Computer Networking

COMP 177 | Fall 2020 | University of the Pacific | Jeff Shafer

Parallel

Network Programming

Upcoming Schedule

- **Project 4 – Python HTTP Server v2**
  - Starts today!
  - Due: November 18^{th}
- **Presentation** - Security & Privacy
  - Proposal due: November 4^{th}
  - Presentation due: November 23^{rd}
  - Peer reviews due: December 2^{nd}

Parallel Network Programming

Concurrency

- **Why do I need concurrency in a web server?**
  - **Many clients making requests in parallel**
  - What if several clients each attempt to download a large file?
    - Ugly to make everyone wait on the first user to finish
    - Eventually other clients would timeout and fail
  - A multi-CPU server should use all its resources (multiple cores) to satisfy multiple clients

Goals

Maximize

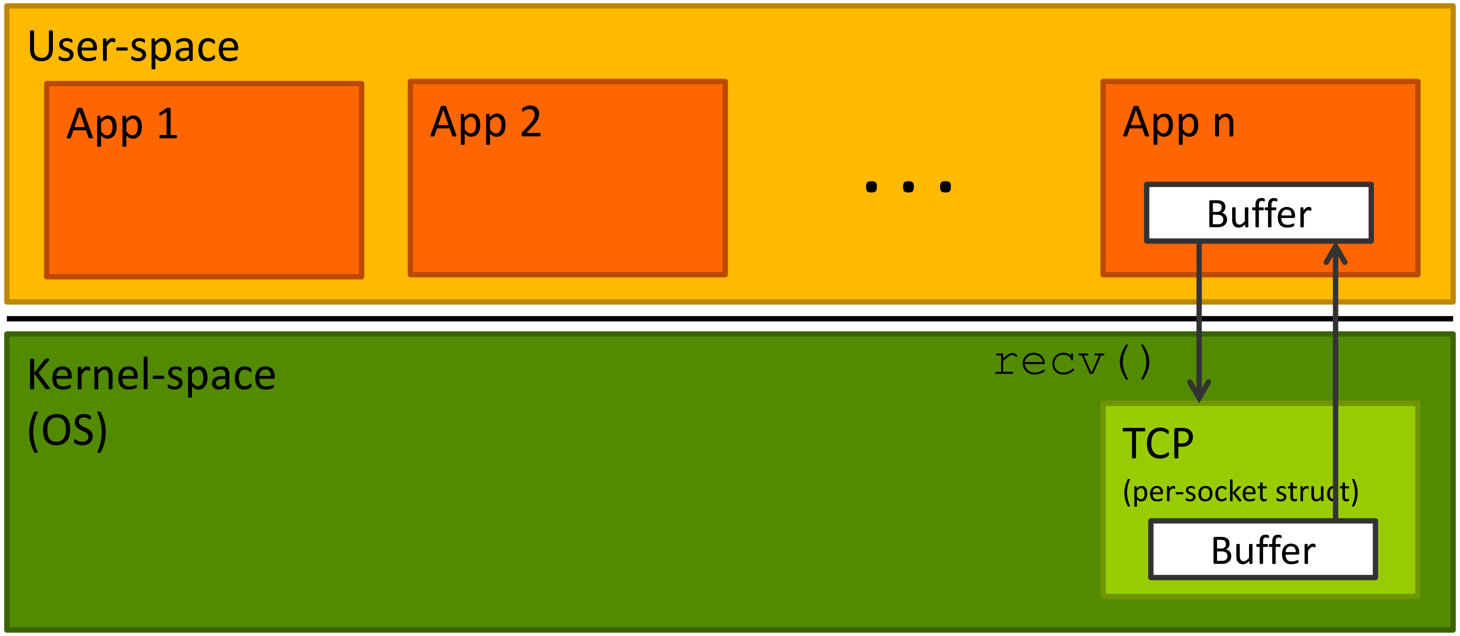
- Request throughput (#/sec)
- Raw data throughput (Mbps)
- Number of concurrent connections

Minimize

- Response times (ms)
- Server CPU utilization
- Server memory usage

Socket `recv()`

- We'll use the `recv()` function for today's examples



`recv()` copies data from kernel space to user-space.
If data is available, the function returns immediately with data

