# 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

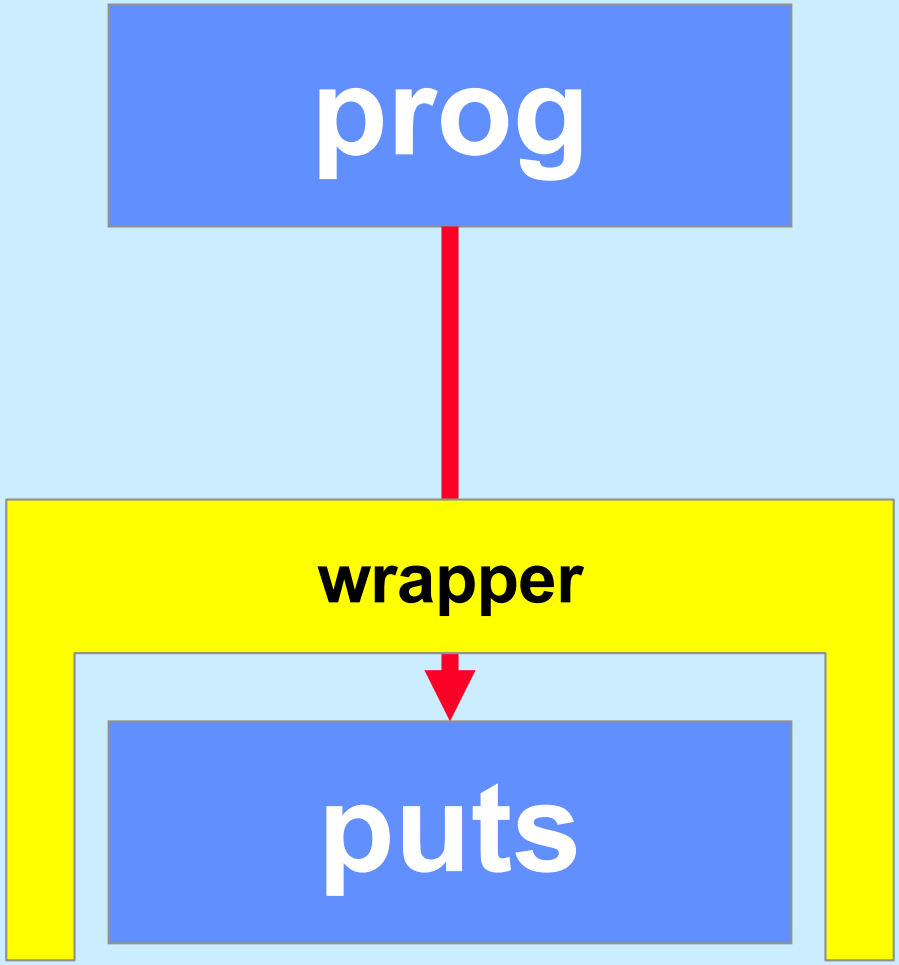
# A Solution

- 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

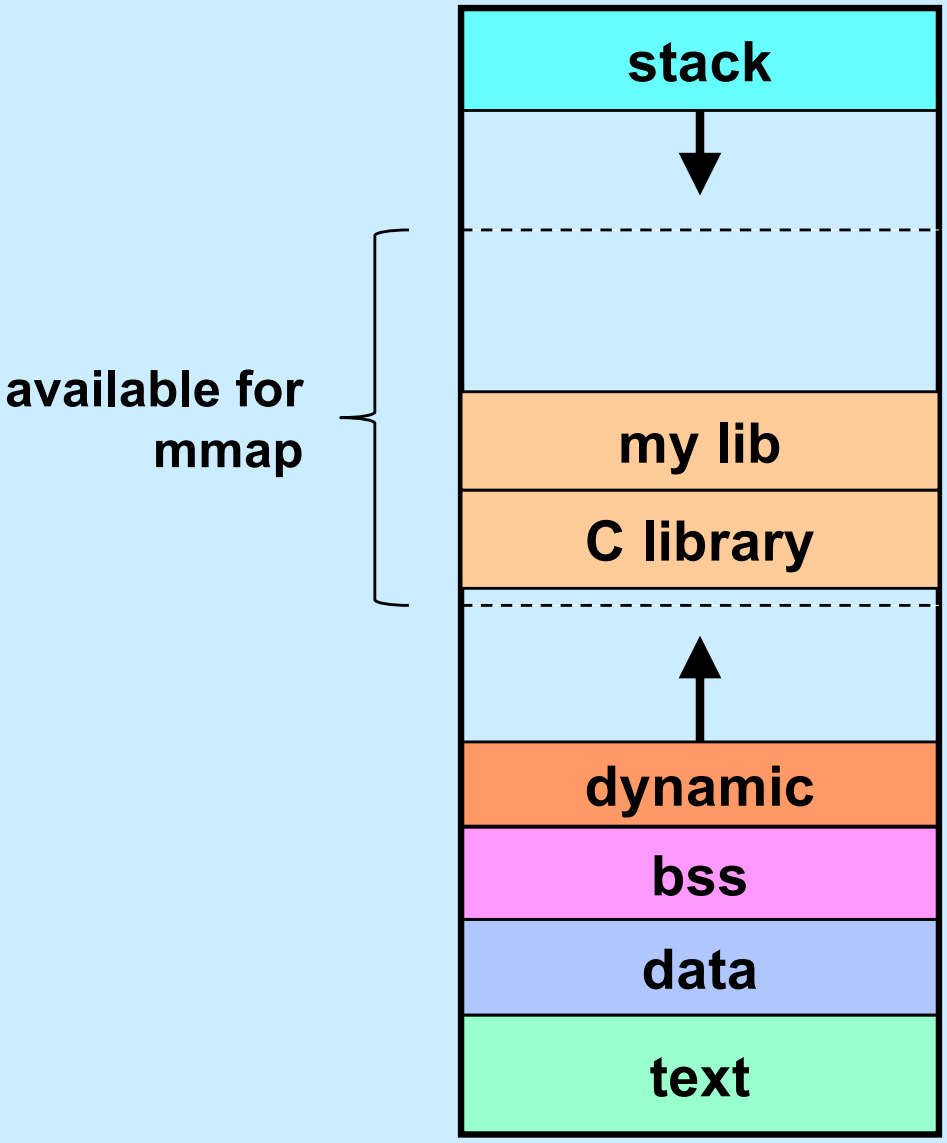
# Environment Variables

- **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**
  - **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

