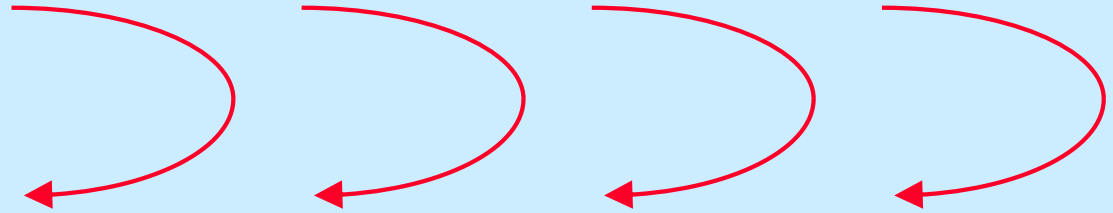
CS 33

Multithreaded Programming (1)

Multithreaded Programming

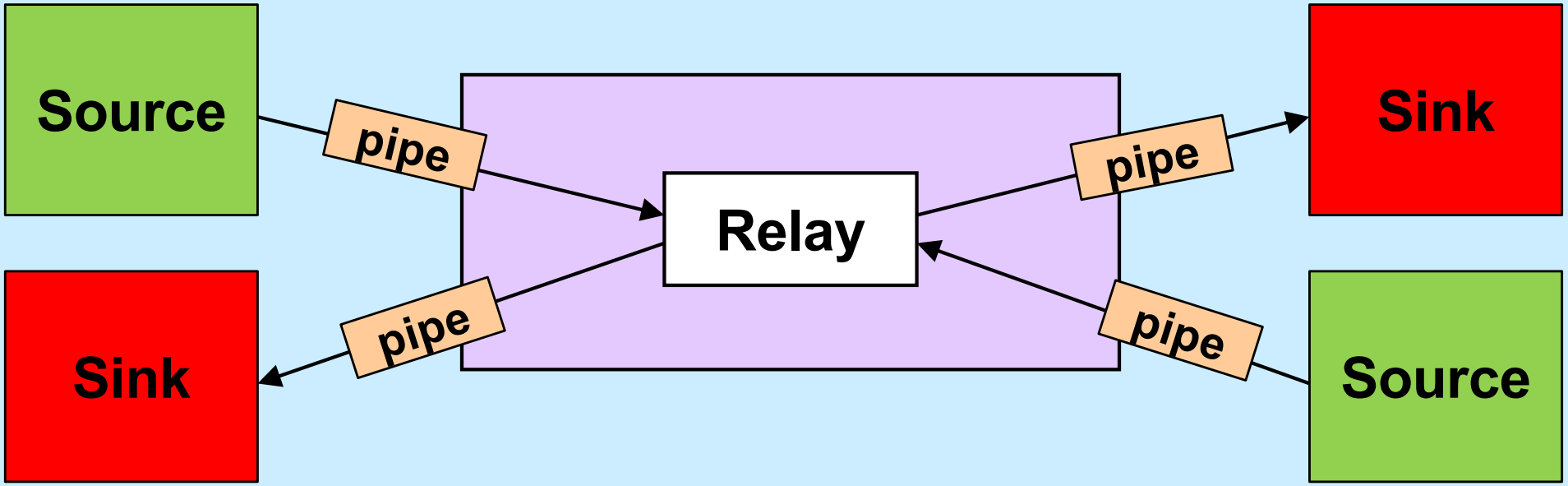
- A thread is a virtual processor
  - an independent agent executing instructions
- Multiple threads
  - multiple independent agents executing instructions in a shared address space

Why Threads?



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

A Simple Example



Life Without Threads

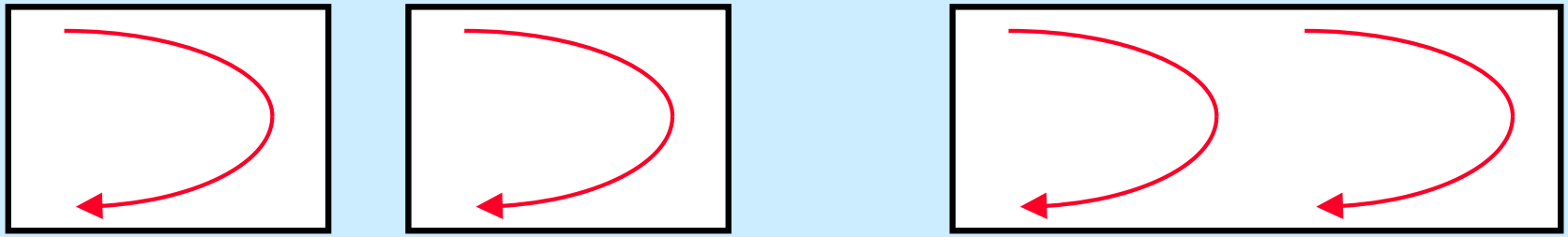
```
void relay(int left, int right) {
    fd_set rd, wr;
    int left_read = 1, right_write = 0;
    int right_read = 1, left_write = 0;
    int sizeLR, sizeRL, wret;
    char bufLR[BSIZE], bufRL[BSIZE];
    char *bufpR, *bufpL;
    int maxFD = max(left, right) + 1;

    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;
}
```

