Threads and Concurrency

ECE 373

Threads of Execution

- Thread – smallest unit of processing that can be scheduled by the OS
  - UNIX-like systems are process oriented
  - WinNT-like systems are thread oriented

- Single CPU core
  - single line of instructions at any one time

- Multiple CPU cores
  - multiple simultaneous threads of execution

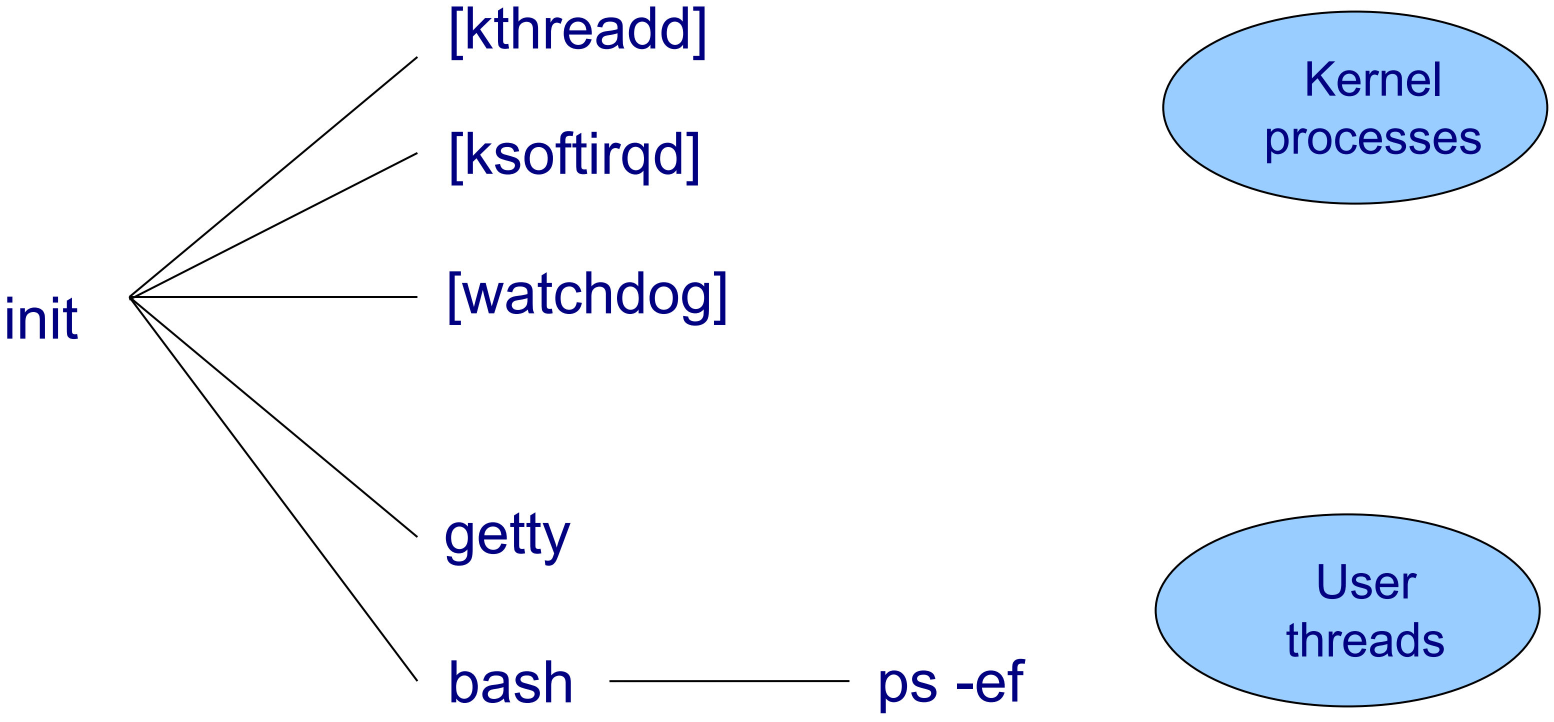
Thread Sources

- Kernel threads
- User processes
- Workqueue threads
- Timer callbacks
- Interrupt handlers

Threads

- Kernel threads
  - Jobs the kernel itself is doing for internal [projects]
  - All have access to the same kernel data
- User context
  - Threads running user jobs, might be running kernel code to service system calls from user code
  - Collected into specific user processes, see only the individual process space data
- Interrupts
  - Not really full threads, but in the mix (unless threaded interrupts…)
- See ps -ef

Linux process tree



init

[kthreadd]

[ksoftirqd]

