CS 33

Libraries

Libraries

- Collections of useful stuff
- Allow you to:
  - incorporate items into your program
  - substitute new stuff for existing items
- Often ugly …

Creating a Library

```
$ gcc -c sub1.c sub2.c sub3.c
$ ls
sub1.c        sub2.c        sub3.c
sub1.o        sub2.o        sub3.o
$ ar cr libpriv1.a sub1.o sub2.o sub3.o
$ ar t libpriv1.a
sub1.o
sub2.o
sub3.o
$
```

Using a Library

```
$ cat prog.c
int main() {
   sub1();
   sub2();
   sub3();
}
$ cat sub1.c
void sub1() {
   puts("sub1");
}
```

```
$ gcc -o prog prog.c -L. -lpriv1
$ ./prog
sub1
sub2
sub3
```

Where does *puts* come from?

```
$ gcc -o prog prog.c -L. \
   -lpriv1 \
   -L/lib/x86_64-linux-gnu -lc
```

Static-Linking: What’s in the Executable

- ld puts in the executable:
      - » (assuming all .c files have been compiled into .o files)
  - – all .o files from argument list (including those newly compiled)
  - – .o files from archives as needed to satisfy unresolved references
    - » some may have their own unresolved references that may need to be resolved from additional .o files from archives
    - » each archive processed just once (as ordered in argument list)
      - order matters!

Example

```
$ cat prog2.c
int main() {
  void func1();
  func1();
  return 0;
}
$ cat func1.c
void func1() {
  void func2();
  func2();
}
$ cat func2.c
void func2() {
}
```

Order Matters ...

```
$ ar t libf1.a
func1.o
$ ar t libf2.a
func2.o
$ gcc -o prog2 prog2.c -L. -lf1 -lf2
$
$ gcc -o prog2 prog2.c -L. -lf2 -lf1
./libf1.a(sub1.o): In function `func1':
func1.c:(.text+0xa): undefined reference to `func2'
collect2: error: ld returned 1 exit status
```

Substitution

```
$ cat myputs.c
int puts(char *s) {
  write(1, "My puts: ", 9);
  write(1, s, strlen(s));
  write(1, "\n", 1);
  return 1;
}
$ gcc –c myputs.c
$ ar cr libmyputs.a myputs.o
$ gcc -o prog prog.c -L. –lpriv1 -lmyputs
$ ./prog
My puts: sub1
My puts: sub2
My puts: sub3
```

An Urgent Problem

- printf is found to have a bug
  - perhaps a security problem
- All existing instances must be replaced
  - there are zillions of instances ...
- Do we have to re-link all programs that use printf?

Dynamic Linking

- Executable is not fully linked
  - contains list of needed libraries
- Linkages set up when executable is run

Benefits

- Without dynamic linking
  - every executable contains copy of printf (and other stuff)
    - » waste of disk space
    - » waste of primary memory
- With dynamic linking
  - just one copy of printf
    - » shared by all

Shared Objects: Unix's Dynamic Linking

1 **Compile program**

2 **Track down references with *ld***

- *archives* (containing *relocatable objects*) in ".a" files are statically linked
- *shared objects* in ".so" files are dynamically linked
  - » names of needed .so files included with executable

3 **Run program**

- *ld-linux.so* is invoked first to complete the linking and relocation steps, if necessary

Creating a Shared Library (1)

```
$ gcc -fPIC -c myputs.c
$ ld -shared -o libmyputs.so myputs.o
$ gcc -o prog prog.c -L. –lpriv1 -lmyputs
$ ./prog
./prog: error while loading shared libraries: libmyputs.so:
cannot open shared object file: No such file or directory
$ ldd prog
linux-vdso.so.1 =>  (0x00007fff953fc000)
libmyputs.so => not found
libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00007f7389174000)
/lib64/ld-linux-x86-64.so.2 (0x00007f7389536000)
```

Creating a Shared Library (2)

```
$ gcc -o prog prog.c -L. –lpriv1 –lmyputs -Wl,-rpath \
  /home/twd/libs
$ ldd prog
linux-vdso.so.1 =>  (0x00007fff235ff000)
libmyputs.so => /home/twd/libs/libmyputs.so (0x00007f821370f000)
libc.so.6 => /lib/x86_64-linux-gnu/libc.so.6 (0x00007f821314e000)
/lib64/ld-linux-x86-64.so.2 (0x00007f8213912000)
$ ./prog
My puts: sub1
My puts: sub2
My puts: sub3
```

