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11032 GNU

Hacking the GNU Linker

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Class Objective

When you finish this class you will:

- Understand compiler optimizations and how they might affect your code
- Understand the link30 process
- Understand *gld* files and how they affect your final code
- Be able to modify linker scripts

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Agenda

- Optimization in the GNU compiler
- Common coding pitfalls
- The GNU linker Steps
- Contents of linker scripts
- Changes to linker scripts
- A complex application

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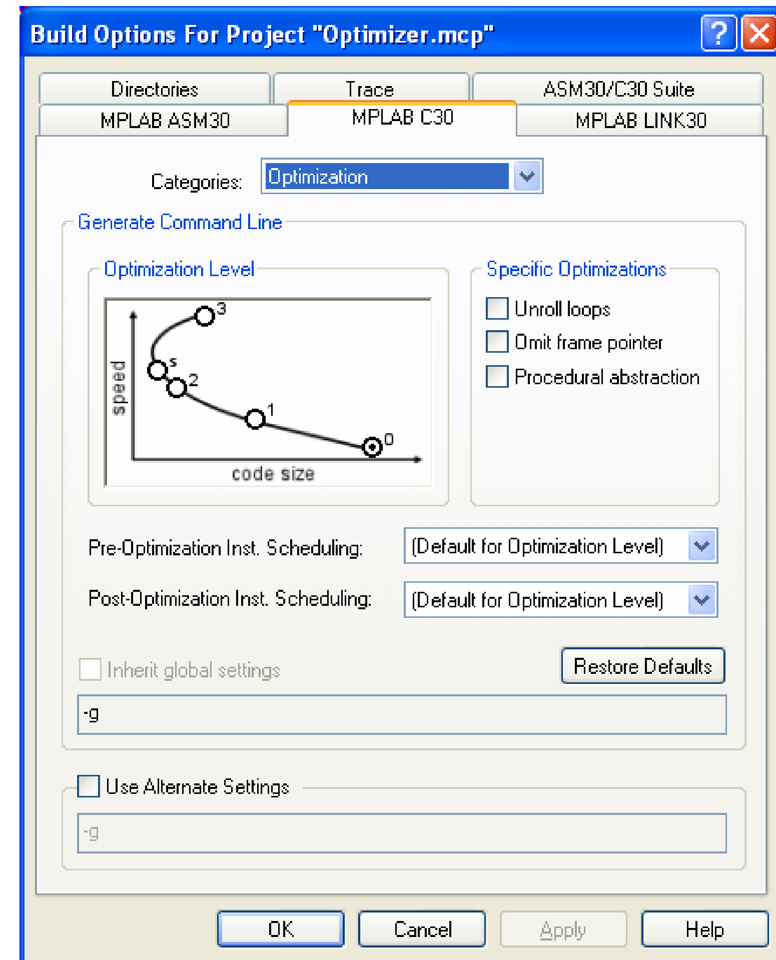
C30 Optimizer

4 levels of optimization

- **-O0 None**
  - Default Level
- **-O1**
  - Try to reduce code size and execution time
    - **If conversion**
    - **Merge constants**
    - **Dead code elimination**
    - **Redundancy analysis**



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C30 Optimizer continued

- **-O2**
  - Optimize yet more
    - **Crossjumping (weak PA)**
    - **Regmove**
    - **Takes longer to evaluate but produces smaller and faster code**
- **-O3**
  - All of the above plus
    - **Inline-functions**
    - **Move invariant branches out of loops**
    - **Note that this does not unroll-loops**
- **-Os**
  - Optimize for speed
    - **Most O2 switches**
    - **Reorder blocks in functions to reduce branches**

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Example of Optimization

```
const unsigned int xadder = 3;
const unsigned int yadder = 3;
int main(void)
{
   unsigned int x, y, z, i;
   // set the bit as an output
   TRISAbits.TRISA0 = 0;
   x = 0;        y = 10;
   for(i = 0; i < 20; i++) {
      x = x + xadder;
      y = y + yadder;
      z = 42;
      LATAbits.LATA0 = !LATAbits.LATA0;
   }
   LATA = x;              // here to ensure values are used after
   LATA = y;              // otherwise they will be optimised out
   LATA = z + 1;
   while (1);
}
```

Level	Size FLASH/RAM	
-O0	321/8	Vars on stack R-M-W
-O1	255/2	x+y+z eval as const, reg tied
-O2	255/2	
-O3	255/0	Fully reg tied
-Os	249/0	
-O3 –funroll-loops	441/0	Unrolled!