[watchdog]

getty

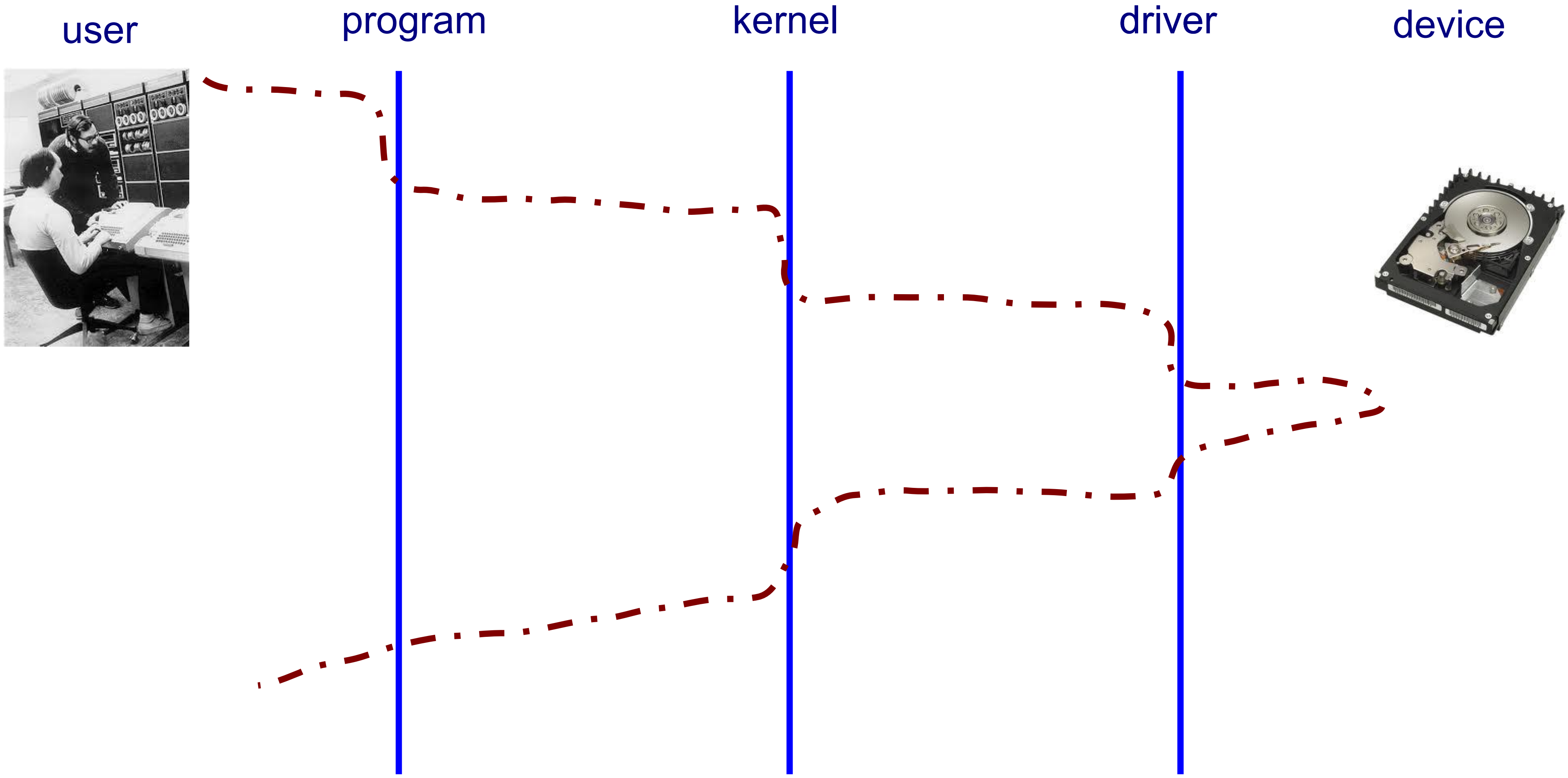
bash

ps -ef

Kernel processes

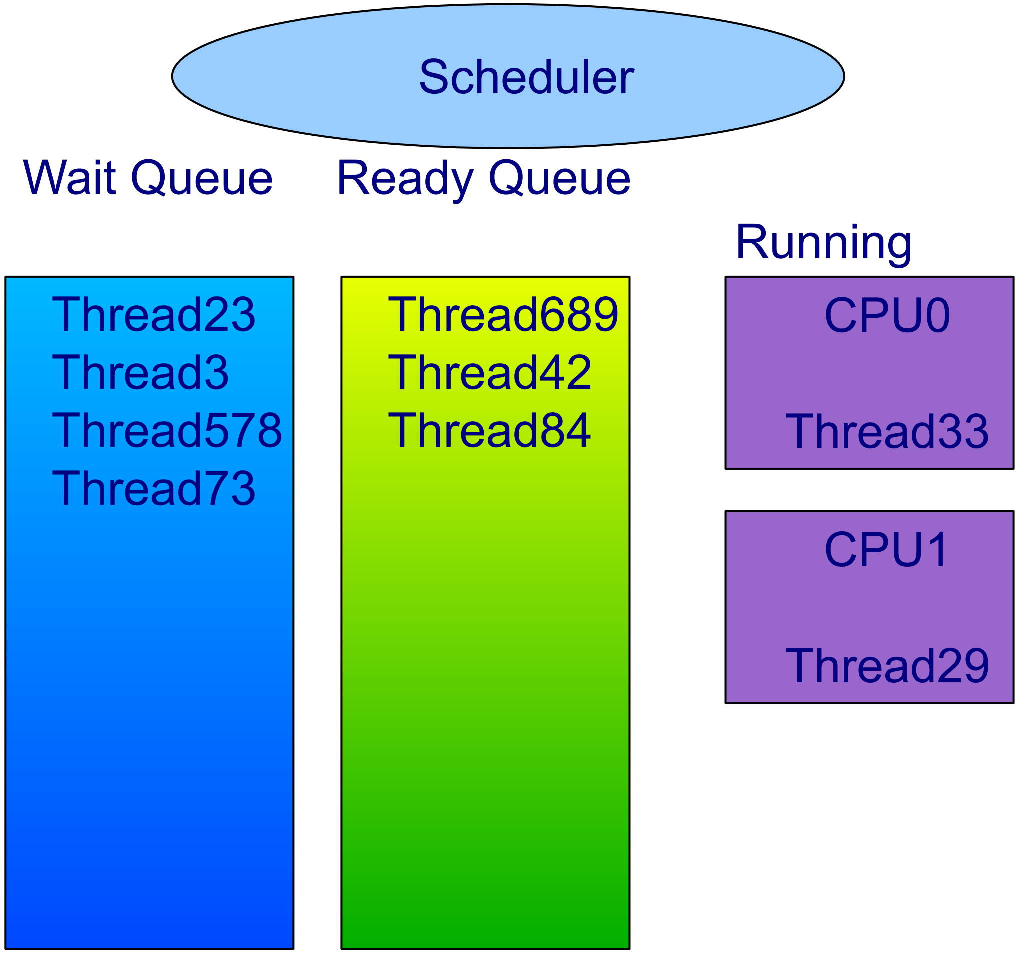
User threads

Thread simple



OS Scheduler

- Chooses which to process/thread to run next on which CPU
  - Ready queue
  - Wait queue
  - Thread priority
  - Time slice
  - Preemption
  - CPU core affinity
  - Etc



