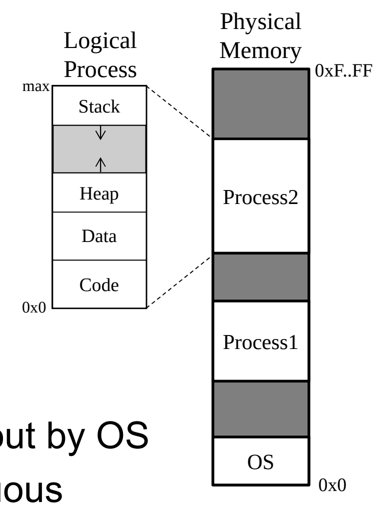
EE445M/EE380L.12
Embedded and Real-Time Systems/ Real-Time Operating Systems

Lecture 10:

Processes, Process Management

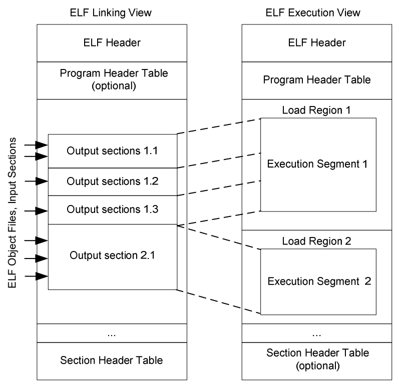
Processes

- OS manages processes
  - CPU scheduling
  - Code/data memory
- Independent programs
  - Separately compiled
  - Logical address space
- Brought in/out of memory
  - On load/exit, swapped in/out by OS
  - Contiguous or non-contiguous



ELF Files

- Executable and Linkable Format (ELF)
  - Linking: sections
    - Object files -> executables
    - Code (RO / .text)
    - Data (RW / .data)
    - Zero data (ZI / .bss)
    - String/symbol table
    - … (debug info) …
  - Execution: segments
    - Executable process image
    - Contiguous load regions
    - One or more sections per segment



Source: infocenter.arm.com

C:\Keil_v5\ARM\ARMCC\BIN\fromelf.exe --text User.axf

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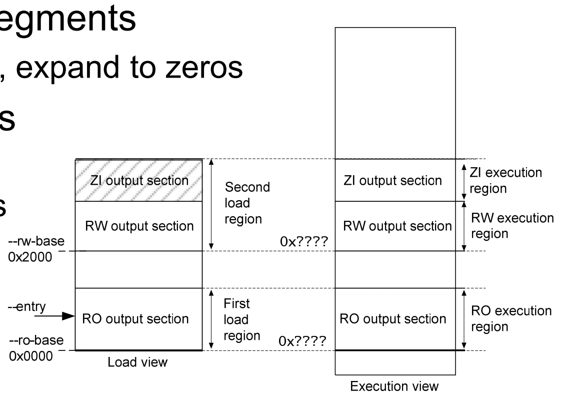
ELF Executable

- Process memory image
  - Load regions/segments
    - ZI empty in file, expand to zeros
  - Base addresses
    - Execution vs. load addresses
- Entry point
  - Starting address of execution



