lecture 5

- *C++ at a Glance*
  - *compiling phases*
  - *symbol resolution (2 files)*
  - *functions -an introduction, compiling again*

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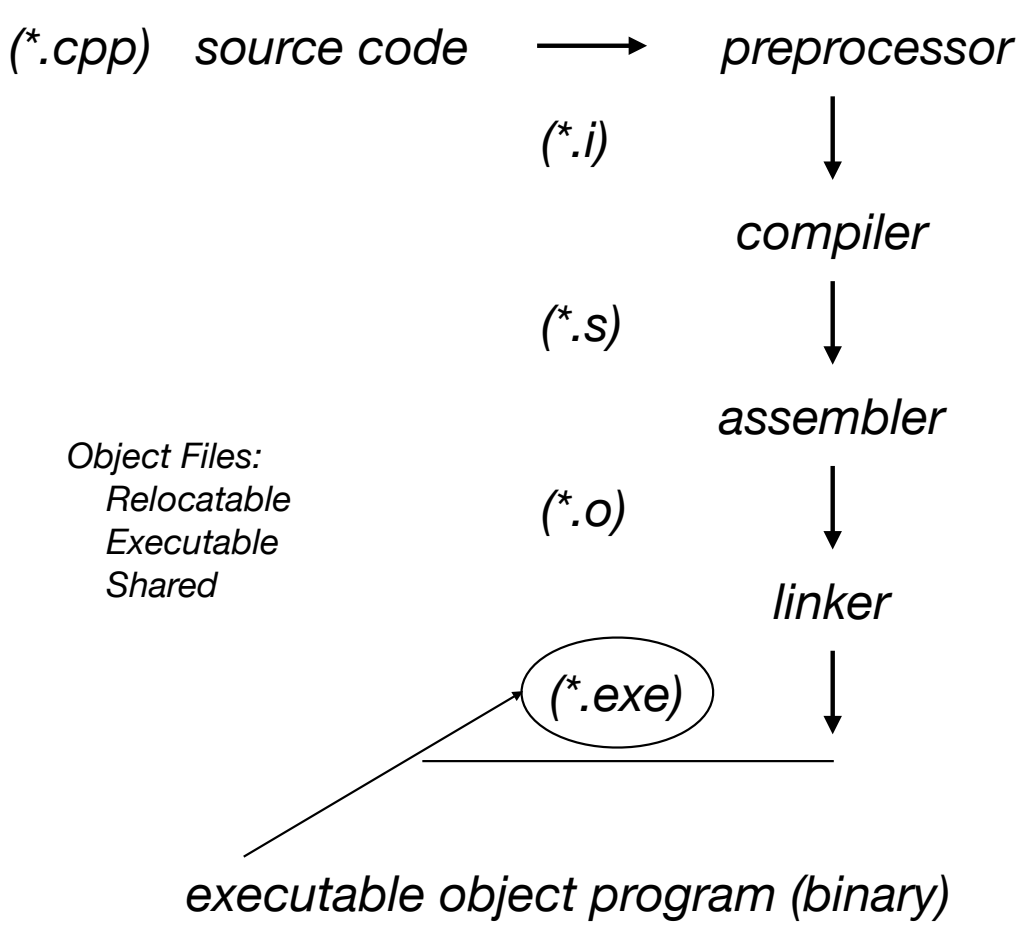
AMATH 483 / 583 High Performance Scientific Computing
Spring Quarter 2025

Compiling



Object Files:
- *Relocatable*
- *Executable*
- *Shared*

statements, insert include code, expand macros, etc.

translates *.i* file into *.s* file -assembly language program; machine instructions in text

translates *.s* file into *.o* file -relocatable object program; encodes assembly machine instructions into binary

combines *.o* relocatable objects with necessary system relocatable objects to create executable object program which can be loaded into memory and executed by the system