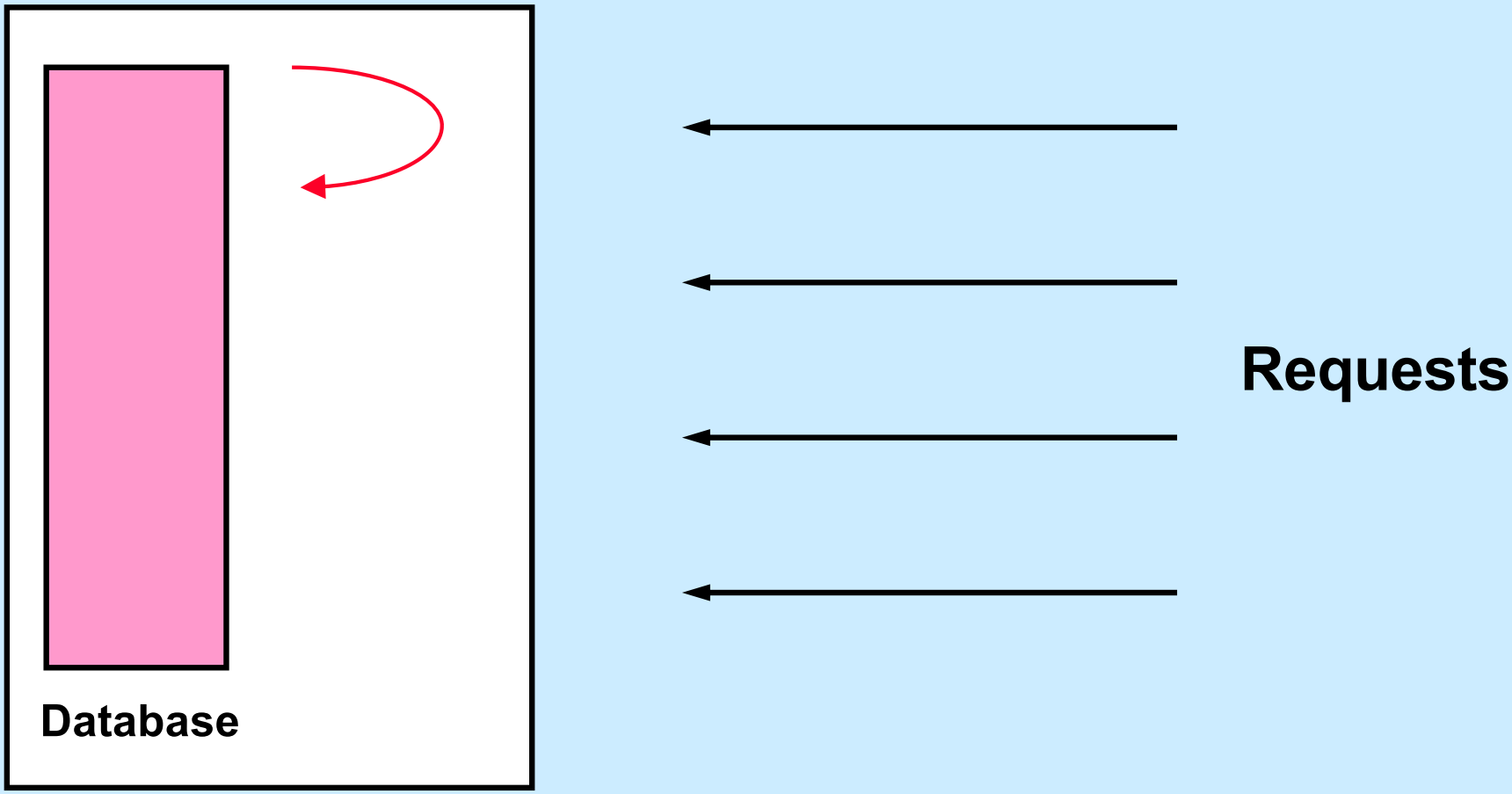
Life With Threads

```
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);
  }
}
```