Blocking -vs- Non-Blocking

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Blocking

- ***Standard*** mode
- When your program calls `recv()`, if no data is available, the OS puts your program to **sleep**
- Your program is "blocked" on `recv()`

Non-Blocking

- ***Special*** mode for many socket calls, including `recv()`
- When your program calls `recv()`, if no data is available, `recv()` **immediately returns**

Synchronous -vs- Asynchronous

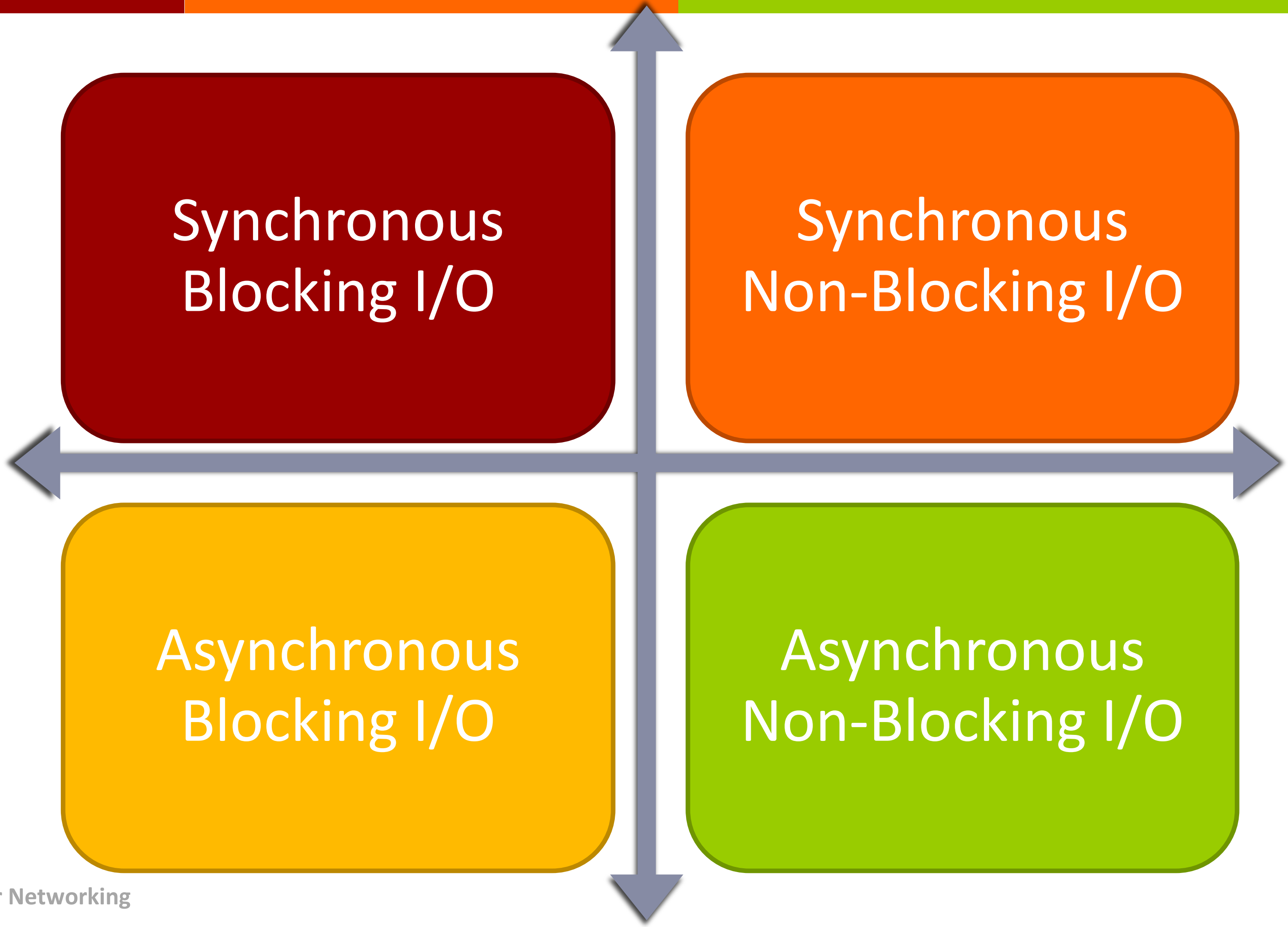
Synchronous

- "With Synchronization"
- One operation at a time…
- Function calls to OS services do not return until action is complete

