Operating Systems CMPSC 473

Concurrency: Channels

November 9, 2023 – Lecture 24

Instructor: Ruslan Nikolaev

Summary

- Previous lectures
  - Data races and race conditions
  - The mutual exclusion approach
  - How to implement locks
  - Pthreads lock API
  - How to use locks
  - Liveness conditions
  - Thread safety
  - Condition variables (+ pthreads API), semaphores
  - Reader-write lock
- Next
  - Channels and Project 3 information
  - Several synchronization problems

Buffered channel

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- Interface:
- Send() – adds message to buffer; if buffer full, block and wait
- Recv() – removes message from buffer; if buffer empty, block and wait

Channels to track resources

```
for (int i = 0; i < num_jobs; i++) {

  thread_create(run_job, &jobs[i]);
}

run_job() {
  ...

}
```

Channels to track resources

```
for (int i = 0; i < num_jobs; i++) {
  channel_send();
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run_job() {
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for (int i = 0; i < num_jobs; i++) {
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}

run_job() {
  ...
  channel_recv();
}
```

Channels to track resources

```
channel_init(# cpu cores);
for (int i = 0; i < num_jobs; i++) {
  channel_send();
  thread_create(run_job, &jobs[i]);
}

run_job() {
  ...
  channel_recv();
}
```

Sharing data using channels

```
average_first_n_results(n) {
  for (int i = 0; i < n; i++) {
    sum += channel_recv();
  }
  return sum / n;
}
run_job() {
  ...
  channel_send(result);
}
```

Channel interface

- channel_create
- channel_send (blocking/non-blocking)
- channel_receive (blocking/non-blocking)
- channel_close
- channel_destroy
- channel_select

Channel assignment

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- Correctly implementing unbuffered version with select is very hard
  - Small amount of extra credit (done individually)
- Tests are not exhaustive – we may release more

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Use pthread_mutex_init

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  (condition variable or semaphore)

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- Buffer is empty → need to wait
  (different condition variable or semaphore)

Question

Q: Suppose you have a variable void* result that you want to return in a parameter void data. What do you do?**

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B. *data = result;

C. **data = result;

D. data = &result;

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A: Yes, they read/modify the buffer → lock needed

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- What if close is called at the same time as send?
  - How do you make things atomic?

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channel_send(chan_t* channel, void* data) {
 if (channel->closed) {
  return CLOSED_ERROR;
 }

 pthread_mutex_lock(&channel->mutex);
 ...
}



channel_close(chan_t* channel) {
 channel->closed = 1;
 return SUCCESS;
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```

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A: Race condition

Q: What about current waiting threads?

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Rule of thumb: destroy = opposite of create

- malloc ←→ free
- buffer_create ←→ buffer_free
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- Q: Why channel_destroy/channel_close separate?
- A: caller ensures no threads using channel in destroy

channel_select(size_t channel_count, select_t* channel_list, size_t* selected_index)

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- If chose receive, then store data in
  channel_list[chosen_index].data

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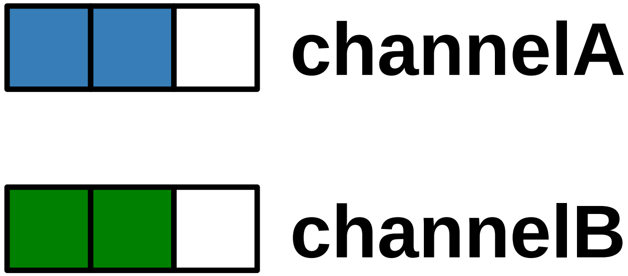
What if:

channelA has data?	**recv from channelA**
channelA empty, channelB not full?	**send on channelB**
channelA empty, channelB full?	**wait**

Select example



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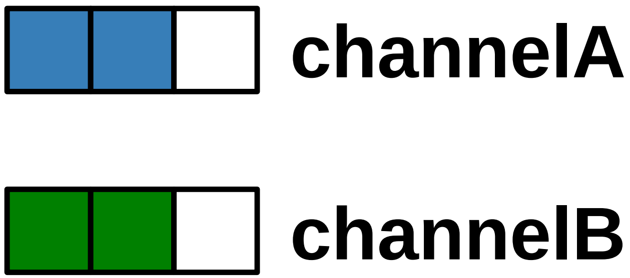

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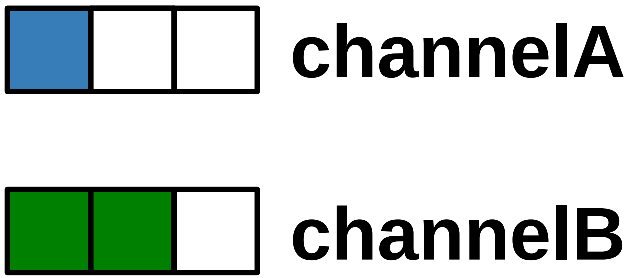

