CS 33

More Libraries

Pipes

Locking Files

A Problem

- You've put together a library of useful functions
  - libgoodstuff.so
- Lots of people are using it
- It occurs to you that you can make it even better by adding an extra argument to a few of the functions
  - doing so will break all programs that currently use these functions
- You need a means so that old code will continue to use the old version, but new code will use the new version

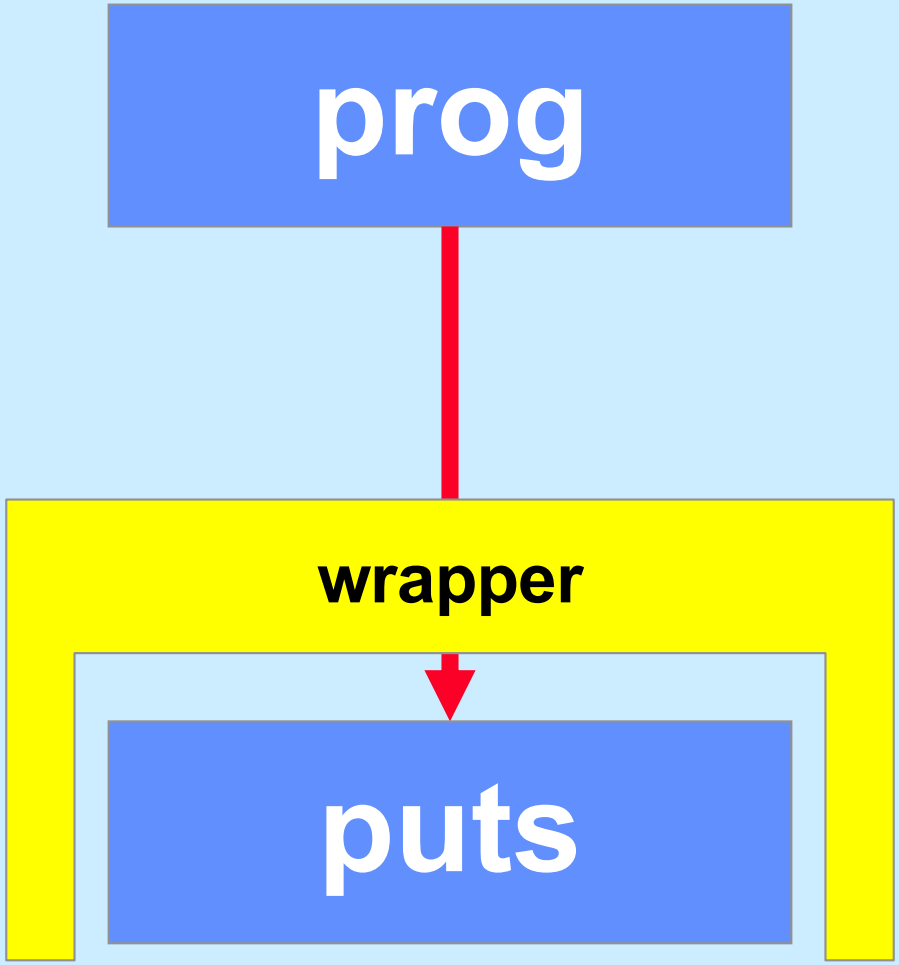
A Solution

- The two versions of your program coexist
  - libgoodstuff.so.1
  - libgoodstuff.so.2
- You arrange so that old code uses the old version, new code uses the new
- Most users of your code don't really want to have to care about version numbers
  - they want always to link with libgoodstuff.so
  - and get the version that was current when they wrote their programs

Versioning

```
$ gcc -fPIC -c goodstuff.c
$ ld -shared -soname libgoodstuff.so.1 \
-o libgoodstuff.so.1 goodstuff.o
$ ln -s libgoodstuff.so.1 libgoodstuff.so
$ gcc -o prog1 prog1.c -L. -lgoodstuff \
-Wl,-rpath .
$ vi goodstuff.c
$ gcc -fPIC -c goodstuff.c
$ ld -shared -soname libgoodstuff.so.2 \
-o libgoodstuff.so.2 goodstuff.o
$ rm -f libgoodstuff.so
$ ln -s libgoodstuff.so.2 libgoodstuff.so
$ gcc -o prog2 prog2.c -L. -lgoodstuff \
-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

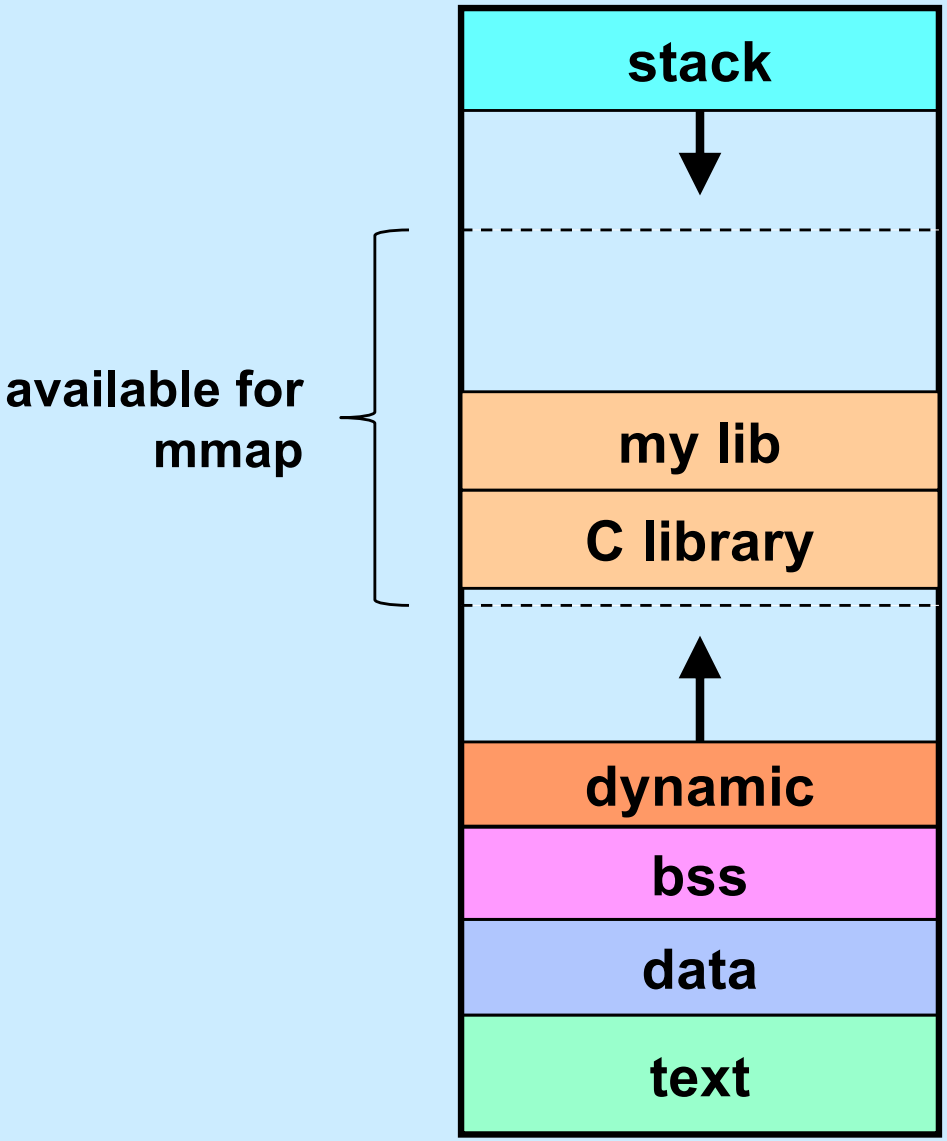
Environment Variables

- Another form of exec
  - `int execve(const char *filename, char *const argv[], char *const envp[]);`
- envp is an array of strings, of the form
  - key=value
- programs can search for values, given a key
- example
  - PATH=~/bin:/bin:/usr/bin:/course/cs0330/bin

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.
$
```