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Undetected Coding Errors

or… what breaks the compiler!

- **Shared variables that should be volatile <u>not</u> marked as volatile**
  - With no optimization the compiler will usually save the results of calculations back to memory
  - O1 and above will try and keep commonly used variables in registers
  - An ISR using the variable will load its own value from memory and store back to memory however the interrupted function will still be using a value cached in a register

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Lab 1

- **Tasks**
  - Set up MPLAB® IDE for later
  - See what optimization does
  - See what MPLAB C30 does

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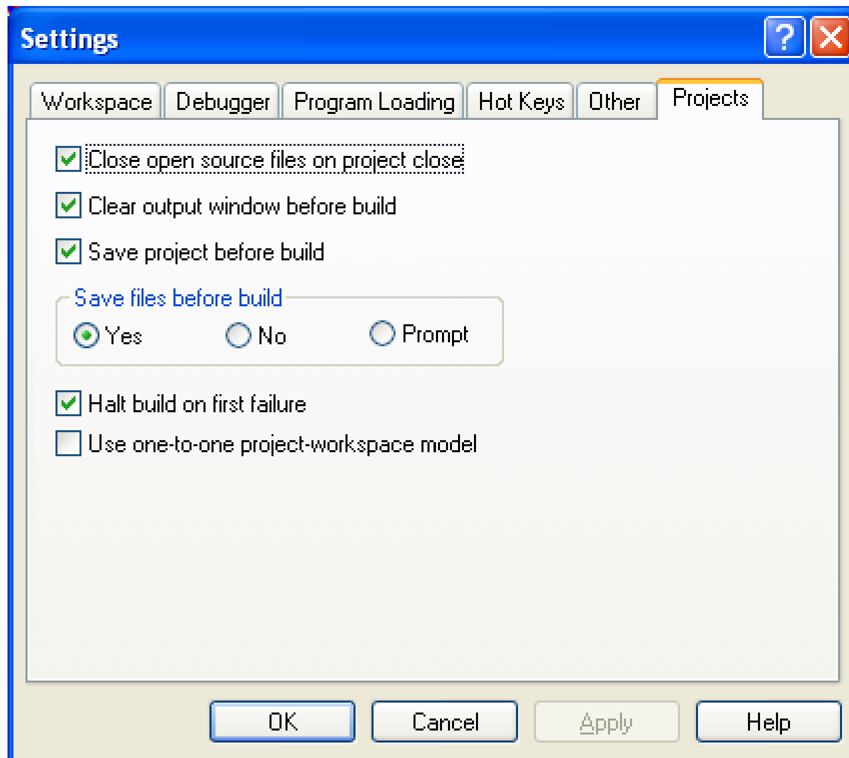
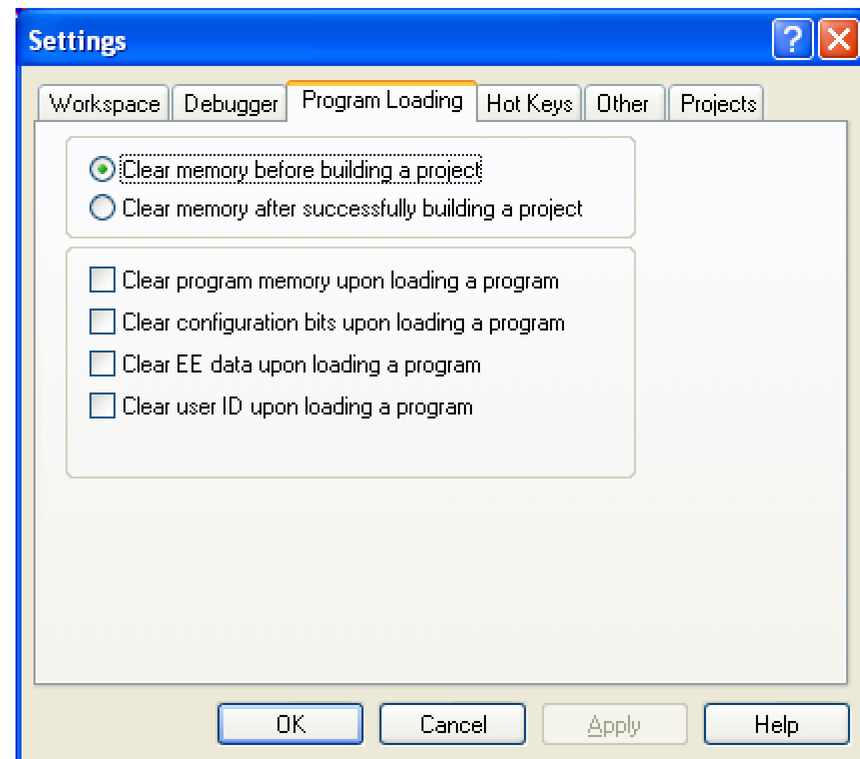
Hands-On!