Compiling

```
bash-3.2$ ls -sltr
total 32
8 -rw-r--r--@ 1 kennethroche  staff  2246 Apr  6 22:53 basic-operations.cpp
8 -rw-r--r--@ 1 kennethroche  staff  2378 Apr  6 23:55 ptr-ref.cpp
8 -rw-r--r--@ 1 kennethroche  staff  1080 Apr  7 08:46 cpp-types.cpp
8 -rw-r--r--@ 1 kennethroche  staff   240 Apr  7 09:56 hello-world.cpp
bash-3.2$ g++ -E hello-world.cpp -o hello-world.i
bash-3.2$ ls -sltr hello*
   8 -rw-r--r--@ 1 kennethroche  staff      240 Apr  7 09:56 hello-world.cpp
4128 -rw-r--r--  1 kennethroche  staff  2112263 Apr  8 23:07 hello-world.i
bash-3.2$ file hello-world.i
hello-world.i: C++ source text, ASCII text, with very long lines (421)
bash-3.2$
```

```
}}
# 45 "/Library/Developer/CommandLineTools/SDKs/MacOSX.sdk/usr/include/c++/v1/iostream" 2 3
# 50 "/Library/Developer/CommandLineTools/SDKs/MacOSX.sdk/usr/include/c++/v1/iostream" 3


namespace std { inline namespace __1 {

extern __attribute__((__visibility__("default"))) istream cin;
extern __attribute__((__visibility__("default"))) ostream cout;
extern __attribute__((__visibility__("default"))) ostream cerr;
extern __attribute__((__visibility__("default"))) ostream clog;


extern __attribute__((__visibility__("default"))) wistream wcin;
extern __attribute__((__visibility__("default"))) wostream wcout;
extern __attribute__((__visibility__("default"))) wostream wcerr;
extern __attribute__((__visibility__("default"))) wostream wclog;


}}
# 2 "hello-world.cpp" 2

int main()
{
    std::cout << "Hello, World!" << std::endl;
    return 0;
}
"hello-world.i" 49324L, 2112263B
```

(.cpp)* *source code* → *preprocessor* → *(*.i)*

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Compiling *(*.i)* → *compiler* → *(*.s)*

```
bash-3.2$ g++ -S hello-world.i -o hello-world.s
clang: warning: treating 'cpp-output' input as 'c++-cpp-output' when in C++ mode, this behavior is deprecated [-Wdeprecated]
bash-3.2$ ls -lstr hello*
   8 -rw-r--r--@ 1 kennethroche  staff      240 Apr  7 09:56 hello-world.cpp
4128 -rw-r--r--  1 kennethroche  staff  2112263 Apr  8 23:07 hello-world.i
 128 -rw-r--r--  1 kennethroche  staff    64939 Apr  8 23:14 hello-world.s
bash-3.2$ file hello-world.s
hello-world.s: assembler source text, ASCII text, with very long lines (327)
bash-3.2$
```

```
        .private_extern __ZNSt3__118__constexpr_strlenB8ue170006EPKc ; -- Begin function _ZNSt3__118__constexpr_strlenB8ue170006EPKc
        .globl  __ZNSt3__118__constexpr_strlenB8ue170006EPKc
        .weak_definition        __ZNSt3__118__constexpr_strlenB8ue170006EPKc
        .p2align        2
__ZNSt3__118__constexpr_strlenB8ue170006EPKc: ; @_ZNSt3__118__constexpr_strlenB8ue170006EPKc
        .cfi_startproc
; %bb.0:
        sub     sp, sp, #32
        .cfi_def_cfa_offset 32
        stp     x29, x30, [sp, #16]             ; 16-byte Folded Spill
        add     x29, sp, #16
        .cfi_def_cfa w29, 16
        .cfi_offset w30, -8
        .cfi_offset w29, -16
        str     x0, [sp, #8]
        ldr     x0, [sp, #8]
        bl      _strlen
        ldp     x29, x30, [sp, #16]             ; 16-byte Folded Reload
        add     sp, sp, #32
        ret
        .cfi_endproc
                                        ; -- End function
        .section        __TEXT,__cstring,cstring_literals
l_.str:                                 ; @.str
        .asciz  "Hello, World!"

.subsections_via_symbols
"hello-world.s" 1671L, 64939B
```

