DISTRIBUTED SYSTEMS

Shivaram Venkataraman

CS 537, Fall 2024

ADMINISTRIVIA

Project 5 grades

Project 6 deadline

HelioCampus feedback

AGENDA / LEARNING OUTCOMES

What are some basic building blocks for systems that span across machines?

RECAP

MULTI QUEUE SCHEDULING

Maintain a queue per CPU
Within each queue, use existing scheduling algorithms

Scalability – Good!

Cache affinity – Good!

Load balance – How?

LINUX: COMPLETELY FAIR SCHEDULER (CFS)

Similar approach to stride scheduler (remember P4!?)

Goal: Divide a CPU using the concept of virtual runtime (vruntime)

Approach: Pick the process which has the lowest vruntime

When to switch processes:

- sched_latency – how long before switch ("fairness window")
- min_granularity

CFS: LOAD BALANCING

Periodically (e.g., 4ms) steal work from other cores

When stealing work, even out the load between the two cores

Topology awareness while work stealing

> Try to steal work more frequently from cores that are "close"
> vs. cores that are "remote" (e.g., on a remote NUMA node)

Load difference is small (less than 25% in practice), no load balancing

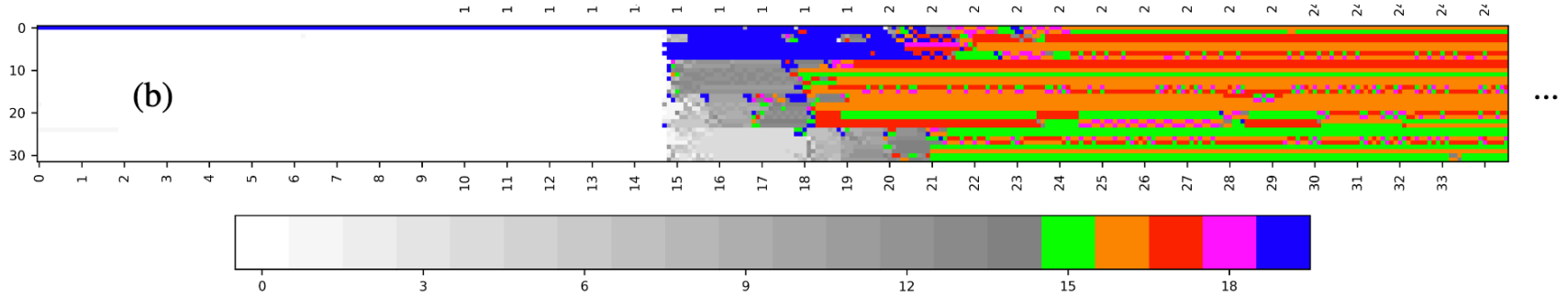


Figure 6: Number of threads per core over time on (a) ULE and (b) CFS. Each line represents a core (32 in total), time passes on the x-axis (in seconds), and colors represent the numbers of threads on the core. Thread counts below 15 are represented in shades of grey. Threads are pinned on core 0 for the first 14.5 seconds of the execution.

Start 512 spinning threads on core 0. Let load balancer work

ULE (BSD SCHEDULER)

Three queues per core: interactive, batch and idle threads

Calculate interactivity based on last 5 seconds

Inside a queue, sort threads by priority (niceness level)

First search interactive queue, then batch queue.

ULE (BSD SCHEDULER)

Aims to even out the number of threads per core (not load)

Choosing a core for a newly created thread: affinity heuristic (topology)

Periodic load balancing only by core 0.

a thread from the most loaded core, the (donor)

to the less loaded core, the (receiver)

DISTRIBUTED SYSTEMS

WHAT IS A DISTRIBUTED SYSTEM?

A distributed system is one where a machine I've never heard of can cause my program to fail.

— *Leslie Lamport*

Definition: More than one machine working together to solve a problem

Examples:

- client/server: web server and web client
- cluster: page rank computation

WHY GO DISTRIBUTED?

WHY GO DISTRIBUTED?