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Hands-On!

- **Example code**
  - Load up and run C:\Masters\11032\optimizer*optimizer.mcw*
    - **Check the output on the logic analyser**
  - Turn on optimisation and observe the output
    - **Add the volatile keyword and run**
- **Also try**
  - C:\Masters\11032\simplescript*simplelink.mcw*
  - Check the output
    - **Add the commented line back in and run it**
    - **What is the problem?**

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More undetected coding errors

- **Inline assembly**
  - Simple *asm* statements work okay at –O0
    - **Assumptions made about register and memory use may not work with optimization turned on**
    - **Use extended asm statements**
      - asm ("swap %0" : "+r"(var));
      - Let the compiler know what resources you are using and what you clobber
  - Attempting Control Flow
    - **Do not use hardware *do* loops**
    - **Move them to a separate .s file and wrap the function properly**
- **Be kind to your compiler**
  - And it will be kind to you

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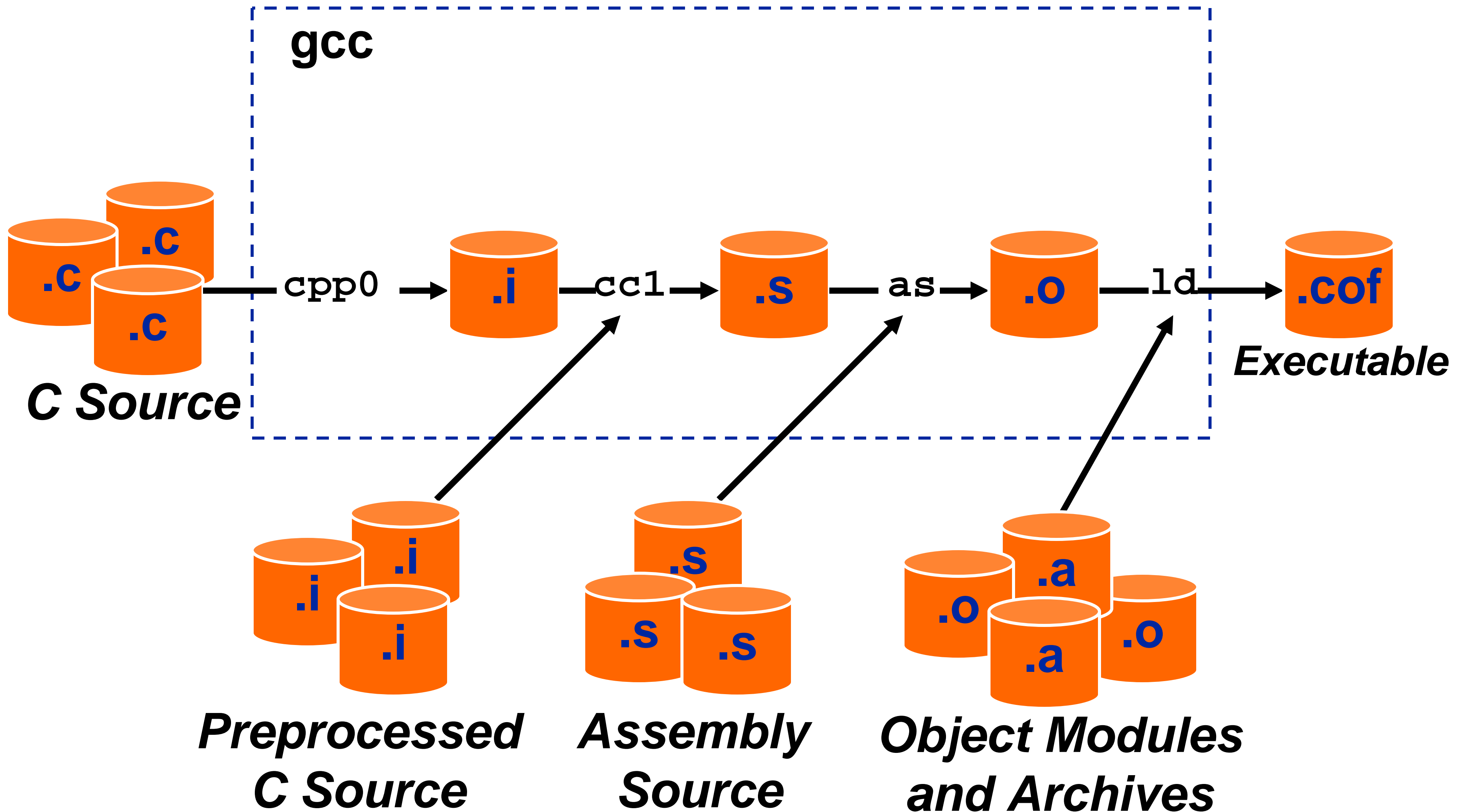
GNU Build Process



