Embedded Software Essentials

Linkers

C1 M2 V5

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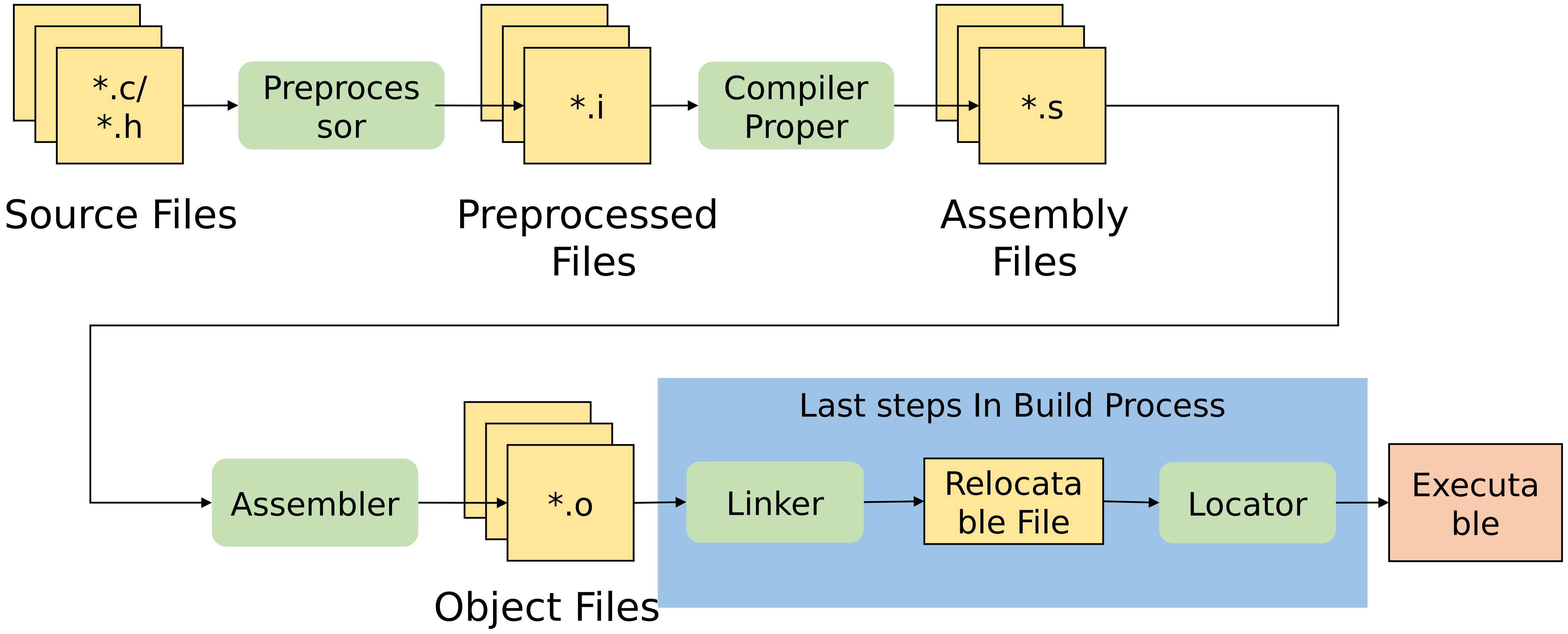
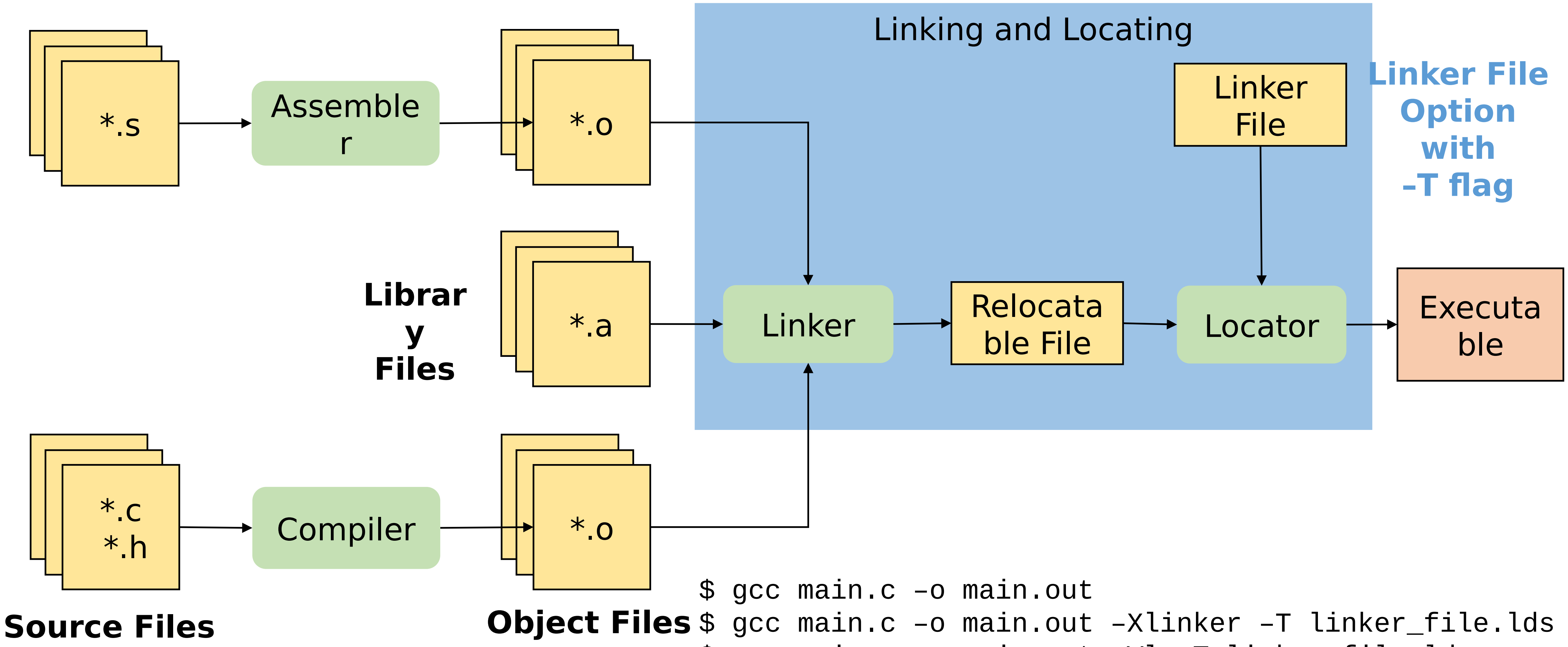
Linking and Locating [S1]