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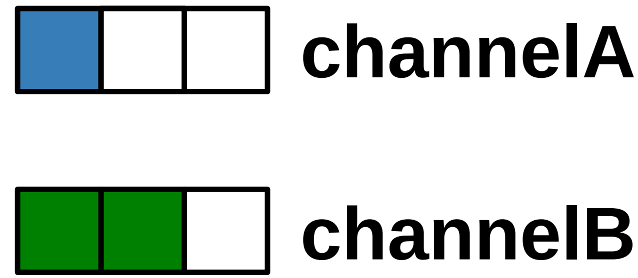
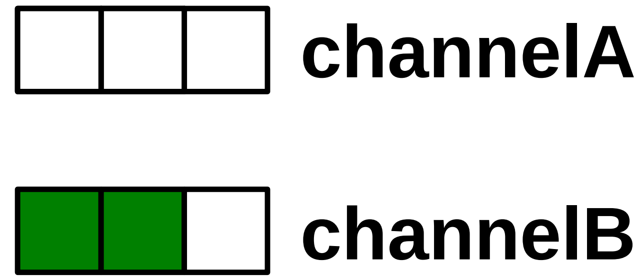


Select example

<u>Thread1</u>

select { recv channelA, send channelB }

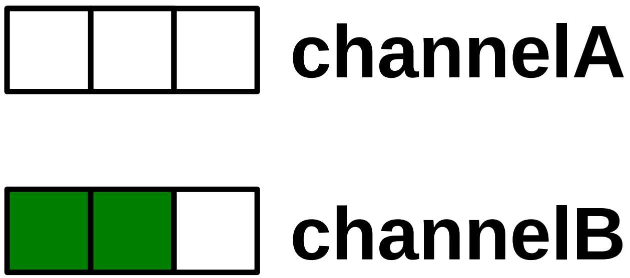
select { recv channelA, send channelB }



Select example

Thread1

select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }



Select example

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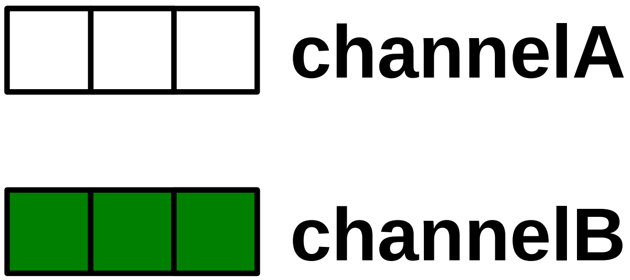

Select example

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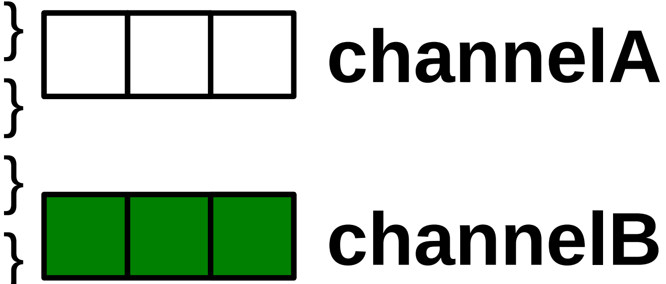
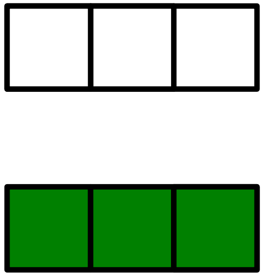


Select example

Thread1

select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }
wait() zZz…



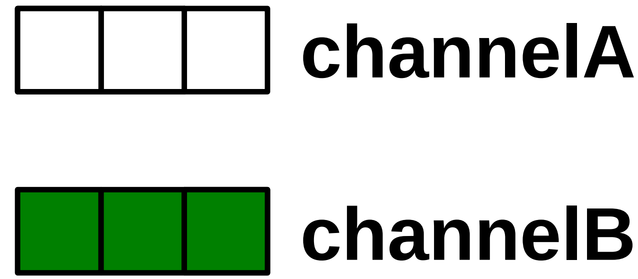
channelA

channelB

Select example

Thread1

select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }
 wait() zZz…



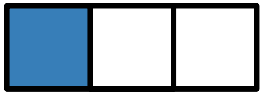
Thread2

send channelA

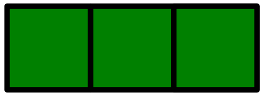
Select example

Thread1

select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }
wait() zZz…



channelA



channelB

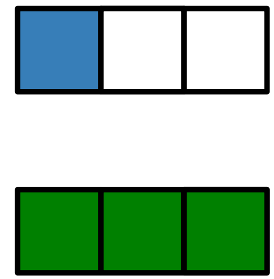
Thread2

send channelA

Select example

Thread1

select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }
wait() zZz…



channelA

channelB

Thread2

send channelA

Select example

<u>Thread1</u>
select { recv channelA, send channelB }
select { recv channelA, send channelB }
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select { recv channelA, send channelB }
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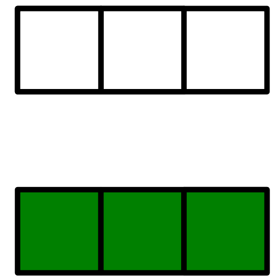

channelA

channelB

<u>Thread2</u>
send channelA

Find work to do → recv channelA

Select example

Thread1

select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }
select { recv channelA, send channelB }
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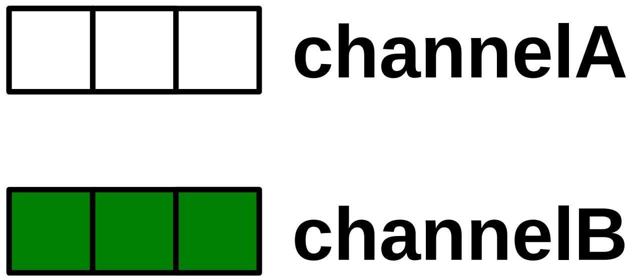