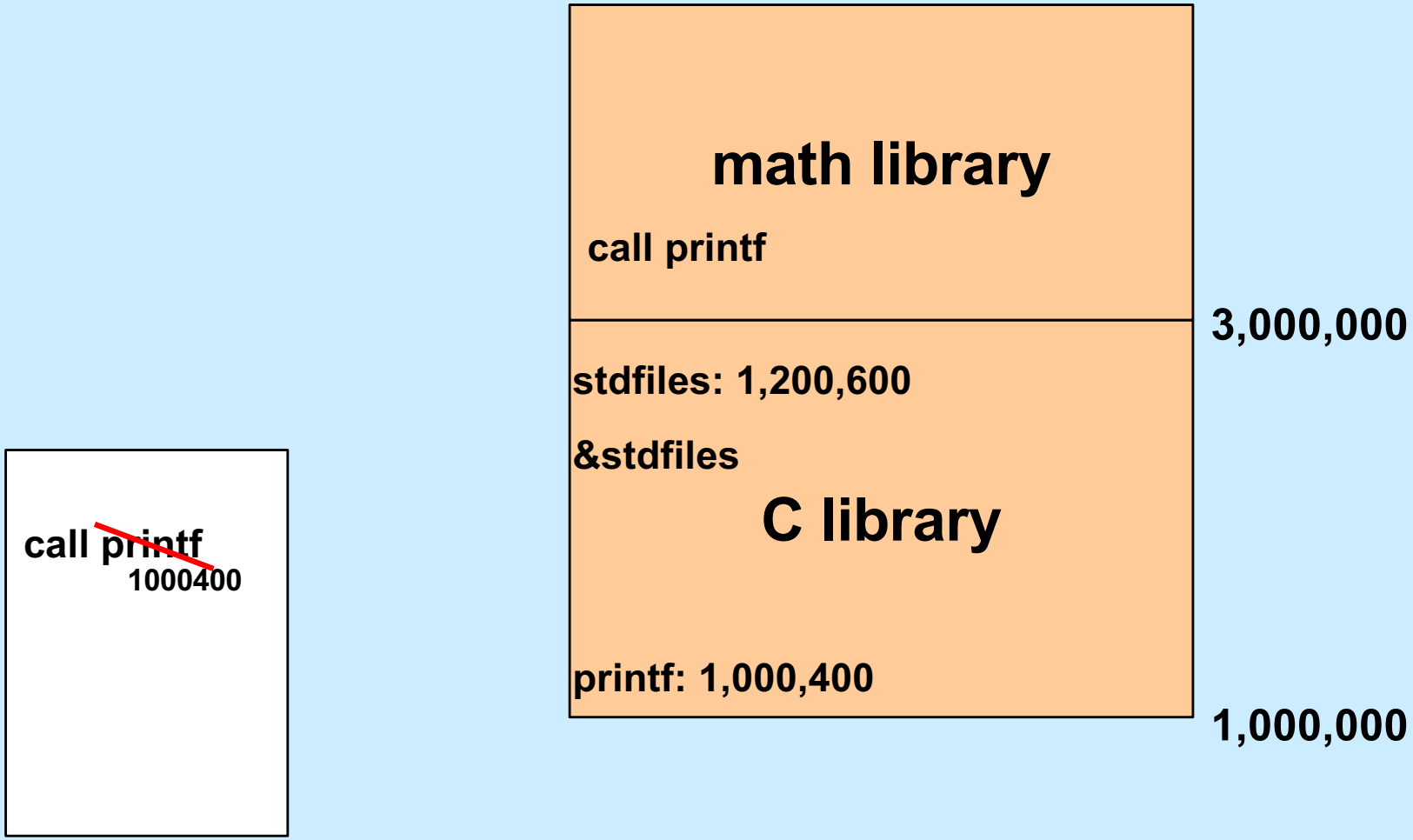
Mmapping Libraries



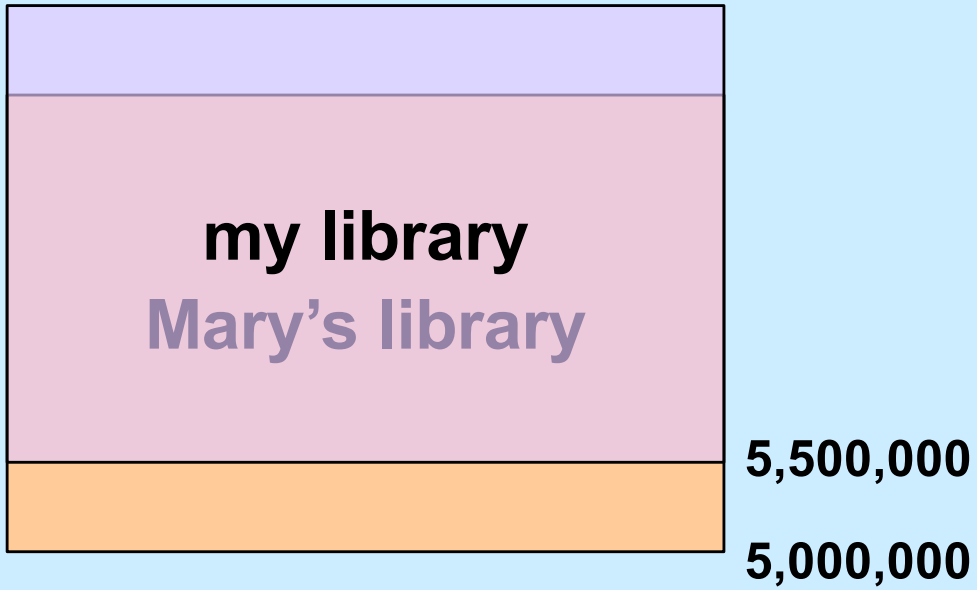
Problem

- How is relocation handled?