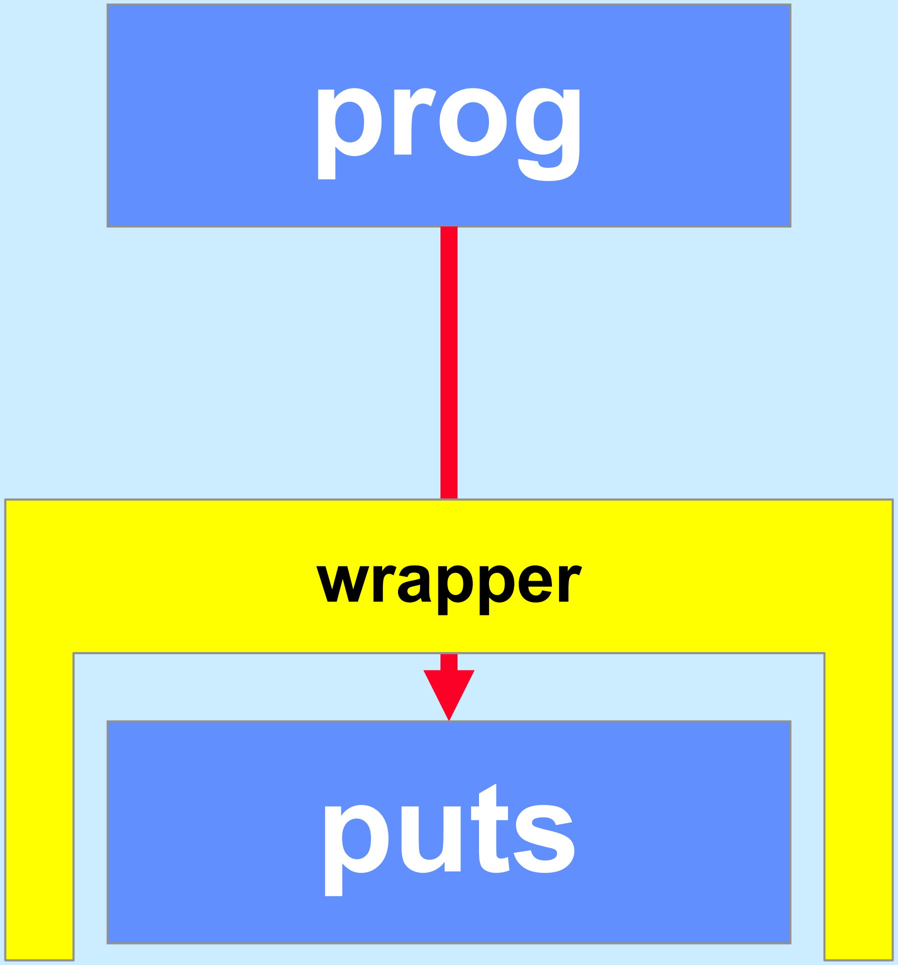
Order Still Matters

- All shared objects listed in the executable are loaded into the address space
  - whether needed or not
- ld-linux.so will find anything that's there
  - looks in the order in which shared objects are listed

Versioning

```
$ gcc -fPIC -c myputs.c
$ ld -shared -soname libmyputs.so.1 \
-o libmyputs.so.1 myputs.o
$ ln -s libmyputs.so.1 libmyputs.so
$ gcc -o prog1 prog1.c -L. -lpriv1 -lmyputs \
–Wl,-rpath .
$ vi myputs.c
$ gcc -fPIC -c myputs.c
$ ld -shared -soname libmyputs.so.2 \
-o libmyputs.so.2 myputs.o
$ rm -f libmyputs.so
$ ln -s libmyputs.so.2 libmyputs.so
$ gcc -o prog2 prog2.c -L. -lpriv1 -lmyputs \
-Wl,-rpath .
```

Interpositioning



How To …

```
int __wrap_puts(const char *s) {
  int __real_puts(const char *);

  write(2, "calling myputs: ", 16);
  return __real_puts(s);
}
```

Compiling/Linking It

```
$ cat tputs.c
int main() {
  puts("This is a boring message.");
  return 0;
}
$ gcc -o tputs -Wl,--wrap=puts tputs.c myputs.c
$ ./tputs
calling myputs: This is a boring message.
$
```

How To (Alternative Approach) …

```
#include <dlfcn.h>

int puts(const char *s) {
  int (*pptr)(const char *);

  pptr = (int(*)())dlsym(RTLD_NEXT, "puts");

  write(2, "calling myputs: ", 16);
  return (*pptr)(s);
}
```

