

Why Learn Assembly Language

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IEEE Spectrum's Top Programming Languages 2022

<https://spectrum.ieee.org/top-programming-languages-2022>

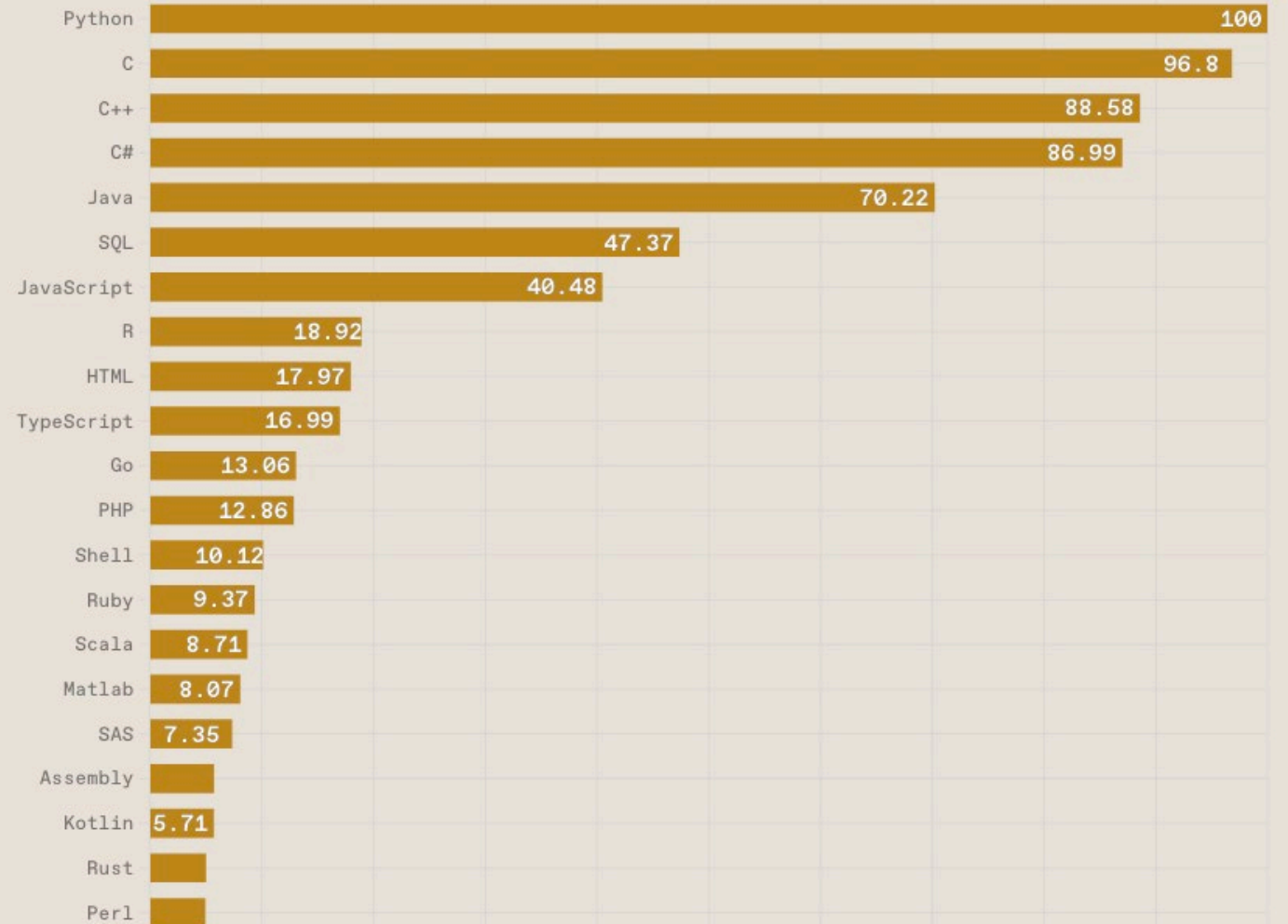
Top Programming Languages 2022

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Spectrum

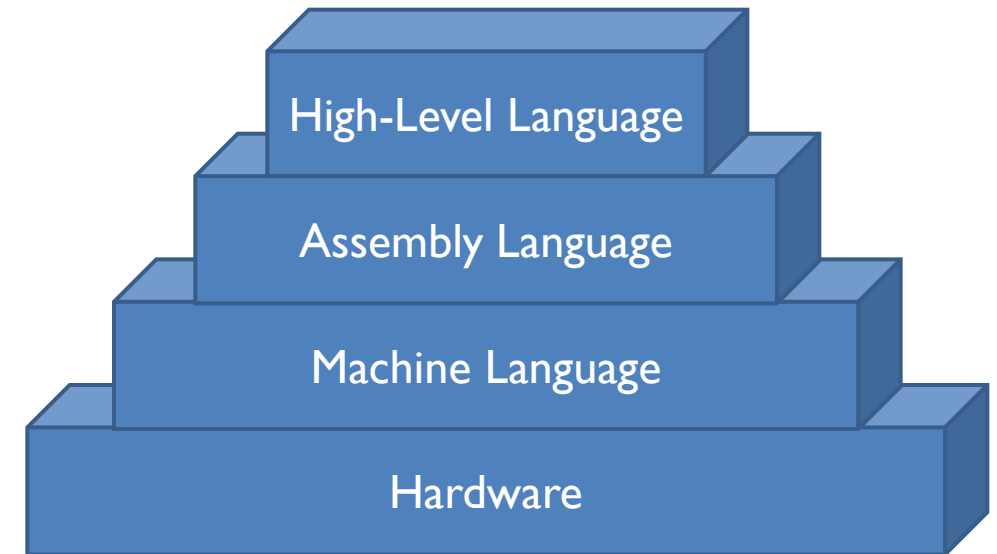
Jobs

Trending



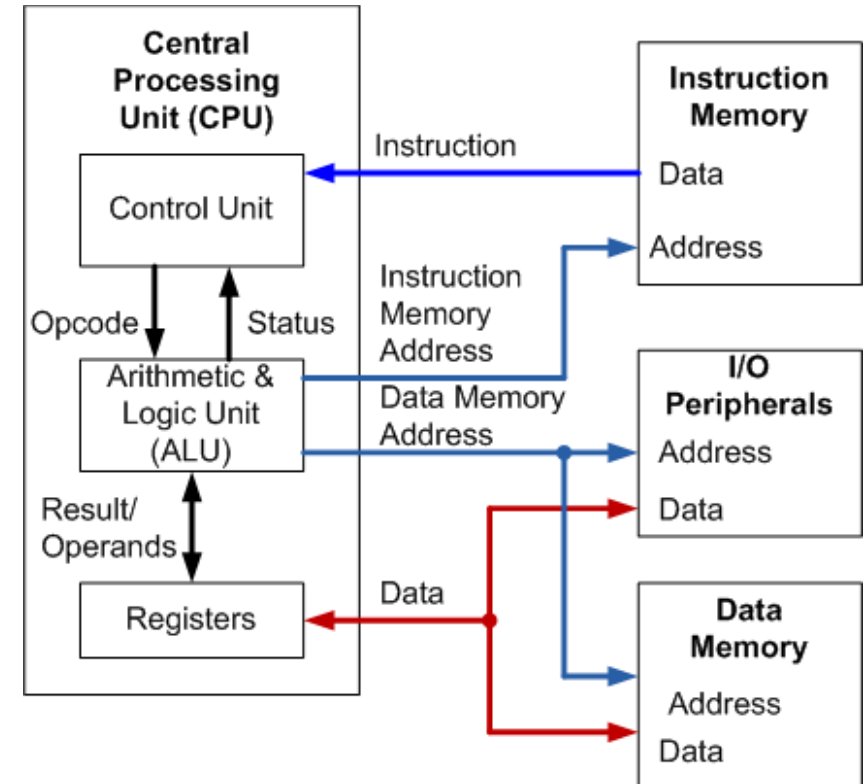
Assembly: Not just another language

- ▶ Assembly vs high level languages (HLLs).
 - ▶ Most embedded systems are programmed in HLLs
 - ▶ Assembly disadvantages
 - ▶ difficult to develop, read, and maintain
 - ▶ bug prone
 - ▶ not portable
- ▶ However, assembly isn't “**just another language**”.
 - ▶ Interface between hardware and software
 - ▶ Implements high-level languages



Assembly: Learn how processors work

- ▶ Learn about the inner workings of a processor
 - ▶ Data representation
 - ▶ Registers
 - ▶ Computer arithmetic
 - ▶ Memory addressing
 - ▶ Instruction set
 - ▶ I/O
- ▶ Provide background knowledge for later courses
 - ▶ computer architecture,
 - ▶ operating systems,
 - ▶ compiler