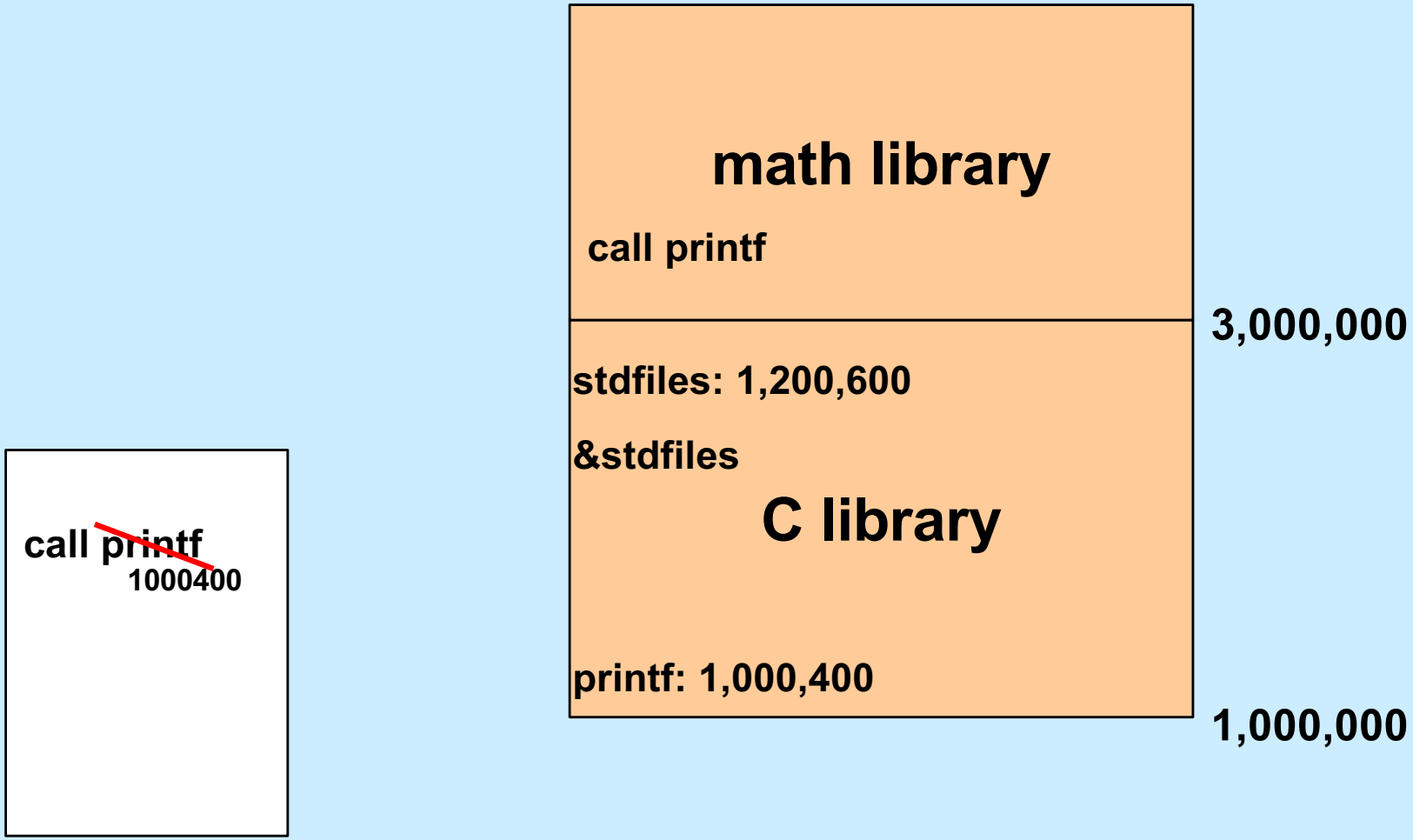


# Problem

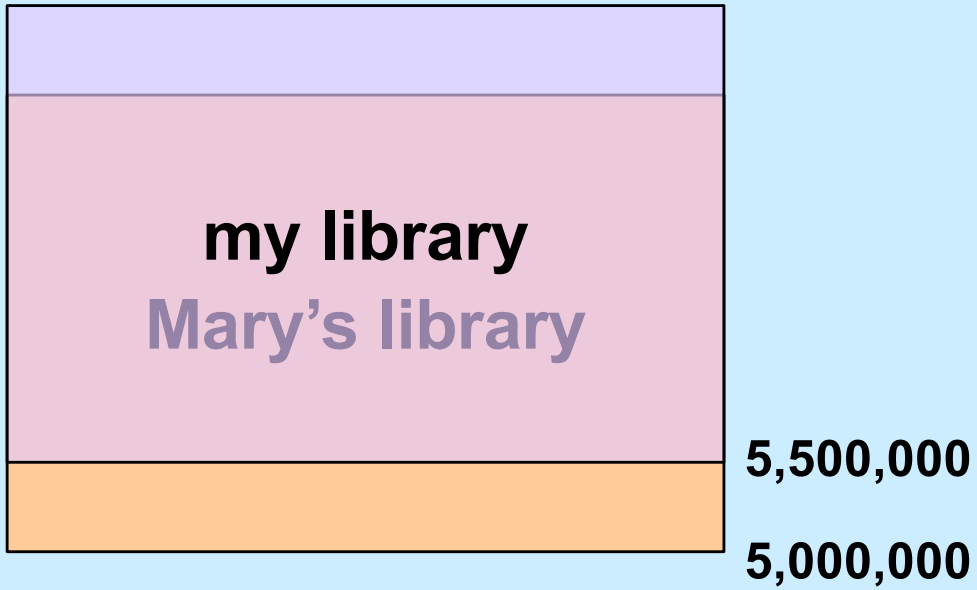
- How is relocation handled?

# Pre-Relocation



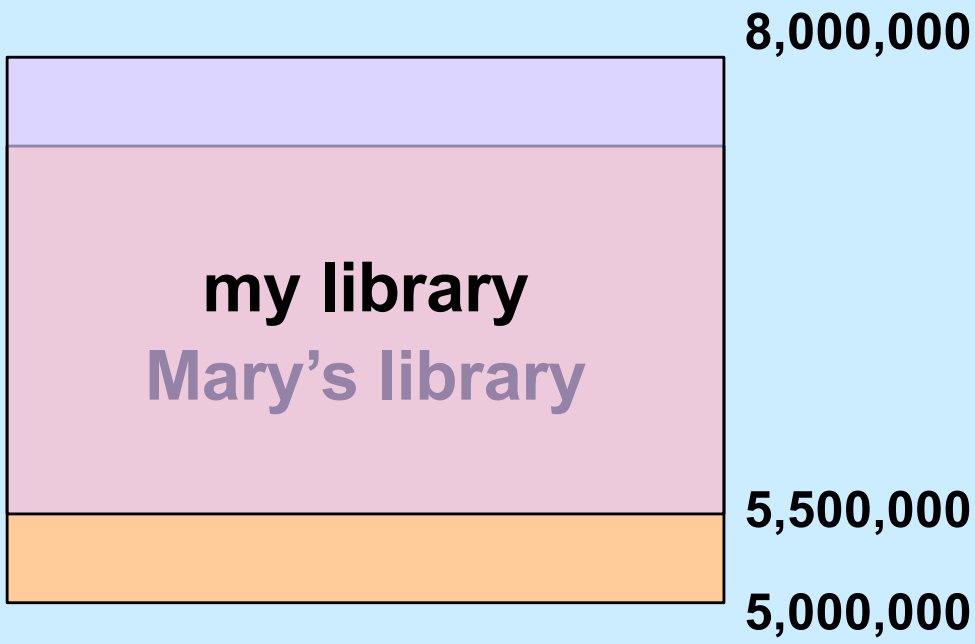

 

