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From Source Code to Executable: Preprocessing, Compiling, and Linking

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From Source Code to Executable: Preprocessing, Compiling, and Linking

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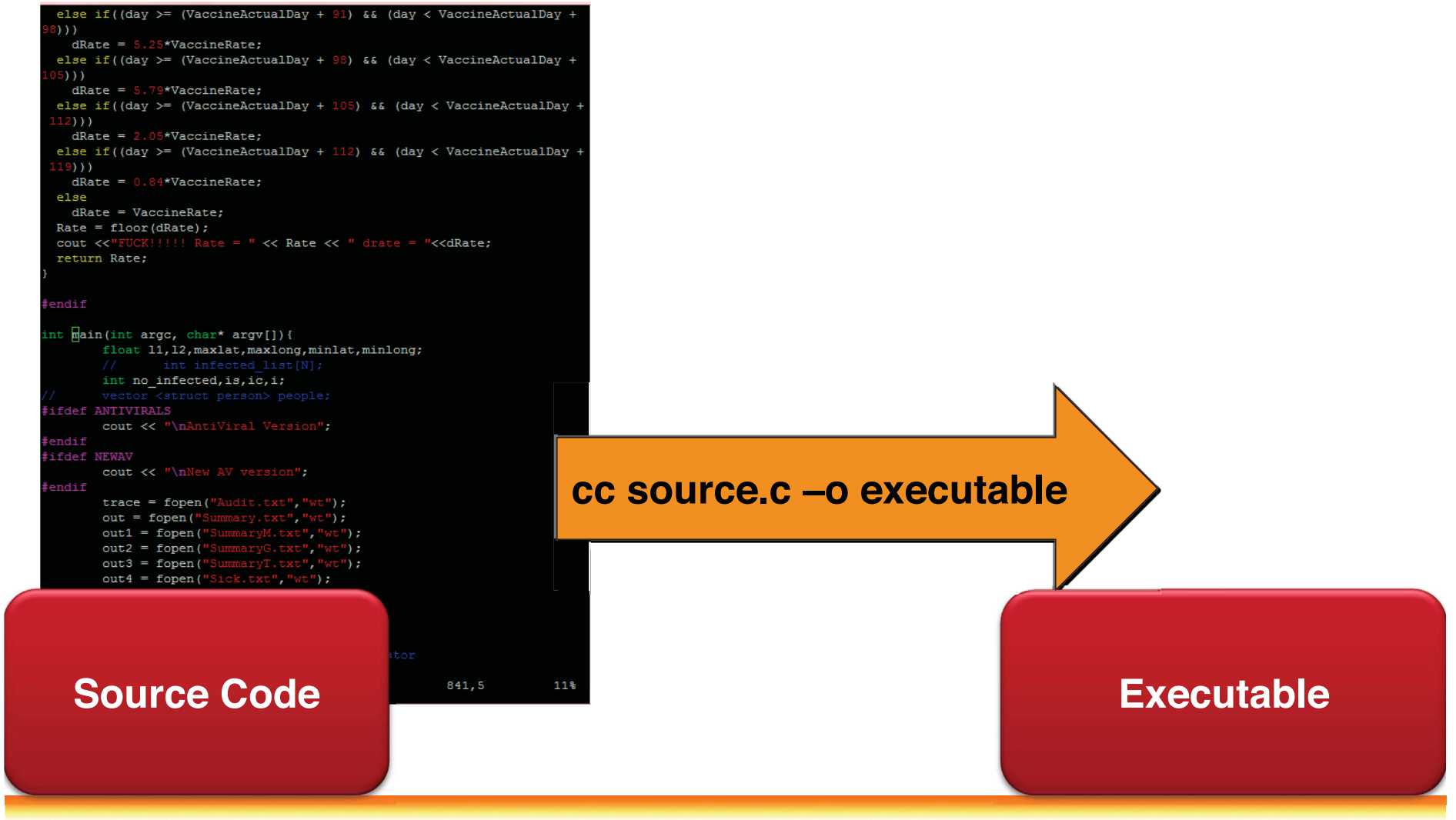
Overview / Compiler

- The preprocess / compile / linking process
  - Individual steps in detail
- Preprocessing in C and Fortran
- The C-preprocessor, typical directives
- Compilers and Vendors
- Compiler Flags
- Linking Flags and Utilities

