Why Linux is not an RTOS:
porting hints

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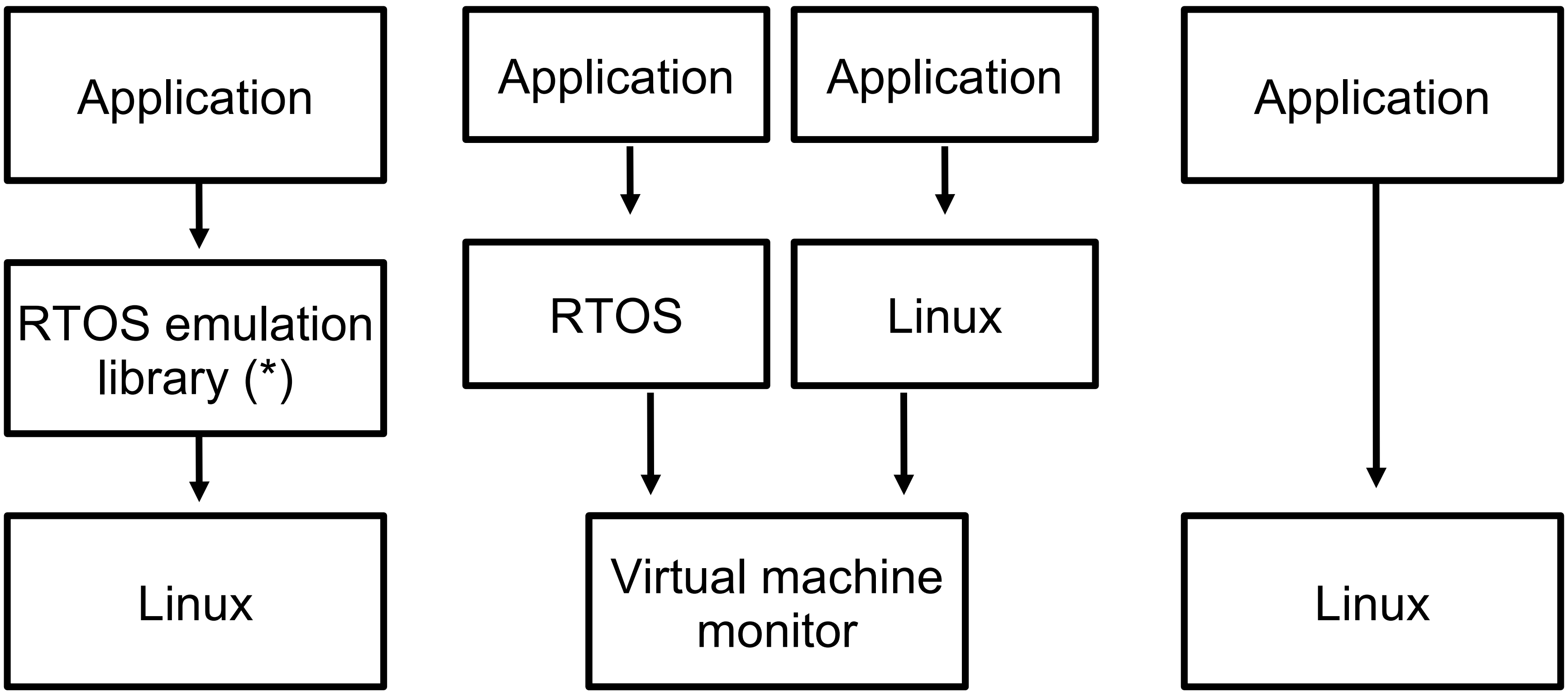
Overview

- Linux is a popular choice as an embedded OS
- Most projects evolve from previous projects often based on an RTOS
- How to get from point A (RTOS) to point B (Linux)?
    - Is Linux an RTOS??