What's Going On …

- gcc/ld
  - compiles code
  - does static linking
    - searches list of libraries
    - adds references to shared objects
- runtime
  - program invokes *ld-linux.so* to finish linking
    - maps in shared objects
    - does relocation and procedure linking as required
  - *dlsym* invokes *ld-linux.so* to do more linking
    - RTLD_NEXT says to use the next (second) occurrence of the symbol

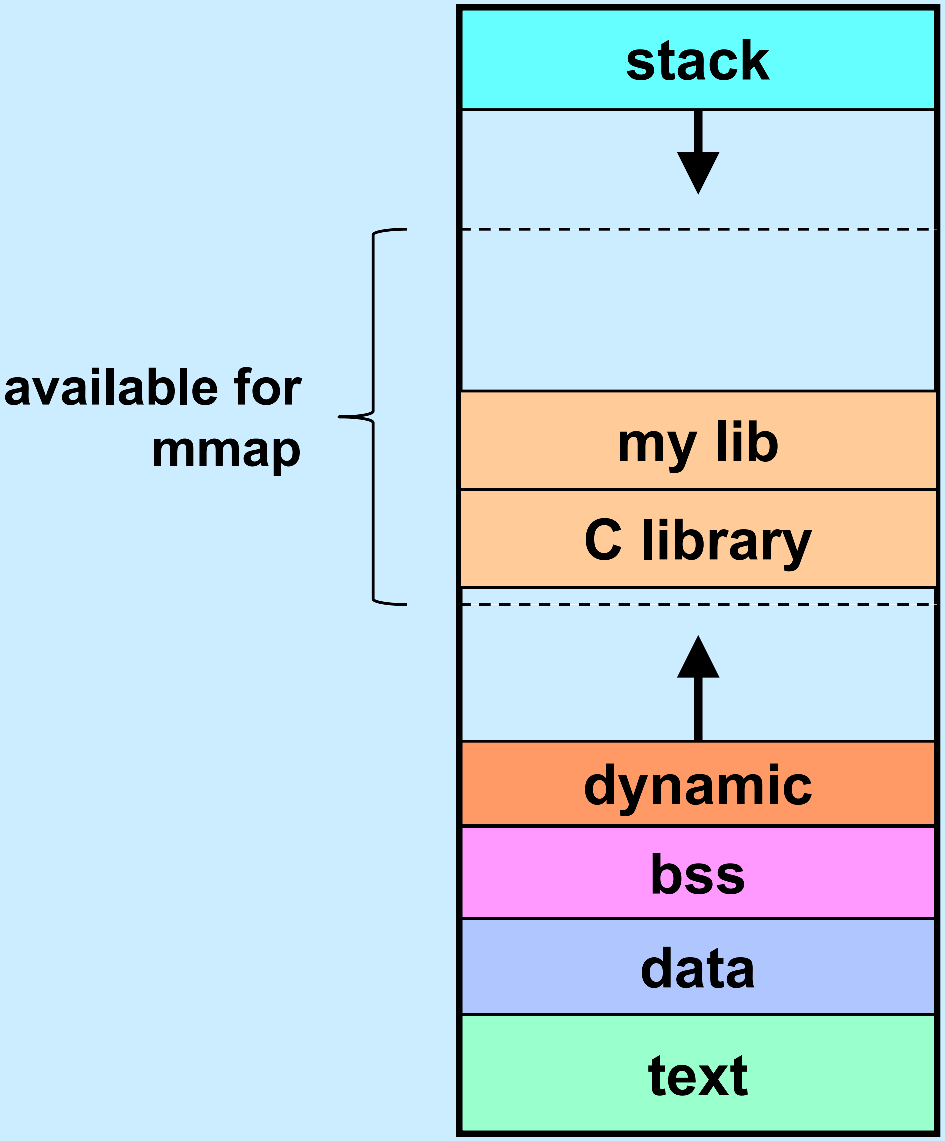
Delayed Wrapping

- LD_PRELOAD
  - environment variable checked by *ld-linux.so*
  - specifies additional shared objects to search (first) when program is started

Example

```
$ gcc -o tputs tputs.c
$ ./tputs
This is a boring message.
$ LD_PRELOAD=./libmyputs.so.1; export LD_PRELOAD
$ ./tputs
calling myputs: This is a boring message.
$
```