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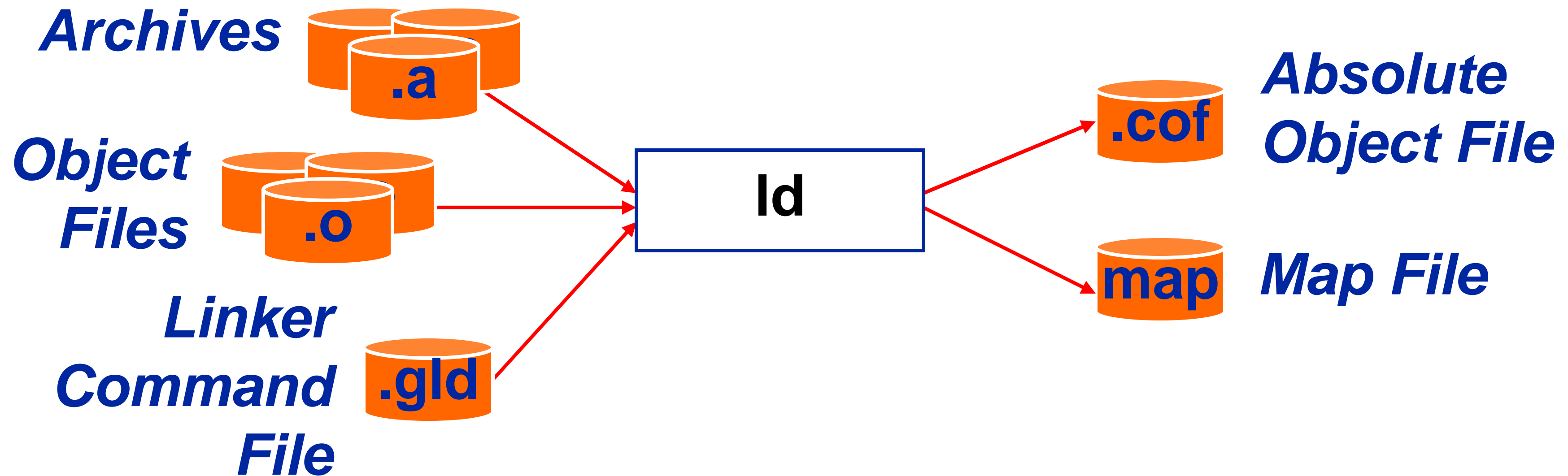
Linker Overview



- Assigns absolute addresses and resolves symbol references
- Command file describes memory organization and logical section location
- Maps input sections from the code to output sections in the hex file

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GNU Linkage Steps

- **Loading Input Files**
  - Check format, Build Tables of Sections
- **Allocating Memory**
  - Generate output sections from input sections
- **Resolving Symbols**
  - Convert symbols into section relative values
  - Match up all externally referenced symbols
- **Creating Special Sections**
  - Such as .handle, and .dinit
- **Computing Absolute Addresses**
  - Convert all section relative addresses into absolutes
- **Building the Output File**

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Linker Scripts *.gld* Files

- Processor Family
- Memory Regions
- Base Addresses
- Reset Section
- Input to Output Section Maps
- Interrupt Vector Tables
- SFR Addresses

