Hosting Notebooks for 100,000 Users

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Outline

Demo

Goals and Challenges

Extension Case Studies

User Identity

Notebook Storage

Multiple Hubs

Sharing Notebooks

Demo

Why Jupyter?

- The hard part of writing a trading algorithm isn't writing the algorithm.
- It's researching the **ideas** behind the algorithm.
  - Exploring and Visualizing Data.
  - Testing Hypotheses
  - Analyzing Results

Project Goals

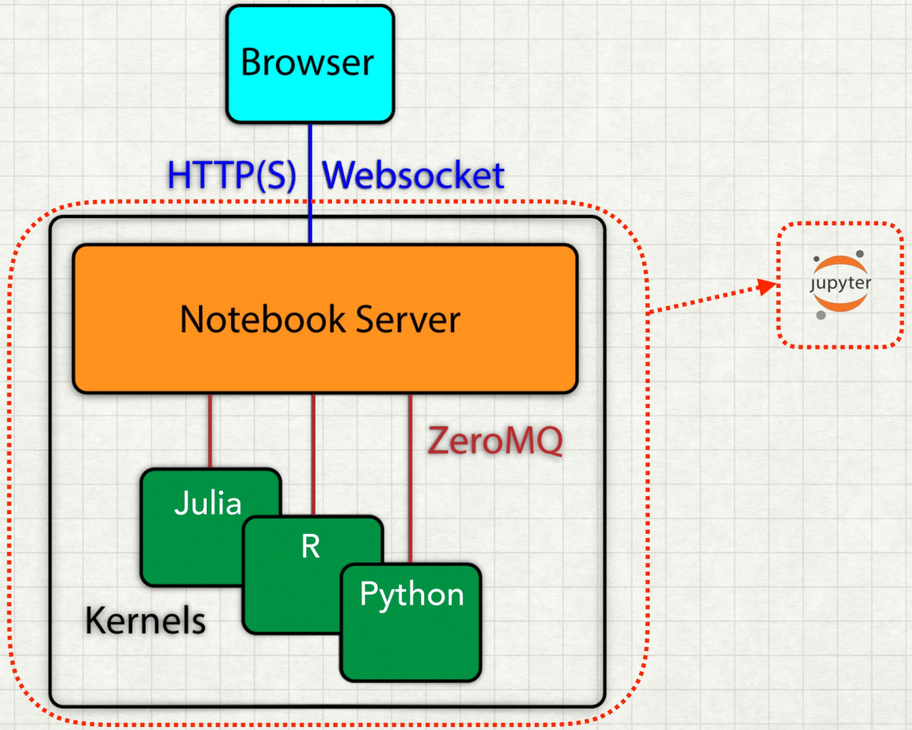
- Integrate Jupyter UI into an existing web application.
- Support 100,000+ users with minimal downtime.
- Allow users to share notebooks with the Quantopian Community.

Challenges

- Scale
  - Financial analyses often RAM and CPU intensive.
  - Must spread users across servers to provide enough resources.
- Reliability
  - You shouldn't lose work if server hardware fails.
  - We shouldn't have downtime during releases.
  - Users should be isolated from one another.
- State
  - Notebooks
  - Kernel Processes
  - User Identity

