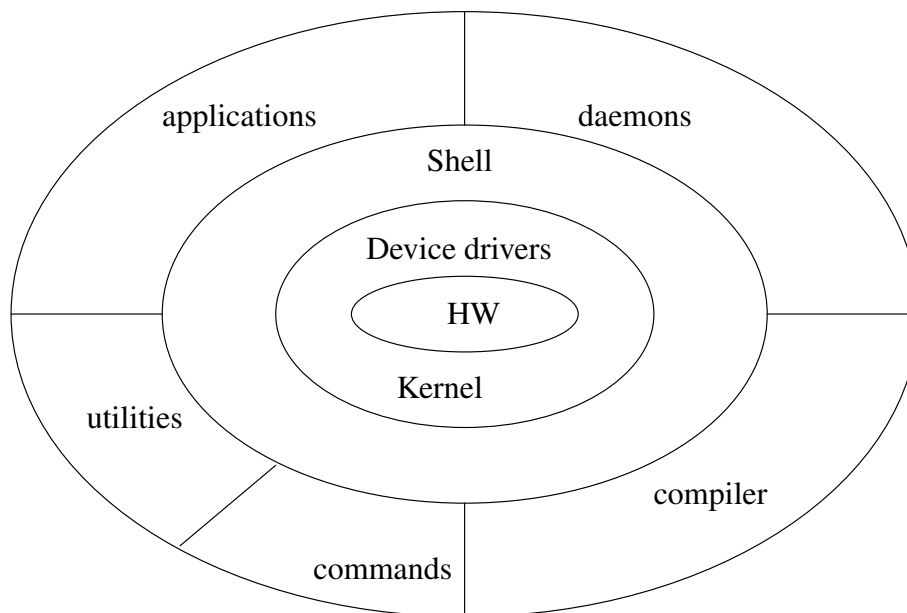


Interrupt handling and context switching

- these two topics are separate and we will examine them in turn

Interrupts



- the user programs and hardware communicates with the kernel through interrupts

Four different kinds of interrupts

- device interrupt, such as a hardware timer, for example the 8253 counter0 reaching 0 on an IBM-PC
- user code issuing a software interrupt, often called a **system call**
- an illegal instruction (divide by zero, or an opcode which the processor does not recognise)
- or a memory management fault interrupt (occurs when code attempts to read from non existent memory)

First level interrupt handler

- the kernel must detect which kind of interrupt has occurred and call the appropriate routine
 - this code is often termed the **first level interrupt handler**

- the pseudo code for the FLIH follows:

First level interrupt handler

```
save program registers and disable interrupts
k = get_interrupt_kind ();
if (k == source 1) service_source1 ();
else if (k == source 2) service_source2 ();
else if (k == source 3) service_source3 ();
else if (k == source 4) service_source4 ();
else if (k == source 5) service_source5 ();
    etc
restore program registers and enable interrupts
return
```

- you may find the hardware on the microprocessor performs the save and restore program registers and disabling/enabling interrupts
 - possibly by one instruction


First level interrupt handler

- you might also find the hardware enables you to determine the source of the interrupt easily
 - most microprocessors have an interrupt vector table
 - typically one vector per source is implemented
- equally, however the code can be ugly as it depends upon the hardware specifications

Example of FLIH in GNU LuK

- GNU LuK (Lean uKernel) is a very small microkernel which allows preemptive processes, interrupt driven devices and semaphores

Example of FLIH in GNU LuK



```
IsrTemplate[ 0] := 0FCH ;    (* cld (disable interrupts) *)
IsrTemplate[ 1] := 050H ;    (* push eax *)
IsrTemplate[ 2] := 051H ;    (* push ecx *)
IsrTemplate[ 3] := 052H ;    (* push edx *)
IsrTemplate[ 4] := 01EH ;    (* push ds *)
IsrTemplate[ 5] := 006H ;    (* push es *)
IsrTemplate[ 6] := 00FH ;    (* push fs *)
IsrTemplate[ 7] := 0A0H ;
IsrTemplate[ 8] := 0B8H ;    (* movl 0x00000010, %eax *)
IsrTemplate[ 9] := 010H ;
IsrTemplate[10] := 000H ;
IsrTemplate[11] := 000H ;
IsrTemplate[12] := 000H ;
IsrTemplate[13] := 08EH ;    (* mov  ax, ds *)
IsrTemplate[14] := 0D8H ;
IsrTemplate[15] := 08EH ;    (* mov  ax, es *)
IsrTemplate[16] := 0C0H ;
IsrTemplate[17] := 08EH ;    (* mov  ax, fs *)
IsrTemplate[18] := 0E0H ;
```


Example of FLIH in GNU LuK



```
IsrTemplate[19] := 068H ;    (* push  interruptnumber *)
IsrTemplate[20] := 000H ;    (* vector number to be overwritten. *)
IsrTemplate[21] := 000H ;    (* this is the single parameter. *)
IsrTemplate[22] := 000H ;    (* to function. *)
IsrTemplate[23] := 000H ;
IsrTemplate[24] := 0B8H ;    (* movl function, %eax *)
IsrTemplate[25] := 000H ;    (* function address to be overwritten *)
IsrTemplate[26] := 000H ;
IsrTemplate[27] := 000H ;
IsrTemplate[28] := 000H ;
```