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Terminology

Section Name	Attribute	Comment
.text	code	Program code
.data	data	Initialized data
.bss	bss	Un-initialized data, (Block Started by Symbol)
.xbss, .ybss	bss, xmemory	Un-initialized data in x/y memory
.xdata, .ydata	data, xmemory	Initialized data in x/y memory
.nbss	bss, near	near memory, excludes X
.ndata	data, near	
.ndconst	data, near	Constants, but in RAM
.pbss	bss, persist	Persistent memory, un-initialized, not zeroed
.dconst	data	
.const	psv	Constant data in PSV space
.eedata	eedata	Data in EEPROM

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Simple Example

- **With the previous hands-on example still open, look at the *gld* file**
  - Cut down version of normal file
  - All unused definitions removed
  - Note the interrupt section where padding has been used to ensure correct alignment

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Memory Regions

- Declare regions of memory that the linker can use to place code and data
- Flags used to help best-fit algorithm

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Memory Regions

```
data   (a!xr) : ORIGIN = 0x800,        LENGTH = 0x7800
reset         : ORIGIN = 0x0,          LENGTH = 0x4
ivt           : ORIGIN = 0x4,          LENGTH = 0xFC
program (xr)  : ORIGIN = 0x400,        LENGTH = 0x2A800
CONFIG1       : ORIGIN = 0xF80000,     LENGTH = 0x2
CONFIG2       : ORIGIN = 0xF80002,     LENGTH = 0x2
FGS           : ORIGIN = 0xF80004,     LENGTH = 0x2
FOSCSEL       : ORIGIN = 0xF80006,     LENGTH = 0x2
FOSC          : ORIGIN = 0xF80008,     LENGTH = 0x2
```

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Reset Section

- **Constructs the *goto* instruction at location 0x000000**
- **__*reset* symbol defined in *crt0.s***
  - initialize SP and SPLIM
  - initialize PSV if __const_length > 0
  - process the .dinit template
    - **or link with *crt1.s***
  - call _main

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Reset Section

```
.reset :
 {
        SHORT(ABSOLUTE(__reset));
        SHORT(0x04);
        SHORT((ABSOLUTE(__reset) >> 16) & 0x7F);
        SHORT(0);
 } >reset
```

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Section Maps

- **Input Sections defined in the application**

```
void filterFunction(int num, int* src);
unsigned char strData[40];
int coefficients[] = { 4, 5, 29, 34};
int __attribute__((section(".mySection")))
   filterData[34];
```

- **Converted to Output Sections in the COF file**
  - Defined by the linker and *gld* file
  - Grouped

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Section Map

```
.text __CODE_BASE :
{
      *(.init);
      *(.handle);
      *(.libc) *(.libm) *(.libdsp);
      *(.lib*);
      *(.text);
} >program
```

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Interrupt Vector Tables

- **Laid out to match the devices *IVT* & *AIVT***
  - One entry per interrupt vector slot
- **C like notation to call user function or default**

Interrupt Vector Table

```
.ivt __IVT_BASE :
{
        ..
        ..
        LONG( DEFINED(__OscillatorFail) ? ABSOLUTE(__OscillatorFail) :
                ABSOLUTE(__DefaultInterrupt));

        ..
        ..
        LONG( DEFINED(__T2Interrupt) ? ABSOLUTE(__T2Interrupt) :
                ABSOLUTE(__DefaultInterrupt));
  } >ivt
```

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SFR Names

- **SFR names allow symbols to be resolved**
- **Two forms**
  - Without '_' for assembly language code
  - With leading '_' to comply with names that the C compiler generates

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Things to do in the linker

- Fix the stack at a specific location and/or length
- Calculate the length of a section or module
- Use one handler for multiple interrupts
- Build a Bootloader

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Stack Size and Allocation

- **Stack is located at the bottom of RAM**
  - Linker defines __*SP_init*
- **Allocated largest available block**
  - Linker defines __*SPLIM_init*

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Stack Size and Allocation

```
.stack 0x1800 :
{
        __SP_init = .;
        . += 0x100;
        __SPLIM_init = .;
        . += 8;
} >data
```