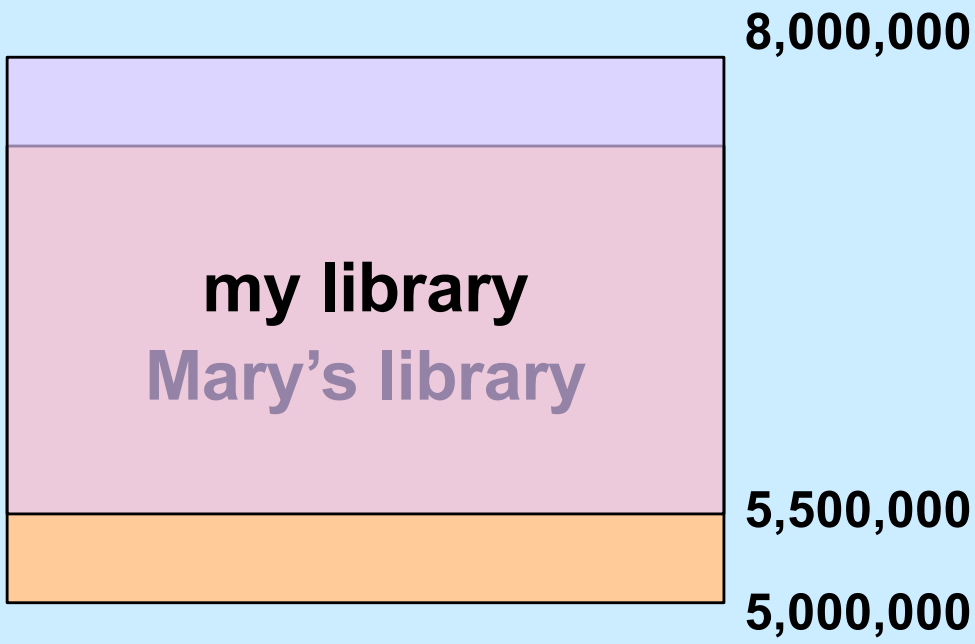
Pre-Relocation



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 *my library* into our address space?