Porting options



(*) for example v2lin [1]
or Mapusoft

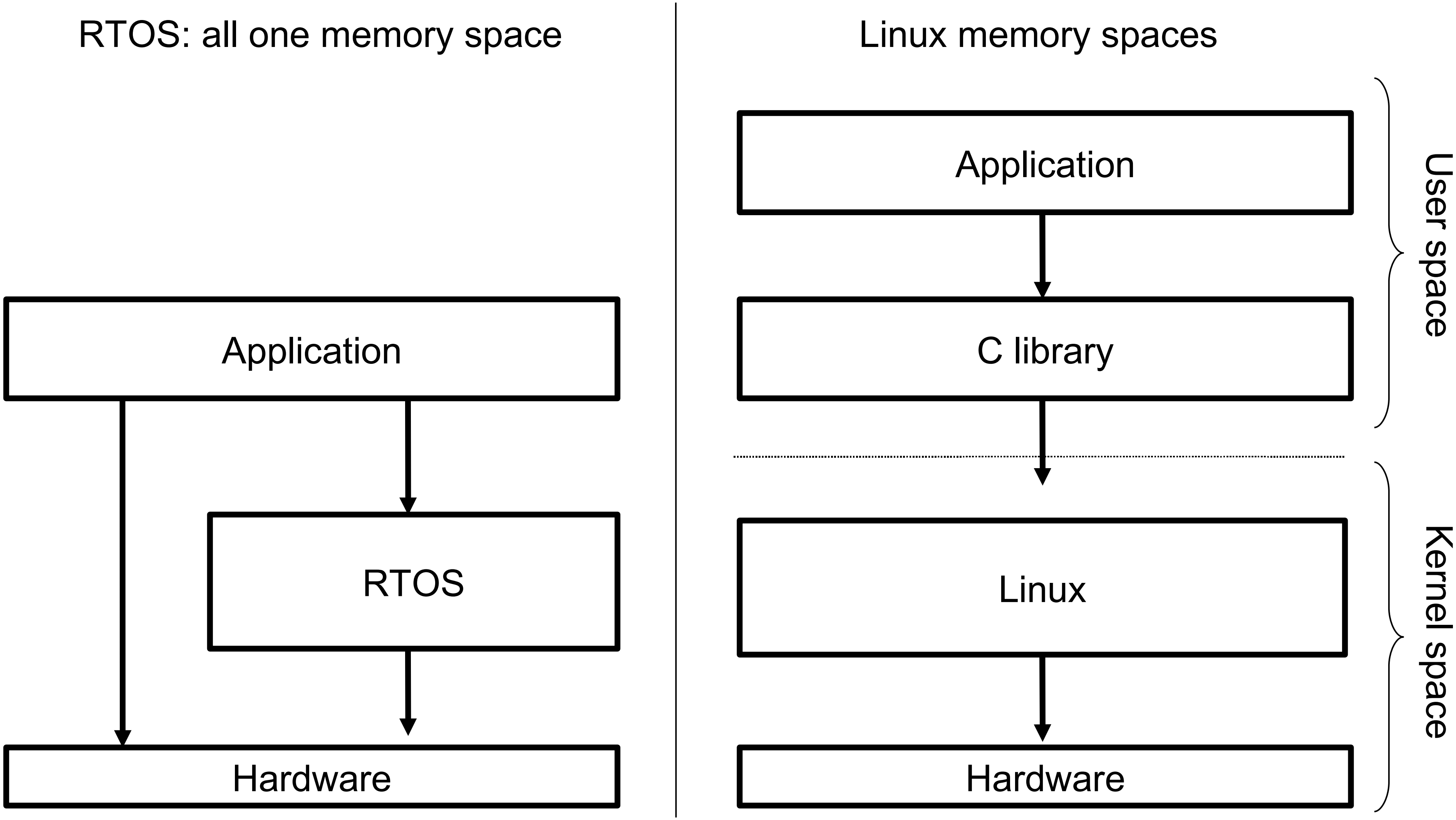
The porting dilemma

- How much existing code can I keep?
- How much effort is required to port my application to Linux?
- What should I look out for?
- What are the gains?