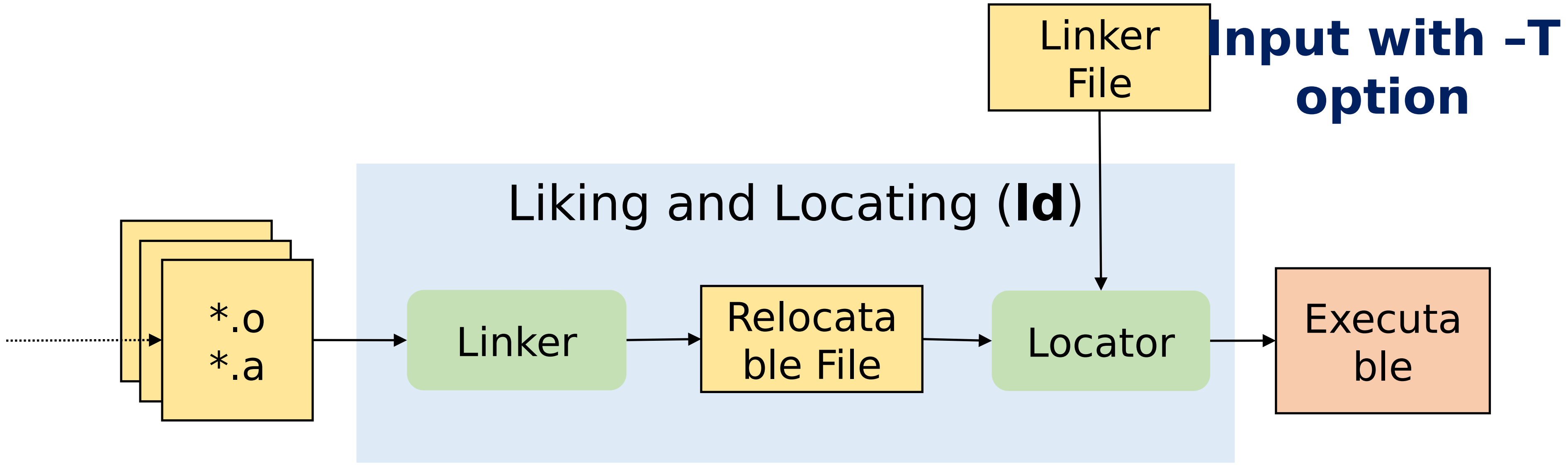
Typical Build Process **[S2]**



```
$ gcc main.c -o main.out
$ gcc main.c -o main.out -Xlinker -T linker_file.lds
$ gcc main.c -o main.out -Wl,-T,linker_file.lds
```

Linkers [S3a]

- Combines all of objects files into a single executable
  - Object code uses **symbols** to reference other functions/variables

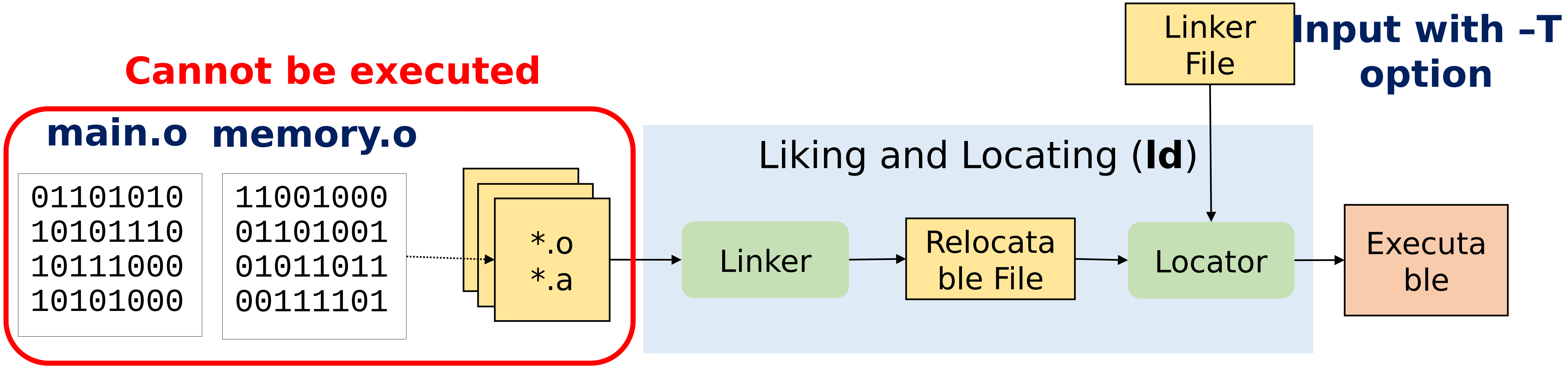


Invoke the linker indirectly from compiler (and with no

```
$ gcc –o main.out main.c
```

Linkers [S3b]

- Combines all of objects files into a single executable
  - Object code uses **symbols** to reference other functions/variables



Invoke the linker indirectly from compiler (and with no

```
$ gcc –o main.out main.c
```

Linking Object Files [S4a]

Three source files (*.h & *.c)

Must convert *.c files into object code

memory.h

```
#include “memory.h”
char memzero(char * src, int length){
  int i;
  for(i = 0; i < length; i++){
    *src++ = 0;
  }
}
```

main.c

```
#include “memory.h”
int main(){
  char arr[10];
  memzero(arr, 10);
  return 0;
}
```

memory.h

```
#ifndef __MEMORY_H__
#define __MEMORY_H__
char memzero(char * src, int length);
#endif /* __MEMORY_H__ */
```

Linking Object Files [S4b]

The object files have many **symbols** that need to be tracked and resolved

memory.h

```
#include “memory.h”
char memzero(char * src, int length){
  int i;
  for(i = 0; i < length; i++){
    *src++ = 0;
  }
}
```

main.c

```
#include “memory.h”
int main(){
  char arr[10];
  memzero(arr, 10);
  return 0;
}
```

memory.h

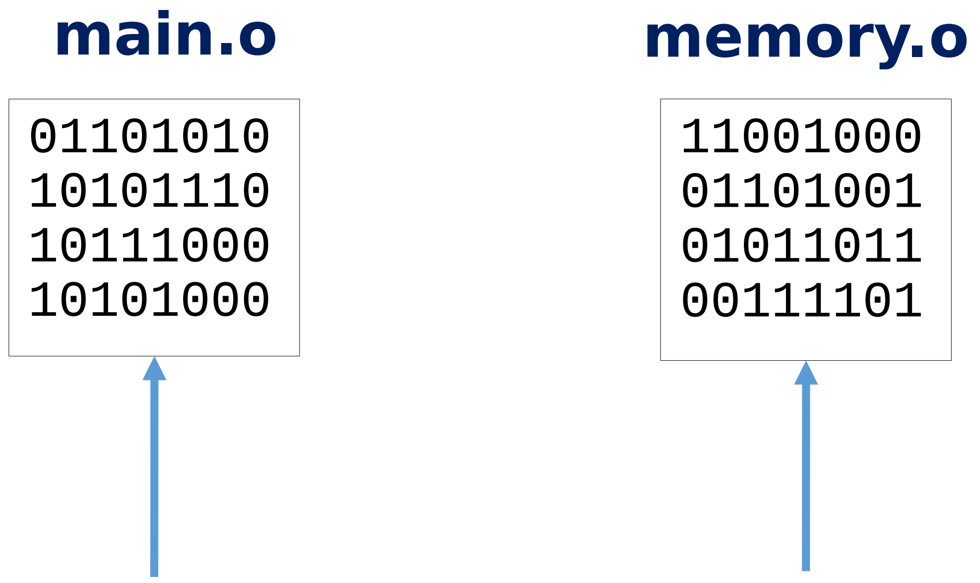
```
#ifndef __MEMORY_H__
#define __MEMORY_H__
char memzero(char * src, int length);
#endif /* __MEMORY_H__ */
```

Linking Object Files [S4c]

After compilation, we have 2 object files (header file provide symbol reference)

Object files are <u>NOT</u> human readable

Symbol tables track important references



main.o has references to symbols defined in memory.o

memory.o has the definitions of these special symbols

Linking Object Files [S4d]

Function memmove is not defined in included files

Causes an error

main.c

```
#include <stdlib.h>
int main(){
  char a[10], b[10];
  memmove(a, b, 10);
  return 0;
}
```

