Build a Micro HTTP Server for Embedded System

Connect to devices more easily

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Outline

- History
- HTTP Protocol
  - Header & Body
- The HTTP Server
  - Concurrency
  - CGI & FastCGI
  - Prototype with Python
  - Automation Test
  - Implemented in C
- Micro HTTP Server on RTOS
  - FreeRTOS
  - Hardware
  - Socket API
  - Select API
  - Assemble Parts
- Demo
  - If the local WiFi is accessible (XD)

Who am I

潘建宏 / Jian-Hong Pan (StarNight)

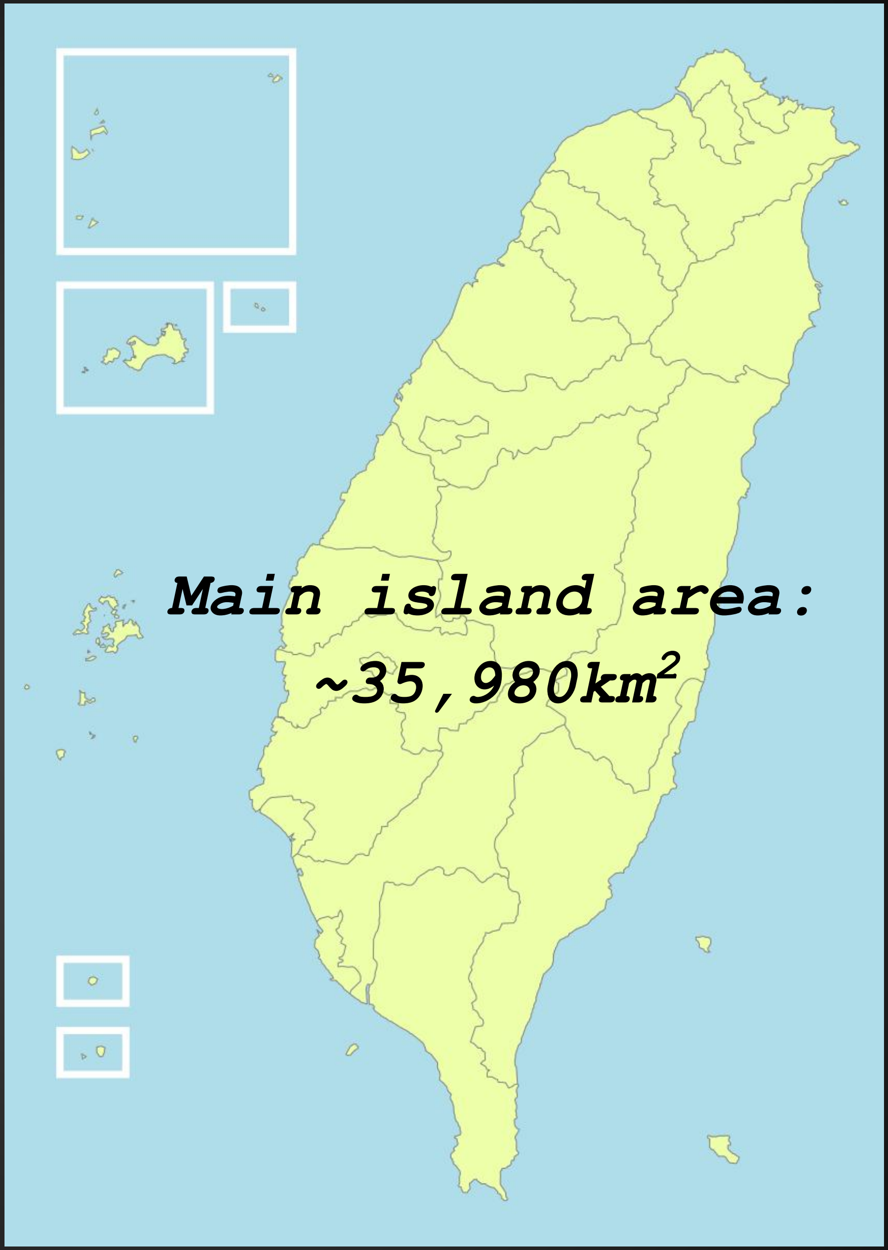
I come from Taiwan !

You can find me at ～

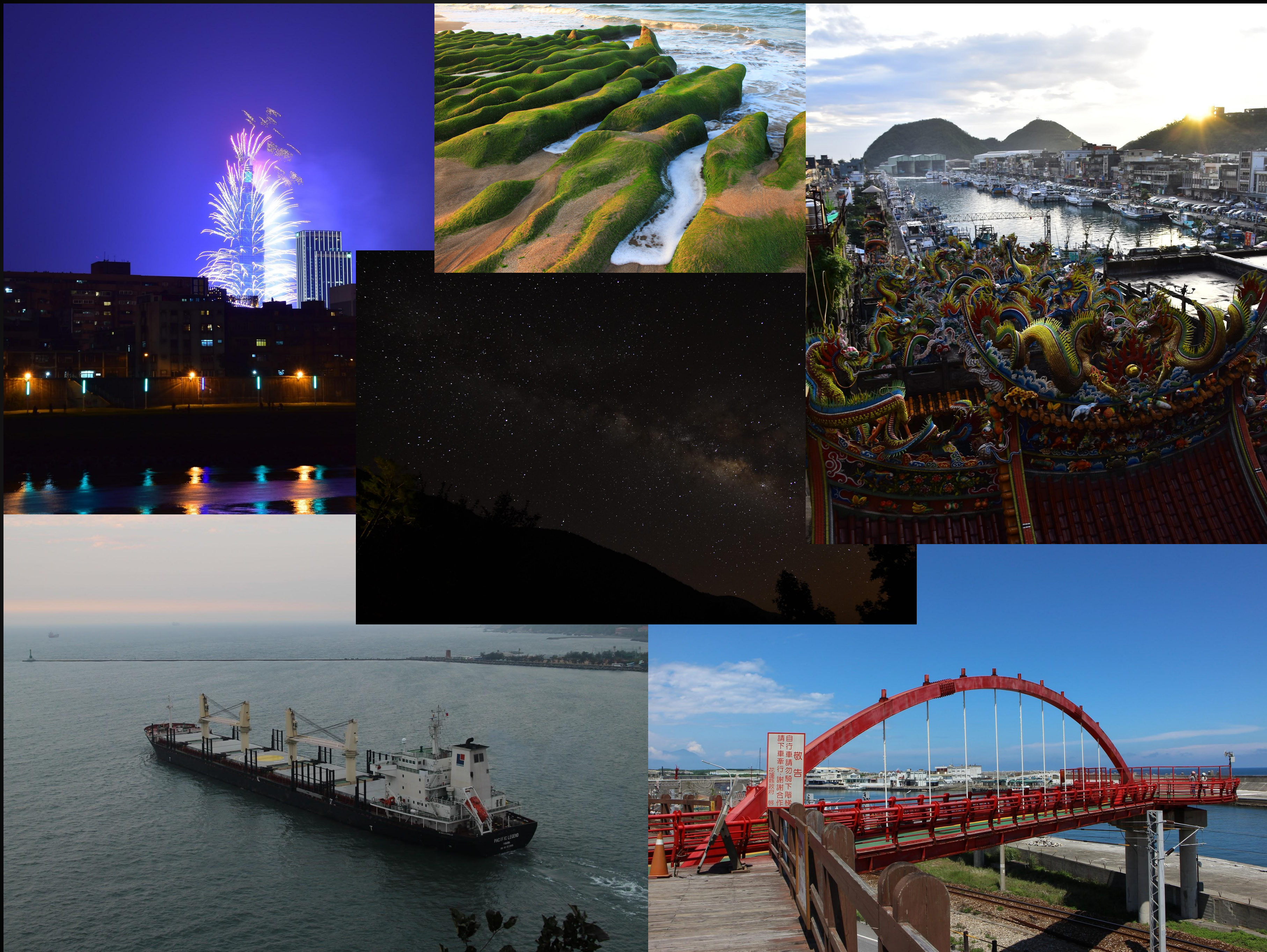
- http://www.slideshare.net/chienhungpan/
- GitHub : starnight
- Facebook : Jian-Hong Pan
- Email : starnight [AT] g.ncu.edu.tw

Taiwan

Formosa

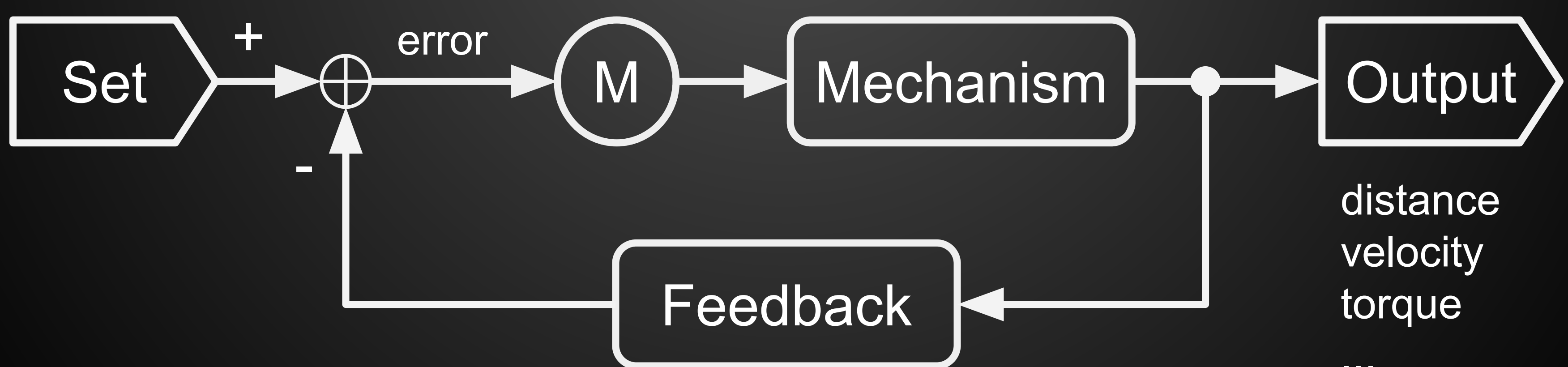


Map: https://upload.wikimedia.org/wikipedia/commons/0/06/Taiwan_ROC_political_division_map.svg

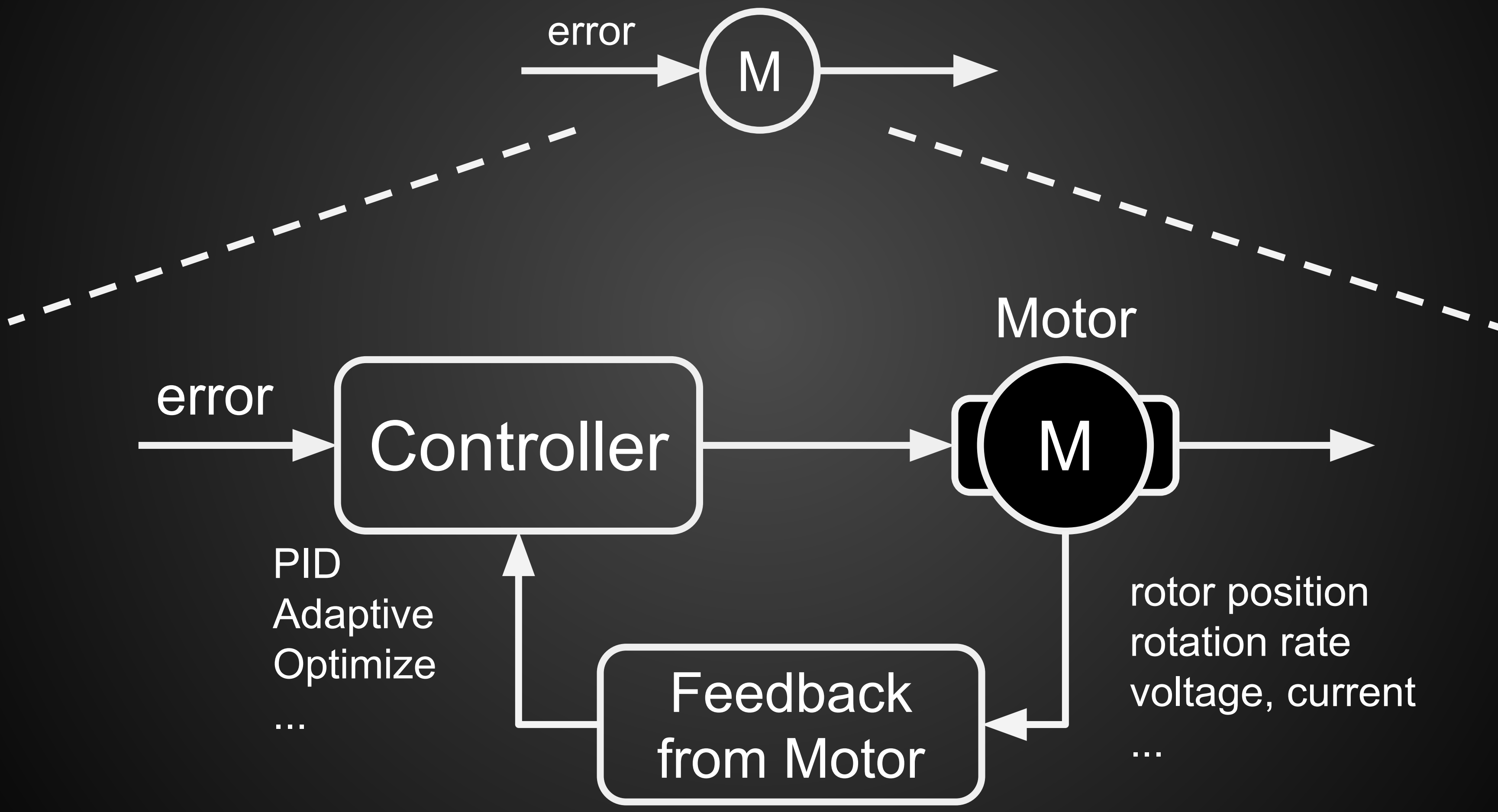

敬告
自行車請勿騎下階梯
請下車牽行，謝謝合作
花蓮縣政府 啓

History

- It starts from machine controlling which controls the machine’s motion.
- It is the motor that most be used as an actuator in the machine controlling.

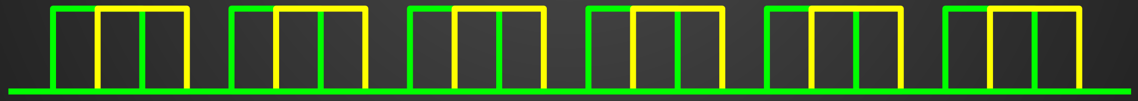


Motor Controlling ...



Measurement of Motor

- Parameters of a motor may changed due to the environment: temperature, humidity..., etc.
- Measure the rotation of the motor:
  - With the encoder which produces square waves.



  - With the sensorless method: the waves of the phases of motor's voltage, current or something else.
- Also for system identification.

Send & Get of the Communication

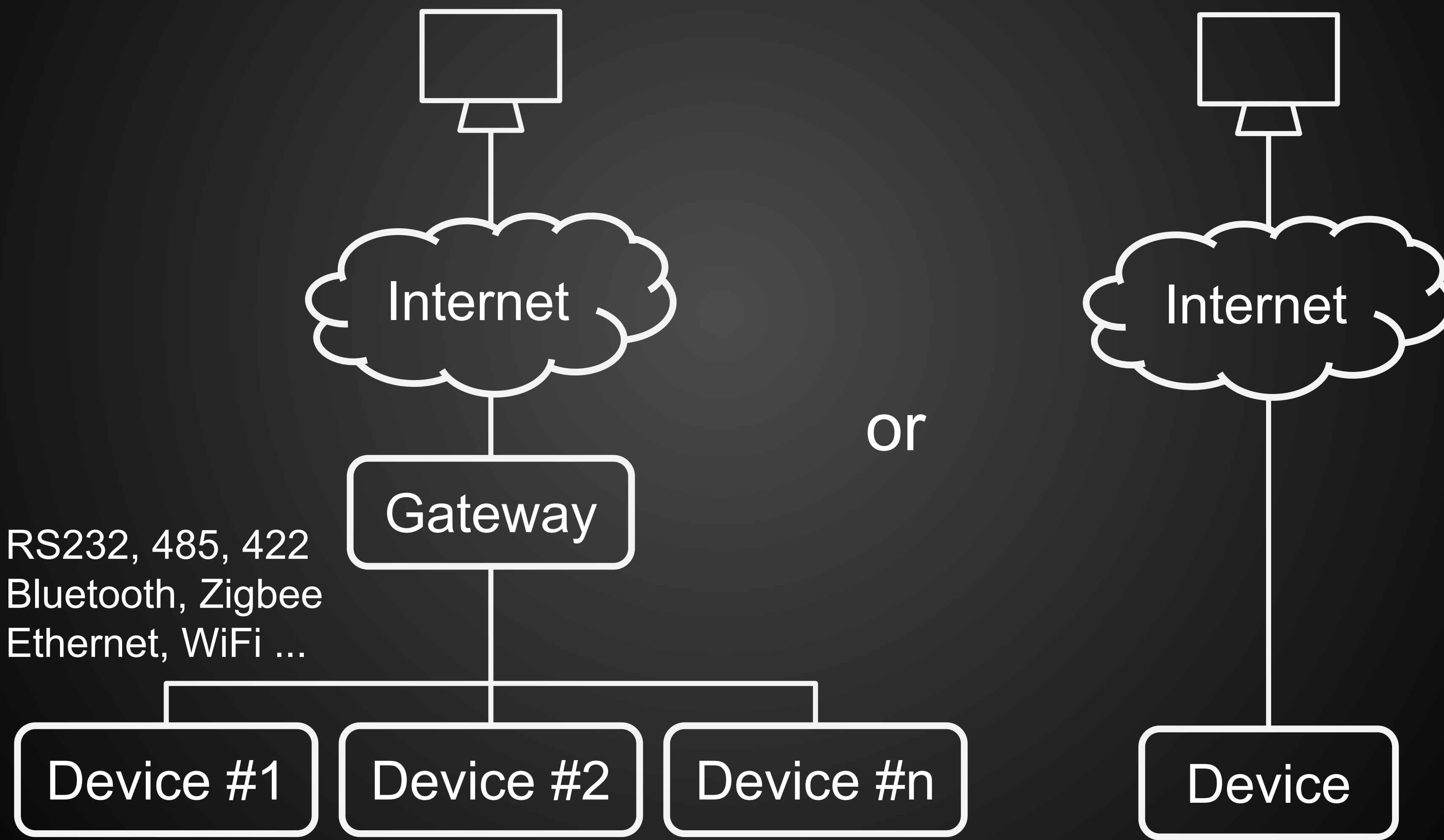
- In traditional, a protocol over the serial port is used for communication between the computer and the controller, measuring instruments.
- The devices are distributed anywhere and the serial ports wiring with the central computer could be a problem.
- Send commands and get values through the communication over serial ports that may not as fast as we want.

Communication over Internet

- Linking the devices with the TCP/IP based internet is possible. It is faster and more convenient for management.
- Protocol over TCP/IP:
  - MQTT, CoAP ...
  - or just RESTful web API on HTTP
  - Choosing depends on case by case.

PS. Internet may not be the best solution for all of the cases, but is one of the candidate.