Notebook Architecture

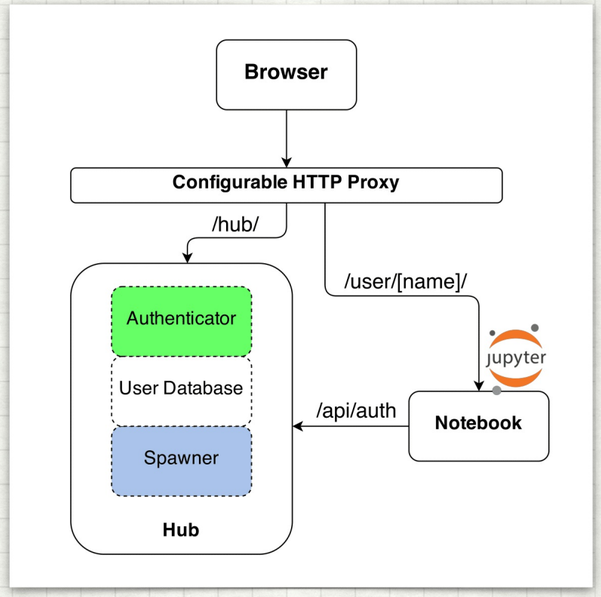
A SINGLE USER JUPYTER NOTEBOOK SERVER



Source: https://github.com/willingc/jupyterhub-jupday-2016

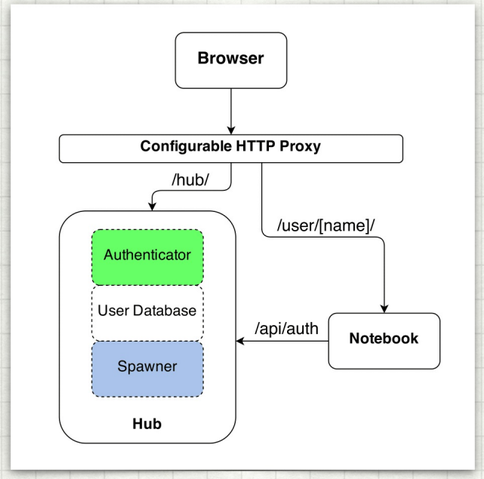
WHAT DOES THE HUB DO?

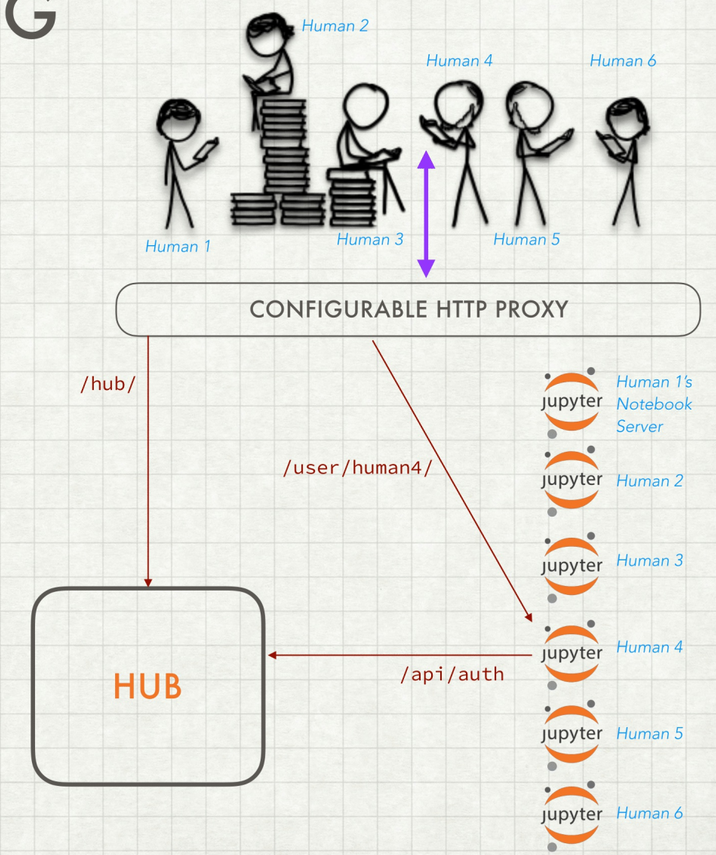
- Manages authentication
- Spawns single-user notebook servers on-demand
- Gives each user a complete notebook server



Source: https://github.com/willingc/jupyterhub-jupday-2016

UNDERSTANDING





Source: https://github.com/willingc/jupyterhub-jupday-2016

User Identity

Default JupyterHub authenticates via Unix username/password.