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Compiling *(*.s)* ⟶ *assembler* ⟶ *(*.o)*

```
bash-3.2$ g++ -c hello-world.s -o hello-world.o
bash-3.2$ ls -lstr hello*
    8 -rw-r--r--@ 1 kennethroche  staff      240 Apr  7 09:56 hello-world.cpp
 4128 -rw-r--r--  1 kennethroche  staff  2112263 Apr  8 23:07 hello-world.i
  128 -rw-r--r--  1 kennethroche  staff    64939 Apr  8 23:14 hello-world.s
   24 -rw-r--r--  1 kennethroche  staff    11816 Apr  8 23:19 hello-world.o
bash-3.2$ file hello-world.o
hello-world.o: Mach-O 64-bit object arm64
bash-3.2$
```

objdump -x (*.o) *:* display header information
objdump -t (*.o) : display the symbol table
objdump -S (*.o) : disassemble plus source code interleaving
objdump -d (*.o) : disassmble the assembly into readable machine instructions

Compiling *(*.s)* ⟶ *assembler* ⟶ *(*.o)*

```
bash-3.2$ g++ -c hello-world.s -o hello-world.o
bash-3.2$ ls -lstr hello*
    8 -rw-r--r--@ 1 kennethroche  staff      240 Apr  7 09:56 hello-world.cpp
 4128 -rw-r--r--  1 kennethroche  staff  2112263 Apr  8 23:07 hello-world.i
  128 -rw-r--r--  1 kennethroche  staff    64939 Apr  8 23:14 hello-world.s
   24 -rw-r--r--  1 kennethroche  staff    11816 Apr  8 23:19 hello-world.o
bash-3.2$ file hello-world.o
hello-world.o: Mach-O 64-bit object arm64
bash-3.2$
```

objdump -x (*.o) *:* display header information
objdump -t (*.o) : display the symbol table
objdump -S (*.o) : disassemble plus source code interleaving
objdump -d (*.o) : disassmble the assembly into readable machine instructions