The compiling process



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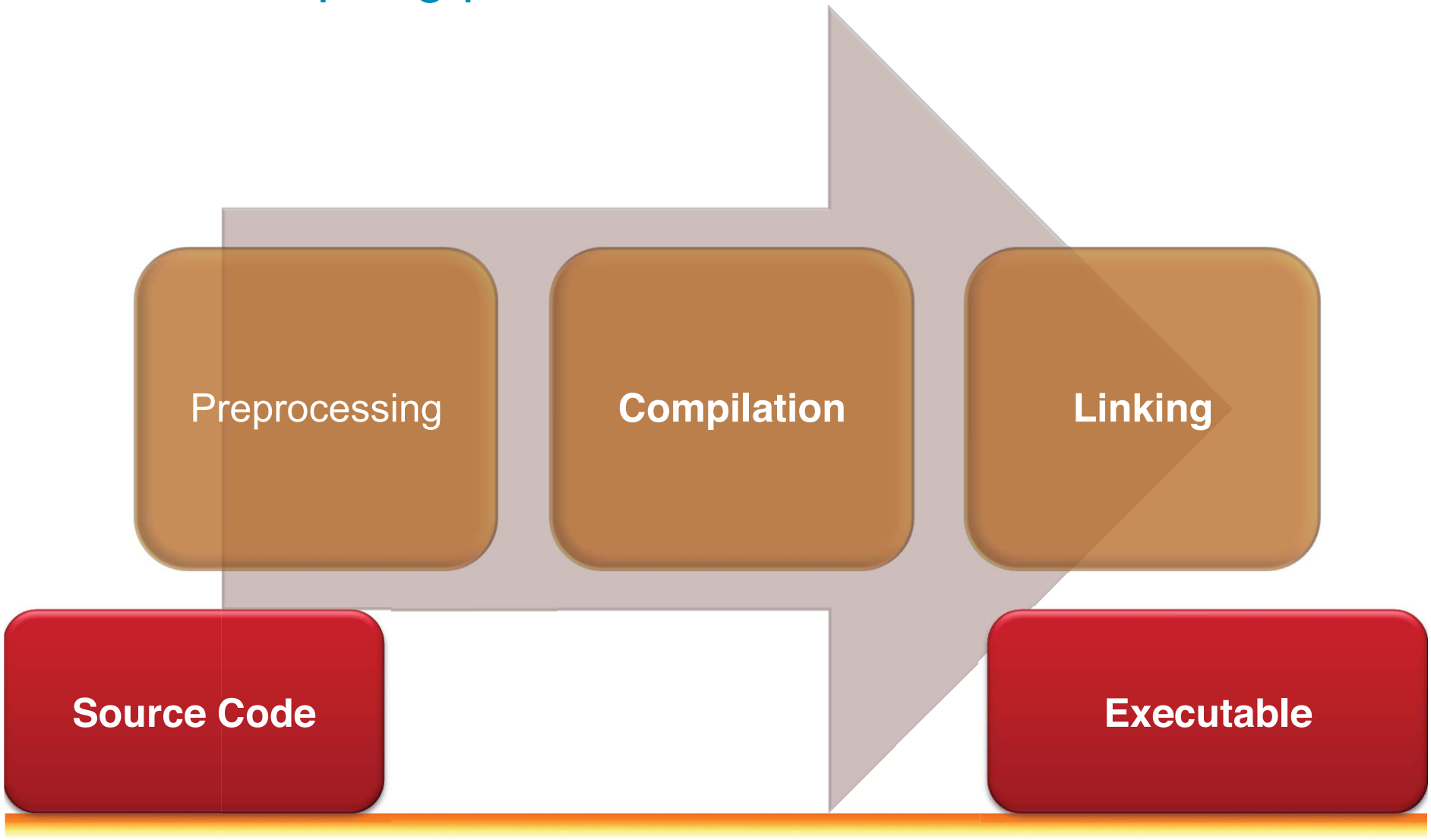
The compiling process



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Example of the process

- Consider the minimal C program ‘hello.c’:

```
#include <stdio.h>

int main (void) {
      printf("hello world\n");
      return 0;
}
```

- What happens if we do?
  > cc hello.c –o hello

Step 1: Preprocessing

- Handles all line in source code with '#' directives
  - File inclusion
  - Conditional compilation
  - Macro expansion
- In our simple example:

```
#include <stdio.h>
```

  - This translates to 'insert file /usr/include/stdio.h' into my source code.
- If you would like to see the pre-processed source:

```
> cc -E hello.c -o hello.pp.c
```

Preprocessing, what is it good for?

- Selective compilation:

```
#include <stdio.h>

int main (void) {

#ifdef LINUX
        printf("hello world from Linux\n");
#else
        printf("hello world from something else");
        return 0;
}
```

- cc –DLINUX hello.c –o hello
  - prints “hello world from Linux”

Step 2: Compilation

Parses Source Language
(lexical + syntactical analysis)

Translate to internal representation (trans-code)

(Optimizations: reorder, merge, eliminate)

Conversion to Assembly
(What the computer actually parses as instructions)

Assembly Language

- cc –S hello.c
  - Produces hello.s

```
.LC0:
        .string "hello world\n"
        .text
.globl main
        .type   main,@function
main:
        pushl   %ebp
        movl    %esp, %ebp
        subl    $8, %esp
        andl    $-16, %esp
        movl    $0, %eax
        subl    %eax, %esp
        subl    $12, %esp
        pushl   $.LC0
        call    printf
        addl    $16, %esp
        movl    $0, %eax
        leave
        ret
```

Optimized Assembly

```
.LC0:
        .string "hello world"
        .text
        .p2align 2,,3
.globl main
        .type   main,@function
main:
        pushl   %ebp
        movl    %esp, %ebp
        subl    $8, %esp
        andl    $-16, %esp
        subl    $12, %esp
        pushl   $.LC0
        call    puts
        xorl    %eax, %eax
        leave
        ret
```