- Bad News: we don't want to give users Unix logins.
- Good News: we already have a login system!
- Better News: JupyterHub authentication is pluggable!

Custom Authenticators!

```
from tornado import gen

from IPython.lib.security import passwd_check
from traitlets import Dict
from jupyterhub.auth import Authenticator

class DictionaryAuthenticator(Authenticator):
    users = Dict(config=True, help="Map from username -> password hash.")

    @gen.coroutine
    def authenticate(self, handler, data):
        username, password = data['username'], data['password']
        try:
            password_hash = self.users[username]
        except KeyError:
            return None
        if passwd_check(password_hash, password):
            return username
        else:
            return None
```

Quantopian OAuthenticator

Slightly more complex:

- Redirect browser to quantopian.com/authorize.
- /authorize
  - Ensure user is logged into Quantopian.
  - Redirect back to HUB/oauth_callback with "OAuth Code".
- /oauth_callback
  - Send the code back to quantopian.com/oauth/token.
  - /oauth/token replies with an "Access Token".
  - Send token to quantopian.com/api/get_resource_id/.
  - /api/get_resource_id/ replies with the user's ID.

Reflections

- OAuth feels a little like overkill for this use-case, but...
- OAuth is standard and widely-available.
- Many good open-source libraries.

Notebook Storage

Jupyter Notebook provides a filesystem interface for storing notebooks.

Filesystem manipulation is abstracted behind by the **Contents API**.

Contents API

Notebook server implements the Contents REST API.

Translates HTTP verbs into filesystem operations.

Verb	Action
GET	Load Notebook
POST	Save Notebook
DELETE	Delete Notebook

...a few extra endpoints for saving/restoring checkpoints.

Contents API Model

```
{
  'content': {
    'metadata': {},
    'nbformat': 4,
    'nbformat_minor': 0,
    'cells': [
       {'cell_type': 'markdown',
        'metadata': {},
        'source': 'Some **Markdown**'},
    ],
  },
  'created': datetime(2015, 7, 25, 19, 50, 19, 19865),
  'format': 'json',
  'last_modified': datetime(2015, 7, 25, 19, 50, 19, 19865),
  'mimetype': None,
  'name': 'a.ipynb',
  'path': 'foo/a.ipynb',
  'type': 'notebook',
  'writable': True,
}
```

Contents HTTP handlers dispatch to a ContentsManager.

Default FileContentsManager translates requests into reads/writes to/from a local directory.

The ContentsManager class used by the notebook application is configurable!

ContentsManager Interface

ContentsManager.get(path[, content, type, ...])	Get a model.
ContentsManager.save(model, path)	Save a model to path.
ContentsManager.delete_file(path)	Delete the file at path.
ContentsManager.rename_file(old_path, new_path)	Rename a file.
ContentsManager.file_exists([path])	Does a file exist at the given path?
ContentsManager.dir_exists(path)	Does a directory exist at the given path?
ContentsManager.is_hidden(path)	Is path hidden?

PGContents

PGContents is drop-in replacement for the default FileContentsManager.

It stores notebooks in a PostgreSQL database instead of on the filesystem.

Mini-Demo

Features

- Fully API-Compatible with Default ContentsManager
- Separate Namespace per User
- Multiple Checkpoints per Notebook
- Configurable Maximum File Size
- (Optional) Encryption at rest via the cryptography Package
- Combine filesystem and postgres storage via HybridContentsManager.

Vanity Metrics

- 65,000+ Users Have Created a Notebook
- 220,000+ Total Notebooks
- 310,000+ Total Checkpoints
- Over 450GB of Notebooks!

Scaling Issues

Surprisingly few...Postgres is awesome!

Most significant issue was running out of database connections.

Fixed by adding transparent connection pooling with pgbouncer.