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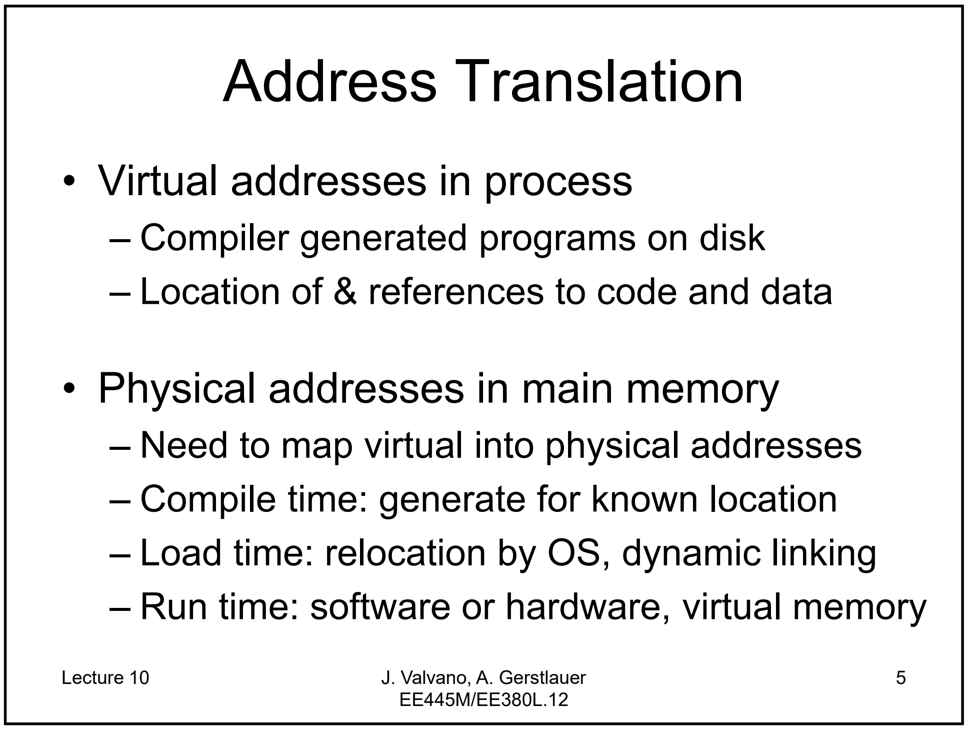
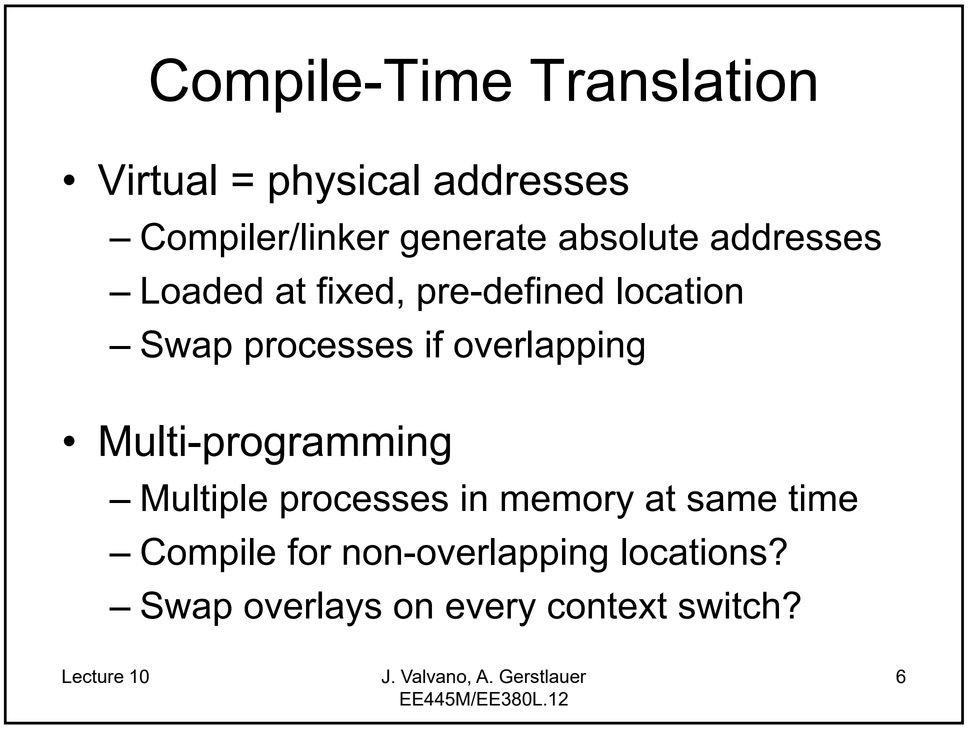


