IEMS 5703
Network Programming and System Design

Lecture 6 - Web and Application Servers

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Web/HTTP Servers

HTTP

- **HTTP** is an application protocol designed for transmitting Web pages and other documents over the Internet
- HTTP is also based on the **client-server model**
- In this lecture, we will introduce:
  - How does an HTTP server (Web server) works?
  - How do we create network applications that use HTTP for communication

Web Servers

What does a basic **Web server** do?

- It is responsible for **serving** Web pages and other documents to Web clients (in most cases the Web browsers)
- Each incoming **request** asks for a file stored in the machine running the Web server (identified by a **path**)
- THe Web server loads the content of the file and sends it to the client
- In the most basic form, a Web server serves **static** content

Web Servers

A simple HTTP server's pseudo-code

```
Open socket, listen at port 80
While true:
    Accept socket connection from client
    While read == true:
        Read request data
    Process request data
    Output response
    Close connection
```

A Simple Web Server in Python

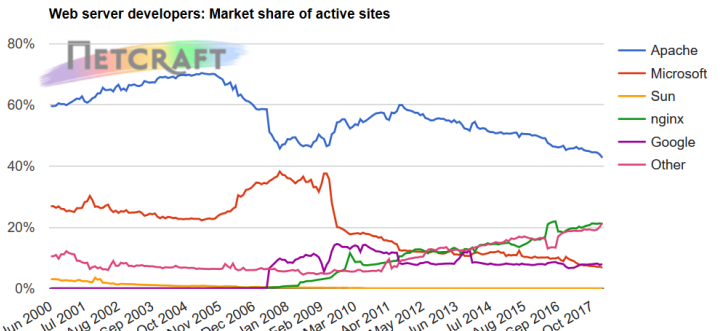
- Python comes with a class **`HTTPServer`**, which is a subclass of **`TCPServer`**
- You can run a simple Web server using the command below, which will start serving content under the folder in which you execute the command

```
$ python3 -m http.server
Serving HTTP on 0.0.0.0 port 8000 ...
127.0.0.1 - - [16/Feb/2018 14:54:32] "GET / HTTP/1.1" 200 -
...
```

- By default it listens on all network interface, and on port 8000. Use **`--help`** to check how you can configure the server

Common Web Servers

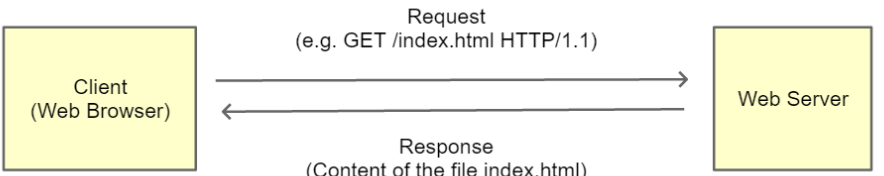
- Many off-the-shelf Web servers can be found. Examples are Apache, Nginx, and Lighttpd



- Ref: https://news.netcraft.com/archives/2018/02/13/february-2018-web-server-survey.html

Functions of a Web Server

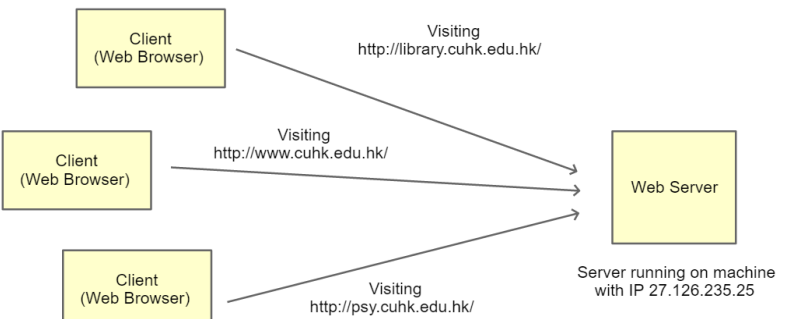
Serving Static Content



Functions of a Web Server

Manage Multiple Domains (Virtual Hosting)