Example of FLIH in GNU LuK



```
IsrTemplate[29] := 0FFH ;    (* call  %eax *)
IsrTemplate[30] := 0D0H ;
IsrTemplate[31] := 058H ;    (* pop  %eax    // remove parameter *)
IsrTemplate[32] := 00FH ;    (* pop  %fs  *)
IsrTemplate[33] := 0A1H ;
IsrTemplate[34] := 007H ;    (* pop  %es  *)
IsrTemplate[35] := 01FH ;    (* pop  %ds  *)
IsrTemplate[36] := 05AH ;    (* pop  %dx  *)
IsrTemplate[37] := 059H ;    (* pop  %cx  *)
IsrTemplate[38] := 058H ;    (* pop  %ax  *)
IsrTemplate[39] := 0CFH ;    (* iret  *)
```

Example of FLIH in GNU LuK

- GNU LuK uses a routine `ClaimIsr` which will copy the `IsrTemplate` into the correct interrupt vector and then overwrite the vector number and function address in the template

Context switching

- the scheduler runs inside the kernel and it decides which process to run at any time
 - processes might be blocked waiting on a semaphore or waiting for a device to respond
 - a process might need to be preemptively interrupted by the scheduler if it were implementing a round robin algorithm

- the minimal primitives to manage context switching in a microkernel or operating system were devised by Wirth 1983 (Programming in Modula-2)
 - NEWPROCESS, TRANSFER and IOTRANSFER (covered later on)

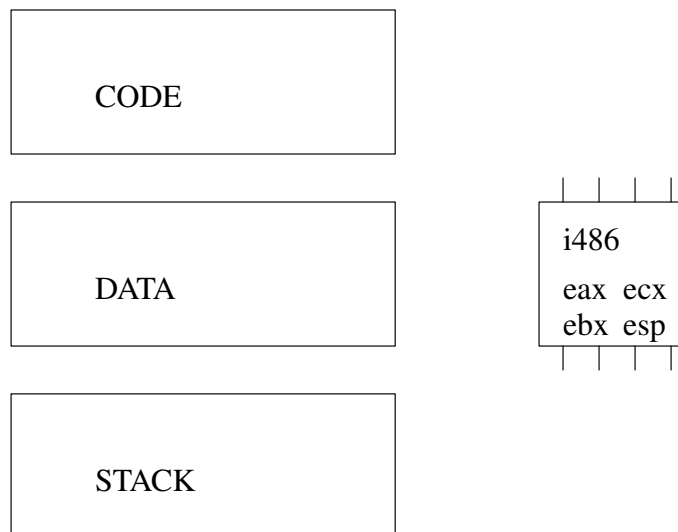
A tiny example of two simple processes in an operating system

```
void Process1 (void)
{
    while (TRUE) {
        WaitForACharacter();
        PutCharacterIntoBuffer();
    }
}

void Process2 (void)
{
    while (TRUE) {
        WaitForInterrupt();
        ServiceDevice();
    }
}
```

Primitives to manage context switching

- firstly let us look at a conventional program running in memory (single program running on a computer)



Primitives to manage context switching

- four main components
 - code
 - data
 - stack
 - processor registers (volatiles)

Concurrency

- suppose we want to run two programs concurrently?
 - we could have two programs in memory. (Two stacks, code, data and two copies of a volatile environment)
 - on a single processor computer we can achieve apparent concurrency by running a fraction of the first program and then run a fraction of the second.
 - if we repeat this then apparent concurrency will be achieved
 - in operating systems multiple concurrent programs are often called *processes*

Concurrency

- what technical problems need to be solved so achieve apparent concurrency?
 - require a mechanism to switch from one process to another
- remember our computer has one processor but needs to run multiple processes
 - the information about a process is contained within the volatiles (or simply: processor registers)

Implementing concurrency

- we can switch from one process 1 to process 2 by:
 - copying the current volatiles from the processor into an area of memory dedicated to process 1
 - now copying some new volatiles from memory dedicated to process 2 into the processor registers



Implementing concurrency

- this operation is call a context switch (as the processors context is switched from process 1 to process 2)
 - by context switching we have a completely new set of register values inside the processor
 - so on the i486 we would change **all** the registers. Some of which include: EAX, EBX, ECX, EDX, ESP and flags
 - note that by changing the ESP register (stack pointer) we have effectively changed stack

Context switching primitives in GNU LuK

- the previous description of context switching is very low level
- in a high level language it is desirable to avoid the assembler language details as far as possible
 - NEWPROCESS
 - TRANSFER
 - IOTRANSFER
- **it is possible to build a microkernel which implements context switching and interrupt driven devices using these primitives without having to descend into assembly language**
 - these are the primitives as defined by Wirth in 1983