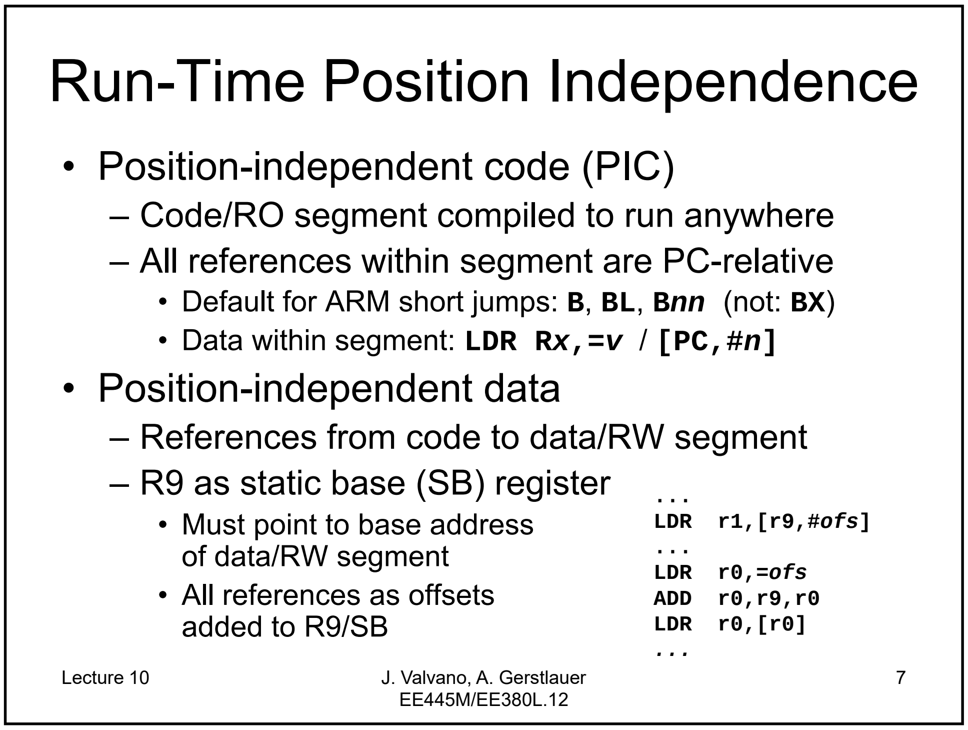
Address Translation

- Virtual addresses in process
  - Compiler generated programs on disk
  - Location of & references to code and data
- Physical addresses in main memory
  - Need to map virtual into physical addresses
  - Compile time: generate for known location
  - Load time: relocation by OS, dynamic linking
  - Run time: software or hardware, virtual memory



Compile-Time Translation

- Virtual = physical addresses
  - Compiler/linker generate absolute addresses
  - Loaded at fixed, pre-defined location
  - Swap processes if overlapping
- Multi-programming
  - Multiple processes in memory at same time
  - Compile for non-overlapping locations?
  - Swap overlays on every context switch?



Run-Time Position Independence

- Position-independent code (PIC)
  - Code/RO segment compiled to run anywhere
  - All references within segment are PC-relative
    - Default for ARM short jumps: **B**, **BL**, **B*nn*** (not: **BX**)
    - Data within segment: **LDR R*x*,=*v*** / **[PC,#*n*]**
- Position-independent data
  - References from code to data/RW segment
  - R9 as static base (SB) register
    - Must point to base address of data/RW segment
    - All references as offsets added to R9/SB

```
...
LDR  r1,[r9,#ofs]
...
LDR  r0,=ofs
ADD  r0,r9,r0
LDR  r0,[r0]
...
```

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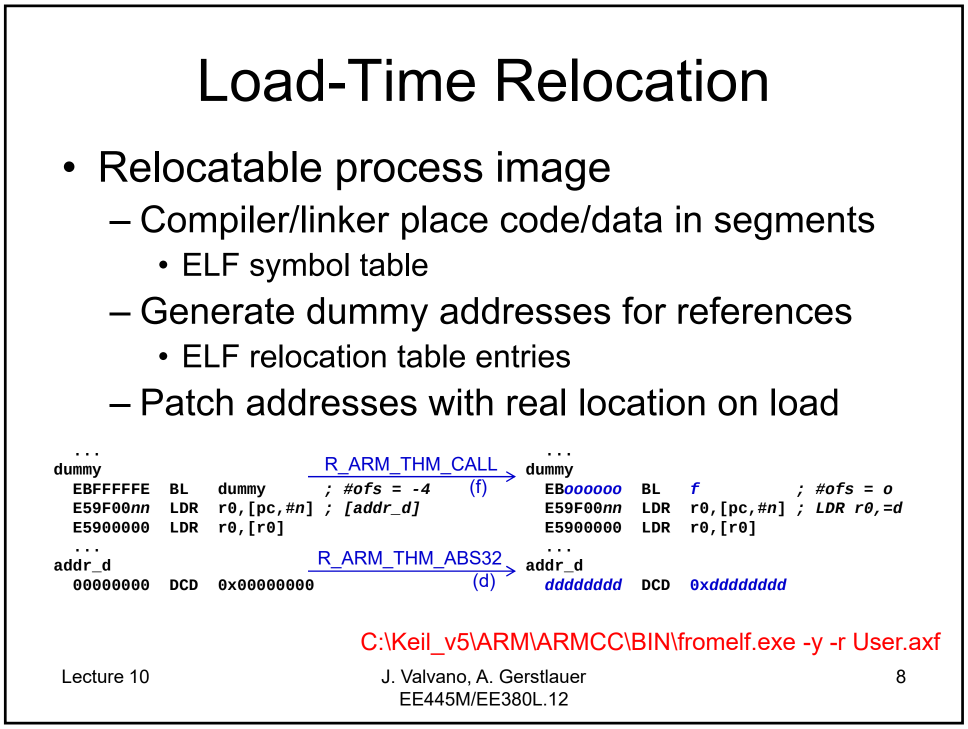