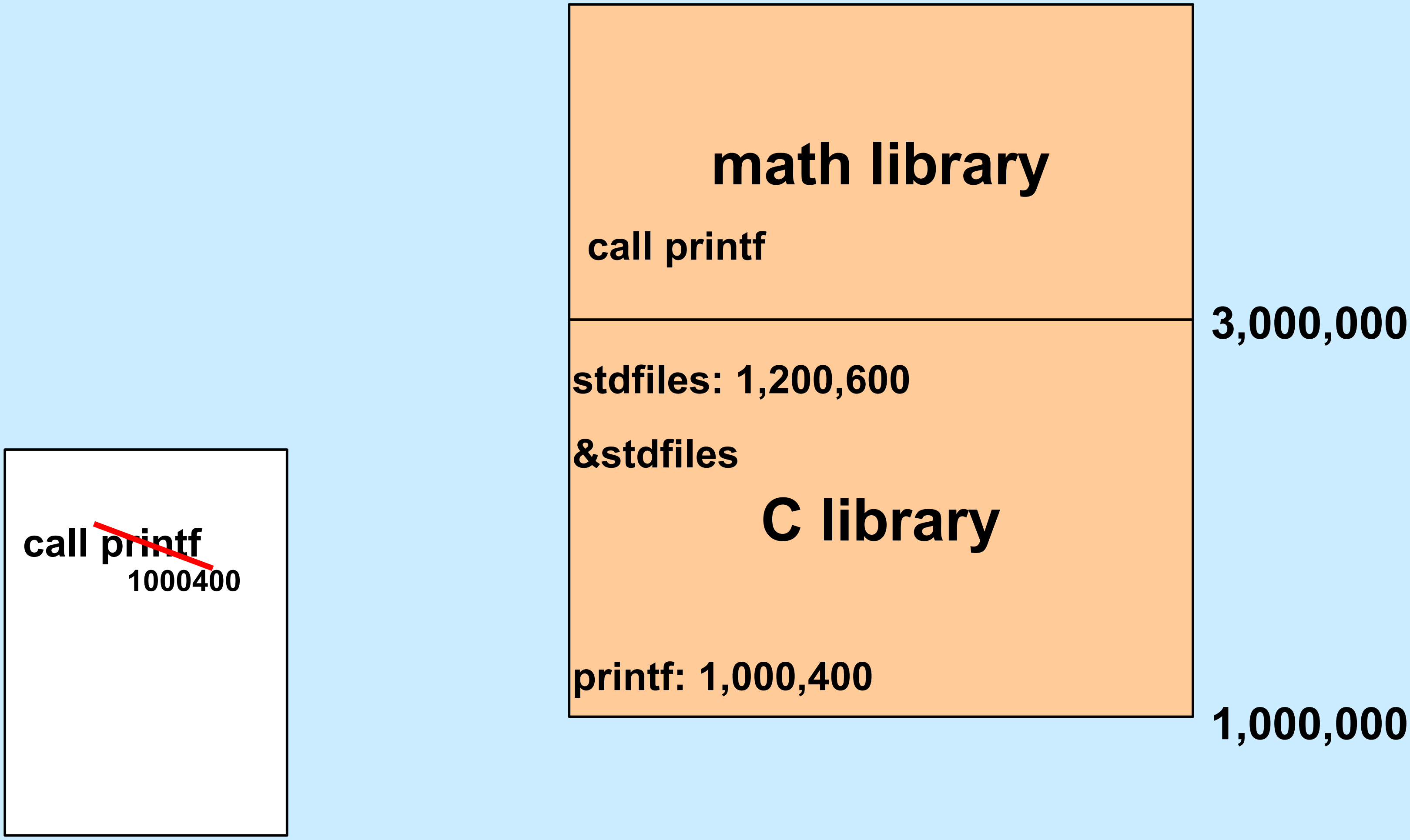
Mmapping Libraries



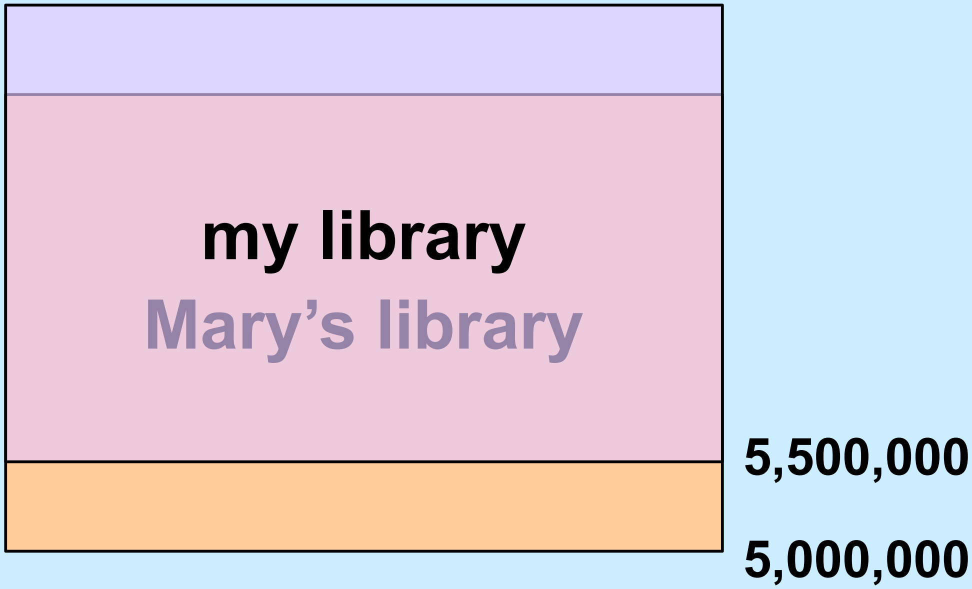
Problem

- How is relocation handled?

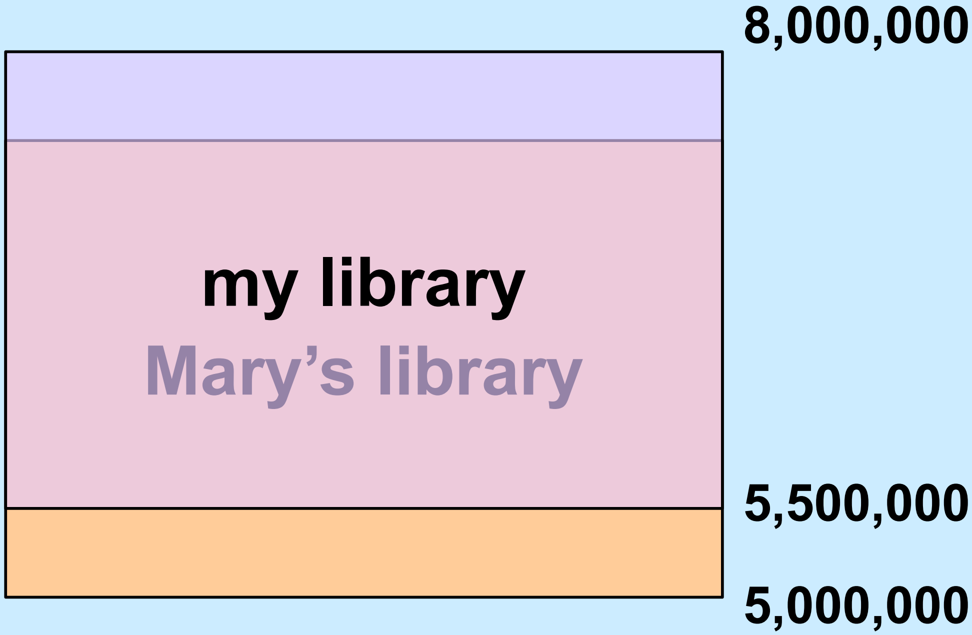
Pre-Relocation



But …



But …



Quiz 1

We need to relocate all references to Mary’s library in my library. What option should we give to *mmap* when we map mylibrary into our address space?

