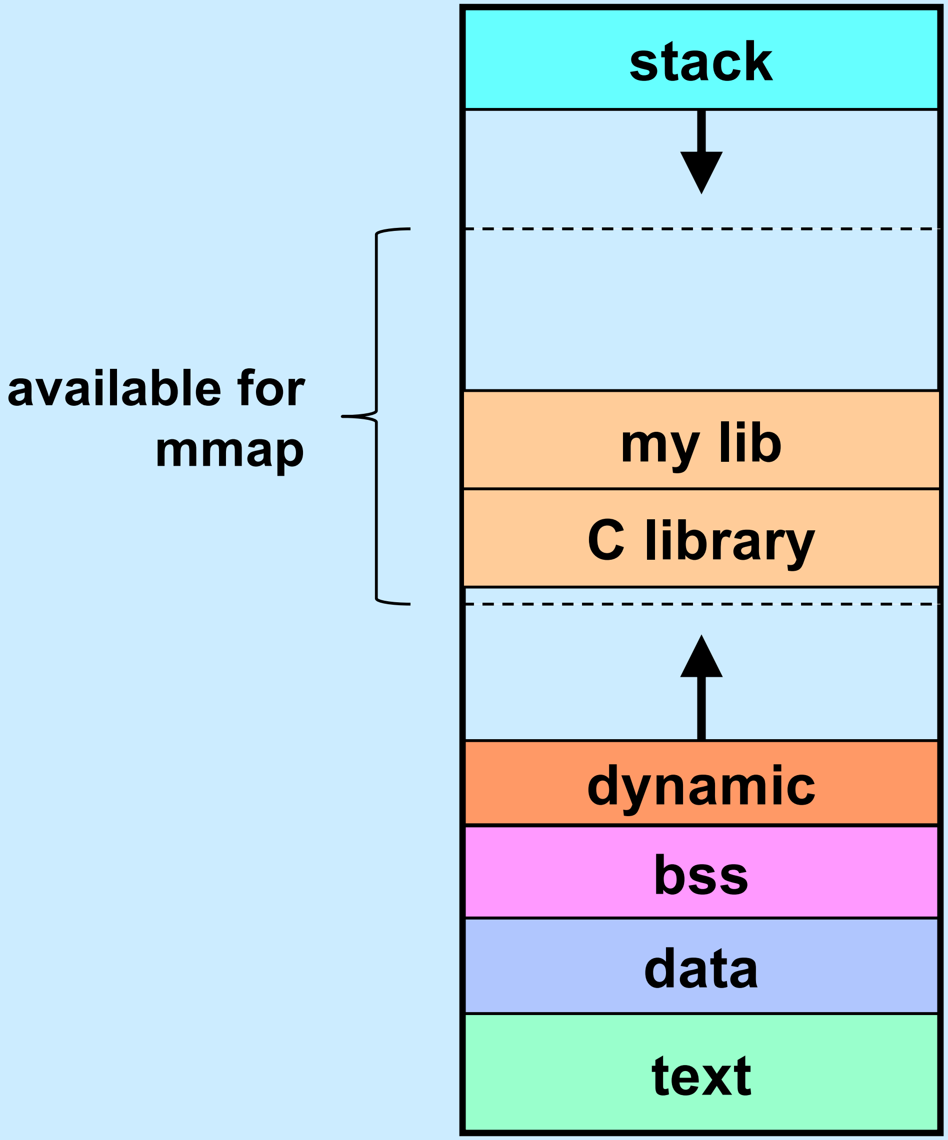
CS 33

Linking and Libraries (2)

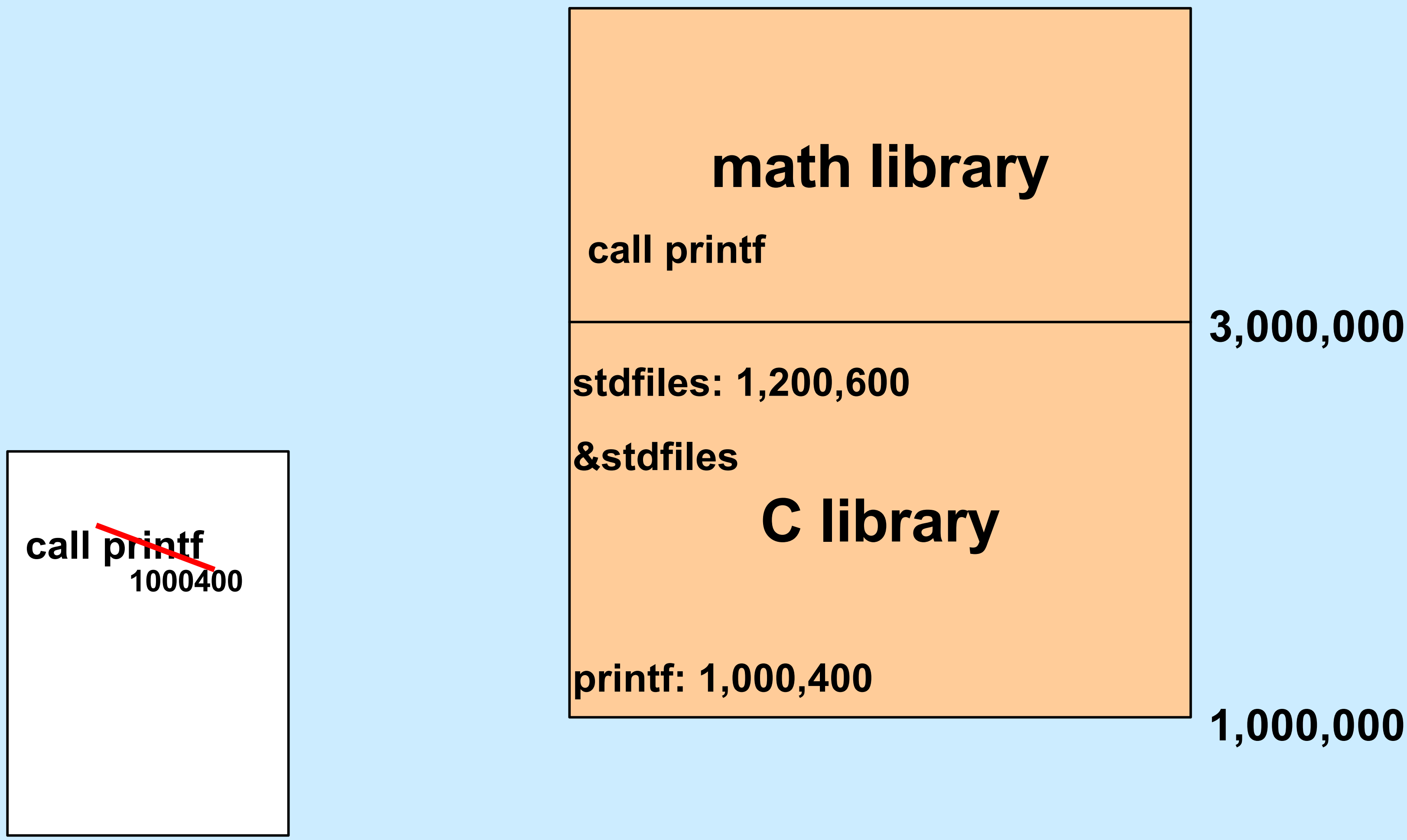
Mmapping Libraries



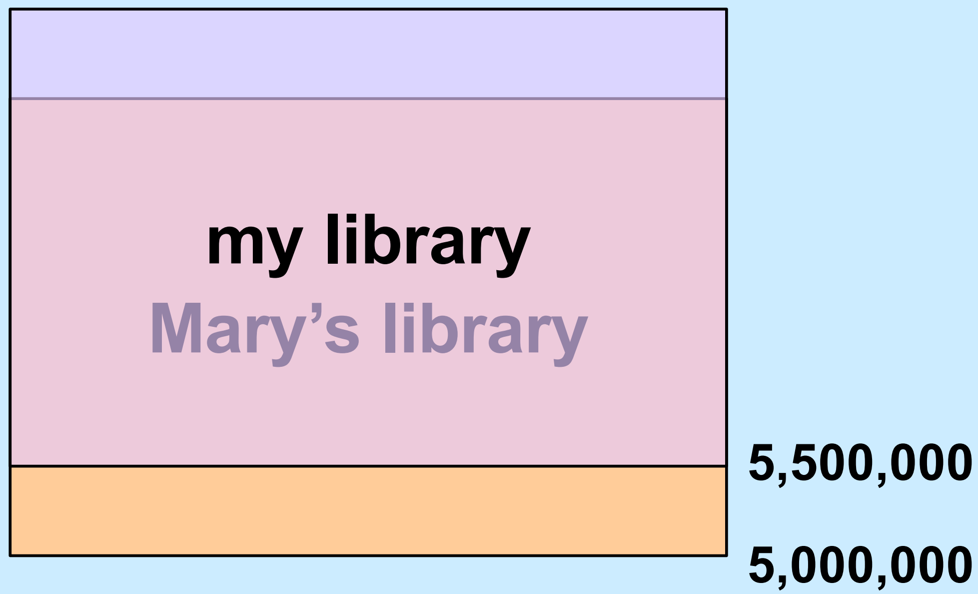
Problem

- How is relocation handled?

