAProxy, and then interactions--particularly those that don't directly involve projects--are otherwise

between the client and the hub. This includes authentication and user settings, billing, and some things involving projects like project creation.

- The pink arrows are communications between the client and a project, and/or processes (such as the Jupyter server) running within a project. Again, this goes through HAproxy, but then pass through the hub proxy which forwards the request directly to the relevant project.
- The red arrows are communication just between a hub and a compute node, such as creating and destroying projects on behalf of a user, or getting status information about the compute node.

This diagram also demonstrates a few possible use cases for clients (certainly not exhaustively). The left-most client has connections both to a hub, and to the proxy associated with that hub, through which it is directly accessing resources on some project.

The second and third clients are both connected to the same hub, and are not connected to any projects (perhaps they're just setting up their accounts, or doing other administrative tasks not related to a project).

The fourth client is connected to the third hub, and is connected to resources on two different projects (albeit on the same comput node) through the same proxy.

This is of course still leaving out a lot of details that would be hard to fit on a single page diagram.

How the Client works

There are of course many different aspects to the question of how the SMC web client works. The easiest way to explain might be go step by step through what happens when a user points their browser to SMC and a page loads. Obviously this assumes we're observing at some particular scale where details like transport protocols are assumed. However, if I just gave a bullet list many points may be unclear, so what follows is a lengthy narrative of what happens.

Let's also assume, for this particular example, that the user has already created and logged into their account, and has at least one project already. So when they first load SMC in their browser, what (currently) happens is they land on the `/projects` page that shows the list of projects they have access to.

Initial page load and connection

When the user first goes to `https://cloud.sagemath.com/` the request is handled by HAproxy which routes it based primarily on the path. In this case the path is just `/` so it is routed to the default backend, which is the nginx server, and is served the default page-- `index.html` . This is a static file generated the last time the administrator ran the webpack build. As previously mentioned there's very little on this page except the blinking "Loading SageMathCloud..." banner you first see (which works entirely in HTML + CSS), followed by some script tags that load the React site and related libraries.

In particular, the last script it loads is called `smc.js` , and this is where everything happens. To understand what's in this script, recall that it was generated by webpack, from one of the webpack build's three entry-points. In this case it's the entry-point named `webapp-smc.coffee` . This in turn "requires" three files in the following order: `smc-webapp/indes.sass` (this is compiled into a CSS stylesheet), `smc-webapp/client_browser.coffee` , and `smc-webapp/entry-point.coffee`). The end result of this you can think of almost as though each of these files were loaded one by one in the browser with `<style>` and `<script>` tags, but in reality they're all glommed together into a single file (sort of like building a single `.a` archive from multiple `.o` object files). When you run in development mode you can see quite explicitly how this works, but this is a detail about webpack and not particular to SMC, so I'll leave it as an excercise.

We'll look first at `client_browser.coffee` because some important things happen here as soon as it loads. This module defines a class called `Connection` (itself a subclass of a more generic class of the same name in `smc-util/client.coffee`). It immediately creates a single instance of this class as a global variable in `client_browser.coffee` named `connection` . It's this `Connection` object that sets up the Primus client and begins setting up communication with a hub as quickly as possible. The Primus client is responsible for the details of setting up WebSockets where available, or falling back on long-polling techniques when not. It's worth noting here that Primus is configured with an HTTP path that it can own for its own protocol communications with the Primus server. By default this path is `/primus` , but SMC has it configured (see `webapp-lib/primus/update_primus.coffee`) to `/hub` .