a) **the MAP_SHARED option**

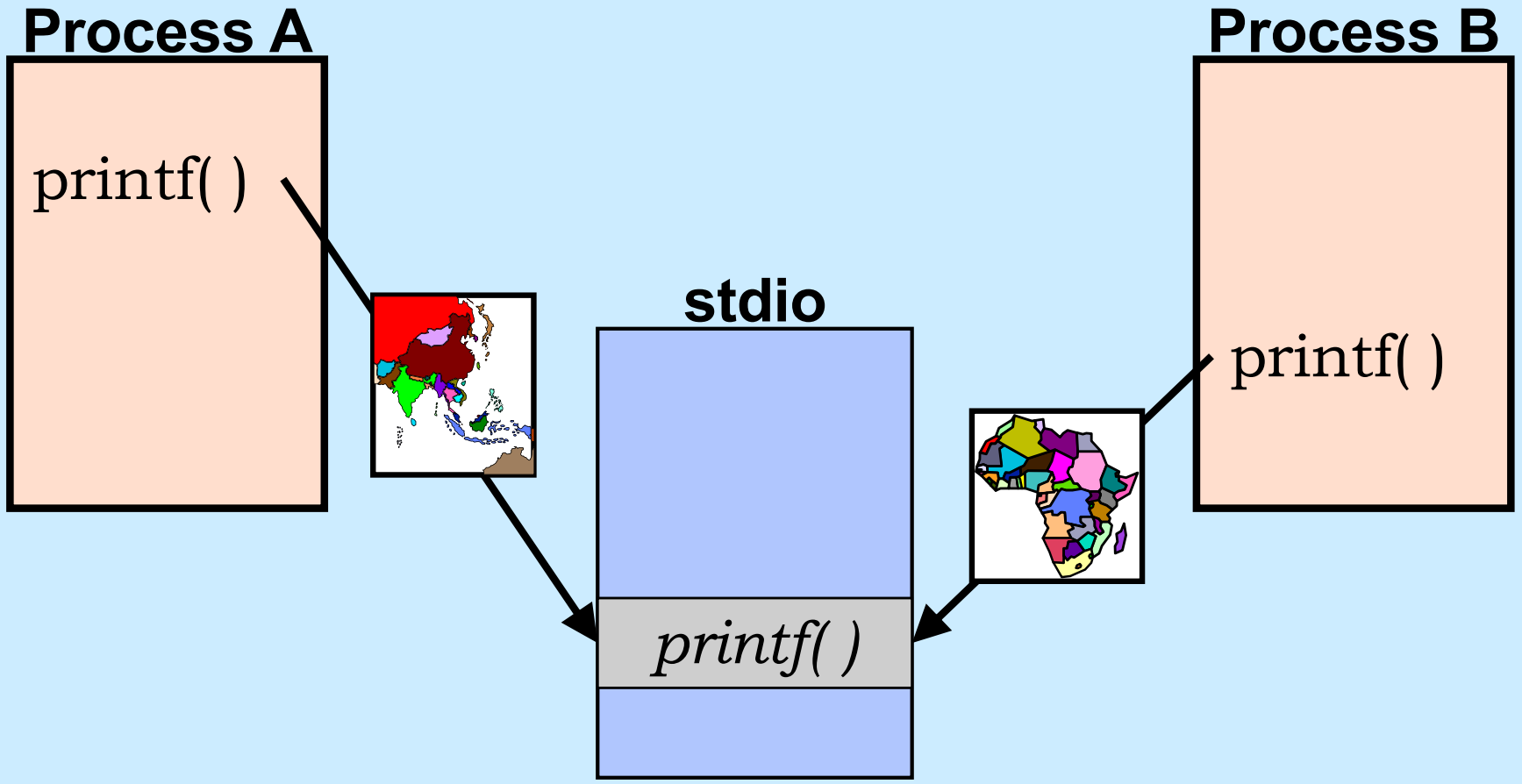
b) **the MAP_PRIVATE option**

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

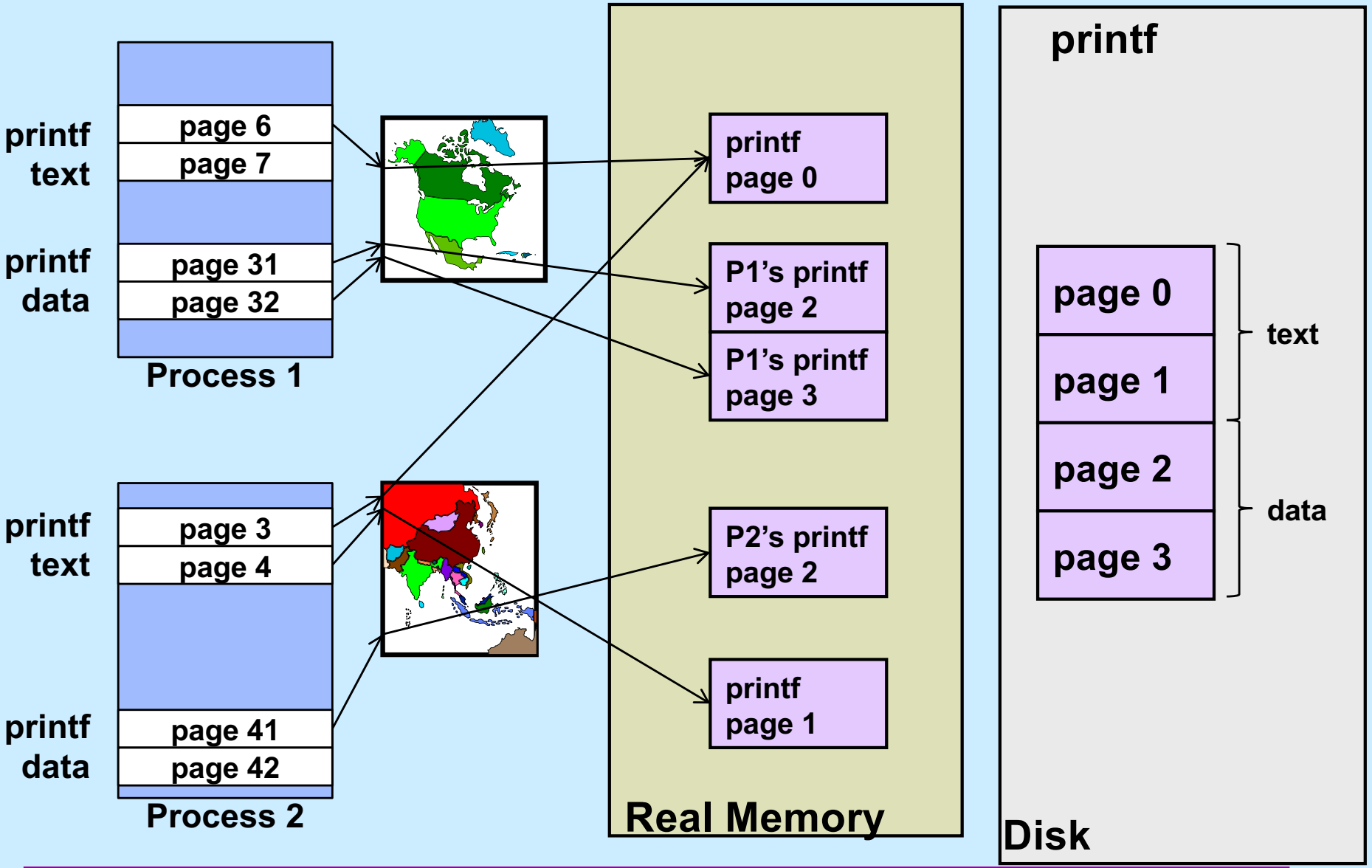
Mapping Shared Objects



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

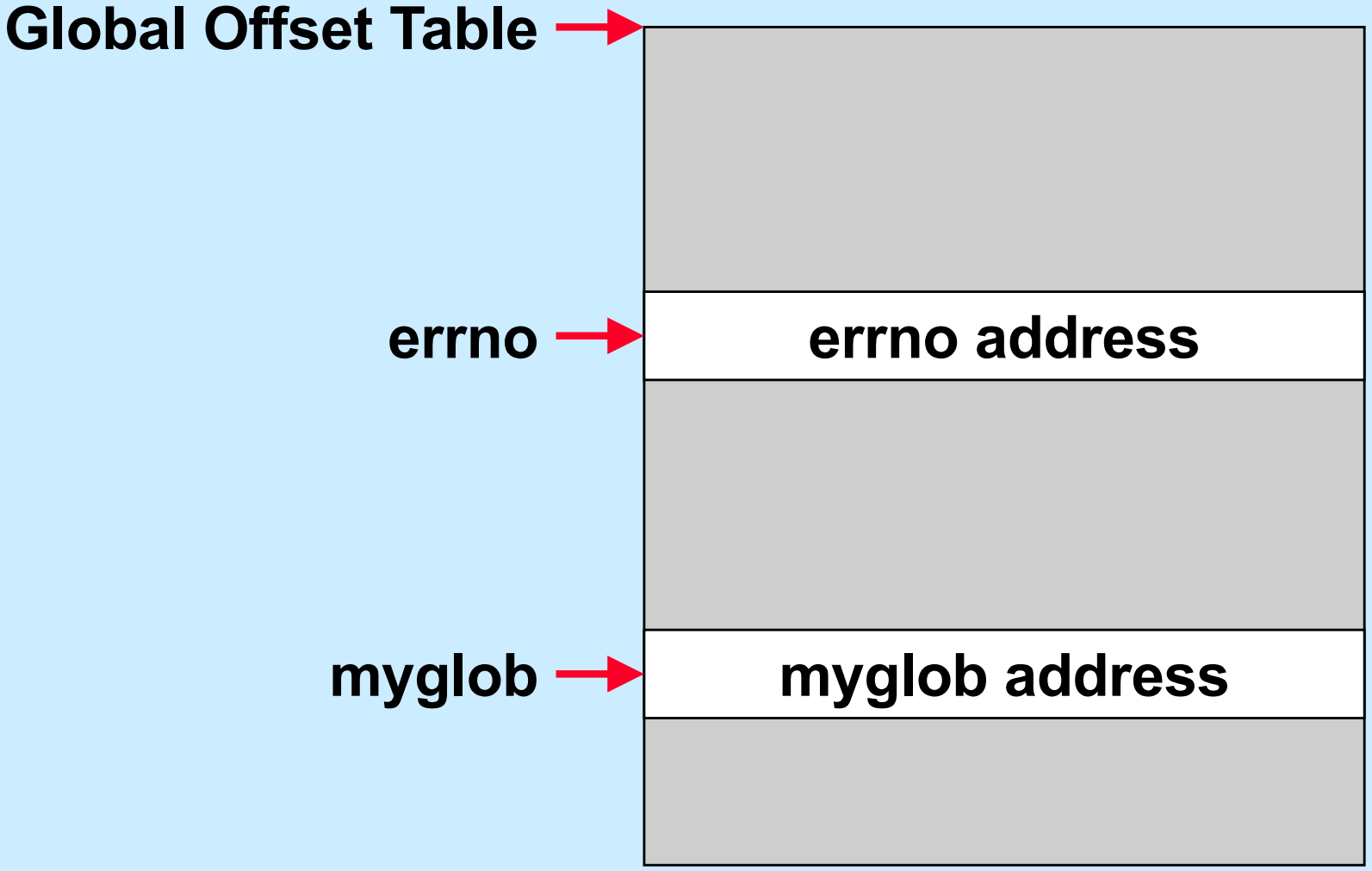
Mapping printf



Position-Independent Code

- Produced by gcc when given the –fPIC flag
- 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



Functions in Shared Objects

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

An Example

```
int main( ) {
    puts("Hello world\n");
    …
    return 0;
}
```

```
0000000000006b0 <main>:
 6b0: 55                          push   %rbp
 6b1: 48 89 e5                    mov    %rsp,%rbp
 6b4: 48 8d 3d 99 00 00 00        lea    0x99(%rip),%rdi
 6bb: e8 a0 fe ff ff              callq  560 <puts@plt>
 …
```

Before Calling puts

```
.PLT0:
  pushq GOT+8(%rip)
  jmp   *GOT+16(%rip)
  nop; nop
  nop; nop
.puts:
  jmp   *puts@GOT(%rip)
.putsnext
  pushq $putsRelOffset
  jmp   .PLT0
.PLT2:
  jmp   *name2@GOT(%rip)
.PLT2next
  pushq $name2RelOffset
  jmp   .PLT0
```