Compiling

Symbol table

```
bash-3.2$ objdump -t hello-world.o

hello-world.o:  file format mach-o arm64

SYMBOL TABLE:
0000000000000000 l     F __TEXT,__text ltmp0
0000000000000d34 l     O __TEXT,__cstring l_.str
0000000000000c88 l     O __TEXT,__gcc_except_tab ltmp1
0000000000000c88 l     O __TEXT,__gcc_except_tab GCC_except_table4
0000000000000cc8 l     O __TEXT,__gcc_except_tab GCC_except_table5
0000000000000cdc l     O __TEXT,__gcc_except_tab GCC_except_table7
0000000000000d00 l     O __TEXT,__gcc_except_tab GCC_except_table35
0000000000000d14 l     O __TEXT,__gcc_except_tab GCC_except_table40
0000000000000d34 l     O __TEXT,__cstring ltmp2
0000000000000d48 l     O __LD,__compact_unwind ltmp3
00000000000008fc  w    F __TEXT,__text .hidden __ZNKSt3__112basic_string
00000000000009c4  w    F __TEXT,__text .hidden __ZNKSt3__112basic_string
00000000000009ec  w    F __TEXT,__text .hidden __ZNKSt3__112basic_stringIcNS_11char_traitsIcEENS_9allocatorIcEEE19__get_short_pointerB8ue170006Ev
0000000000000750  w    F __TEXT,__text .hidden __ZNKSt3__112basic_stringIcNS_11char_traitsIcEENS_9allocatorIcEEE4dataB8ue170006Ev
0000000000000950  w    F __TEXT,__text .hidden __ZNKSt3__112basic_stringIcNS_11char_traitsIcEENS_9allocatorIcEEE9__is_longB8ue170006Ev
0000000000000350  w    F __TEXT,__text .hidden __ZNKSt3__113basic_ostreamIcNS_11char_traitsIcEEE6sentrycvbB8ue170006Ev
0000000000000a20  w    F __TEXT,__text .hidden __ZNKSt3__117__compressed_pairINS_12basic_stringIcNS_11char_traitsIcEENS_9allocatorIcEEE5__repES5_E5firstB8ue170006Ev
0000000000000664  w    F __TEXT,__text .hidden __ZNKSt3__119ostreambuf_iteratorIcNS_11char_traitsIcEEE6failedB8ue170006Ev
0000000000000a44  w    F __TEXT,__text .hidden __ZNKSt3__122__compressed_pair_elemINS_12basic_stringIcNS_11char_traitsIcEENS_9allocatorIcEEE5__repELi0ELb0EE5__getB8ue170006Ev
0000000000000bf8  w    F __TEXT,__text .hidden __ZNKSt3__15ctypeIcE5widenB8ue170006Ec
00000000000005e8  w    F __TEXT,__text .hidden __ZNKSt3__18ios_base5flagsB8ue170006Ev
0000000000000af8  w    F __TEXT,__text .hidden __ZNKSt3__18ios_base5rdbufB8ue170006Ev
00000000000006c0  w    F __TEXT,__text .hidden __ZNKSt3__18ios_base5widthB8ue170006Ev
0000000000000600  w    F __TEXT,__text .hidden __ZNKSt3__19basic_iosIcNS_11char_traitsIcEEE4fillB8ue170006Ev
0000000000000ad4  w    F __TEXT,__text .hidden __ZNKSt3__19basic_iosIcNS_11char_traitsIcEEE5rdbufB8ue170006Ev
0000000000000b40  w    F __TEXT,__text .hidden __ZNKSt3__19basic_iosIcNS_11char_traitsIcEEE5widenB8ue170006Ec
0000000000000b10  w    F __TEXT,__text .hidden __ZNSt3__111char_traitsIcE11eq_int_typeB8ue170006Eii
0000000000000b38  w    F __TEXT,__text .hidden __ZNSt3__111char_traitsIcE3eofB8ue170006Ev
0000000000000308  w    F __TEXT,__text .hidden __ZNSt3__111char_traitsIcE6lengthB8ue170006EPKc
00000000000008e8  w    F __TEXT,__text .hidden __ZNSt3__112__to_addressB8ue170006IKcEEPT_S3_
0000000000000714  w    F __TEXT,__text .hidden __ZNSt3__112basic_stringIcNS_11char_traitsIcEENS_9allocatorIcEEEC1B8ue170006Emc
00000000000007a4  w    F __TEXT,__text .hidden __ZNSt3__112basic_stringIcNS_11char_traitsIcEENS_9allocatorIcEEEC2B8ue170006Emc
0000000000000090  w    F __TEXT,__text .hidden __ZNSt3__113basic_ostreamIcNS_11char_traitsIcEEElsB8ue170006EPFRS3_S4_E
0000000000000a58  w    F __TEXT,__text .hidden __ZNSt3__114pointer_traitsIPKcE10pointer_toB8ue170006ERS1_
00000000000006d8  w    F __TEXT,__text .hidden __ZNSt3__115basic_streambufIcNS_11char_traitsIcEEE5sputnB8ue170006EPKcl
00000000000008d4  w    F __TEXT,__text .hidden __ZNSt3__116__non_trivial_ifILb1ENS_9allocatorIcEEEC2B8ue170006Ev
000000000000036c  w    F __TEXT,__text .hidden __ZNSt3__116__pad_and_outputB8ue170006IcNS_11char_traitsIcEEEENS_19ostreambuf_iteratorIT_T0_EES6_PKS4_S8_S8_RNS_8ios_baseES4_
```

Common Information Stored in a Symbol Table:

- **Identifier Name:** The actual name of the variable, function, or other entities.
- **Type:** The data type of the identifier (e.g., integer, float, function returning void).
- **Scope Level:** Indicates where in the code the identifier is accessible (e.g., local, global).
- **Memory Location:** The address or offset where the identifier's value is stored.
- **Attributes:** Additional properties, such as whether a variable is constant, volatile, or static.