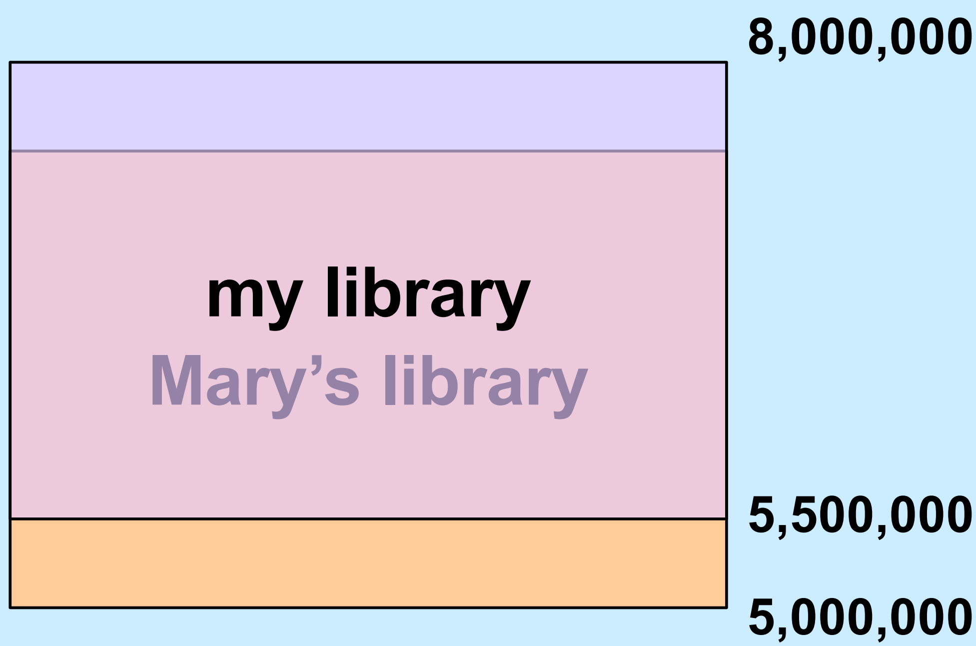
Pre-Relocation



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**

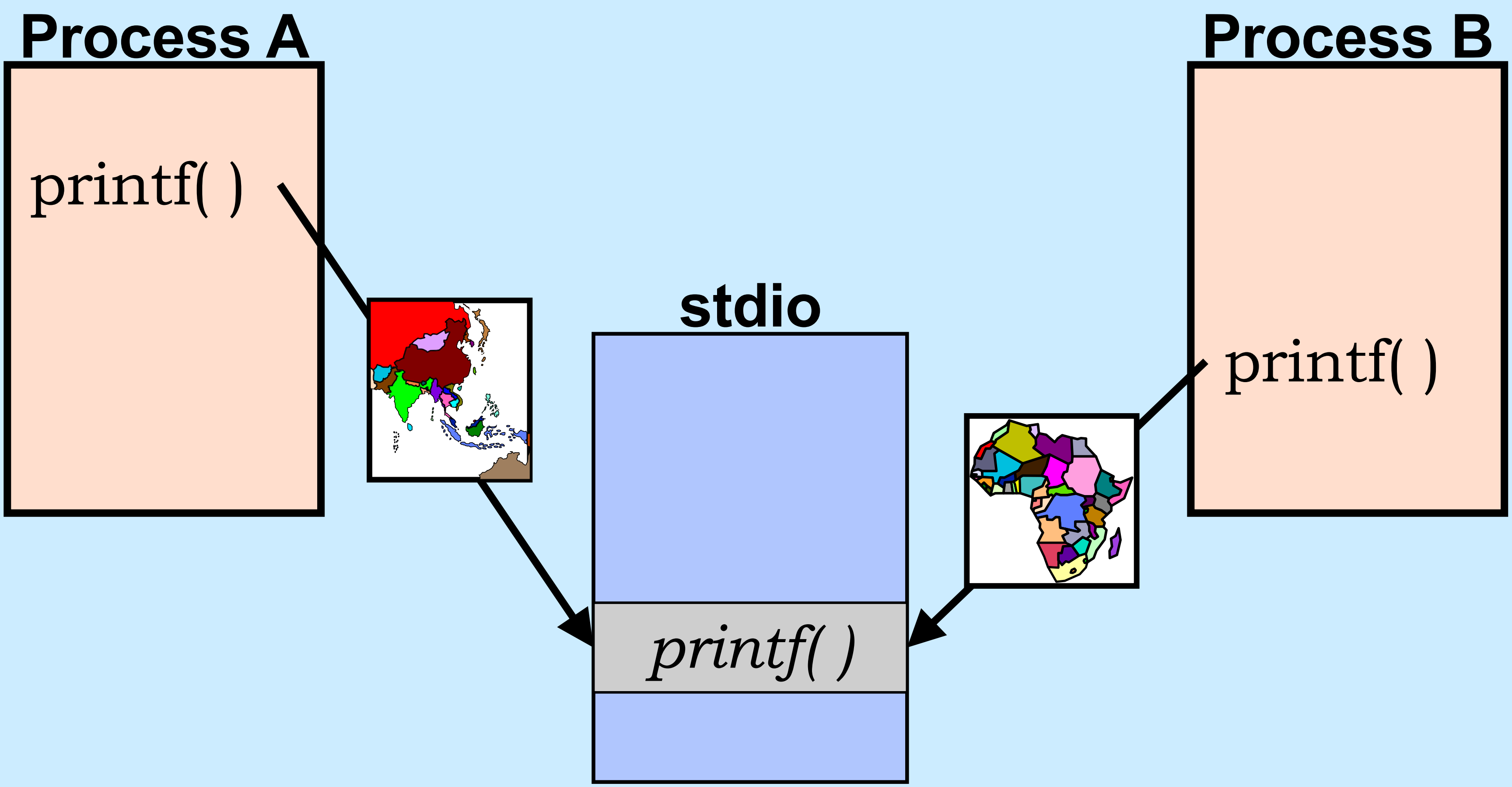
b) **the MAP_SHARED option**

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

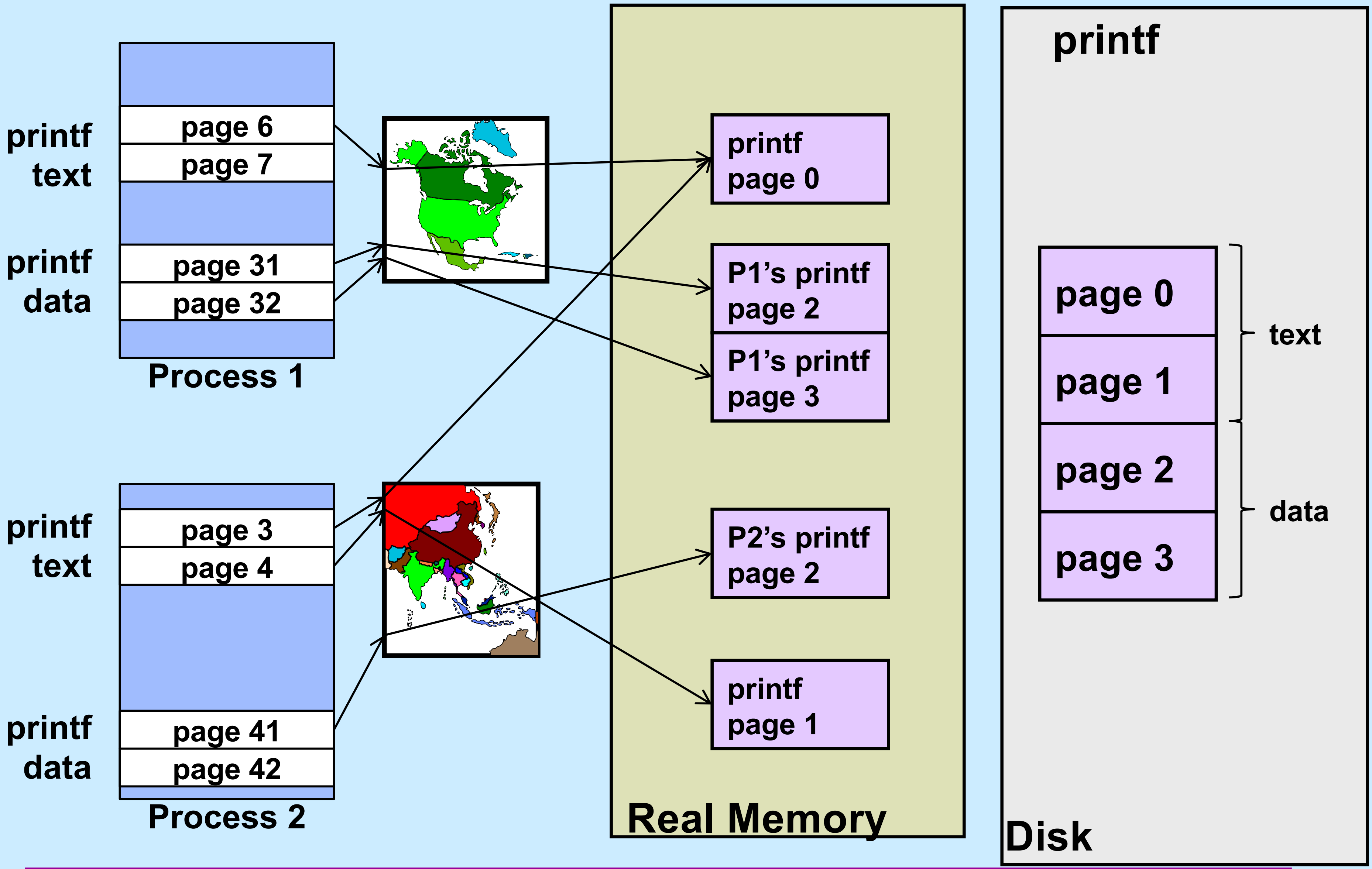