Procedure-Linkage Table

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


puts:
   .quad .putsnext
name2:
   .quad .PLT2next
```

Relocation info:

```
GOT_offset(puts), symx(puts)
```

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

Relocation Table

After Calling puts

```
.PLT0:
  pushq GOT+8(%rip)
  jmp   *GOT+16(%rip)
  nop; nop
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.puts:
  jmp   *puts@GOT(%rip)
.putsnext
  pushq $putsRelOffset
  jmp   .PLT0
.PLT2:
  jmp   *name2@GOT(%rip)
.PLT2next
  pushq $name2RelOffset
  jmp   .PLT0
```

Procedure-Linkage Table

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


puts:
   .quad puts
name2:
   .quad .PLT2next
```

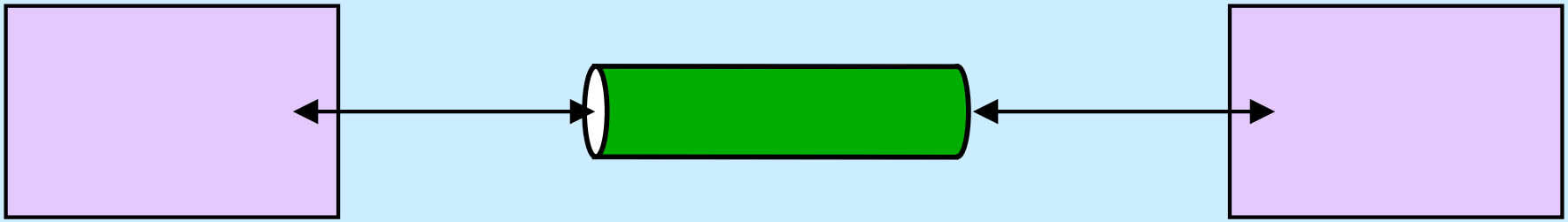
Relocation info:

```
GOT_offset(puts), symx(puts)
```