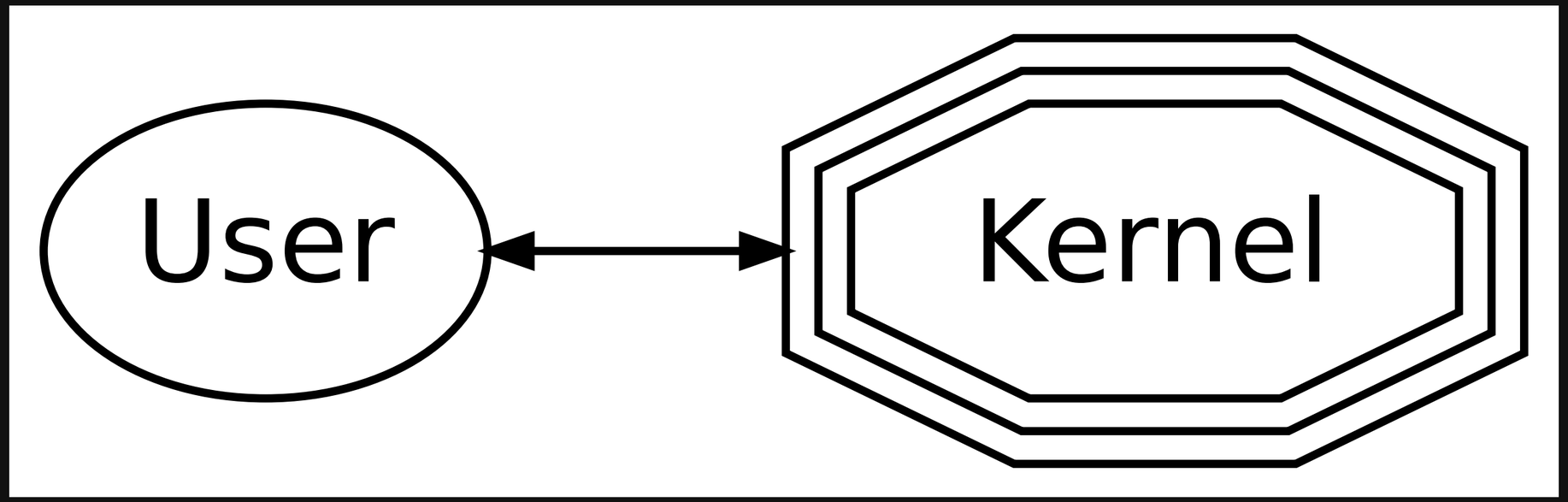
Multiple Hubs

Observation:

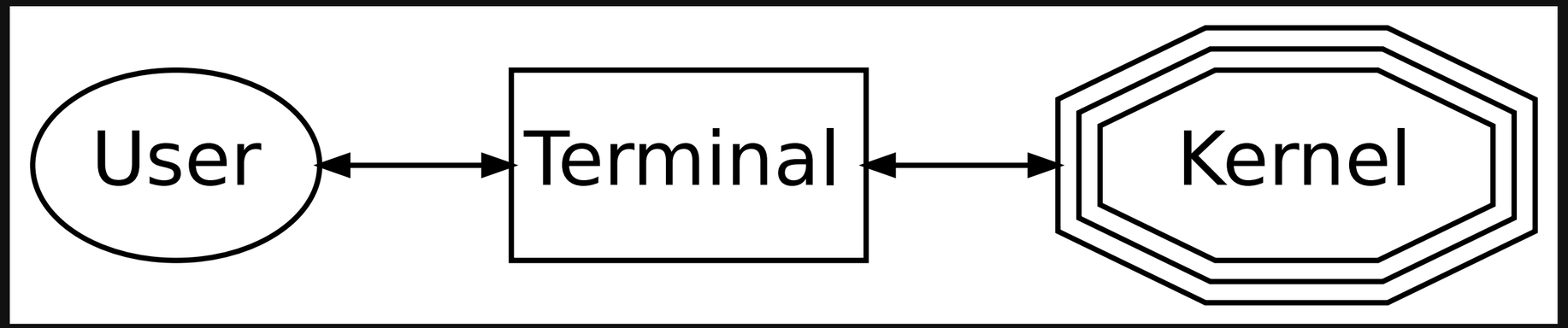
Jupyter projects are series of increasingly-elaborate **lies**.