Mapping Shared Objects



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

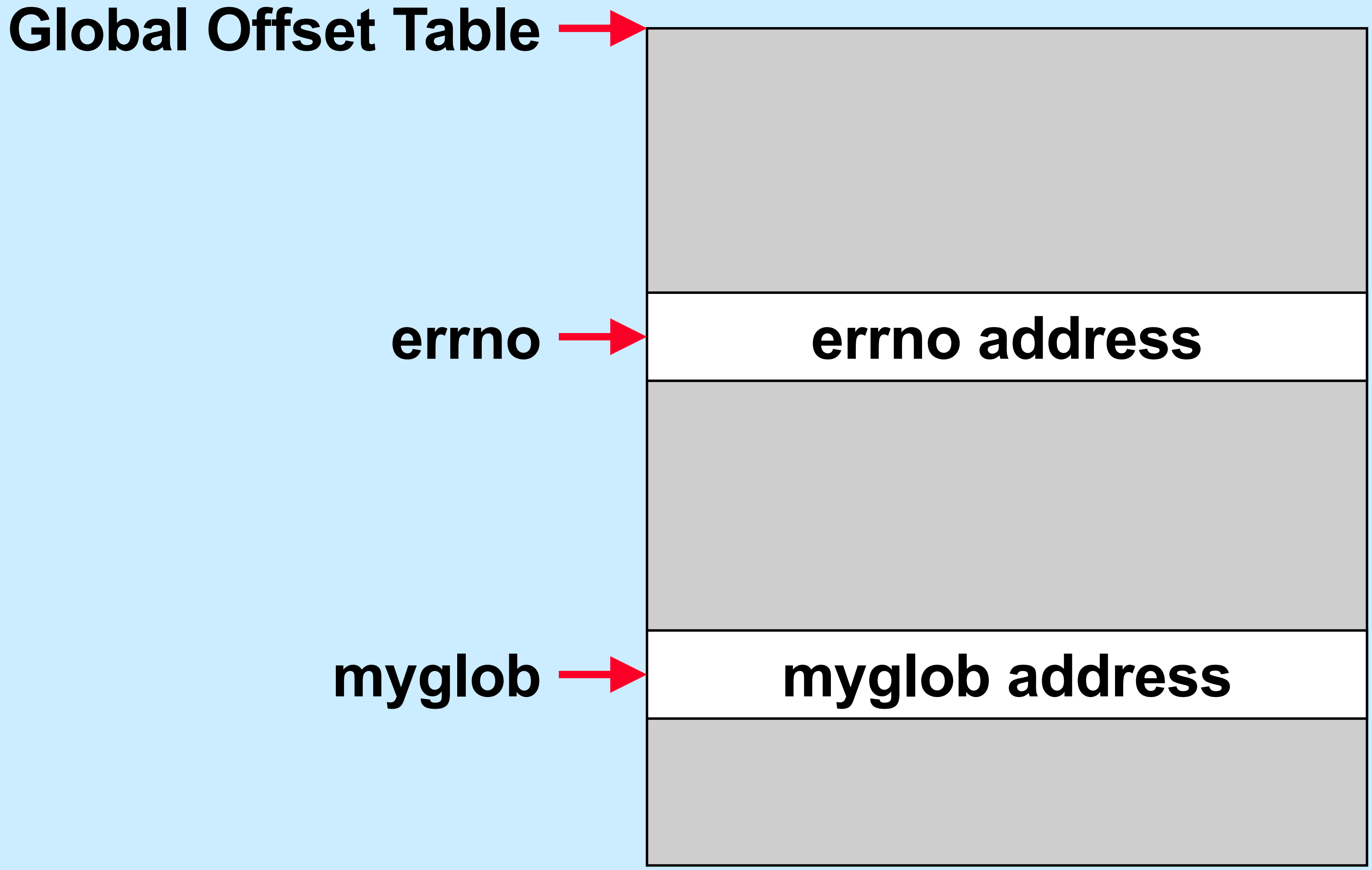
Mapping printf



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;
}
```

```
00000000000006b0 <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

Not a Quiz!