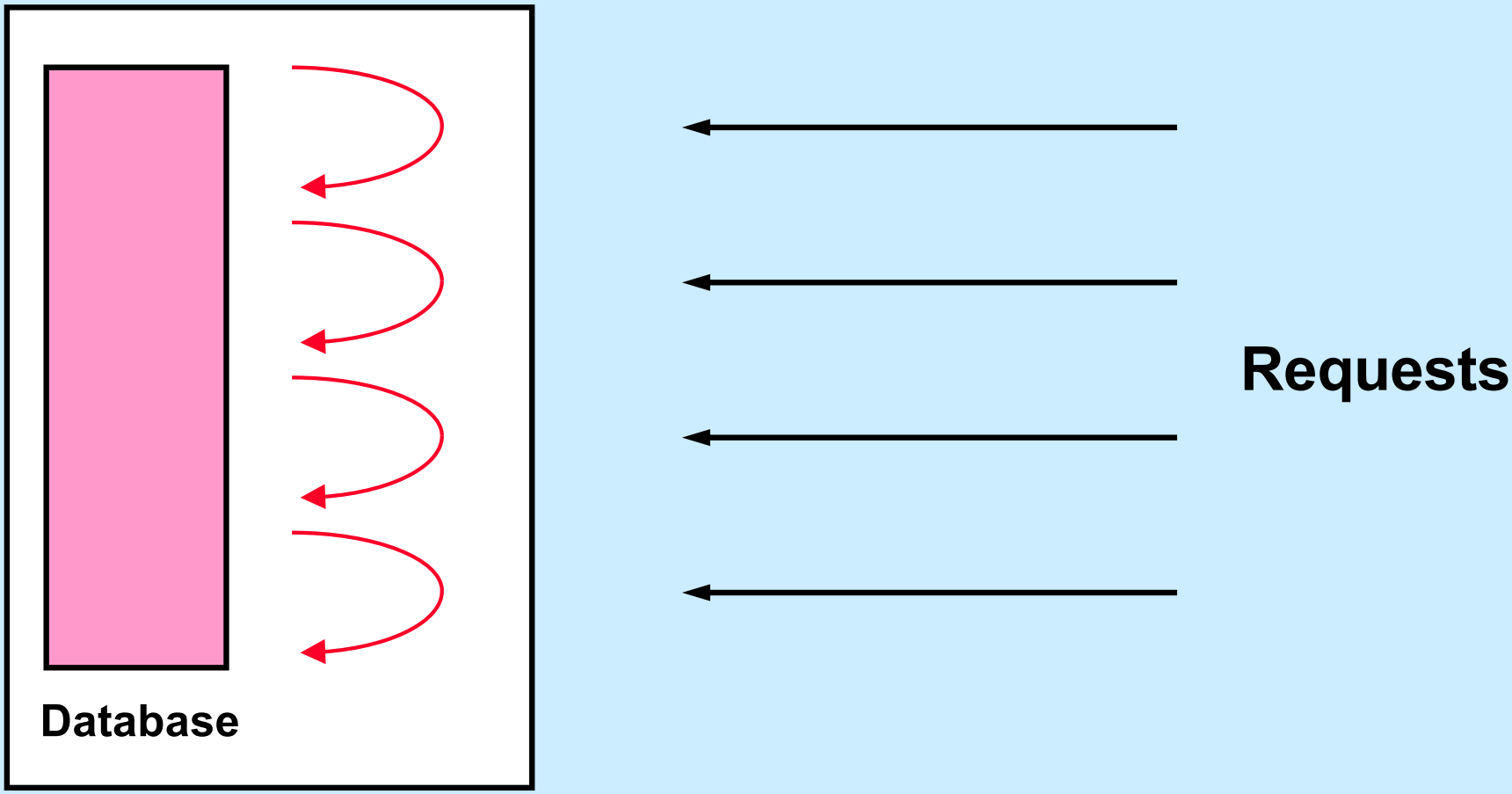
Processes vs. Threads



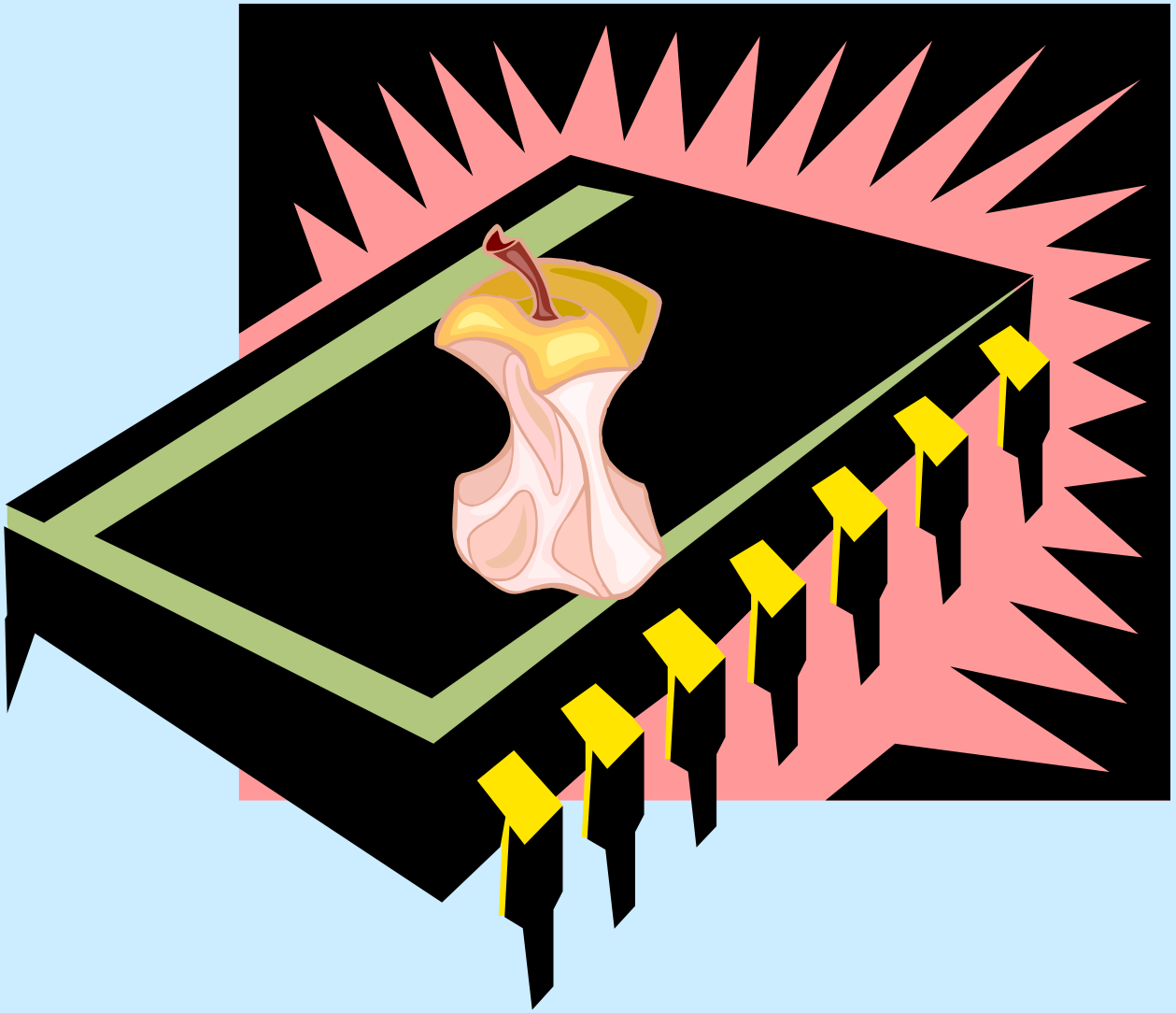
Single-Threaded Database Server



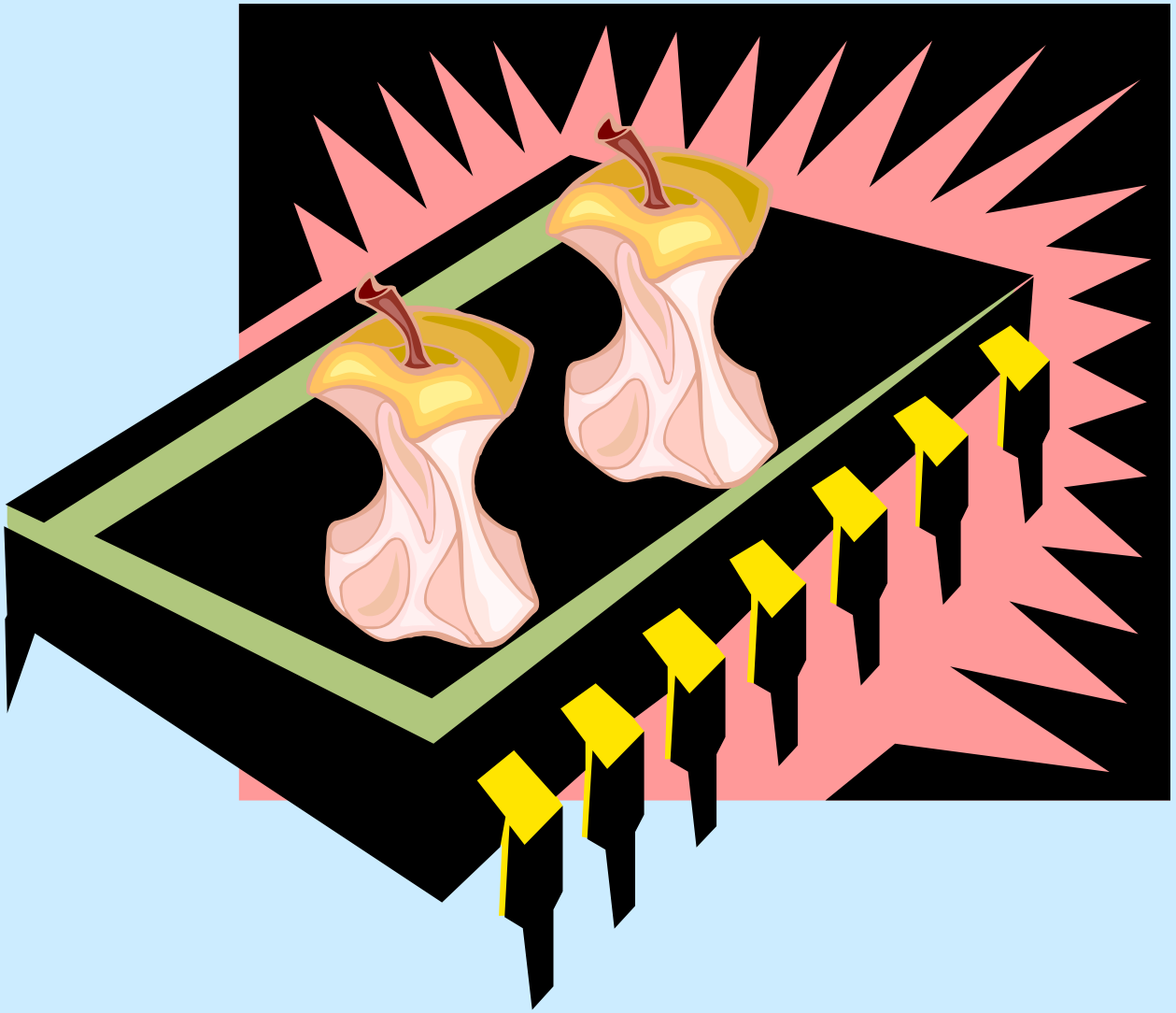