???

memory.h

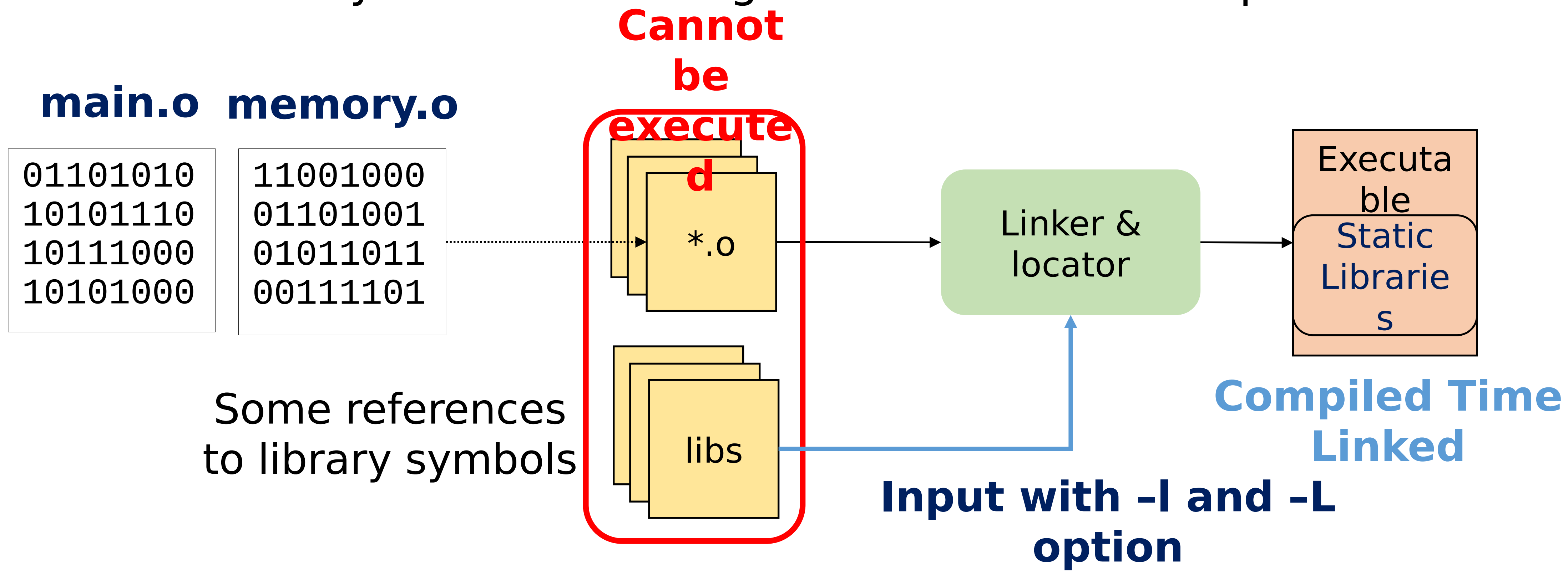
```
#include “memory.h”
char memzero(char * src, int length){
  int i;
  for(i = 0; i < length; i++){
    *src++ = 0;
  }
}
```

memory.h

```
#ifndef __MEMORY_H__
#define __MEMORY_H__
char memzero(char * src, int length);
#endif /* __MEMORY_H__ */
```

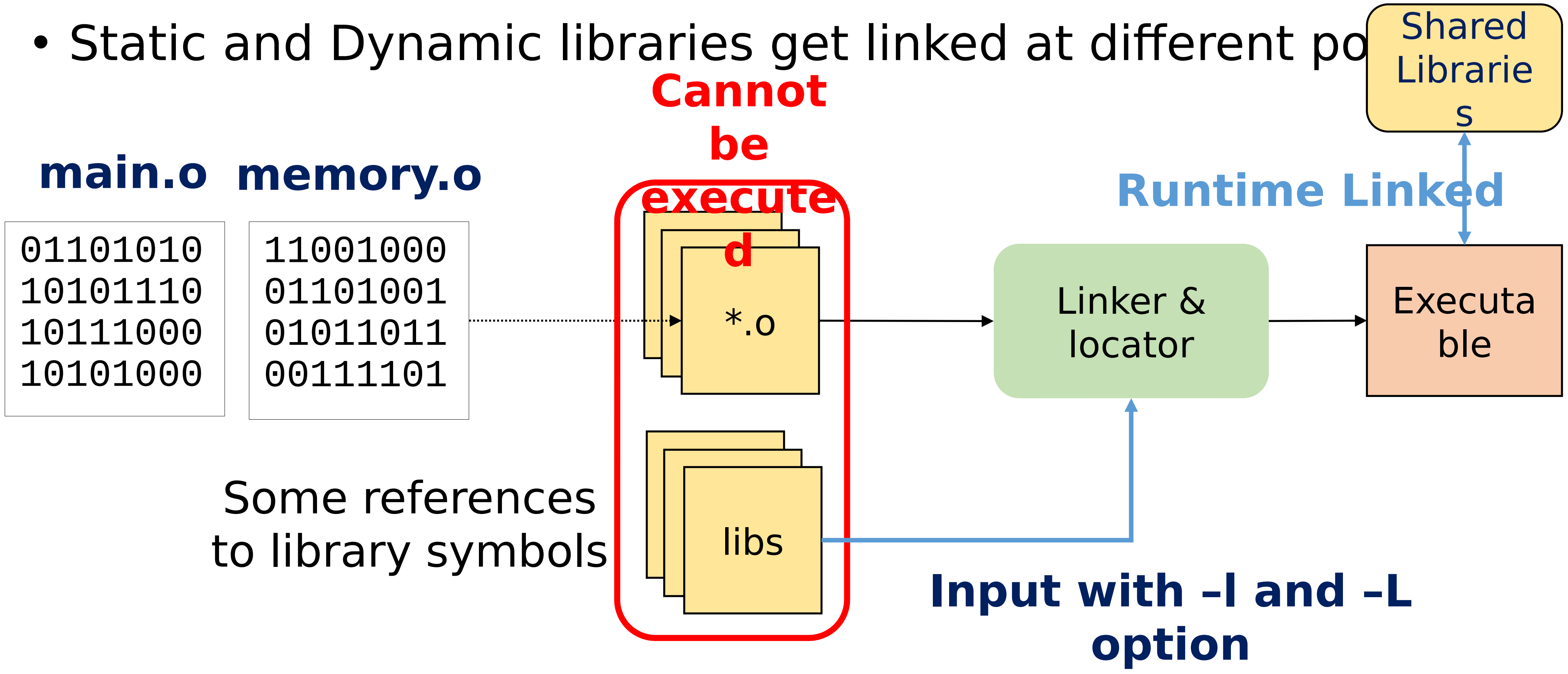
Libraries [S6a]

- Linker must know **name** and **path** to library to link with it
  - Static and Dynamic libraries get linked at different points



Libraries [S6b]

- Linker must know **name** and **path** to library to link with it
  - Static and Dynamic libraries get linked at different po



Linking Object Files [S7]

Standard libraries can be statically or dynamically linked

Entry and exit points from main are included in a standard library that is automatically included by the linker

Can stop auto link of standard libs with –**nostdlib** flag

How do we enter main?

How do we exit or return from main?