a) the MAP_SHARED option

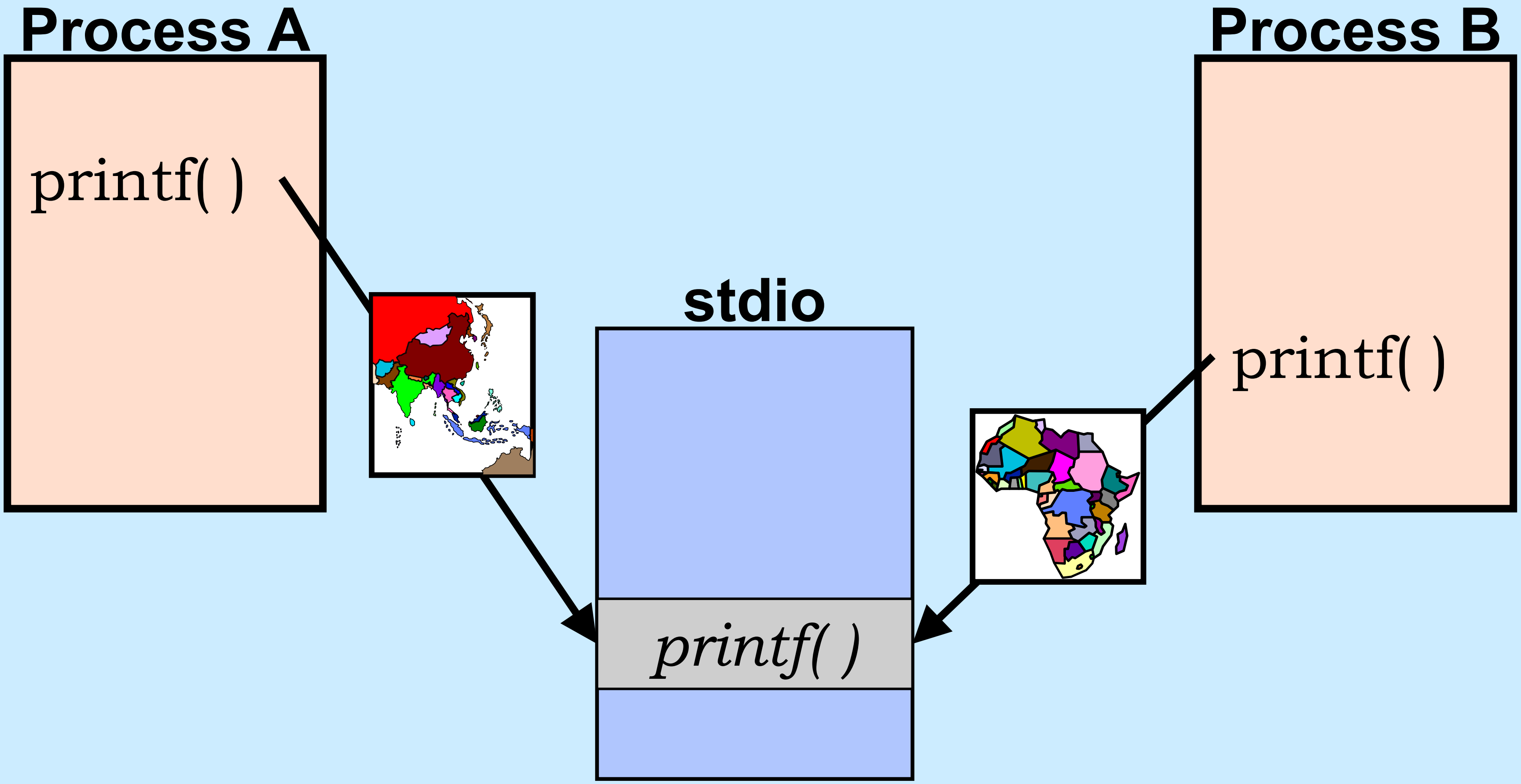
b) the MAP_PRIVATE option

c) mmap can’t be used in this situation

Relocation Revisited

- Modify shared code to effect relocation
  - result is no longer shared!
- Separate shared code from (unshared) addresses
  - position-independent code (PIC)
  - code can be placed anywhere
  - addresses in separate private section
    - » pointed to by a register

Mapping Shared Objects



Process A

printf( )

stdio

printf( )