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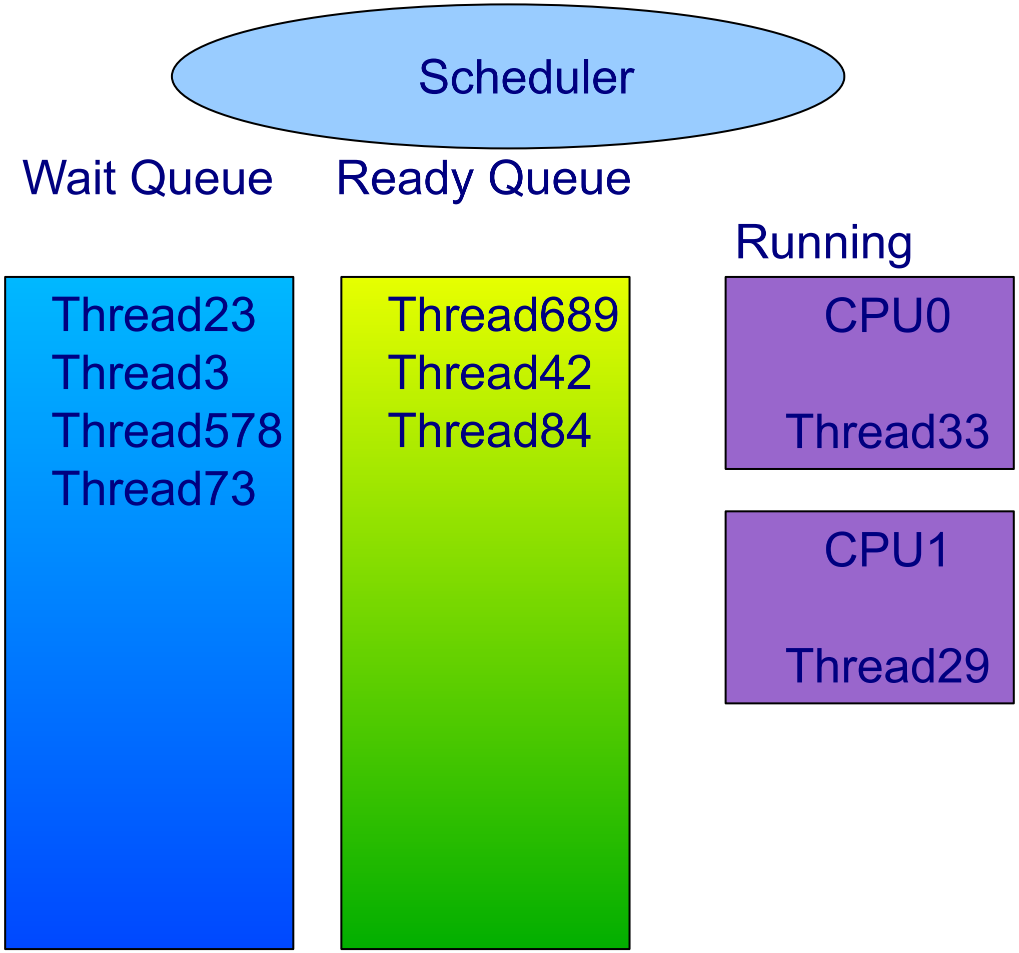
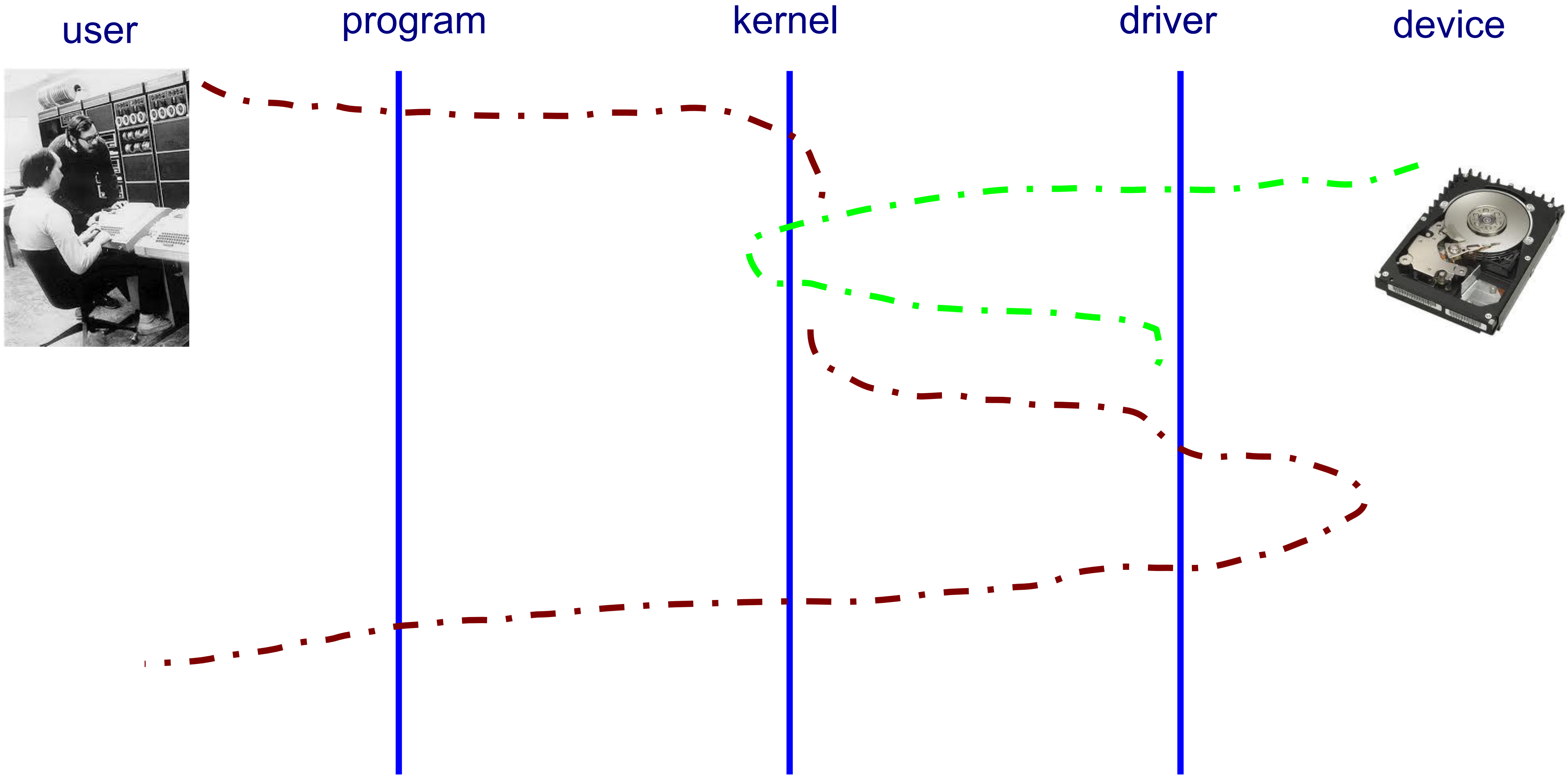