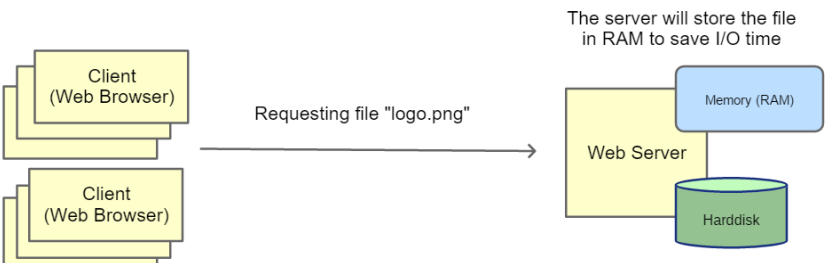
- Assume that the three domains all map to the same IP address
- The Web server needs to determine what to server given the domain in the request



Functions of a Web Server

Caching

- When some files are frequently accessed by the clients, a Web server can keep the contents in the RAM to avoid repeated I/O



Other Functions

- HTTP Authentication (restrict access using username and password)
- Executing serer-side scripts
- URL redirection / URL Rewriting
- Reverse proxying (redirect requests to application servers)
- Traffic control
- ...

Types of HTTP Servers

In order to **server multiple clients** more efficiently, there are different implementations using different concurrent programming methods

- **Multi-threading**: Create a new thread to handle a new request
- **Multi-processing**: Create a new process to handle a new request
- **Pre-fork Workers**: Create a pool of workers (either processes or threads) in advance to handle new requests
- **Event-driven** / **asynchronous** approach

Nginx

- A web server "with a strong focus on high concurrency, performance and low memory usage"
- A free and open source software developed by Igor Sysoev (a Russian software engineer)
- Use an event-driven (asynchronous) approach to hand HTTP requests Avoid waiting for blocking system calls (e.g. read from socket, read from file in memory or from disk)
- Addition functions such as reverse proxy with caching, load balancing, and support other new protocols such as SPDY or WebSocket

Serving Dynamic Content

HTTP Servers vs. Application Servers

- For running a Website with mostly **static content**, a Web server is sufficient
- However, building an application or service involves more complex server-side logic, and very often you will need to generate content dynamically. Examples:
  - Loading the **profile page** of a user in a Web application
  - Providing **personalized** recommendations
  - Applications requiring updating data stored in a **database**
  - A Web application that provides language translation **services**
  - ...
- You need an **application server**!

HTTP Servers vs. Application Servers

- These two types of servers have different requirements

HTTP Servers

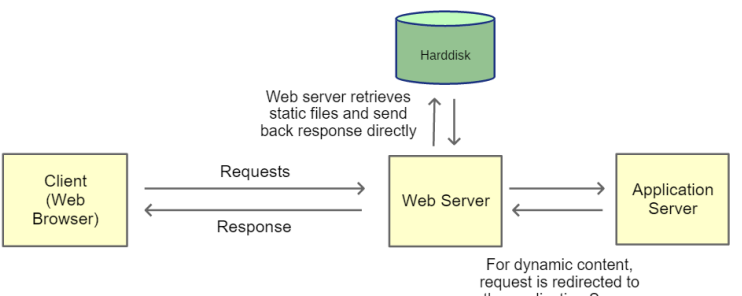
- Has to be stable and secure
- Serve static files or content quickly
- Be configurable
- Be able to handle many requests at a time (concurrency issues)
- Be language agnostic

Application Servers

- Execute business logic
- Development using high-level languages is usually more efficient
- Interface with other components to execute the business logic (e.g. database, message queues, other Web services)

HTTP Servers vs. Application Servers

- If your application uses **HTTP**, then a Web server will help you handle most of the common HTTP-related functions
- You can focus on the implementation of the **logic** of your application
- The Web server will send requests to the application server for carrying out computation or for retrieving dynamic content



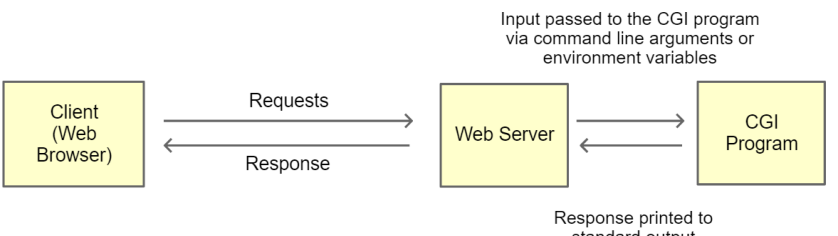
Interface with Application Servers

How does a Web server communicates with an application?