# But …



# 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_PRIVATE option**

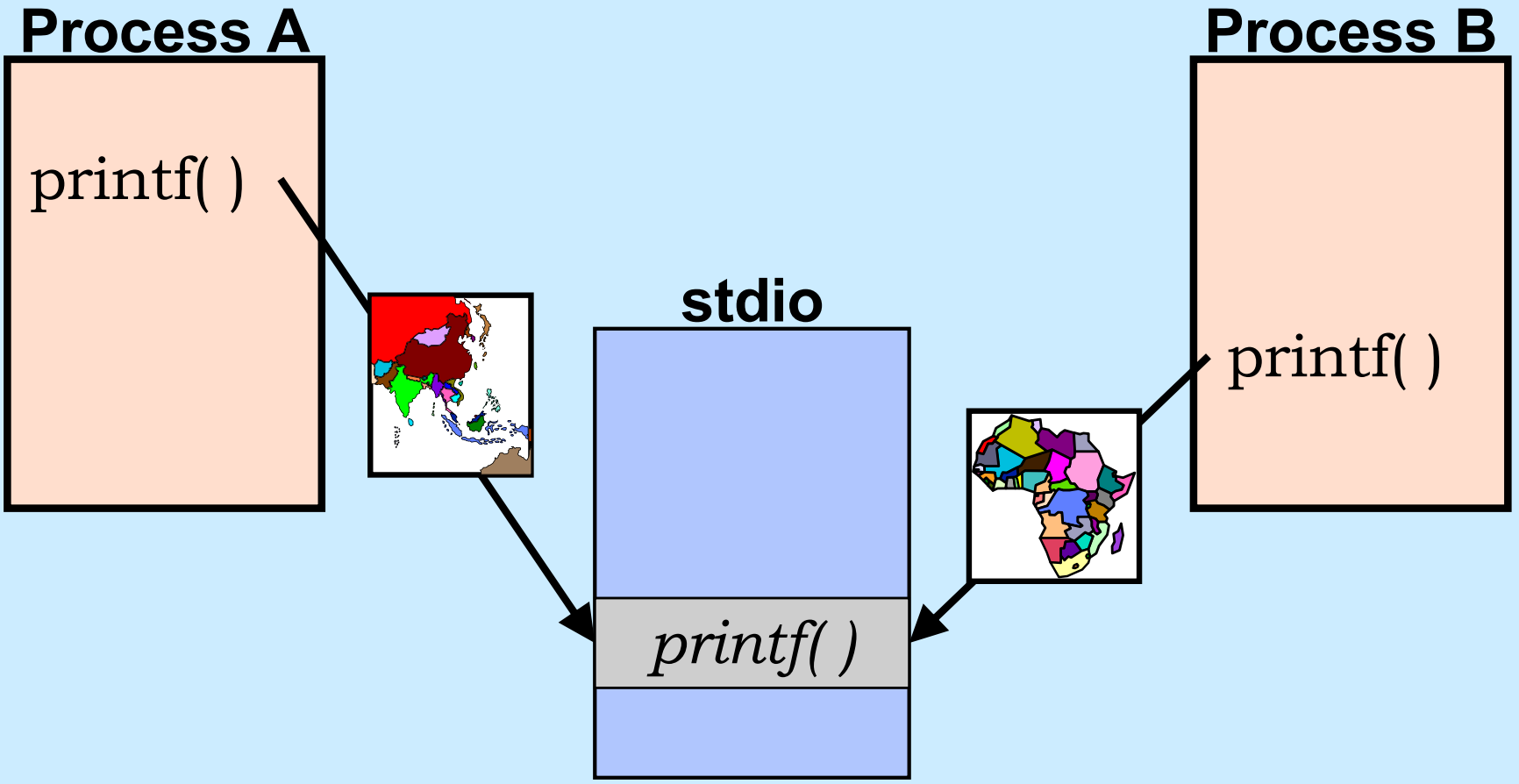
b) **the MAP_SHARED option**

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

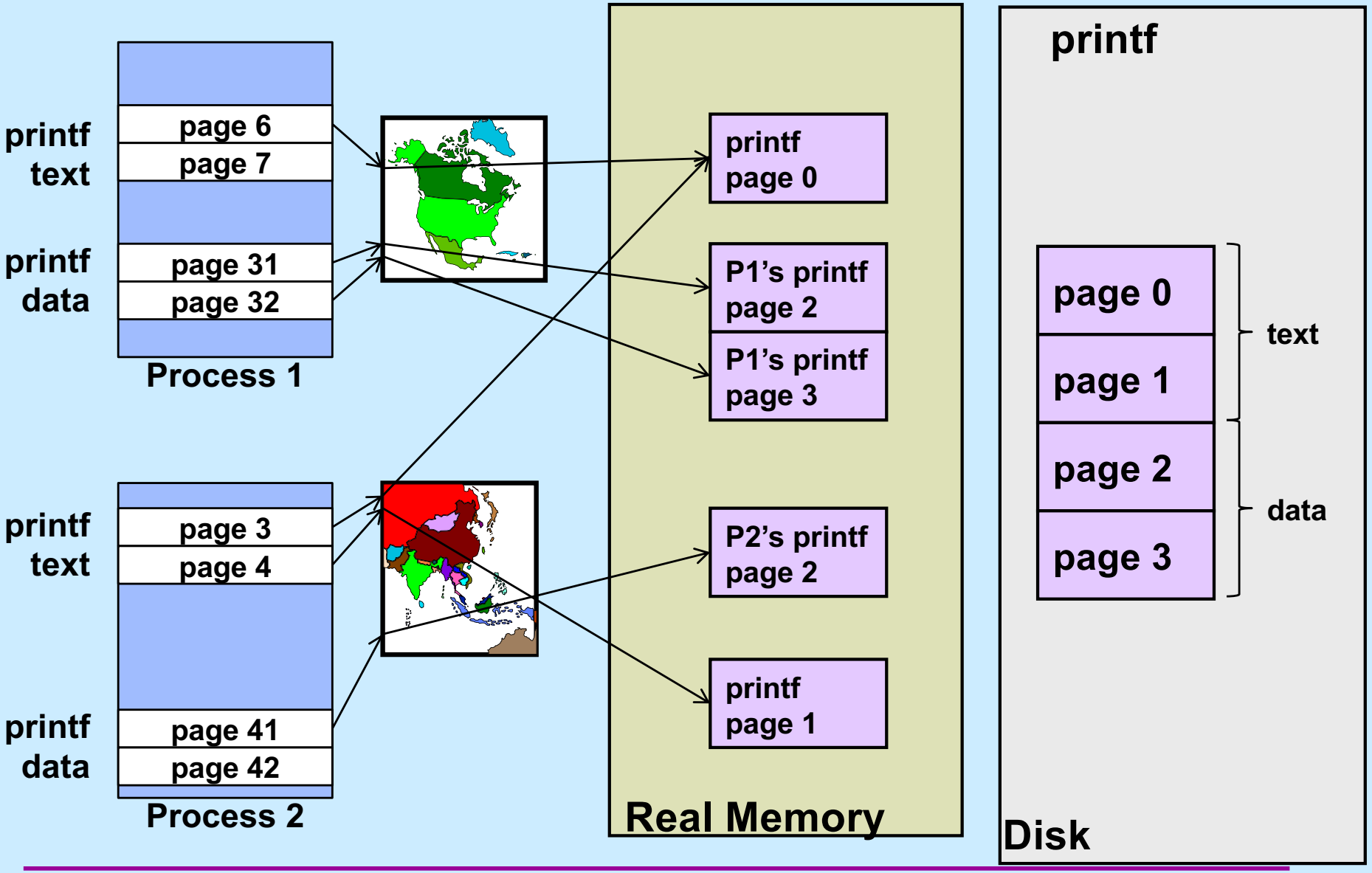


# Mapping printf into the Address Space

- 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

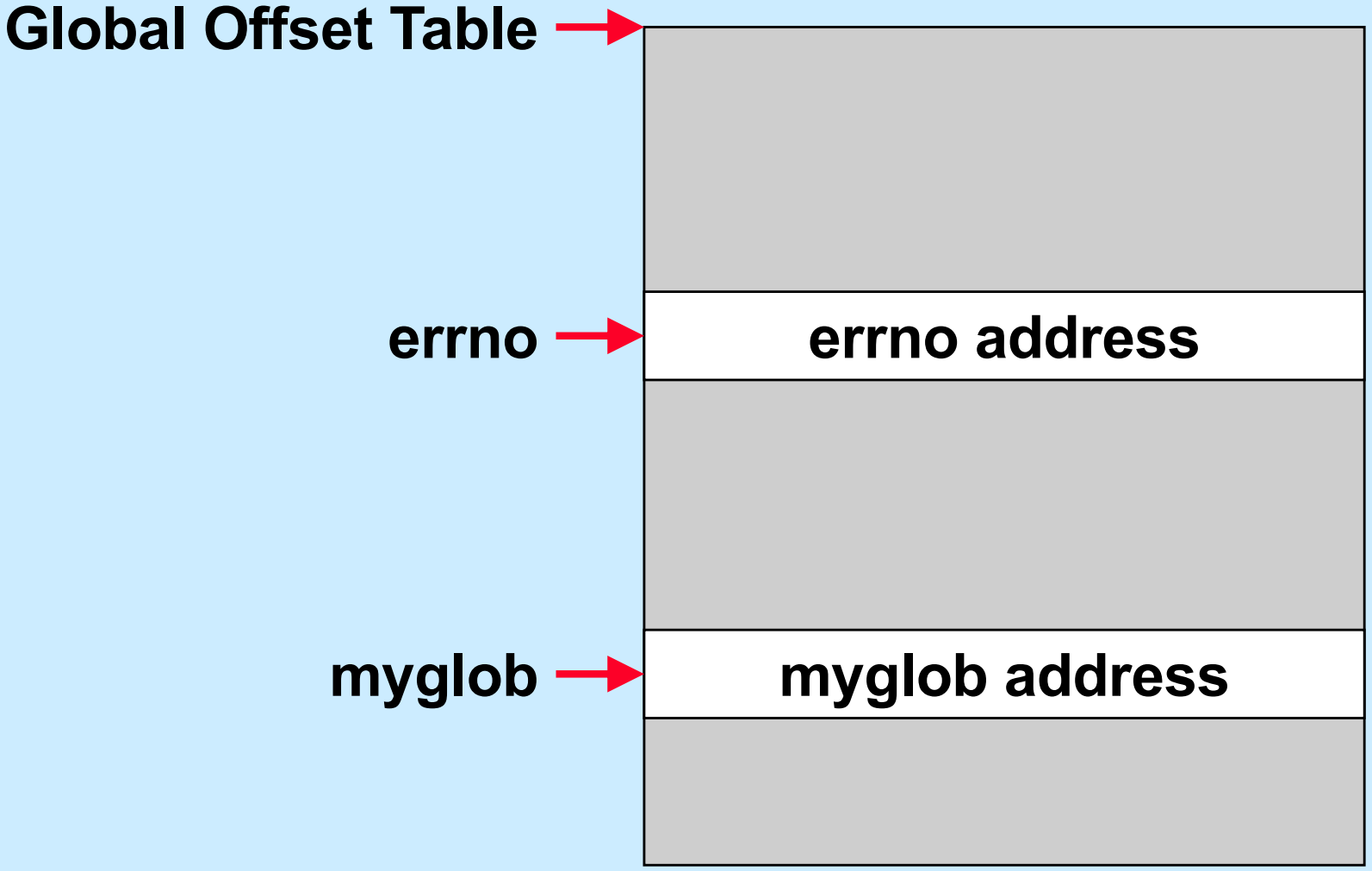
# Mapping printf



# 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



# 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
  