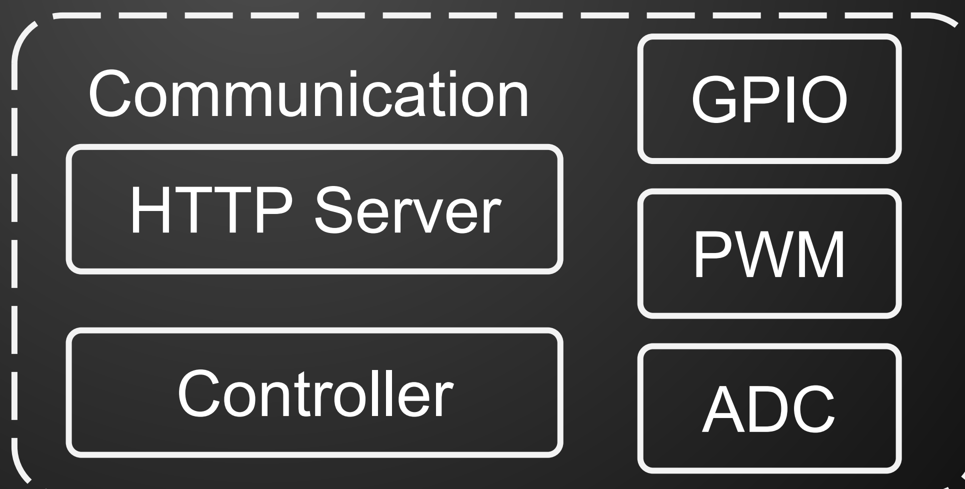
In General


Internet
Gateway
RS232, 485, 422
Bluetooth, Zigbee
Ethernet, WiFi ...
Device #1
Device #2
Device #n
or
Internet
Device

For My Condition

Full Stack / IoT
is fancy ! ! !

I just want to have an HTTP server on the embedded system.

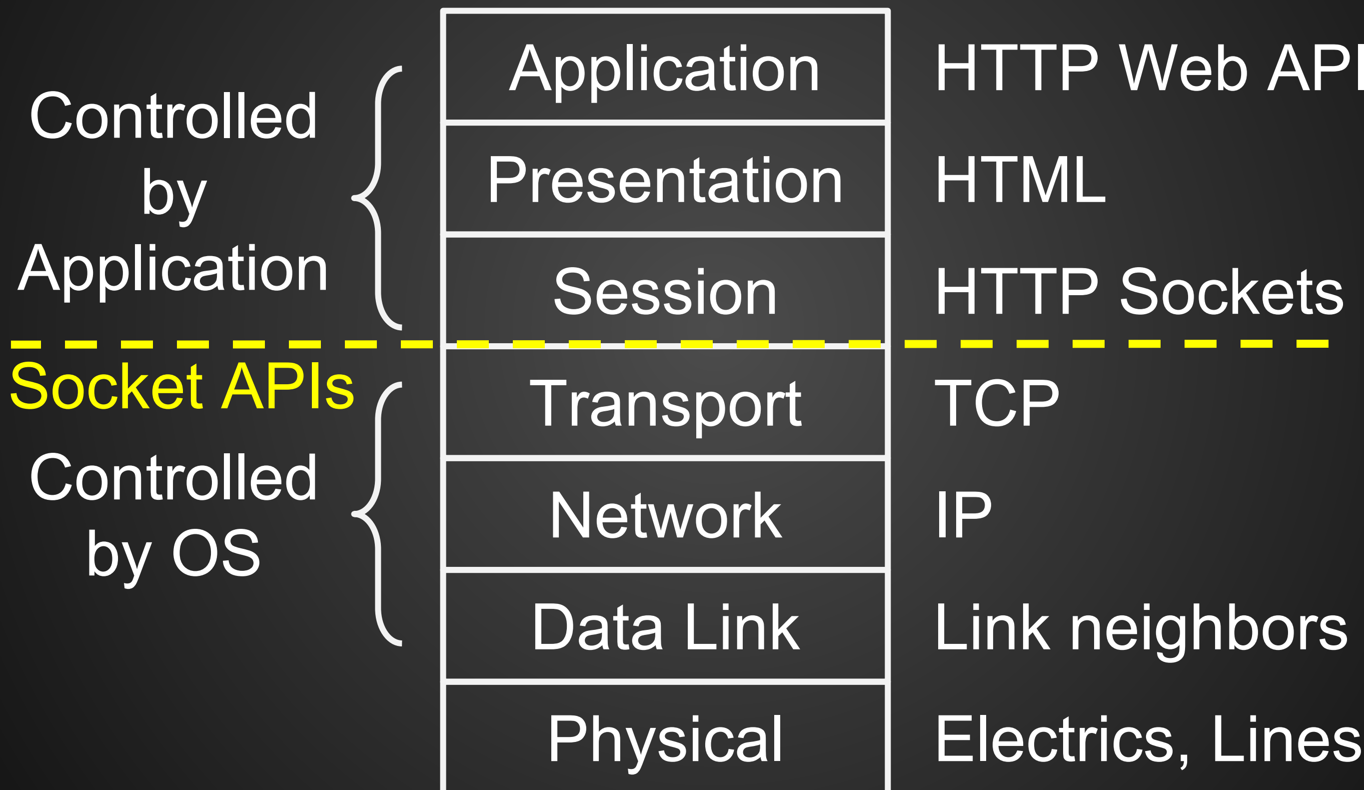


Limitations

- Considering the size and power restrictions, most embedded devices have limited resources. (MCU level)
  - Less processors: Usually has only one processor, single thread.
  - Less memory: On-chip RAM < 1MB.
  - Less storage: On-chip flash < 1MB.
  - Lower speed grade: Clock rate < 1GHz.
  - The on chip OS may even not provide process, thread APIs.
- The Apache, NGINX... HTTP server could not be placed in that restricted environment.

PS. The numbers mentioned above may not be the real numbers, but they are around that grade levels.

HTTP Server on OSI 7 Layers



Reference: Wiki OSI model https://en.wikipedia.org/wiki/OSI_model

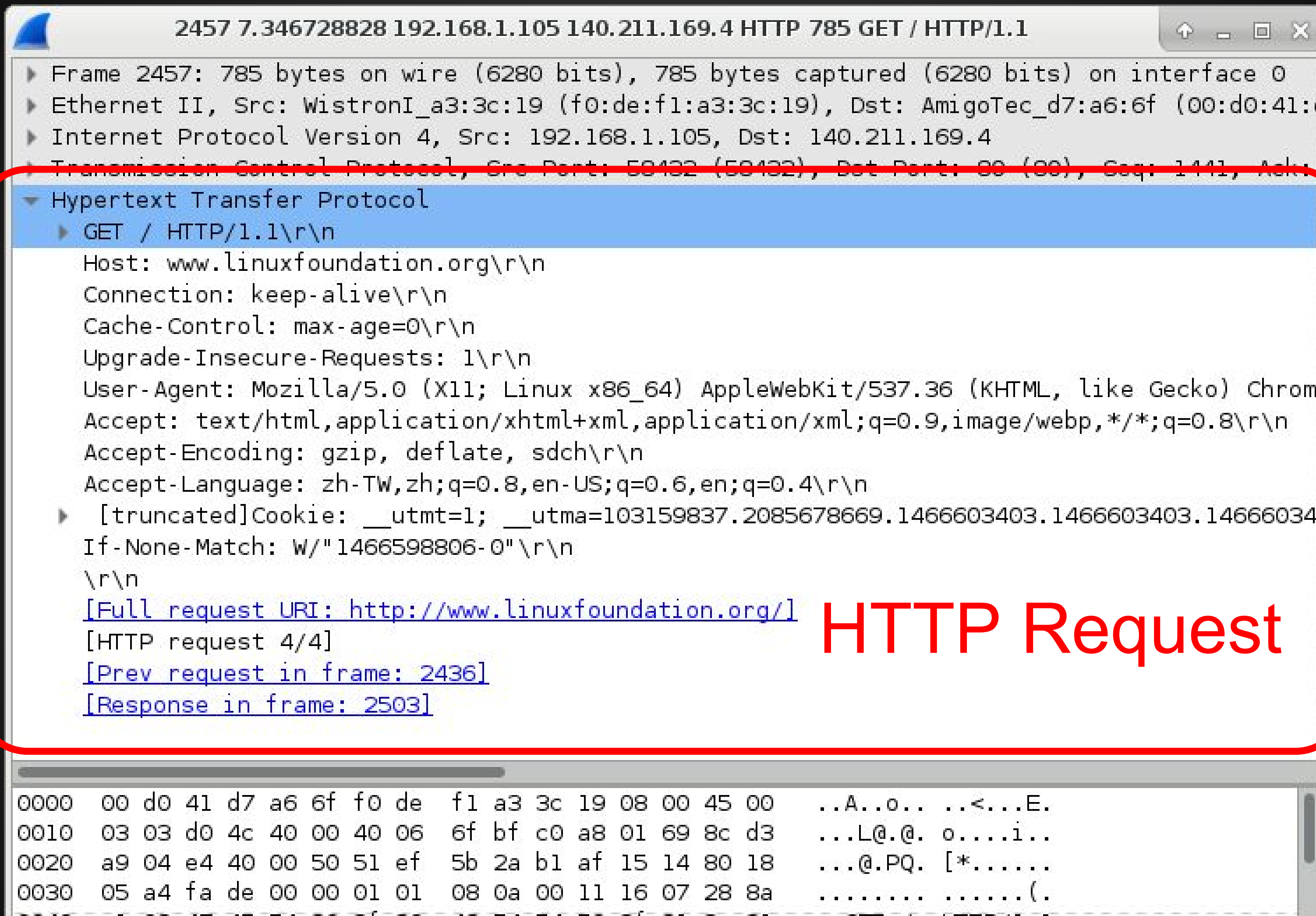
RFC 2616 HTTP/1.1

Hypertext Transfer Protocol -- HTTP/1.1
https://tools.ietf.org/html/rfc2616

Overall Operation

- *The HTTP protocol is a request/response protocol.*
- *A client sends a request to the server in the form of a request method, URI, and protocol version, followed by a MIME-like message containing request modifiers, client information, and possible body content over a connection with a server.*
- *The server responds with a status line, including the message's protocol version and a success or error code, followed by a MIME-like message containing server information, entity metainformation, and possible entity-body content.*

Reference: RFC 2616 [1.4 Overall Operation]


2457 7.346728828 192.168.1.105 140.211.169.4 HTTP 785 GET / HTTP/1.1
Frame 2457: 785 bytes on wire (6280 bits), 785 bytes captured (6280 bits) on interface 0
Ethernet II, Src: WistronI_a3:3c:19 (f0:de:f1:a3:3c:19), Dst: AmigoTec_d7:a6:6f (00:d0:41:
Internet Protocol Version 4, Src: 192.168.1.105, Dst: 140.211.169.4
Transmission Control Protocol, Src Port: 58432 (58432), Dst Port: 80 (80), Seq: 1441, Ack:
Hypertext Transfer Protocol
GET / HTTP/1.1\r\n
Host: www.linuxfoundation.org\r\n
Connection: keep-alive\r\n
Cache-Control: max-age=0\r\n
Upgrade-Insecure-Requests: 1\r\n
User-Agent: Mozilla/5.0 (X11; Linux x86_64) AppleWebKit/537.36 (KHTML, like Gecko) Chrom
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,*/*;q=0.8\r\n
Accept-Encoding: gzip, deflate, sdch\r\n
Accept-Language: zh-TW,zh;q=0.8,en-US;q=0.6,en;q=0.4\r\n
[truncated]Cookie: __utmt=1; __utma=103159837.2085678669.1466603403.1466603403.146660340
If-None-Match: W/"1466598806-0"\r\n
\r\n
[Full request URI: http://www.linuxfoundation.org/]
[HTTP request 4/4]
[Prev request in frame: 2436]
[Response in frame: 2503]
HTTP Request
0000 00 d0 41 d7 a6 6f f0 de f1 a3 3c 19 08 00 45 00 ..A..o.. ..<...E.
0010 03 03 d0 4c 40 00 40 06 6f bf c0 a8 01 69 8c d3 ...L@.@. o....i..
0020 a9 04 e4 40 00 50 51 ef 5b 2a b1 af 15 14 80 18 ...@.PQ. [*......
0030 05 a4 fa de 00 00 01 01 08 0a 00 11 16 07 28 8a ....(.

2503 7.771270413 140.211.169.4 192.168.1.105 HTTP 581 HTTP/1.1 200 OK (text/html)

HTTP Response

```
▸ Transmission Control Protocol, Src Port: 80 (80), Dst Port: 58432 (58432), Seq: 24112, Ac
▸ [11 Reassembled TCP Segments (14195 bytes): #2473(1368), #2475(1368), #2477(1368), #2479(
▾ Hypertext Transfer Protocol
  ▸ HTTP/1.1 200 OK\r\n
    Server: nginx\r\n
    Date: Wed, 22 Jun 2016 13:51:07 GMT\r\n
    Content-Type: text/html; charset=utf-8\r\n
    Transfer-Encoding: chunked\r\n
    Connection: keep-alive\r\n
    Vary: Accept-Encoding\r\n
    Etag: W/"1466598806-0"\r\n
    Cache-Control: public, max-age=0\r\n
    Last-Modified: Wed, 22 Jun 2016 12:33:26 +0000\r\n
    Expires: Sun, 11 Mar 1984 12:00:00 GMT\r\n
    Vary: Cookie\r\n
    Content-Encoding: gzip\r\n
    \r\n
    [HTTP response 4/4]
    [Time since request: 0.424541585 seconds]
    [Prev request in frame: 2436]
    [Prev response in frame: 2443]
    [Request in frame: 2457]
  ▸ HTTP chunked response
    Content-encoded entity body (gzip): 13812 bytes -> 57466 bytes
▾ Line-based text data: text/html
    <!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Strict//EN" "http://www.w3.org/TR/xhtml1/D
    <html xmlns="http://www.w3.org/1999/xhtml" xml:lang="en" lang="en" dir="ltr">\n
    \n
    <head>\n
    <meta http-equiv="Content-Type" content="text/html; charset=utf-8" />\n
      <title>The Linux Foundation</title>\n
      <meta http-equiv="Content-Type" content="text/html; charset=utf-8" />\n
    <!--[if IE 6]>\n
```

HTTP Message - Message Types

- *HTTP messages consist of requests from client to server and responses from server to client.*
- *Request (section 5) and Response (section 6) messages use the generic message format of RFC 822 [9] for transferring entities (the payload of the message).*
- *Both types of message consist of a start-line, zero or more header fields (also known as "headers"), an empty line (i.e., a line with nothing preceding the CRLF) indicating the end of the header fields, and possibly a message-body.*

```
generic-message = start-line
                  *(message-header CRLF)
                  CRLF
                  [ message-body ]

start-line      = Request-Line | Status-Line
```

Reference: RFC 2616 [4.1 Message Types]

HTTP Message - Message Headers

- *HTTP header fields, which include general-header (section 4.5), request-header (section 5.3), response-header (section 6.2), and entity-header (section 7.1) fields.*
- *Each header field consists of a name followed by a colon (":") and the field value. Field names are case-insensitive. The field value MAY be preceded by any amount of LWS, though a single SP is preferred.*

message-header	=	*field-name ":" [field-value]*
field-name	=	*token*
field-value	=	**(field-content | LWS)*
field-content	=	*<the OCTETs making up the field-value and consisting of either *TEXT or combinations of token, separators, and quoted-string>*

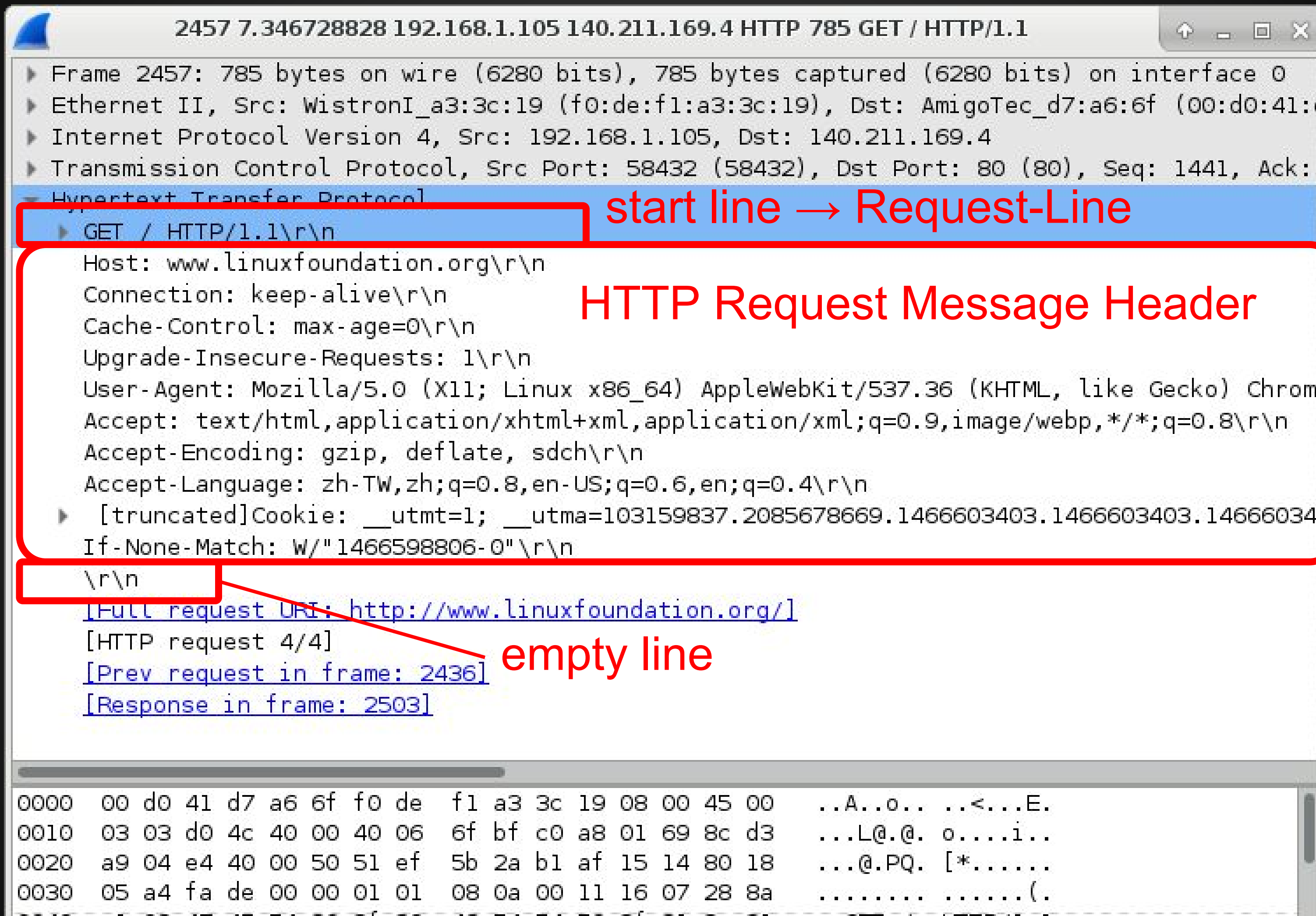
Reference: RFC 2616 4.2 Message Headers

HTTP Message - Message Body

- *The message-body (if any) of an HTTP message is used to carry the entity-body associated with the request or response.*

message-body = entity-body
| <entity-body encoded as per Transfer-Encoding>

Reference: RFC 2616 [4.3 Message Body]


2457 7.346728828 192.168.1.105 140.211.169.4 HTTP 785 GET / HTTP/1.1
Frame 2457: 785 bytes on wire (6280 bits), 785 bytes captured (6280 bits) on interface 0
Ethernet II, Src: WistronI_a3:3c:19 (f0:de:f1:a3:3c:19), Dst: AmigoTec_d7:a6:6f (00:d0:41:
Internet Protocol Version 4, Src: 192.168.1.105, Dst: 140.211.169.4
Transmission Control Protocol, Src Port: 58432 (58432), Dst Port: 80 (80), Seq: 1441, Ack:
Hypertext Transfer Protocol
GET / HTTP/1.1\r\n
start line → Request-Line
Host: www.linuxfoundation.org\r\n
Connection: keep-alive\r\n
Cache-Control: max-age=0\r\n
Upgrade-Insecure-Requests: 1\r\n
User-Agent: Mozilla/5.0 (X11; Linux x86_64) AppleWebKit/537.36 (KHTML, like Gecko) Chrom
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,image/webp,*/*;q=0.8\r\n
Accept-Encoding: gzip, deflate, sdch\r\n
Accept-Language: zh-TW,zh;q=0.8,en-US;q=0.6,en;q=0.4\r\n
[truncated]Cookie: __utmt=1; __utma=103159837.2085678669.1466603403.1466603403.1466603
If-None-Match: W/"1466598806-0"\r\n
HTTP Request Message Header
\r\n
empty line
[Full request URI: http://www.linuxfoundation.org/]
[HTTP request 4/4]
[Prev request in frame: 2436]
[Response in frame: 2503]
0000 00 d0 41 d7 a6 6f f0 de f1 a3 3c 19 08 00 45 00 ..A..o.. ..<...E.
0010 03 03 d0 4c 40 00 40 06 6f bf c0 a8 01 69 8c d3 ...L@.@. o....i..
0020 a9 04 e4 40 00 50 51 ef 5b 2a b1 af 15 14 80 18 ...@.PQ. [*......
0030 05 a4 fa de 00 00 01 01 08 0a 00 11 16 07 28 8a ....(.

