

CS 33

Linking and Libraries (2)

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

```
$ gcc -fPIC -c myputs.c
$ ld -shared -o libmyputs.so myputs.o
$ gcc -o prog prog.c -fPIC -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

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**

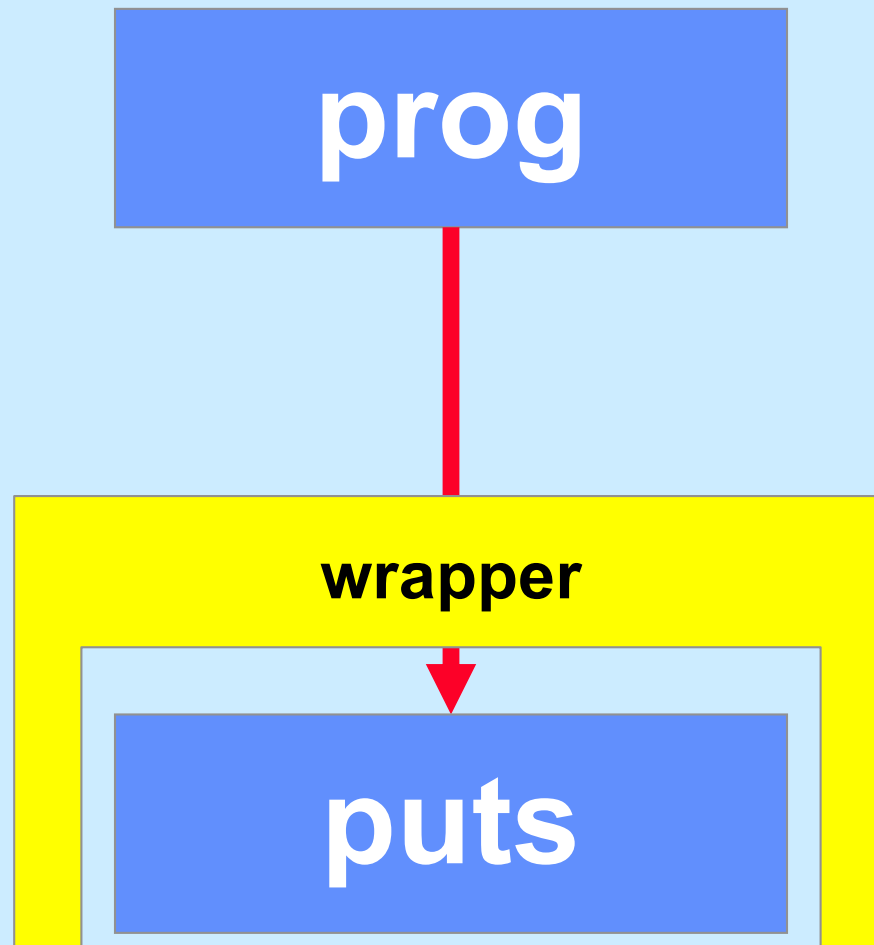
A Solution

- **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

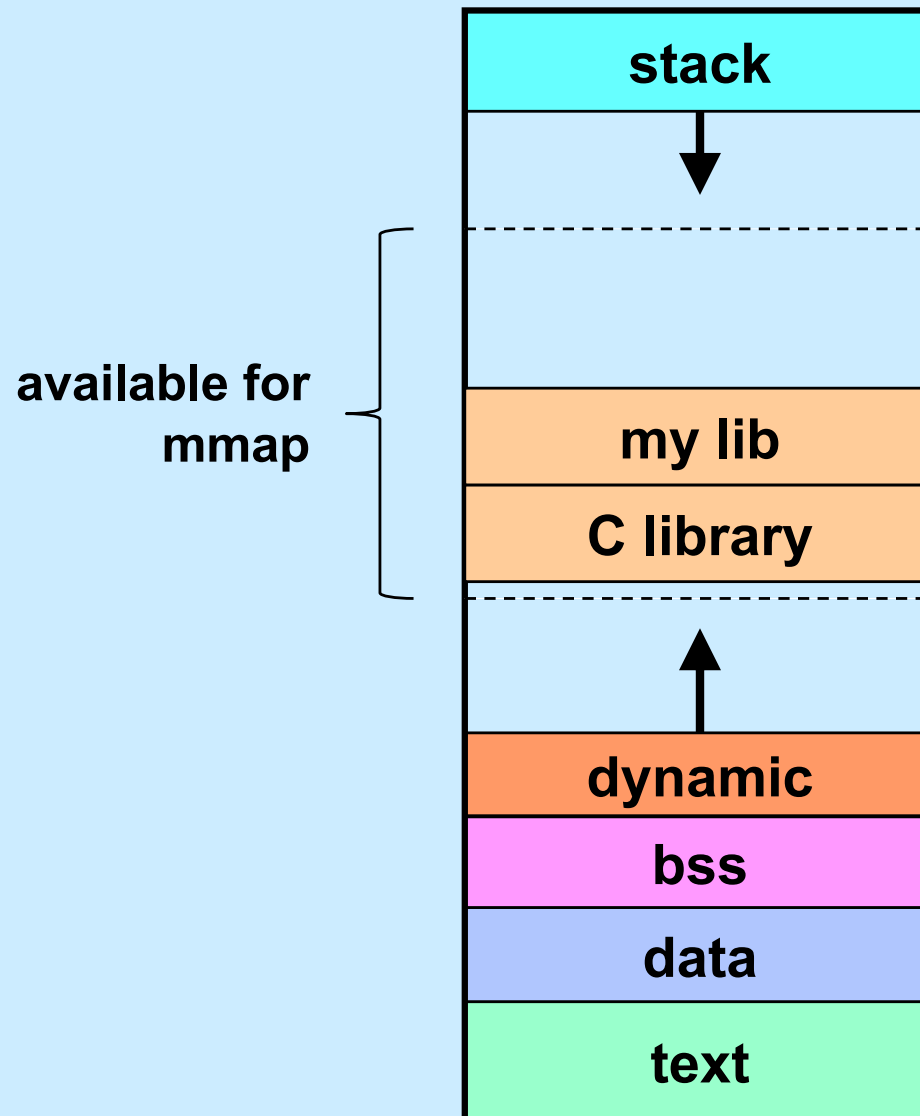
Environment Variables