Load-Time Relocation

- Relocatable process image
  - Compiler/linker place code/data in segments
    - ELF symbol table
  - Generate dummy addresses for references
    - ELF relocation table entries
  - Patch addresses with real location on load

```
 ...                                                 ...
dummy                          R_ARM_THM_CALL       dummy
 EBFFFFFE  BL   dummy      ; #ofs = -4   (f)         EBoooooo  BL   f            ; #ofs = o
 E59F00nn  LDR  r0,[pc,#n] ; [addr_d]                E59F00nn  LDR  r0,[pc,#n] ; LDR r0,=d
 E5900000  LDR  r0,[r0]                              E5900000  LDR  r0,[r0]
 ...                                                 ...
addr_d                         R_ARM_THM_ABS32      addr_d
 00000000  DCD  0x00000000               (d)         dddddddd  DCD  0xdddddddd
```

C:\Keil_v5\ARM\ARMCC\BIN\fromelf.exe -y -r User.axf

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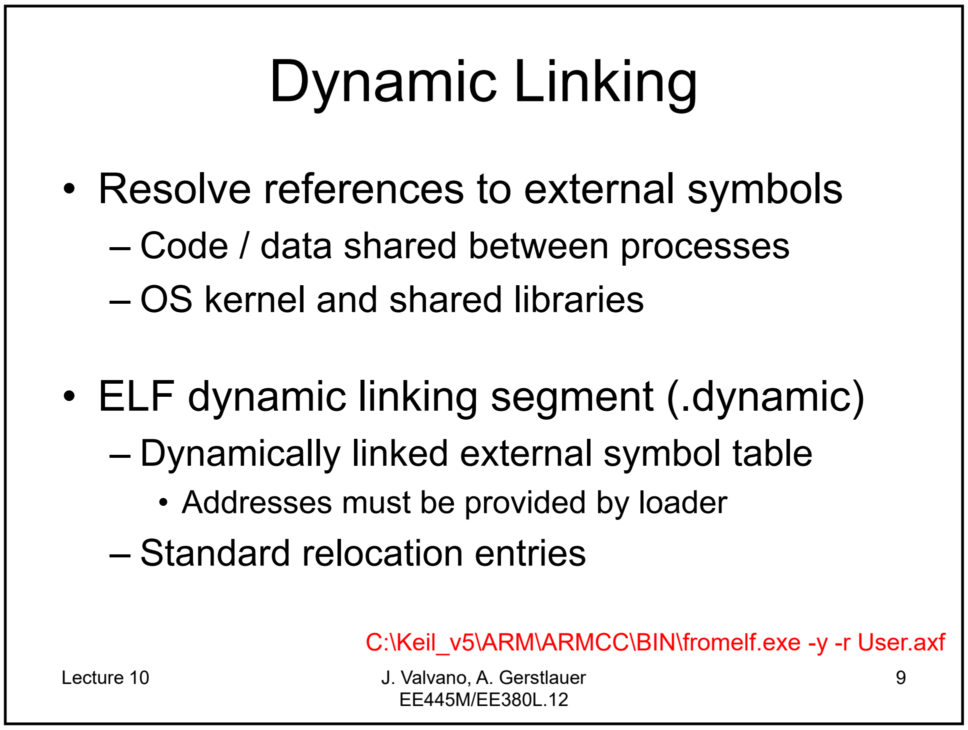

Dynamic Linking

- Resolve references to external symbols
  - Code / data shared between processes
  - OS kernel and shared libraries
- ELF dynamic linking segment (.dynamic)
  - Dynamically linked external symbol table
    - Addresses must be provided by loader
  - Standard relocation entries