More computing power

More storage capacity

Fault tolerance

Data sharing

NEW CHALLENGES

System failure: need to worry about partial failure

Communication failure: links unreliable

- bit errors
- packet loss
- node/link failure

COMMUNICATION OVERVIEW

Raw messages: UDP

Reliable messages: TCP

Remote procedure call: RPC

RAW MESSAGES: UDP

UDP : User Datagram Protocol

API:

- reads and writes over socket file descriptors
- messages sent from/to ports to target a process on machine

Provide minimal reliability features:

- messages may be lost
- messages may be reordered
- messages may be duplicated
- only protection: checksums to ensure data not corrupted

RAW MESSAGES: UDP

Advantages

- Lightweight
- Some applications make better reliability decisions themselves (e.g., video conferencing programs)

Disadvantages

- More difficult to write applications correctly

Course feedback:
https://heliocampusac.wisc.edu

QUIZ 22

1. Why is cache affinity important?

2. Order the following processes by priority, from highest to lowest.

3. What is an advantage of single queue (SQMS) scheduling?

4. What is an advantage of multiple queue (MQMS) scheduling?

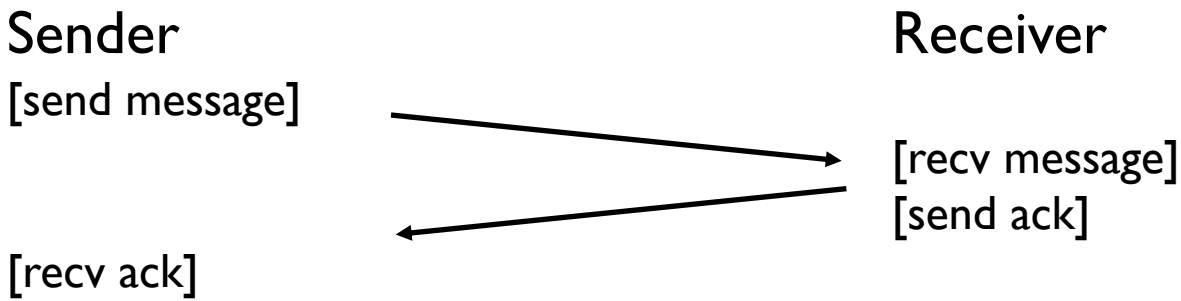
RELIABLE MESSAGES: LAYERING STRATEGY

TCP: Transmission Control Protocol

Using software to build

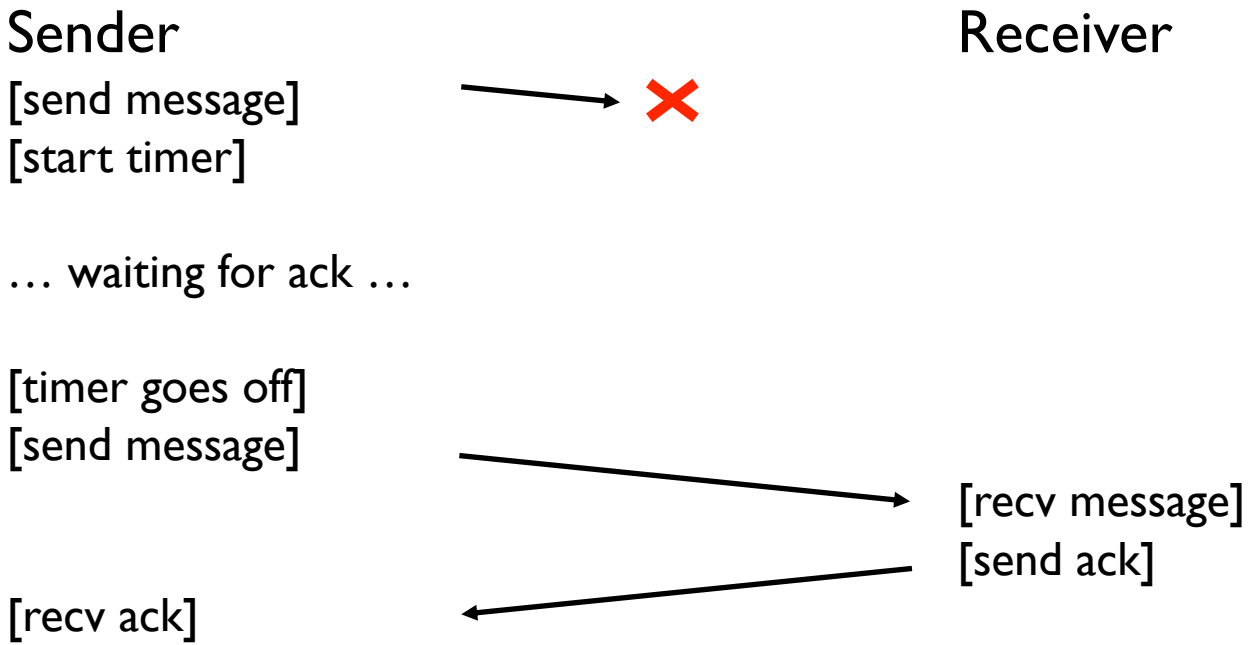
reliable logical connections over unreliable physical connections

TECHNIQUE #1: ACK



Ack: Sender knows message was received
What to do about message loss?