Assembly: Faster and smaller

- ▶ Assembly program runs faster than HLLs.
 - ▶ Performance critical codes must be written in assembly.
 - ▶ Use profiling tools to find the performance bottleneck and rewrite that code section in assembly
 - ▶ Latency-sensitive applications, such as aircraft controller
 - ▶ Some C compilers do not use some special Thumb instructions, such as **ROR** (Rotate Right) and **RRX** (Rotate Right Extended).
- ▶ Cost-sensitive applications
 - ▶ Assembly consumes little memory
 - ▶ Embedded devices, where the size of code is limited, wash machine controller, automobile controllers

Assembly: The only choice sometimes

- ▶ Hardware/processor specific code,
 - ▶ Special instructions not supported by a compiler
 - ▶ **CPSID I** ; *Disable IRQ by setting PRIMASK*
 - ▶ **CPSIE I** ; *Enable IRQ by clearing PRIMASK*
 - ▶ **MSR/MSR** ; *Read/write to special registers*
 - ▶ **WFI** ; *Enter low-power & wait for interrupt*

```
// Enable Interrupts
__attribute__((always_inline))
static inline void __enable_irq(void)
{
    __asm("cpsie i");
}

// Disable Interrupts
__attribute__((always_inline))
static inline void __disable_irq(void)
{
    __asm("cpsid i");
}
```

cmsis_armcc.h

Assembly: The only choice sometimes

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 - ▶ `MSR/MSR` ; *Read/write to special registers*
 - ▶ `WFI` ; *Enter Low-power & wait for interrupt*
- ▶ Startup Code
 - ▶ the stack and heap areas
 - ▶ interrupt vector table
 - ▶ default implementation of ISRs
 - ▶ written in assembly, and possible in C with inline assembly
 - ▶ C version is toolchain dependent

```
...
Stack_Size EQU 0x400;
                AREA STACK,NOINIT,READWRITE,ALIGN=3
Stack_Mem SPACE Stack_Size
__initial_sp

Heap_Size EQU 0x200;
                AREA HEAP, NOINIT, READWRITE, ALIGN=3
__heap_base
Heap_Mem SPACE Heap_Size
__heap_limit

__Vectors
    DCD __initial_sp          ; Top of Stack
    DCD Reset_Handler        ; Reset Handler
    DCD NMI_Handler          ; NMI Handler
    DCD HardFault_Handler    ; Hard Fault Handler
    DCD MemManage_Handler    ; MPU Fault Handler
    DCD BusFault_Handler     ; Bus Fault Handler
    DCD UsageFault_Handler   ; Usage Fault Handler
    ...
```

startup_stm32l476xx.s

Assembly: The only choice sometimes

▶ Hardware/processor specific code,

- ▶ Special instructions not supported by a compiler
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 - ▶ `CPSIE I` ; *Enable IRQ by clearing PRIMASK*
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▶ Startup code

- ▶ the stack and heap areas
- ▶ interrupt vector table
- ▶ default implementation of ISRs
- ▶ written in assembly, and possible in C with inline assembly
- ▶ C version is toolchain dependent

▶ Device driver

- ▶ access machine-dependent registers and I/O
- ▶ control exact code behavior in critical sections

```
static inline u8 __raw_readb(const volatile
void __iomem *addr) {
    u8 val;
    asm volatile("ldrb %0, %1"
        : "=r" (val)
        : "Qo" (*(volatile u8 __force *)addr));
    return val;
}

static inline void __raw_writeb(u8 val,
volatile void __iomem *addr) {
    asm volatile("strb %1, %0"
        : : "Qo" (*(volatile u8 __force *)addr),
        "r" (val));
}
```

Linux 5.6, /arch/arm/include/asm/io.h

Assembly: Help you write better HLLs

▶ Help you understand and write HLLs better

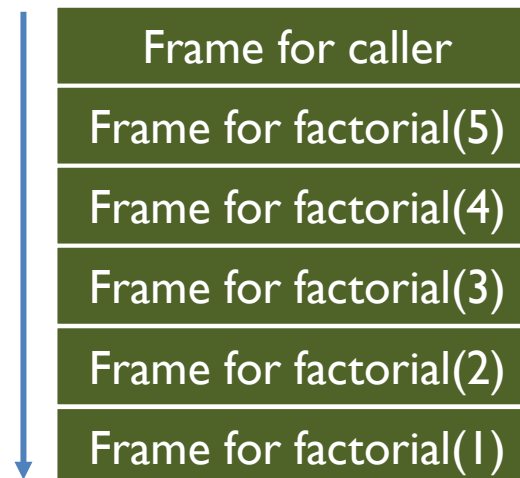
- ▶ Low-level data representation
- ▶ C Pointers
 - ▶ Reference & dereference
- ▶ Passing parameters to functions:
 - ▶ Pass by reference
 - ▶ Pass by value
- ▶ Variables declared as **volatile** or **static**
- ▶ Inefficiency of recursive function: stack operations

```
*p += 100
```

```
LDR r0, =p
LDR r1, [r0]
ADD r1, r1, #100
STR r1, [r0]
```

```
int* pi;
int volatile* pvi;
int* volatile vpi;
```