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*

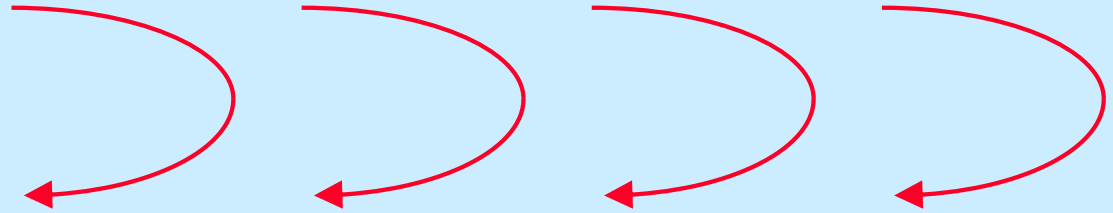
# CS 33

## Multithreaded Programming (1)

# Multithreaded Programming

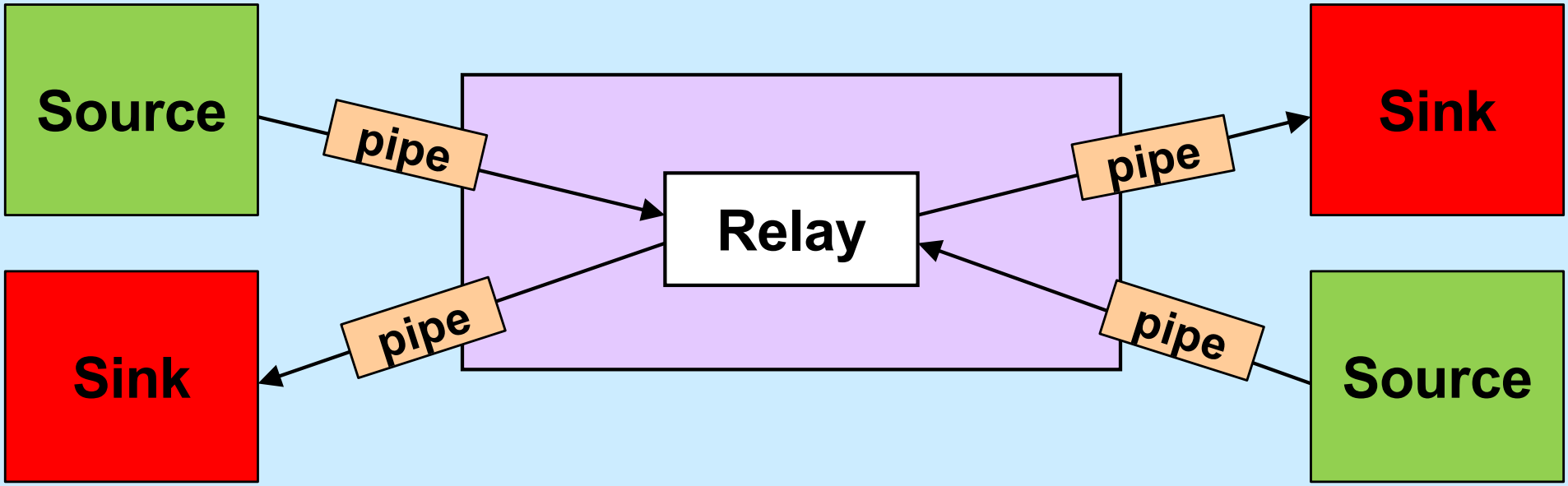
- A thread is a virtual processor
  - an independent agent executing instructions
- Multiple threads
  - multiple independent agents executing instructions

# Why Threads?



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