- **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**
 - `export PATH=~/bin:/bin:/usr/bin:/course/cs0330/bin`

Example

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

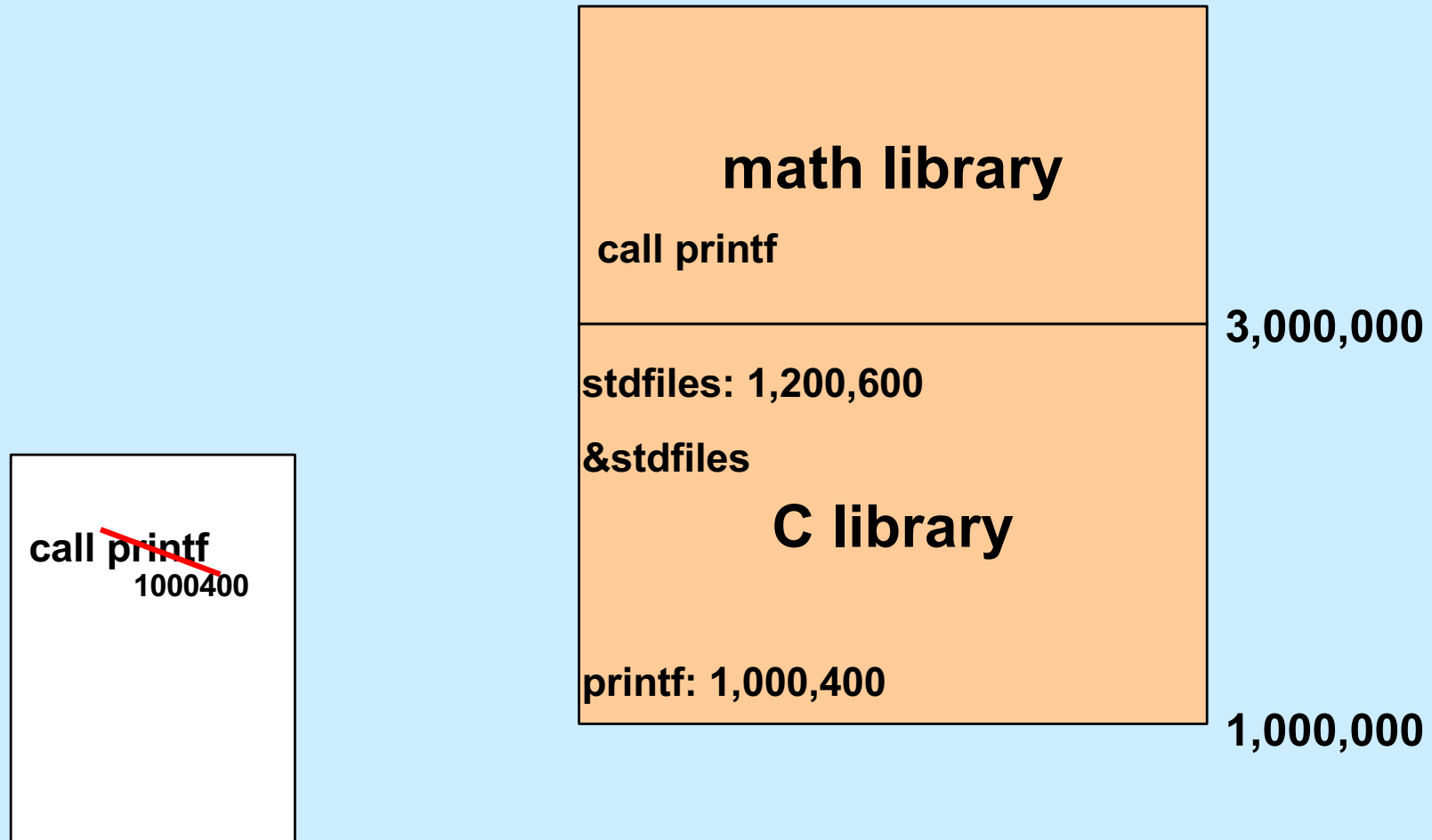
Mmapping Libraries



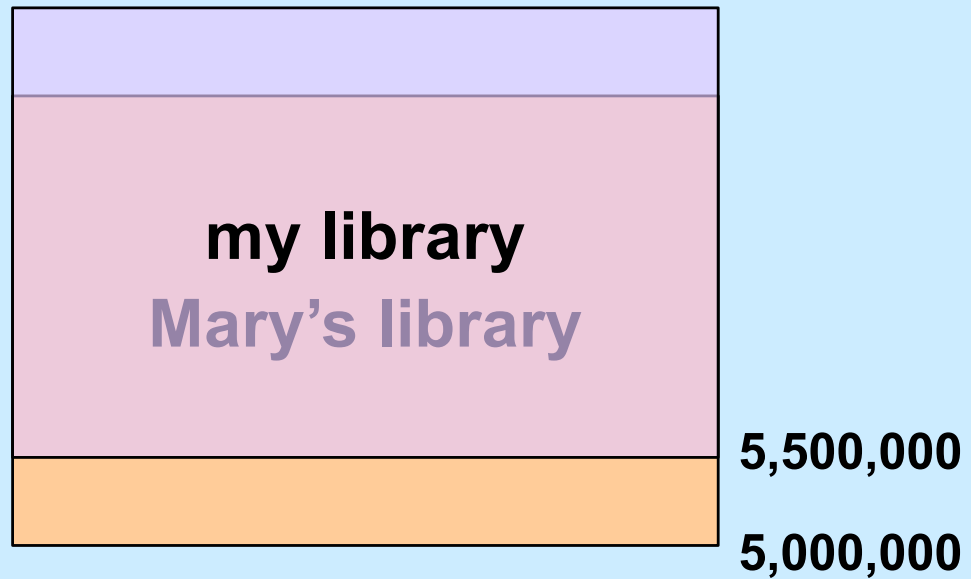
Problem

- **How is relocation handled?**

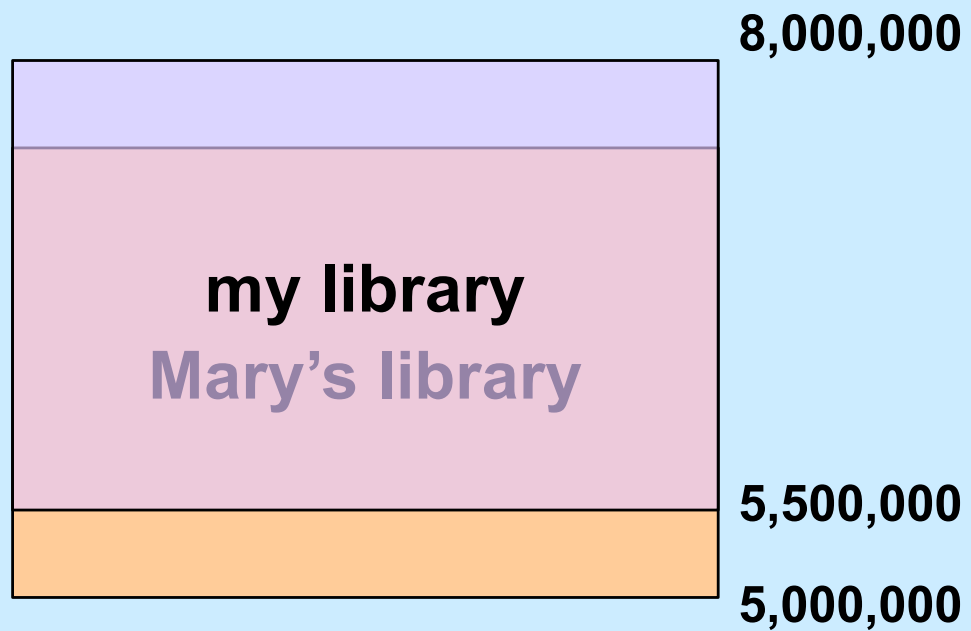
Pre-Relocation



But ...



But ...



Quiz 1

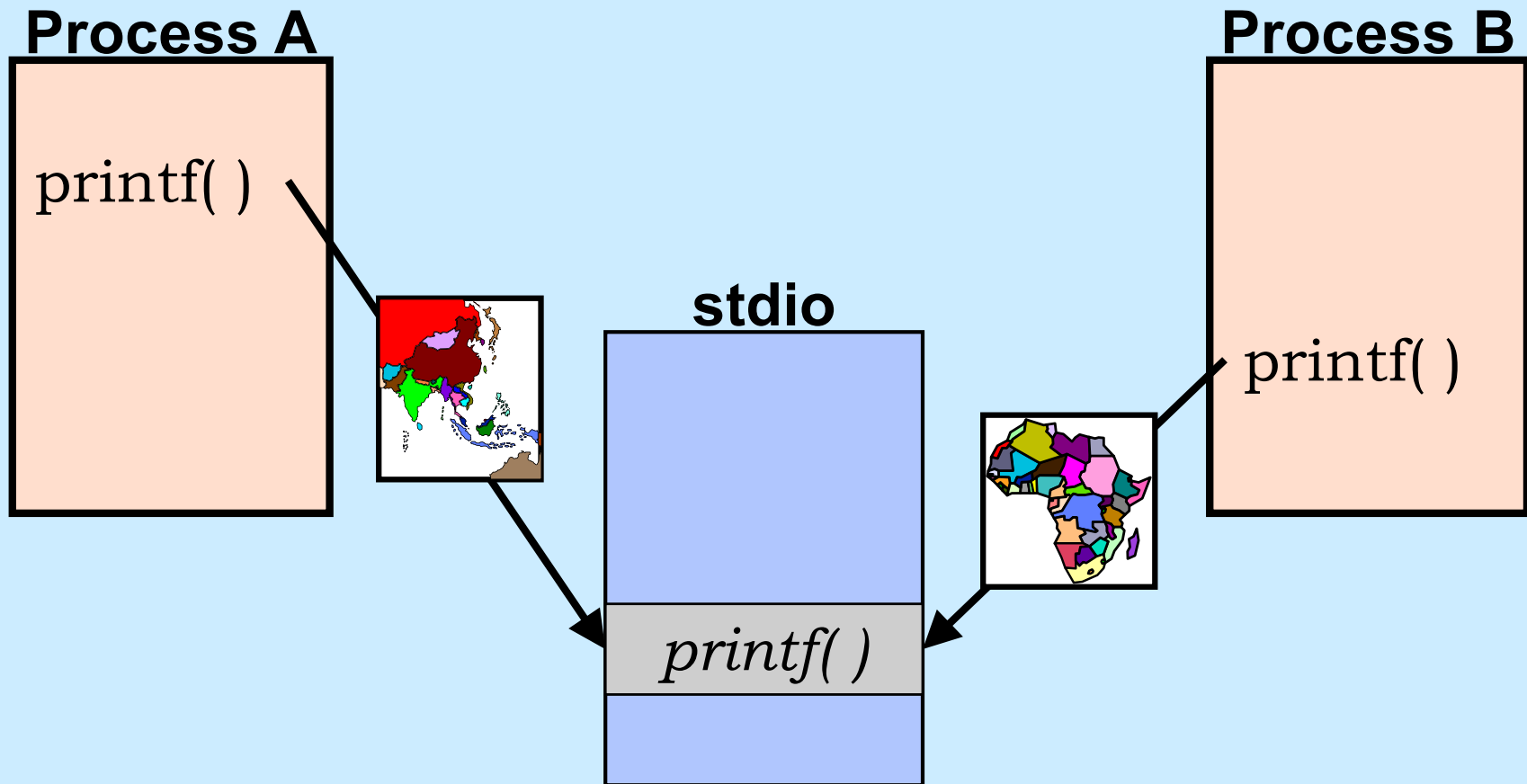