Stack grows in
recursive phase



Stack shrinks in
regression phase

Assembly: Help you write better HLLs

```
uint32_t x = 1;
int32_t y = -1;

if (x > y)
    printf("Of course.")
else
    printf("Something is wrong!");
```

Output:

Something is wrong!

```
r0 = 0x00000001 ; x = 1
r1 = 0xFFFFFFFF ; y = -1
```

```
CMP r0, r1
BLS else ; Branch on Unsigned Lower than or Same
```

compiling main.c...

linking...

Program Size: Code=640 RO-data=424 RW-data=8 ZI-data=5472

FromELF: creating hex file...

".\Objects\project.axf" - 0 Error(s), 0 Warning(s).

Build Time Elapsed: 00:00:01

The C standard dictates that when a signed integer and an unsigned integer of the same size are compared, the signed integer is converted to an unsigned integer, hence $0xFFFFFFFF = 2^{32} - 1 = 4,294,967,295$ (UINT_MAX), instead of -1

Assembly: Help you write better HLLs

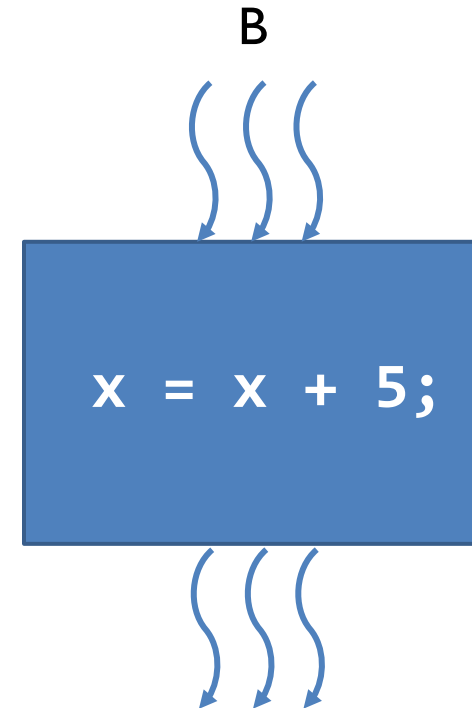
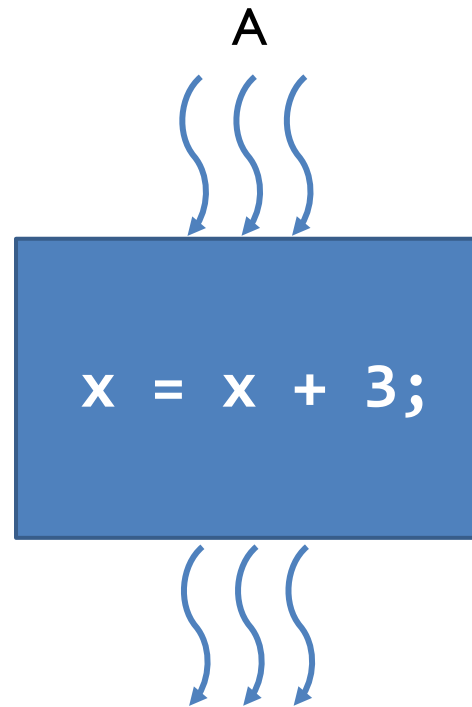
```
uint32_t x = 1;
int32_t y = -1;

if ((int32_t) x > y)
    printf("Of course.")
else
    printf("Something is wrong!");
```