Section 11.11
ASM30/LINK30
manual

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C Equivalent

- **It is also possible to define a stack in C**
  - Use symbol names *_SP_init* and *_SPLIM_init*
  - Fix their locations using the address attribute
  - Must not be initialised by crt0.s
  - Note the guardband

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C Stack allocation

```
int __attribute__((address(0x1800), persistent)) _SP_init[128];
int __attribute__((address(0x1900), persistent)) _SPLIM_init[4];

int main(void)
{
        unsigned int x;
        ..
        ..
}
```

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Length of Sections

- **A Bootloader may need to know the length of a module or section**
  - Used for CRC checking the app
  - Only calculated at link time
  - Stored along with the program code

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Length of Sections

```
.text __CODE_BASE :
{
        LONG(SIZEOF(.text));
        LONG(.tEnd - .tStart);
        *(.init);
         *(.handle);
         *(.libc) *(.libm) *(.libdsp); *(.lib*);
         .tStart = . ;
         *(.text);
         .tEnd = . ;
} >program
```

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Common Interrupt Handler

- **One interrupt handler can handle multiple interrupts:**

```
void __attribute__((interrupt)) _CommonHandler(void)
{
        // do something then clear interrupt sources
        IFS0bits.T2IF = IFS0bits.T3IF = 0;
}
```

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Common Interrupt Handler

```
.ivt __IVT_BASE :
{
  ..
  LONG( DEFINED(__T2Interrupt) ? ABSOLUTE(__T2Interrupt) :
         ABSOLUTE(__DefaultInterrupt));
  LONG( DEFINED(__T3Interrupt) ? ABSOLUTE(__T3Interrupt) :
         ABSOLUTE(__DefaultInterrupt));
} >ivt
```

```
.ivt __IVT_BASE :
{
  ..
  LONG( DEFINED(__CommonHandler) ? ABSOLUTE(__CommonHandler) :
         ABSOLUTE(__DefaultInterrupt));
  LONG( DEFINED(__CommonHandler) ? ABSOLUTE(__CommonHandler) :
         ABSOLUTE(__DefaultInterrupt));
} >ivt
```

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Common Interrupts in C

```
// declare the T3 Interrupt routine and alias it to T2 ISR
void __attribute__((interrupt, auto_psv, alias("_T2Interrupt")))
        _T3Interrupt(void);


// the T2 ISR handler
void __attribute__((interrupt, auto_psv)) _T2Interrupt(void)
{
        // toggle the state
        bState = !bState;
        IFS0bits.T2IF = IFS0bits.T3IF = 0;
}
```

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Bootloaders

- **For 16-bit, Bootloaders are common**
  - AN851, Examples for all 16-bit devices
- **Frequently, customer specific needs**
  - Special memory layout
  - Common functions (3DES, TCP/IP)
- **What changes are needed to gld files?**
  - Only examples, customers will differ
- **How to demonstrate and test Bootloaders?**
  - Running two applications in MPLAB® IDE is possible