- Interrupts mess with scheduler plans

Thread, interrupted



user

program

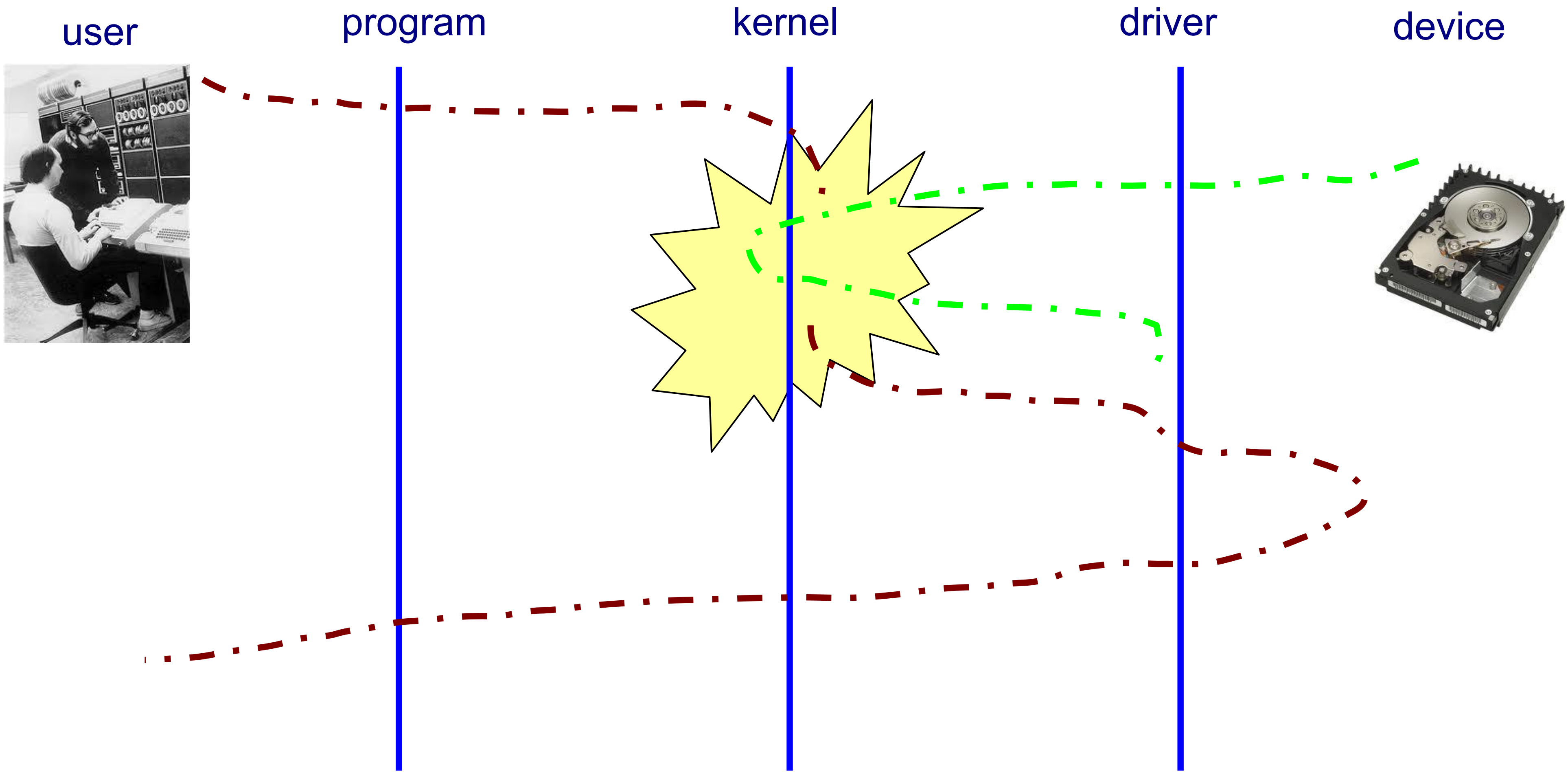
kernel

driver

device

Concurrency and conflict

- Multiple threads could hit data at same time



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Concurrency and conflict