Assembly: Help you write better HLLs

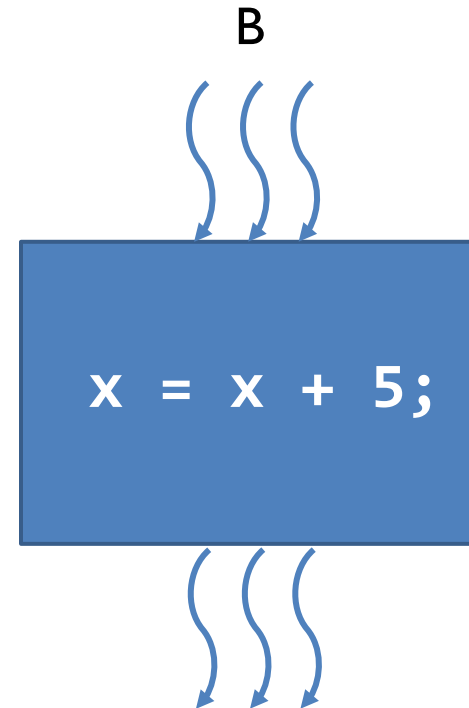
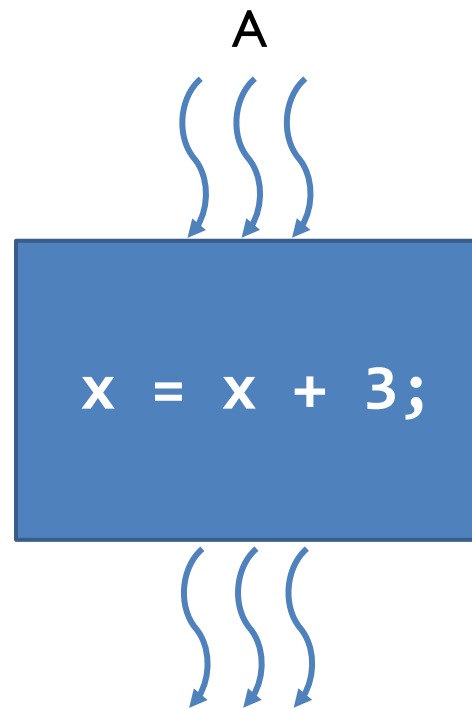
x = 1;



What is the final value of x?

Assembly: Help you write better HLLs

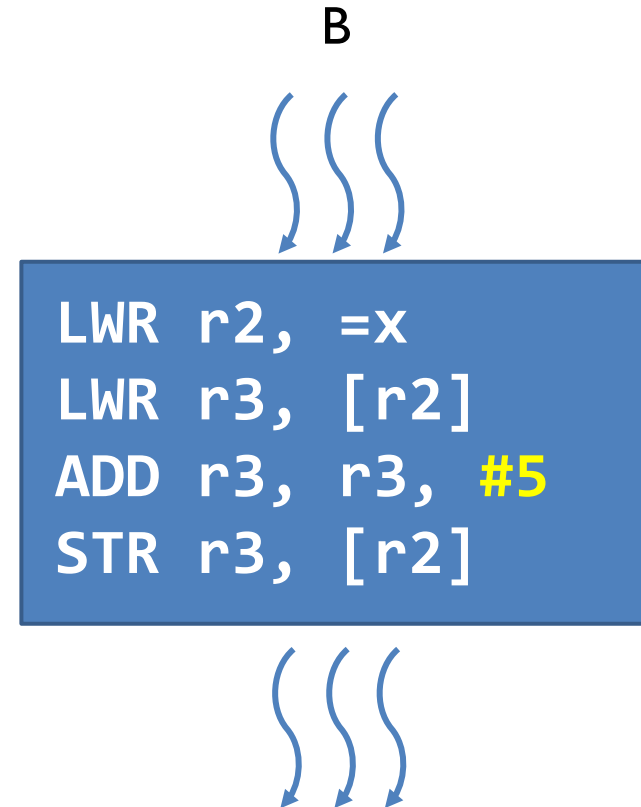
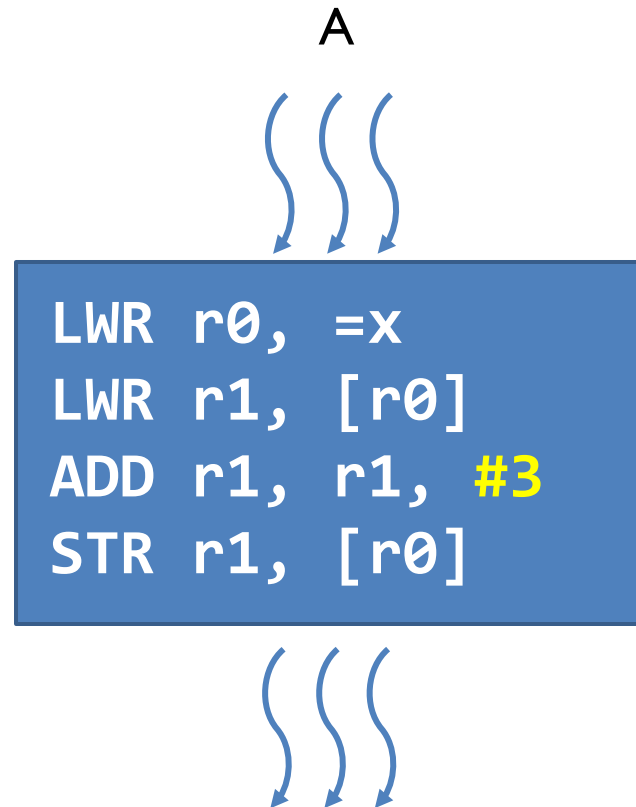
x = 1;



x = 4, 6, 9;