- via executing **console applications** (e.g. CGI)
- via plug-in or **modules** (e.g. mod_php in Apache)
- via **TCP** connections (e.g. FastCGI)
- via other specific **programming interfaces** (e.g. WSGI)

Common Gateway Interface (CGI)

- A standard protocol for interfacing external application with a Web server
- **CGI programs** are executable programs that run on the Web server machine
- The Web server creates a new process by executing the CGI programs
- CGI programs print response to the **standard output**, which will be collected by the Web server to produce the final response to the client.



Limitation of CGI

- For each request to invoke a CGI program, a new process is created, which will be terminated at the end of the execution
- The **overhead** to start and terminate the process can be huge
- Consider Assignment 2 in which we use SqueezeNet for object recongition:
- In a sample run:
  - Time to import Tensorflow, Keras and SqueezeNet, and to load the pre-trained model: **2.03 seconds**
  - Time to process one image and generate predictions: **0.14 seconds**

Beyond CGI

- CGI is suitable only for relatively simple tasks or when the overhead of starting the process is small
- To reduce **overhead**, it is necessary to:
  - Do initialization only once
  - Pre-load data and logic necessary for the tasks
- In other words, it is desirable to have a **persistent** process running to serve incoming requests
- Some solutons: FastCGI, SCGI, Python's WSGI

Web Server Gateway Interface (WSGI)

- WSGI refers to the Web Server Gateway Interface (See also PEP 3333)
- Specify the interface through which a Web server and an application communicate
- If an application is written according to the specification, it will be able to run on any server developed according to the same specification
- Applications and servers that use the WSGI interface are said to be **WSGI compliant**

Why WSGI?

- Web servers are not capable of running Python applications
- For Apache, there is a module named **mod_python**, which enables Apache to execute Python codes
- However, **mod_python** is
  - not a standard specifications
  - no longer under active development
- Hence, the Python community came up with **WSGI** as a standard interface for Python Web applications

Why WSGI servers and WSGI applications?

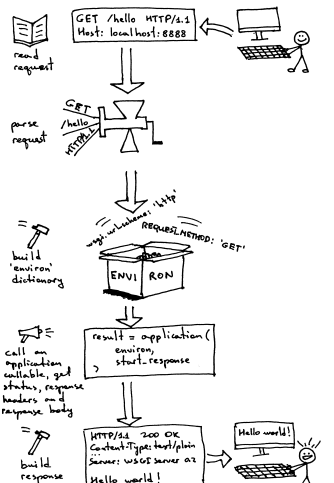
- It is an example of **de-coupling**
- Applications focus on how to get things done (e.g. business logic, updating databases, serving dynamic content, etc.)
- Servers focus on how to route requests, handle simultaneous connections, optimise computing resources, etc.
- As an application developer, you can focus on developing the functions and features, without worrying about how to interface with the Web server

WSGI Flow

When there is a new request

1. The server invokes the application
2. Parameters are passed to the application using environment variables
3. The server also provides a callback function to the application
4. The application processes the request
5. The application returns the response to the server using the callback function provided by the server

Ref: https://ruslanspivak.com/lsbaws-part2/



Example

- A simple WSGI-compatible application that returns "Hello World"

```
def application(environ, start_response):
    start_response(‘200 OK’, [(‘Content-Type’, ‘text/plain’)])
    yield ‘Hello World\n’
```

- **`environ`** contains parameters that the server passes to the application (e.g. parameters in the query string)
- **`start_response`** is a callback function provided by the server, the application uses it to return the HTTP response