Asynchronous

- "Without Synchronization"
- Function calls to OS services return immediately, while OS action can proceed independently of user program

Combine Methods



Synchronous Blocking I/O

- Program requests data from OS
- `recv()` only returns once data is available
- Works fine for managing one socket
  - **How about *two* sockets with different clients?**

Pseudo-code:

```
data = socket1.recv()
# Data now available
```

Synchronous Non-Blocking I/O

- Program requests data from OS
- `recv()` will return immediately, but may not have any data
- Busy-wait loop wastes CPU time

Pseudo-code:

```
socket1.blocking(off)
data = socket1.recv()
while(!data)
    data = socket1.recv()

# Data now available
```

- **How would this work if we had *two* sockets to manage?**

Asynchronous Blocking I/O

- `recv()` still blocking
- Busy-wait loop replaced with **new** `select()` **function** that **tests multiple sockets at once**
- Give `select()` separate list of sockets
  - Want to `recv()`
  - Want to `send()`
  - Check for error

Pseudo-code:

```
list_recv = (socket1)
list = select(list_recv)
ready_sock = list[0]
data = ready_sock.recv()
# Data now available
```

- `select()` returns the subset of lists that are **ready** (for send/recv/err)
- Not the most efficient function…

Asynchronous Non-Blocking I/O

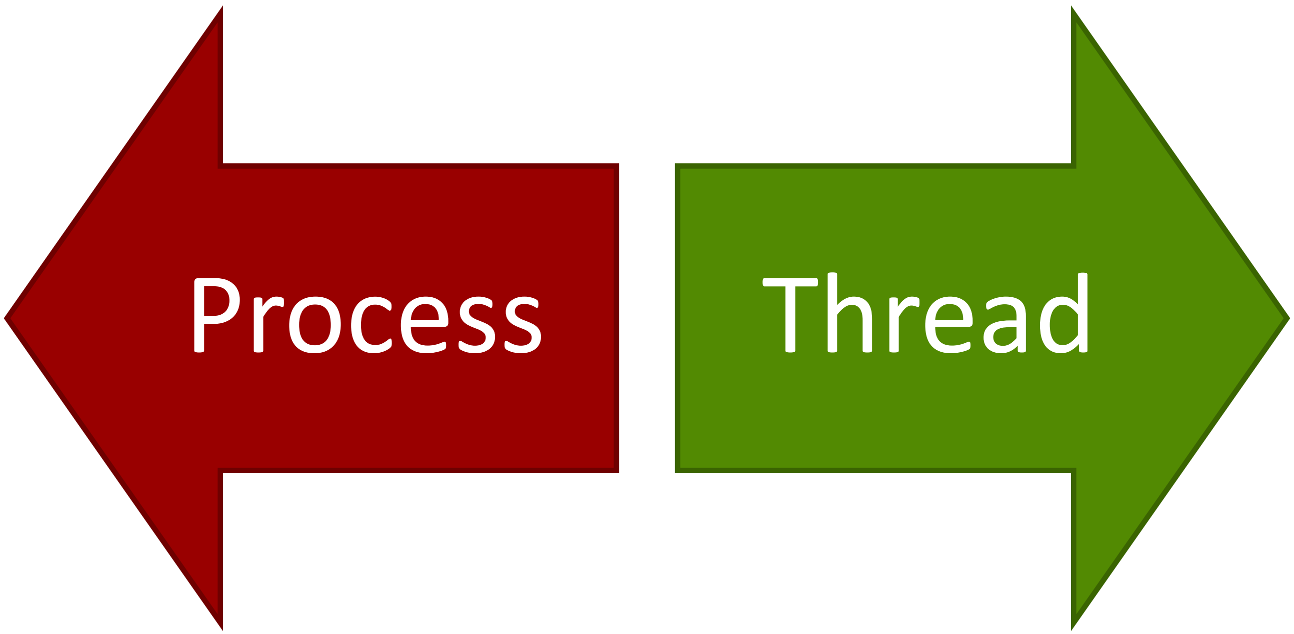
- `recv()` returns immediately
- In background, OS performs `recv()` work
- When ready, OS calls a "callback" function in your program

Pseudo-code:

```
data = socket.q_recv(done)
# Do something else
# in program

fun done()
    # When called, data
    # is available
```

Processes -vs- Threads



What's the difference?