They present the **illusion** of talking directly to a kernel, but add layers of indirection.

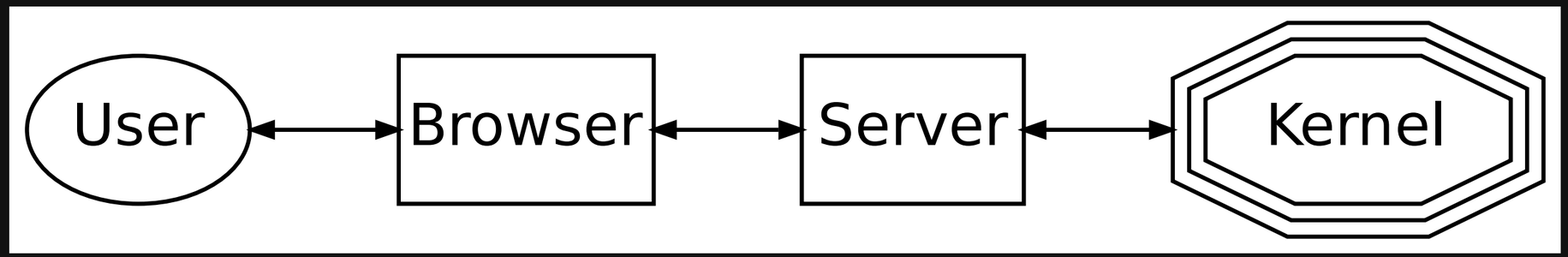
IPython



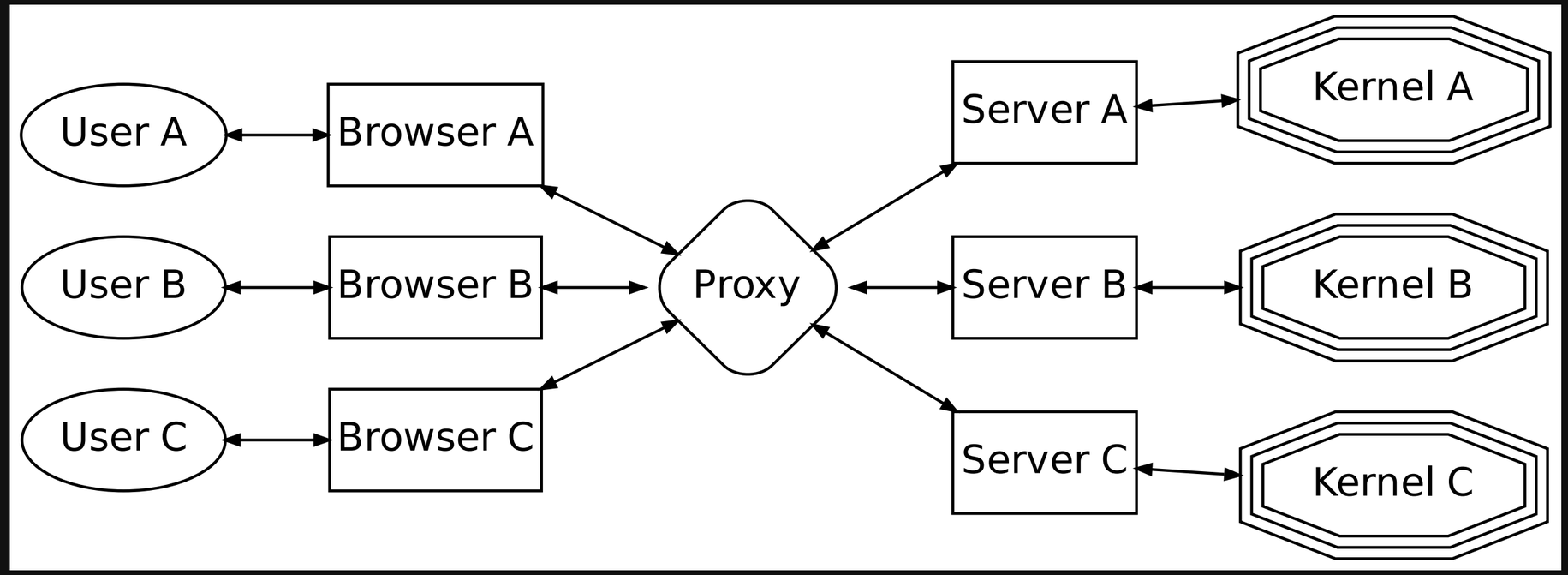
Jupyter Console



Jupyter Notebook



JupyterHub


User A