Web Frameworks

- You do not need to directly implementing the WSGI interface in your application, as there are many **Web frameworks** that will help you development an application more easily
- In this course, we will talk about Flask
  - Relatively easy to pick up
  - Debug mode that assists your development
  - Many plugins and modules
- Other options:
  - Django: A comprehensive Web framework following the model-view-controller (MVC) architectural pattern
  - Bottle: A micro-framework like Flask, but more lightweight and requires no dependencies on other modules
- For more, see https://wiki.python.org/moin/WebFrameworks/

Developing Web Applications using Flask

Flask

- Flask is a Python framework for developing WSGI compatible Web / HTTP applications
- To use Flask, install it using `pip`:

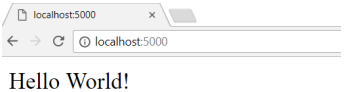
```
$ pip3 install Flask
```

- A Flask "Hello World" Application

```python
from flask import Flask
app = Flask(__name__)

@app.route('/')
def hello_world():
    return 'Hello World!'

if __name__ == '__main__':
    app.run()
```

Flask

```python
from flask import Flask

# Create a Flask application
app = Flask(__name__)

# Define a new route at "/"
@app.route('/')
def hello_world():
    return 'Hello World!'

if __name__ == '__main__':
    # Run the application at
    # the default port (5000)
    app.run()
```



Routes

- Define different routes (paths) for different functions
- An HTTP request to a particular path will invoke the corresponding function

```
from flask import Flask
app = Flask(__name__)

@app.route('/')
def index():
    return 'Index Page'

@app.route('/hello')
def hello():
    return 'Hello World'
```

Note: If you define the url with a **trailing slash**, like `@app.route('/about/')`, accessing it without a trailing slash will cause Flask to redirect to the canonical URL with the trailing slash. However, if you define the url without a trailing slash, like `@app.route('/about')`, accessing it with a trailing slash will produce a **404 "Not Found"** error.

Dynamic Routes

- You can change part of the path to be a variable that can be used to change the behaviour of a function
- Specifiy **`<variable>`** in the route, and let the function receive an argument:

```
@app.route('/user/<username>')
def show_user_profile(username):
    message = "Hello {}!".format(username)
    return message

# Use <type:variable> to restrict the data type
@app.route('/post/<int:post_id>')
def show_post(post_id):
    message = "This is Post {:d}".format(post_id)
    return message
```

GET and POST Requests

- By default, a route only answers to HTTP **GET** requests
- You can change this by providing the methods explicitly when defining the route

```
from flask import request

# Accepts both GET and POST method
# Perform different tasks depending on the method
@app.route('/login', methods=['GET', 'POST'])
def login():
    # request is an object containing information
    # about the request received from the client
    if request.method == 'POST':
        # Check user's username and password
        ...
    else:
        # Presents the login form
        ...
```

Passing Data to the Application

- Your app will almost always need to pass some data to the server
- In the query string when using GET (e.g. the ID of a news article)
- In the HTTP body when using POST (e.g. the username and password for signing in)
- You can access the data submitted from the client using the **`request`** object in Flask

```
@app.route('/get_news', methods=['GET'])
def get_news():
    news_id = request.args.get("news_id")
    ...

@app.route('/like_news', methods=[POST'])
def like_news():
    news_id = request.form.get("news_id")
    ...
```

Generating Response

- Response can be classified into two types:
  - **Human-readable** (e.g. Web page coded in HTML)
  - **Machine-readable** (e.g. XML, JSON)
- Your application may need to return both types of response, depending on which functions get called
- Many Websites provide different both types of response (**Web pages** and **APIs**)
- For example, consider https://openweathermap.org/:
  - Web page showing the weather of Hong Kong
  - API Response containing weather information of Hong Kong in JSON format

One Page Introduction to HTML

- Hypertext Markup Language (HTML) is used to describe the structure of a Web page, and informs the Web browser how the page content should be **displayed**
- It is commonly used with JavaScript and Cascading Style Sheets to create the user interface of a Web page

```
<html>
    <head><title>Example Page</title></head>
    <body>
        <div>
            <h1>Hello!</h1>
            This is an <b>example</b> page
        </div>
    </body>
</html>
```