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***

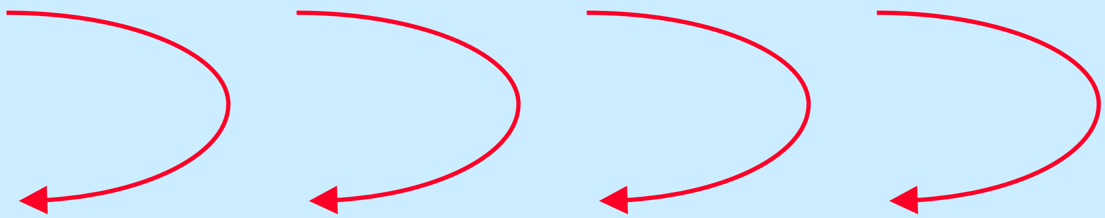
CS 33

Multithreaded Programming (1)

Multithreaded Programming

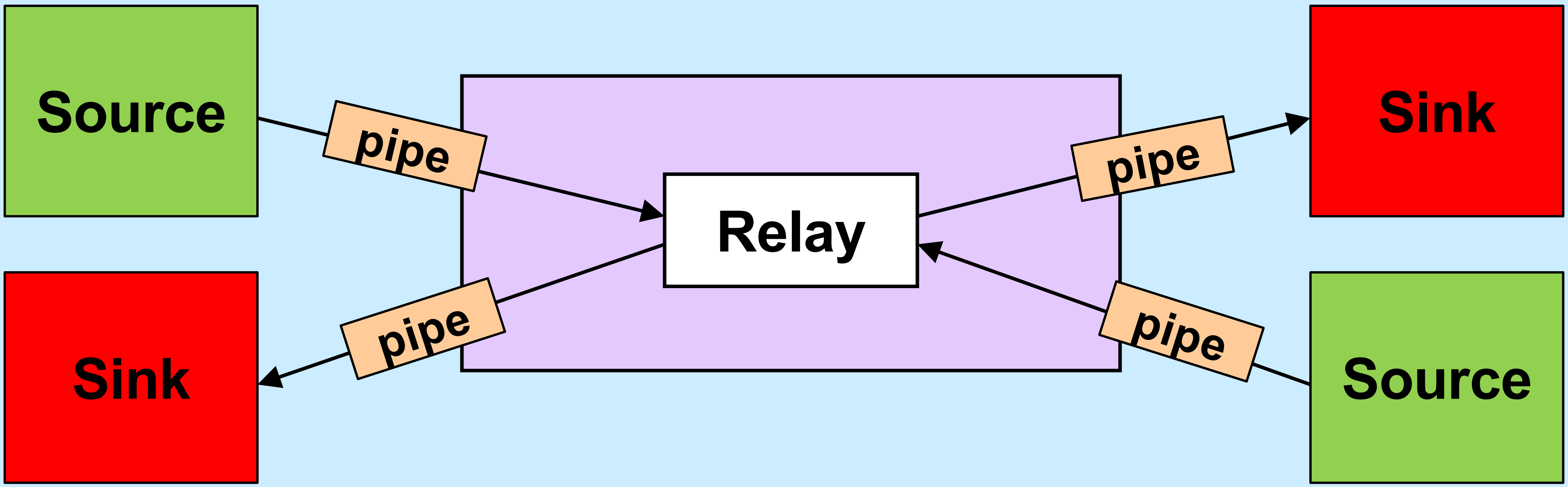
- A thread is a virtual processor
  - an independent agent executing instructions
- Multiple threads
  - multiple independent agents executing instructions

Why Threads?



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

A Simple Example



Life Without Threads

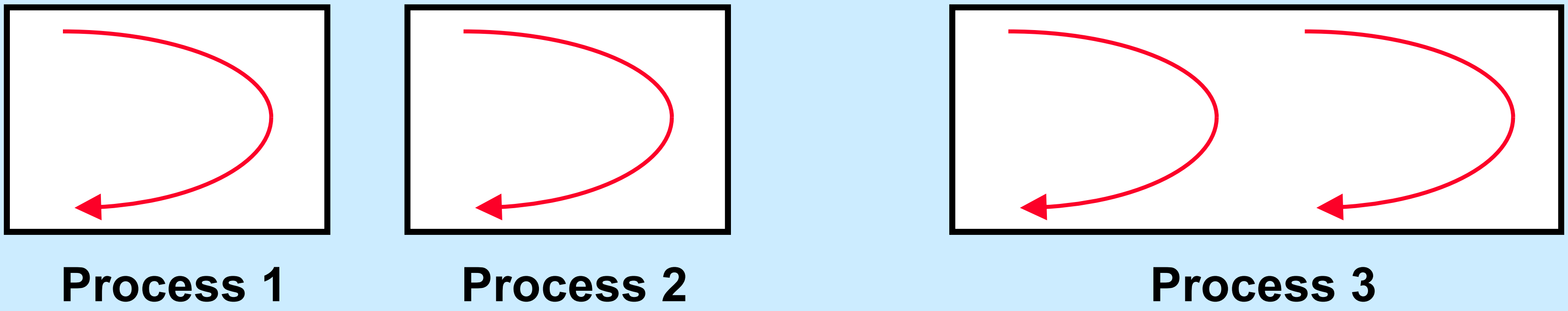
```
void relay(int left, int right) {
    fd_set rd, wr;
    int left_read = 1, right_write = 0;
    int right_read = 1, left_write = 0;
    int sizeLR, sizeRL, wret;
    char bufLR[BSIZE], bufRL[BSIZE];
    char *bufpR, *bufpL;
    int maxFD = max(left, right) + 1;

    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;
  }
```

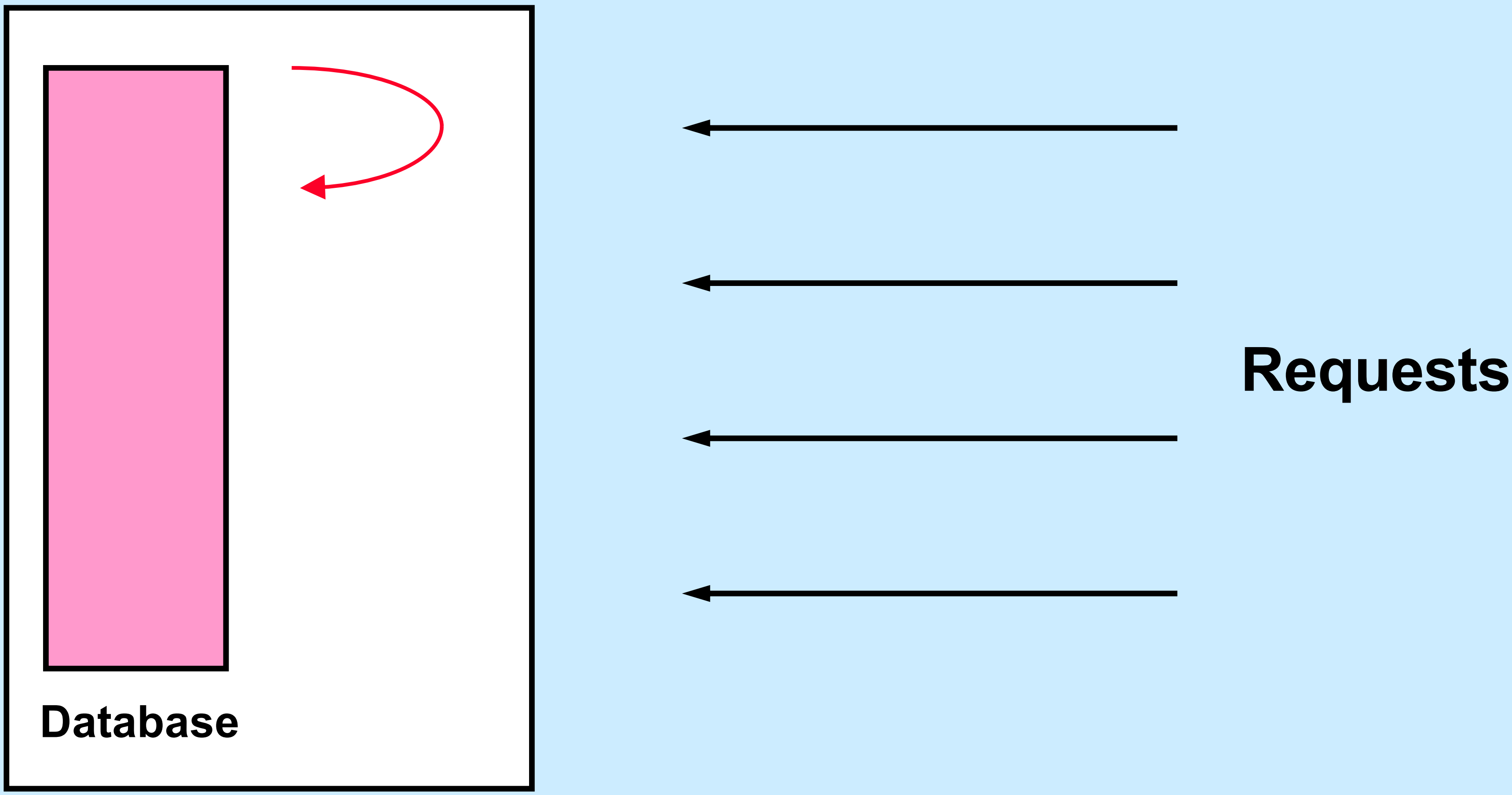

Life With Threads

```
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);
  }
}
```