Assembly: Help you write better HLLs

x = 1;



x = 4, 6, 9;

Assembly: Help you write better HLLs

x = 1;

A

```
LWR r0, =x  
LWR r1, [r0]  
ADD r1, r1, #3  
STR r1, [r0]
```

x = 4

x = 9

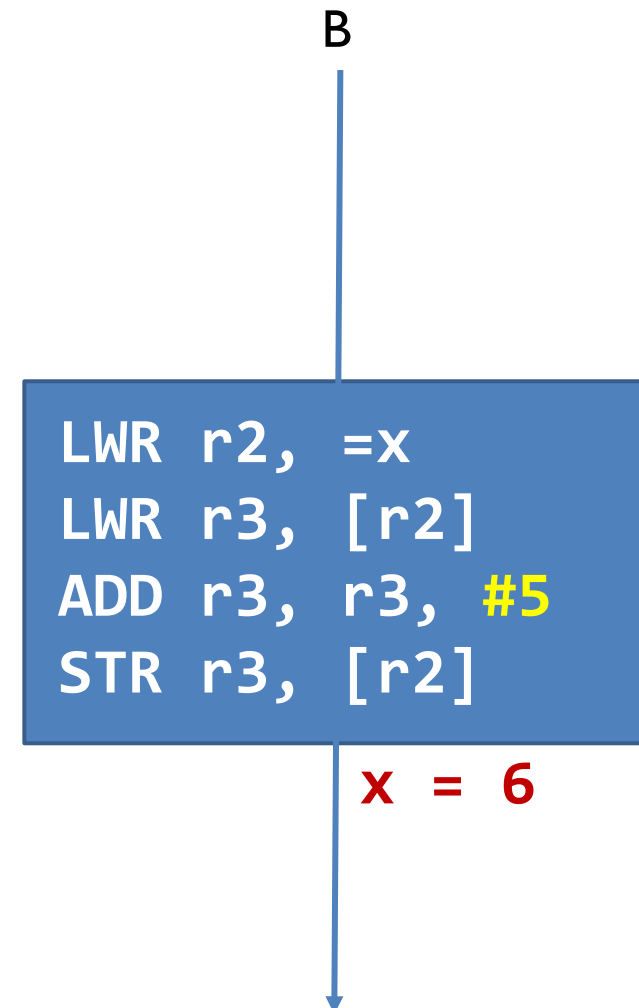
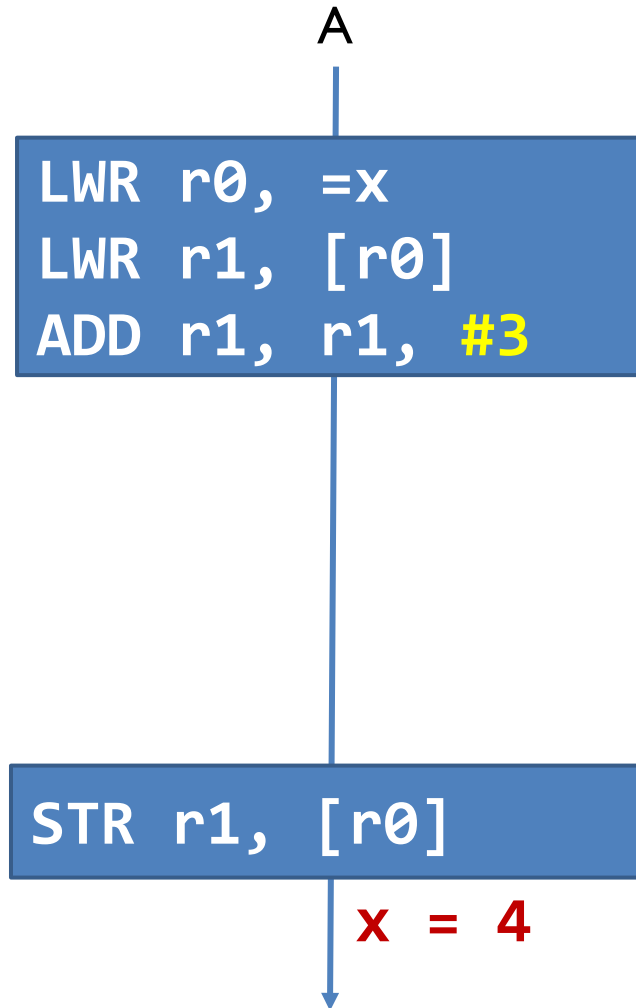
B

```
LWR r2, =x  
LWR r3, [r2]  
ADD r3, r3, #5  
STR r3, [r2]
```