Multithreaded Database Server



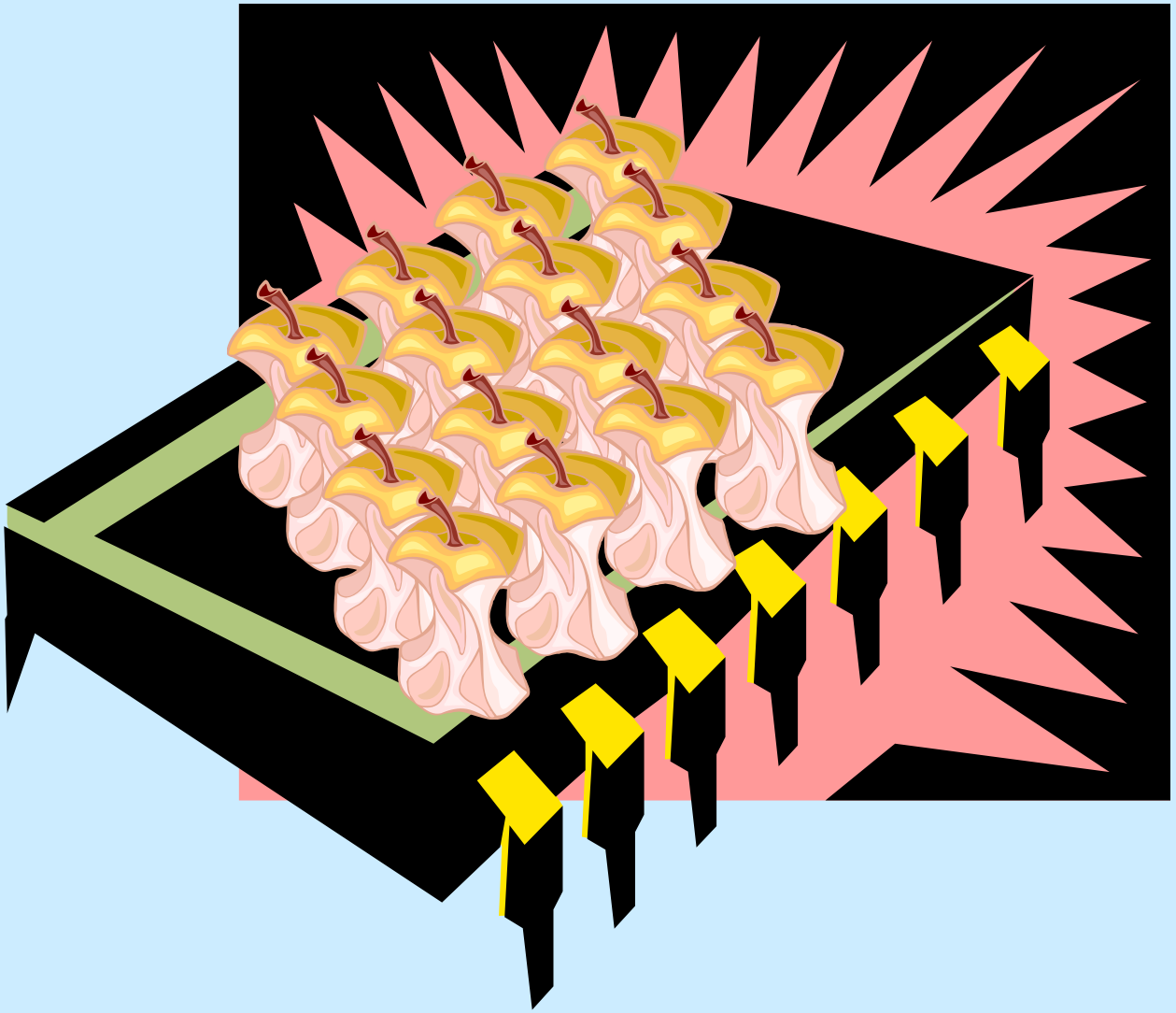
Single-Core Chips



Dual-Core Chips



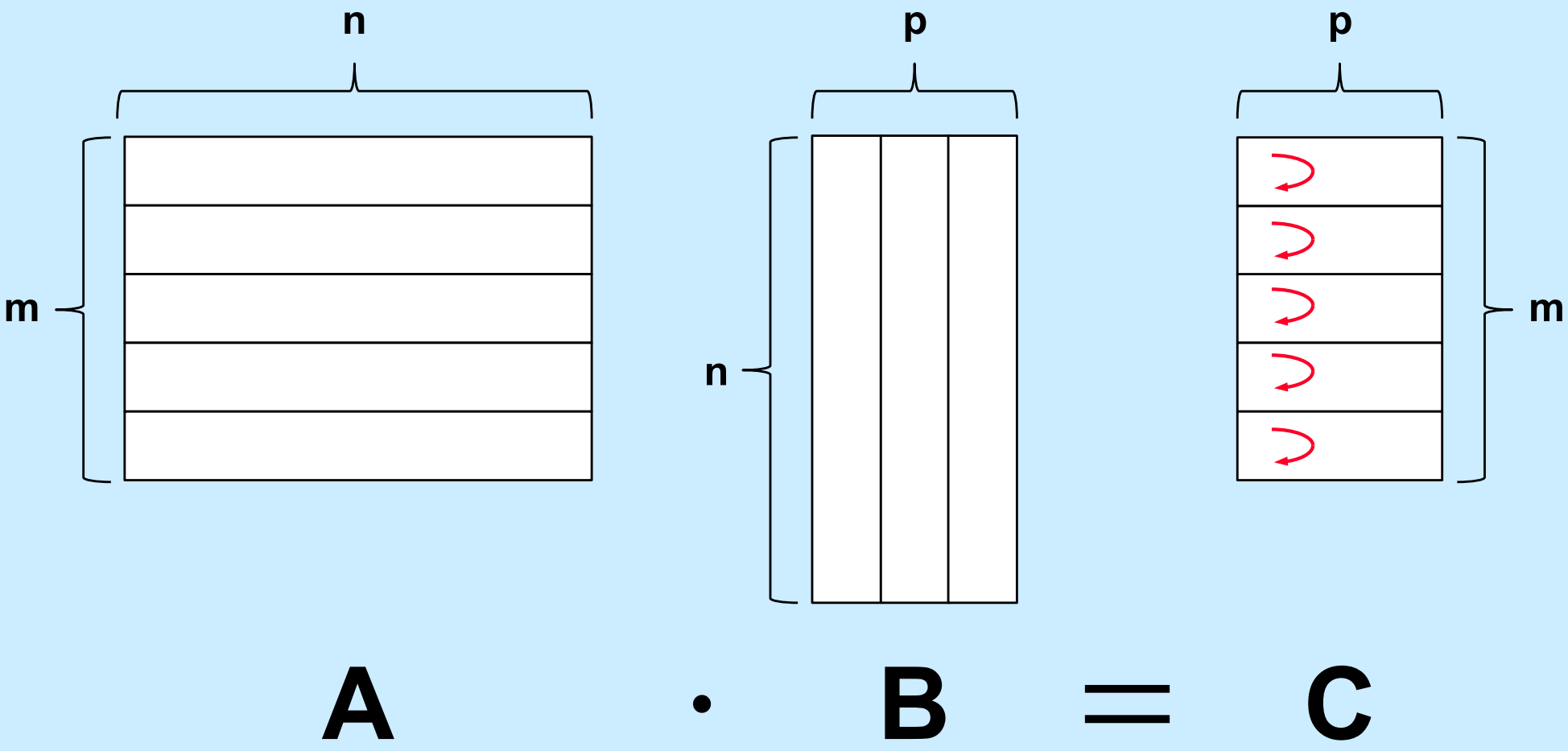
Multi-Core Chips