We need to relocate all references to Mary's library in my library. What option should we give to *mmap* when we map my library into our address space?

- a) the MAP_PRIVATE option**
- b) the MAP_SHARED 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

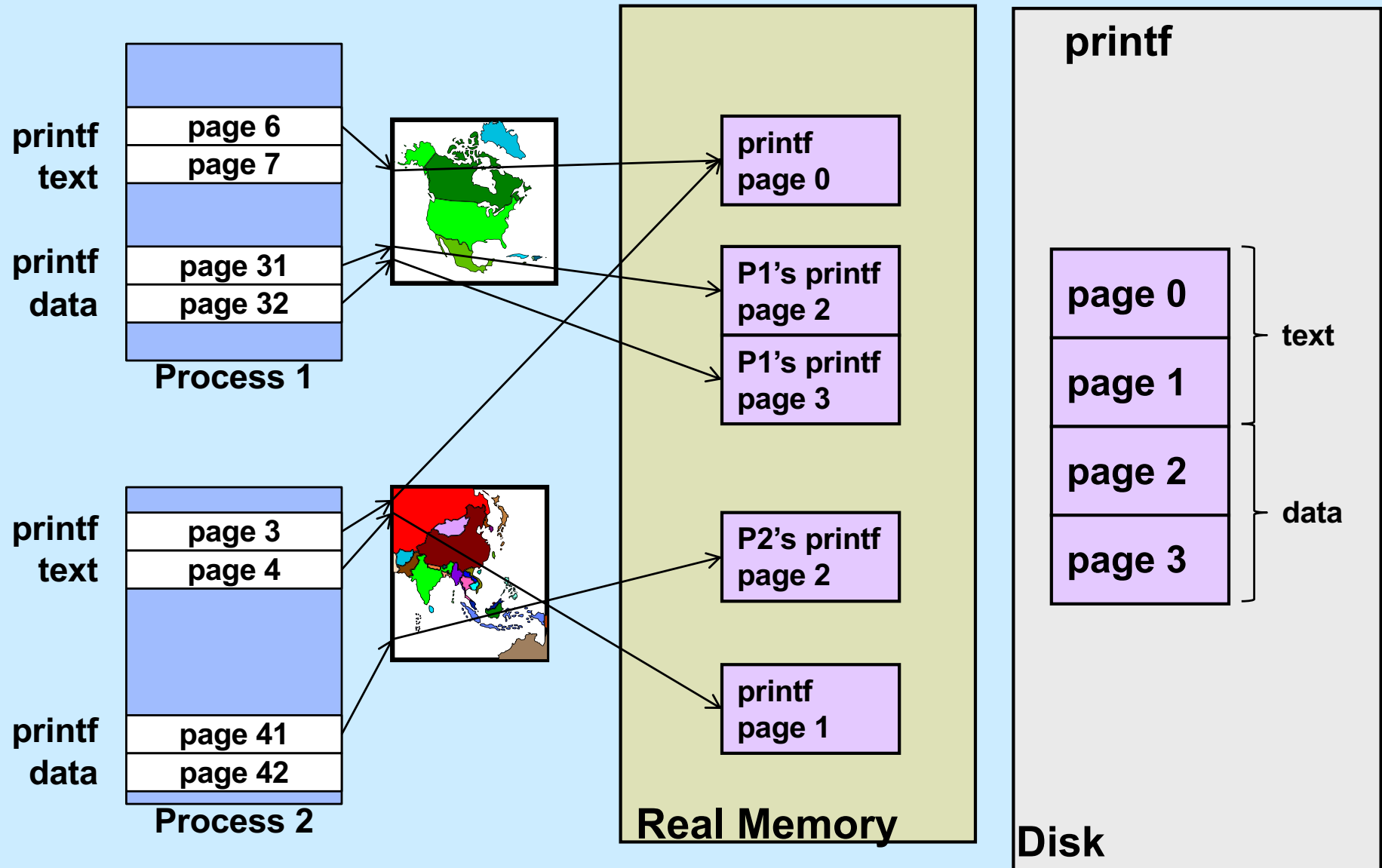
Mapping Shared Objects



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

Global Offset Table →

errno →

errno address

myglob →

myglob address

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;  
}
```

