



**The Abdus Salam
International Centre for Theoretical Physics**



2068-6

**Advanced School in High Performance and GRID Computing -
Concepts and Applications**

30 November - 11 December, 2009

**From Source Code to Executable:
Preprocessing, Compiling, and Linking
(Part 2)**

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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

```
else if((day >= (VaccineActualDay + 91) && (day < VaccineActualDay + 98)))
    dRate = 5.25*VaccineRate;
else if((day >= (VaccineActualDay + 98) && (day < VaccineActualDay + 105)))
    dRate = 5.79*VaccineRate;
else if((day >= (VaccineActualDay + 105) && (day < VaccineActualDay + 112)))
    dRate = 2.05*VaccineRate;
else if((day >= (VaccineActualDay + 112) && (day < VaccineActualDay + 119)))
    dRate = 0.84*VaccineRate;
else
    dRate = VaccineRate;
Rate = floor(dRate);
cout << "FUCK!!!! Rate = " << Rate << " drate = " << dRate;
return Rate;
}

#endif

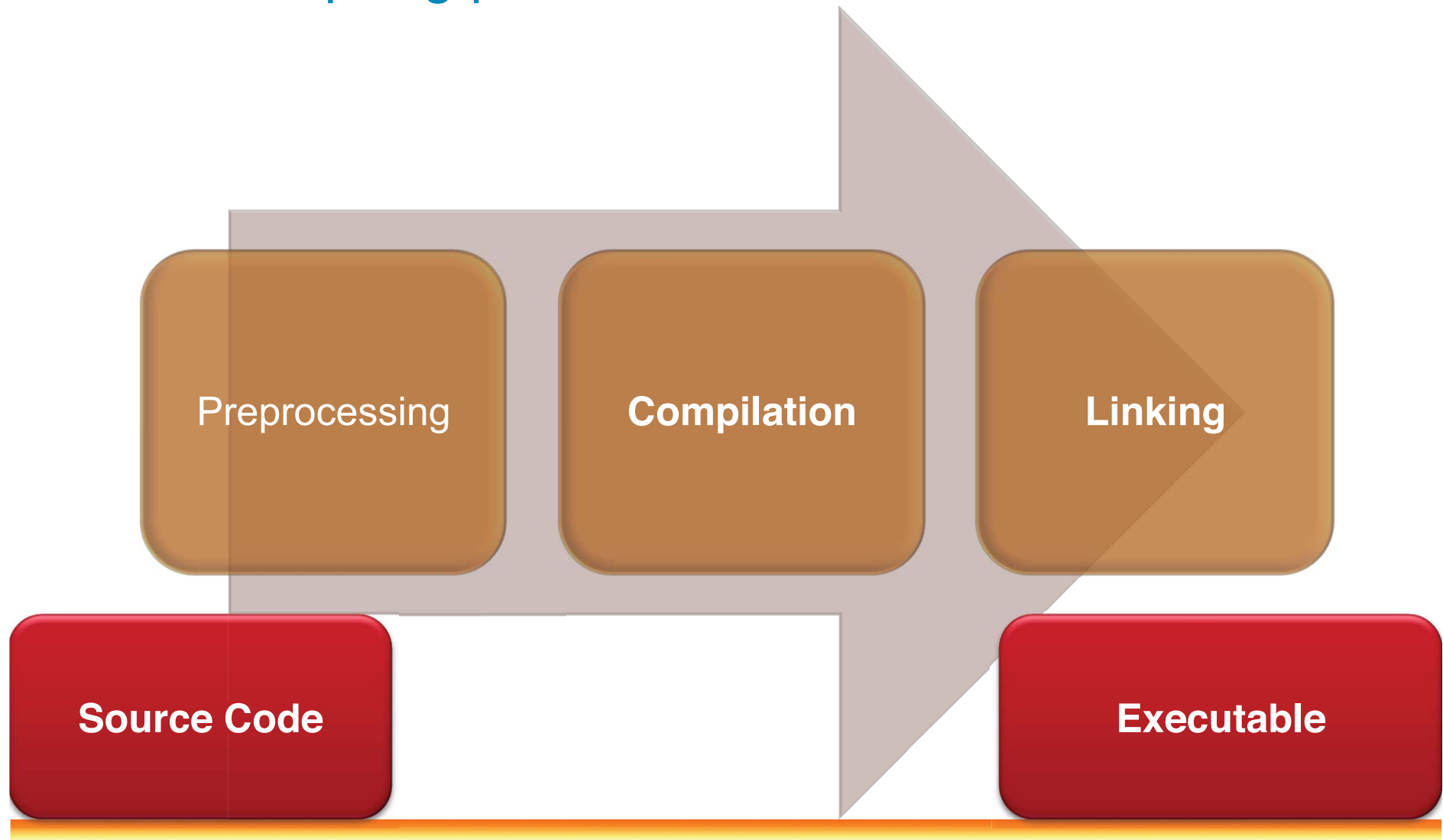
int main(int argc, char* argv[]){
    float l1,l2,maxlat,maxlong,minlat,minlong;
    // int infected_list[N];
    int no_infected,is,ic,i;
    // vector<struct person> people;
#ifdef ANTIVIRALS
    cout << "\nAntiViral Version";
#endif
#ifdef NEWAV
    cout << "\nNew AV version";
#endif
    trace = fopen("Audit.txt","wt");
    out = fopen("Summary.txt","wt");
    out1 = fopen("SummaryM.txt","wt");
    out2 = fopen("SummaryG.txt","wt");
    out3 = fopen("SummaryI.txt","wt");
    out4 = fopen("Sick.txt","wt");
}
```

cc source.c -o executable

Source Code

Executable

The compiling process



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.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.