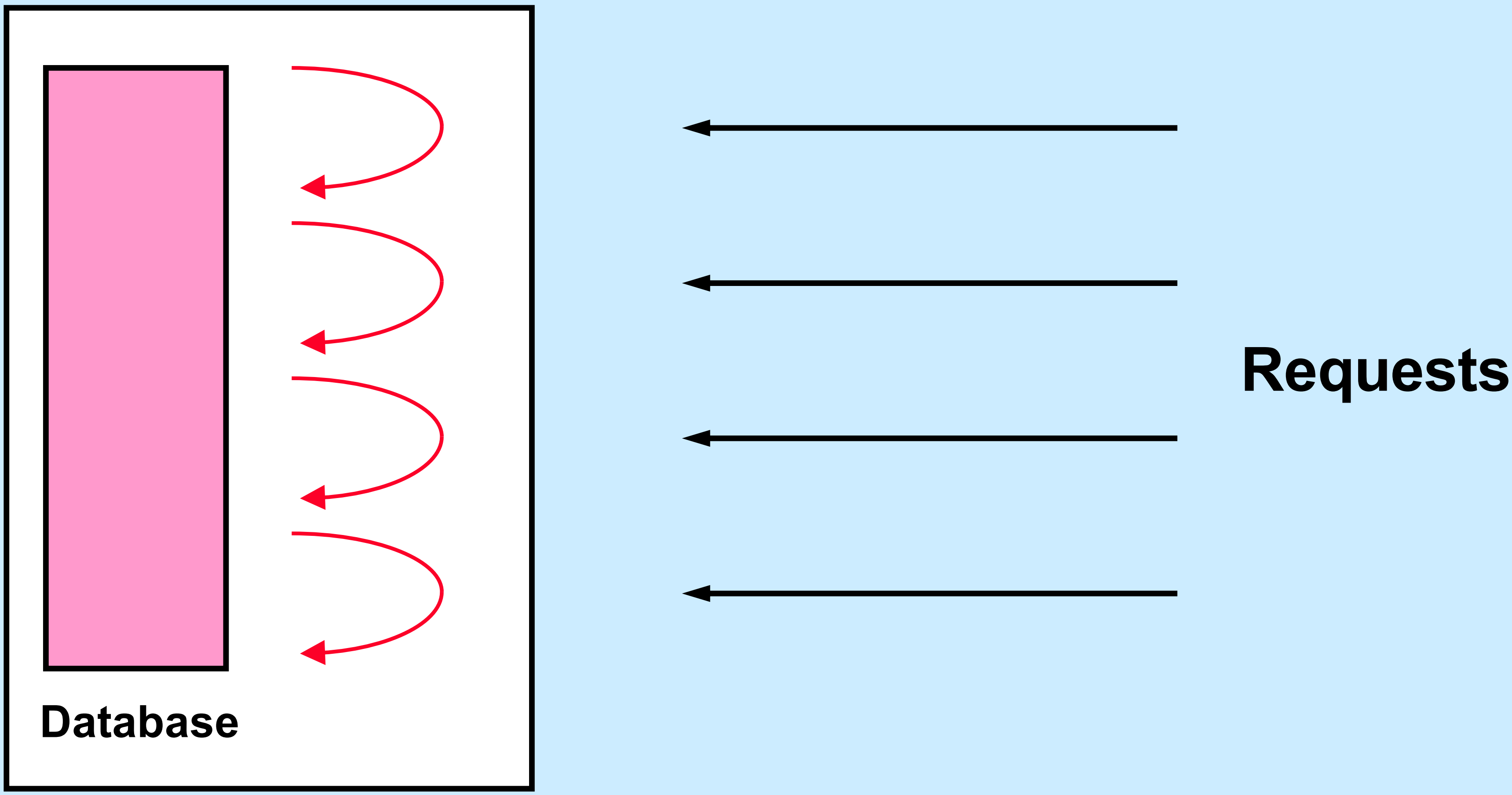

Processes vs. Threads



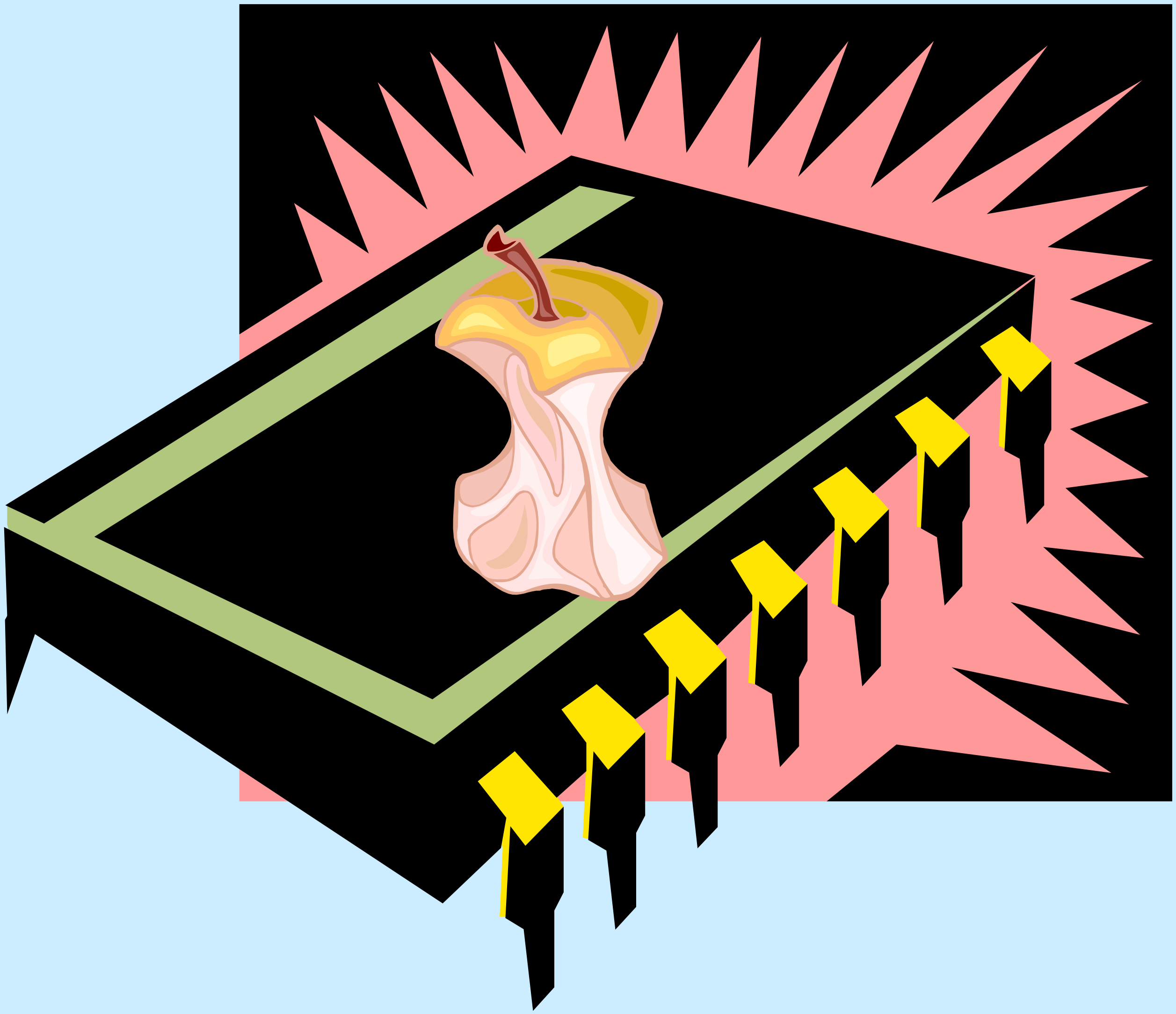
Single-Threaded Database Server



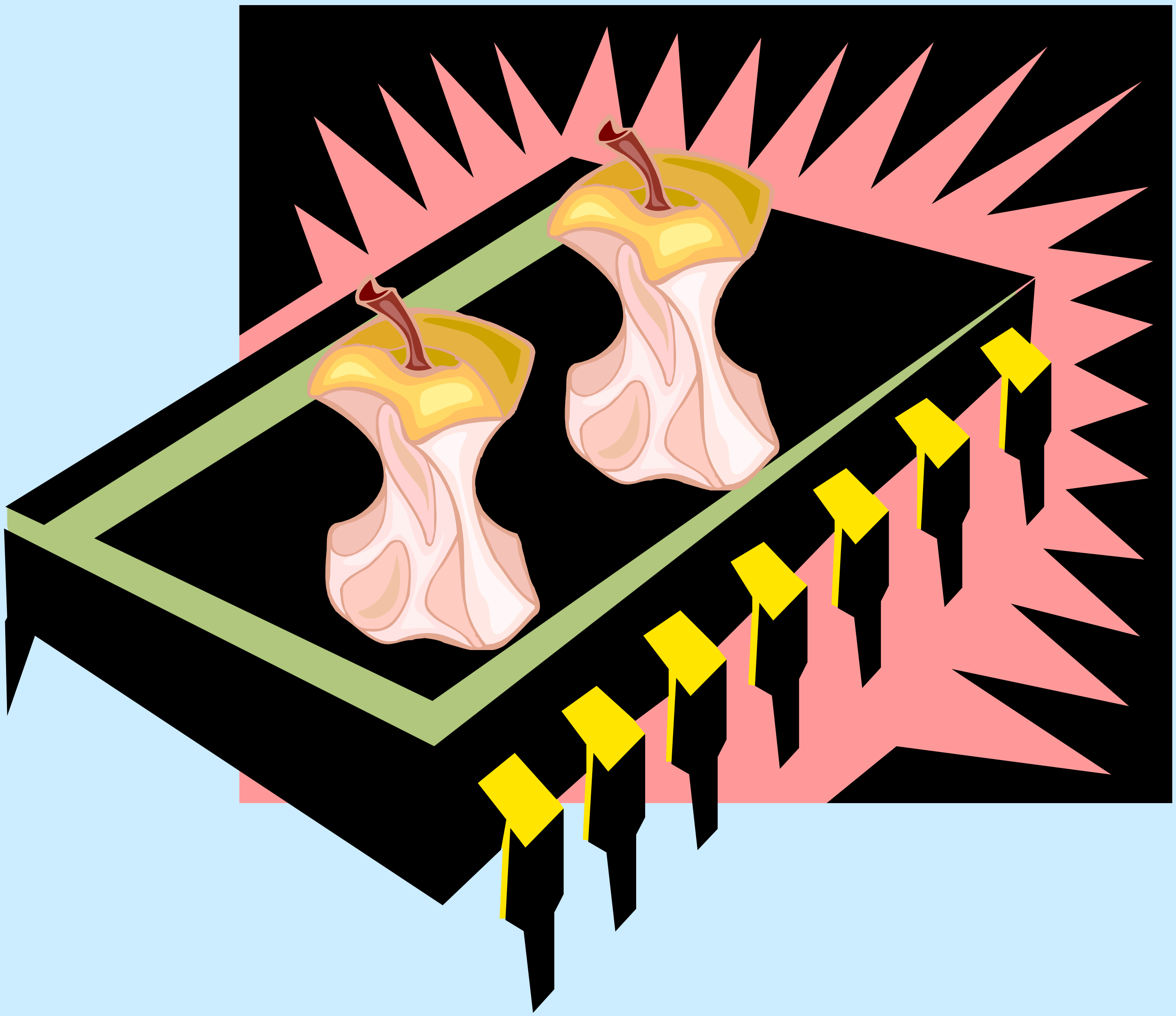
Multithreaded Database Server



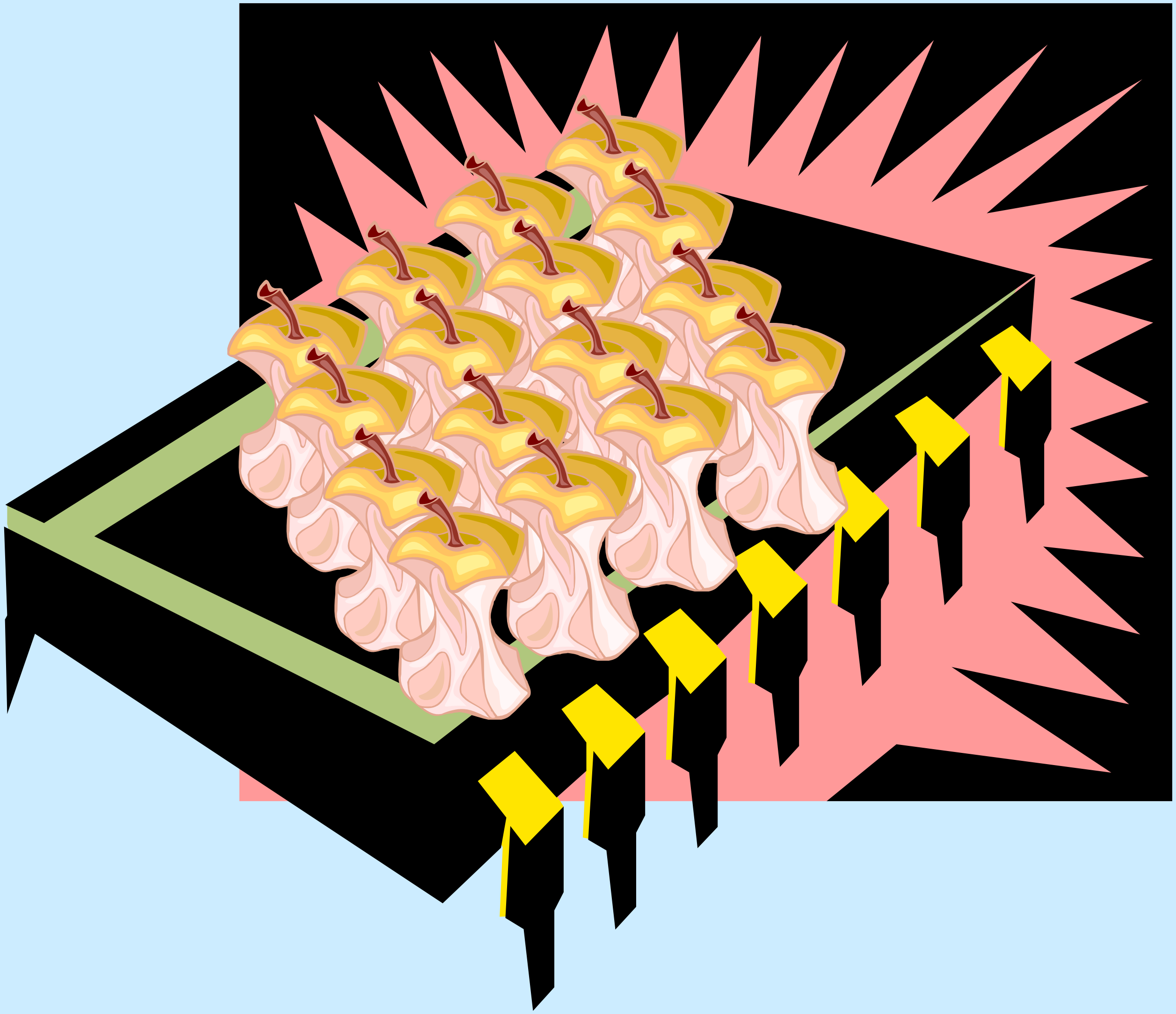
Single-Core Chips



Dual-Core Chips



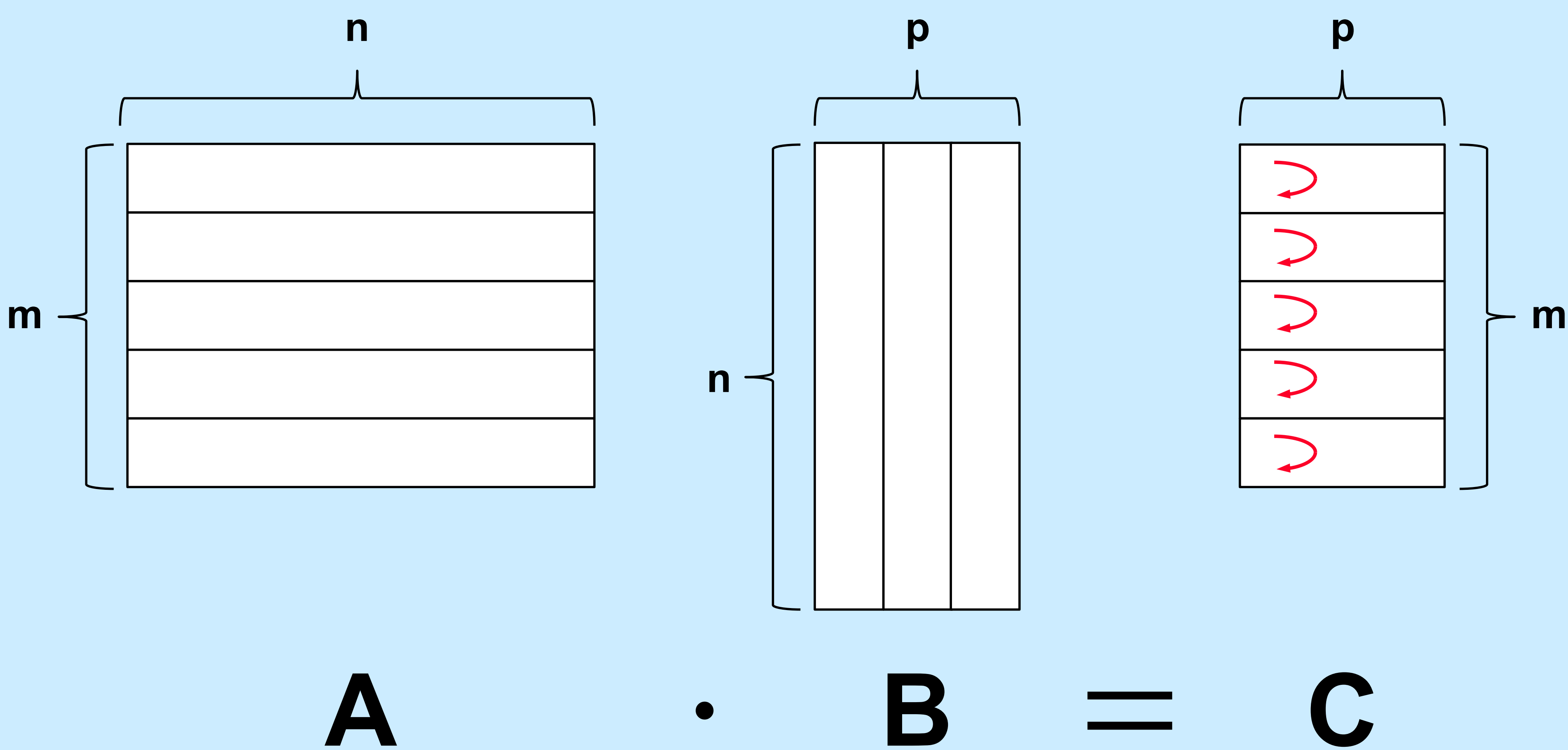
Multi-Core Chips



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

Creating Threads

```
long A[M][N], B[N][P], C[M][P];
...
for (i=0; i<M; i++)    // create worker threads
  pthread_create(&thr[i], 0, matmult, i);

...


void *matmult(void *arg) {
  long i = (long)arg;
  // compute row i of the product C of A and B
  ...
}
```

When Is It Finished?

```
long A[M][N], B[N][P], C[M][P];
...
for (i=0; i<M; i++)    // create worker threads
 pthread_create(&thr[i], 0, matmult, i));

for (i=0; i<M; i++)   // wait for termination
  pthread_join(thr[i], 0);

printResult(C); // shouldn't do this until