# A Simple Example



# Life Without Threads

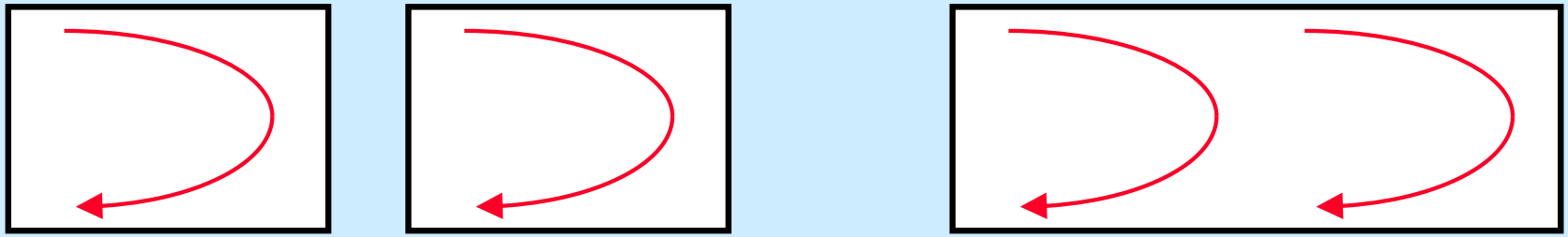
```
void relay(int left, int right) {
    fd_set rd, wr;
    int left_read = 1, right_write = 0;
    int right_read = 1, left_write = 0;
    int sizeLR, sizeRL, wret;
    char bufLR[BSIZE], bufRL[BSIZE];
    char *bufpR, *bufpL;
    int maxFD = max(left, right) + 1;

    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

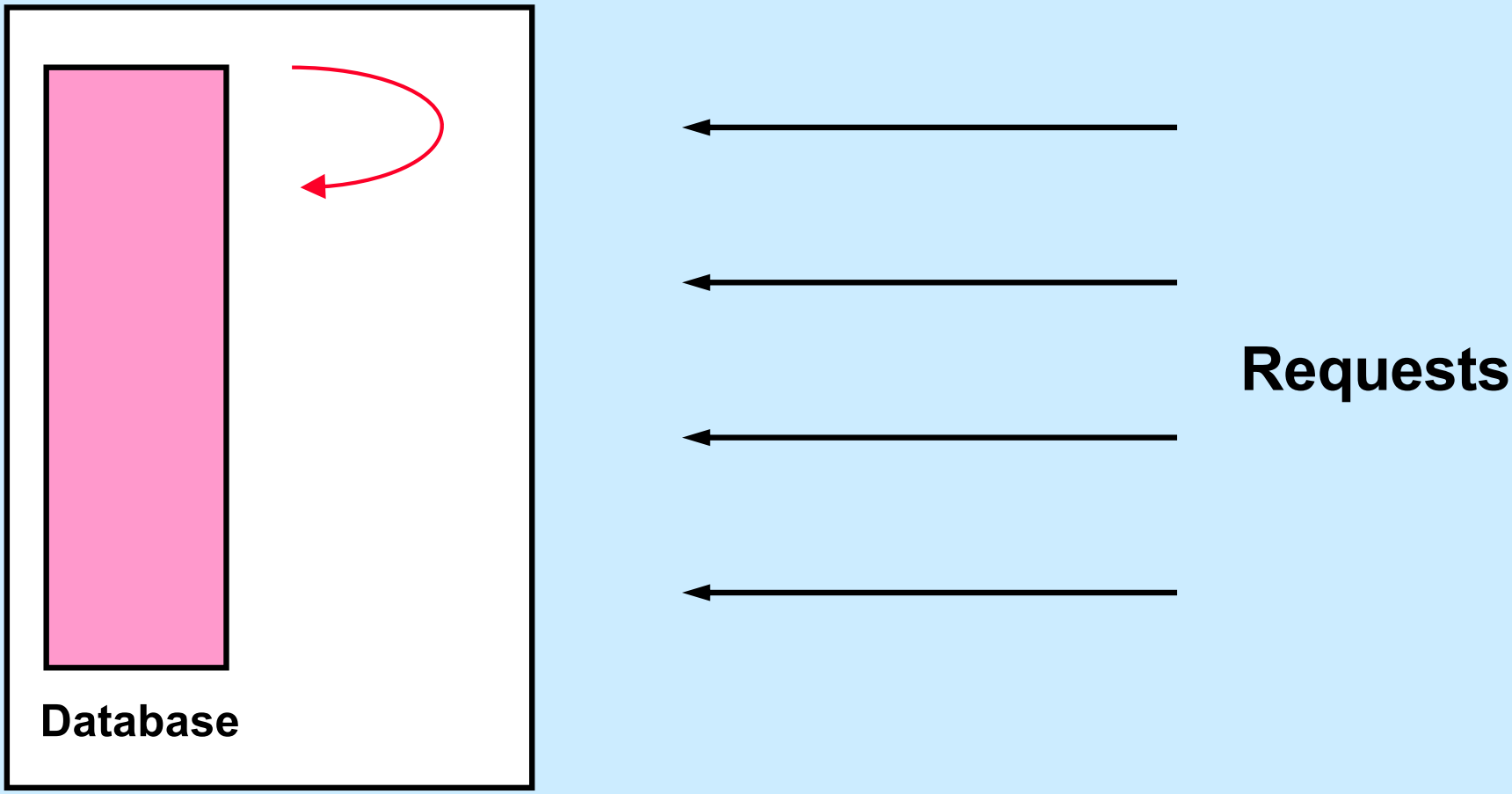
```
void copy(int source, int destination) {
  struct args *targs = args;
  char buf[BSIZE];