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  ... */
}
```

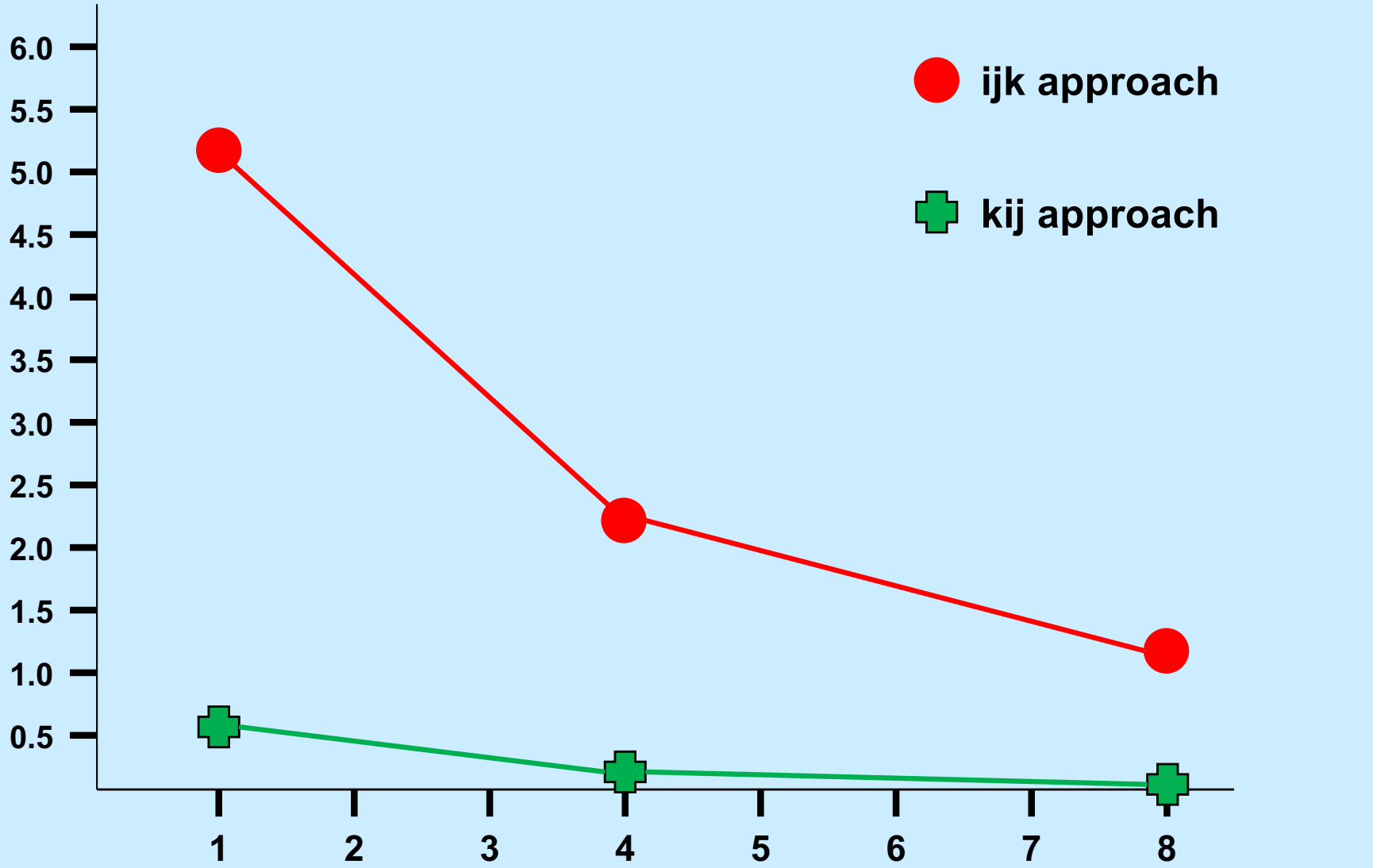
Example (3)

```
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