Processes -vs- Threads

Processes

- Use multi cores/CPUs
- **Separate memory** space
- Can communicate with other processes only by **IPC** (inter-process comm.)
- **"Safer"** to program (other processes can't hurt you)
- **"Heavy-weight"** - Slower to start a new process (lots of OS work)

Threads

- Use multi cores/CPUs
- **Same memory** space
- Can communicate with other threads by **shared memory**
- **"Harder"** to program (other buggy threads can easily corrupt your memory + synchronization is hard!)
- **"Light-weight"** - Fast to start a new thread (minimal OS work)

Processes -vs- Threads

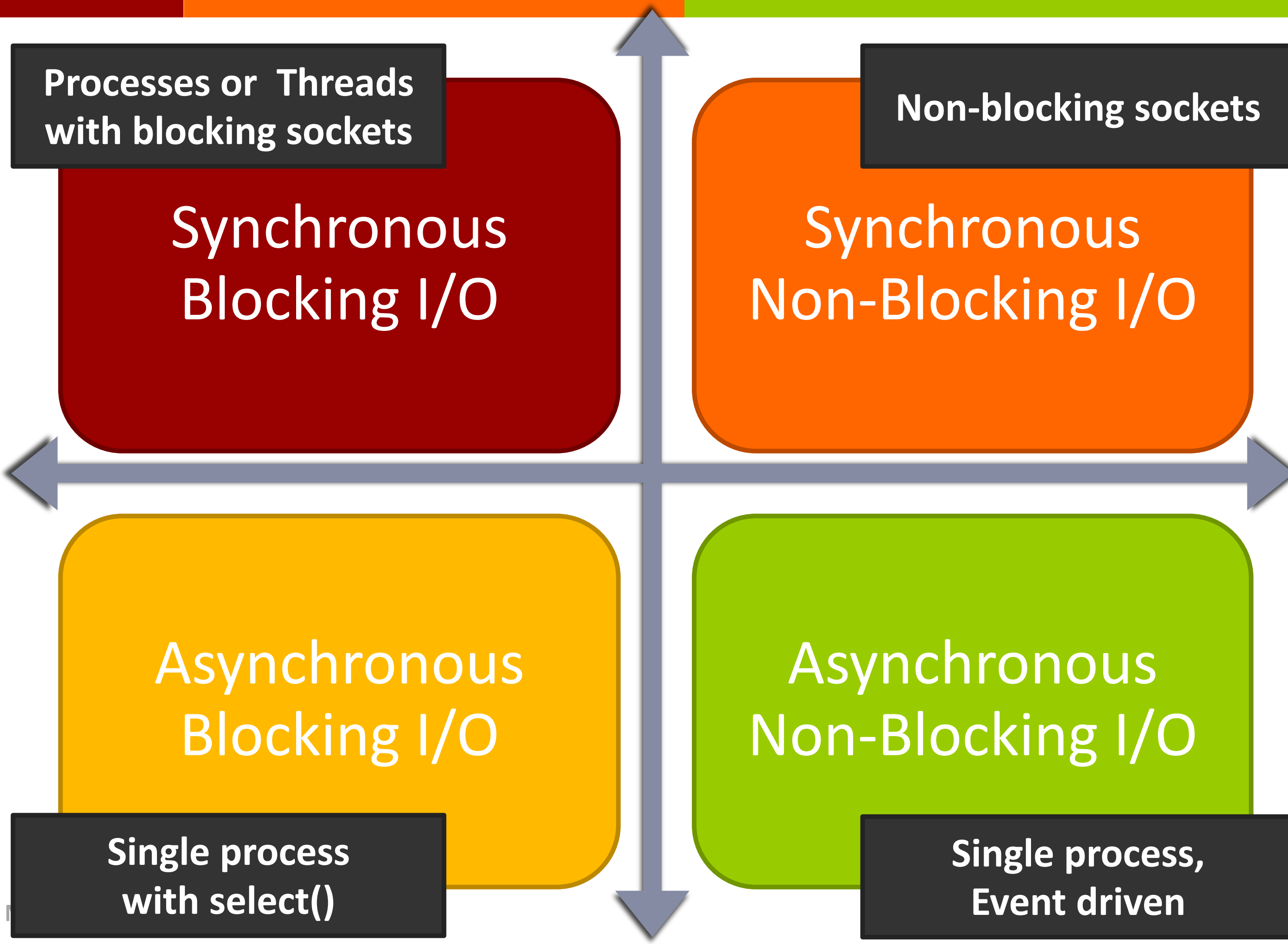
Processes

- Slow start?
  - Typical servers start a "pool" of processes when launched
  - Requests are quickly assigned to an already-running process when received
- Shared data?
  - Need to use OS IPC mechanisms to communicate
  - Needed to assign requests to processes, store log data from processes to single file, …

Threads

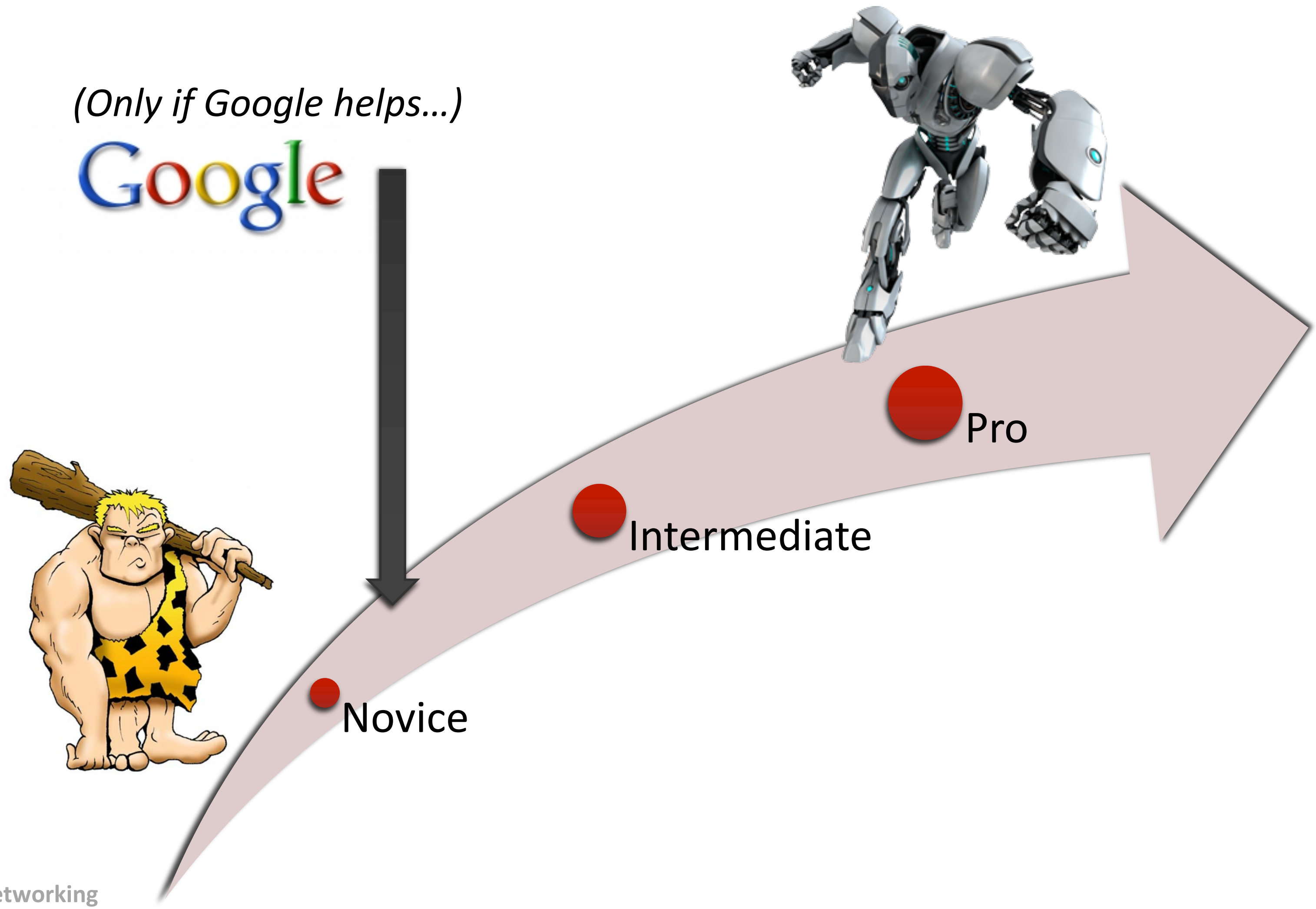
- Fast start?
  - OK to start threads "on demand"
- Shared data?
  - Need synchronization (locks, semaphores, etc…) to prevent corruption of shared data