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Compiling

disassembly

```
bash-3.2$ objdump -d hello-world.o | more

hello-world.o:  file format mach-o arm64

Disassembly of section __TEXT,__text:

0000000000000000 <ltmp0>:
       0: d10083ff      sub     sp, sp, #32
       4: a9017bfd      stp     x29, x30, [sp, #16]
       8: 910043fd      add     x29, sp, #16
       c: 52800008      mov     w8, #0
      10: b9000be8      str     w8, [sp, #8]
      14: b81fc3bf      stur    wzr, [x29, #-4]
      18: 90000000      adrp    x0, 0x0 <ltmp0+0x18>
      1c: f9400000      ldr     x0, [x0]
      20: 90000001      adrp    x1, 0x0 <ltmp0+0x20>
      24: 91000021      add     x1, x1, #0
      28: 94000000      bl      0x28 <ltmp0+0x28>
      2c: 90000001      adrp    x1, 0x0 <ltmp0+0x2c>
      30: 91000021      add     x1, x1, #0
      34: 94000000      bl      0x34 <ltmp0+0x34>
      38: b9400be0      ldr     w0, [sp, #8]
      3c: a9417bfd      ldp     x29, x30, [sp, #16]
      40: 910083ff      add     sp, sp, #32
      44: d65f03c0      ret

0000000000000048 <__ZNSt3__1lsB8ue170006INS_11char_traitsIcEEEERNS_13basic_ostreamIcT_EES6_PKc>:
      48: d100c3ff      sub     sp, sp, #48
      4c: a9027bfd      stp     x29, x30, [sp, #32]
      50: 910083fd      add     x29, sp, #32
      54: f81f83a0      stur    x0, [x29, #-8]
      58: f9000be1      str     x1, [sp, #16]
      5c: f85f83a8      ldur    x8, [x29, #-8]
      60: f90007e8      str     x8, [sp, #8]
      64: f9400be8      ldr     x8, [sp, #16]
      68: f90003e8      str     x8, [sp]
      6c: f9400be0      ldr     x0, [sp, #16]
      70: 94000000      bl      0x70 <__ZNSt3__1lsB8ue170006INS_11char_traitsIcEEEERNS_13basic_ostreamIcT_EES6_PKc+0x28>
      74: f94003e1      ldr     x1, [sp]
      78: aa0003e2      mov     x2, x0
      7c: f94007e0      ldr     x0, [sp, #8]
      80: 94000000      bl      0x80 <__ZNSt3__1lsB8ue170006INS_11char_traitsIcEEEERNS_13basic_ostreamIcT_EES6_PKc+0x38>
      84: a9427bfd      ldp     x29, x30, [sp, #32]
      88: 9100c3ff      add     sp, sp, #48
      8c: d65f03c0      ret
```

Compiling

(.o)* ⟶ *Linker* ⟶ *(*.exe)*

```
bash-3.2$ g++ -o xhello hello-world.o
bash-3.2$ ls -lstr *hello*
    8 -rw-r--r--@ 1 kennethroche  staff      240 Apr  7 09:56 hello-world.cpp
 4128 -rw-r--r--  1 kennethroche  staff  2112263 Apr  8 23:07 hello-world.i
  128 -rw-r--r--  1 kennethroche  staff    64939 Apr  8 23:14 hello-world.s
   24 -rw-r--r--  1 kennethroche  staff    11816 Apr  8 23:19 hello-world.o
   80 -rwxr-xr-x  1 kennethroche  staff    39624 Apr  8 23:37 xhello
bash-3.2$ file xhello
xhello: Mach-O 64-bit executable arm64
bash-3.2$ ./xhello
Hello, World!
bash-3.2$
```

```cpp
#include <iostream>

void print_hello(const int ival) {
    std::cout << "Your integer: " << ival << std::endl;
}

int main() {
    print_hello(3);
    return 0;
}
```

g++ -o xhw2 kr-hw2.cpp

./xhw2

Your integer: 3

function in same source code file resolution: internal linkage

```cpp
#include <iostream>

void print_hello(const int ival) {
    std::cout << "Your integer: " << ival << std::endl;
}
```

hw3-fnc.cpp

Two source code files

```cpp
// note there are no includes here ...
void print_hello(const int ival);

int main() {
    print_hello(3);
    return 0;
}
```

hw3.cpp

function interface declared here

```cpp
#include <iostream>

void print_hello(const int ival) {
    std::cout << "Your integer: " << ival << std::endl;
}
```

```cpp
// note there are no includes here ...
void print_hello(const int ival);

int main() {
    print_hello(3);
    return 0;
}
```

g++ -c -std=c++14 hw3.cpp

ls -lstr hw3.o
684 Apr 4 11:27 hw3.o

g++ -o xhw3 hw3.o

Undefined symbols for architecture x86_64:
  "print_hello(int)", referenced from:
      _main in hw3.o
ld: symbol(s) not found for architecture x86_64
clang: error: linker command failed with exit code 1 (use -v to see invocation)

```cpp
#include <iostream>

void print_hello(const int ival) {
    std::cout << "Your integer: " << ival << std::endl;
}
```