x = 9

Assembly: Help you write better HLLs

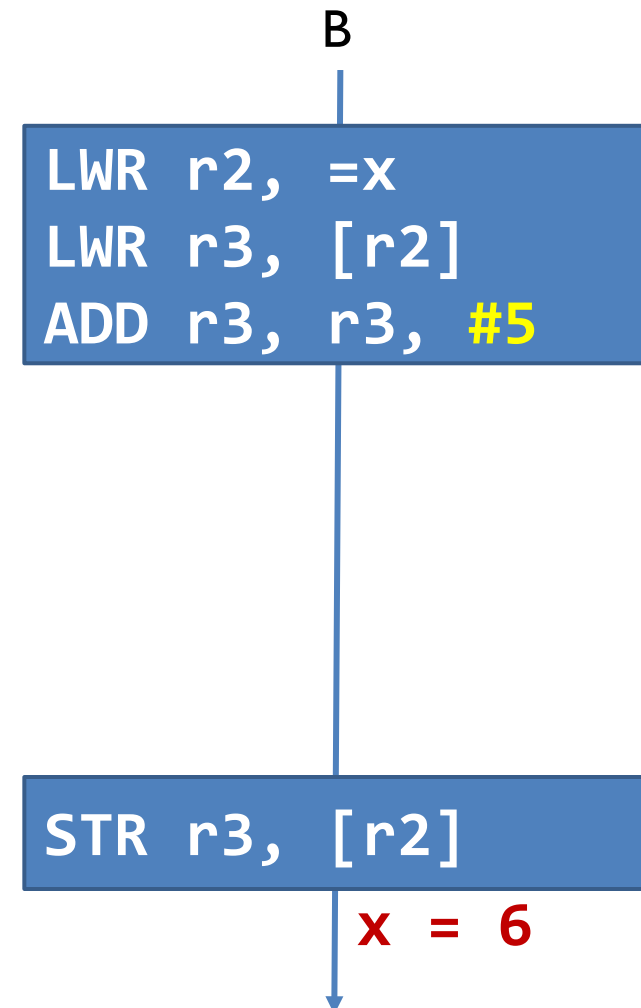
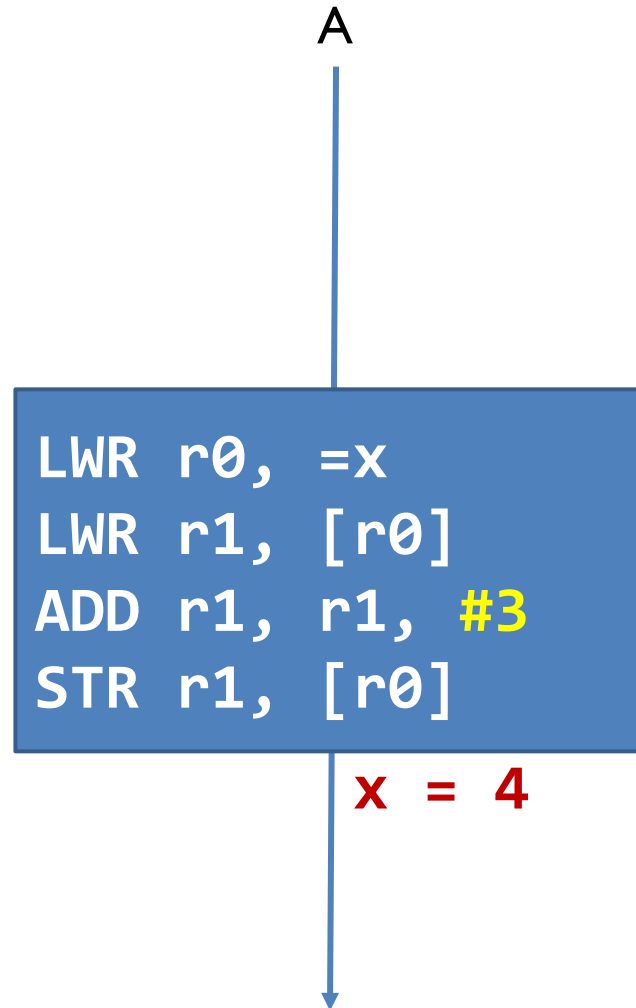
x = 1;



x = 4

Assembly: Help you write better HLLs

x = 1;