                // workers have terminated
```

Example (1)

```
#include <stdio.h>
#include <pthread.h>
#include <string.h>

#define M   3
#define N   4
#define P   5

long A[M][N];
long B[N][P];
long C[M][P];

void *matmult(void *);
```

```
main( ) {
  long i;
  pthread_t thr[M];
  int error;

  // initialize the matrices
  ...
```

Example (2)

```
  for (i=0; i<M; i++) {   // create worker threads
   if (error = pthread_create(
        &thr[i],
        0,
        matmult,
        (void *)i)) {
     fprintf(stderr, "pthread_create: %s", strerror(error));
     exit(1);
   }
  }
  for (i=0; i<M; i++) // wait for workers to finish their jobs
   pthread_join(thr[i], 0)

  /* print the results  ... */
}
```

Example (3)

```
void *matmult(void *arg) {
  long row = (long)arg;
  long col;
  long i;
  long t;

  for (col=0; col < P; col++) {
   t = 0;
   for (i=0; i<N; i++)
     t += A[row][i] * B[i][col];
   C[row][col] = t;
  }
  return(0);
}
```


Compiling It

```
% gcc -o mat mat.c -pthread
```


Termination

```
pthread_exit((void *) value);

return((void *) value);


pthread_join(thread, (void **) &value);
```

Detached Threads

```
start_servers( ) {
  pthread_t thread;
  int i;

  for (i=0; i<nr_of_server_threads; i++) {
    pthread_create(&thread, 0, server, 0);
    pthread_detach(thread);
  }
  ...
}

void *server(void * arg ) {
  ...
}
```


Complications

```
void relay(int left, int right) {
  pthread_t LRthread, RLthread;

  pthread_create(&LRthread,
      0,
      copy,
      left, right);           // Can't do this ...
  pthread_create(&RLthread,
      0,
      copy,
      right, left);           // Can't do this  ...
}
```


Multiple Arguments

```
typedef struct args {
  int src;
  int dest;
} args_t;

void relay(int left, int right) {
  args_t LRargs, RLargs;
  pthread_t LRthread, RLthread;
  ...
  pthread_create(&LRthread, 0, copy, &LRargs);
  pthread_create(&RLthread, 0, copy, &RLargs);
}
```