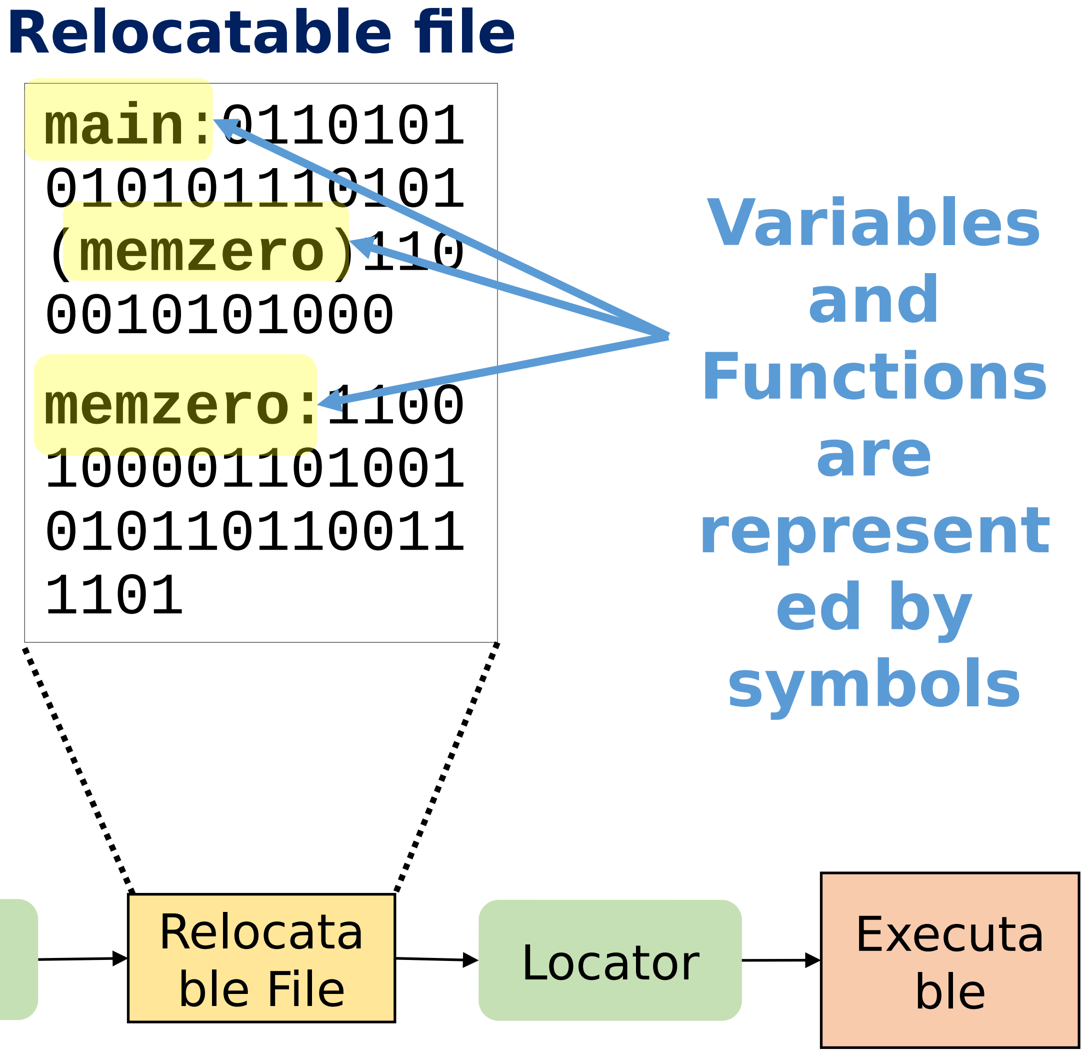
main.c

```
#include <stdlib.h>
#include <stdio.h>
int main(){
  char arr[10];

  printf(“Hello World\n”);

  return 0;
}
```

Linking Object Files [S8]

After linking, we have 1 object files, and the symbols between the two are **resolved**

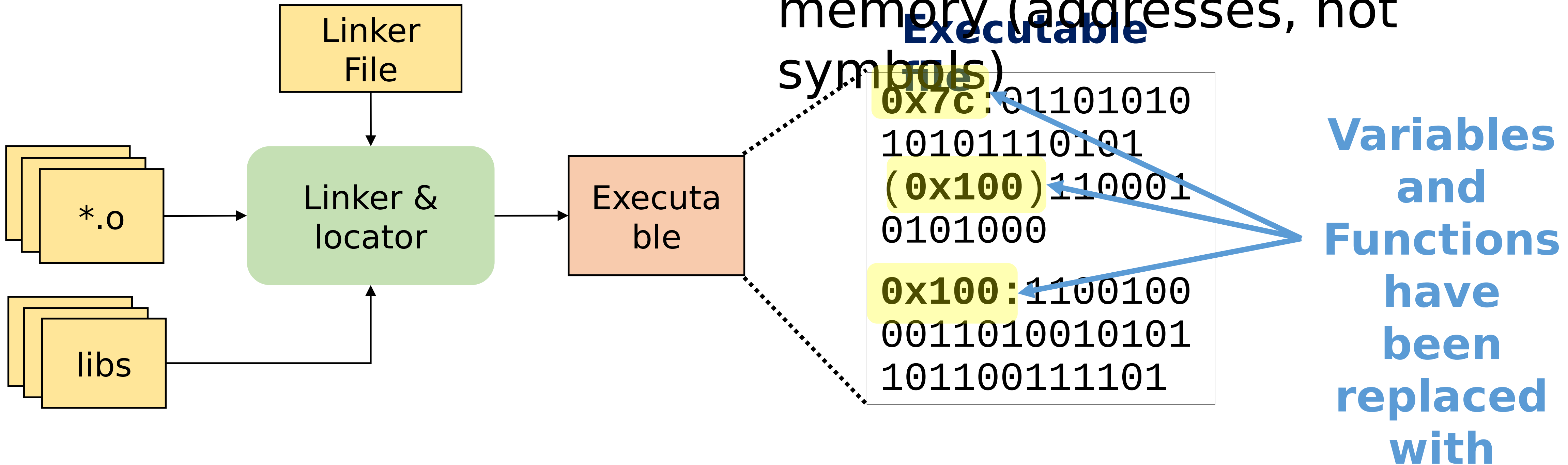
Relocatable & Executable files are NOT human readable



Linking Object Files [S9]