TECHNIQUE #2: TIMEOUT



TIMEOUT

How long to wait?

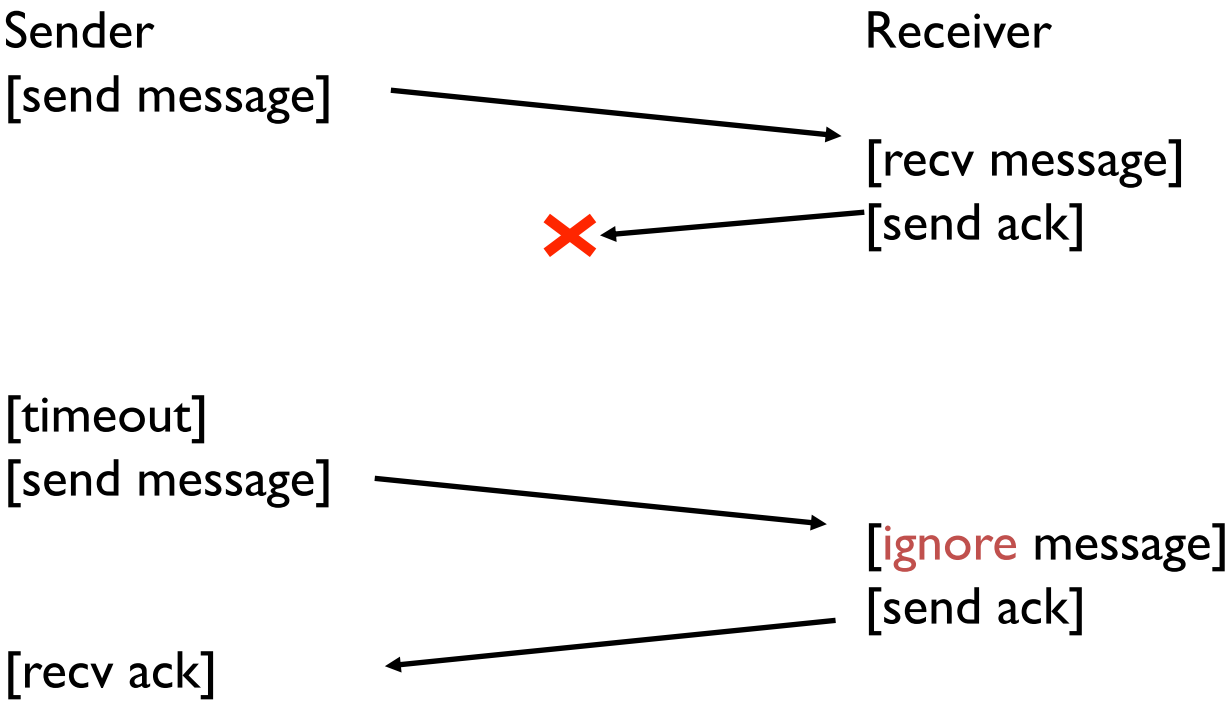
Too long?

- System feels unresponsive

Too short?

- Messages needlessly re-sent
- Messages may have been dropped due to overloaded server. Resending makes overload worse!

LOST ACK PROBLEM



SEQUENCE NUMBERS

Sequence numbers

- senders gives each message an increasing unique seq number
- receiver knows it has seen all messages before N

Suppose message K is received.

- if K <= N, Msg K is already delivered, ignore it
- if K = N + 1, first time seeing this message
- if K > N + 1 ?

TCP

TCP: Transmission Control Protocol

Most popular protocol based on seq nums

Buffers messages so arrive in order

Timeouts are adaptive

COMMUNICATIONS OVERVIEW

Raw messages: UDP

Reliable messages: TCP

Remote procedure call: RPC

RPC

Remote **P**rocedure **C**all

What could be easier than calling a function?

Approach: create wrappers so calling a function on another machine feels just like calling a local function!

RPC

Machine A

```
int main(…) {
        int x = foo(”hello”);
}

int foo(char *msg) {
        send msg to B
        recv msg from B
}
```

Machine B

```
int foo(char *msg) {
        …
}

void foo_listener() {
        while(1) {
                recv, call foo
        }
}
```

RPC

Machine A

```
int main(…) {
        int x = foo(”hello”);
}

int foo(char *msg) {
        send msg to B
        recv msg from B
}
```

client wrapper

Machine B

```
int foo(char *msg) {
        …
}

void foo_listener() {
        while(1) {
                recv, call foo
        }
}
```

server wrapper

RPC TOOLS

RPC packages help with two components

(1) Runtime library

- Thread pool
- Socket listeners call functions on server

(2) Stub generation

- Create wrappers automatically
- Many tools available (rpcgen, thrift, protobufs)

