9/30 CS240 - Mesa

Announcements

For next class (Thursday 10/2)

1. Read:
   Cooperative Task Management without Manual Stack Management **Only §1–3**
   Why Threads Are a Bad Idea (for most purposes)
   Why Events Are a Bad Idea (for high-concurrency servers)
2. No reading questions

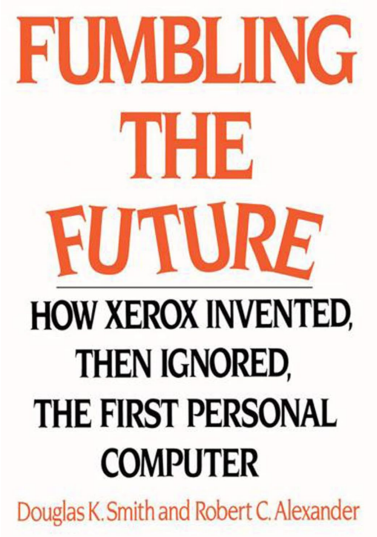
Slides available on website Schedule for the day

When saying something in class, please state your first name the first time you say something.

Paper Background

- Xerox PARC utopia in the 1970s
  - Workstations, Ethernet, laser printers, …
  - Custom hardware, software stack, new language & OS
  - Turing Awards

5.88Mhz CPU Microcoded
100KB RAM
2.5 MB Disk



Paper Overview

- Academic research meets real world needs
    - Semaphores - Edsger Dijkstra 1960s P(sema)/V(sema)
    - Monitors - Per Brinch Hansen and C. A. R. Hoare 1970s
- Why monitors?
- Experience paper - Proof?

What are the races? What bad things could happen?

```
struct BoundedStackWithRace {

    var items: array[0..N-1] of T
    var top: int := 0                // number of elements currently in stack

    procedure push(x: T)
        if top == N do
            return with Error("Stack is full")
        items[top] := x
        top := top + 1

    procedure pop(): T
        if top == 0 do
            return with Error("Stack is empty")
        top := top - 1
        x := items[top]
        return x
}
```

Example of early Unix critical section

```
struct buf *getblk(dev_t dev) {
    struct buf *bp;

    /* enter critical section */
    spl6();           // raise interrupt priority to block disk interrupts

    while ( (bp = bfreelist.av_forw) == NULL ) {
        /* no free buffer, sleep */
        sleep(&bfreelist, PRIBIO);
        spl6();       // re-raise level after sleep
    }

    /* remove from free list */
    bfreelist.av_forw = bp->av_forw;
    bp->b_flags |= B_BUSY;

    /* exit critical section */
    spl0();           // restore interrupts

    return bp;
}
```

What are the monitor invariants?

```
monitor BoundedStack {

    var items: array[0..N-1] of T
    var top: int := 0                // number of elements currently in stack

    procedure push(x: T)
        if top == N do
            return with Error("Stack is full")
        items[top] := x
        top := top + 1

    procedure pop(): T
        if top == 0 do
            return with Error("Stack is empty")
        top := top - 1
        x := items[top]
        return x
}
```

Add waiting - Why doesn't this work?

```
monitor BoundedStack {

    var items: array[0..N-1] of T
    var top: int := 0                  // number of elements currently in stack

    procedure push(x: T)
        while top == N do              // wait until someone pops
            sleep(1)
        items[top] := x
        top := top + 1

    procedure pop(): T
        while top == 0 do               // wait until someone pushes
            sleep(1)
        top := top - 1
        x := items[top]
        return x
}
```

Add condition variables

```
monitor BoundedStack {
    var items: array[0..N-1] of T
    var top: int := 0                // number of elements currently in stack
    condition notFull, notEmpty

    procedure push(x: T)
        while top == N do
            wait(notFull)            // wait until someone pops
        items[top] := x
        top := top + 1
        signal(notEmpty)

    procedure pop(): T
        while top == 0 do
            wait(notEmpty)           // wait until someone pushes
        top := top - 1
        x := items[top]
        signal(notFull)
        return x
}
```

Should we make signal() conditional?

Hoare monitors

```
monitor BoundedStack {
    var items: array[0..N-1] of T
    var top: int := 0                // number of elements currently in stack
    condition notFull, notEmpty

    procedure push(x: T)
        if top == N do
            wait(notFull)            // wait until someone pops
        items[top] := x
        top := top + 1
        signal(notEmpty)

    procedure pop(): T
        if top == 0 do
            wait(notEmpty)           // wait until someone pushes
        top := top - 1
        x := items[top]
        signal(notFull)
        return x
}
```

LockSets and monitors

If you ran the Eraser lockset algorithm on a program written in Mesa, would it be possible for a lockSet to ever have more than one lock in it?