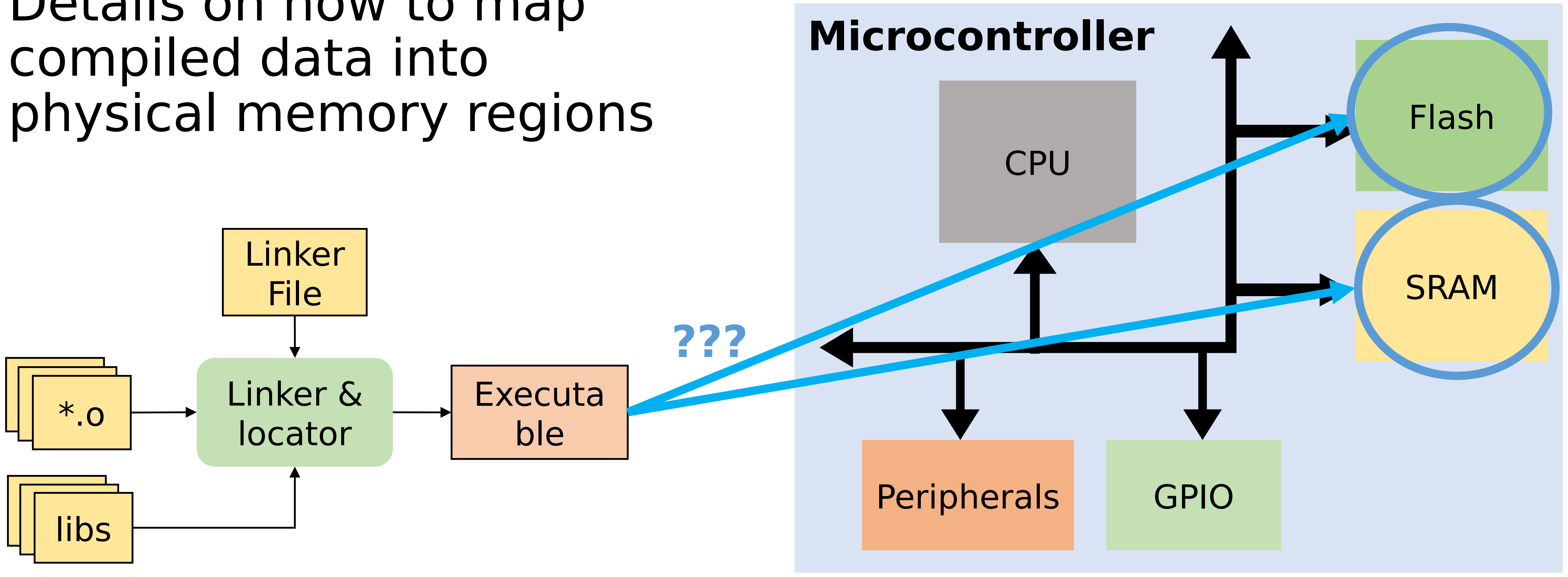
After locating, symbols are removed and direct **addresses** get assigned into the object code

The processor understands **machine code** (binary encoded instructions). These must have direct references to memory (addresses, not symbols)



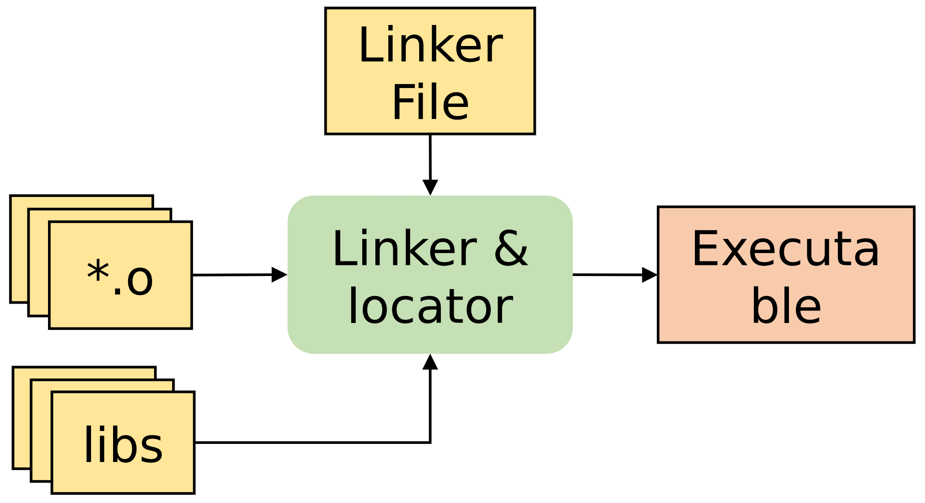
Linker Files [S10]

- Details on how to map compiled data into physical memory regions



Linker Scripts Details [S11]

- Code sections to memory regions map
- Start and Sizes of memory regions
- Access attributes of memory regions
- Report checking for over-allocation
- Entry points of the program



Example Memory Regions:

RAM/SRAM
FLASH (MAIN)
EEPROM
VECTORS
BOOTLOADER

Example code/data sections:

.bss
.data
.text
.isr_vectors
.heap

Entry Point Example:

ENTRY(Reset_Handle r)

Example Linker Script Contents [S12a]

```
MEMORY
{
    MAIN               (RX) : origin = 0x00000000,
length = 0x00040000
    SRAM_DATA  (RW) : origin = 0x20000000, length
= 0x00010000
}
```

Physical Memory Regions

```
SECTIONS
{
    .intvecs:   > 0x00000000
    .text   :   > MAIN
    .const  :   > MAIN
    .cinit  :   > MAIN
    .pinit  :   > MAIN
     .data   :   > SRAM_DATA
    .bss    :   > SRAM_DATA
    .heap :   > SRAM_DATA
    .stack  :   > SRAM_DATA
(HIGH)
}
```

Compiled Memory Sections

Example Linker Script Contents [S12b]

```
MEMORY
{
   MAIN           (RX) : origin = 0x00000000, length =
0x00040000
   SRAM_DATA  (RW) : origin = 0x20000000, length = 0x00010000
}
```

Physical Memory Regions

Each “code” section output from compilation is then mapped into memory regions

```
SECTIONS
{
   .intvecs:   > 0x00000000
   .text   :   > MAIN
   .const  :   > MAIN
   .cinit  :   > MAIN
   .pinit  :   > MAIN
    .data   :   > SRAM_DATA
   .bss    :   > SRAM_DATA
   .heap :   > SRAM_DATA
   .stack  :   > SRAM_DATA
(HIGH)
}
```

Compiled Memory Sections

Example Linker Script Contents [S12c]

```
MEMORY
{
  MAIN          (RX) : origin = 0x00000000, length =
0x00040000
  SRAM_DATA  (RW) : origin = 0x20000000, length =
0x00010000
}
```

Physical Memory Regions

```
SECTIONS
{
    .intvecs:   > 0x00000000
    .text   :   > MAIN
    .const  :   > MAIN
    .cinit  :   > MAIN
    .pinit  :   > MAIN
     .data   :   > SRAM_DATA
    .bss    :   > SRAM_DATA
    .heap :   > SRAM_DATA
    .stack  :   > SRAM_DATA
(HIGH)
}
```

Compiled Memory Sections

Specifies the location the compiled region should map into physical memory

Example Linker Script Contents [S12c]

```
MEMORY
{
  MAIN            (RX) : origin = 0x00000000, length =
0x00040000
  SRAM_DATA  (RW) : origin = 0x20000000, length =
0x00010000
}
```

Physical Memory Regions

```
SECTIONS
{
   .intvecs:   > 0x00000000
   .text   :   > MAIN
   .const  :   > MAIN
   .cinit  :   > MAIN
   .pinit  :   > MAIN
    .data   :   > SRAM_DATA
   .bss    :   > SRAM_DATA
   .heap :   > SRAM_DATA
   .stack  :   > SRAM_DATA
(HIGH)
}
```

Compiled Memory Sections

Specifies the location the compiled region should map into physical memory

→ **This is the "relocating" that the locator does**

Example Linker Script Contents [S12d]

```
MEMORY
{
    MAIN          (RX) : origin = 0x00000000, length =
0x00040000
    SRAM_DATA  (RW) : origin = 0x20000000, length =
0x00010000
}
```

Physical Memory Regions

Specifies the location the compiled region should map into physical memory

```
SECTIONS
{
    .intvecs:   > 0x00000000
    .text   :   > MAIN
    .const  :   > MAIN
    .cinit  :   > MAIN
    .pinit  :   > MAIN
     .data   :   > SRAM_DATA
    .bss    :   > SRAM_DATA
    .heap :   > SRAM_DATA
    .stack  :   > SRAM_DATA
(HIGH)
}
```