WRAPPER GENERATION

Wrappers must do conversions:

- client arguments to message
- message to server arguments
- convert server return value to message
- convert message to client return value

Need uniform endianness (wrappers do this)

Conversion is called marshaling/unmarshaling, or serializing/deserializing

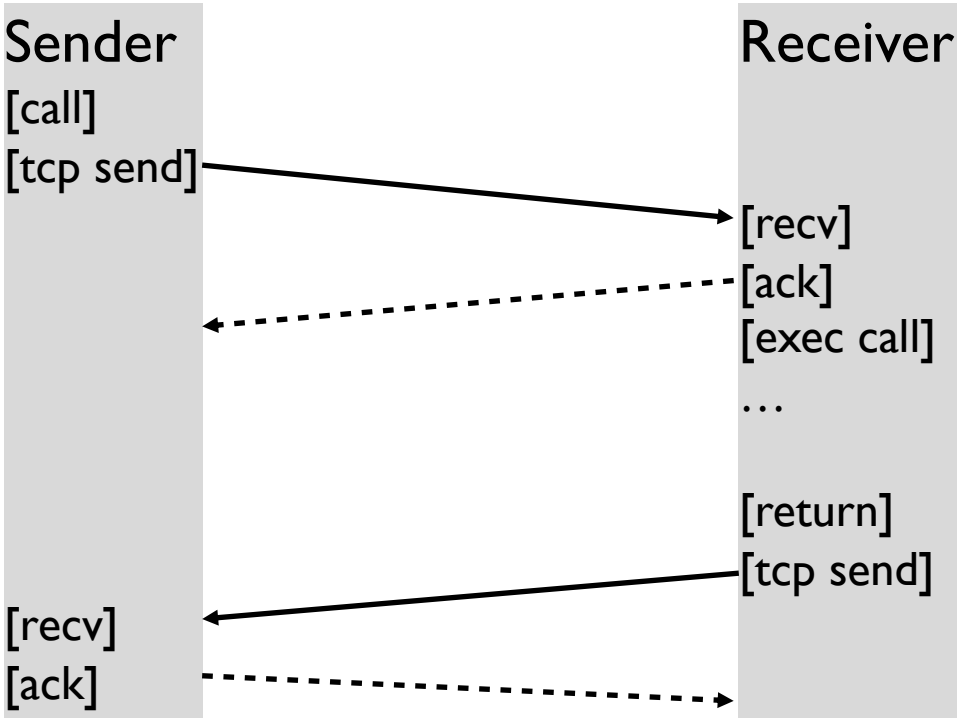
WRAPPER GENERATION: POINTERS

Why are pointers problematic?

Address passed from client not valid on server

Solutions? Smart RPC package: follow pointers and copy data

RPC OVER TCP?


Sender
[call]
[tcp send]
[recv]
[ack]
Receiver
[recv]
[ack]
[exec call]
…
[return]
[tcp send]

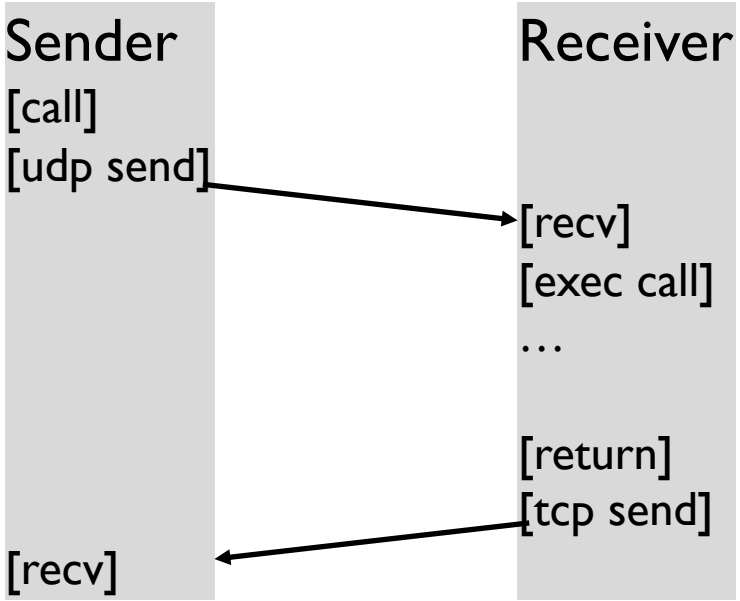
RPC OVER UDP

Strategy: use function return as implicit ACK

Piggybacking technique

What if function takes a long time?

then send a separate ACK



NEXT STEPS

Review for Midterm 3

Last lecture!