Browser A
User B
Browser B
User C
Browser C
Proxy
Server A
Server B
Server C
Kernel A
Kernel B
Kernel C

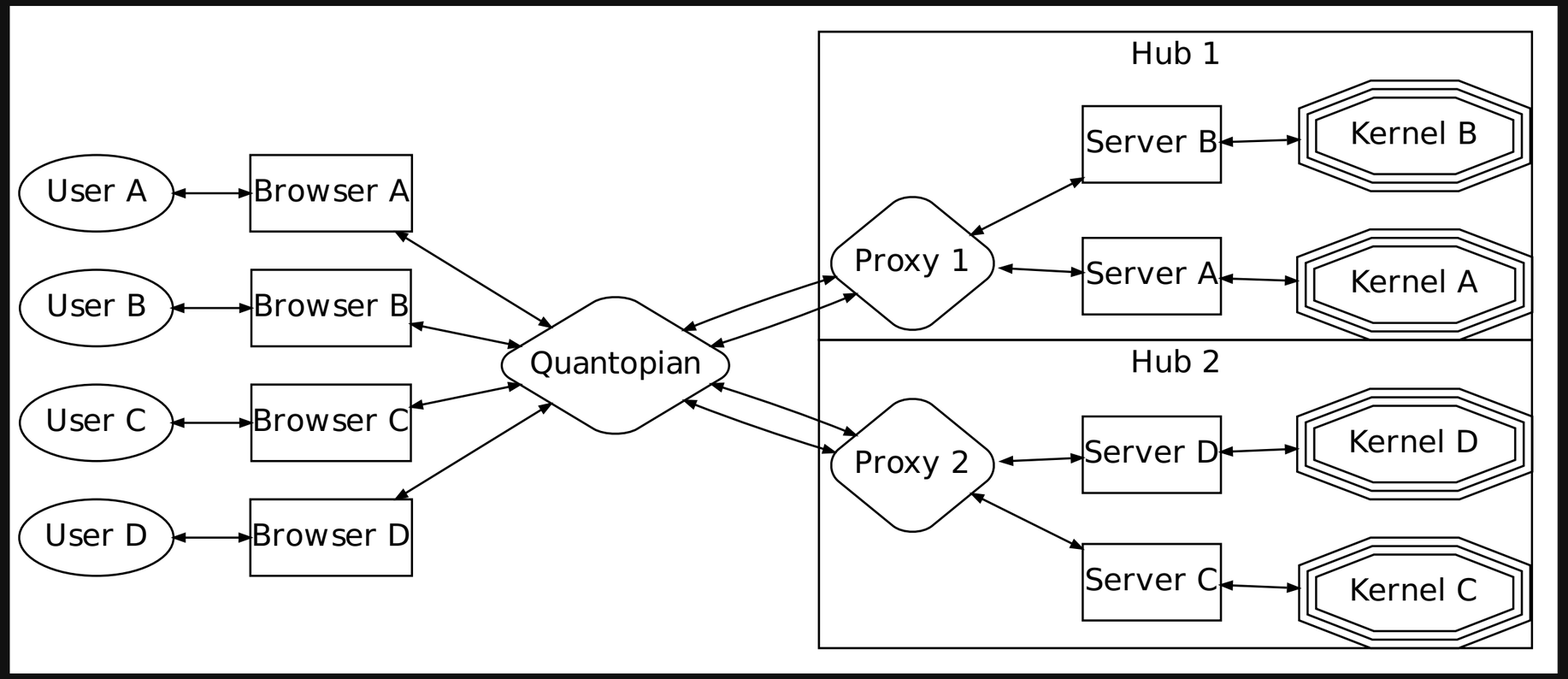
Observation:

We want the **illusion** of having a single JupyterHub, but with multiple real hubs.