How to Support Concurrency?



And now, a note about Python…

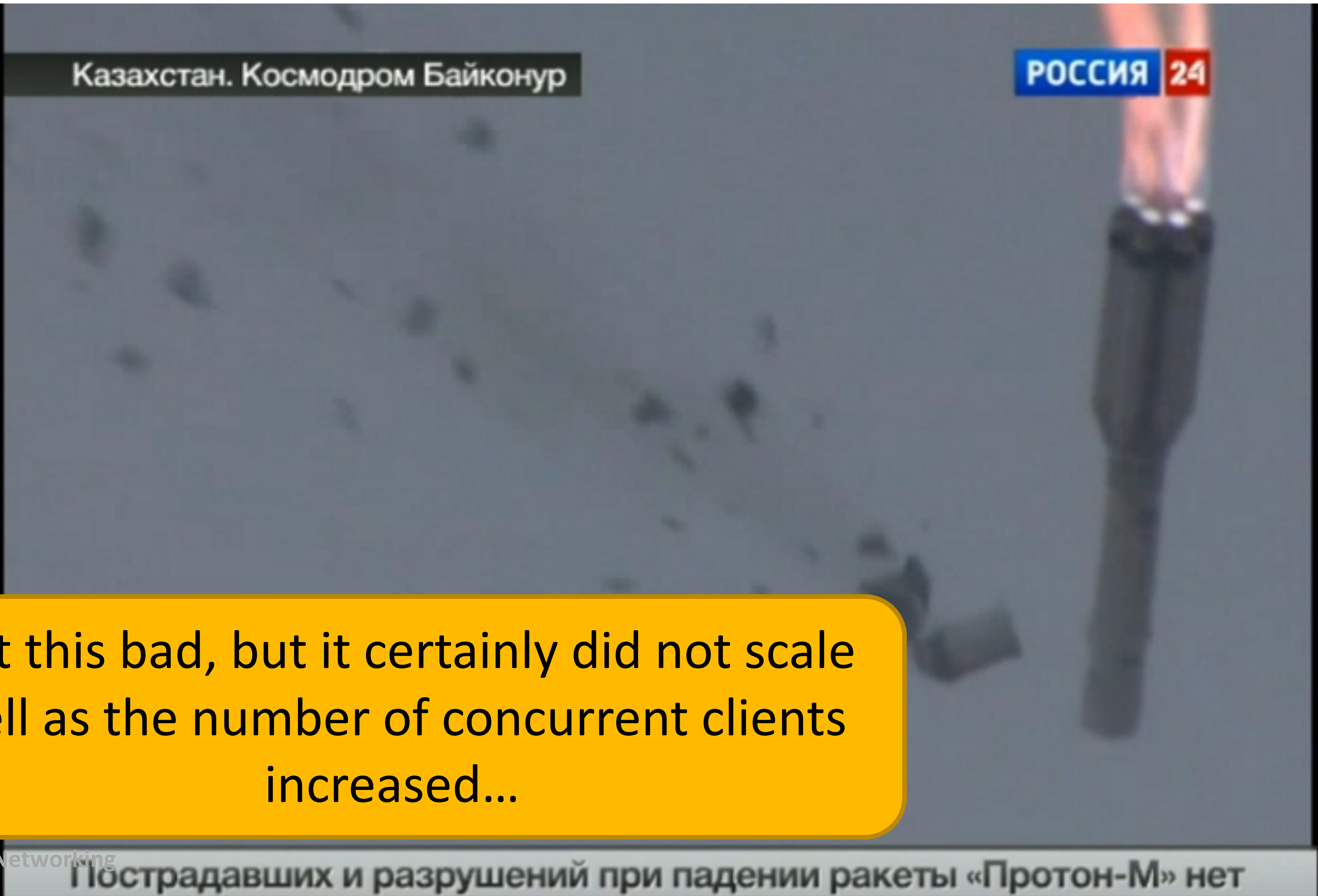
My Skill Level in Python



So before assigning class projects, I wrote a Python web server using **threads**.