Compiled Memory Sections

Example Linker Script Contents [S12e]

```
MEMORY
{
    MAIN            (RX) : origin = 0x00000000, length =
0x00040000
    SRAM_DATA  (RW) : origin = 0x20000000, length =
0x00010000
}
```

Physical Memory Regions

Specifies the start address and length of the region for the memory map (in bytes)

```
SECTIONS
{
    .intvecs:   > 0x00000000
    .text   :   > MAIN
    .const  :   > MAIN
    .cinit  :   > MAIN
    .pinit  :   > MAIN
     .data   :   > SRAM_DATA
    .bss    :   > SRAM_DATA
    .heap :   > SRAM_DATA
    .stack  :   > SRAM_DATA
(HIGH)
}
```

Compiled Memory Sections

Example Linker Script Contents [S12e]

- Linker file can calculate memory segments
    - Can throw an errors if memory space is invalid

```
HEAP_SIZE  = DEFINED(__heap_size__)  ? __heap_size__  : 0x0400;
STACK_SIZE  = DEFINED(__stack_size__)  ? __stack_size__  : 0x0800;

__StackTop   = ORIGIN(SRAM_DATA) + LENGTH(SRAM_DATA);
__StackLimit = __StackTop - STACK_SIZE;
 ASSERT(__StackLimit >= __HeapLimit, “Region SRAM_DATA overflowed!")
```

Example Linker Script Contents [S12c]

```
MEMORY
{
  MAIN           (RX) : origin = 0x00000000, length =
0x00040000
  SRAM_DATA  (RW) : origin = 0x20000000, length =
0x00010000
}
```

Physical Memory Regions

Specifies the location the compiled region should map into physical memory

```
SECTIONS
{
    .intvecs:   > 0x00000000
    .text   :   > MAIN
    .const  :   > MAIN
    .cinit  :   > MAIN
    .pinit  :   > MAIN
     .data   :   > SRAM_DATA
    .bss    :   > SRAM_DATA
    .heap :   > SRAM_DATA
    .stack  :   > SRAM_DATA
(HIGH)
}
```

Compiled Memory Sections

Example Linker Script Contents [S12f]

```
MEMORY
{
    MAIN          (RX) : origin = 0x00000000, length = 0x00040000
    SRAM_DATA  (RW) : origin = 0x20000000, length = 0x00010000
}
```

Physical Memory Regions

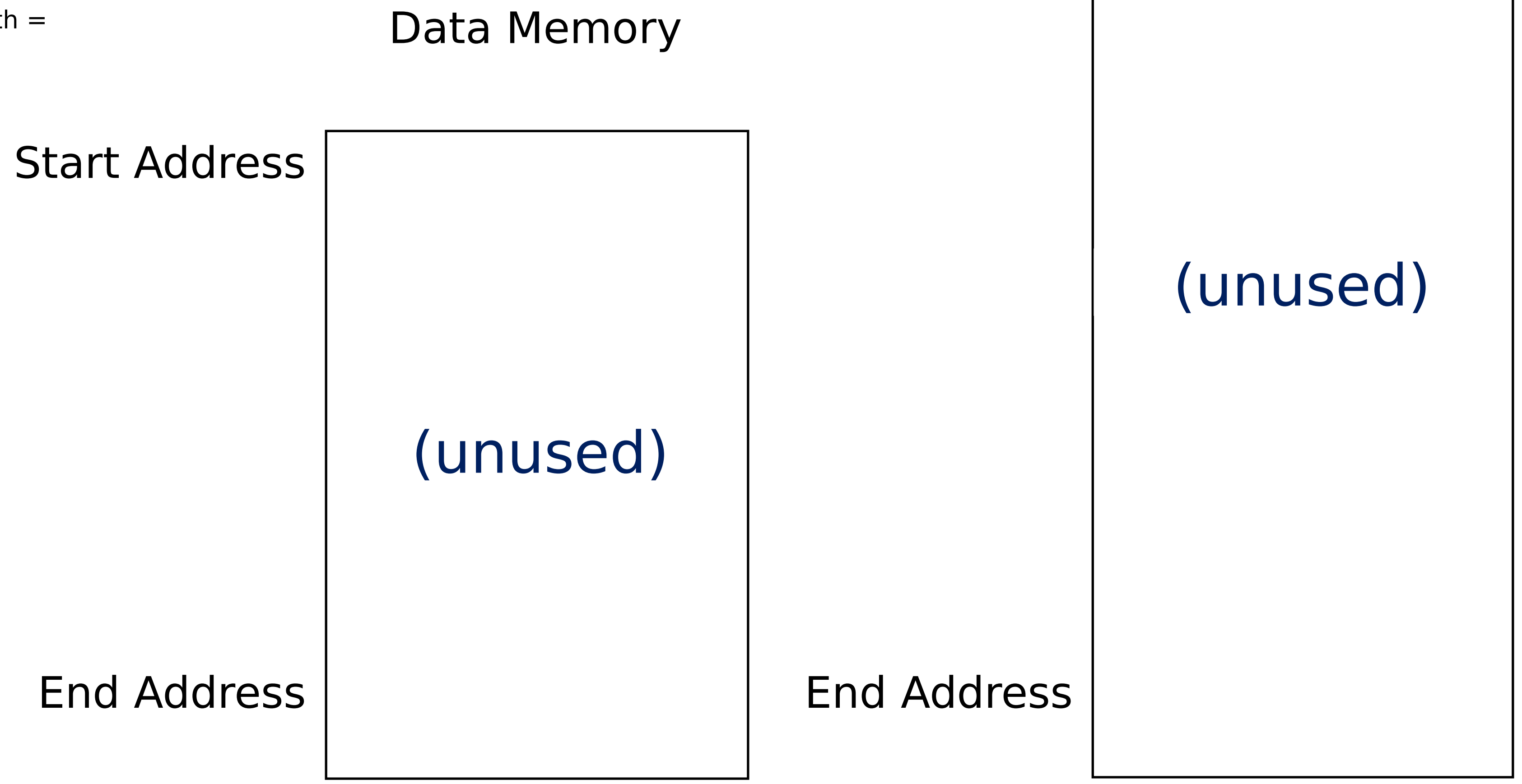
Specifies the access properties of the region

```
SECTIONS
{
    .intvecs:   > 0x00000000
    .text   :   > MAIN
    .const  :   > MAIN
    .cinit  :   > MAIN
    .pinit  :   > MAIN
    .data   :   > SRAM_DATA
    .bss    :   > SRAM_DATA
    .heap :   > SRAM_DATA
    .stack  :   > SRAM_DATA (HIGH)
}
```