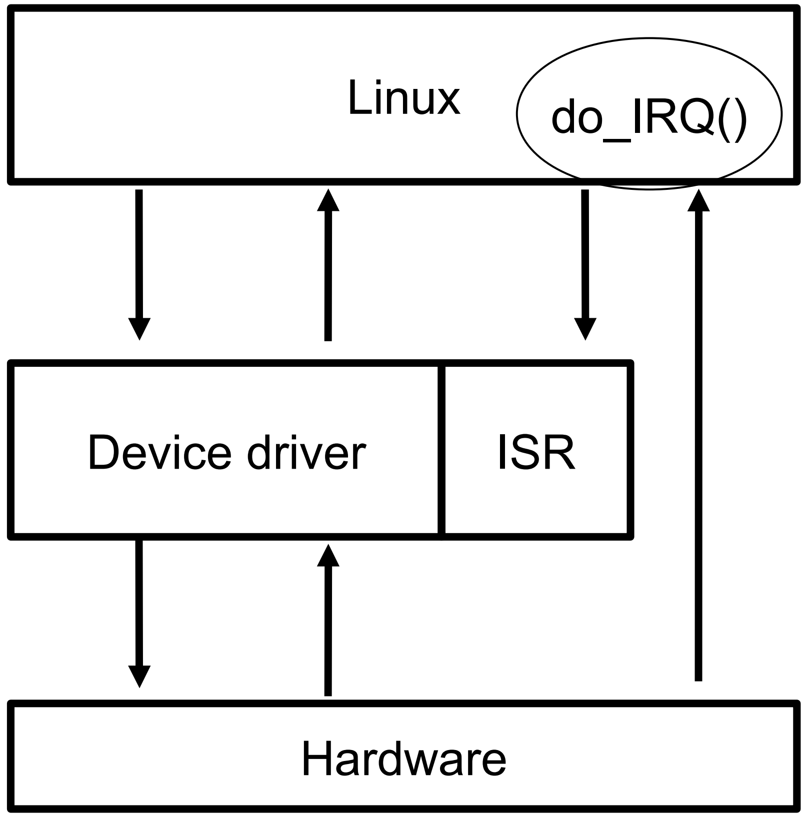
Why Linux is not an RTOS

- Applications run in “user space”
- All hardware interaction is in “kernel space”
- All i/o via files and sockets
- Applications are processes
- Default scheduling policy is time shared
- POSIX API
- Is Linux real-time?

Different memory models



Device drivers



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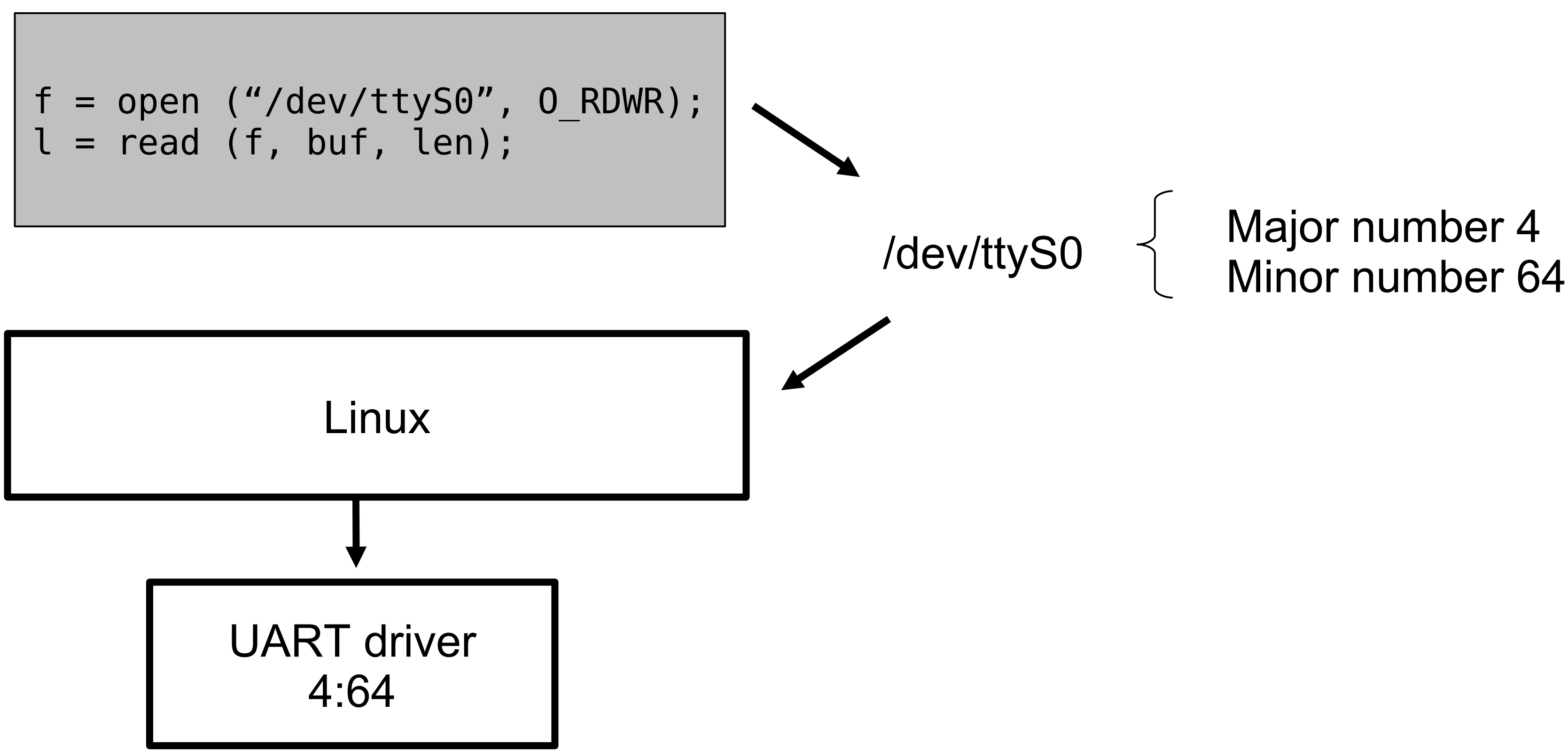
Everything is a file