```

Performance



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

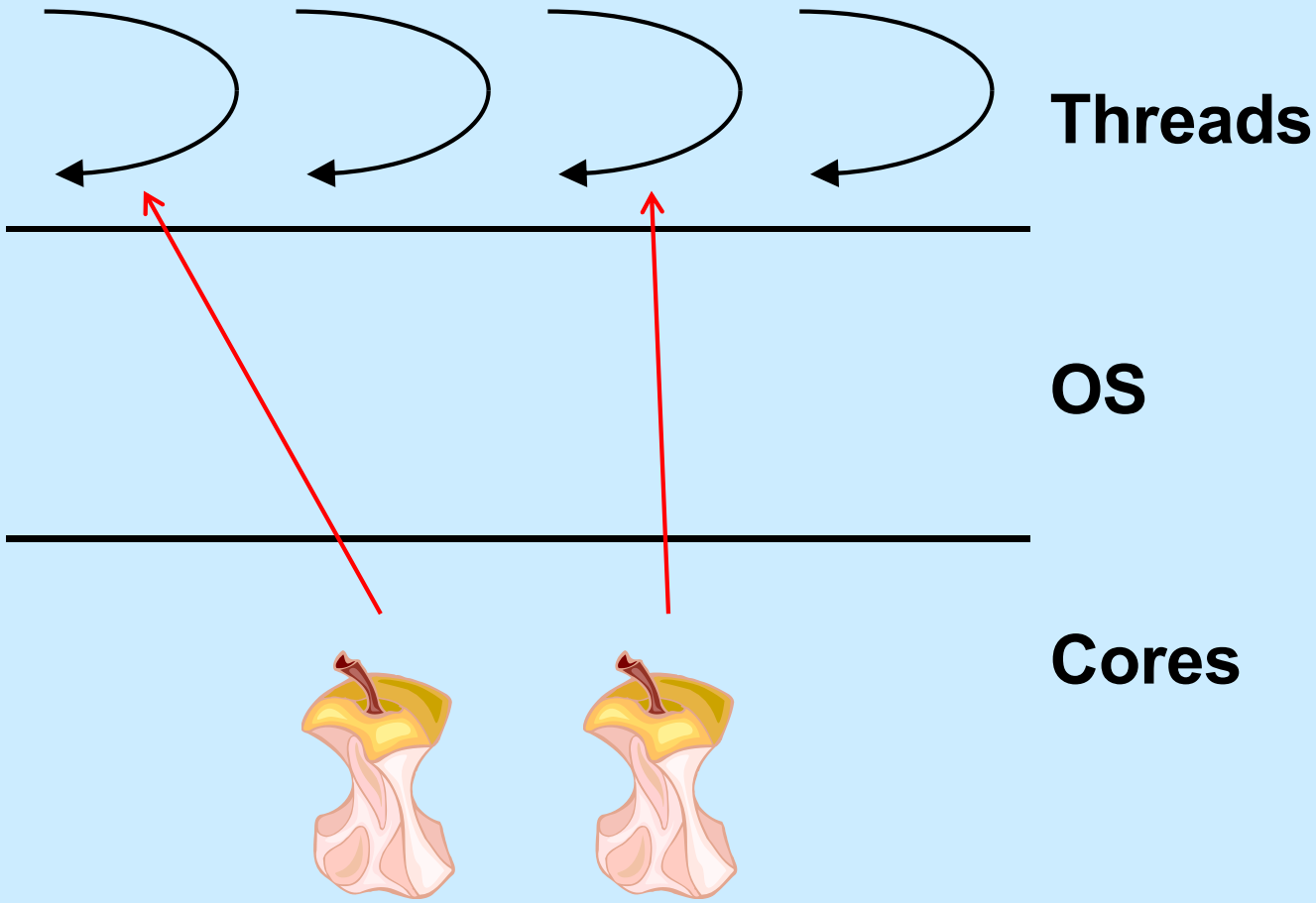
```
typedef struct args {
  int src;
  int dest;
} args_t;