00000000000000006b0 <main>:

6b0: 55

6b1: 48 89 e5

6b4: 48 8d 3d 99 00 00 00

6bb: e8 a0 fe ff ff

...

push %rbp

mov %rsp,%rbp

lea 0x99(%rip),%rdi

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
    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 puts
name2:
    .quad .PLT2next
```

Relocation info:

GOT_offset(puts) , symx(puts)

GOT_offset(name2) , symx(name2)

Relocation Table

Quiz 2

On the second and subsequent calls to *puts*

- a) control goes directly to *puts*
- b) control goes to an instruction that jumps to *puts*
- c) control still goes to *ld-linux.so*, but it now transfers control directly to *puts*

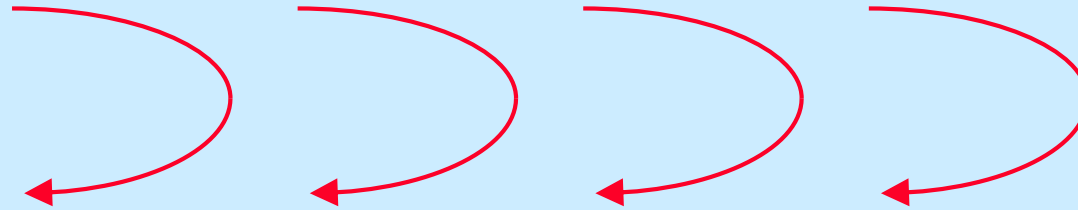
CS 33

Multithreaded Programming (1)

Multithreaded Programming

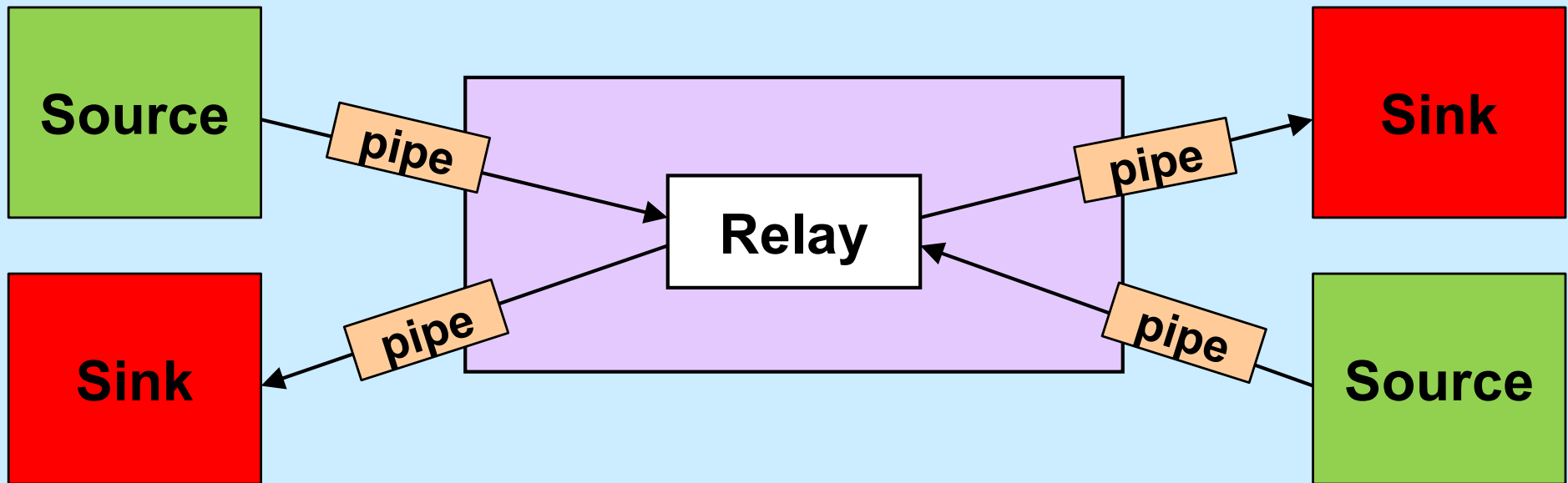
- **A thread is a virtual processor**
 - an independent agent executing instructions
- **Multiple threads**
 - multiple independent agents executing instructions

Why Threads?



- Many things are easier to do with threads
- Many things run faster with threads

A Simple Example



Life Without Threads