C:\Keil_v5\ARM\ARMCC\BIN\fromelf.exe -y -r User.axf

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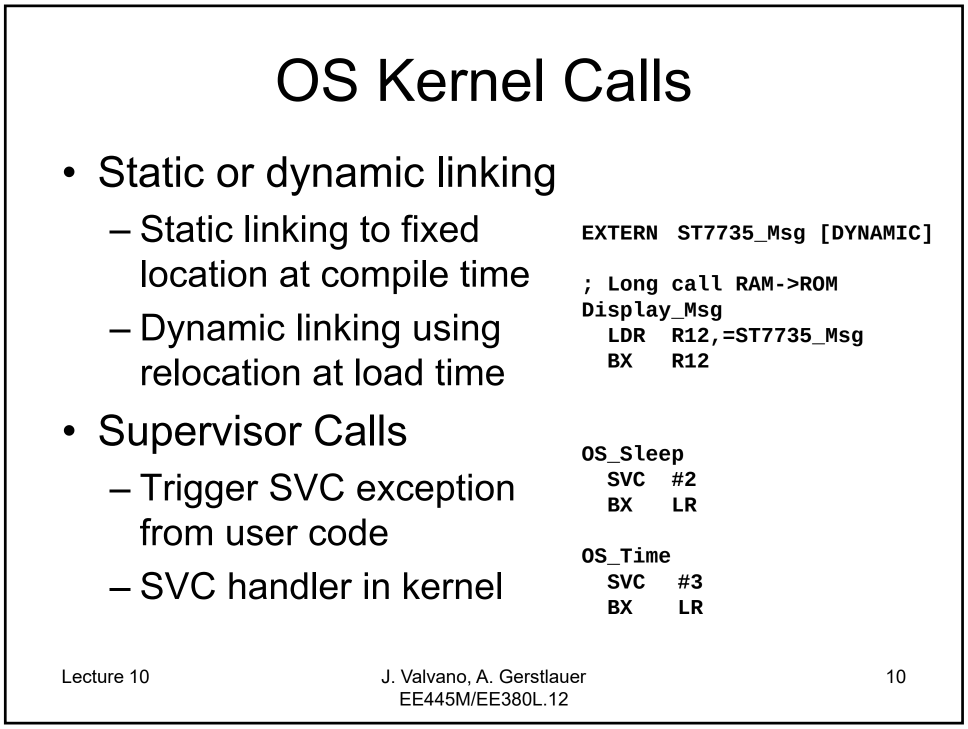

OS Kernel Calls

- Static or dynamic linking
  - Static linking to fixed location at compile time
  - Dynamic linking using relocation at load time
- Supervisor Calls
  - Trigger SVC exception from user code
  - SVC handler in kernel

```
EXTERN  ST7735_Msg [DYNAMIC]

; Long call RAM->ROM
Display_Msg
  LDR  R12,=ST7735_Msg
  BX   R12


OS_Sleep
  SVC  #2
  BX   LR

OS_Time
  SVC   #3
  BX    LR
```

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SVC Handler

Exception stack:
- R0-R3, R12
- LR
- Return address
- PSR

```
SVC_Handler
    LDR  R12,[SP,#24]   ; Return address
    LDRH R12,[R12,#-2]  ; SVC instruction is 2 bytes
    BIC  R12,#0xFF00    ; Extract ID in R12
    LDM  SP,{R0-R3}     ; Get any parameters
    …
    BL OS_xxx           ; Call OS routine by ID
    …
    STR  R0,[SP]        ; Store return value
    BX   LR             ; Return from exception
```

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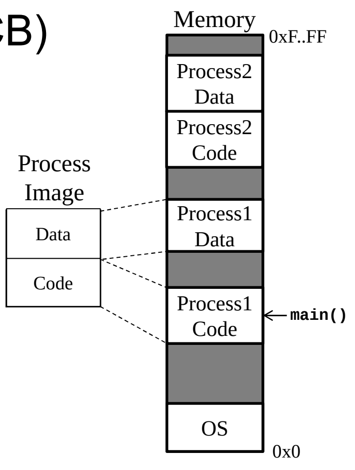
Process Management

- Process Control Block (PCB)
  - Process ID (PID)
  - Code & data segment
  - One or more threads
    - Main and child threads
  - Priority
  - …
- Parent process in TCBs



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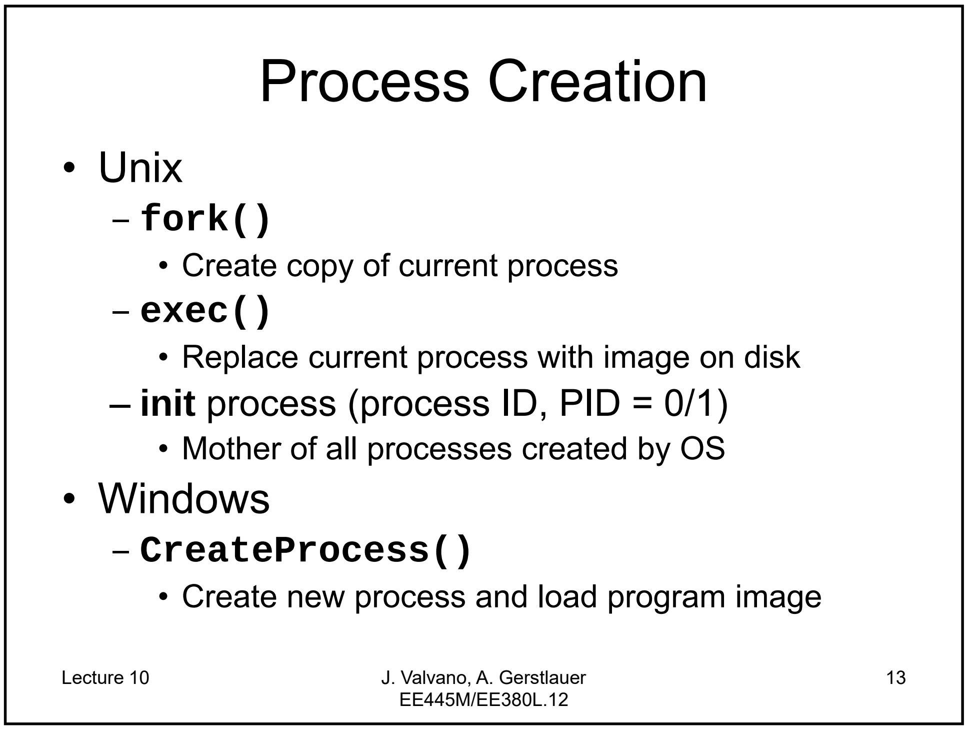