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 1

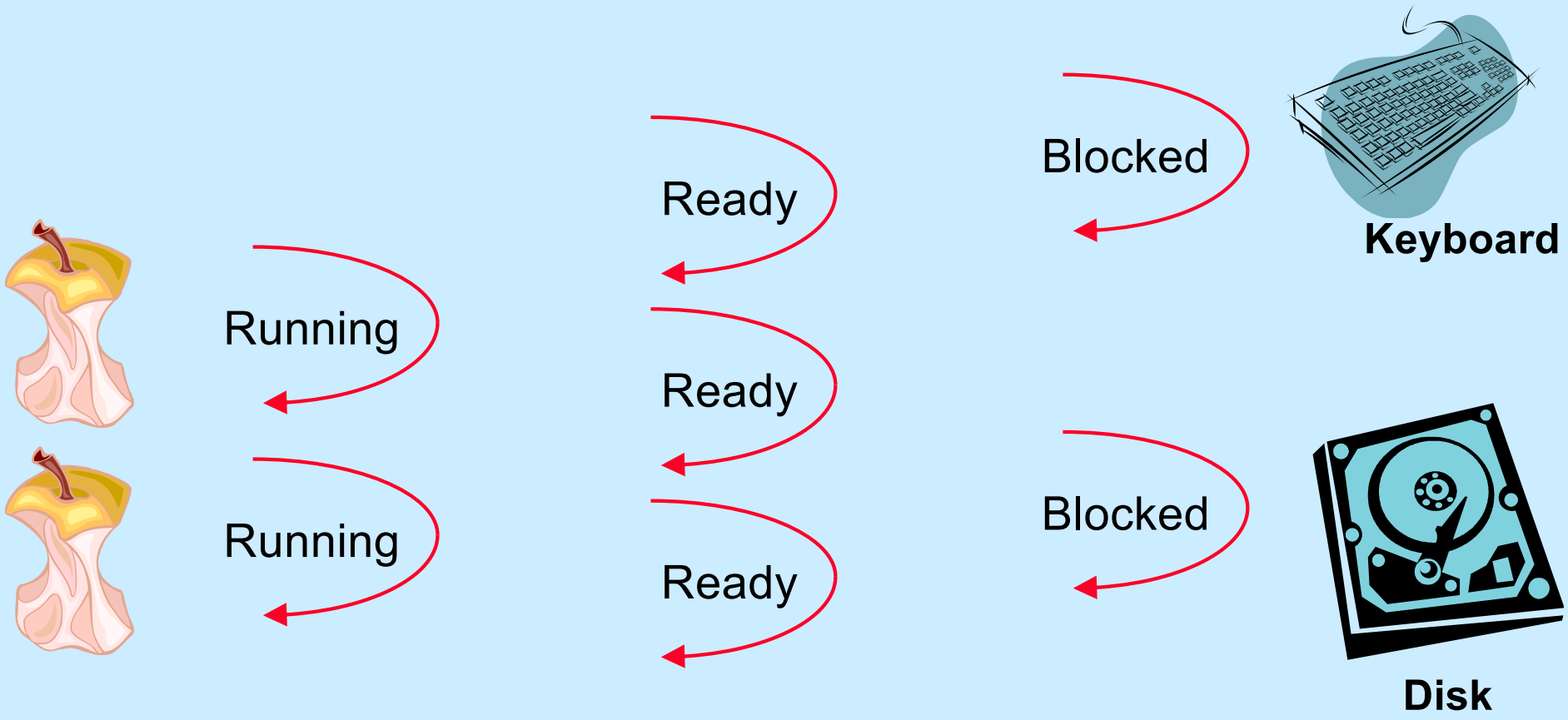
Does this work?

a) yes
b) no
c) it depends upon the word size

Execution



Multiplexing Processors



Quiz 2

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

Cost of Threads

```
void *work(long n) {
    volatile long x=2;

    for (long i=0; i<n; i++) {
        long oldx = x;
        x *= x;
        x /= oldx;
    }
    return 0;
}
```

Cost of Threads

```
int main(int argc, char *argv[]) {
   long nthreads = atol(argv[1]);
   long iterations = atol(argv[2]);
   long val = iterations/nthreads;

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

Cost of Threads

```
void *work(long n) {
    volatile long x=2;

    for (long i=0; i<n; i++) {
        long oldx = x;
        x *= x;
        x /= oldx;
    }
    return 0;
}
```

Not a Quiz

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);

...
```

Mutual Exclusion

Threads and Mutual Exclusion

Thread 1:

```
x = x+1;
 /*
   movl x,%eax
   incr %eax
   movl %eax,x
 */
```

Thread 2:

```
x = x+1;
 /*
   movl x,%eax
   incr %eax
   movl %eax,x
 */
```

Quiz 3

Suppose gcc produces the following code. Will it still be the case that x's value might not be incremented by 2?