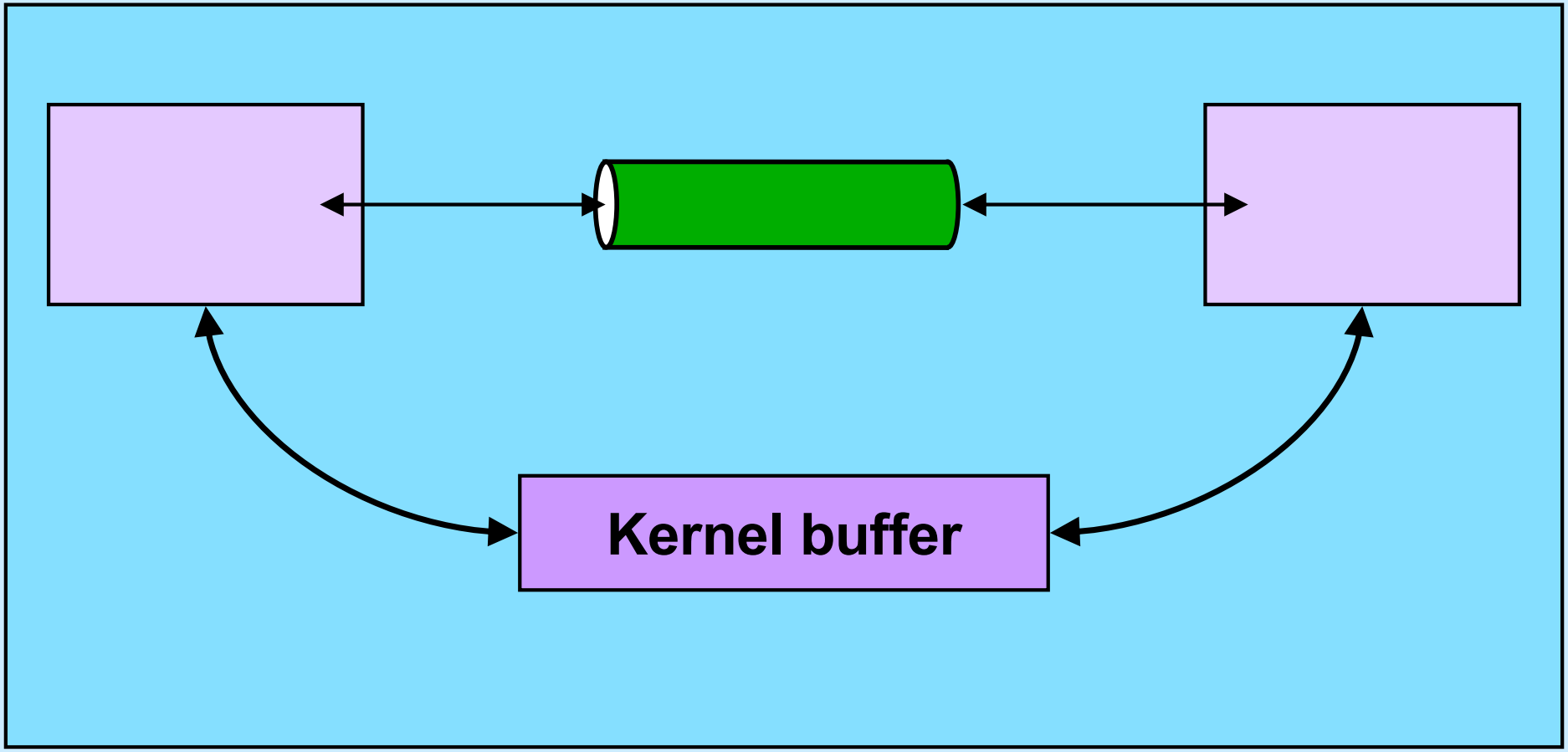
```
GOT_offset(name2), symx(name2)
```

Relocation Table

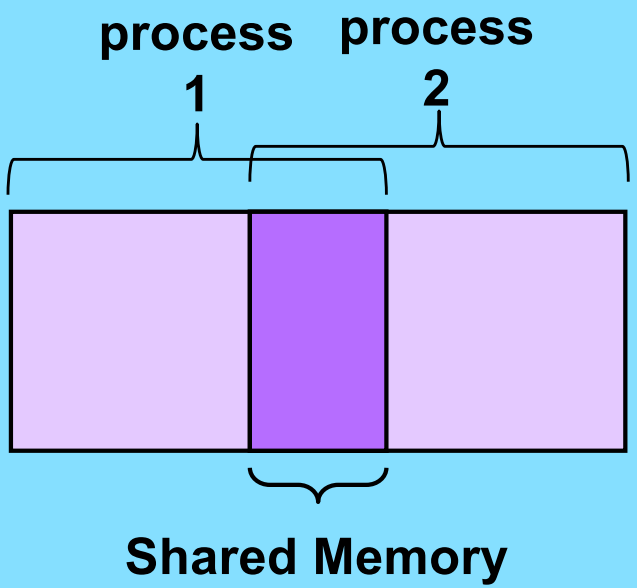
Interprocess Communication (IPC): Pipes



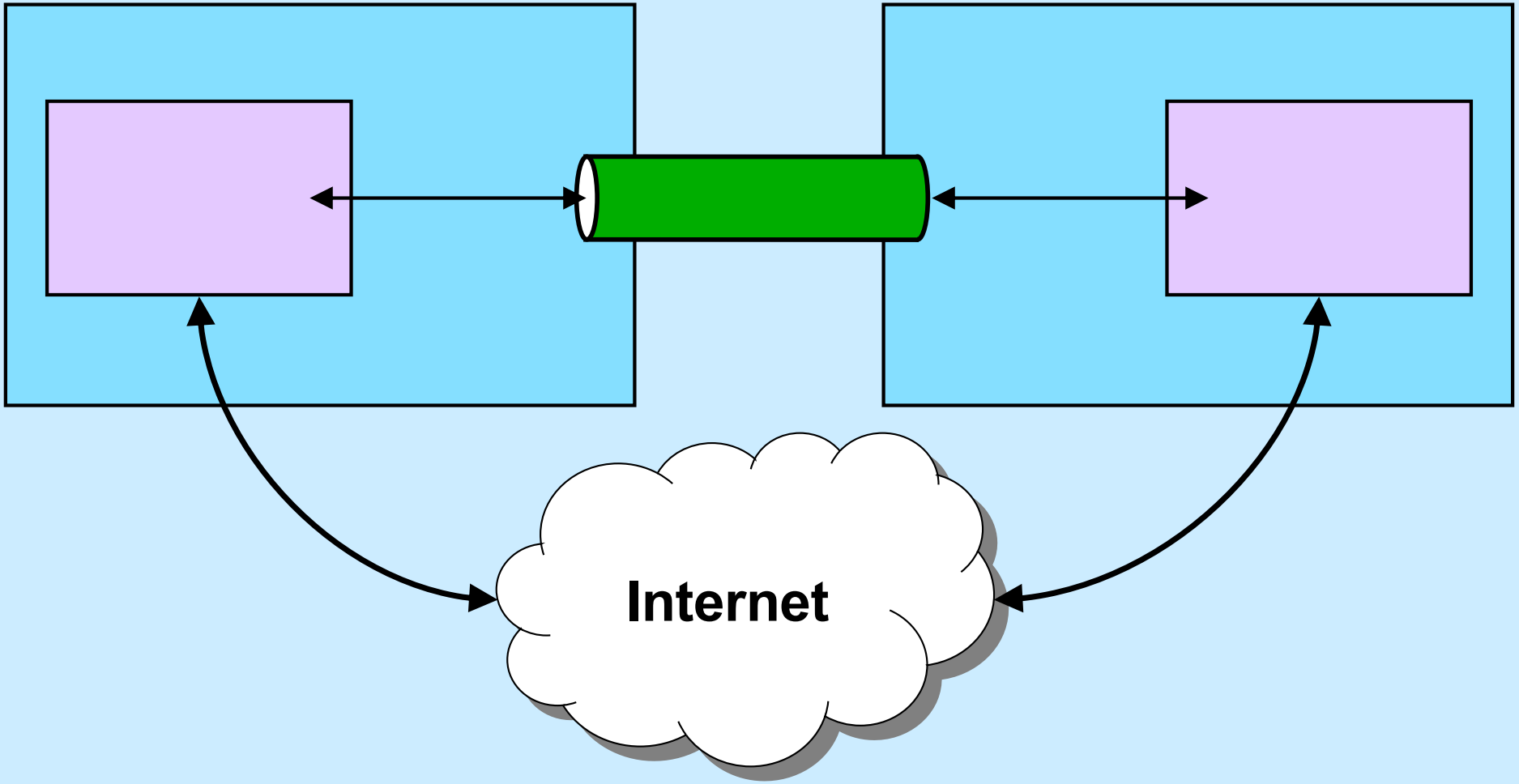
Interprocess Communication: Same Machine I



Interprocess Communication: Same Machine II

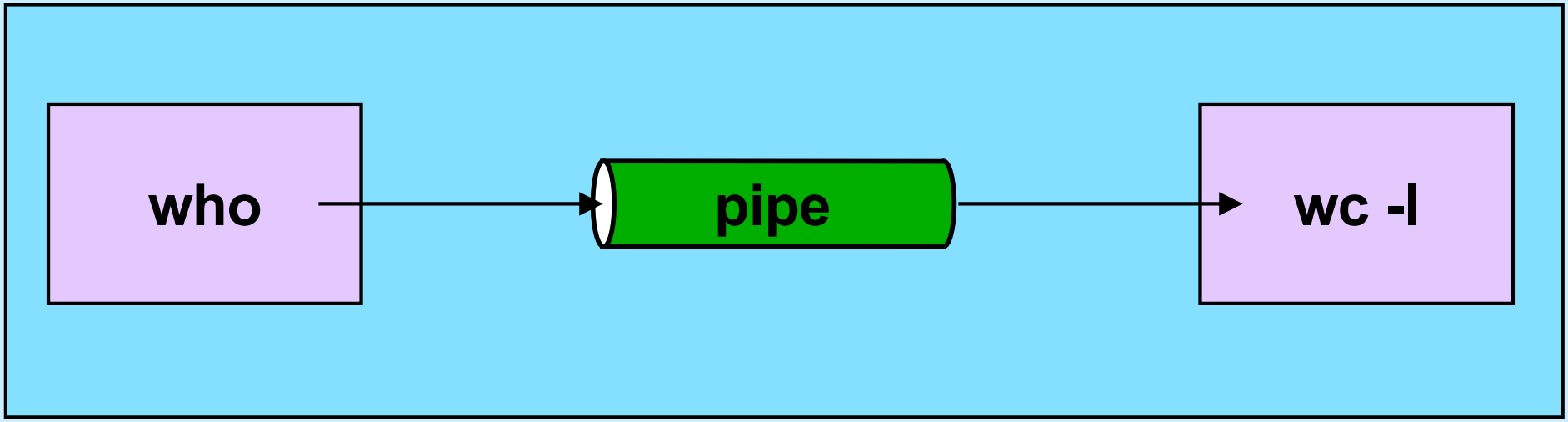


Interprocess Communication: Different Machines



Intramachine IPC

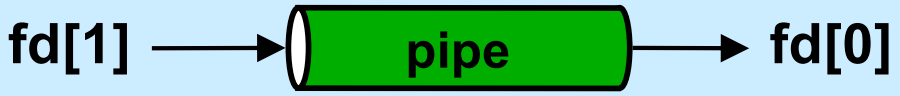
```
$cslab2e who | wc -l
```



Intramachine IPC

```
$cslab2e who | wc -l
```

```
int fd[2];
pipe(fd);
if (fork() == 0) {
  close(fd[0]);
  close(1);
  dup(fd[1]); close(fd[1]);
  execl("/usr/bin/who", "who", 0); // who sends output to pipe
}
if (fork() == 0) {
  close(fd[1]);
  close(0);
  dup(fd[0]); close(fd[0]);
  execl("/usr/bin/wc", "wc", "-l", 0); // wc's input is from pipe
}
close(fd[1]); close(fd[0]);
// …
```



Intermachine Communication

- **Can pipes be made to work across multiple machines?**
  - **covered soon ...**
    - » **what happens when you type**

```
who | ssh cslab3a wc -l
```

?