Request

- *A request message from a client to a server includes, within the first line of that message, the method to be applied to the resource, the identifier of the resource, and the protocol version in use.*

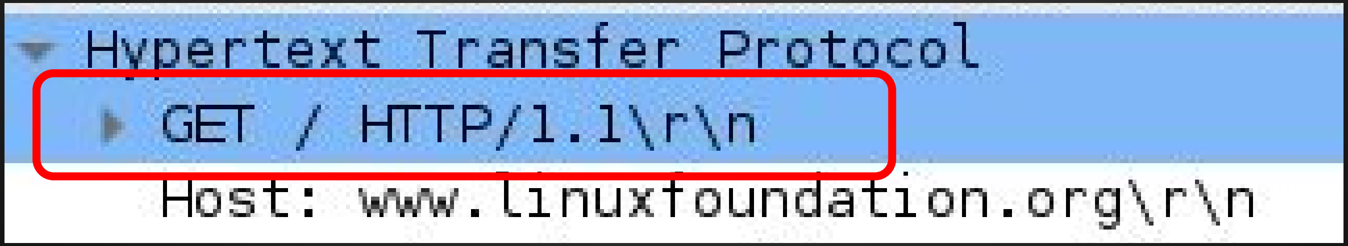
```
Request   =  Request-Line
             *(( general-header
             | request-header
             | entity-header ) CRLF)
             CRLF
             [ message-body ]
```

Reference: RFC 2616 [5 Request]

Request-Line

- *The Request-Line begins with a method token, followed by the Request-URI and the protocol version, and ending with CRLF. The elements are separated by SP characters. No CR or LF is allowed except in the final CRLF sequence.*

Request-Line = Method SP Request-URI SP HTTP-Version CRLF



Reference: RFC 2616 [5.1 Request-Line]

Method

- *The Method token indicates the method to be performed on the resource identified by the Request-URI. The method is case-sensitive.*

```
Method = "OPTIONS"
       | "GET"
       | "HEAD"
       | "POST"
       | "PUT"
       | "DELETE"
       | "TRACE"
       | "CONNECT"
       | extension-method
```

Reference: RFC 2616 [5.1.1 Method]

Request-URI

- *The Request-URI is a Uniform Resource Identifier (section 3.2) and identifies the resource upon which to apply the request.*

Request-URI = ""*
| absoluteURI
| abs_path
| authority

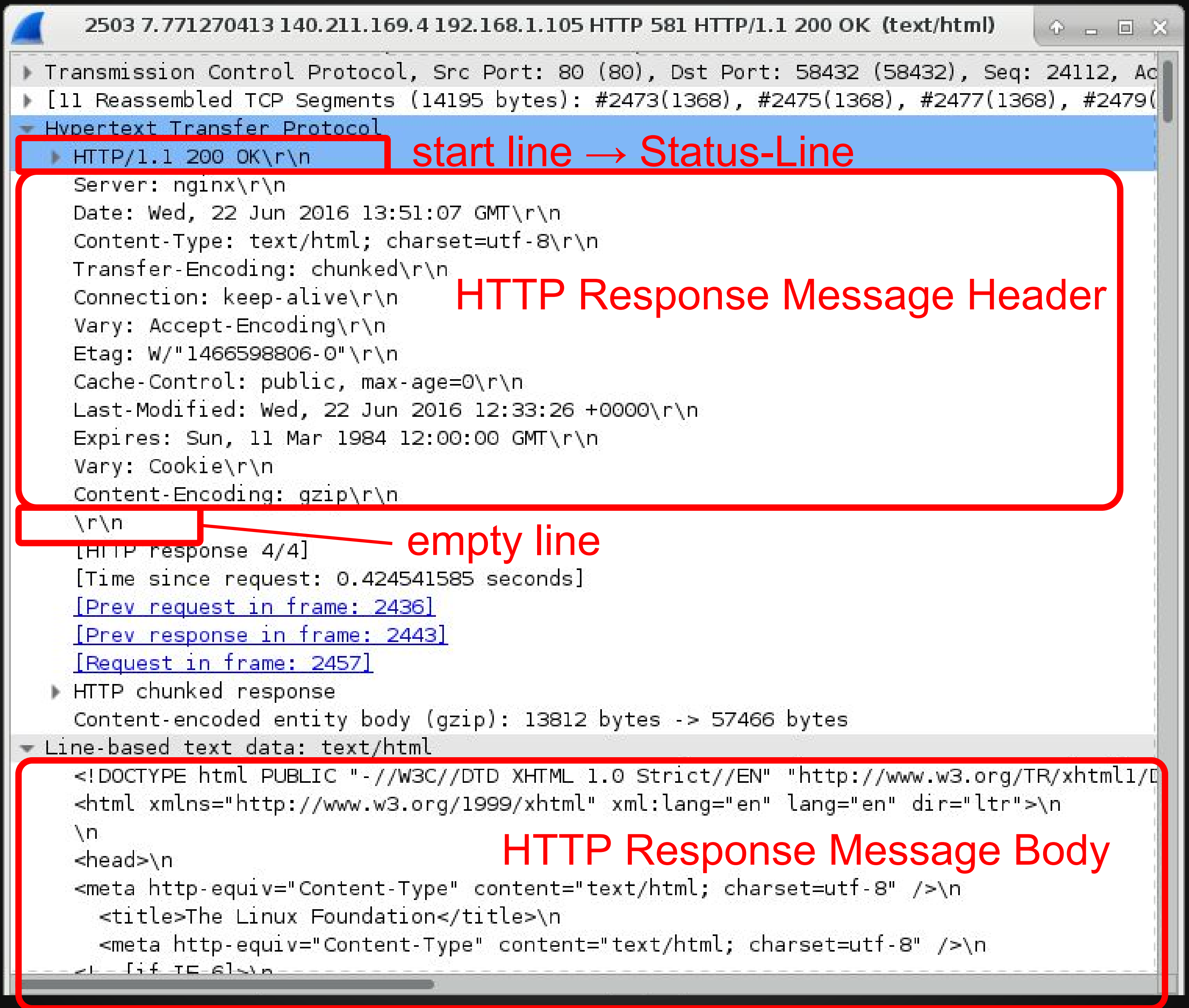
Reference: RFC 2616 5.1.2 Request-URI

Request Header Fields

- *The request-header fields allow the client to pass additional information about the request, and about the client itself, to the server. These fields act as request modifiers, with semantics equivalent to the parameters on a programming language method invocation.*

```
request-header  =  Accept
                   | Accept-Charset
                   | Accept-Encoding
                   | Accept-Language
                   | Authorization
                   | Expect
                   ...
```

Reference: RFC 2616 [5.3 Request Header Fields]



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Transmission Control Protocol, Src Port: 80 (80), Dst Port: 58432 (58432), Seq: 24112, Ac
[11 Reassembled TCP Segments (14195 bytes): #2473(1368), #2475(1368), #2477(1368), #2479(
Hypertext Transfer Protocol
HTTP/1.1 200 OK\r\n
start line → Status-Line
Server: nginx\r\n
Date: Wed, 22 Jun 2016 13:51:07 GMT\r\n
Content-Type: text/html; charset=utf-8\r\n
Transfer-Encoding: chunked\r\n
Connection: keep-alive\r\n
HTTP Response Message Header
Vary: Accept-Encoding\r\n
Etag: W/"1466598806-0"\r\n
Cache-Control: public, max-age=0\r\n
Last-Modified: Wed, 22 Jun 2016 12:33:26 +0000\r\n
Expires: Sun, 11 Mar 1984 12:00:00 GMT\r\n
Vary: Cookie\r\n
Content-Encoding: gzip\r\n
\r\n
empty line
[Time since request: 0.424541585 seconds]
[Prev request in frame: 2436]
[Prev response in frame: 2443]
[Request in frame: 2457]
HTTP chunked response
Content-encoded entity body (gzip): 13812 bytes -> 57466 bytes
Line-based text data: text/html
<!DOCTYPE html PUBLIC "-//W3C//DTD XHTML 1.0 Strict//EN" "http://www.w3.org/TR/xhtml1/D
<html xmlns="http://www.w3.org/1999/xhtml" xml:lang="en" lang="en" dir="ltr">\n
\n
<head>\n
HTTP Response Message Body
<meta http-equiv="Content-Type" content="text/html; charset=utf-8" />\n
<title>The Linux Foundation</title>\n
<meta http-equiv="Content-Type" content="text/html; charset=utf-8" />\n

Response

- *After receiving and interpreting a request message, a server responds with an HTTP response message.*

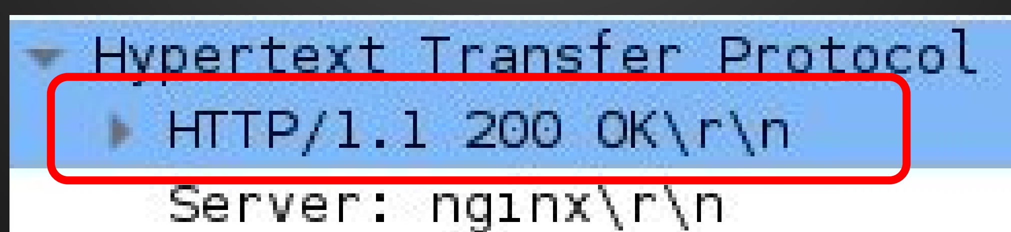
```
Response = Status-Line
           *(( general-header
           | response-header
           | entity-header ) CRLF)
           CRLF
           [ message-body ]
```

Reference: RFC 2616 6 Response

Status-Line

- *The first line of a Response message is the Status-Line, consisting of the protocol version followed by a numeric status code and its associated textual phrase, with each element separated by SP characters. No CR or LF is allowed except in the final CRLF sequence.*

Status-Line = HTTP-Version SP Status-Code SP Reason-Phrase CRLF



Reference: RFC 2616 [6.1 Status-Line]

Status Code and Reason Phrase

- *The Status-Code element is a 3-digit integer result code of the attempt to understand and satisfy the request. These codes are fully defined in section 10. The Reason-Phrase is intended to give a short textual description of the Status-Code.*

  - 1XX: Informational - Request received, continuing process

  - 2XX: Success - The action was successfully received, understood, and accepted

  - 3XX: Redirection - Further action must be taken in order to complete the request

  - 4XX: Client Error - The request contains bad syntax or cannot be fulfilled

  - 5XX: Server Error - The server failed to fulfill an apparently valid request

Reference: RFC 2616 [6.1.1 Status Code and Reason Phrase]

Response Header Fields

- *The response-header fields allow the server to pass additional information about the response which cannot be placed in the Status- Line.*
- *These header fields give information about the server and about further access to the resource identified by the Request-URI.*

response-header = Accept-Ranges
| Age
| ETag
| Location
...

Reference: RFC 2616 [6.2 Response Header Fields]

Entity

- *Request and Response messages MAY transfer an entity if not otherwise restricted by the request method or response status code.*
- *An entity consists of entity-header fields and an entity-body, although some responses will only include the entity-headers.*

Reference: RFC 2616 7 Entity

Entity Header Fields

- *Entity-header fields define metainformation about the entity-body or, if no body is present, about the resource identified by the request.*
- *Some of this metainformation is OPTIONAL; some might be REQUIRED by portions of this specification.*

```
entity-header    =   Allow               | Content-Encoding
                     | Content-Language  | Content-Length
                     | Content-Location  | Content-MD5
                     | Content-Range     | Content-Type
                     | Expires           | Last-Modified
                     | extension-header

extension-header =   message-header
```

Reference: RFC 2616 [7.1 Entity Header Fields]

Entity Body

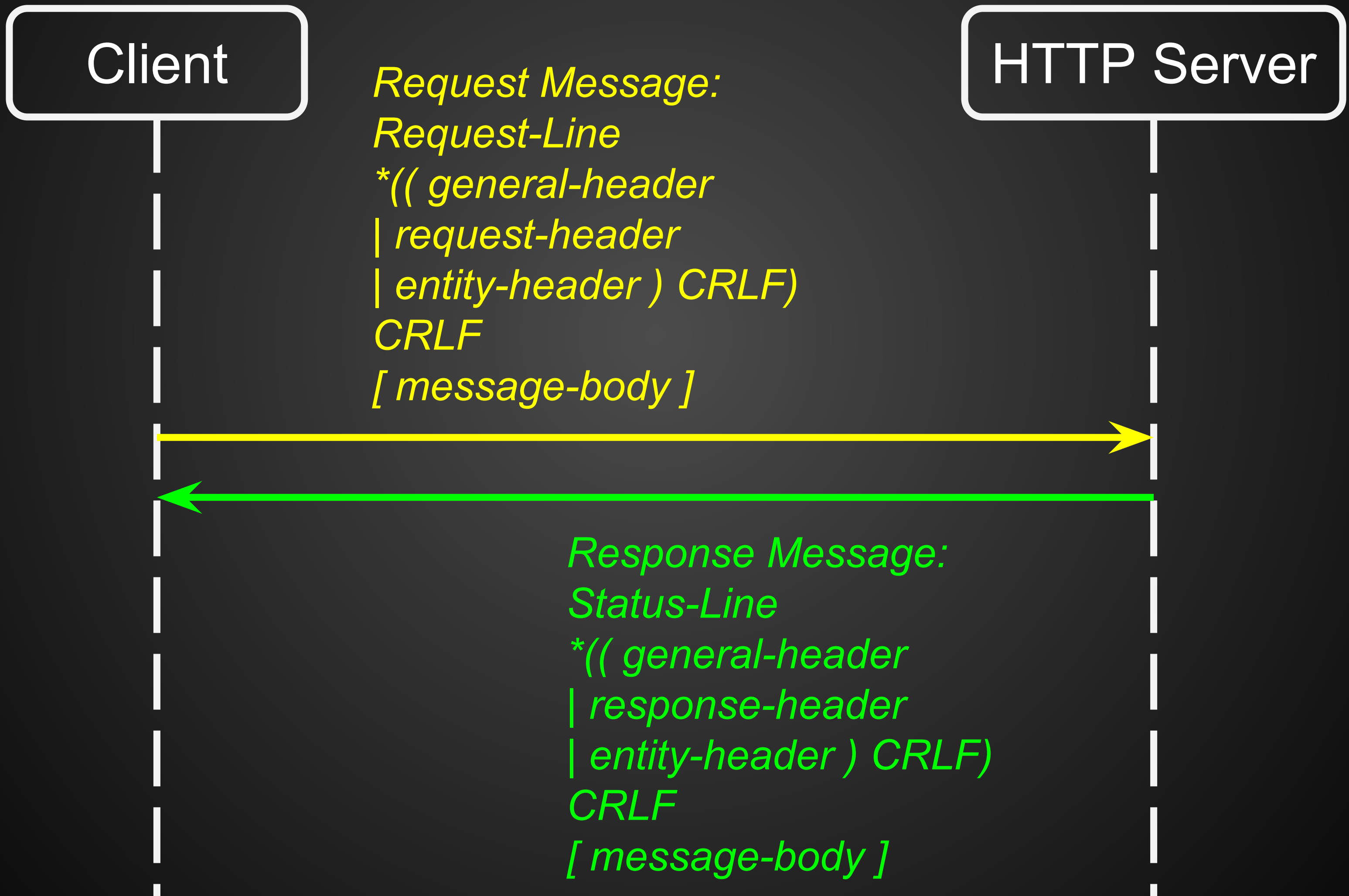
- *The entity-body (if any) sent with an HTTP request or response is in a format and encoding defined by the entity-header fields.*

  extension-header = message-header

- *An entity-body is only present in a message when a message-body is present, as described in section 4.3.*
- *The entity-body is obtained from the message-body by decoding any Transfer-Encoding that might have been applied to ensure safe and proper transfer of the message.*

Reference: RFC 2616 [7.2 Entity Body]