Context switching primitives in GNU LuK

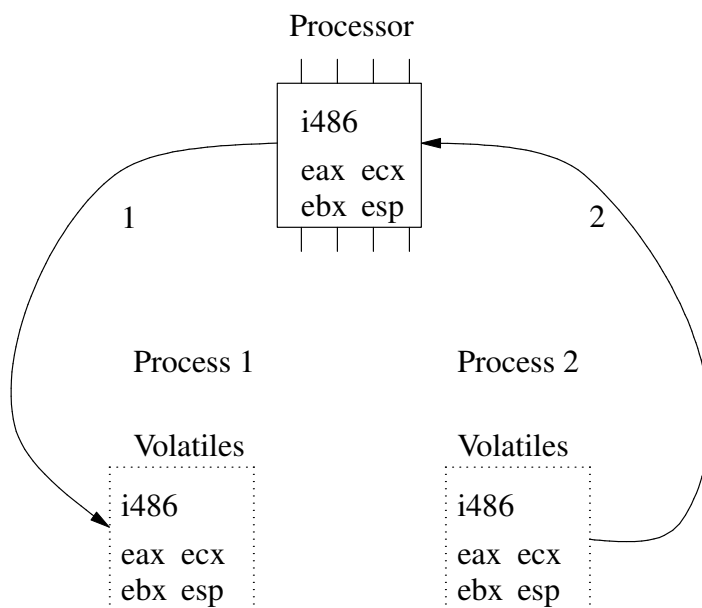
- the primitives NEWPROCESS, TRANSFER and IOTRANSFER are concerned with copying *Volatiles between process and processor*
- the procedure TRANSFER transfers control from one process to another process
- these primitives are *low level* primitives
 - they are normally wrapped up by higher level functions:
 - for example: `initProcess` uses NEWPROCESS which is similar to `new_thread` in Python

TRANSFER

- the C definition is:

```
typedef void *PROCESS;  
  
extern void SYSTEM_TRANSFER (PROCESS *p1, PROCESS p2);
```

- and it performs the following action:



IOTRANSFER

```
extern void SYSTEM_IOTRANSFER (PROCESS *first,  
                                PROCESS *second,  
                                unsigned int interruptNo);
```

- the procedure IOTRANSFER allows process contexts to be changed when an interrupt occurs
- its function can be explained in two stages
 - firstly it transfers control from one process to another process (in exactly the same way as TRANSFER)
 - secondly when an interrupt occurs the processor is context switched back to the original process
- the implementation of IOTRANSFER involves interaction with the FLIH

NEWPROCESS

```
extern void SYSTEM_NEWPROCESS (void (*p) (void), void *a,  
                                unsigned long n,  
                                PROCESS *new);
```

- p is a pointer to a function.
 - this function will be turned into a process
 - a the start address of the new processes stack
 - n the size in bytes of the stack
 - new a variable of type PROCESS which will contain the volatiles of the new process

How is TRANSFER implemented?

- or how do we implement a context switch?
 - first we push all registers onto the stack
 - second we need to save the current running processes stack pointer into the running process control block
 - third we need to restore the next process stack pointer into the microprocessors stack pointer
 - fourth we pop all registers from the stack

How is TRANSFER implemented?

```
void SYSTEM_TRANSFER (PROCESS *p1, PROCESS p2)
{
    onOrOff toOldState;

    toOldState = turnInterrupts(Off);
    asm volatile ("pusha ; pushf"); /* push all registers */
    /* remember p1 is the address of a PROCESS */
    asm volatile ("movl %[p1], %%eax ; movl %%esp, (%%eax)"
        :: [p1] "rm" (p1)); /* p1 := top of stack */
    asm volatile ("movl %[p2], %%eax ; movl %%eax, %%esp"
        :: [p2] "rm" (p2)); /* top of stack := p2 */
    asm volatile ("popf ; popa"); /* restore all registers */
    toOldState := turnInterrupts(toOldState);
}
```

asm volatile

■ means inline an assembly instruction

How is TRANSFER implemented?

- the parameters `("movl %[p1], %%eax ; movl %%esp, (%%eax) "`
`:: [p1] "rm" (p1)) ;`
- means
 - move `p1` into register `%eax`
 - move `%esp` into the address pointed to by `%eax`
 - `p1` is a variable which may be in a register or in memory
 - `p1` is an input to the assembly instruction

Conclusion

- we have seen the structure of a FLIH
- we have seen how three primitives can be used to create processes, context switch between processes and react to interrupts
- we have seen how a context switch might be implemented

Further reading

- Abraham Silberschatz, Operating System Concepts
 - section 3.2.3 (Context Switch)
 - section 19.3.2.5 Exceptions and Interrupts
-
- [newprocess, transfer and iotransfer](https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/68683/eth-3135-01.pdf?sequence=1&isAllowed=y) `<https://www.research-collection.ethz.ch/bitstream/handle/20.500.11850/68683/eth-3135-01.pdf?sequence=1&isAllowed=y>`
 - pages 27, 28, 29