Multiple Arguments

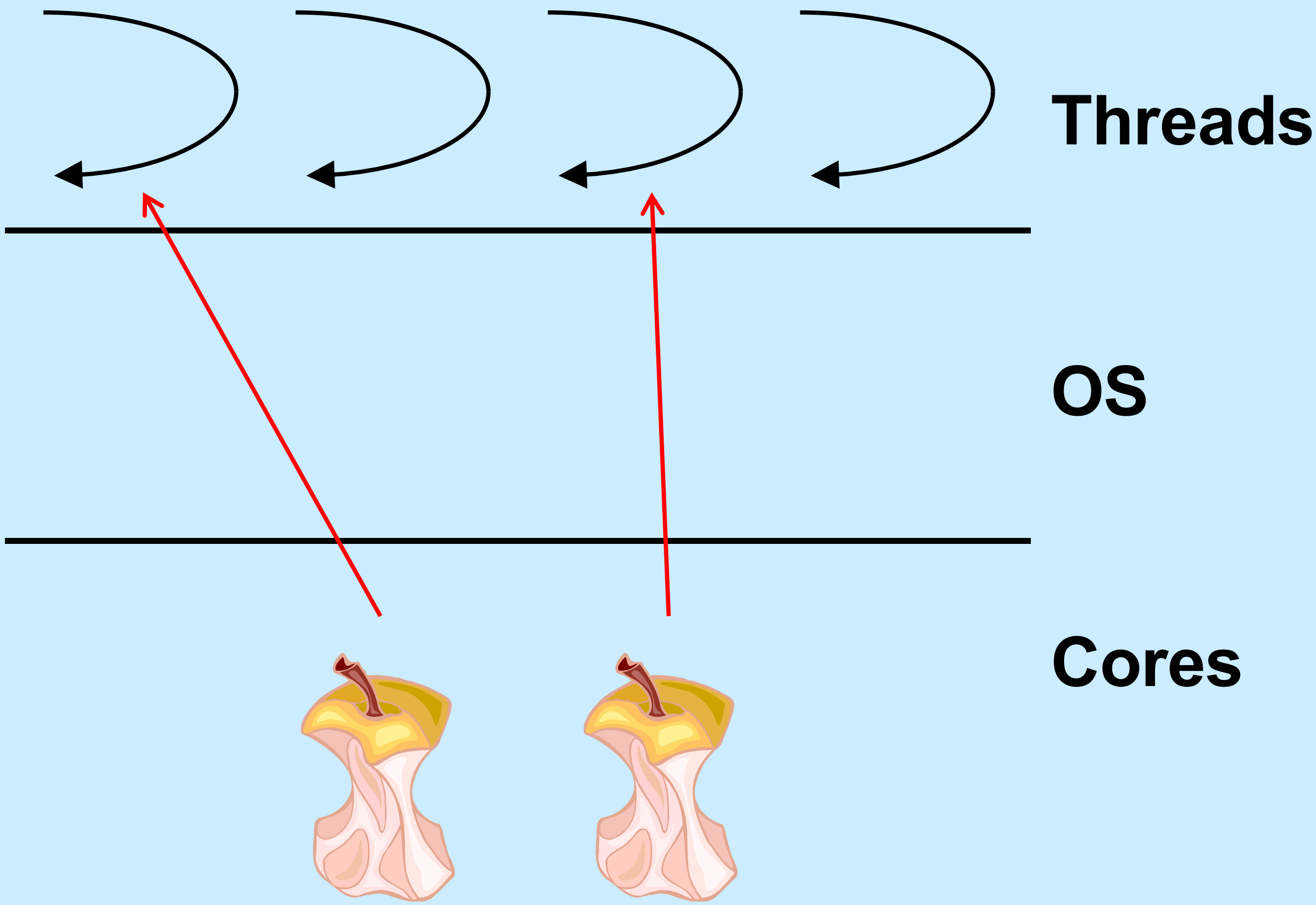
```
typedef struct args {
  int src;
  int dest;
} args_t;

void relay(int left, int right) {
  args_t LRargs, RLargs;
  pthread_t LRthread, RLthread;
  ...
  pthread_create(&LRthread, 0, copy, &LRargs);
  pthread_create(&RLthread, 0, copy, &RLargs);
}
```

Quiz 2

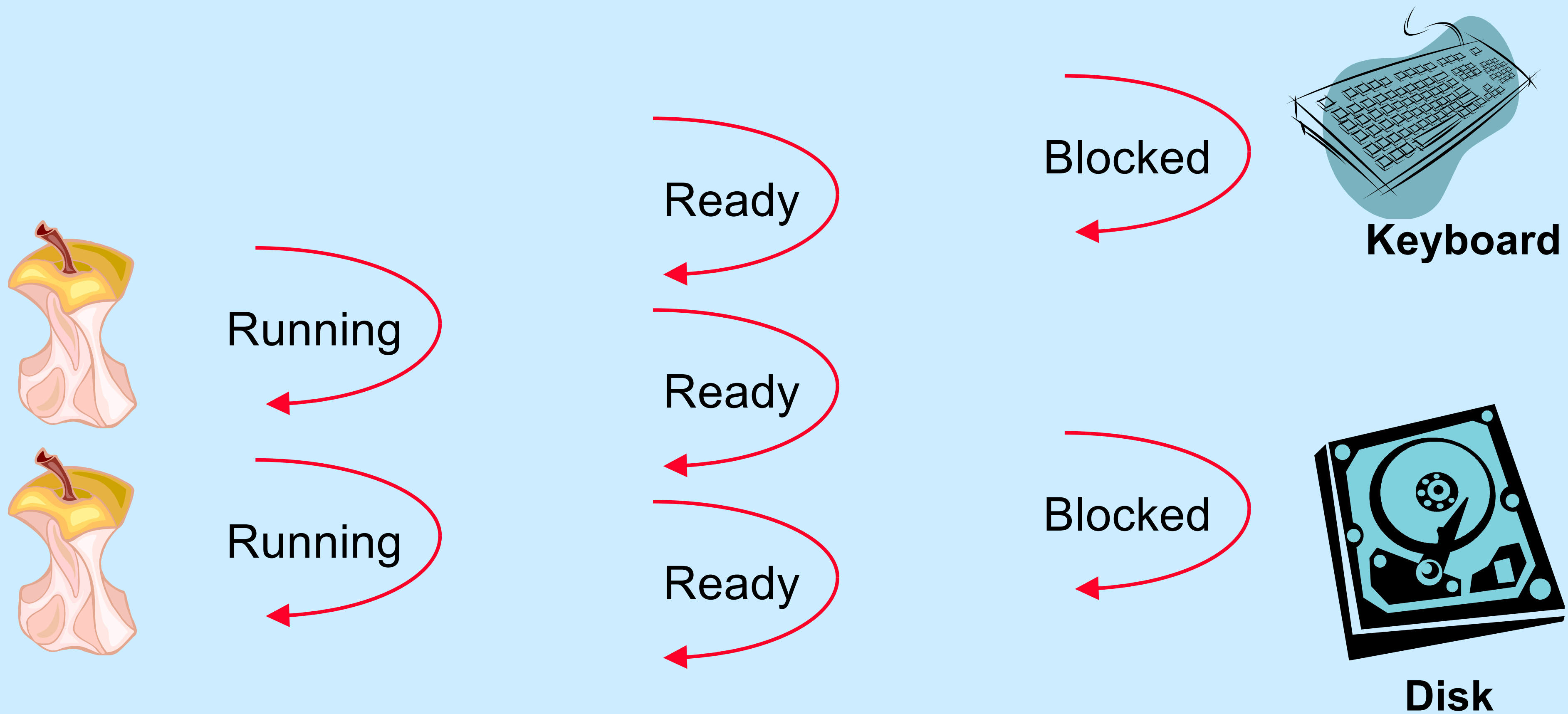
Does this work?

a) yes
b) no

Execution



Multiplexing Processors



Quiz 3

```
  pthread_create(&tid, 0, tproc, (void *)1);
  pthread_create(&tid, 0, tproc, (void *)2);

  printf("T0\n");

  ...

void *tproc(void *arg) {
  printf("T%dl\n", (long)arg);
  return 0;
}
```

In which order are things printed?

a) T0, T1, T2
b) T1, T2, T0
c) T2, T1, T0
d) indeterminate

Cost of Threads

```
int main(int argc, char *argv[]) {
   ...
   val = niters/nthreads;

   for (i=0; i<nthreads; i++)
      pthread_create(&thread, 0, work, (void *)val);
   pthread_exit(0);
   return 0;
}

void *work(void *arg) {
   long n = (long)arg; int i, j; volatile long x;

   for (i=0; i<n; i++) {
      x = 0;
      for (j=0; j<1000; j++)
         x = x*j;
   }
   return 0;
}
```


Cost of Threads

```
int main(int argc, char *argv[]) {
   ...
   val = niters/nthreads;

   for (i=0; i<nthreads; i++)
      pthread_create(&thread, 0, work, (void *)val);
   pthread_exit(0);
   return 0;
}

void *work(void *arg) {
   long n = (long)arg; int i, j; volatile long x;

   for (i=0; i<n; i++) {
      x = 0;
      for (j=0; j<1000; j++)
         x = x*j;
   }
   return 0;
}
```

Quiz 4

This code runs in time *n* on a 4-core processor when *nthreads* is 8. It runs in time *p* on the same processor when *nthreads* is 400.

a) *n* << *p* (slower)
b) *n* ≈ *p* (same speed)
c) *n* >> *p* (faster)

Problem

```
pthread_create(&thread, 0, start, 0);

…



void *start(void *arg) {
  long BigArray[128*1024*1024];
  …
  return 0;
}
```

Thread Attributes

```
pthread_t thread;
pthread_attr_t thr_attr;

pthread_attr_init(&thr_attr);

...

/* establish some attributes */

...

pthread_create(&thread, &thr_attr, startroutine, arg);

...
```

Stack Size

```
pthread_t thread;
pthread_attr_t thr_attr;

pthread_attr_init(&thr_attr);
pthread_attr_setstacksize(&thr_attr, 130*1024*1024);

...

pthread_create(&thread, &thr_attr, startroutine, arg);

...
```