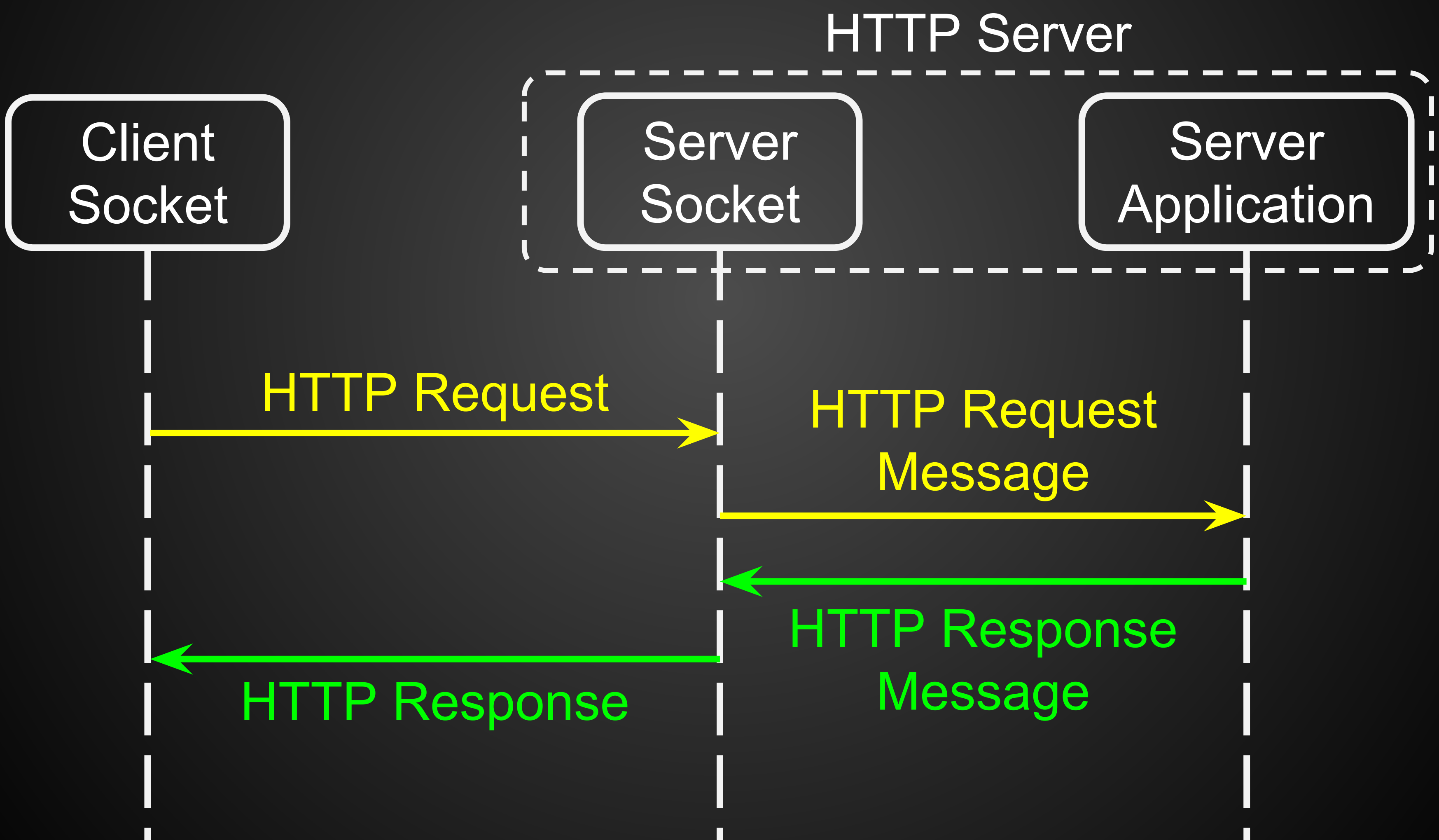
After Sockets connected



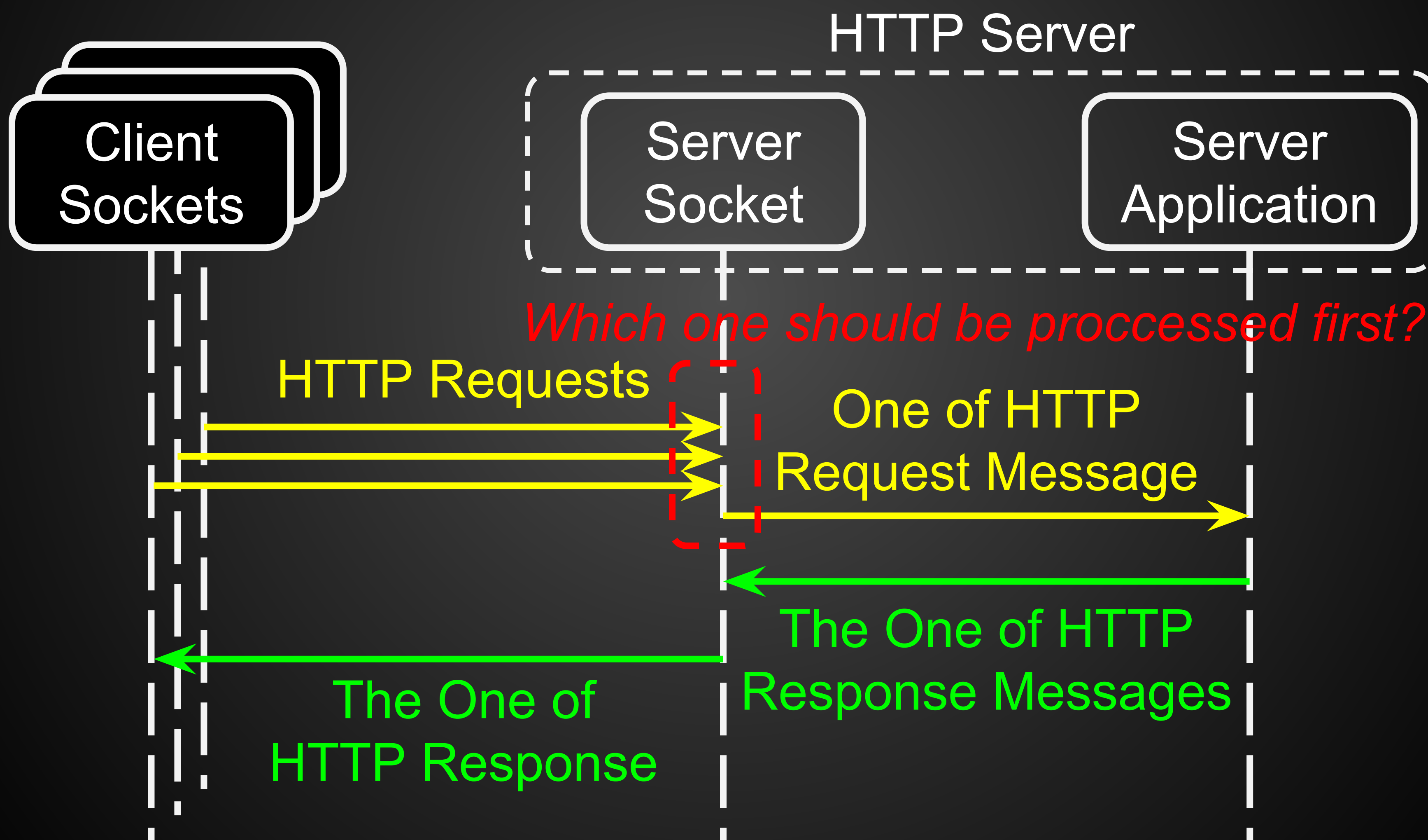
The HTTP Server

Concurrency & Backend

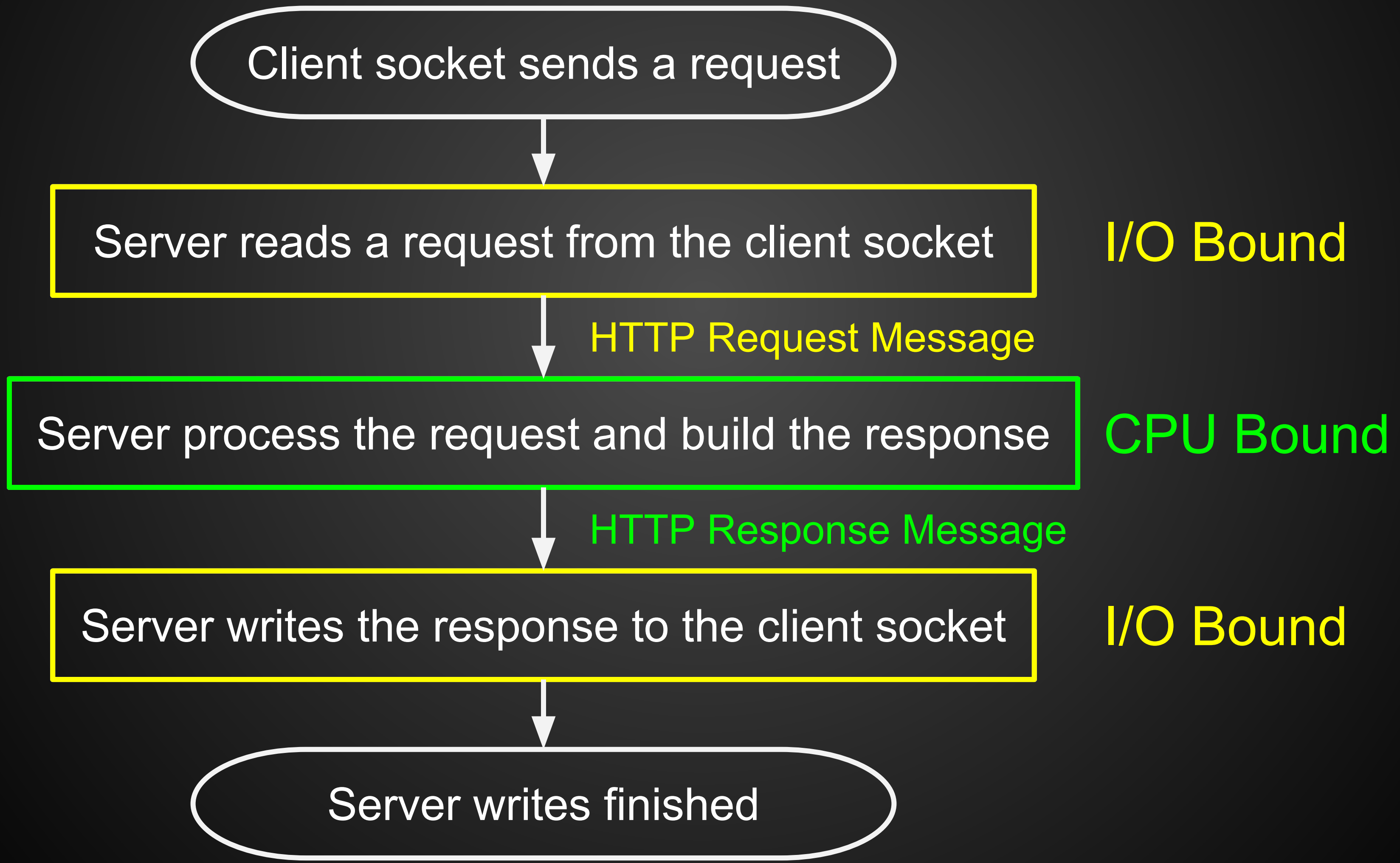
Single Server Thread & Single Client



Single Server Thread & Multi-Clients



Flow Chart of Server Socket



I/O Bound

- CPU runs faster than I/O devices. If system needs the resources of I/O devices, it will be blocked to wait for the resources.
- If there is only one client socket and request, it may not be the problem.
- If there are two or more clients and requests at the same time, the blocked I/O will hang up the server. Clients may get responses slowly or even be timeout.

Concurrency

- The server could use the process (*fork()*) or thread (*pthread library*) APIs to serve multiple clients at the same time.
  - Socket works great in blocking mode.
  - Process or thread APIs must be provided by OS. (Resources considering.)
  - Overhead of context switching.
- Use I/O Multiplexing & Non-Blocking sockets.
  - It could be used in the single thread situation.
  - Compared with the process and thread, it is less resources required.
  - No more processes or threads, no context switching.

I/O Multiplexing & Non-Blocking

- *select()* monitors the sockets' (*fd_set*) status flag and returns the status of <u>all sockets</u>. It exists in most OSes.
- *poll()* works like select(), but represents in different form (*pollfd*).
- *epoll()* monitors sockets' status and trigger the related events. It returns <u>only triggered events</u> array. It has been implemented since Linux 2.6.
- *recv()*, *send()* in non-blocking mode.
- Use *fcntl()* to set the O_NONBLOCK (non-blocking) flag of the socket on.

RFC 3857 CGI

The Common Gateway Interface Version 1.1
https://tools.ietf.org/html/rfc3875

Server Application - CGI

Abstract

The Common Gateway Interface (CGI) is a simple interface for running external programs, software or gateways under an information server in a platform-independent manner. Currently, the supported information servers are HTTP servers.

Reference: RFC 3857 Abstract

Terminology

- *'script'*

  <u>The software that is invoked by the server according to this interface.</u> It need not be a standalone program, but could be a dynamically-loaded or shared library, or even a subroutine in the server.

- *'meta-variable'*

  <u>A named parameter which carries information from the server to the script.</u> It is not necessarily a variable in the operating system's environment, although that is the most common implementation.

Reference: RFC 3857 [1.4. Terminology]

Steps for CGI

1. Apache HTTP Server receives a request and parse it.
2. The server puts the request header into the environment variables, then forks to have a child process which inherits parent's environment variables.
3. The child process executes the CGI script and gets the request header fields from environment variables, the request body from **STDIN**.
4. The Apache HTTP Server will have the response which is produced and written from the **STDOUT** of the child process.

FastCGI

- *It is a variation on the earlier CGI.*
- *Instead of creating a new process for each request, FastCGI uses persistent processes to handle a series of requests. These processes are owned by the FastCGI server, not the web server.*
- *To service an incoming request, the web server sends environment information and the page request itself to a FastCGI process over a socket (in the case of local FastCGI processes on the web server) or TCP connection (for remote FastCGI processes in a server farm).*
- *Responses are returned from the process to the web server over the same connection, and the web server subsequently delivers that response to the end-user.*
- *The connection may be closed at the end of a response, but both the web server and the FastCGI service processes persist.*

Reference: Wiki FastCGI

NSAPI

Netscape Server Application Programming Interface

- *Applications that use NSAPI are referred to as NSAPI plug-ins. Each plug-in implements one or more Server Application Functions (SAFs).*
- *Unlike CGI programs, NSAPI plug-ins run inside the server process. Because CGI programs run outside of the server process, CGI programs are generally slower than NSAPI plug-ins.*
- *Running outside of the server process can improve server reliability by isolating potentially buggy applications from the server software and from each other.*
- *NSAPI SAFs can be configured to run at different stages of request processing.*

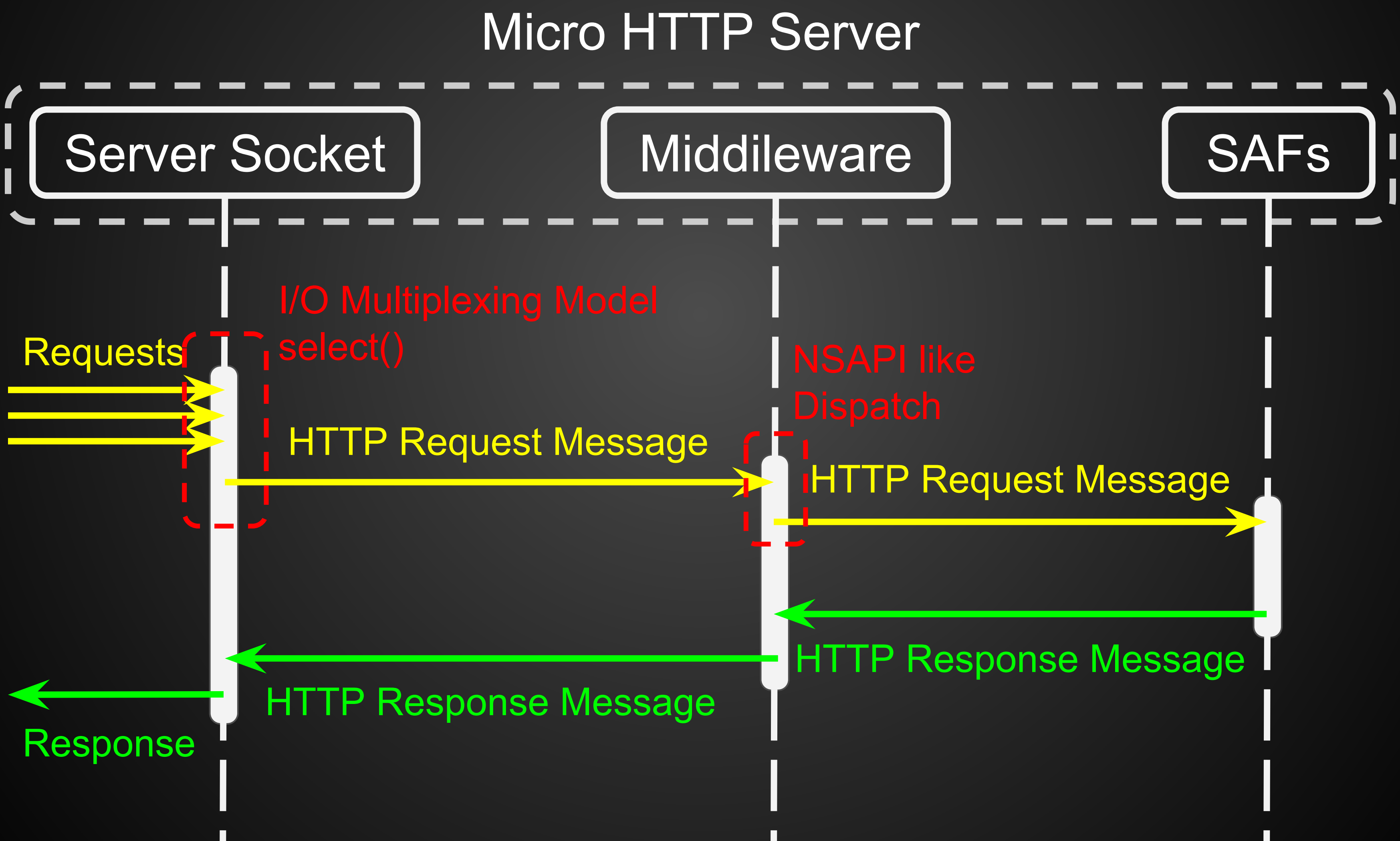
Reference: Wiki NSAPI

Micro HTTP Server

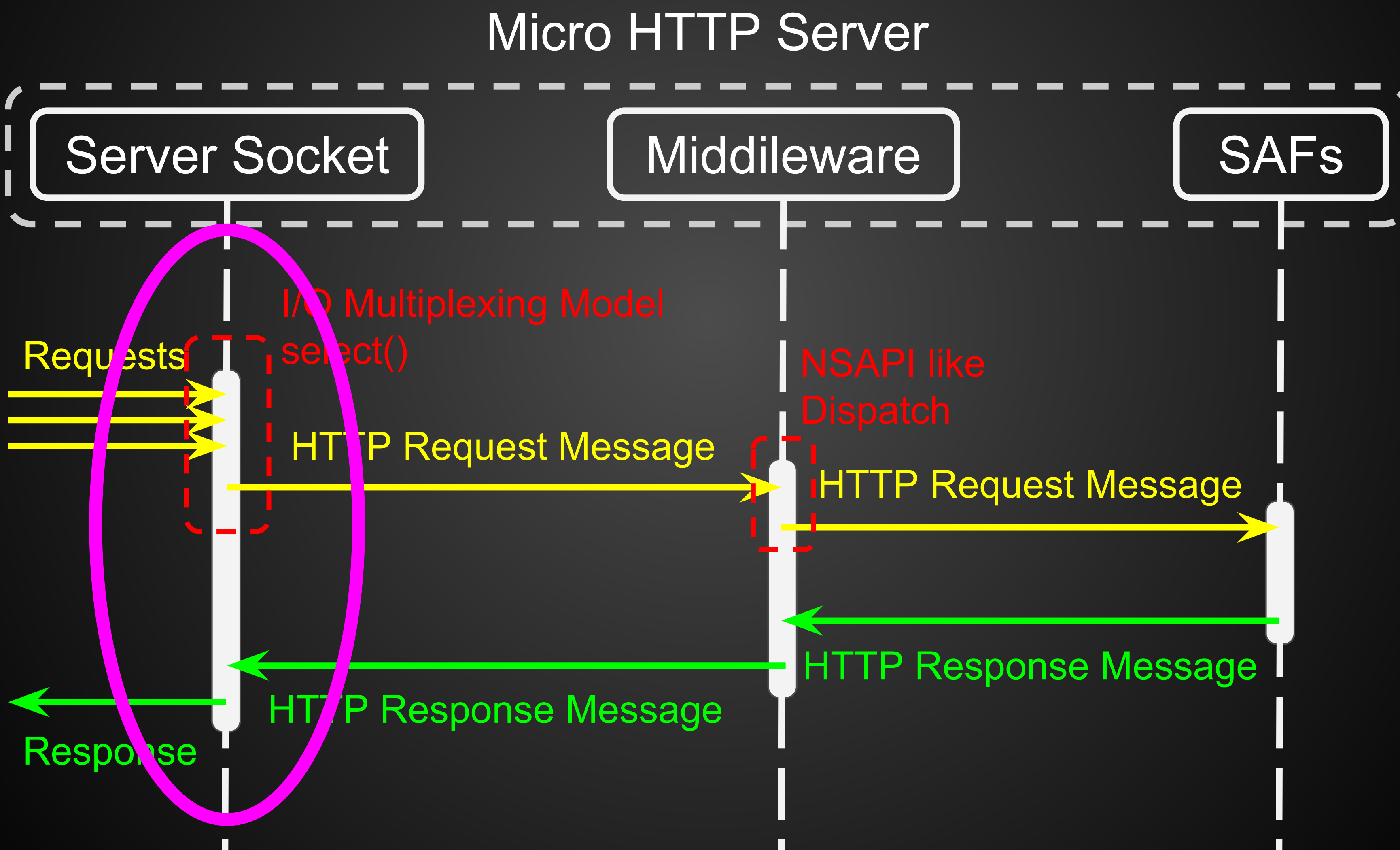
- It could work on limited resources embedded system.
- It could process multiple HTTP clients concurrently.
- It parses the HTTP request message and passes the message to corresponding server application functions (SAFs) according to the Request-Line. (Like NSAPI)
- The SAFs process with the HTTP request message and build the HTTP response message.
- The server application functions can collaborate like a chain. Therefore, each server application function only does a simple job.