a) yes
b) no

Thread 1:

```
x = x+1;
 /*
  incr x
 */
```

Thread 2:

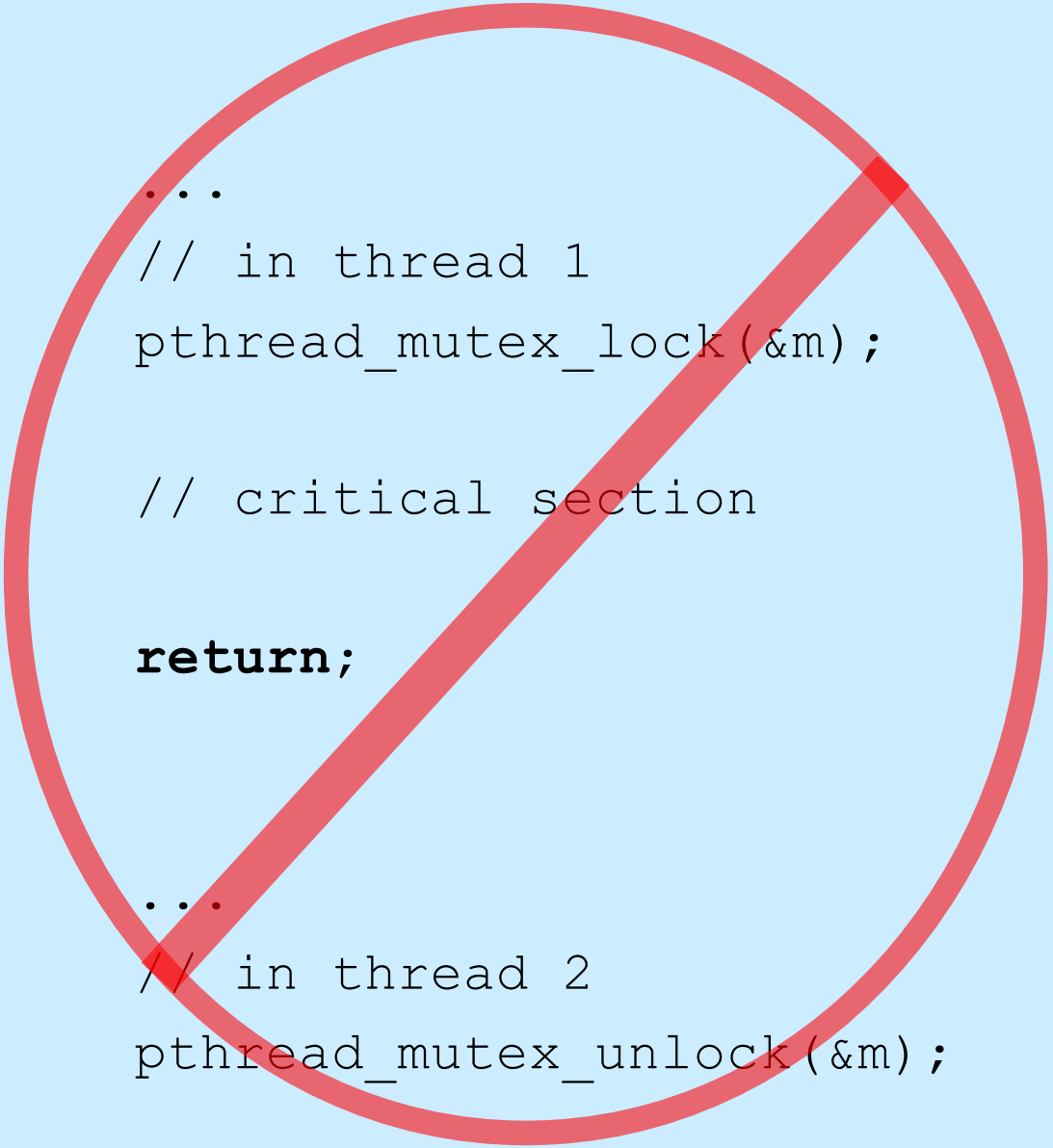
```
x = x+1;
 /*
  incr x
 */
```

POSIX Threads Mutual Exclusion

```
pthread_mutex_t m =
      PTHREAD_MUTEX_INITIALIZER;
      // shared by both threads
int x; // ditto

  pthread_mutex_lock(&m);

  x = x+1;

  pthread_mutex_unlock(&m);
```

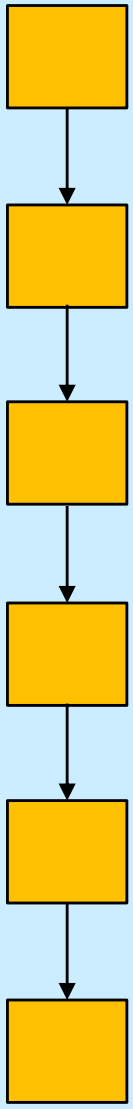
Correct Usage

```
pthread_mutex_lock(&m);

// critical section

pthread_mutex_unlock(&m);
```



```
...
// in thread 1
pthread_mutex_lock(&m);

// critical section

return;


...
// in thread 2
pthread_mutex_unlock(&m);
```

A Queue




```
void enqueue(node_t *item) {
    pthread_mutex_lock(&mutex);
    item->next = NULL;
    if (tail == NULL) {
        head = item;
        tail = item;
    } else {
        tail->next = item;
    }
    pthread_mutex_unlock(&mutex);
}
```

```
node_t *dequeue() {
    node_t *ret;
    pthread_mutex_lock(&mutex);
    if (head == NULL) {
        ret = NULL;
    } else {
        ret = head;
        head = head->next;
        if (head == NULL)
            tail = NULL;
    }
    pthread_mutex_unlock(&mutex);
    return ret;
}
```