Compiled Memory Sections

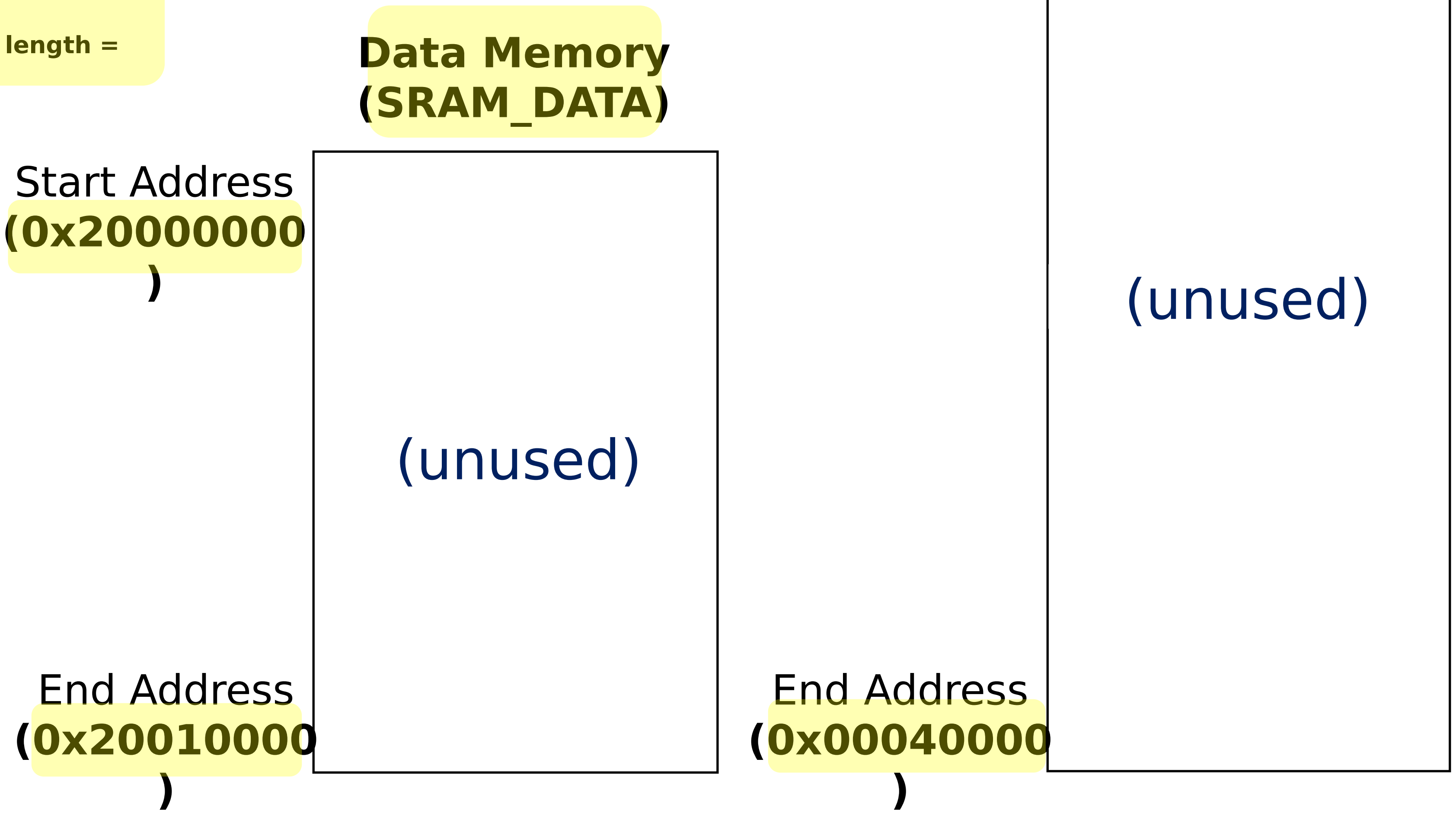
Memory Segments [S13a]

```
MEMORY
{
    MAIN            (RX) : origin = 0x00000000, length =
0x00040000
    SRAM_DATA  (RW) : origin = 0x20000000, length =
0x00010000
}

SECTIONS
{
    .intvecs:   > 0x00000000
    .text   :   > MAIN
    .const  :   > MAIN
    .cinit  :   > MAIN
    .pinit  :   > MAIN
     .data   :   > SRAM_DATA
    .bss    :   > SRAM_DATA
    .heap :   > SRAM_DATA
    .stack  :   > SRAM_DATA
(HIGH)
}
```



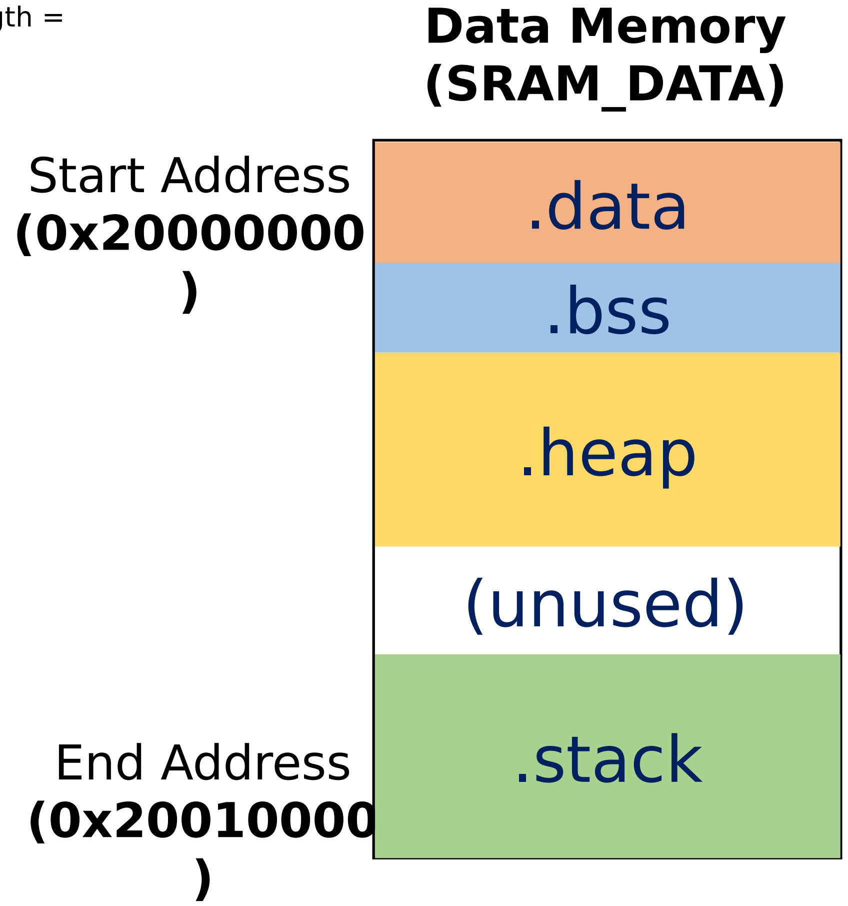
Memory Segments [S13b]