Process Creation

- Unix
  - **`fork()`**
    - Create copy of current process
  - **`exec()`**
    - Replace current process with image on disk
  - **init** process (process ID, PID = 0/1)
    - Mother of all processes created by OS
- Windows
  - **`CreateProcess()`**
    - Create new process and load program image

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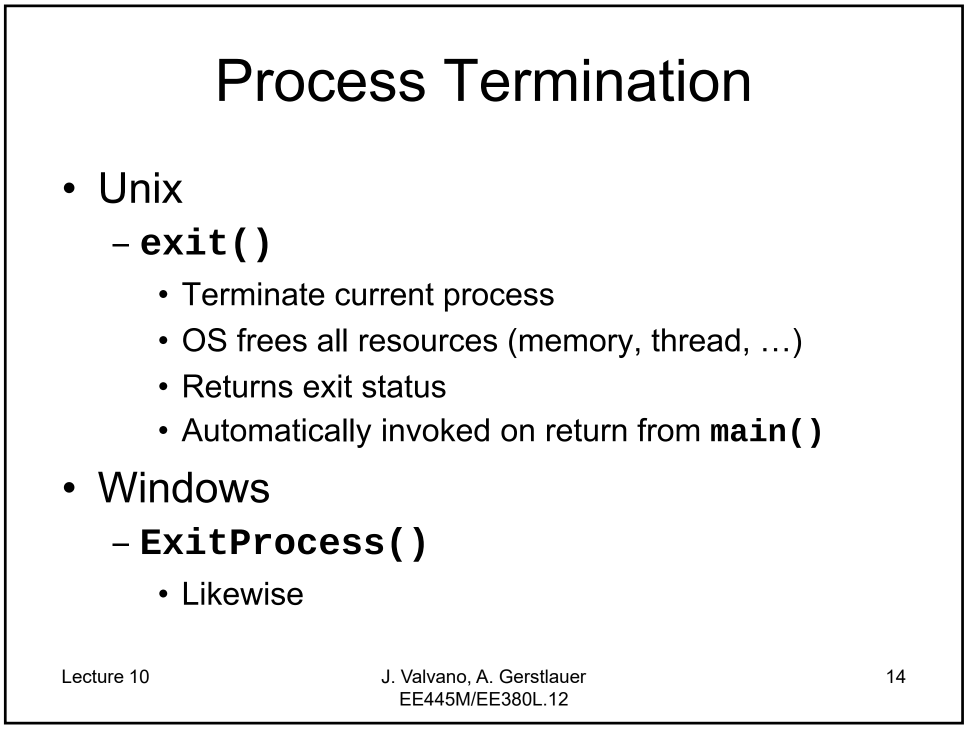

Process Termination

- Unix
  - **`exit()`**
    - Terminate current process
    - OS frees all resources (memory, thread, …)
    - Returns exit status
    - Automatically invoked on return from **`main()`**
- Windows
  - **`ExitProcess()`**
    - Likewise