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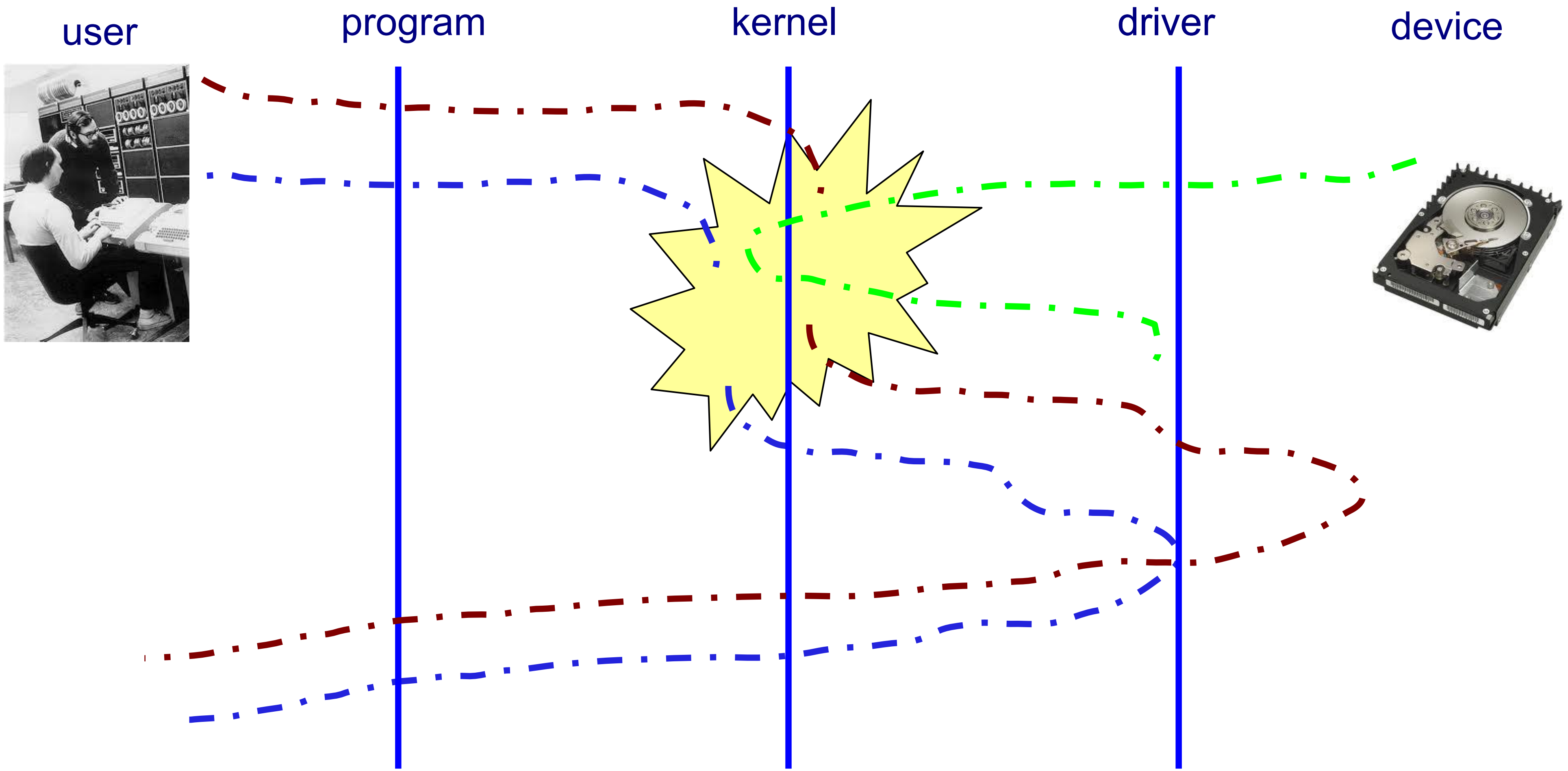

Example: conflict

- User thread 1 asks for data
  - Driver requests data from HW, sleeps while waiting
- User thread 2 removes device
  - Driver removes data structures
- HW interrupt to finish data retrieval
  - Driver interrupt handler tries to access removed data struct
  - Uh oh...