https://github.com/starnight/MicroHttpServer

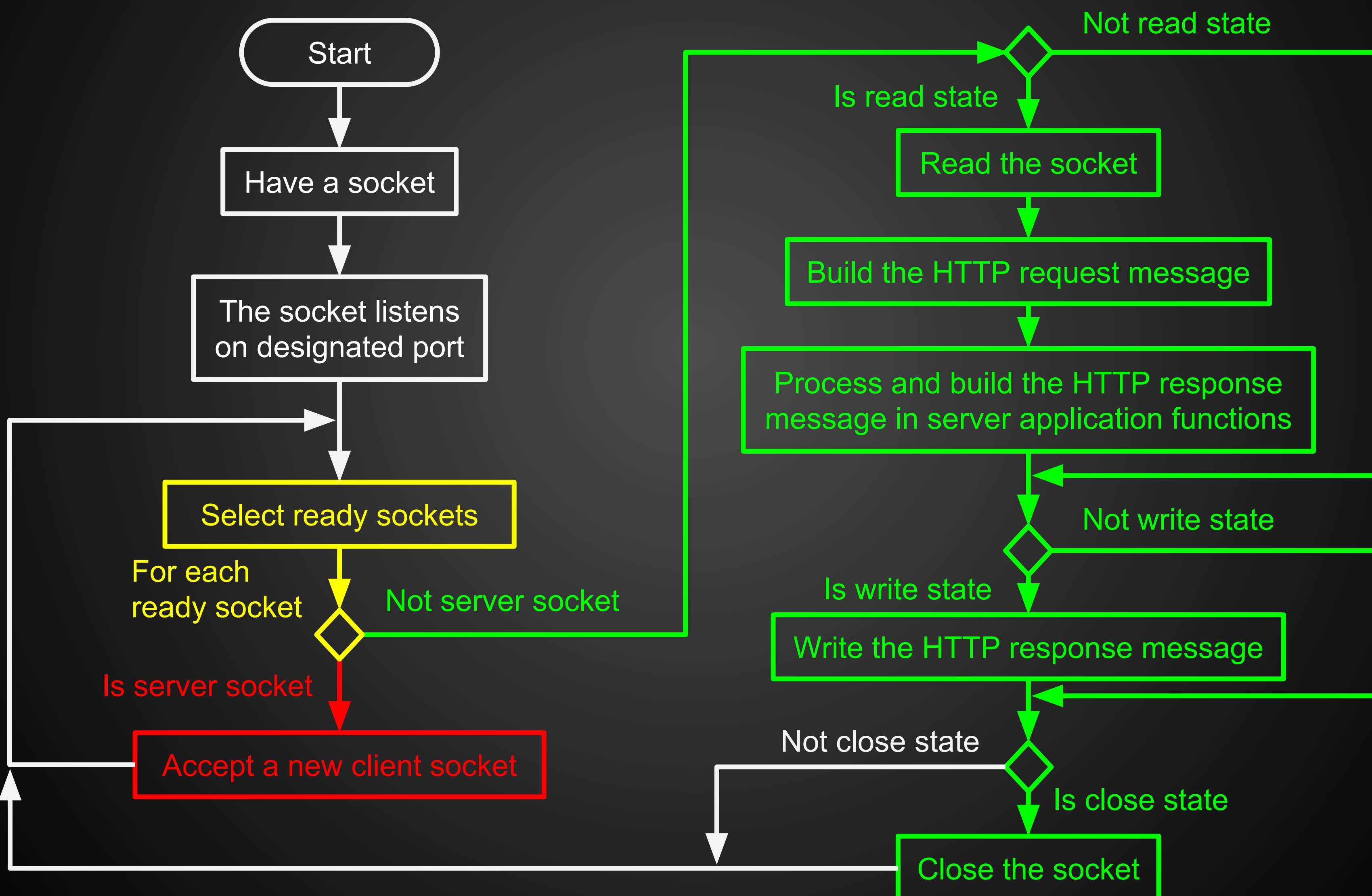
Sequential Diagram



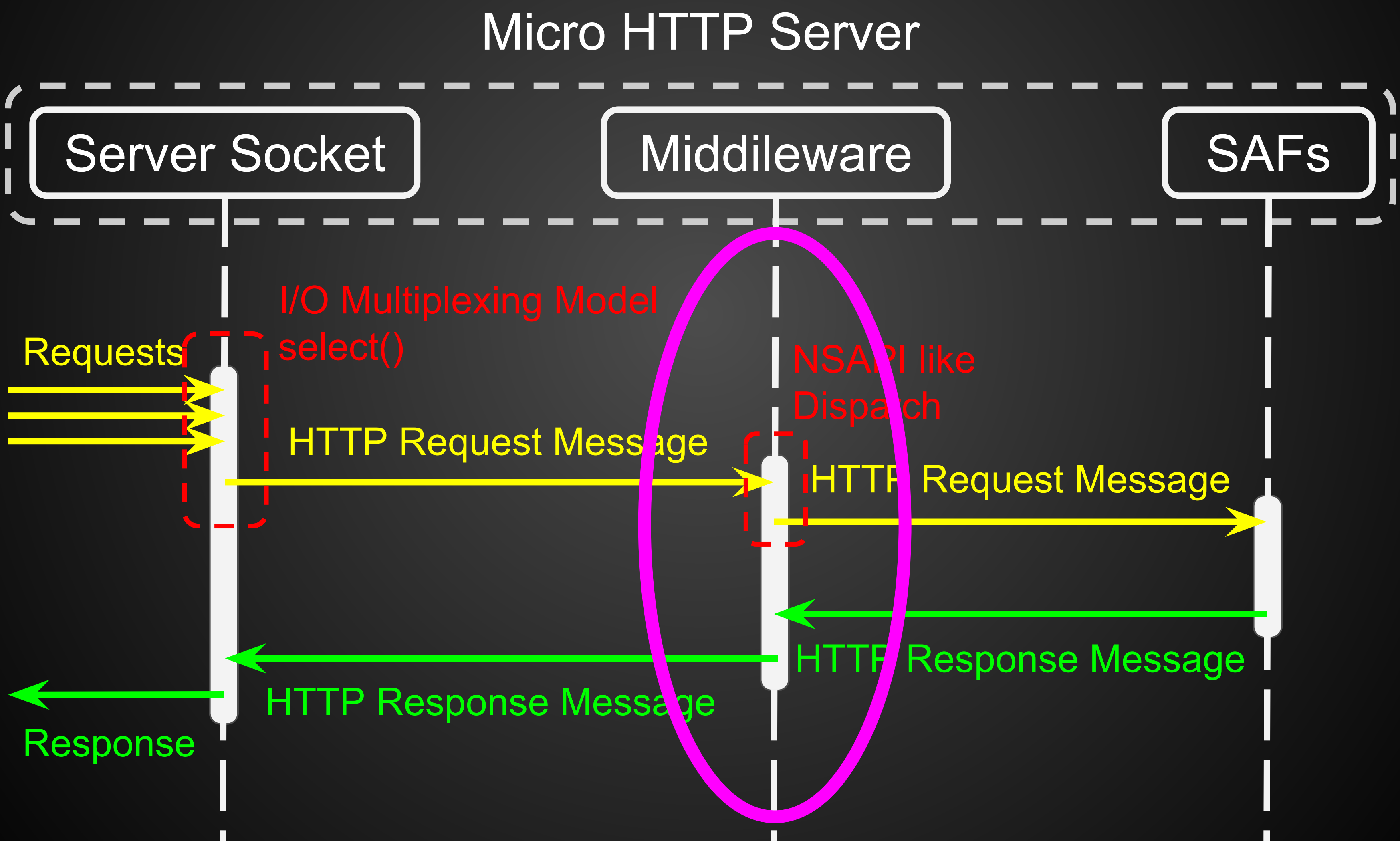
Sequential Diagram



Server Socket Flow Chart

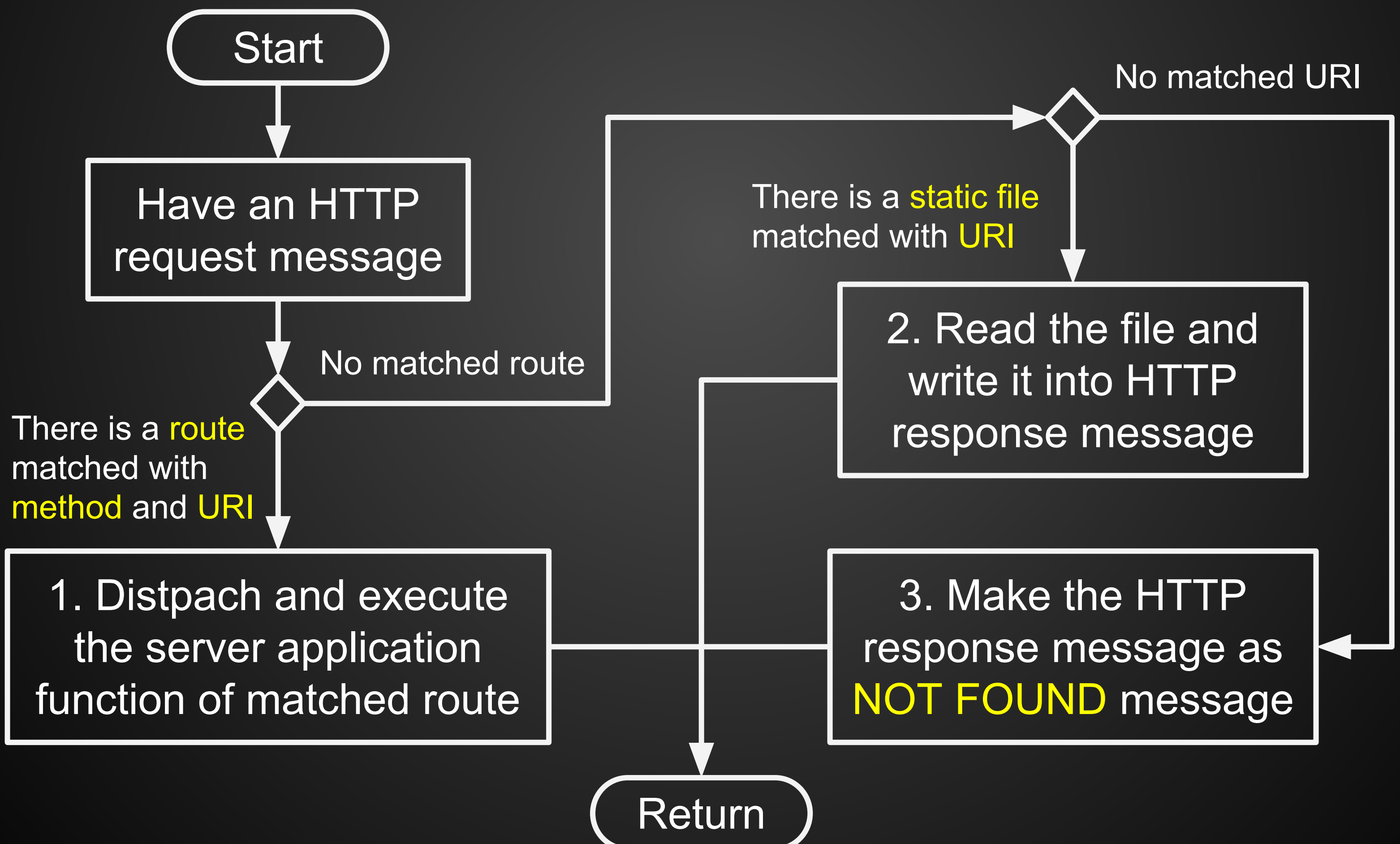


Sequential Diagram



Middileware - Route Flow Chart

Register routes before the server starts!



Prototype with Python

- The py-version of the repository.
- Python is so convenient to do prototypes.
- Because of that, there is a little different between Python and C version, and is more simple with I/O multiplexing and the states of ready sockets in part of 'Server Socket'.
- Both Python and C version's 'Middleware' models are the same.
- Users only have to register the routes, the server application functions (SAFs) of the routes and start the HTTP server.

Works in Python 3.2 up!

Make sure the encoding during reading and writing sockets.

Directory Tree in Python Version

- lib/:

  server.py: The Python Version Micro HTTP Server.

  middleware.py: The Python Version Micro HTTP Server middleware.
- static/:

  static files: HTML, JS, Images ...
- main.py: The entry point of Python Version Micro HTTP Server example.
- app.py: The web server application functions of Python Version Micro HTTP Server example.

Example of Python Version

```
from lib.server import HTTPServer
from lib.middleware import Routes
import app

server = HTTPServer(port=8000)
routes = Routes()
routes.AddRoute("GET", "/", app.WellcomePage)
routes.AddRoute("GET", "/index.html", app.WellcomePage)
routes.AddRoute("POST", "/fib", app.Fib)

server.RunLoop(routes.Dispatch)
```

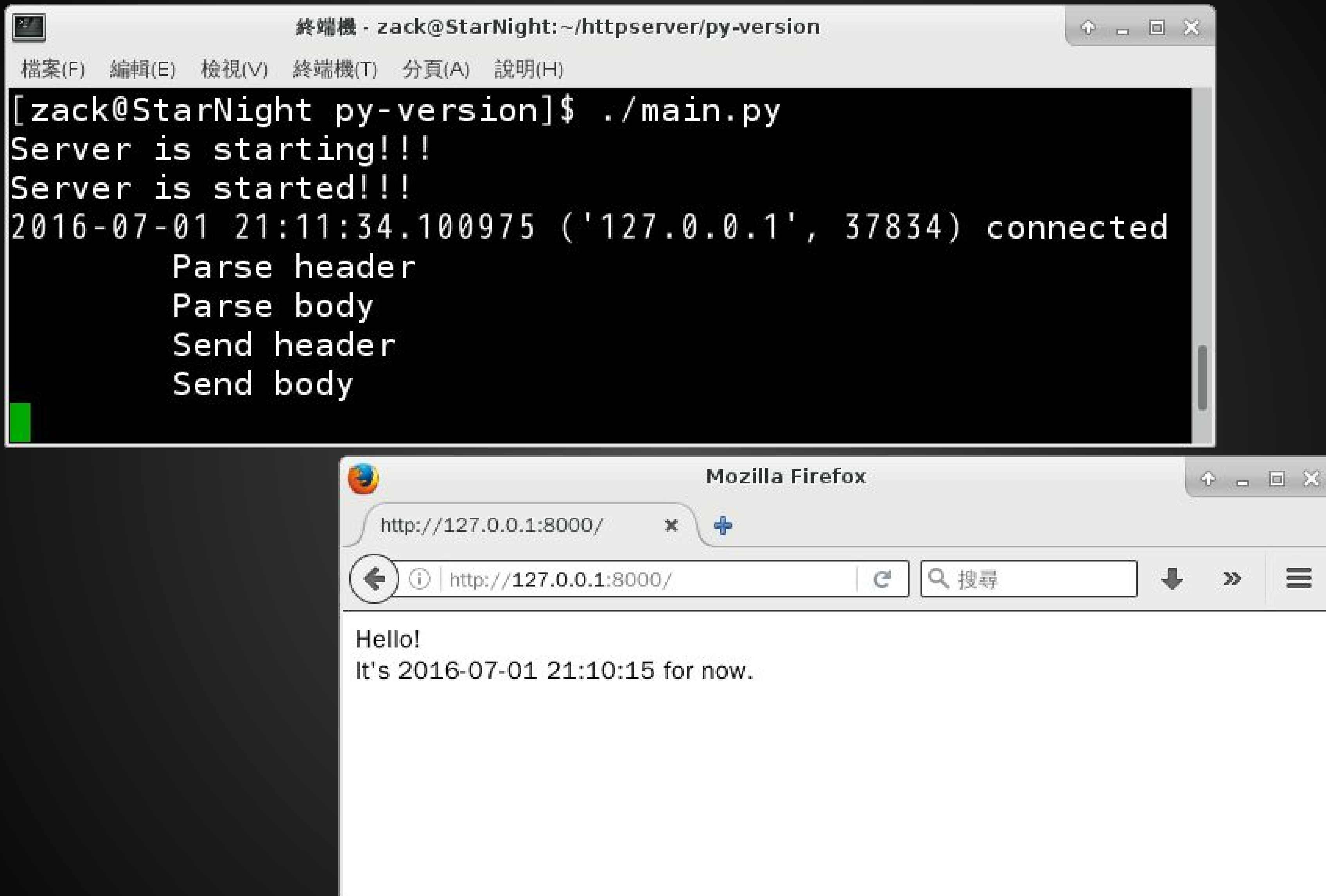
Register the routes

The callback for new request

Run the HTTP server

```python
def WellcomePage(req, res):
    '''Default wellcome page which makes
    response message.'''
    # Build HTTP message body
    res.Body = "<html><body>Hello!<br>"
    res.Body += "It's {} for now.".format(
        datetime.now().strftime("%Y-%m-%d %H:%M:%S"))
    res.Body += "</body></html>"

    # Build HTTP message header
    res.Header.append(["Status", "200 OK"])
    res.Header.append(
        ["Content-Type", "text/html; charset=UTF-8;"])
```


終端機 - zack@StarNight:~/httpserver/py-version
檔案(F) 編輯(E) 檢視(V) 終端機(T) 分頁(A) 說明(H)
[zack@StarNight py-version]$ ./main.py
Server is starting!!!
Server is started!!!
2016-07-01 21:11:34.100975 ('127.0.0.1', 37834) connected
Parse header
Parse body
Send header
Send body
Mozilla Firefox
http://127.0.0.1:8000/
http://127.0.0.1:8000/
搜尋
Hello!
It's 2016-07-01 21:10:15 for now.

Automation Test

- The sub-directory autotest/ of the repository
- Write a test application client.py which acts as an HTTP client with the Python unittest library.
- Have an HTTP client with 4 actions: Connect, Request with GET method, Request with POST method, Close.
- Have an unittest class which will execute the test scenarios.

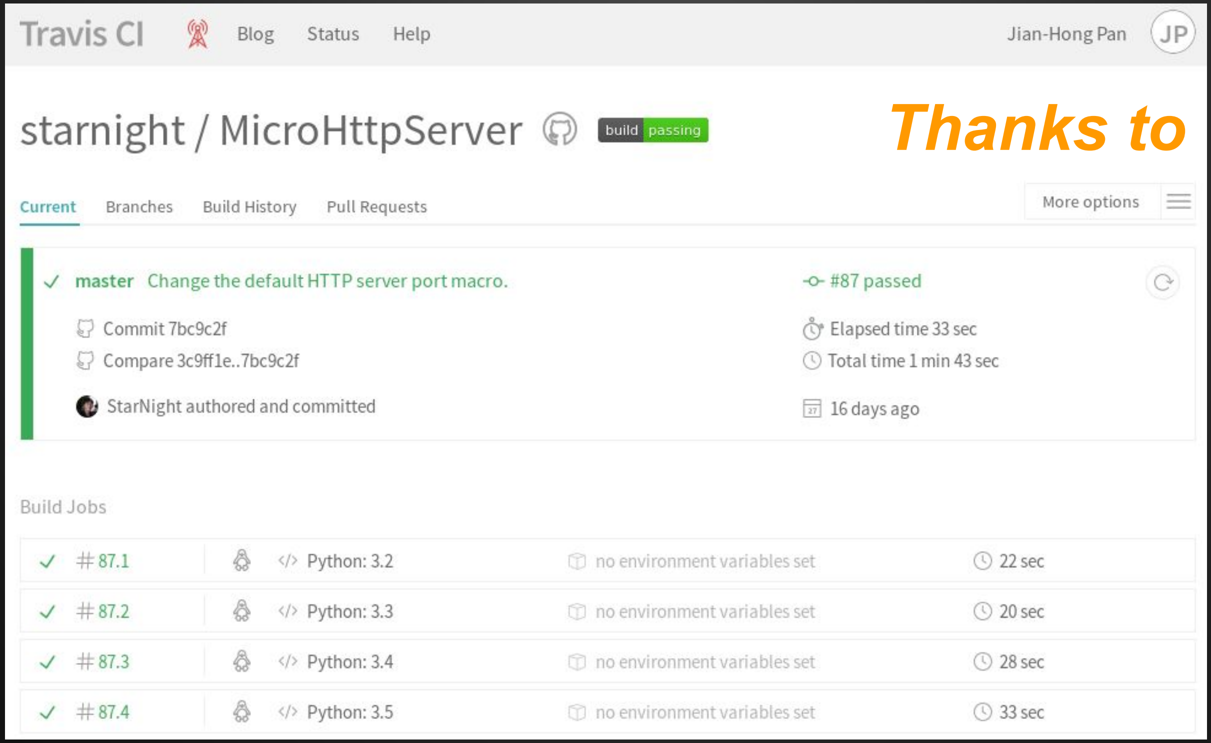
Test Scenarios

- Only connect and close actions.
- Connect, request GET method with a specific URI and check the response and close.
- Connect, request POST method with a specific URI and check the response and close.
- Multiple clients request concurrently.
- Request different URIs to make sure the SAFs work correctly.