Would Eraser be able to detect a race condition in a Mesa program?

Nested Monitors

- What is the problem with nested monitors? What choices are there?
- Interaction with software engineering
- Deadlock

Monitor routine types

- Entry
- Internal
- External

Describe each type.

Would it make sense to call from one type to another?

Monitors efficiency - Should we make signal() conditional?

```
monitor BoundedStack {
    var items: array[0..N-1] of T
    var top: int := 0                // number of elements currently in stack
    condition notFull, notEmpty

    procedure push(x: T)
        while top == N do
            wait(notFull)            // wait until someone pops
        items[top] := x
        top := top + 1
        signal(notEmpty)

    procedure pop(): T
        while top == 0 do
            wait(notEmpty)           // wait until someone pushes
        top := top - 1
        x := items[top]
        signal(notFull)
        return x
}
```

Exceptions

What do these keyword do:

- RETURN WITH ERROR[(arguments)]
- UNWIND

What happens for you forget an UNWIND handler on an entry routine?

Weird stack

Machine microcode support

Execution Speed

Construct	*Time (ticks)*
simple instruction	1
call + return	30
monitor call + return	50
process switch	60
WAIT	15
NOTIFY, no one waiting	4
NOTIFY, process waiting	9
FORK+JOIN	1,100

ProcessState queues

Ready queue

Monitor lock queue

Condition variable queue

Fault queue

Naked Notify

Purpose

Monitor records

Priorities

Reading questions

1. Explain from the Mesa paper: "[…] while any procedure suitable for forking can also be called sequentially, the converse is not generally true."
2. Consider the memory allocation code in the Mesa paper.
    1. The paper states this code has a bug. What is it and what is the fix?
    2. Intuitively, how would you change this code to work with Hoare wakeup semantics?
    3. What happens if we make *Expand* an *Entry* routine?
    4. What happens if we make the WAIT call just put the current thread at the end of the run queue?
    5. Give the main monitor invariant for this code.

ChatGPT discussion suggestion

Historical & Conceptual Context

- **Why Mesa?**
  What problems at Xerox PARC were they solving with Mesa (systems programming in a high-level language)?
- **Comparison to contemporaries**: Unix, monitors in Hoare's original work, concurrent Pascal.
- **Hardware/software co-design**: How the Alto influenced Mesa's design.

Monitors as a Synchronization Primitive

- **The "monitor" abstraction**: what problem it solves compared to semaphores.
- **Mesa flavor** vs. Hoare's original:
  - *Mesa*: signaling process doesn't transfer CPU immediately.
  - *Hoare*: waiter runs immediately.
- **Implications for reasoning about correctness**.
  (E.g., Mesa requires re-checking predicates after WAIT).

Condition Variables & Signaling Semantics

- **WAIT and NOTIFY mechanics**:
  Why Mesa treats condition variables as queues, and why signals are *hints*.
- **Lost wakeup problem**: How Mesa handles it, and how it differs from Hoare monitors.
- **Device interaction**: naked NOTIFY → race with external devices, solution via binary-semaphore switch.
- **Design tradeoffs**: Performance vs. programmer reasoning complexity.

ChatGPT suggestions page 2

Implementation Issues

- **Mesa stack allocated from the heap**: why, and what flexibility this enabled (activation records, coroutines, etc.).
- **Register model**: impact of Alto's architecture (e.g., lack of hardware support for concurrency).
- **Compiler support**: how much the language vs. runtime system enforces monitor discipline.

Practical Experience & Pitfalls

- **Static vs. dynamic shared data**: early monitors assumed static globals; Mesa shows the importance of dynamically allocated monitored objects.
- **Granularity of locks**: too big (low concurrency) vs. too fine (complexity).
  Deadlocks: programmer responsibility in Mesa—was this acceptable?

Lessons for Later Systems

- **Legacy in modern systems**:
  - Monitors in Java, C#, and OS kernels.
  - Condition variables in pthreads (more like Mesa than Hoare).
- **Did Mesa's design "win"?**
  Why do most modern languages adopt Mesa semantics, despite the harder reasoning burden?
- **How this connects to later OS research**: Eraser (race detection), exokernels, virtualization.

Open-ended Discussion Prompts

- are the tradeoffs between language-level enforcement (Mesa) vs. library-level abstractions (e.g., pthreads)?
- Should signaling semantics prioritize ease of reasoning (Hoare) or efficiency/practicality (Mesa)?
- Would Mesa's approach still be relevant if hardware had provided stronger synchronization primitives?
- How might Mesa monitors change if designed in today's multicore environment?