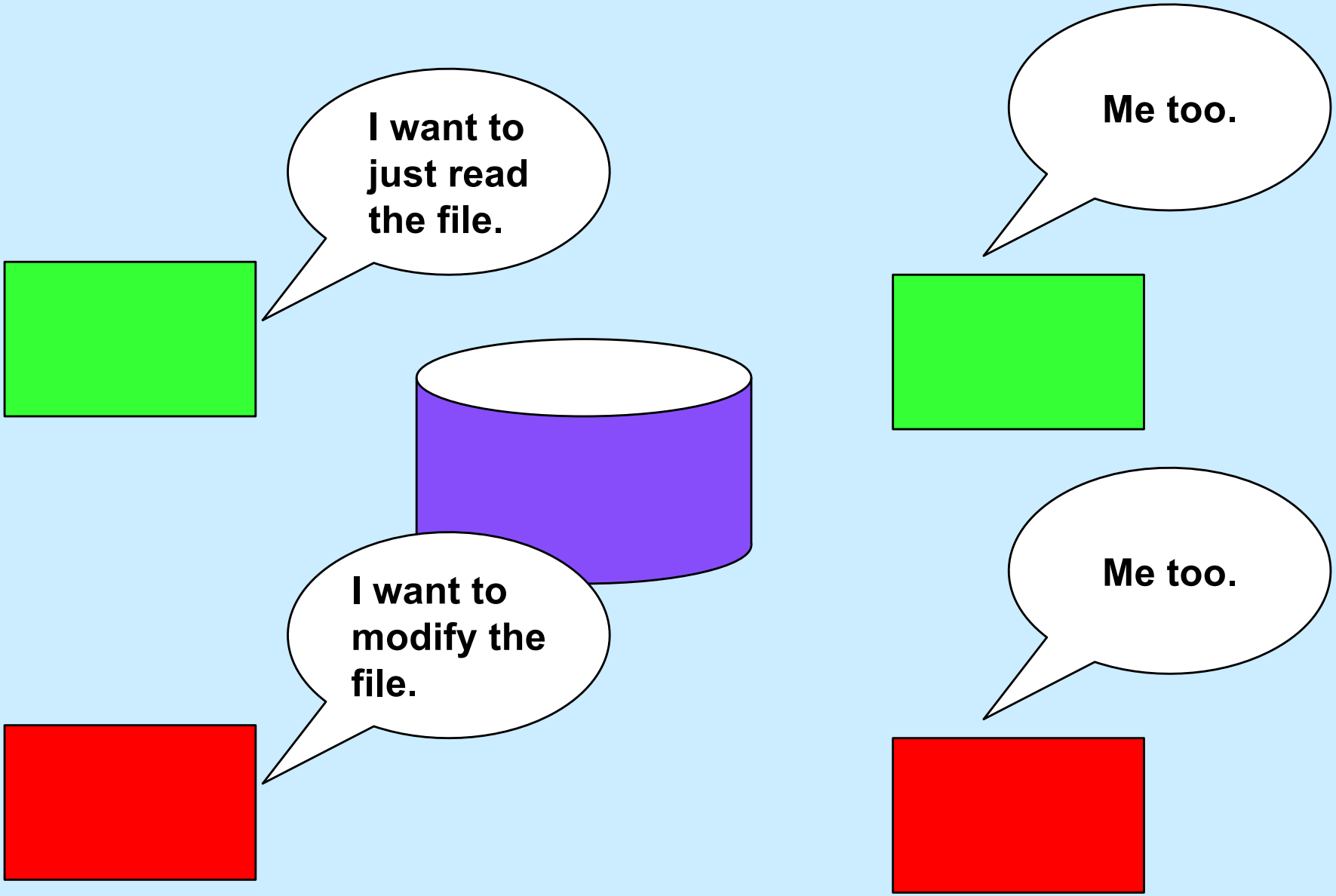
Sharing Files

- You're doing a project with a partner
- You code it as one 15,000-line file
  - the first 7,500 lines are yours
  - the second 7,500 lines are your partner's
- You edit the file, changing 6,000 lines
  - it's now 5am
- Your partner completes her changes at 5:01am
- At 5:02am you look at the file
  - your partner's changes are there
  - yours are not

Lessons

- Never work with a partner
- Use more than one file
- Read up on git
- Use an editor and file system that support file locking

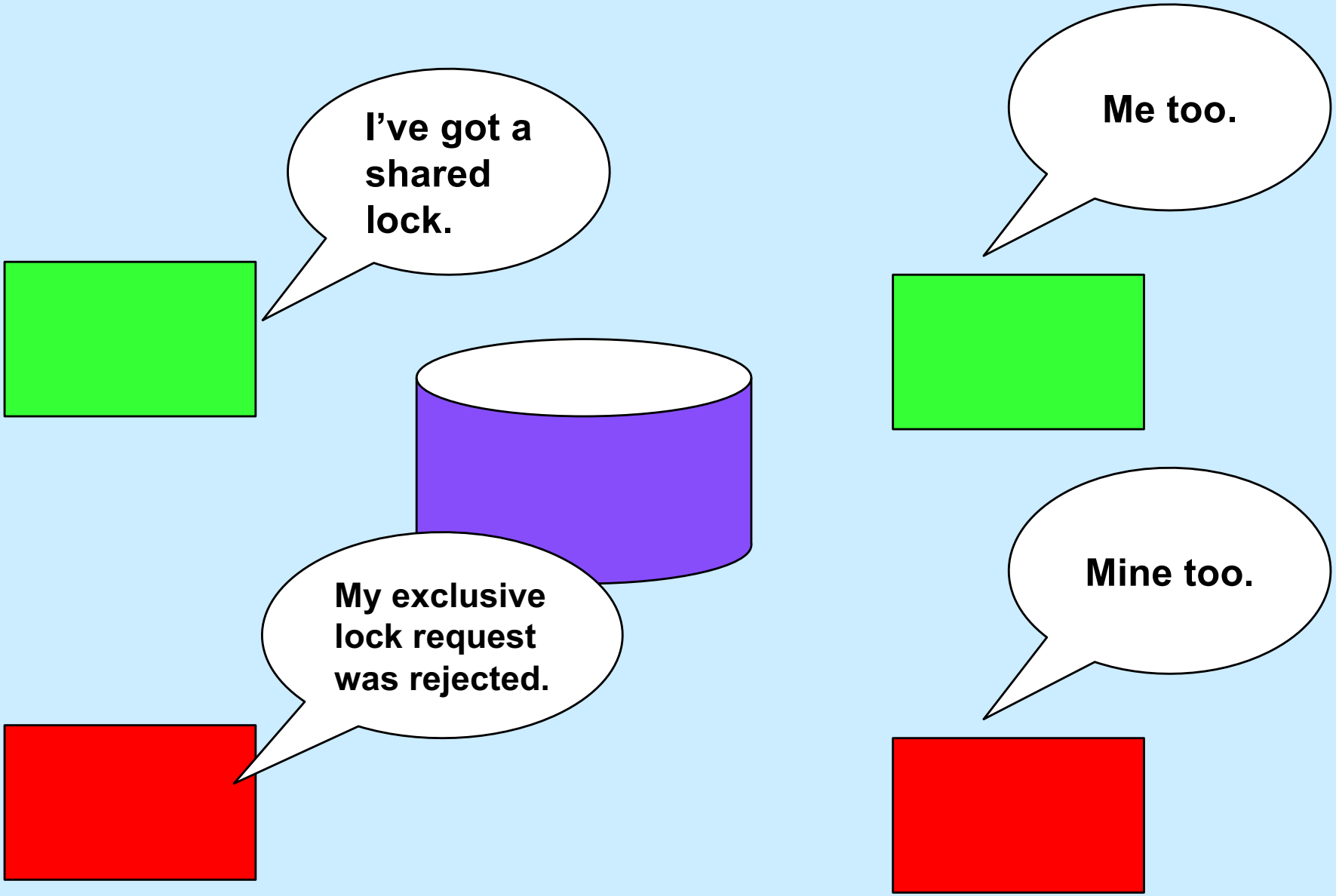
What We Want ...