JavaScript Object Notation (JSON)

- JSON is a data format commonly used for data exchange
- It has the same syntax as the definition of an object in JavaScript
- Can be directly converted into Python dictionaries or lists using the `json` module
- A JSON file with a list of students taking a course:

```
[
    {
        "first_name": "Peter",
        "last_name": "Chan",
        "student_id": "12345678"
    },
    {
        "first_name": "May",
        "last_name": "Wong",
        "student_id": "23456789"
    }
]
```

JSON

- JSON is basically made up of **lists** and **dictionaries**
- You can convert JSON to and from Python data structures using the `json` module

```
import json

# Converts a string of JSON into Python data structure
data_str = '[{"x": 1}, {"x": 3}, {"x": 5}]'
data = json.loads(data_str)
# Now data[0]["x"] is 1

# Serialize a Python list to a JSON string
data_str = json.dumps(data)
```

Generating HTML Response in Flask

- In Flask, you can return HTML directly as a string

```
@app.route('/')
def index():
    return """
        <html>
            <head>
                <title>My Homepage</title>
            </head>
            <body>
                Welcome!
            </body>
        </html>
    """
```

Generating HTML Response in Flask

- More conveniently, you can use HTML templates that are stored under a **`templates`** folder

```
from flask import render_template

@app.route('/')
def index():
    # return the content of index.html
    return render_template('index.html')
```

- Flask uses the **`Jinja2`** template engine, which is very powerful for generating dynamic HTML pages
- See http://flask.pocoo.org/docs/0.12/quickstart/#rendering-templates for some examples

Generating JSON Response in Flask

- When you are developing an API, you will probably need to return data in JSON format
- You should use the **`jsonify`** function provided by Flask, which will set the **`Content-Type`** header in the response to **`application/json`**

```
from flask import jsonify

@app.route('/get_news', methods=['GET'])
def get_news():
    news_id = request.args.get("news_id")
    articles = get_news_from_db(news_id)
    return jsonify(status="OK", data=articles)
```

▼ **Response Headers** view source

Content-Length: 44
Content-Type: application/json
Date: Sun, 18 Feb 2018 00:56:44 GMT
Server: Werkzeug/0.12.2 Python/3.5.2

Example

- Let's assume we are developing an API for finding the sum of two numbers:

```
from flask import jsonify

@app.route('/add', methods=['GET'])
def add():
    # Retrieve values of a and b from query string
    a = request.args.get("a", 0, type=int)
    b = request.args.get("b", 0, type=int)
    sum = a + b

    # Return a JSON response
    return jsonify(status="OK", sum=sum)
```

- Output of sending a HTTP GET request to the path **/add?a=5&b=6**:

```
{
    "status": "OK",
    "sum": 11
}
```

Testing a Flask Application

- You can test your application by simply execute the python script, for example:

```
$ python app.py
 * Running on http://127.0.0.1:5000/ (Press CTRL+C to quit)
```

- By default, Flask will execute the app using an **internal Web server** on port 5000, and the APIs can only be accessed from within the same machine (note the **127.0.0.1** address)
- You can change the address and port by using the arguments in the `run()` function. For example:

```
app.run(host="0.0.0.0", port=8080)
```