  while(1) {
    int len = read(source, buf, BSIZE);
    write(destination, buf, len);
  }
}
```

# Processes vs. Threads



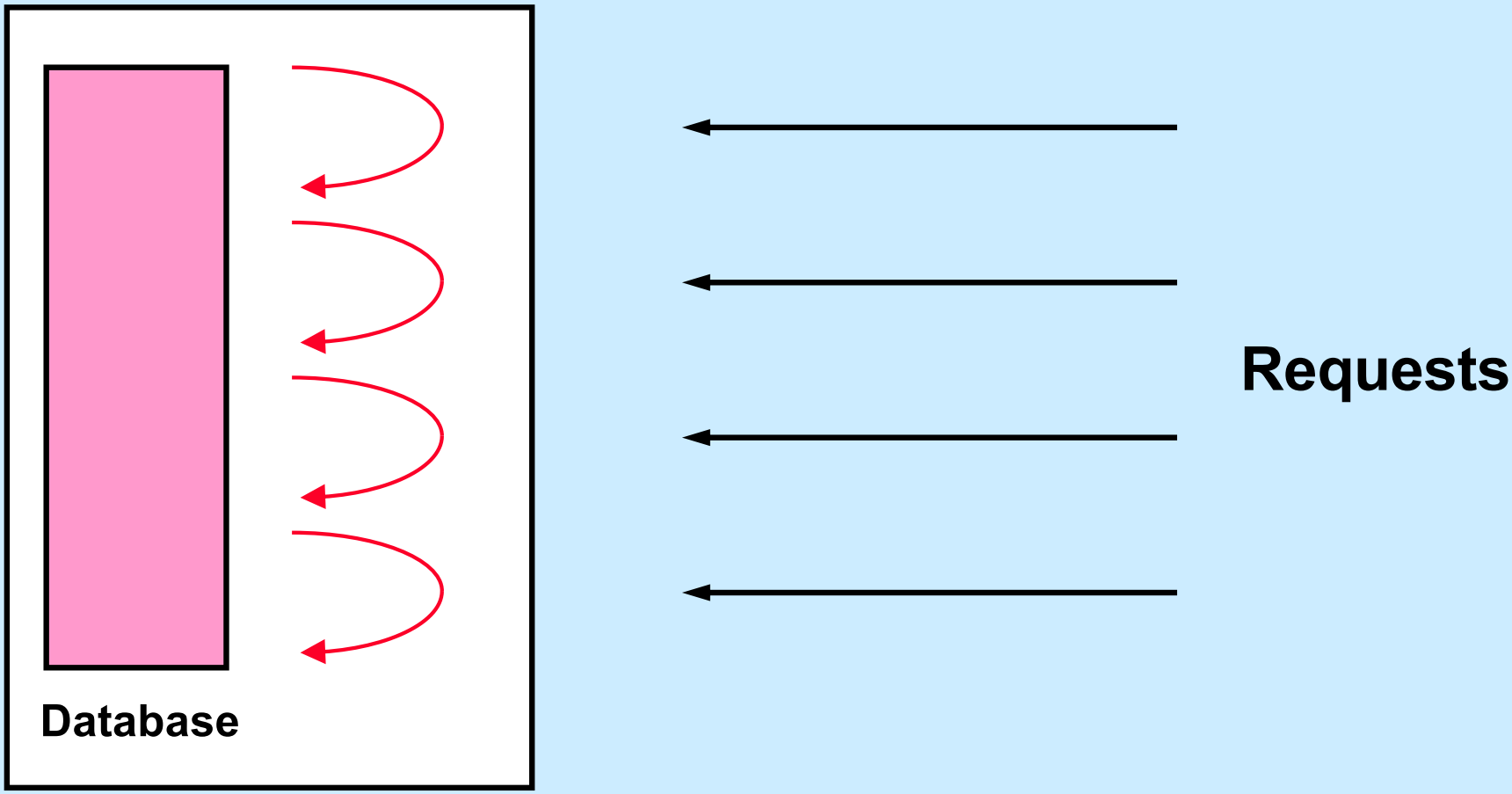

 