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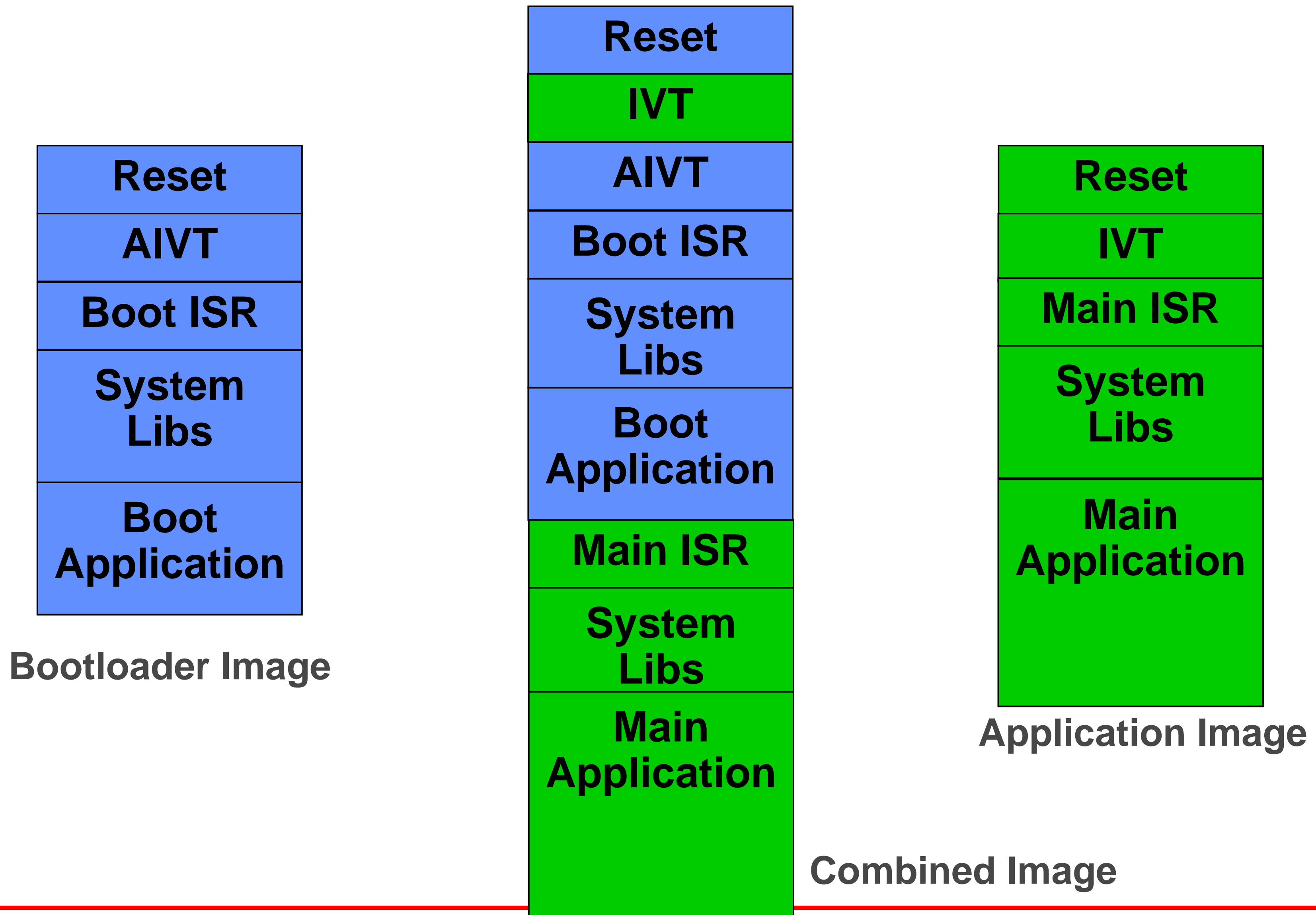
Bootloader Memory Layout



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Task Outline

- Restrict the Bootloader to a limited section of memory
- Define the application address range
- Make the Bootloader call the main code
- Handle interrupt sources in the Bootloader and application
- Prevent the application overwriting the reset section and aivt tables
- Prove it works in the simulator!

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Hands-On Tasks

- **In the Bootloader**
  - Modify the gld file so that the program section starts at 0x200 and is 0x200 in length
  - Change the __CODE_BASE to 0x200
  - Verify that the gld only has an aivt section and no ivt section
  - Define a function pointer in bootloader.c and set it to the main application entry point (0x400)
  - Switch in the aivt whilst waiting for a timeout
  - Switch out the aivt and call the main application

- **In the main application**
  - Verify in the gld file that the program section starts at 0x400 and is 0x2A800 long
  - Comment out the .reset output section
  - Verify that the gld only has an ivt section and no aivt section

- **In MPLAB® IDE**
  - Ensure multiple project views are enabled
  - Settings>Program Loading
    - **Clear all tick boxes**
  - Set Bootloader as active project
  - Make application (using right-click)
  - Make Bootloader
  - Debug->Animate

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Suggestions for Linker Files

- **Modify one item at a time**
  - Test and retest
  - Customers have most success by just modifying output sections
- **The linker is extremely fragile**
  - Try to use C attributes whenever possible
  - Trying to be too clever will break the linker

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Summary

- **Compiler optimizations affect code density and speed**
  - They can have side effects on your code
- **The linker is a powerful way of laying out your application in memory**
  - Many modifications can be done in ‘C’
  - But some can only be done at the link stage
- ***gld* Files define how the linker works**
  - Complex applications may require *gld* changes
  - Modify these files with care

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Any Questions?

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References

- MPLAB® C30 C Compiler User's Guide – DS51284
- MPLAB ASM30, MPLAB LINK30 and Utilities User's Guide – DS51317

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