Continous Integration

Use Travis CI:

https://travis-ci.org/starnight/MicroHttpServer



Thanks to Travis CI!

.travis.yml in the repository

- language: Python
- python version: 3.2 ~ 3.5
- before_script:

  Build (if needed) and excute Python and C version Micro HTTP Server in background
- script:

  Execute the test application to test the Python and C version Micro HTTP Server

```
Using worker: worker-linux-docker-1b92445e.prod.travis-ci.org:travis-linux-13

Build system information                                                    system_info

$ export DEBIAN_FRONTEND=noninteractive                                     fix.CVE-2015-7547
3.5 is not installed; attempting download
$ git clone --depth=50 --branch=master https://github.com/starnight/MicroHttpServer.git starnight/MicroHttpServer     git.checkout     0.77s

This job is running on container-based infrastructure, which does not allow use of 'sudo', setuid and setguid executables.
If you
See ht
$ sourc

$ pythc
Python
$ pip -
pip 7.1
Could r
$ cd py
$ pythc
$ SERVE
$ echo
$ cd ..
$ make
$ ./mic
$ SERVE
$ echo
$ cd ..
$ pythc
```

```
        Send header
        Send body
2016-06-14 10:19:15.882214 ('127.0.0.1', 46925) connected
        Parse header
        Parse body
        Send header
        Send body
2016-06-14 10:19:15.883523 ('127.0.0.1', 46927) connected
        Parse header
        Parse body
        Send header
        Send body
.
----------------------------------------------------------------------
Ran 9 tests in 0.214s

OK


The command "python autotest/client.py localhost:8000" exited with 0.
$ kill $SERVER_PYTHON_PID                                                   0.00s

/home/travis/build.sh: line 390:  2438 Terminated              python main.py  (wd: ~/build/starnight/MicroHttpServer/py-version)

The command "kill $SERVER_PYTHON_PID" exited with 0.
```

Micro HTTP Server in C

- The c-version of the repository.
- Also could be test with the automated test application and integrated with Travis CI.
- The C version is more efficient than the Python version. (The comparison could be found in the automated test result.)
- The C version also could be ported on embedded system.
    - The system must provides socket APIs.
    - The file system is provided for the static files.

Directory Tree in C Version

- lib/:

  server.c & .h: The C Version Micro HTTP Server.

  middleware.c & .h: The C Version Micro HTTP Server middleware.

- static/:

  static files: HTML, JS, Images ...

- main.c: The entry point of C Version Micro HTTP Server example.
- app.c & h: The web server application functions of C Version Micro HTTP Server example.
- Makefile: The makefile of this example.

Example of C Version

```c
#include "server.h"
#include "middleware.h"
#include "app.h"

/* The HTTP server of this process. */
HTTPServer srv;

int main(void) {
    /* Register the routes. */
    AddRoute(HTTP_GET, "/index.html", HelloPage);
    AddRoute(HTTP_GET, "/", HelloPage);
    AddRoute(HTTP_POST, "/fib", Fib);
    /* Initial the HTTP server and make it listening on MHS_PORT. */
    HTTPServerInit(&srv, MHS_PORT);
    /* Run the HTTP server forever. */
    /* Run the dispatch callback if there is a new request */
    HTTPServerRunLoop(&srv, Dispatch);
    return 0; }
```

```c
#include <string.h>
#include <stdlib.h>
#include "app.h"

void HelloPage(HTTPReqMessage *req, HTTPResMessage *res) {
    int n, i = 0, j;
    char *p;
    char header[] = "HTTP/1.1 200 OK\r\nConnection: close\r\n"
                    "Content-Type: text/html; charset=UTF-8\r\n\r\n";
    char body[] = "<html><body>Hello!<br>許功蓋<br></body></html>";

    /* Build header. */
    p = (char *)res->_buf;
    n = strlen(header);
    memcpy(p, header, n);
    p += n;    i += n;
    /* Build body. */
    n = strlen(body);
    memcpy(p, body, n);
    p += n;    i += n;
    /* Set the length of the HTTP response message. */
    res->_index = i; }
```

Micro HTTP Server C APIs

GitHub repository Wiki

https://github.com/starnight/MicroHttpServer/wiki/C-API


終端機 - zack@StarNight:~/httpserver/c-version
檔案(F) 編輯(E) 檢視(V) 終端機(T) 分頁(A) 說明(H)
[zack@StarNight c-version]$ ./microhttpserver
Listening
Accept 1 client. 127.0.0.1:57176
Parse Header
Parse body


Mozilla Firefox
http://localhost:8001/
http://localhost:8001/
搜尋
Hello!
許功蓋
GET
/
HTTP/1.1
Host: localhost:8001
User-Agent: Mozilla/5.0 (X11; Linux x86_64; rv:47.0) Gecko/20100101 Firefox/47.0
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;q=0.8
Accept-Language: en-US,en;q=0.5
Accept-Encoding: gzip, deflate
DNT: 1
Connection: keep-alive
Cache-Control: max-age=0

Micro HTTP Server on Embedded System

Ported on STM32F4-Discovery with FreeRTOS for Example

FreeRTOS on STM32F4-Discovery

- The Micro HTTP Server needs the socket APIs which provides by the OS. Therefore, we need an OS on the development board.
- Putting a heavy Linux OS on the limited resource board may not be a good idea. Having a light weight RTOS will be a better solution.
- Considering finding the documents and usability, FreeRTOS is chosen because of the mentioned above.

FreeRTOS is Free which means Freedom

The License could be found at
http://www.freertos.org/license.txt

FreeRTOS

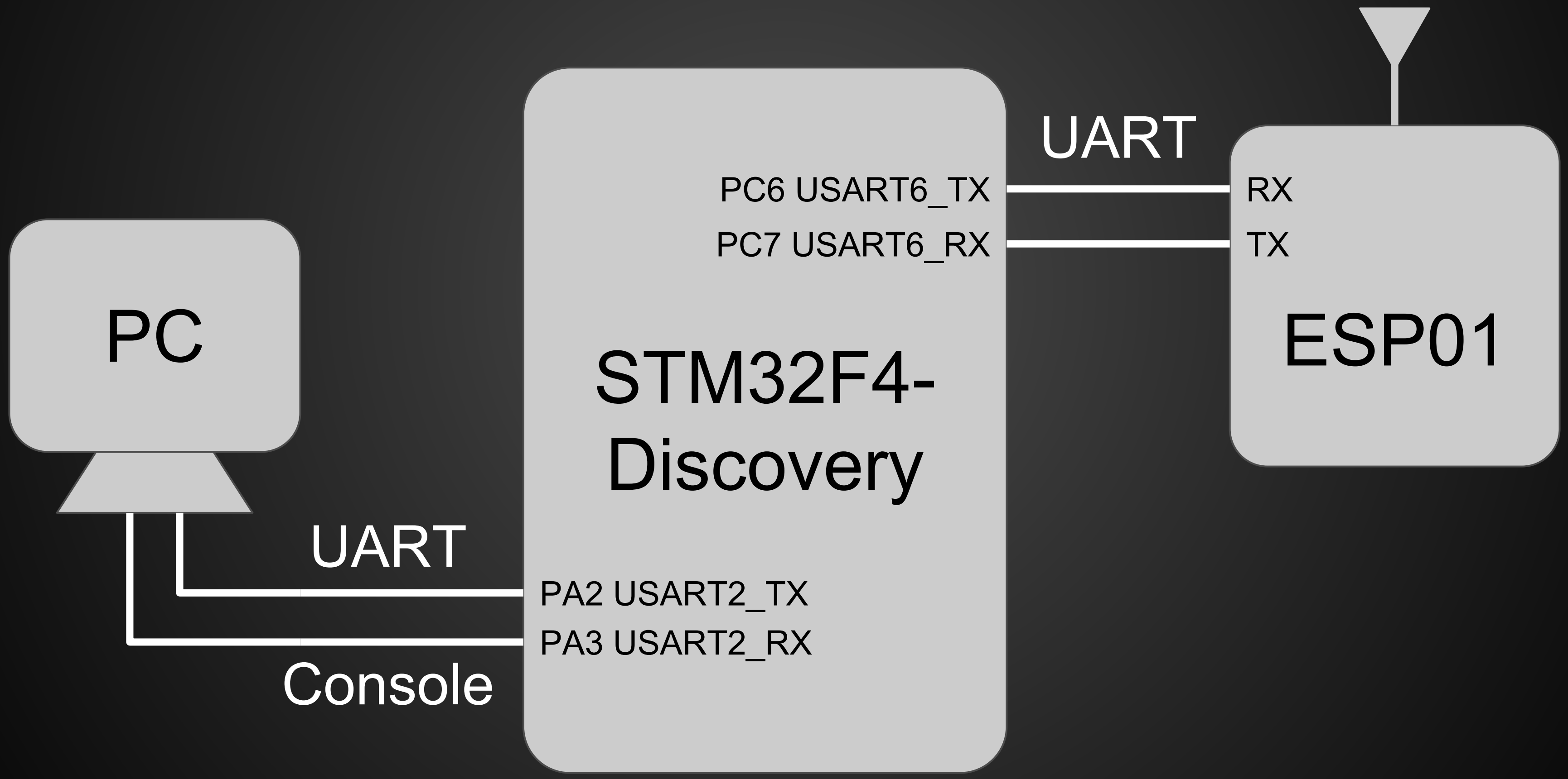
- Features Overview
  - http://www.freertos.org/FreeRTOS_Features.html
- FreeRTOS introduced in Wiki of CSIE, NCKU
  - http://wiki.csie.ncku.edu.tw/embedded/freertos
- RTOS objects
  - tasks, queues, semaphores, software timers, mutexes and event groups
- Pure FreeRTOS does not provide socket related APIs!!! T^T

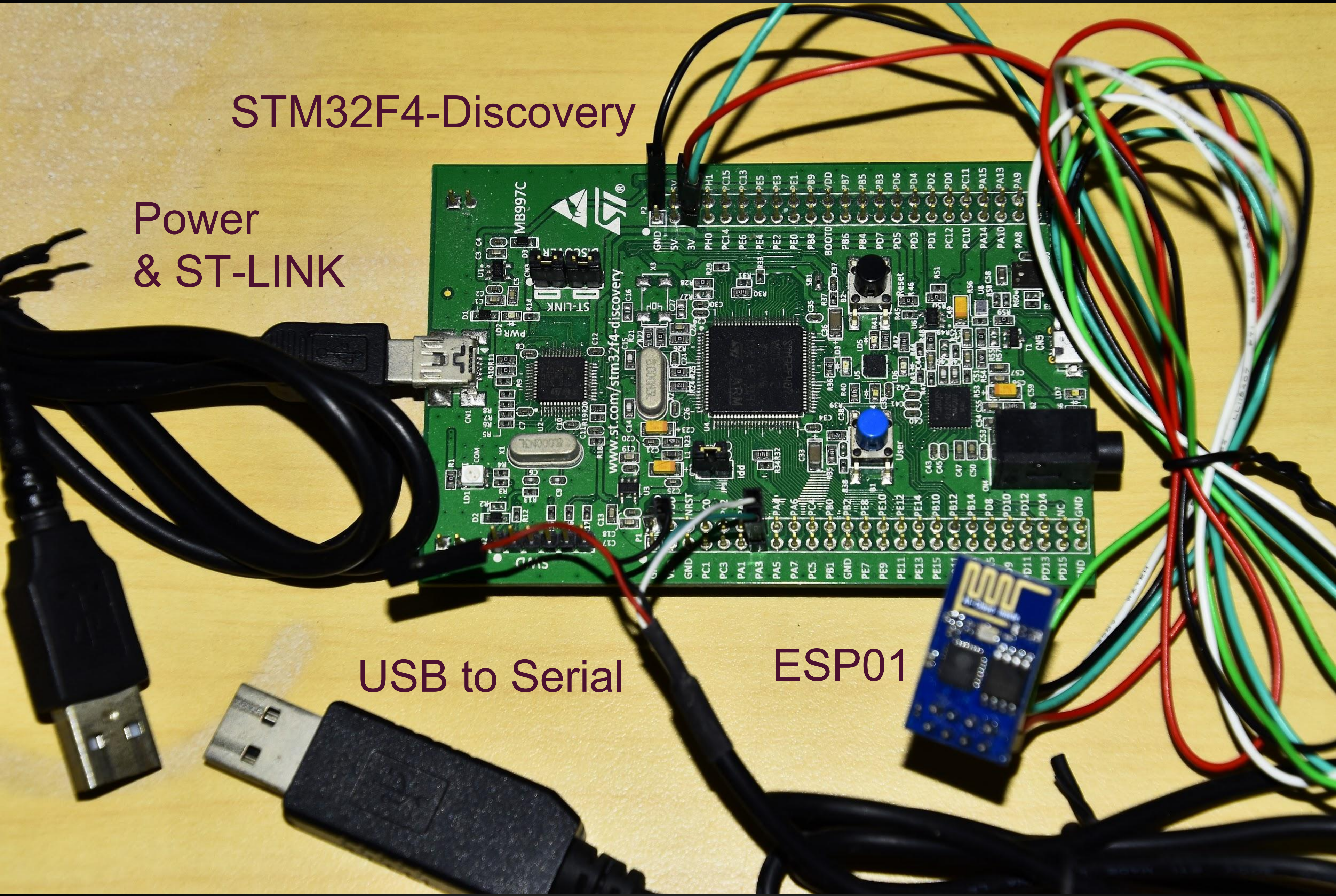
Hardware

- STM32F4-Discovery as mainboard
  - STM32F407VG: Cortex-M4
  - USART × 2:
    - 1 for connecting to WiFi module
    - 1 for serial console
  - 4 LEDs for demo
- ESP01 as WiFi module
  - ESP8266 series
    - UART connecting to STM32F4-Discovery

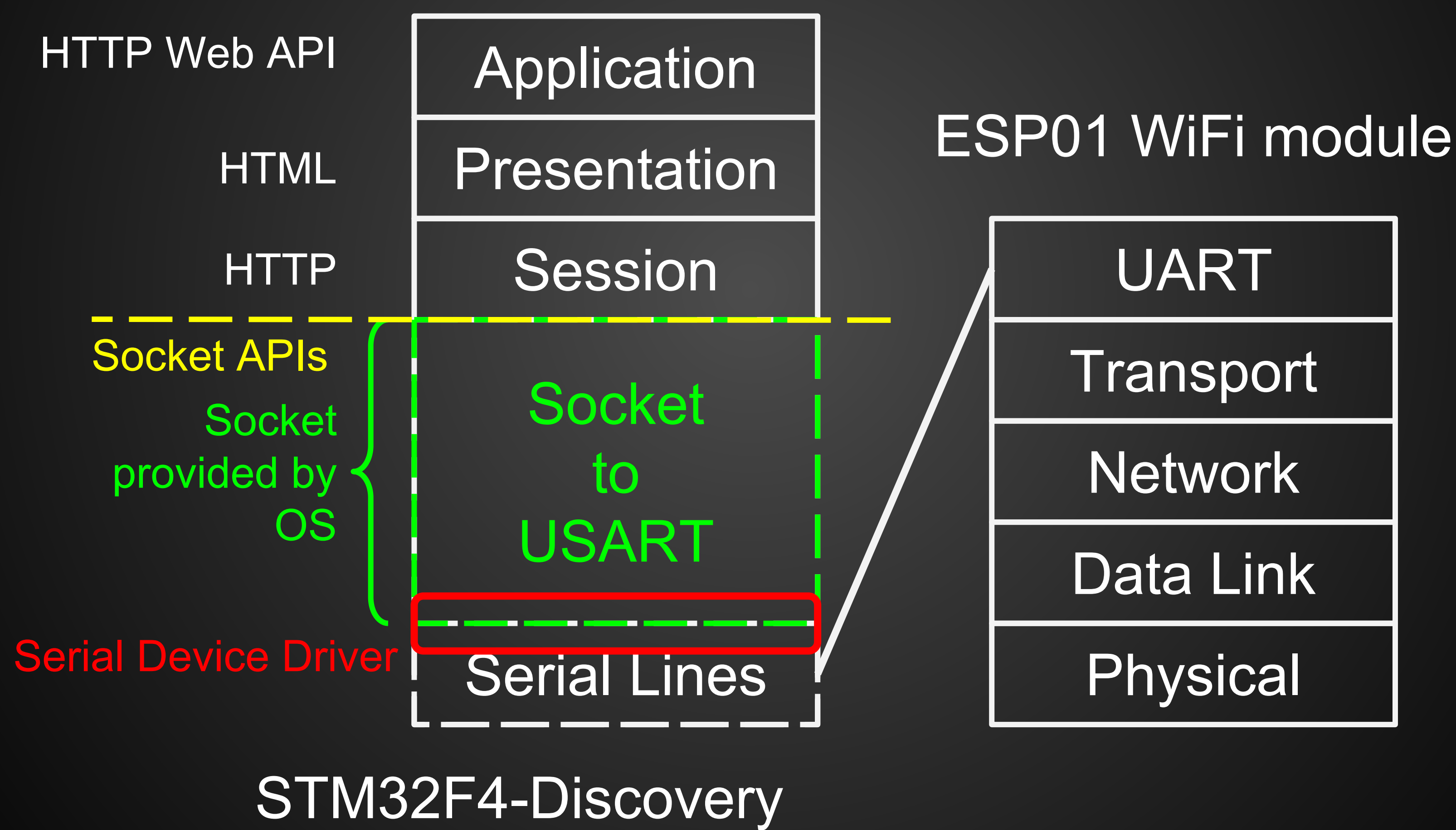
No general internet connection (including Wifi) on borad. So ...

Communication Wiring




STM32F4-Discovery
Power
& ST-LINK
USB to Serial
ESP01

HTTP Server on STM32F4-Discovery



Socket API

- Data Types:
  - socket, sockaddr_in
- Constant Flags
- Initial socket:
  - socket()
  - bind()
- Server's works:
  - listen()
  - accept()
- I/O:
  - send()
  - recv()
- Release I/O:
  - shutdown()
  - close()
- Manipulate I/O
  - setsockopt()
  - fcntl()

Select API

- Data types:
  - fd_set
  - struct timeval
- I/O Multiplexing:
  - select()
  - FD_ZERO()
  - FD_SET()
  - FD_CLR()
  - FD_ISSET()

We also need
ESP8266 & serial drivers
which communicates with
ESP01 through UART!