# Single-Threaded Database Server



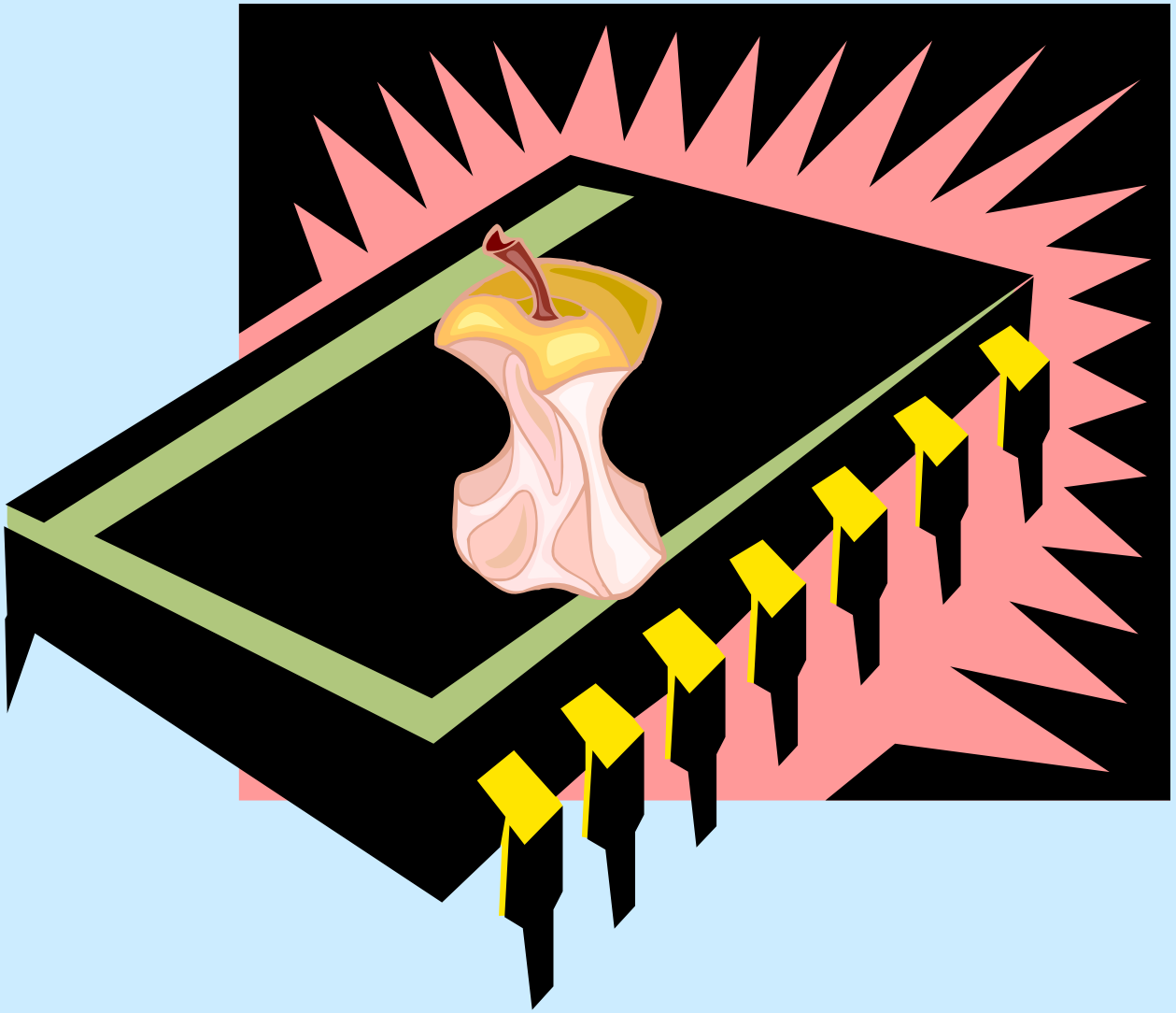

 

# Multithreaded Database Server

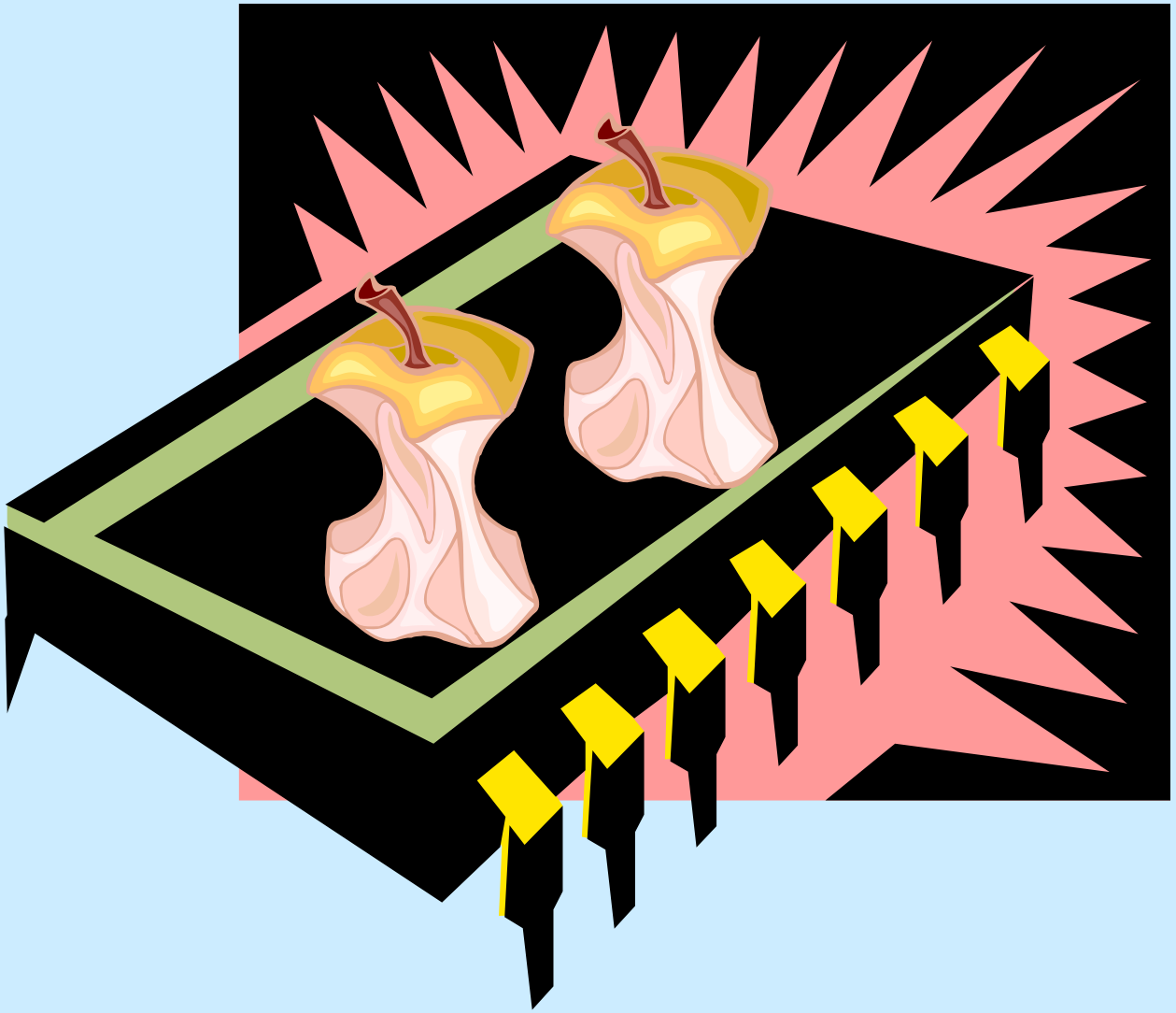


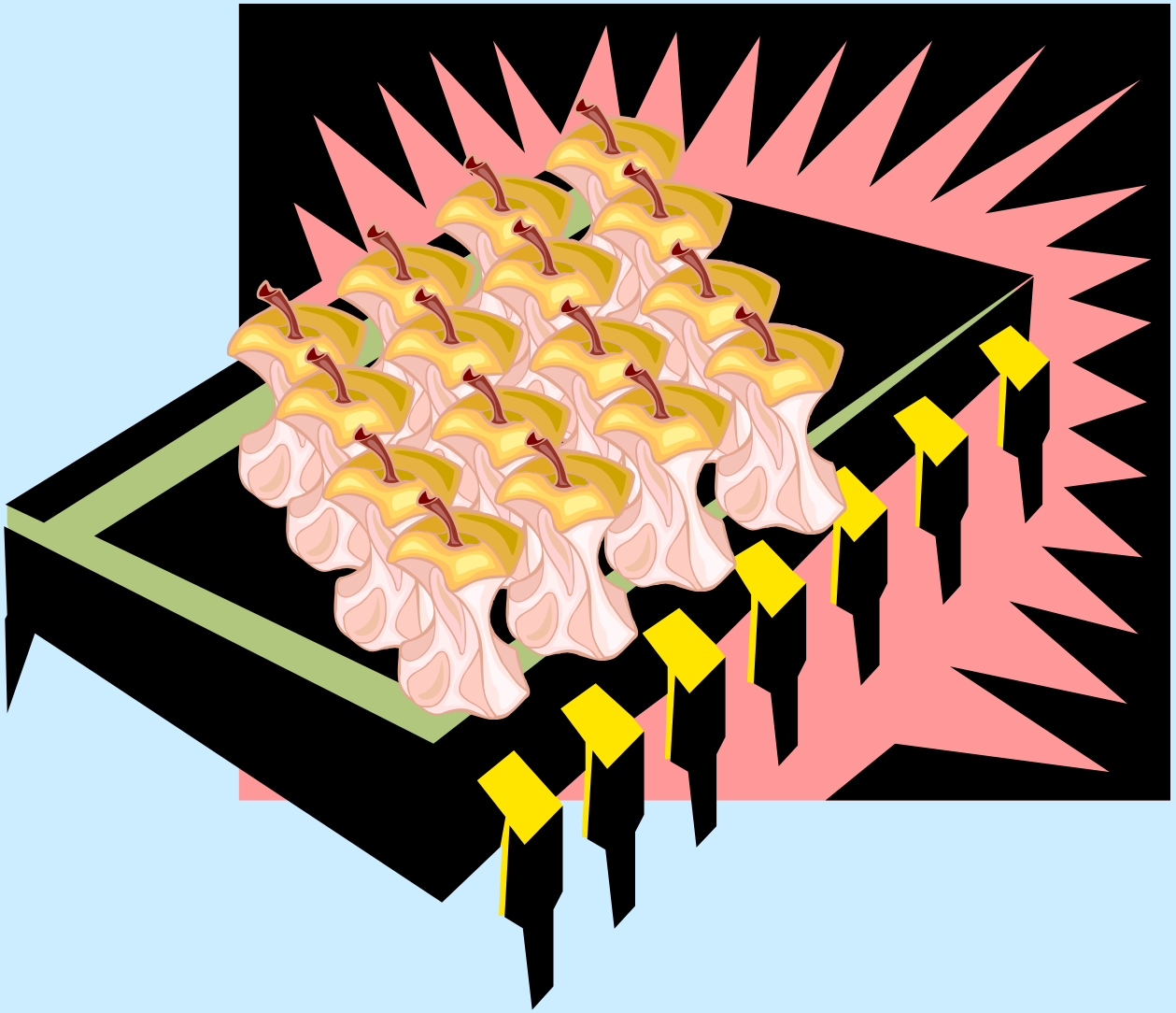