g++ -c -std=c++14 hw3.cpp

ls -lstr kr-cgpt-hw3.o
684 Apr 4 11:27 hw3.o

g++ -c -std=c++14 hw3-fnc.cpp

ls -lstr hw3-fnc.o
12816 Apr 4 11:32 hw3-fnc.o

g++ -o xhw3 hw3.o hw3-fnc.o

./xhw3
Your integer: 3

```cpp
// note there are no includes here ...
void print_hello(const int ival);

int main() {
    print_hello(3);
    return 0;
}
```

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Conditional: IF

```cpp
// IF
bool condition1 = false;
if (condition1)
{
    // do things if <condition1> is TRUE
    std::cout << "hello from COND1: " << std::endl;
}
else if (!condition1)
{
    //do things if <condition1> is FALSE since ~FALSE = TRUE
    std::cout << "hello from NOT COND1: " << std::endl;
}
else
{
    //this case cannot be base on my code, but is useful very often
}
```

Conditional: TERNARY (?:)

```cpp
// TERNARY
//  (condition) ? (use if condition TRUE) : (use if condition FALSE)
int w = (condition1) ? -1 : 1;
std::cout << "w: " << w << " COND: " << condition1 << std::endl;
w = (w > 0) ? 0 : 1;
std::cout << "w: " << w << std::endl;
```

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Conditional: SWITCH

```
switch (w)
{
case 0: // code block for when w=0 case ...
    std::cout << "switch case 0!" << std::endl;
    break; // this is significant
case 1:    // code block for when w=1 case ..
    std::cout << "switch case 1!" << std::endl;
    break;
default: // if none of the cases are true, do this
    std::cout << "switch case default!" << std::endl;
    break; // good practice ...
}
```

Conditional Loop: WHILE

```
// WHILE LOOP
int l = 0;
while (l < 10)
{                                   // do stuff
    std::cout << l << " ";
    l++;
}
std::cout << std::endl;
// l = ???
std::cout << "after WHILE l = " << l << std::endl;
```

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Conditional Loop: DO-WHILE

```
// DO-WHILE LOOP
l = 10;
do
{ // do stuff
    std::cout <<"in DO-WHILE: " << l << " ";
    l++;
} while (l < 10);
std::cout << std::endl;
// l = ???
std::cout << "after DO-WHILE l = " << l << std::endl;
```

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Loop: FOR

```
// FOR
//  for (init cntr1, init cntr2; condition; increment cntrs){//do stuff}
int k;
for (l = 0, k = 3; k >= 0; l++, k--)
{
    std::cout << "l: " << l << " k: " << k << std::endl;
}
std::cout << "AFTER FOR l: " << l << " k: " << k << std::endl;
```

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Loop: FOR (infinite, w/ break condition)

```
// infinite loop w/ break condition
int loopbreak = 0;
for (;;)
{ // buyer beware! useful but ...
    if (loopbreak == 4)
        break;
    std::cout << "break loop";
    // do stuff
    loopbreak++;
}
std::cout << "AFTER FOR loopbreak: " << loopbreak << std::endl;
```

```
// infinite loop
for (;;)
{ // buyer beware! useful but ...
    std::cout << "inf-loop!";
}
```

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Loop: FOR (continue)

```
// FOR w/ CONTINUE
for (k = 0; k < 4; k++)
{
    if (k == 2)
        continue;
    std::cout << "k: " << k << std::endl;
}
std::cout << "AFTER FOR CONTINUE k: " << k << std::endl;
```

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Loop iterator: FOR (iterators in containers … more later)

```
// iterating in containers
int a[3] = {1, 2, 3};
for (int &l : a) //iterator scope initializer
    std::cout << "a[]: " << l << std::endl;
std::cout << "AFTER iterator l: " << l << std::endl;
```

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FUNCTIONs

```
void fnc(std::string a, std::string b = "hpc is cool")
{
    std::cout << a << " " << b << std::endl;
}
```

```
// FUNCTIONS ...
fnc("Hi there"); // default issued
fnc("Hi there"," I want cookies!"); // default overridden
```

End Lecture 5