```
void relay(int left, int right) {
    fd_set rd, wr;
    int left_read = 1, right_write = 0;
    int right_read = 1, left_write = 0;
    int sizeLR, sizeRL, wret;
    char bufLR[BSIZE], bufRL[BSIZE];
    char *bufpR, *bufpL;
    int maxFD = max(left, right) + 1;

    fcntl(left, F_SETFL, O_NONBLOCK);
    fcntl(right, F_SETFL, O_NONBLOCK);

    while(1) {
        FD_ZERO(&rd);
        FD_ZERO(&wr);
        if (left_read)
            FD_SET(left, &rd);
        if (right_read)
            FD_SET(right, &rd);
        if (left_write)
            FD_SET(left, &wr);
        if (right_write)
            FD_SET(right, &wr);

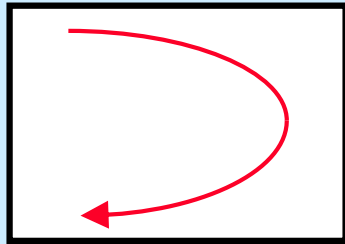
        select(maxFD, &rd, &wr, 0, 0);
```

```
        if (FD_ISSET(left, &rd)) {
            sizeLR = read(left, bufLR, BSIZE);
            left_read = 0;
            right_write = 1;
            bufpR = bufLR;
        }
        if (FD_ISSET(right, &rd)) {
            sizeRL = read(right, bufRL, BSIZE);
            right_read = 0;
            left_write = 1;
            bufpL = bufRL;
        }
        if (FD_ISSET(right, &wr)) {
            if ((wret = write(right, bufpR, sizeLR)) == sizeLR) {
                left_read = 1; right_write = 0;
            } else {
                sizeLR -= wret; bufpR += wret;
            }
        }
        if (FD_ISSET(left, &wr)) {
            if ((wret = write(left, bufpL, sizeRL)) == sizeRL) {
                right_read = 1; left_write = 0;
            } else {
                sizeRL -= wret; bufpL += wret;
            }
        }
    }
    return 0;
}
```

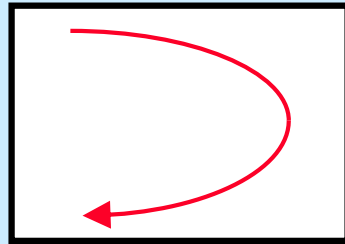
Life With Threads

```
void copy(int source, int destination) {  
    struct args *targs = args;  
    char buf[BSIZE];  
  