Assembler

- Assembler (as) translates assembly to binary
  - Creates so-called object files

```
> cc -c hello.c
> nm hello.o
00000000     T main
             U printf
```

Linker

- The Linker (ld) puts it all together
  - Adds startup code and library code to binary for creation of final executable.

```
>ld -o hello hello.o
>./hello
>hello world
```

Adding Libraries

- Libraries are a powerful tool to give programmers access to optimized or highly used functions
- libmath example
  - exp(double) is a function provided by libmath.

```
#include <math.h>
#include <stdio.h>
int main(int argc, char **argv)
{
        printf("exp(2.0)=%f\n", exp(2.0));
        return 0;
}
```

To compile: cc –lm hello.c –o hello

Practical Compiling Issues

- Preprocessing in C and Fortran
  - C/C++ mandatory
  - Optional in Fortran
    - Often implicit via file name: name.F, name.F90, name.FOR
- Can set define variables on the command line
  - -DDEF_ARR=200
  - Use capital letters to signal a define

C Pre-processor directives

- #define MYVAL 100
- #undef MYVAL
- #if defined(MYVAL) && defined(__LINUX)
- #elif(MYVAL < 200)
- #else
- #endif
- #include “myfile.h”
- #include <mysysfile.h>

Compilers: GNU, PGI, Intel (and pathScale)

- We will only cover C/C++, and Fortran 77/95
- GNU: gcc, g++, g77, gfortran
  - Free open-source (http://www.gcc.gnu.org)
  - 'native' compilers on Linux and Mac OS X
  - Available on virtually all computing architectures
  - C/C++ are very good, Fortran not so good.
- PGI: pgcc, pgCC, pgf77, pgf90
  - Commercial with trial, x86 and x86_64
  - Quite good if you need optimized Fortran code
- Intel: icc, icpc, ifort
  - Commercial with trial and non-commercial for Linux
  - x86, ia64 (Itanium) and EM64t (x86_64)
  - Available for Linux, Windows, and Mac OS X

Common Compiler Flags

- Optimization: -O, -O0, -O1, -O2, etc.
  - Predefined sets of optimization strategies
  - Can alter semantics (be careful)
  - For example: -O1 in gcc yields:

```
-fauto-inc-dec -fcprop-registers -fdce -fdefer-pop
-fdelayed-branch -fdse -fguess-branch-probability
-fif-conversion2 -fif-conversion -finline-small-functions
-fipa-pure-const -fipa-reference -fmerge-constants
-fsplit-wide-types -ftree-builtin-call-dce -ftree-ccp
-ftree-ch -ftree-copyrename -ftree-dce
-ftree-dominator-opts -ftree-dse -ftree-fre -ftree-sra
-ftree-ter -funit-at-a-time
```

- -g
  - Turns on debugging symbols

Common Compiler Flags

- Some flags are integral to normal compilation

-c	Compile only
-Dx	Preprocessor define
-I/some/dir	search for include files here
-L/some/dir	search for libraries
-lname	link library named libname

```
> cc –c hello.cpp –I/usr/local/include
   –L/usr/local/lib  –lm -DLINUX –o hello
```

Special Compiler Flags: GNU

- -mtune=i686 -march=i386 (-mcpu sets both)
  - optimize for i686 cpu, use i386 instruction set
- -funroll-loopsheuristic
  - loop unrolling (for floating point codes)
- -fopenmp
  - turns on OpenMP multithreaded parallelism
- -ffast-mathreplace
  - some constructs with faster alternatives
- -fomit-frame-pointeruse
  - stack pointer as general purpose register
- -mieee-fpturn
  - on IEEE754 compliance / comparisons

Special Compiler Flags: PGI

- -tp=px, -tp=amd64, -tp=x64, -tp=piv
  - generate architecture specific code
- -pc=64
  - set floating-point rounding mode to 64-bit
- -Munroll
  - loop unrolling,
- -Mvect
  - vectorization (loop scheduling)
- -fast, -fastsse
  - short cuts to optimization flags
- -mp
  - Turns on OpenMP
- -Mipa
  - turn on interprocedural analysis
- -Kieee
  - turn on IEEE floating point

Special Compiler Flags: Intel

- -tpp6
  - set cpu type, v10 supports GNU style
- -pc64
  - set floating point rounding to 64-bit
- -ip, ipo
  - interprocedural optimization
- -axPW
  - generate SSE, SSE3 instructions
- -unroll
  - heuristic loop unrolling
- -openmp
  - turn on OpenMP
- -i-static
  - link compiler runtime statically
- -mp
  - force IEEE floating point handling
- -mp1
  - almost force IEEE floating point
- -fast
  - shortcut for -xP -O3 -ipo -no-prec-div

Where to go?

- Each of these compilers have hundreds of flags
  - You will very likely not need to know but a few to do your work and get decently optimized code.
  - First place to look is documentation
  - The compiler man page should tell you every flag and what it does.