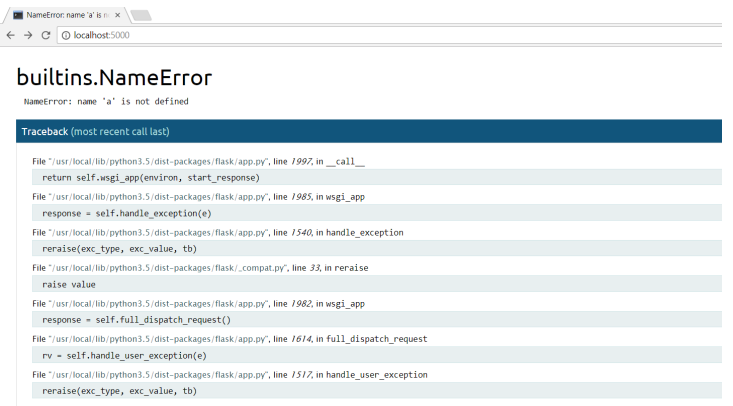
Enabling Debug Mode

- For testing and debugging purposes, you can enable the DEBUG mode of Flask by `app.run(debug=True)`
- When you execute the script again, you will see

```
$ python app.py
 * Running on http://127.0.0.1:5000/ (Press CTRL+C to quit)
 * Restarting with stat
 * Debugger is active!
 * Debugger pin code: 211-226-346
```

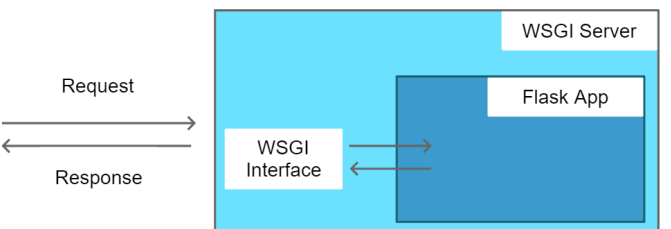
Enabling Debug Mode

- If some exceptions occur during the execution of the Flask application, you will see a debug interface. For example:



Deploying Flask Applications

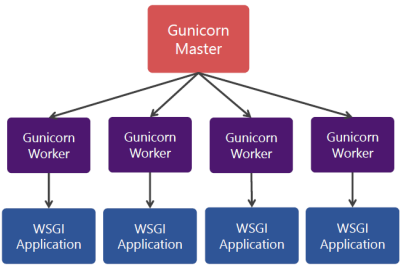
- The internal Web server of Flask is only for **testing** and **development** purposes
- For deploying the application for production use, you need a proper HTTP WSGI server to **host** your application
- The HTTP WSGI server will load your application on start up, and route requests to the application



Gunicorn

- Gunicorn is a Python WSGI HTTP Server for Unix / Linux systems.
- It acts as a **container** of a WSGI application
- It manages one or more instances of the application (multiple workers)
- Architecture of Gunicorn
  - A **pre-fork worker** model
  - A master process managers a set of worker processes
  - Each worker process runs a copy of your application

```
$ pip3 install gunicorn
```



Gunicorn

- Basic Usage (See Documentation)

```
$ gunicorn [OPTIONS] $(MODULE_NAME):$(VARIABLE_NAME)
```

- For example:

```
$ gunicorn app:app -b localhost:8000 -w 4
```

- A Flask app called `app` defined inside a file called `app.py`
- Running on port `8000` on `localhost`
- Create **4** worker processes

Number of Workers

- Depends on your application's design and also the configurations of the server (e.g. number of cores of CPUs)
- In general: **2n + 1**, where n = number of cores
- Based on the assumption that half of the workers are doing I/O while half of the workers are doing computation
- There are **TWO** main types of Gunicorn workers

- **Sync Workers**: Default type – handles a single request at a time
  - Suitable for applications that do not do something that consume an undefined amount of time or resources
- **Async Workers**: For non-blocking request processing
  - Use this if your application has I/O bound operations (i.e. need to wait for I/O events to finish)

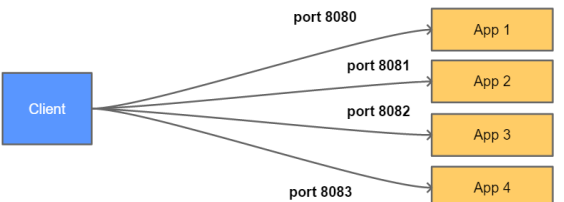
Example

```
from flask import Flask
import time
import random
app = Flask(__name__)

@app.route("/sleep/")
def go_sleep():
    x = random.randint(1,3)
    time.sleep(x)
    return str(x)

if __name__ == "__main__":
    app.run()
```

- If you use sync workers, a worker can only serve a new request after one request has been finished
- Using async workers (e.g. gevent or eventlet), a worker will switch to serve another request while one is waiting for I/O (or any other blocking operation)