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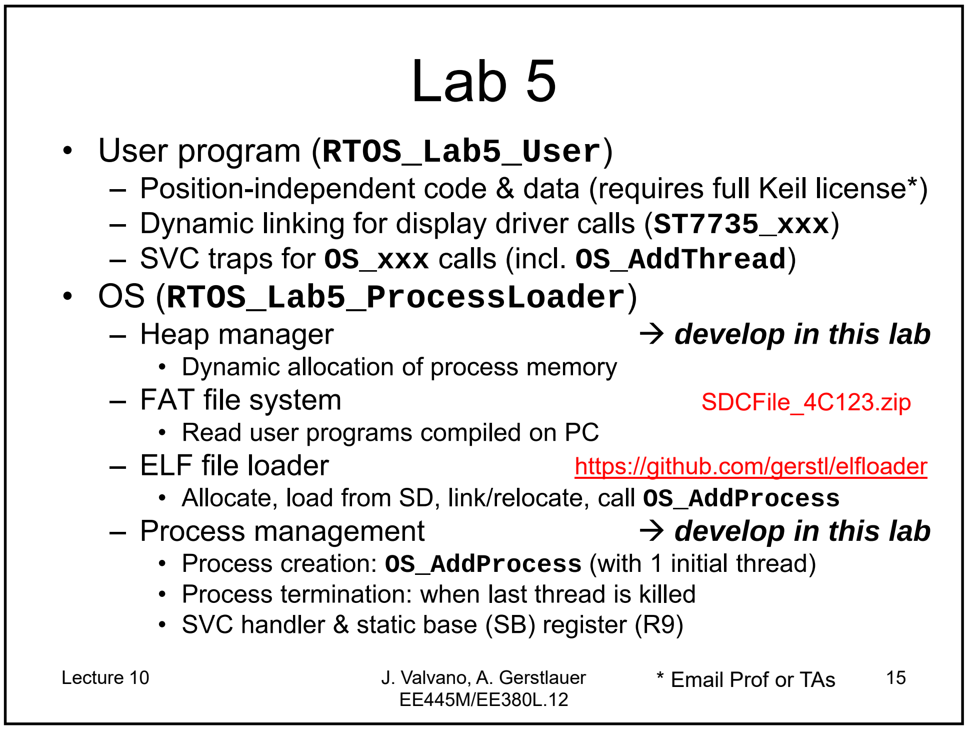

Lab 5

- User program (**`RTOS_Lab5_User`**)
  - Position-independent code & data (requires full Keil license*)
  - Dynamic linking for display driver calls (**`ST7735_xxx`**)
  - SVC traps for **`OS_xxx`** calls (incl. **`OS_AddThread`**)
- OS (**`RTOS_Lab5_ProcessLoader`**)
  - Heap manager → ***develop in this lab***
    - Dynamic allocation of process memory
  - FAT file system SDCFile_4C123.zip
    - Read user programs compiled on PC
  - ELF file loader https://github.com/gerstl/elfloader
    - Allocate, load from SD, link/relocate, call **`OS_AddProcess`**
  - Process management → ***develop in this lab***
    - Process creation: **`OS_AddProcess`** (with 1 initial thread)
    - Process termination: when last thread is killed
    - SVC handler & static base (SB) register (R9)

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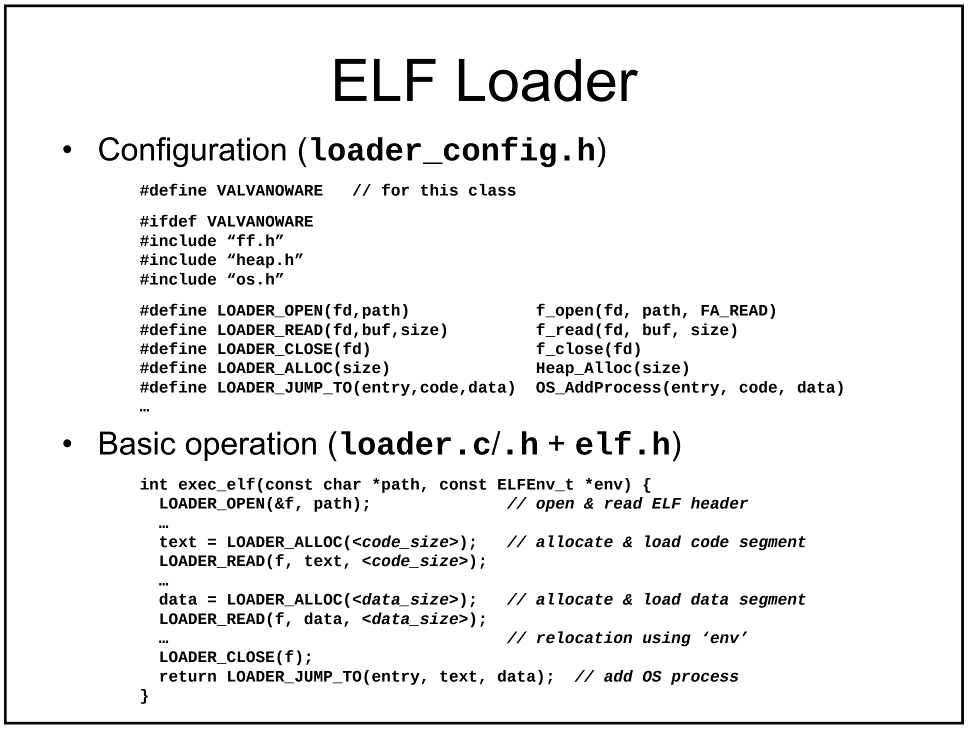