For example, to read characters from first serial port, open device node (file) /dev/ttyS0



My device doesn't look like a file!

- File read & write operations work well with byte streams - such as a serial port
- How about a robot arm?
- The ioctl function allows any interaction you want

```
struct robot_control_block rc;

f = open (“/dev/robot”, O_RDWR);
...
ioctl (f, SET_ROBOT_PARAMTERS, &rc);
...
```

Hint 1

- Identify all code that accesses hardware directly
- Design a file-based interface
  - Use ioctl for things that do not naturally fit the file concept
- Make this into a device driver
- Remember: keep device drivers as simple as possible
  - All the complicated stuff should be in the application

Cheating: user space drivers

- mmap allows an application direct access to device memory
  - But, cannot handle interrupts
  - No control of CPU cache or instruction queue
  - Not the "Linux way"
- The Linux User IO subsystem uses mmap to provide a flexible framework for user space drivers
  - UIO [2]

mmap example

```
#include <sys/mman.h>

#define IO_PHYS_ADDRESS  0x90600000
#define ARM_POS 0x0034
#define ARM_MOTION 0x0038

int main (int argc, char *argv[])
{
    unsigned led_dat;
    int mh;
    char *ptr;

    mh = open ("/dev/mem", O_RDWR);
    ptr = mmap (0, 0x1000, PROT_READ | PROT_WRITE, MAP_SHARED,
                mh, IO_PHYS_ADDRESS);
    ...
    *(unsigned int*)(ptr + ARM_POS) = new_pos;
    while (*(unsigned int*)(ptr + ARM_MOTION) != 0)
        sleep (1);
    ...
```