Assuming one or more hubs are already running (the full server-side story should be described in another chapter), HAproxy recognizes the path `/hub` and forward's Primus's connection to start talking to one of the hubs. Each connection Primus makes is handled by an object that Primus calls a "spark". (This name is used so as to not be confused with an actual "socket" or something like that, since Primus is abstracting out the details of the underlying I/O method). Most of SMC's code doesn't use the word "spark" and just uses "conn" or "connection".) Each spark is given a unique ID, which may be reused in some cases for example when restablishing a previously established connection. However, let's assume this is a brand new connection. Each hub maintains a hash table mapping from

this connection ID to an instance of a `Client` class (`smc-hub/hub.coffee`) that is used to manage the hub's connection to each client. Since this is a brand new connection the ID is not yet in the hub's table, so it creates a new `Client` from this connection and writes the client's ID to the socket so that the client can know it too. After the client `Connection` receives its ID, it installs its default "ondata" handler--a callback function that serves as an entry point to the handlers for all subsequent data it receives from the hub.

Redux setup

So far all we've described is what happens when `client_browser.coffee` runs. Next in the list is a module called `smc-webapp/entry-point.coffee` . This is where we actually set up the user interface (note that that doesn't happen at all if we can't at least establish a connection to a hub first--there are also fallbacks for displaying messages to the user in case there are delays in making that connection). The first module loaded from `entry-point.coffee` with any notable side-effect `smc-react.coffee` . This initializes a single instance of a class called `AppRedux` which it exports to other modules with the variable name `redux` .

`AppRedux` is the driver for SMC's own very-high-level wrapper around Redux. Explaining this is difficult unless you've read at least the introduction to Redux earlier in this document, if not read and understood the full documentation for Redux. `AppRedux` maintains a sort of Redux meta-store. It contains only a single actual Redux store (as created with `redux.createStore`), but this is used to manage any number of sub-stores represented by key/value pairs at the top level of the main store's state. The reason for this is that each page in SMC's UI might have its own state that is mostly independent of the state of other pages. For example the "account" page may have state that is mostly independent of the "project" page's state, so the full state of the application looks something like:

```
{
    "account": { <...account page state...> },
    "projects": { <...projects page state...>},
    ...
}
```

There is even a sub-store called "page" for managing the overall current state of the CLI, such as what the currently active tab is.

There are a few reasons for organizing things this way:

- It keeps the application state fairly sanely organized, with sub-states for each page, and easy routing of actions to the sub-states the affect.
- However, since the entire state is stored in a single Redux store (as opposed to, say, having separate stores for each page) it is also possible to produce actions that affect multiple pages, or even other parts of the application state that are not tied to a particular page or view. I don't know for sure if it's actually used this way currently (it might not be) but at least it's a possibility.
- The `AppRedux` class makes it possible for each page/view to independently and dynamically register a sub-store for itself. The `AppRedux` instance that is passed throughout the application then serves as a sane way to manage all the known state stores.

  > In fact, much of `AppRedux` 's API mimics the Redux library's own top-level API. So instead of calling `redux.createStore()` for each sub-store, one actually calls `AppRedux.createStore()` (the latter has some important differences from the former, however, which we'll come to later). In fact, since SMC names the `AppRedux` singleton `redux` , one *does* in fact literally call `redux.createStore()` , but it's important to be clear that here `redux` is an instance of `AppRedux` , not the Redux library itself.

The whole thing is fairly smart, and almost nothing about this framework is particular to SageMathCloud--it could (and probably should) be factored out into a stand-alone package at some point. We haven't explained everything about it yet either but will add more details soon.

Anyways, all that's happened so far is the `AppRedux` singleton has been created. No stores have been added to it yet. But it's important to explain what it is before moving forward.

Server stats

Continuing to follow `entry-point.coffee` , the next module that's loaded is one called `smc-webapp/redux_server_stats.coffee` . This actually sets up a "synchronized table"--a client side view of one of the database tables--and attaches this to the `AppRedux` , which also carries around a collection of synchronized tables. The tables are actually *not* part of the Redux store, and are probably just attached here for convenience's sake, though this may seem a little confusing at first. Some of this also appears to be legacy code, and it's not clear how much of it is going to stay around, especially as RethinkDB is in the process of being removed. The `SyncTable` class

this creates an instance of is also quite complicated, so considering that and the fact that its future is unclear I won't investigate it any more deeply for now.