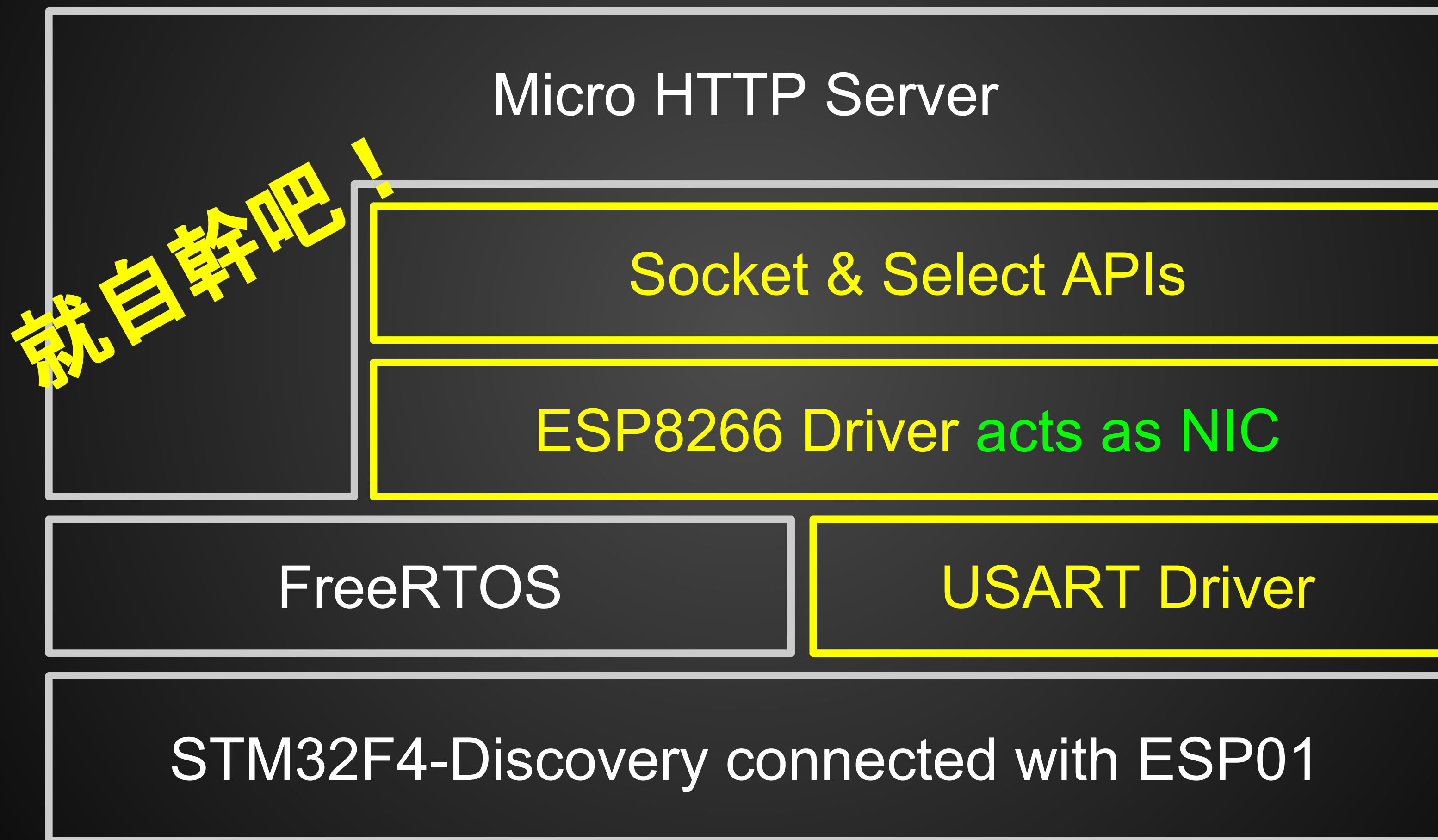
The protocol of the communication between the MCU and ESP01 is AT commands!

AT Commands of ESP01

https://cdn.sparkfun.com/assets/learn_tutorials/4/0/3/4A-ESP8266__AT_Instruction_Set__EN_v0.30.pdf

- AT+CWJAP: Connect to AP
- AT+CIFSR: Get local IP address
- AT+CIPMUX: Enable multiple connections
- AT+CIPSERVER: Configure as TCP server
- AT+CIPSEND: Send data
- AT+CIPCLOSE: Close TCP or UDP connection
- [num],CONNECT: A new client connected (Not listed)
- +IPD: Receive network data

Micro HTTP Server on FreeRTOS



Yellow blocks need to be implemented

Principles of Implementation

1. **Implement the used APIs as much as possible!**

2. **Mocking may be used if the function is not important!** → To reduce the complexity

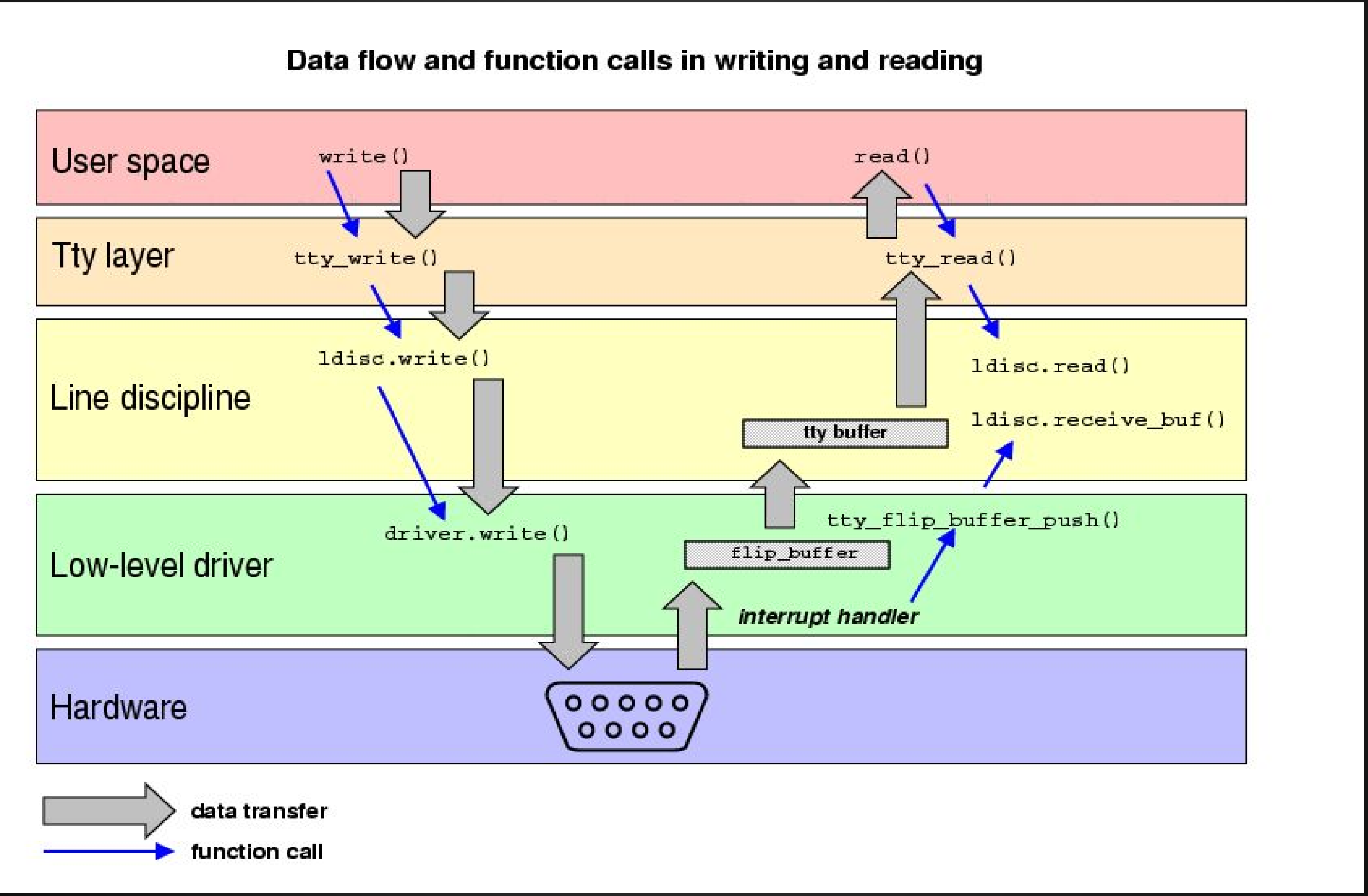
Socket & Select APIs' Header Files

Refer to and copy Linux header files directly.

To make it simple, merge the variety header files which are included and rewrite them into several files.

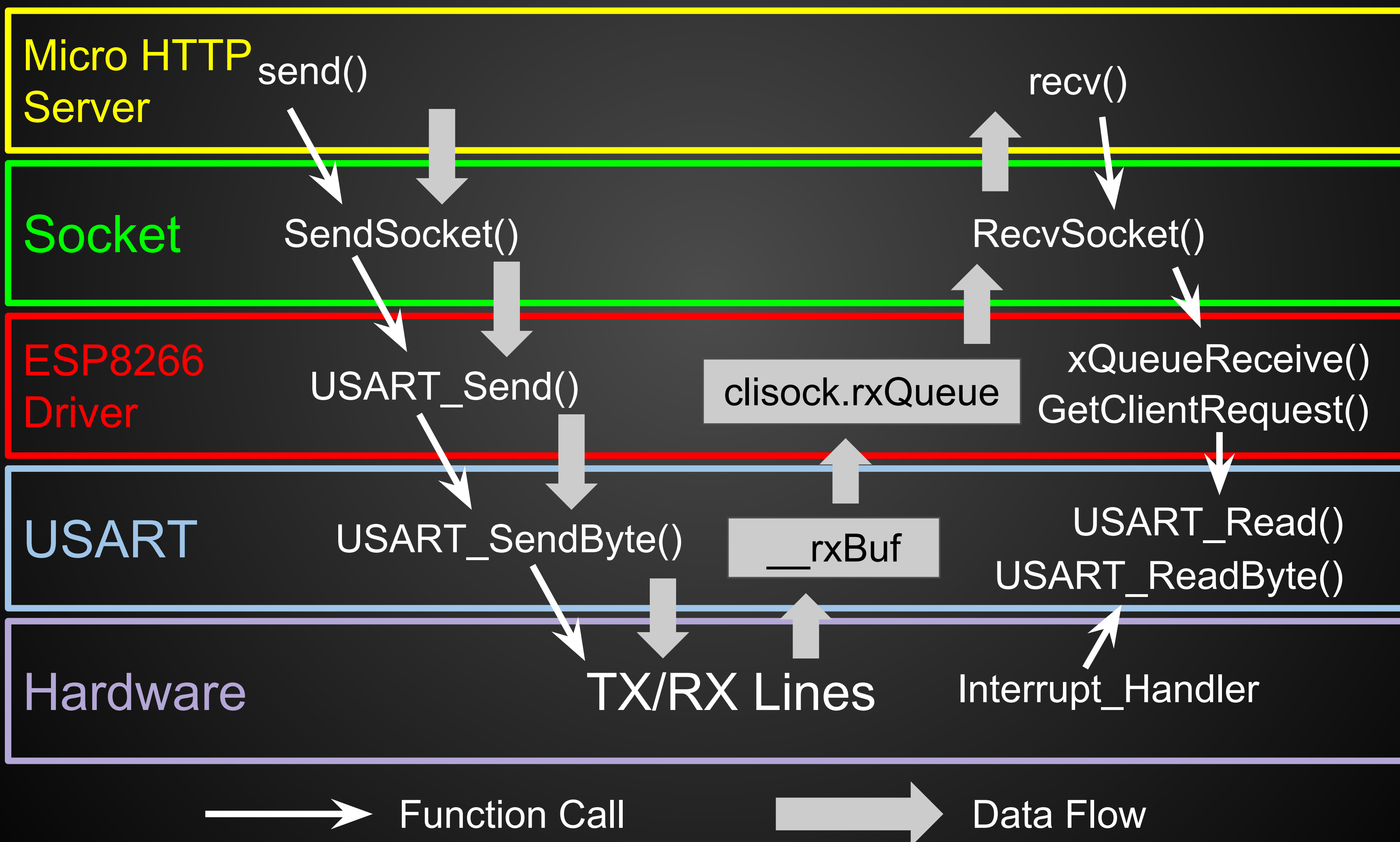
Thanks to Open Source!!!

Reference Serial Drivers of Linux



Reference: Serial Drivers http://www.linux.it/~rubini/docs/serial/serial.html

Data Flow and Function Calls



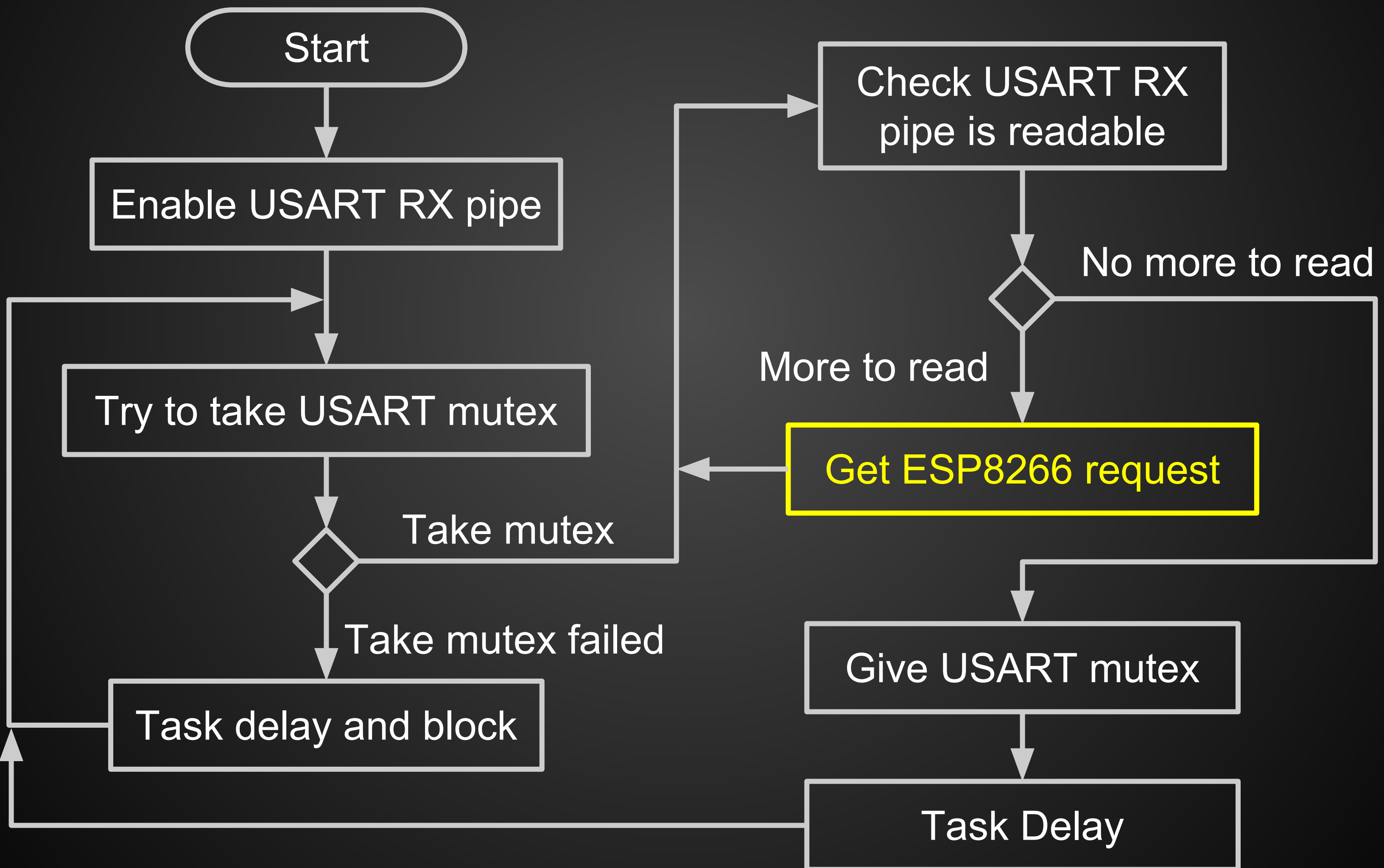
ESP8266 Driver

- Initial the USART channel
- Makes ESP01 as a network interface
  - Translates the system calls to AT commands
- Manage socket resources
  - The file descriptors of sockets
- USART channel mutex
  - Both the vESP8266RTask and vESP8266TTask communicate with ESP01 through the same USART channel
- Join an access point

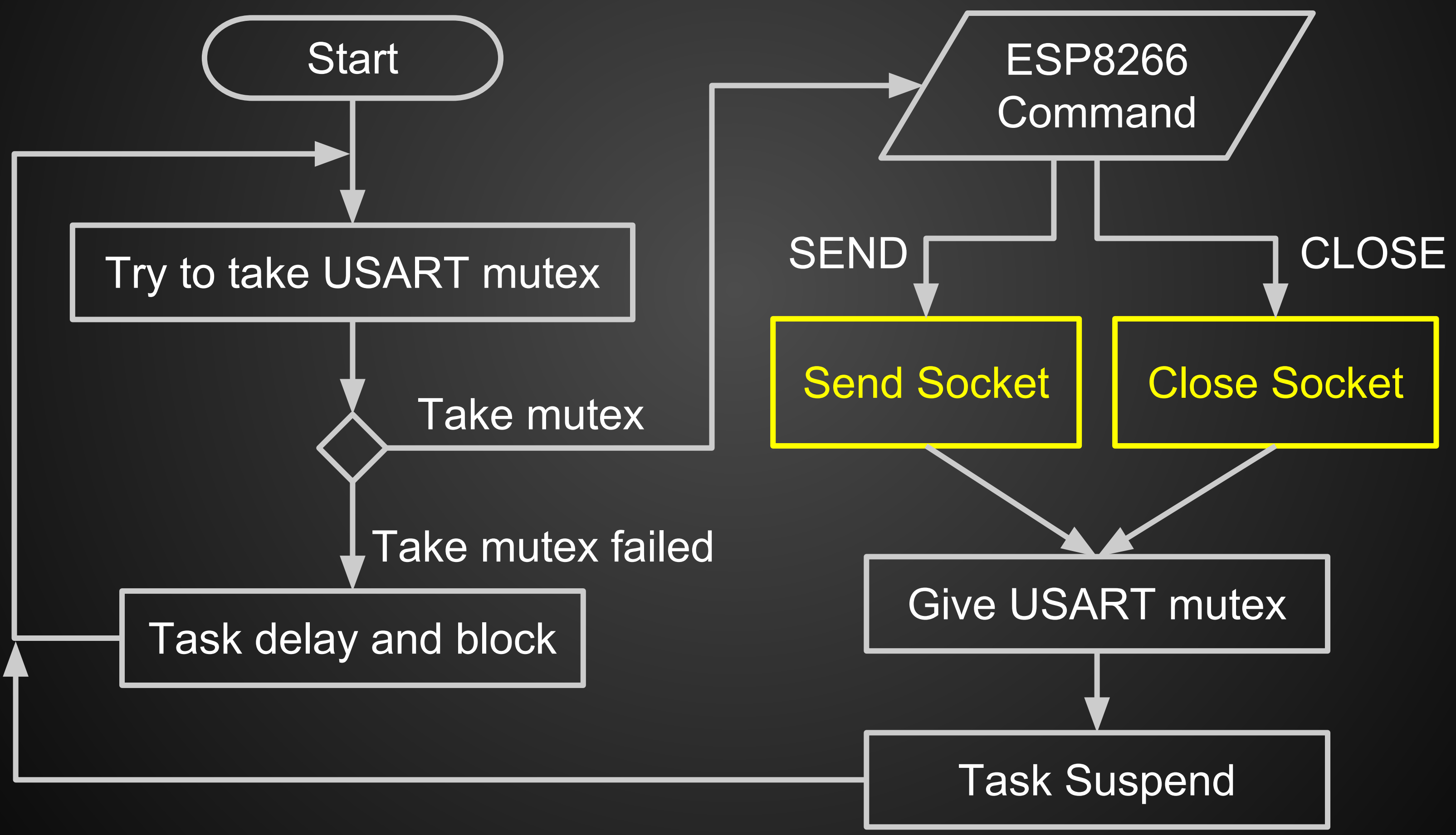
ESP8266 Driver Cont.