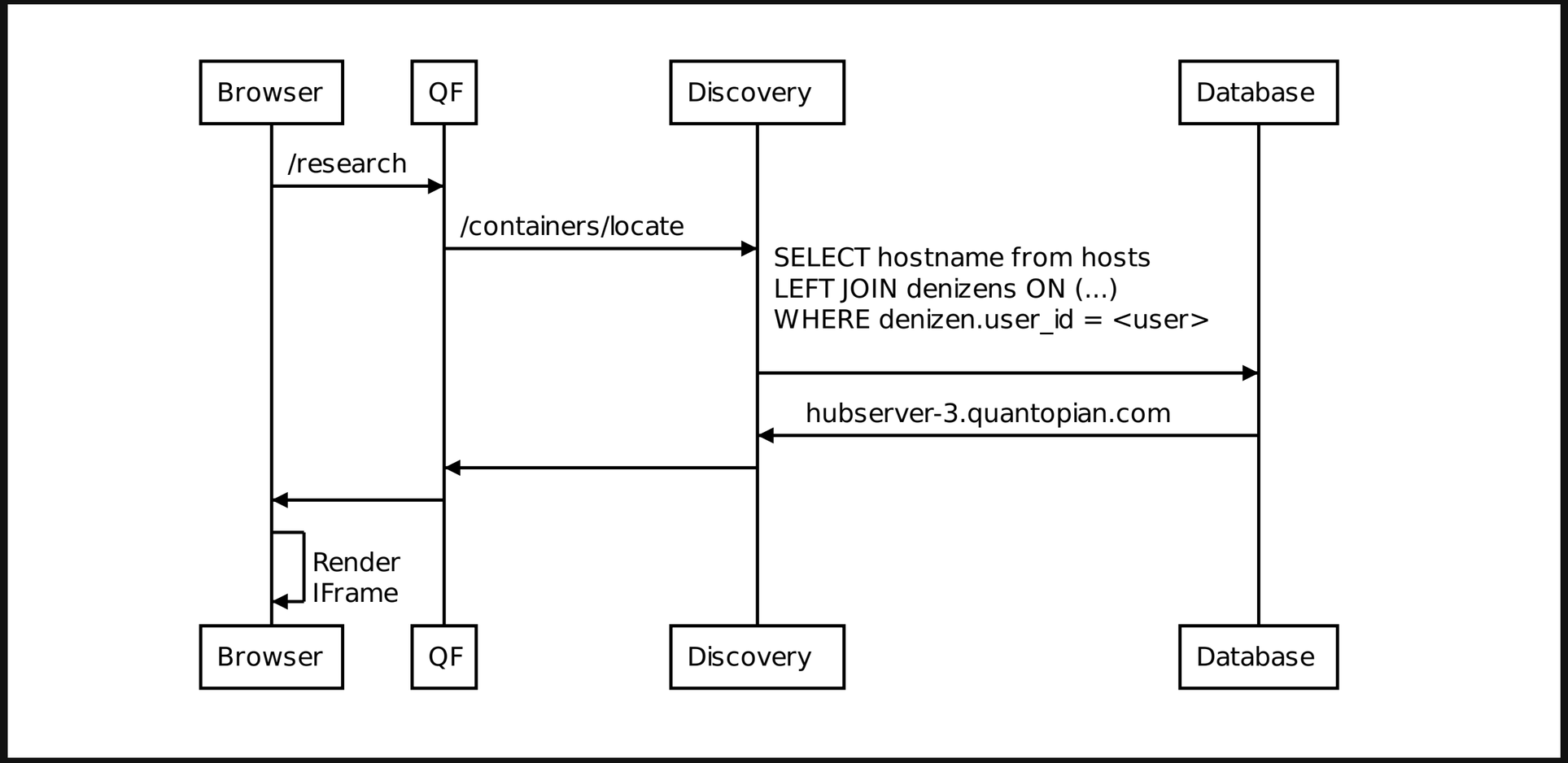
We also want to **embed** the Hub in another web page.