Thread2
send channelA

Find work to do → recv channelA
select { recv channelA, send channelB }

Select example

Thread1

select { recv channelA, send channelB }

select { recv channelA, send channelB }

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select { recv channelA, send channelB }

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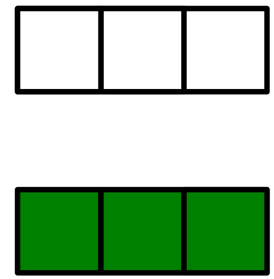

channelA

channelB

Thread2

send channelA

Find work to do → recv channelA

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Select example

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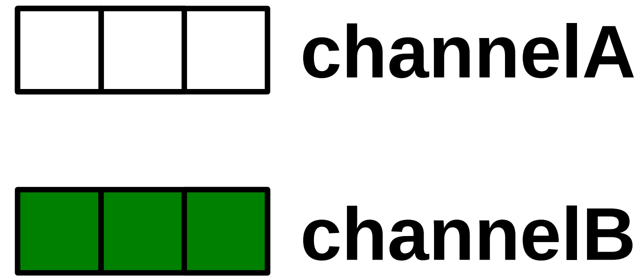

<u>Thread2</u>

send channelA

Find work to do → recv channelA
select { recv channelA, send channelB }
  wait() zZz…

recv channelB

Select example

Thread1

select { recv channelA, send channelB }
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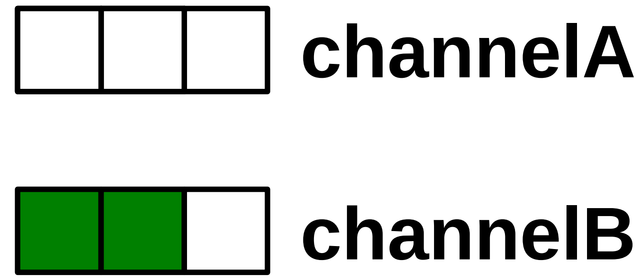

Thread2

send channelA

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recv channelB

Select example

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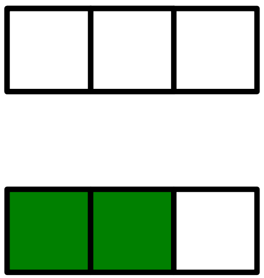

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recv channelB

Select example

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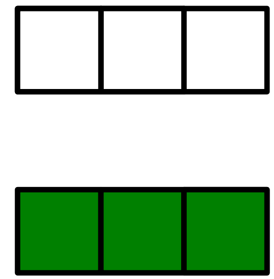

channelA

channelB

Thread2

send channelA

Find work to do → recv channelA
select { recv channelA, send channelB }
wait() zZz…

recv channelB

Find work to do → send channelB

Select challenge

Select challenge

- Key challenge: waiting on multiple channels

Select challenge

- Key challenge: waiting on multiple channels
  - (e.g., either recv channelA <u>OR</u> send channelB)

Select challenge

- Key challenge: waiting on multiple channels
  - (e.g., either recv channelA <u>OR</u> send channelB)
- Q: How to wait?

Select challenge

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- A: Semaphore/condition variable, but can’t wait on multiple

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- A: Within select function as a local variable
- Q: How does the send/receive know about it?
- A: It just needs a pointer
- Q: What about multiple simultaneous select calls…
- A: Think about it

Selected food for thought

Selected food for thought

- Q: Why use a semaphore vs condition variable for signaling?

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- Q: What do you need to do before/after you modify/access channel data?
- Hint: what is the purpose of this assignment?

Multi-threading gdb commands

- info threads – lists all your threads
- thread NUM – switch to thread; see info threads for NUM
- thread apply all CMD – run CMD on all threads
  (e.g., thread apply all backtrace)
- backtrace is your friend – see where threads are stuck
- frame NUM – switch function call; see backtrace for NUM
- info locals – show all local variables in current function
- p VAR – p for printing any variable or parameter VAR
- p EXPR – print any expression EXPR
  (e.g., p channel->closed, p *channel, p *channel_list[1].channel->buffer)
- Ctrl-C – stop executing and break
- attach PID – connect to program with gdb after the fact

Summary

- Today's lecture
  - Channels
    - Model for synchronization via message passing
    - E.g. heavily used in Google's Go programming language and are very useful frameworks for high-level concurrent programming
  - Relevant information for Project 3
    - Challenges with select
  - GDB cheatsheet