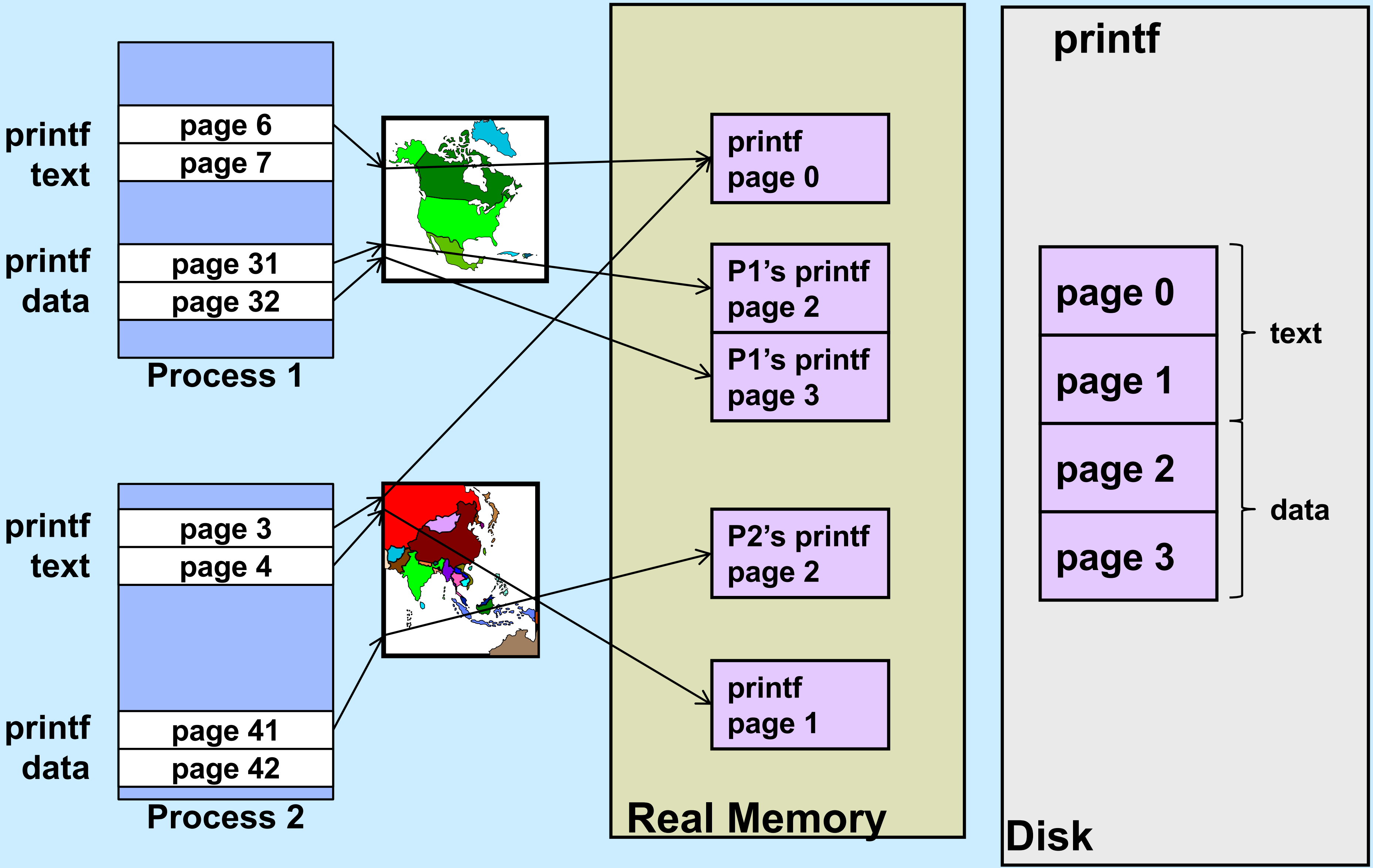
Process B

printf( )

Mapping printf into the Address Space

- Printf's text
  - read-only
  - can it be shared?
    - » yes: use MAP_SHARED
- Printf's data
  - read-write
  - not shared with other processes
  - initial values come from file
  - can mmap be used?
    - » MAP_SHARED wouldn't work
      - changes made to data by one process would be seen by others
    - » MAP_PRIVATE does work!
      - mapped region is initialized from file
      - changes are private