We render the hub in an iframe to kill two birds with one stone.

Multi-Hub


Hub 1
Server B
Kernel B
User A
Browser A
Proxy 1
Server A
Kernel A
User B
Browser B
Quantopian
Hub 2
User C
Browser C
Proxy 2
Server D
Kernel D
User D
Browser D
Server C
Kernel C

Hub Discovery



Implementation Notes

Discovery routing logic is very simple. We just choose the hub with the least users.

We subclass the base JupyterHub class to add additional logic for registering/heartbeating with discovery:

```
class QuantopianJupyterHub(JupyterHub):

    @gen.coroutine
    def initialize(self, *args, **kwargs):
        yield super().initialize(*args, **kwargs)

        yield self.do_discovery_start()

        # Heartbeat immediately, then register a callback to poll.
        yield self.do_discovery_heartbeat()
        PeriodicCallback(
            self.do_discovery_heartbeat,
            1e3 * self.discovery_heartbeat_interval,
        ).start()
```

```
@gen.coroutine
def do_discovery_heartbeat(self):
    try:
        yield self._make_discovery_request('heartbeat')
        self.consecutive_failed_heartbeats = 0
    except HTTPError as e:
        self.consecutive_failed_heartbeats += 1
        self.log.exception(
            "Heartbeat %d failed",
            self.consecutive_failed_heartbeats
        )
        if self.consecutive_failed_heartbeats >= \
           self.consecutive_failed_heartbeats_before_shutdown:
            self.log.error("Too many failed heartbeats. Shutting Down.")
            self.trigger_graceful_shutdown()
        raise
```

Sharing Notebooks

Quantopian is a **community** of authors and researchers.

Users need to be able to **share** and **discuss** their findings.

Notebooks are an **ideal** format for sharing exploratory research.

Sharing/Cloning Extensions

Two Parts:

- An **nbextension** (UI/Javascript).
- A **serverextension** (Backend/Python).

NBExtension

- Adds a **Share** button to each cell.
- Share button marks the cell as a "showcase cell" in notebook metadata, then sends a POST with notebook content to the server.

Server Extension

- Adds a request handler to the notebook server.
- Request handler receives POST from nbextension, nbconverts to HTML, and uploads HTML + .ipynb to S3.

Sharing Notes

NBExtension + Server Extension combo makes it relatively easy to add arbitrarily powerful functionality to the notebook.

Server-side APIs are generally more robust and stable.

Part of the motivation behind **JupyterLab** is adding more well-defined APIS for frontend extensions.

Conclusions

Jupyter Applications are amazingly extensible and customizable.

Extensions I didn't have time to talk about:

- Memory Monitor Extension
- Interactive DataFrame Widget
- Custom Completions
- Custom Kernel Restarter
- Custom Notebook Server Spawner
- ...

Conclusions

State is the enemy of robustness and scalability.

Lots of problems become way easier if we don't have to worry about state.

Conclusions

~~Jupyter is built on a throne of lies.~~

Appropriate use of indirection allows us to compose complex applications from simple parts.

Special Thanks:

- Brian Granger
- Carol Willing
- Kyle Kelley
- Min Ragan-Kelley
- The IPython/Jupyter Team
- David Michalowicz
- Karen Rubin
- Tim Shawver
- The Quantopian Team

Questions?

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