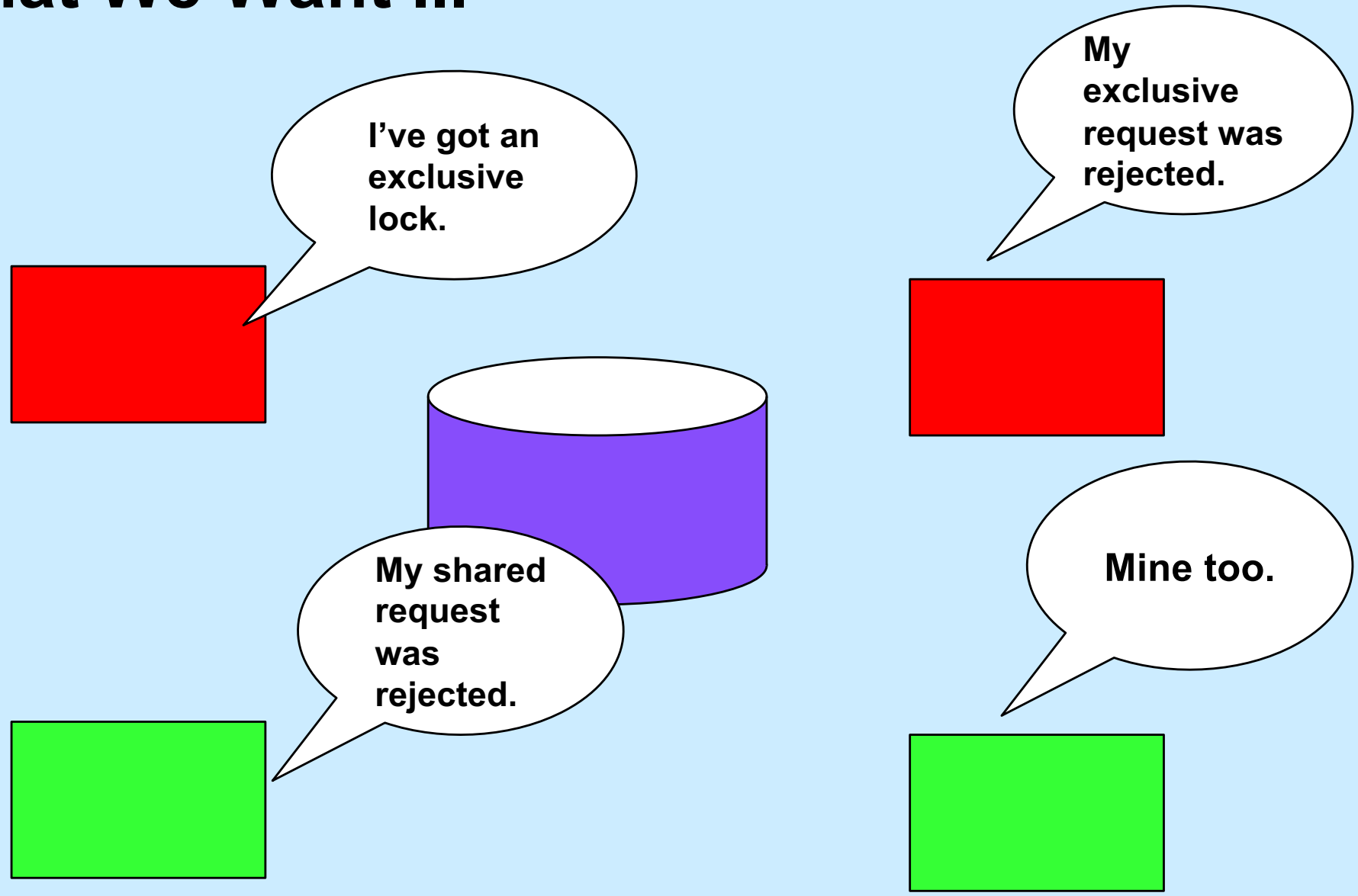
Types of Locks

- Shared (readers) locks
  - any number may have them at same time
  - may not be held when an exclusive lock is held
- Exclusive (writers) locks
  - only one at a time
  - may not be held when a shared lock is held

What We Want ...



What We Want ...



Locking Files

- **Early Unix didn't support file locking**
- **How did people survive?**
  - `open("file.lck", O_RDWR|O_CREAT|O_EXCL, 0666);`
    - » **operation fails if *file.lck* exists, succeeds (and creates file.lck) otherwise**
    - » **requires cooperative programs**

Locking Files (continued)

- How it's done in "modern" Unix
  - "advisory locks" may be placed on files
    - » may request shared (readers) or exclusive (writers) lock
      - *fcntl* system call
    - » either succeeds or fails
    - » *open*, *read*, *write* always work, regardless of locks
    - » a lock applies to a specified range of bytes, not necessarily the whole file
    - » requires cooperative programs

Locking Files (still continued)

- **How to:**

```
struct flock fl;
fl.l_type = F_RDLCK;        // read lock
// fl.l_type = F_WRLCK;     // write lock
// fl.l_type = F_UNLCK;     // unlock
fl.l_whence = SEEK_SET;     // starting where
fl.l_start = 0;             // offset
fl.l_len = 0;               // how much? (0 = whole file)
fd = open("file", O_RDWR);
if (fcntl(fd, F_SETLK, &fl) == -1)
  if ((errno == EACCES) || (errno == EAGAIN))
    // didn't get lock
  else
    // something else is wrong
else
  // got the lock!
```

Locking Files (yet still continued)

- Making locks mandatory:
  - if the file's permissions have group execute permission off and set-group-ID on, then locking is enforced
    - » *read*, *write* fail if file is locked by someone other than the caller
  - however …
    - » difficult to implement on distributed file systems (such as used at Brown CS)

Quiz 2

- **Your program currently has a shared lock on a portion of a file. It would like to "upgrade" the lock to be an exclusive lock. Would there be any problems with adding an option to *fcntl* that would allow the holder of a shared lock to wait until it's possible to upgrade to an exclusive lock, then do the upgrade?**

  a) **at least one major problem**

  b) **either no problems whatsoever or some easy-to-deal-with problems**