ELF Loader

- Configuration (**`loader_config.h`**)

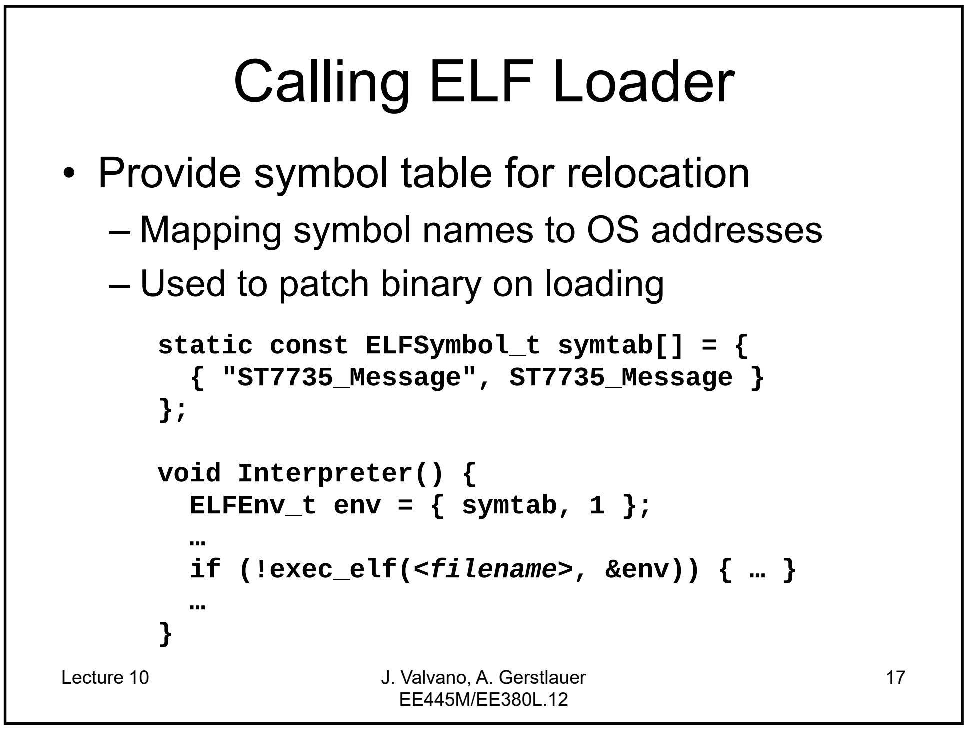
```
#define VALVANOWARE   // for this class

#ifdef VALVANOWARE
#include “ff.h”
#include “heap.h”
#include “os.h”

#define LOADER_OPEN(fd,path)             f_open(fd, path, FA_READ)
#define LOADER_READ(fd,buf,size)         f_read(fd, buf, size)
#define LOADER_CLOSE(fd)                 f_close(fd)
#define LOADER_ALLOC(size)               Heap_Alloc(size)
#define LOADER_JUMP_TO(entry,code,data)  OS_AddProcess(entry, code, data)
…
```

- Basic operation (**`loader.c`**/**`.h`** + **`elf.h`**)

```
int exec_elf(const char *path, const ELFEnv_t *env) {
  LOADER_OPEN(&f, path);              // open & read ELF header
  …
  text = LOADER_ALLOC(<code_size>);   // allocate & load code segment
  LOADER_READ(f, text, <code_size>);
  …
  data = LOADER_ALLOC(<data_size>);   // allocate & load data segment
  LOADER_READ(f, data, <data_size>);
  …                                   // relocation using ‘env’
  LOADER_CLOSE(f);
  return LOADER_JUMP_TO(entry, text, data);  // add OS process
}
```



Calling ELF Loader

- Provide symbol table for relocation
  - Mapping symbol names to OS addresses
  - Used to patch binary on loading

```
static const ELFSymbol_t symtab[] = {
  { "ST7735_Message", ST7735_Message }
};

void Interpreter() {
  ELFEnv_t env = { symtab, 1 };
  …
  if (!exec_elf(<filename>, &env)) { … }
  …
}
```