    while(1) {  
        int len = read(source, buf, BSIZE);  
        write(destination, buf, len);  
    }  
}
```

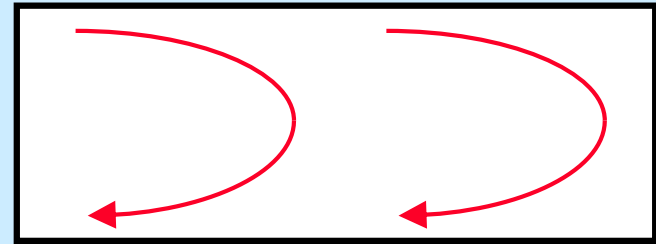
Processes vs. Threads



Process 1

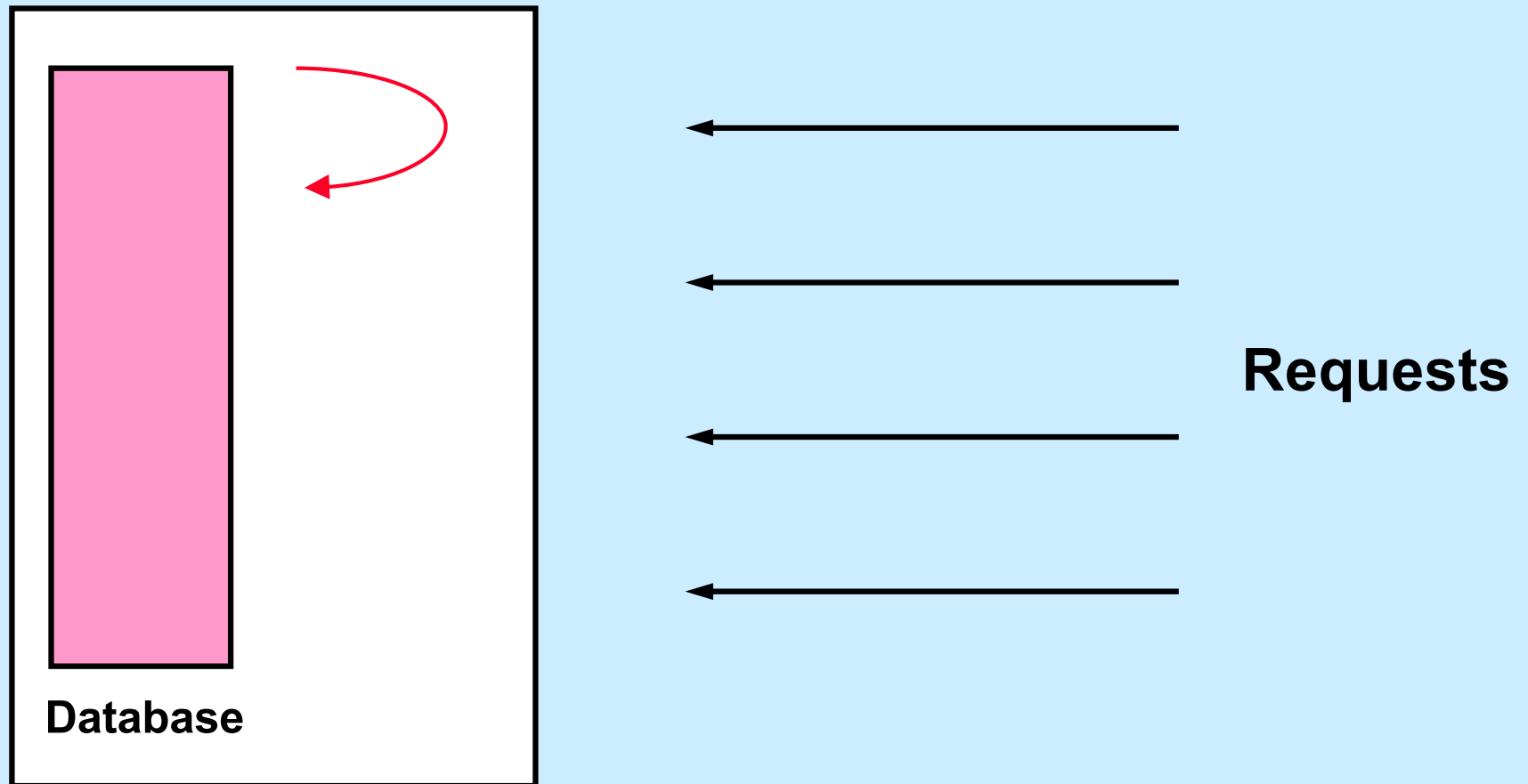


Process 2

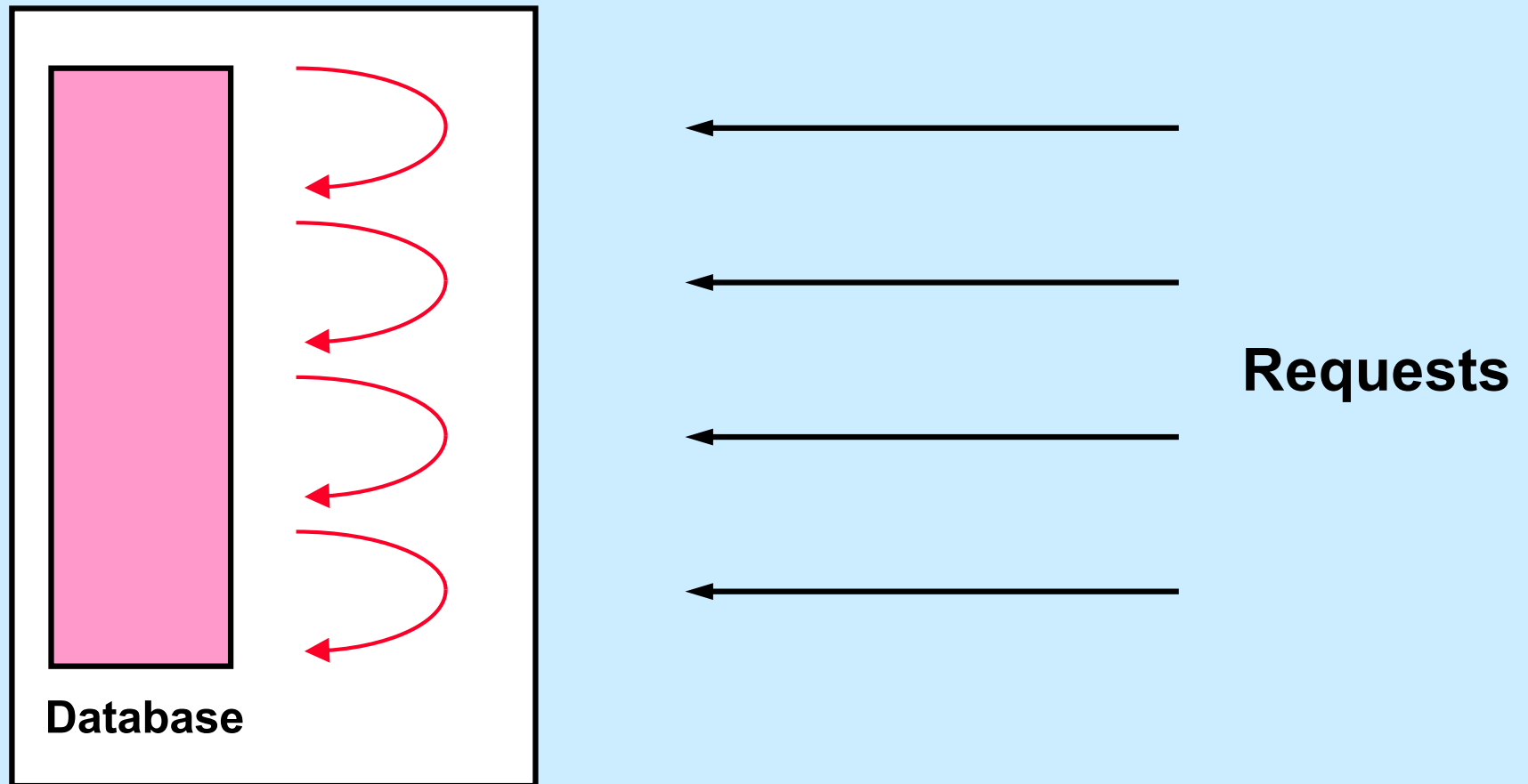


Process 3

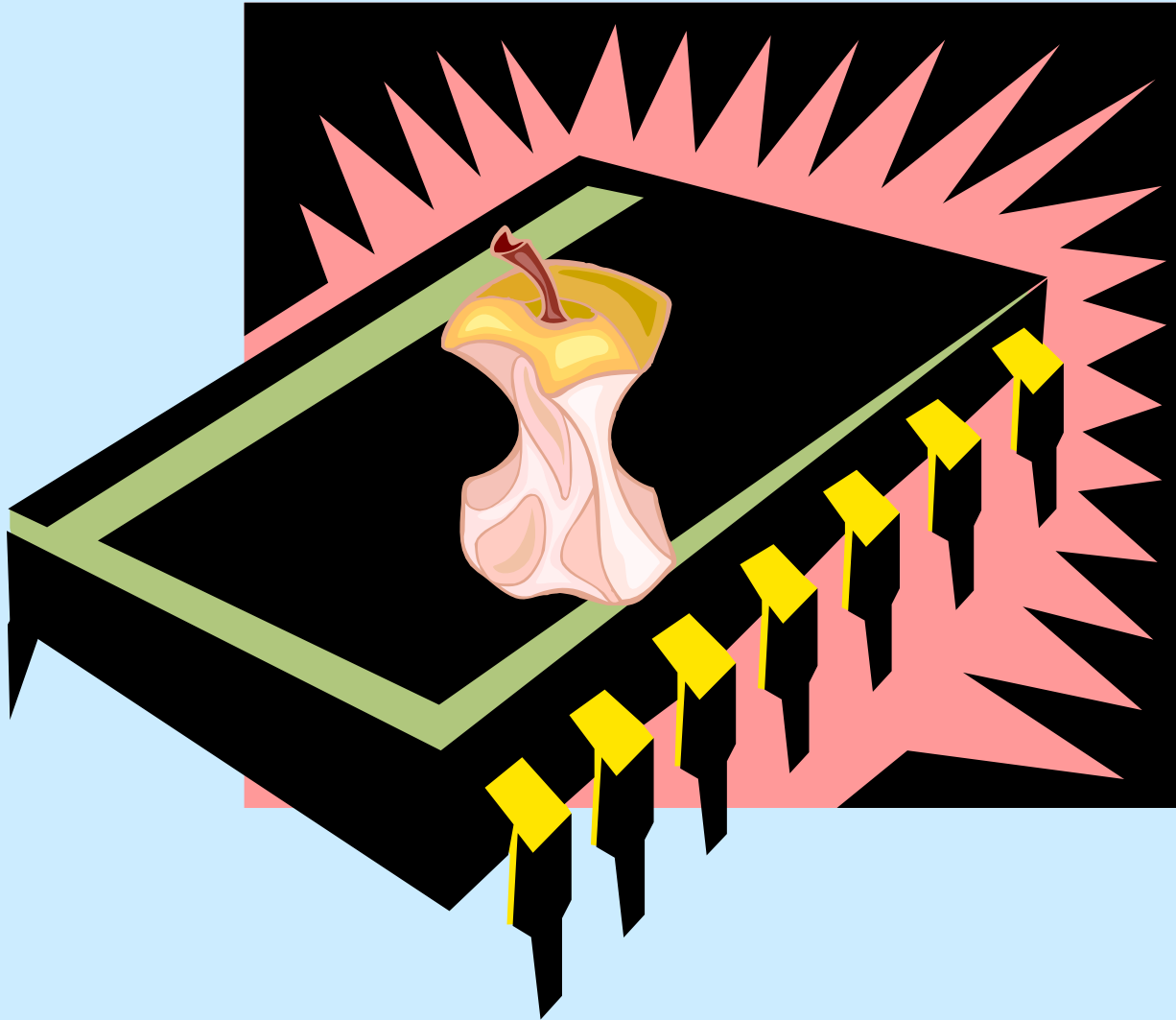