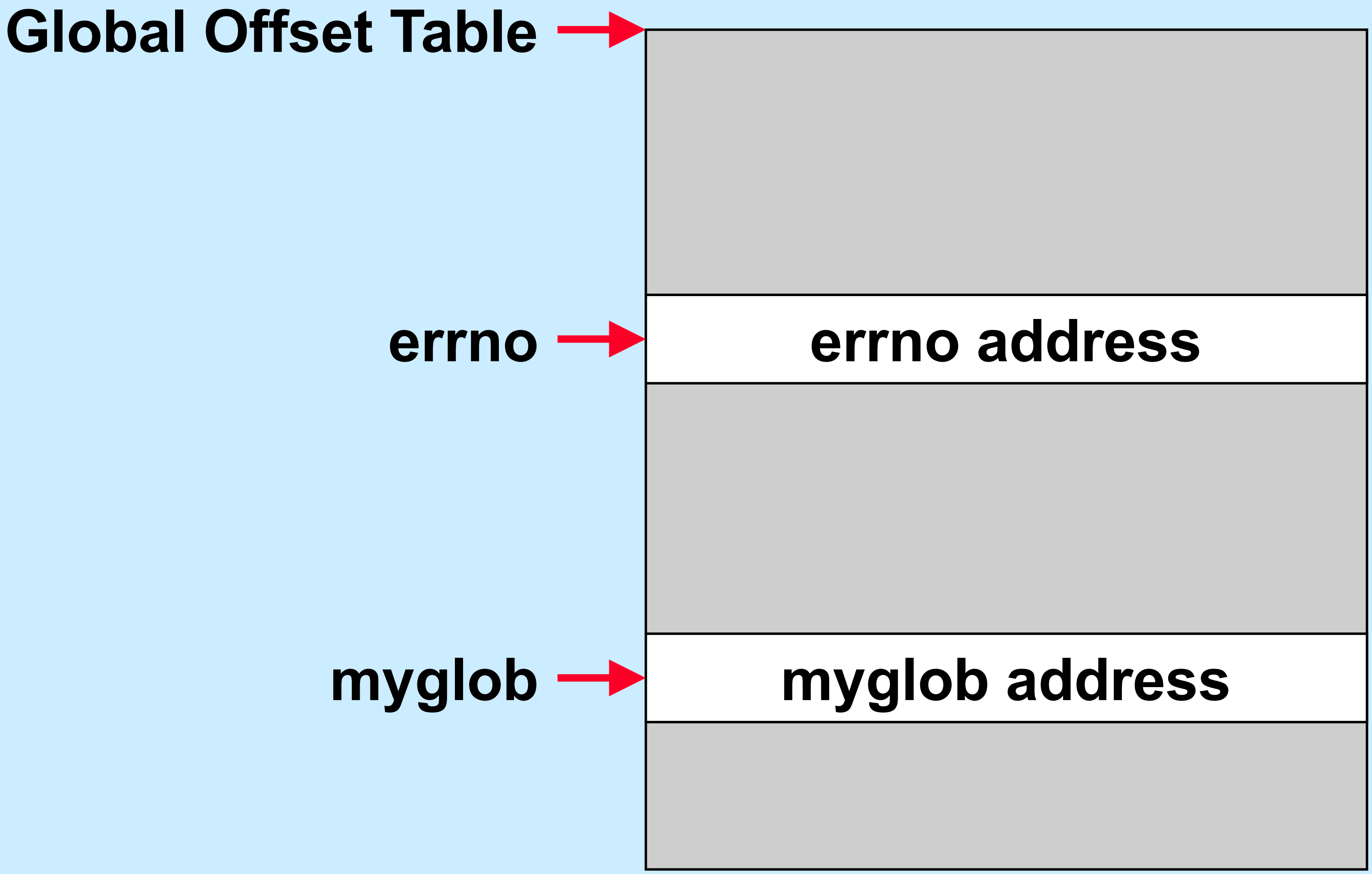
Mapping printf



Position-Independent Code

- Processor-dependent; x86-64:
  - each dynamic executable and shared object has:
    - » procedure-linkage table
      - shared, read-only executable code
      - essentially stubs for calling functions
    - » global-offset table
      - private, read-write data
      - relocated dynamically for each process
    - » relocation table
      - shared, read-only data
      - contains relocation info and symbol table

Global-Offset Table: Data References



Procedures in Shared Objects

- Lots of them
- Many are never used
- Fix up linkages on demand

Before Calling Name1

```
.PLT0:
  pushq GOT+8(%rip)
  jmp   *GOT+16(%rip)
  nop; nop
  nop; nop
.PLT1:
  jmp   *name1@GOTPCREL(%rip)
.PLT1next
  pushq $name1RelOffset
  jmp   .PLT0
.PLT2:
  jmp   *name2@GOTPCREL(%rip)
.PLT2next
  pushq $name2RelOffset
  jmp   .PLT0
```

Procedure-Linkage Table

```
GOT:
   .quad _DYNAMIC
   .quad identification
   .quad ld-linux.so


name1:
   .quad .PLT1next
name2:
   .quad .PLT2next
```

Relocation info:

```
GOT_offset(name1), symx(name1)
```

```
GOT_offset(name2), symx(name2)
```

Relocation Table

After Calling Name1

```
.PLT0:
  pushq GOT+8(%rip)
  jmp   *GOT+16(%rip)
  nop; nop
  nop; nop
.PLT1:
  jmp   *name1@GOTPCREL(%rip)
.PLT1next
  pushq $name1RelOffset
  jmp   .PLT0
.PLT2:
  jmp   *name2@GOTPCREL(%rip)
.PLT2next
  pushq $name2RelOffset
  jmp   .PLT0
```

Procedure-Linkage Table

```
GOT:
   .quad _DYNAMIC
   .quad identification
   .quad ld-linux.so


name1:
   .quad name1
name2:
   .quad .PLT2next
```

Relocation info:

```
GOT_offset(name1), symx(name1)
GOT_offset(name2), symx(name2)
```

Relocation Table