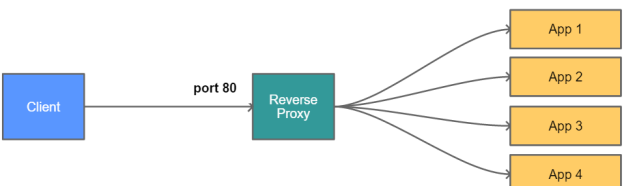
Running Multiple Applications

- It is common to have multiple applications running on the same machine
- If we allow clients to connect to each applications directly, we need to specify different port numbers



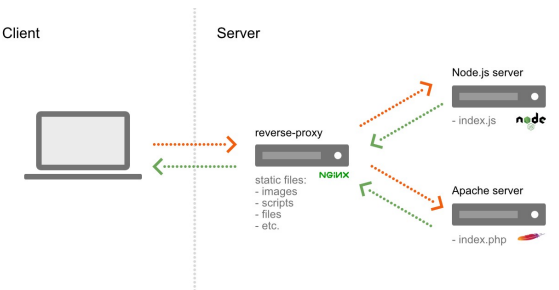
Reverse Proxy

- To make it easier for the client to make requests, we usually use a **reverse proxy server** to relay requests to different applications
- Clients always send requests to a **Web server on port 80**, which will **redirect** requests to different apps depending on the **URL**



Nginx as a Reverse Proxy

- **Nginx** is a Web server but can also be configured as a reverse proxy server
- It can proxy requests to another HTTP server or even a non-HTTP server
- It supports the following non-HTTP protocol: FastCGI, uwsgi, SCGI, memcached
- It can also serve **static pages** more efficiently, and also act a **cache**



Ref: https://medium.com/@francoisromain/setup-node-js-apache-nginx-reverse-proxy-with-docker-1f5a5cb3e71e

Configuring Nginx

- Nginx can be configured by editing the configuration files
- In Ubuntu, configuration files are usually stored under `/etc/nginx/`
- A main configuration file named `nginx.conf`
- One or more configuration files for each of the sites hosted by the server (see `/etc/nginx/site-available` and `/etc/nginx/site-enabled`)
- Examples and references: http://nginx.org/en/docs/http/load_balancing.html

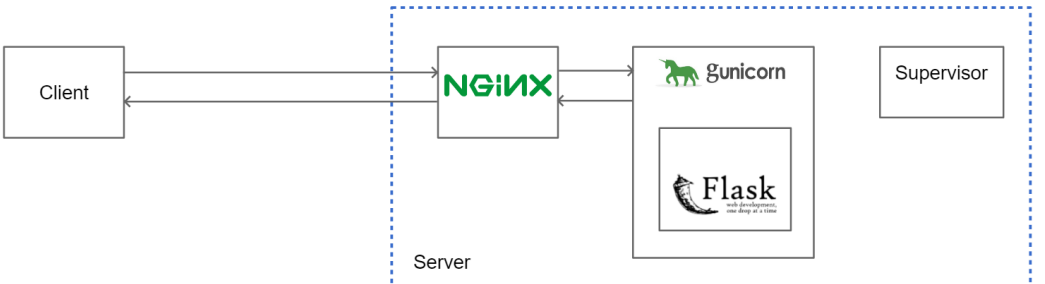
Supervisor

- Usually, we control the gunciorn process using Supervisor
- It is a **process control system** can be used to control and monitor other programs
- It can be used to **start/stop** a process, or automatically **restart** a process if it terminates
- Install via `pip3 install supervisor`
- An example config file (put under `/etc/supervisor/conf.d/`):

```
[program:myapp]
command = /home/albert/myapp/env/bin/gunicorn app:app -b localhost:8080
directory = /home/albert/myapp
user = albert
autostart = true
autorestart = true
stdout_logfile = /home/albert/myapp/log.txt
redirect_stderr = true
```

Summary

- Deploying a **Flask** app using **Nginx**, **Gunicorn** and **Supervisor**



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