# Single-Core Chips



# Dual-Core Chips



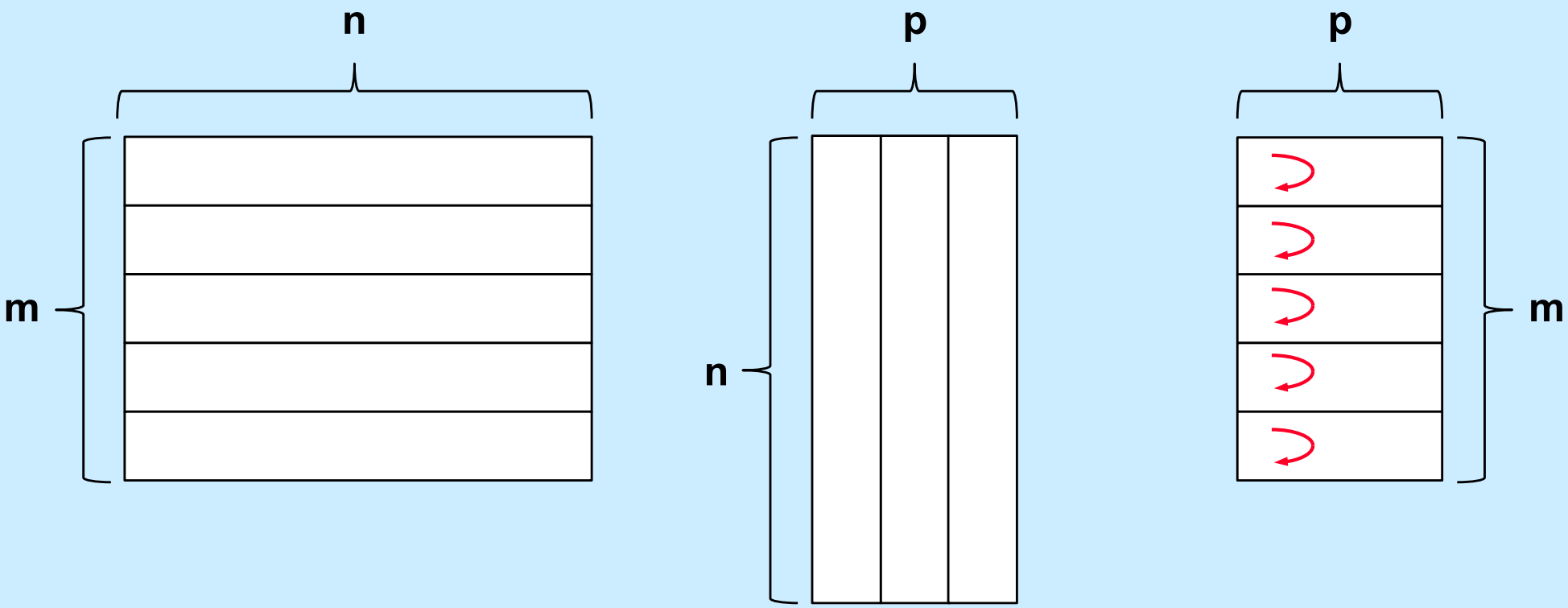
# Multi-Core Chips



# 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