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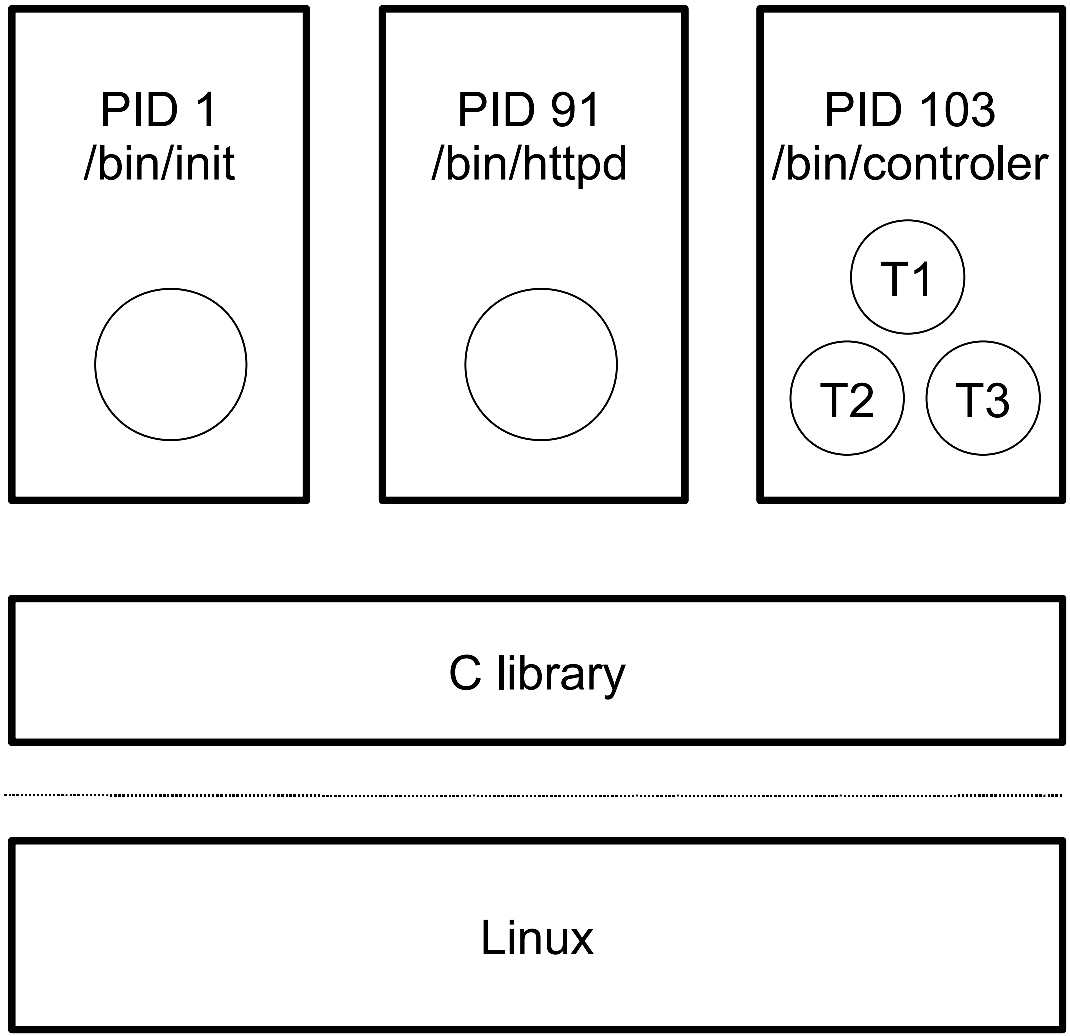
Processes



Process =
address space
+
program
+
thread of execution

Some process have
> 1 thread

Pros and cons of processes

- Pro
  - Protected memory space
  - Resources (memory, open files) released when exit
  - Easy to re-start a failed process
- Con
  - Communication between processes quite slow & cumbersome

Pros and cons of threads

- Pro
  - Easy communication using shared variables, mutexes and condition variables
  - Similar memory model to RTOS tasks
- Con
  - No memory protection between threads in the same process

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Scheduling policies

- SCHED_OTHER
  - Time share: fairness. Priority set by scheduler
- SCHED_FIFO
  - Fixed priority (1 to 99); preempts SCHED_OTHER
  - Use this for real-time activities
- SCHED_RR
  - As SCHED_FIFO but tasks of same priority time-slice
  - Default quantum is 100 ms

Hint 2

- Make closely-coupled groups of RTOS tasks into POSIX threads within a process
- Separate RTOS tasks with little interaction into separate processes
- Make real time threads SCHED_FIFO
  - Use Rate Monotonic Analysis or similar to choose priorities [3]
- All non real-time threads should be SCHED_OTHER

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POSIX

- POrtable Operating System Interface
  - IEEE standard 1003.1
- Most RTOS functions map to POSIX one-to-one
  - Tasks to POSIX threads
  - Semaphores and mutexes to POSIX semaphores, mutexes and condition variables
  - Message queues to POSIX message queues
  - Watchdog timers to POSIX clocks and timers

Look out for

- POSIX Threads
  - Threads run immediately they are created
  - Not possible to terminate an arbitrary thread
- POSIX semaphores and mutexes
  - POSIX has many types of mutex, including priority inheritance. See [4]
  - POSIX does have semaphores but they are not much used. See [5] for a discussion on mutexes vs semaphores

Library and kernel versions

- For full POSIX compliance in Linux you need current versions of Linux and the C library
  - Kernel >= 2.6.22
  - GNU C library >= 2.5
- Beware uClibc [6]
  - Small, “embeddable” C library
  - Good for small systems with <= 16MiB storage
  - BUT, lacks many POSIX functions

Hint 3

- You are going to have to re-write some code
- Where possible, re-factor code around shared data
  - Write accessor functions to hide data structure from rest of the program
  - Protect against concurrent access using a mutex
  - In the literature this is called a *monitor* [7] - makes future maintenance and porting much easier