Order matters

Instance 1	Instance 2	Value
read very_important_count		5
add 5 + 1 = 6		6
write very_important_count		6
	read very_important_count	6
	add 6 + 1 = 7	7
	write very_important_count	7

Order matters

Instance 1	Instance 2	Value
read very_important_count		5
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Order matters

Instance 1	Instance 2	Value
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	`read very_important_count`	6
	`Add 6 + 1 = 7`	7
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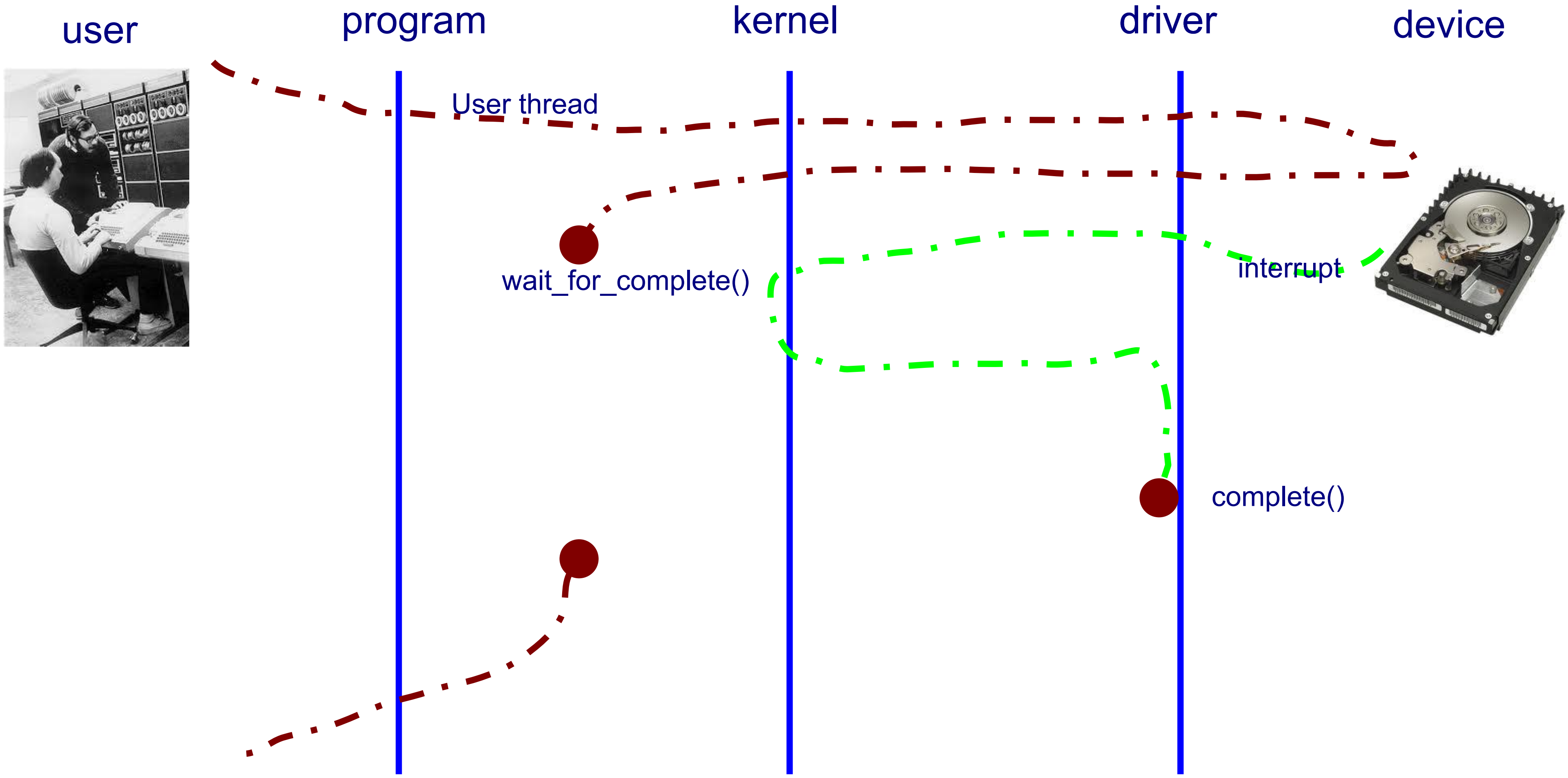
Instance 1	Instance 2	Value
`read very_important_count`		5
	`read very_important_count`	5
`add 5 + 1 = 6`		6
	`Add 5 + 1 = 6`	6
`write very_important_count`		6
	`write very_important_count`	6

Coordination needed

- Multiple threads could hit data at same time

- Tools:
  - Completions
  - Semaphore
  - Atomic action – increment, decrement
  - Mutex
  - Spin lock
  - RCU