- vESP8266RTask
  - A persistent task parses the active requests from ESP01 (connect for accept, the requests from client’s sockets)
- vESP8266TTask
  - A persistent task deals the command going to be sent to ESP01 (socket send, socket close)
- Socket ready to read
  - Check the socket is ready to be read for I/O multiplexing to monitor the socket’s state
- Socket ready to write
  - Check the socket is ready to be written for I/O multiplexing to monitor the socket’s state

Flow of vESP8266RTask



Flow of vESP8266TTask



Select System Call

*int select(int nfds, fd_set *readfds, fd_set *writefds,*
*fd_set *exceptfds, struct timeval *timeout);*

select() and pselect() allow a program to monitor multiple file descriptors, waiting until one or more of the file descriptors become "ready" for some class of I/O operation (e.g., input possible). A file descriptor is considered ready if it is possible to perform a corresponding I/O operation (e.g., read(2) without blocking, or a sufficiently small write(2)).

Reference: Linux Programmer's Manual [SELECT(2)]

Select System Call Cont.

- ***readfds*** *will be watched to see if characters become available for reading (more precisely, to see if a read will not block; in particular, a file descriptor is also ready on end-of-file).*
- ***writefds*** *will be watched to see if space is available for write (though a large write may still block).*
- ***exceptfds*** *will be watched for exceptions.*
- ***nfds*** *is the highest-numbered file descriptor in any of the three sets, plus 1.*
- ***timeout*** *argument specifies the interval that select() should block waiting for a file descriptor to become ready.*

Reference: Linux Programmer's Manual [SELECT(2)]

Select System Call Cont.

- On **success**, select() and pselect() return the number of file descriptors contained in the three returned descriptor sets (that is, the total number of bits that are set in readfds, writefds, exceptfds) which may be zero if the timeout expires before anything interesting happens.
- On **error**, -1 is returned, and errno is set to indicate the error; the file descriptor sets are unmodified, and timeout becomes undefined.

Reference: Linux Programmer's Manual SELECT(2)

fd_set

[Linux/include/uapi/linux/posix_types.h]()

```
typedef struct {
    unsigned long fds_bits[ __FD_SETSIZE /
                              (8 * sizeof(long))];
} __kernel_fd_set;
```

[Linux/include/linux/types.h]()

```
typedef  __kernel_fd_set  fd_set;
```

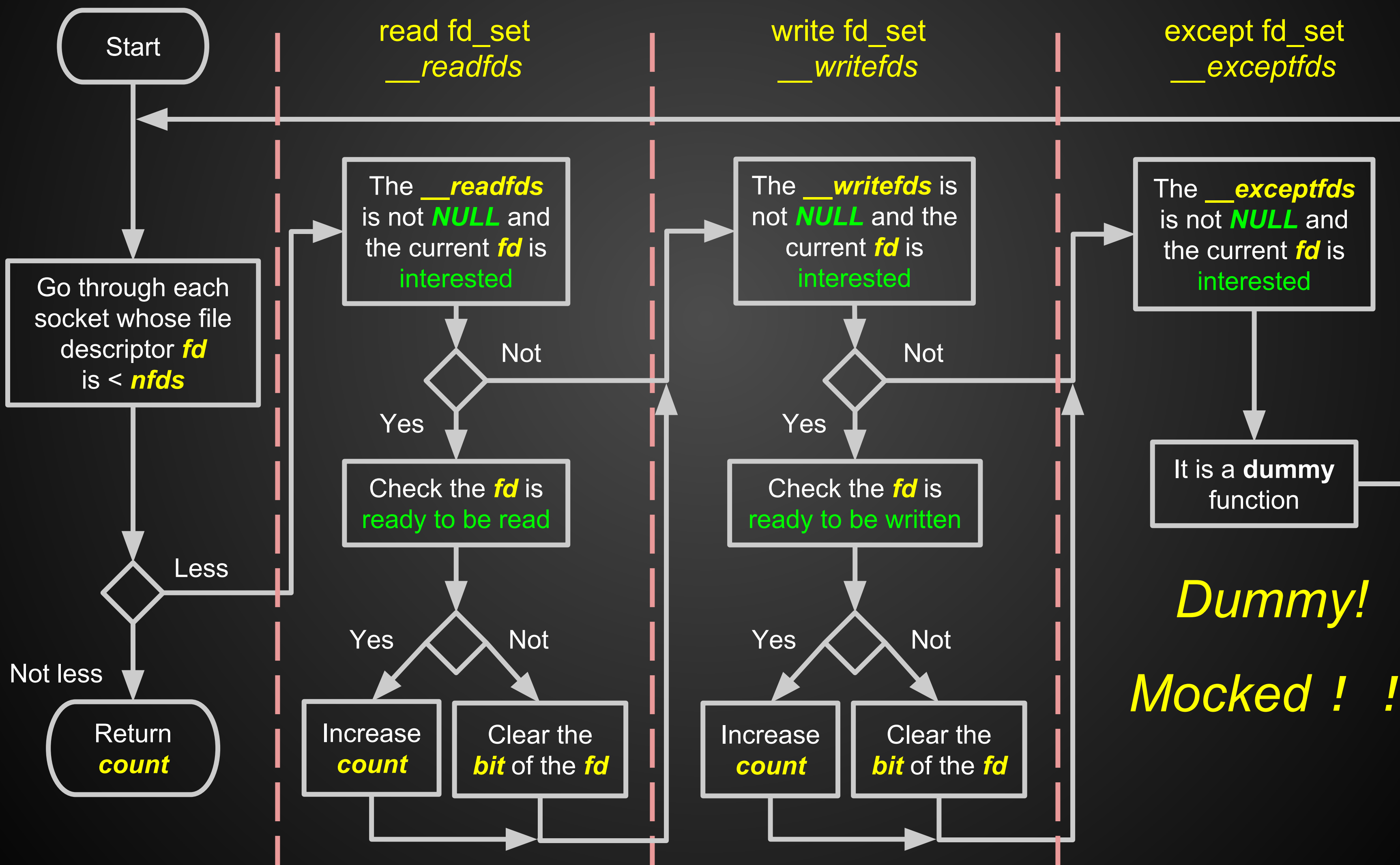
I make it as the data type of ***uint64_t*** !!!

typedef uint64_t fd_set;

Bits Array	fd=0	fd=1	fd=2	fd=3	fd=4	fd=5	fd=6	...

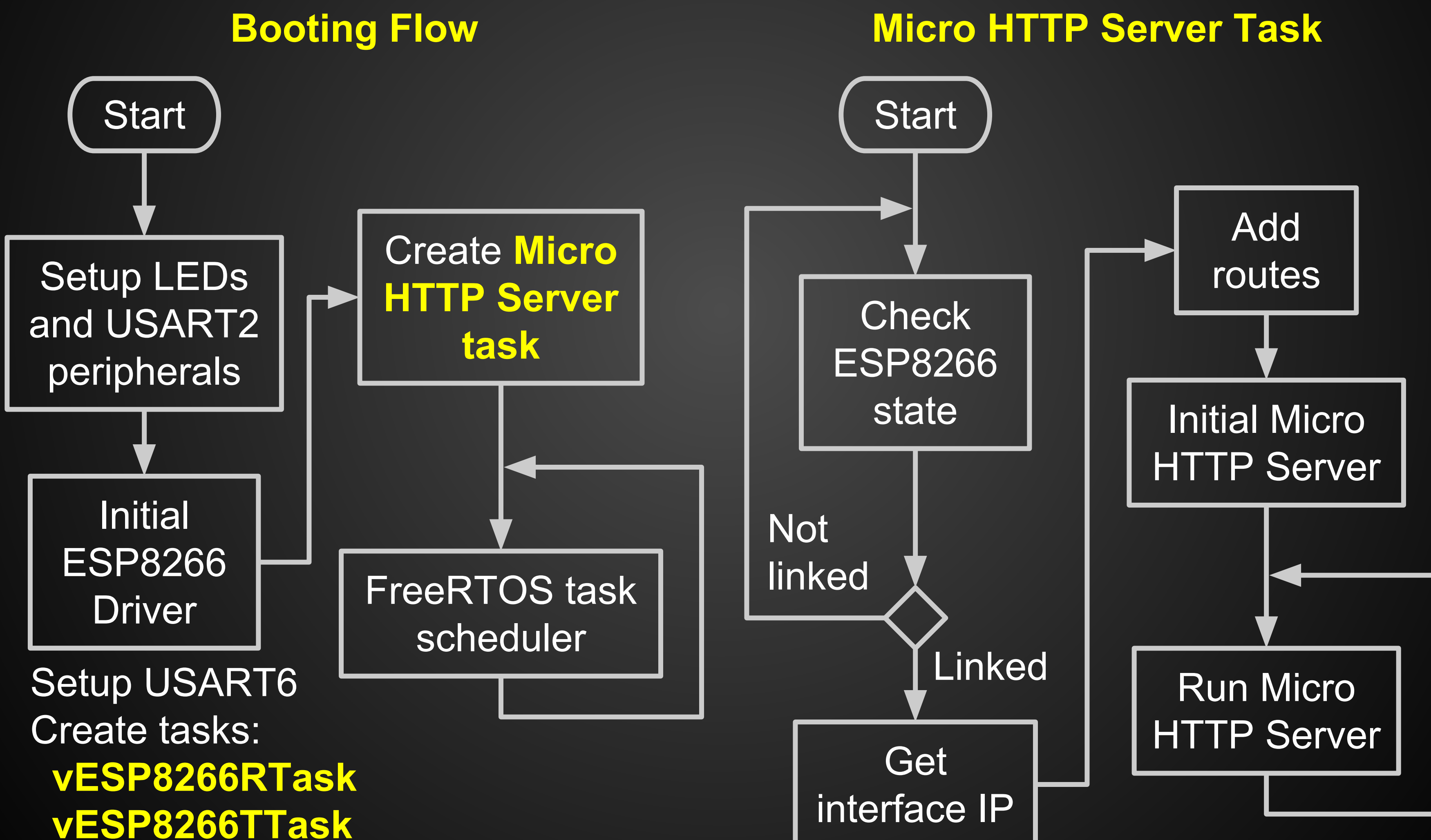
=> Each bit of fd_set corresponds to one file descriptor in order.

Select System Call Implementation

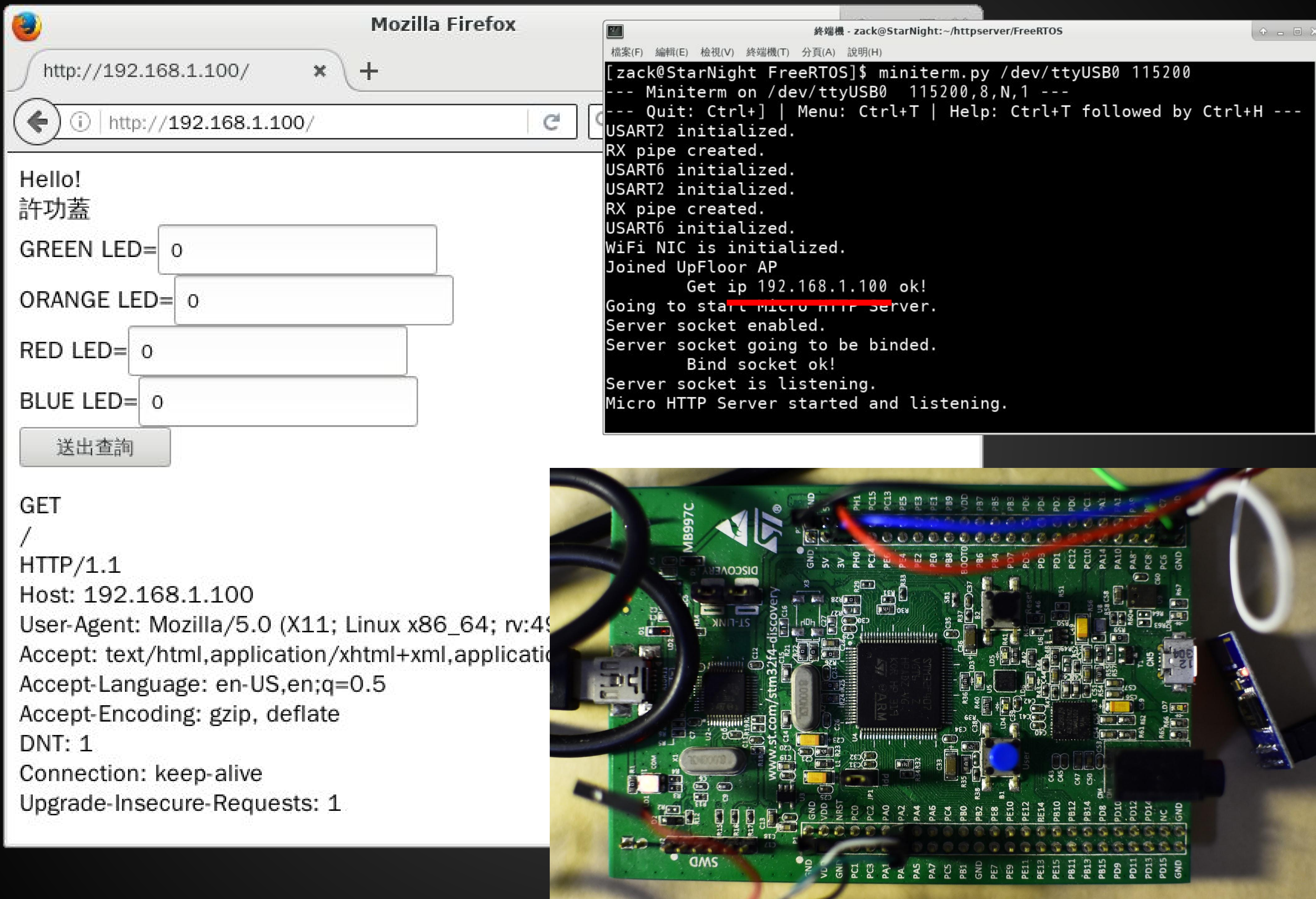


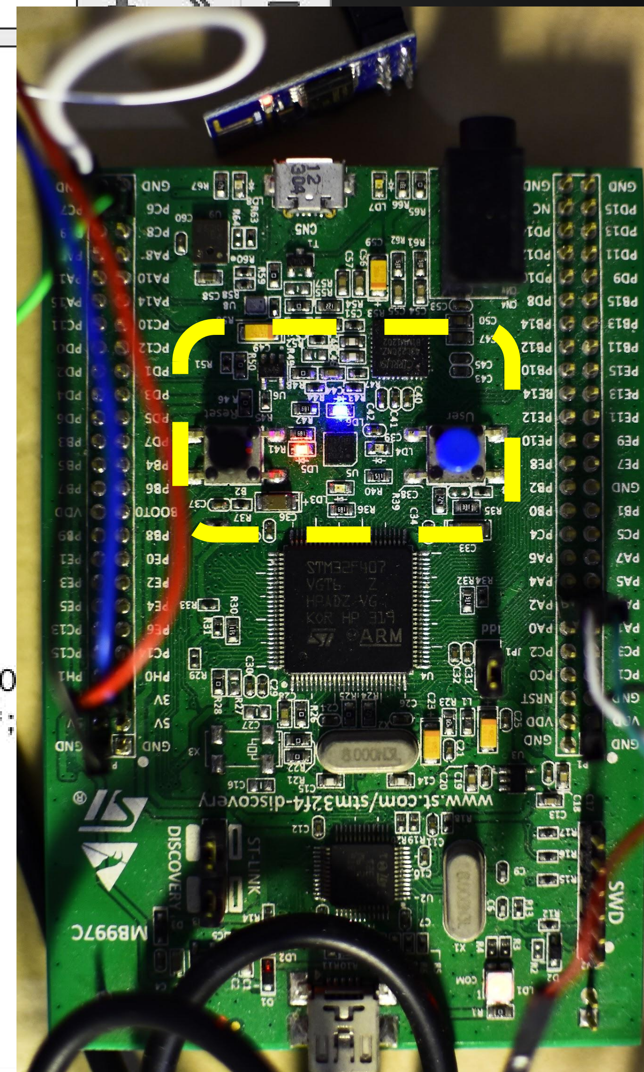
Assemble Parts Together

Overall Flow Diagram



Demo


Mozilla Firefox
http://192.168.1.100/
http://192.168.1.100/
Hello!
許功蓋
GREEN LED= 0
ORANGE LED= 0
RED LED= 0
BLUE LED= 0
送出查詢
GET
/
HTTP/1.1
Host: 192.168.1.100
User-Agent: Mozilla/5.0 (X11; Linux x86_64; rv:4
Accept: text/html,application/xhtml+xml,applicati
Accept-Language: en-US,en;q=0.5
Accept-Encoding: gzip, deflate
DNT: 1
Connection: keep-alive
Upgrade-Insecure-Requests: 1
終端機 - zack@StarNight:~/httpserver/FreeRTOS
檔案(F) 編輯(E) 檢視(V) 終端機(T) 分頁(A) 說明(H)
[zack@StarNight FreeRTOS]$ miniterm.py /dev/ttyUSB0 115200
--- Miniterm on /dev/ttyUSB0 115200,8,N,1 ---
--- Quit: Ctrl+] | Menu: Ctrl+T | Help: Ctrl+T followed by Ctrl+H ---
USART2 initialized.
RX pipe created.
USART6 initialized.
USART2 initialized.
RX pipe created.
USART6 initialized.
WiFi NIC is initialized.
Joined UpFloor AP
Get ip 192.168.1.100 ok!
Going to start Micro HTTP Server.
Server socket enabled.
Server socket going to be binded.
Bind socket ok!
Server socket is listening.
Micro HTTP Server started and listening.
MB997C
DISCOVERY
ST-LINK
www.st.com/stm32f4-discovery
SWD


Mozilla Firefox
http://192.168.1.100/led
http://192.168.1.100/led
搜尋
Hello!
許功蓋
GREEN LED= 0
ORANGE LED= 0
RED LED= 1
BLUE LED= 1
送出查詢
POST
/led
HTTP/1.1
Host: 192.168.1.100
User-Agent: Mozilla/5.0 (X11; Linux x86_64; rv:49.0) Gecko/20100
Accept: text/html,application/xhtml+xml,application/xml;q=0.9,*/*;
Accept-Language: en-US,en;q=0.5
Accept-Encoding: gzip, deflate
Referer: http://192.168.1.100/led
DNT: 1
Connection: keep-alive
Upgrade-Insecure-Requests: 1
Content-Type: application/x-www-form-urlencoded
Content-Length: 29


Reference

- RFC 2616 HTTP 1.1 https://tools.ietf.org/html/rfc2616
- RFC 3875 CGI https://tools.ietf.org/html/rfc3875
- FastCGI https://en.wikipedia.org/wiki/FastCGI
- NSAPI https://en.wikipedia.org/wiki/Netscape_Server_Application_Programming_Interface
- Django & Twisted by Amber Brown @ PyCon Taiwan 2016 https://www.youtube.com/watch?v=4b3rKZTW3WA
- eserv https://code.google.com/archive/p/eserv/source
- tinyhttpd http://tinyhttpd.cvs.sourceforge.net/viewvc/tinyhttpd/tinyhttpd/
- GNU Libmicrohttpd https://www.gnu.org/software/libmicrohttpd/

Thank you ~

and

Q & A