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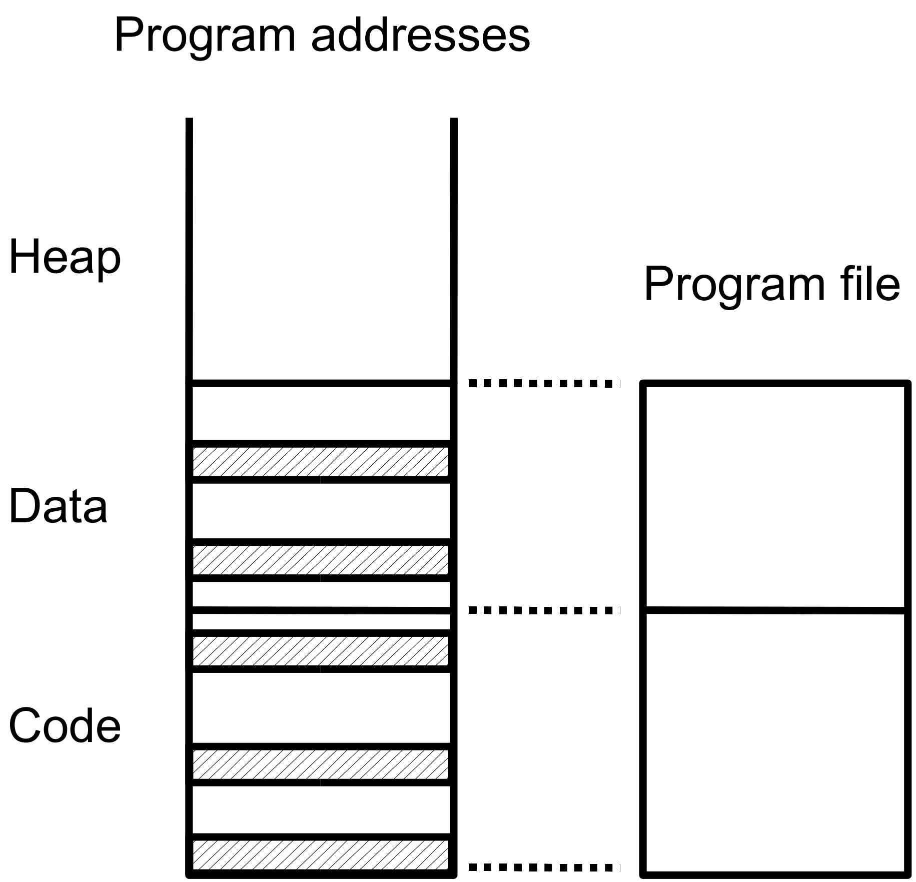
Is Linux real time?

- ✓ Deterministic scheduler
- ✓ Static priorities (SCHED_FIFO)
- ✓ Priority inheritance mutexes
- ✓ Lockable memory - stops demand paging
- ✓ High resolution timers
- ? Deterministic interrupt response