Single-Threaded Database Server



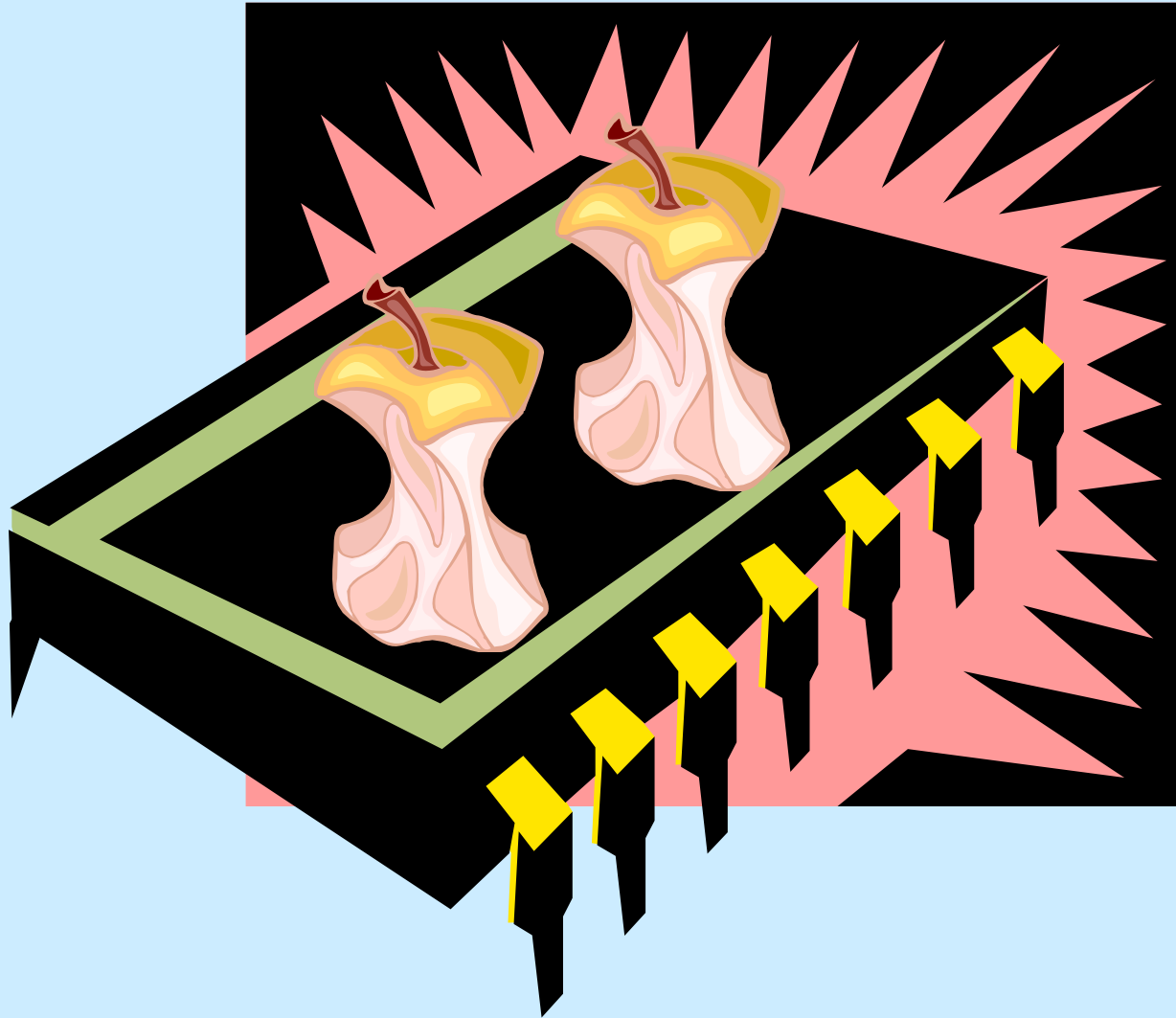
Multithreaded Database Server



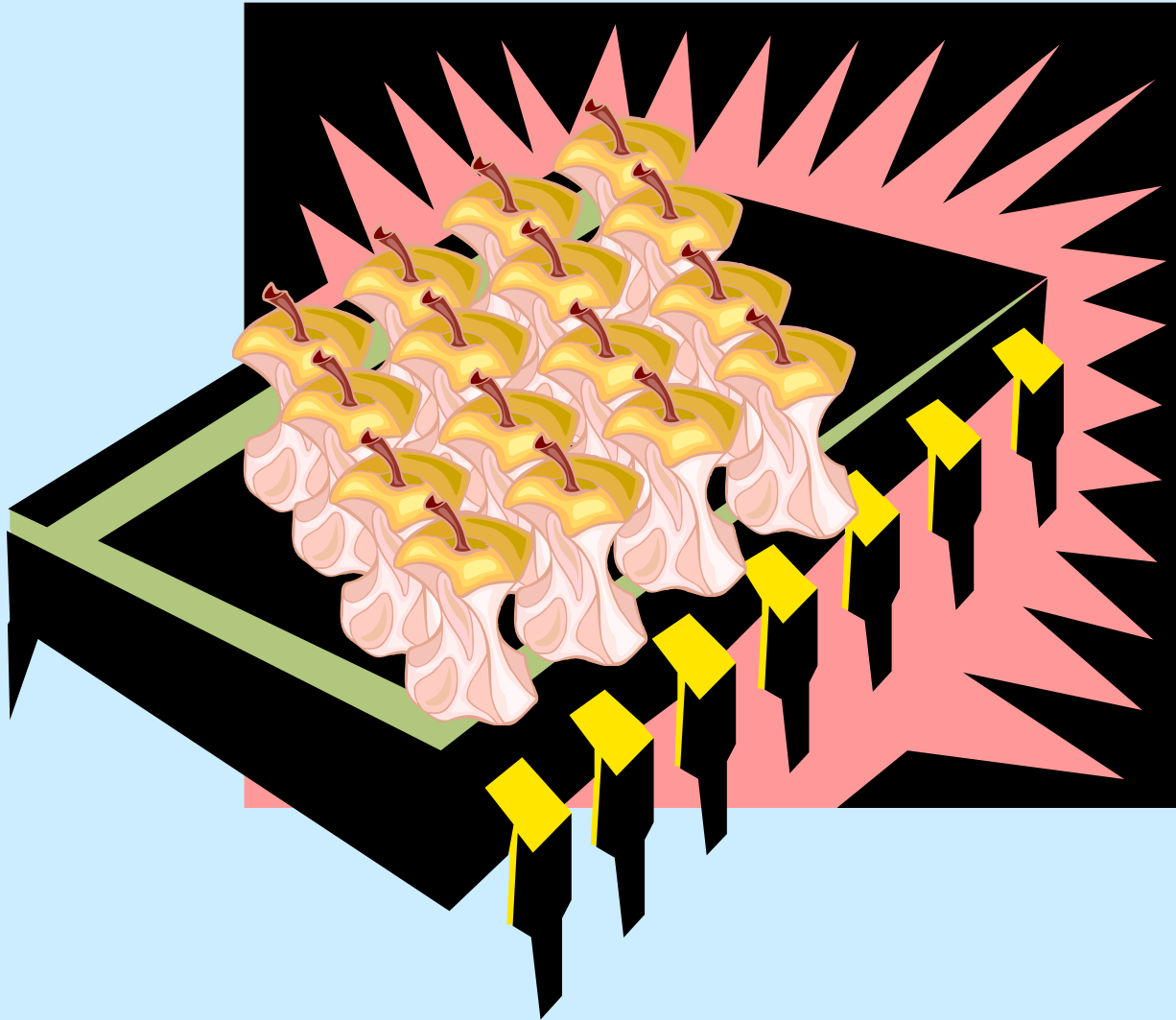
Single-Core Chips



Dual-Core Chips



Multi-Core Chips



Good News/Bad News

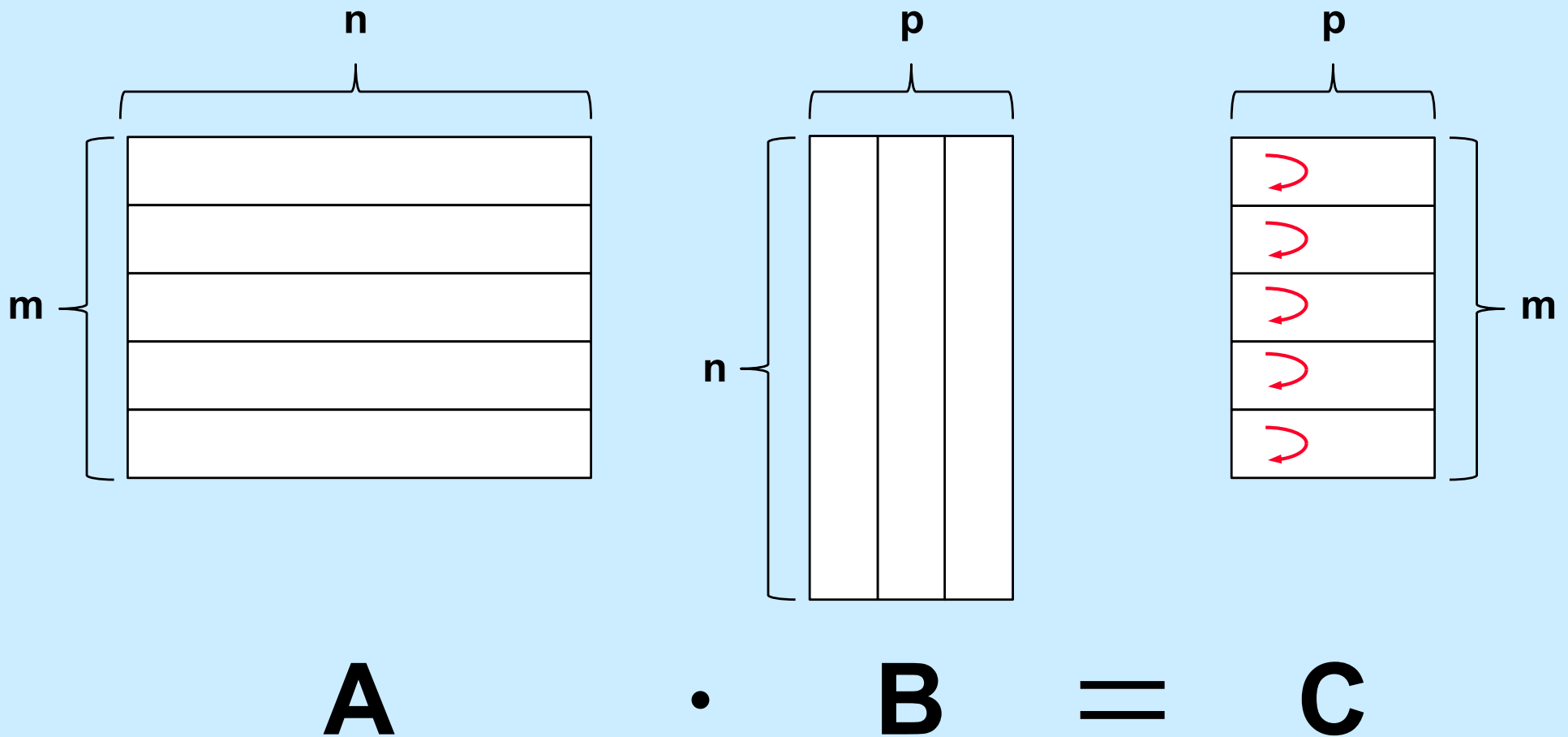
Good news

- multi-threaded programs can take advantage of multi-core chips (single-threaded programs cannot)

Bad news

- it's not easy
 - » must have parallel algorithm
 - employing at least as many threads as processors
 - threads must keep processors busy
 - doing useful work

Matrix Multiplication Revisited



Standards

- **POSIX 1003.4a → 1003.1c → 1003.1j**
- **Microsoft**
 - **Win32/64**