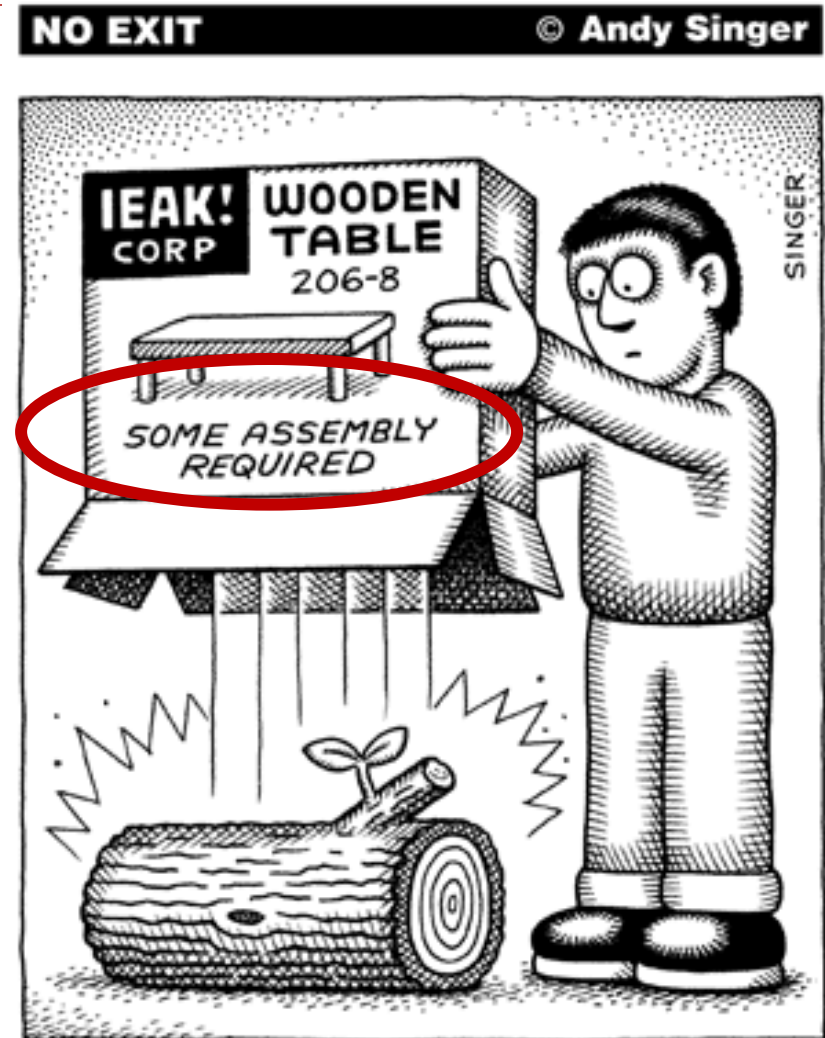
x = 6

Why should we learn Assembly?

- ▶ Assembly isn't "just another language".
 - ▶ Help you understand how does the processor work
- ▶ Assembly program runs faster than high-level language.
 - ▶ Performance critical codes may need to be written in assembly.
 - ▶ Use the profiling tools to find the performance bottle and rewrite that code section in assembly
 - ▶ Latency-sensitive applications, such as aircraft controller
 - ▶ Standard C compilers do not use some operations available on ARM processors, such ROR (Rotate Right) and RRX (Rotate Right Extended).
- ▶ Hardware/processor specific code,
 - ▶ Processor booting code
 - ▶ Device drivers
 - ▶ Compiler, assembler, linker
 - ▶ A test-and-set atomic assembly instruction can be used to implement locks and semaphores.
- ▶ Cost-sensitive applications
 - ▶ Embedded devices, where the size of code is limited, wash machine controller, automobile controllers
- ▶ Better understand high-level programming languages

Recap: Why Learn Assembly?

- ▶ Gain insights about what is under the hood of a processor
- ▶ Assembly should be used for performance critical sessions
- ▶ Assembly must be used for processor-dependent instructions that are not supported by compilers
- ▶ Understanding assembly helps us write better HLLs
- ▶ Reverse engineering of software without source code, for security attacks/defenses



www.andysinger.com

References

- ▶ The Untold Story of Assembly
 - ▶ <https://www.youtube.com/watch?v=2RM5HTpdSqY>