Demand paging

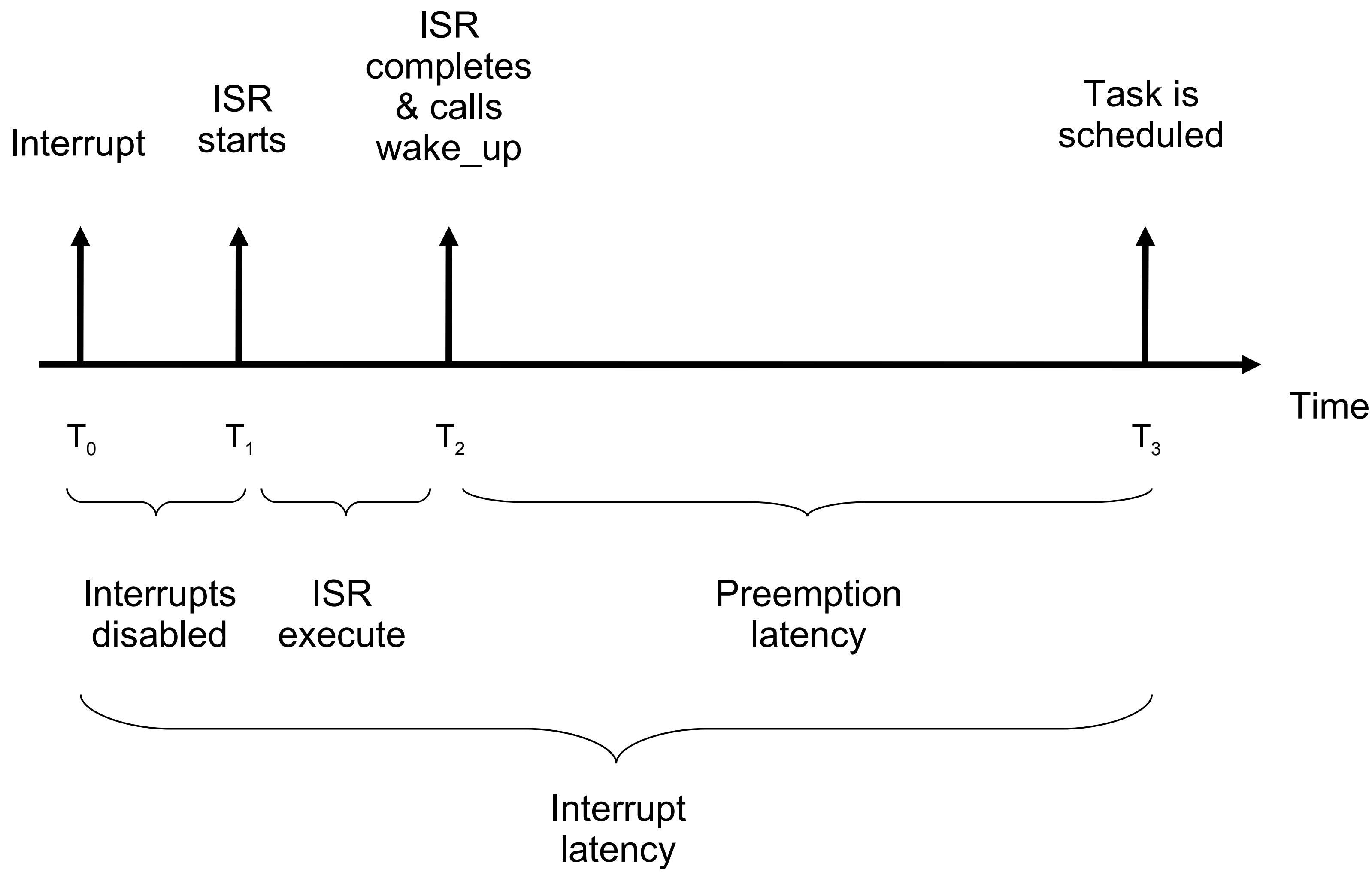


- Pages of code and data are read from the program file on demand 4KiB at a time
- Causes jitter in real-time programs

Hint:
You can page in and lock all memory using

```
mlockall (MCL_FUTURE);
```

Interrupt latency



Kernel preemption options

- Default - no preemption in kernel mode
  - Good for throughput, bad for real-time
- Preemptible kernel
  - Reduces jitter in preemption latency
  - Good for soft real-time
- PREEMPT_RT [8]
  - Reduces jitter in all three areas
  - Good for “firm” real-time
  - Not in the main line kernel yet

Hint 4

- In a real-time system, work out what deadlines you have and how much jitter you can accept
- Lock memory in any process with real-time threads with mlockall
- For soft real-time with jitter ~ millisecond enable kernel preemption
- For “firm” real-time with jitter ~ 10's or 100's microseconds use the PREEMPT_RT patch

Summary

- Porting to Linux will require some code refactoring
  - Hardware requires device drivers
  - Tasks become threads in one or more processes
  - Map RTOS functions onto POSIX
  - Select real time model
- Is Linux an RTOS?
  - No: it is a complete operating system!

References

[1] v2lin - VxWorks API for Linux
http://v2lin.sourceforge.net/

[2] UIO: user-space drivers
http://lwn.net/Articles/232575

[3] Rate-monotonic scheduling
http://en.wikipedia.org/wiki/Rate-monotonic_scheduling

[4] Mutex mutandis: understanding mutex types and attributes
http://www.embedded-linux.co.uk/tutorial/mutex_mutandis

[5] Mutex vs. Semaphores
http://www.feabhas.com/blog/labels/Semaphore.html

[6] uClibc: A C library for embedded Linux
http://www.uclibc.org/

[7] Monitor (synchronization)
http://en.wikipedia.org/wiki/Monitor_(synchronization)

[8] The PREEMPT_RT real time patch series
http://www.kernel.org/pub/linux/kernel/projects/rt/