Once working, I measured its performance…

Results were "sub optimal"



Not this bad, but it certainly did not scale well as the number of concurrent clients increased…

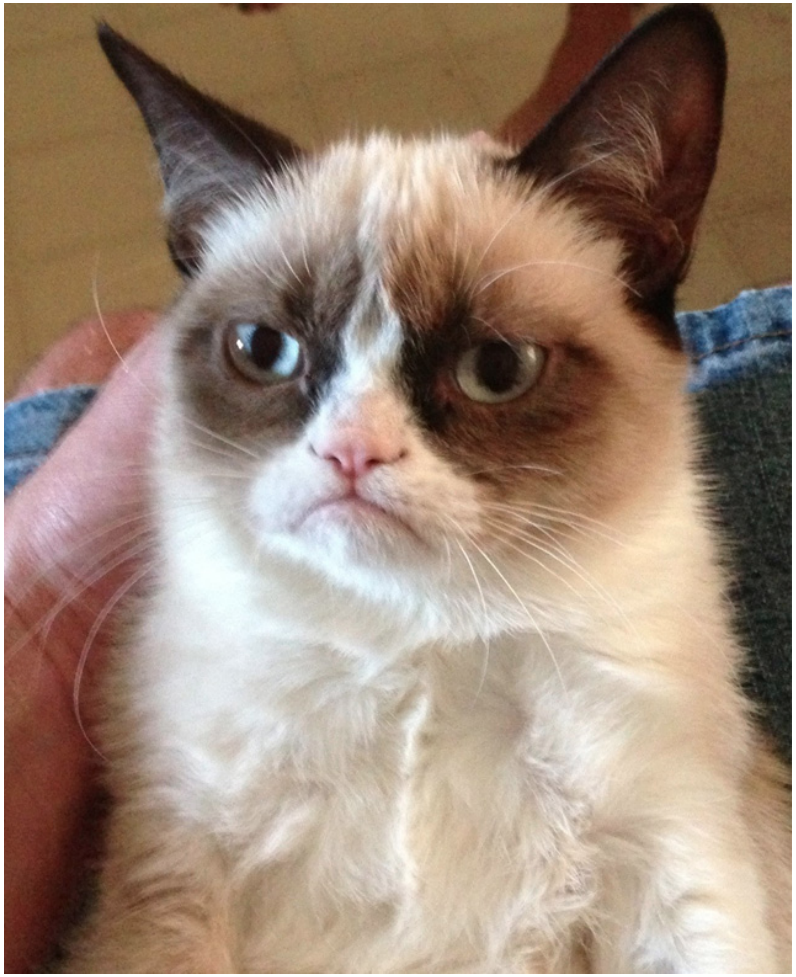
Threads in Python

- Python is an **interpreted language**
  - Several different interpreters exist…
  - **Most common interpreter** is written in C (“**CPython**”)
- CPython has a global lock (GIL = Global Interpreter Lock)
  - Lock prevents two threads from running in the interpreter and manipulating memory at same time
  - Allows interpreter to run safely (correctly), perform garbage collection, etc…

Threads in Python

- Effect of GIL (lock) on concurrency
  - I can have multiple threads working on OS-related tasks (`send`, `recv`, …) in parallel
  - But the GIL blocks multiple threads from running Python native code concurrently ☹
    - See: http://www.dabeaz.com/python/UnderstandingGIL.pdf
- So, while the Python *language* has nice threads, the CPython *implementation* limits the performance benefit

Threads in Python



- **Perfectly OK to use threads for class projects**
  - **Educational**
  - **Good practice** for other languages!
  - Server code will look elegant
- Just don't expect a massive performance boost from parallelism