Waiting for the completion



Atomic action

- CPU instructions for atomic increment, decrement, test_and_set
  - https://elixir.bootlin.com/linux/latest/source/arch/x86/include/asm/atomic.h#L95
- All cores must coordinate CPU cache – expensive

```
atomic_inc(x)
atomic_inc_and_test(x)
set_bit(n, *s)
clear_bit(n, *s)
test_bit(n, *s)
```

```
static inline void atomic_inc(atomic_t *v)
{
        asm volatile(LOCK_PREFIX "incl %0"
                        : "+m" (v->counter));
}
```

Semaphore

Semaphore

- Counter that many threads can inc/dec
  - Usually starts positive, each user decrements to start, inc when done
  - If zero, next process must wait
- Thread A might start operation, sleep, then thread B might finish
- Use atomic inc/dec to implement counter

```
struct semaphore sem;
sema_init(&sem, val);
down(&sem);
up(&sem);
```

Spinlock

Spinlock

- While not have lock, try again
  - Tight spin
  - Unlimited spin can "hang" thread, block other operations

```
while (test_and_set(3, &bit_string))
      /* tight loop */ ;
```

- Alternative is a sleep spin
  - Less CPU intense...
  - ... but might miss a window of opportunity

```
while (test_and_set(3, &bit_string))
       usleep(2);
```

- Linux:

```
spinlock_t slock;
spin_lock_init(&slock);
spin_lock(&slock);
spin_unlock(&slock);
spin_trylock(&slock);
```

Mutex

Mutex

- Mutual Exclusion
  - Everyone waits until the thread is done
  - Thread A gets lock, only thread A can release it
- Other threads will sleep while waiting for lock
- Good for blocking access to data, other resource
- Like spinlock, but more restrictive
- Linux:

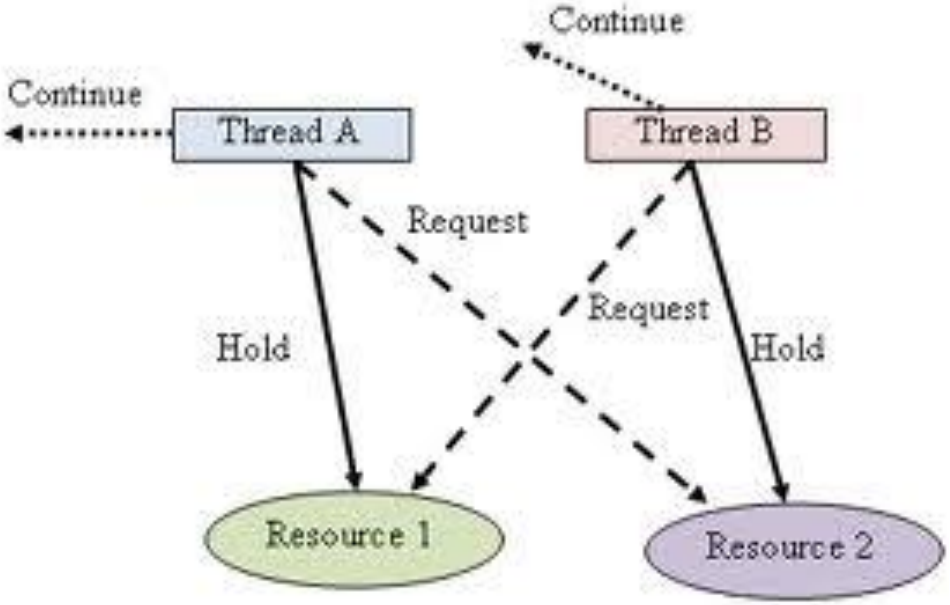
```
struct mutex mlock;
mutex_init(&mlock);
mutex_lock(&mlock);
mutex_unlock(&mlock);
```

Deadlock

Deadlock

- Deadlock possible with multiple locks
  - Process A gets lock 1, wants lock 2
  - Process B gets lock 2, wants lock 1

- Now what?
  - Linux does some checking



Watch out

- Blocking processes
  - Slowing other threads, whole system
  - Priority inversion – low prio thread holds lock, high prio thread can't continue
- Granularity
  - Lock smallest amount of code possible
- Balancing lock/unlock
- CPU communication overhead
- Hard to debug because of timing related

Reading

- LDD3 – Chapter 5: Concurrency
- LDD3 – Chapter 10: Interrupts
- ELDD – Chapter 2: Concurrency, pgs 39-48
- ELDD – Chapter 3: Kernel Facilities
- ELDD – Chapter 4: Interrupt Handling, pgs 92-103
- Linux src – ../Documentation/atomic_ops.txt