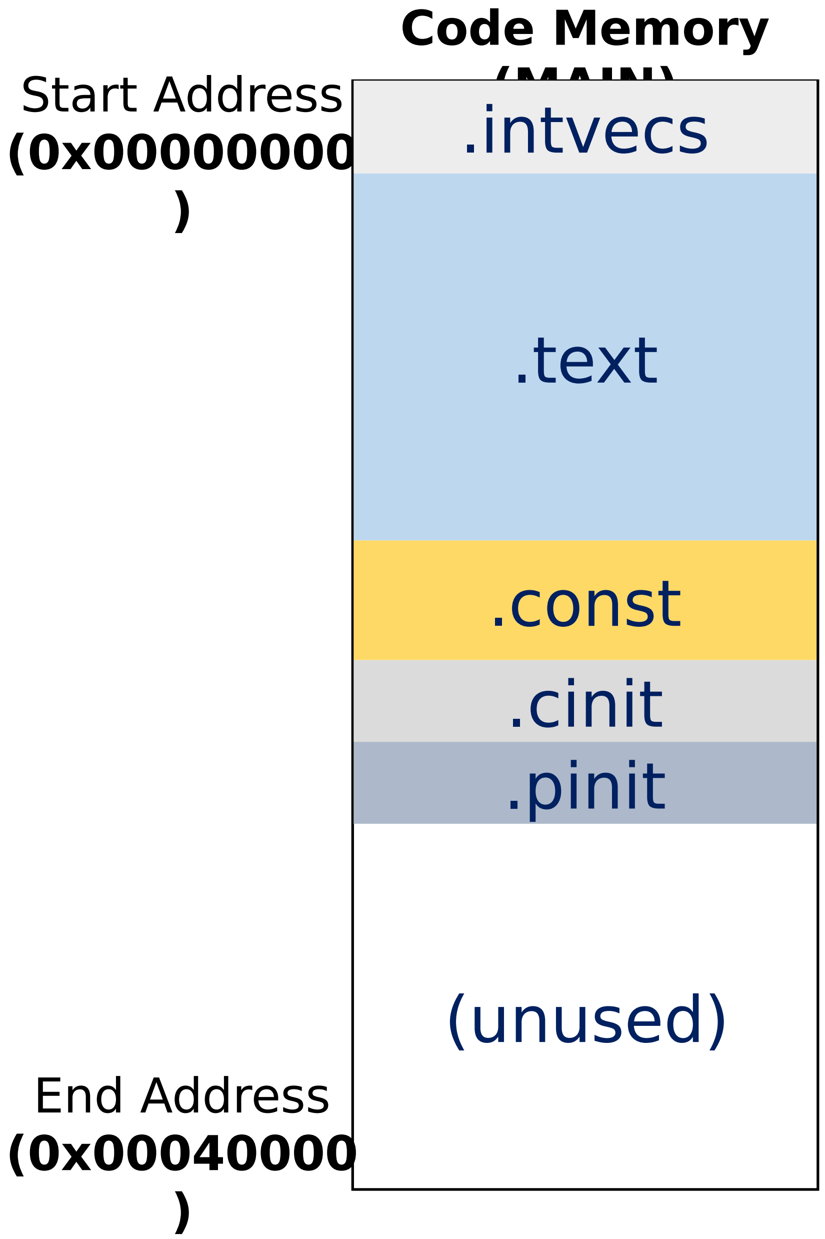
```
MEMORY
{
   MAIN           (RX) : origin = 0x00000000, length =
0x00040000
   SRAM_DATA  (RW) : origin = 0x20000000, length =
0x00010000
}

SECTIONS
{
    .intvecs:   > 0x00000000
    .text   :   > MAIN
    .const  :   > MAIN
    .cinit  :   > MAIN
    .pinit  :   > MAIN
     .data   :   > SRAM_DATA
    .bss    :   > SRAM_DATA
    .heap :   > SRAM_DATA
    .stack  :   > SRAM_DATA
(HIGH)
}
```



Memory Segments [S13c]

```
MEMORY
{
    MAIN           (RX) : origin = 0x00000000, length =
0x00040000
    SRAM_DATA  (RW) : origin = 0x20000000, length =
0x00010000
}

SECTIONS
{
   .intvecs:   > 0x00000000
   .text   :   > MAIN
   .const  :   > MAIN
   .cinit  :   > MAIN
   .pinit  :   > MAIN
    .data   :   > SRAM_DATA
   .bss    :   > SRAM_DATA
   .heap :   > SRAM_DATA
   .stack  :   > SRAM_DATA
(HIGH)
}
```





Linker Flags [S14a]

Option & Format	Purpose
`-map [NAME]`	Outputs a memory map file [NAME] from the result of linking
`-T [NAME]`	Specifies a linker script name [NAME]
`-o [NAME]`	Place the output in the filename [NAME]
`-0<#>`	The level of optimizations from [#=0-3] (-O0, -O1, -O2, -O3)
`-Os`	Optimize for memory size
`-z stacksize=[SIZE]`	The amount of stack space to reserve
`-shared`	Produce a shared library (dynamic linking library)
`-l[LIB]`	Link with library
`-L[DIR]`	Include the following library path
`-Wl,<OPTION>`	Pass option to linker from compiler
`-Xlinker <OPTION>`	Pass option to linker from compiler

Passing Flags to Linker from Compiler [S14b]

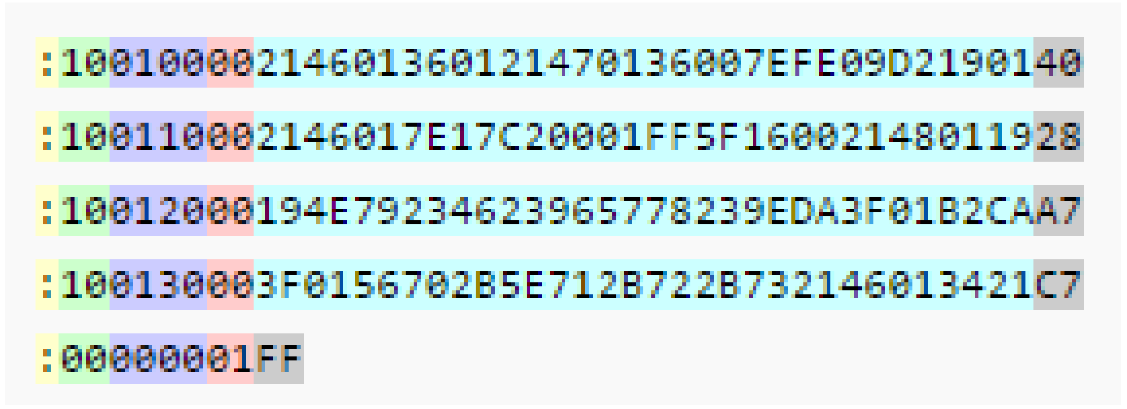
- You can pass arguments from the compiler to the linker

```
$ gcc <other-options-here> -Xlinker –Map=main.map
$ gcc <other-options-here> -Xlinker –T=mkl25z_lnk.ld
```

```
$ gcc <other-options-here> -Wl,option
$ gcc <other-options-here> -Wl,-Map,main.map
$ gcc <other-options-here> -Wl,-Map=main.map
```

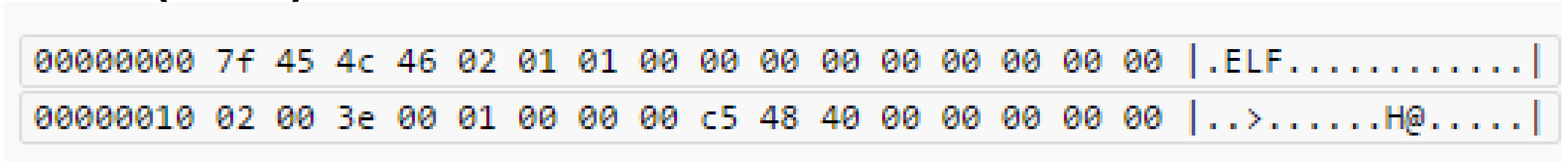
Executable File Formats [S15]

- Executable and Linkable Format (ELF)
- Common Object File Format (COFF)
- Intel Hex Record
- Motorola S Record (SREC)
- ARM Image Format (AIF)



```
:10010000214601360121470136007EFE09D2190140
:100110002146017E17C20001FF5F16002148011928
:10012000194E79234623965778239EDA3F01B2CAA7
:100130003F0156702B5E712B722B732146013421C7
:00000001FF
```

Intel Hex Record Example File[3]



```
00000000 7f 45 4c 46 02 01 01 00 00 00 00 00 00 00 00 00 |.ELF............|
00000010 02 00 3e 00 01 00 00 00 c5 48 40 00 00 00 00 00 |..>......H@.....|
```

ELF File Example[4]