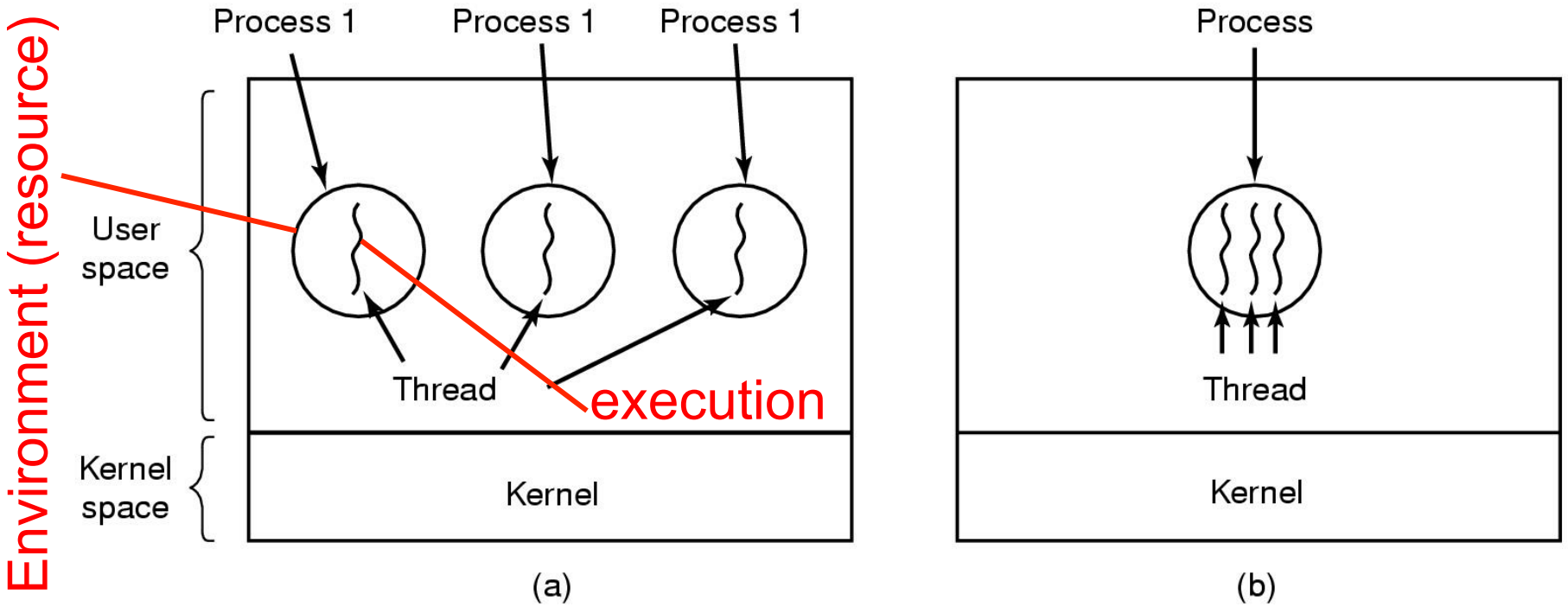
Threads: appendix

Processes vs. Threads



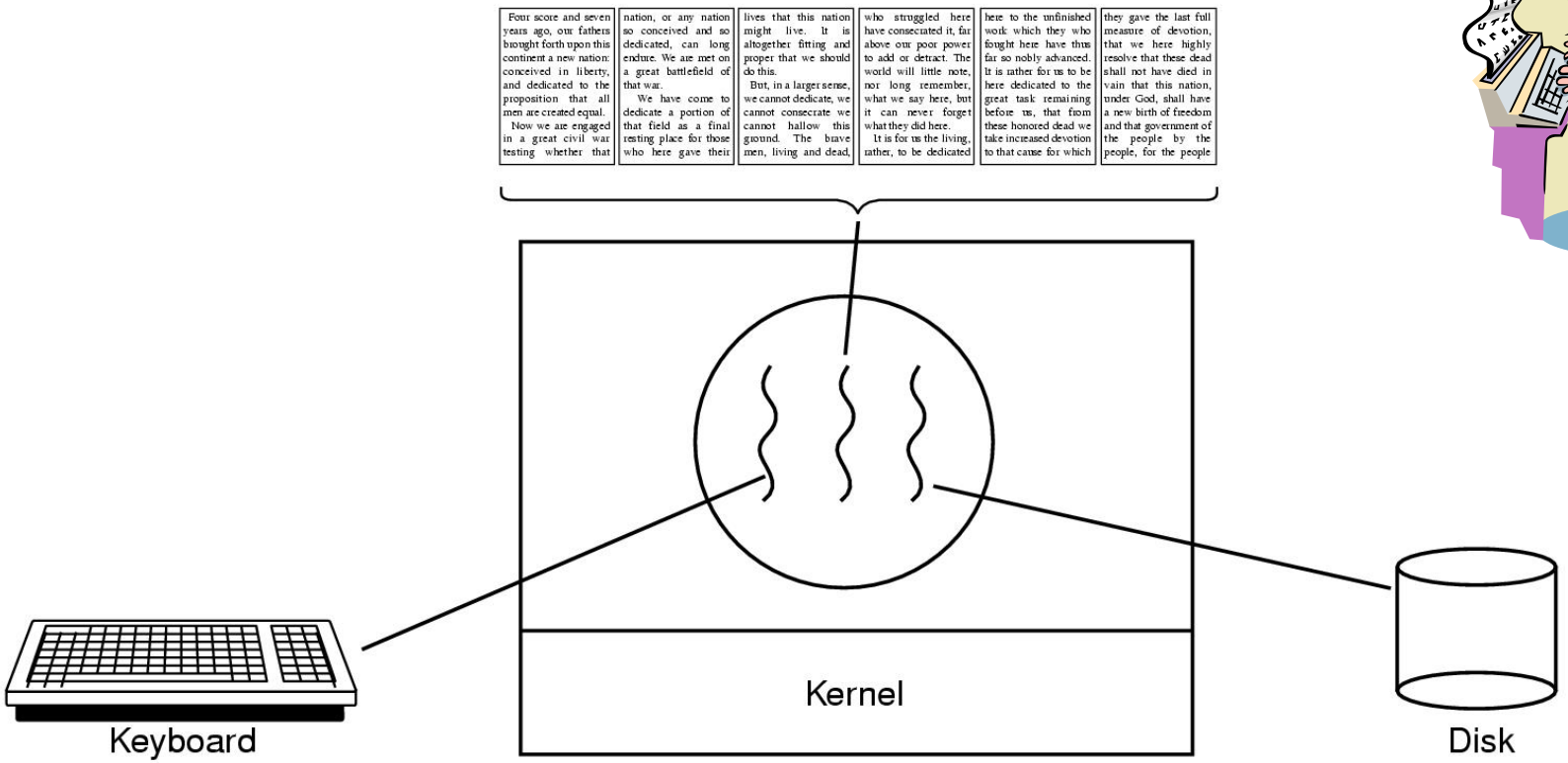
a) Three processes each with one thread
b) One process with three threads

Processes vs. Threads

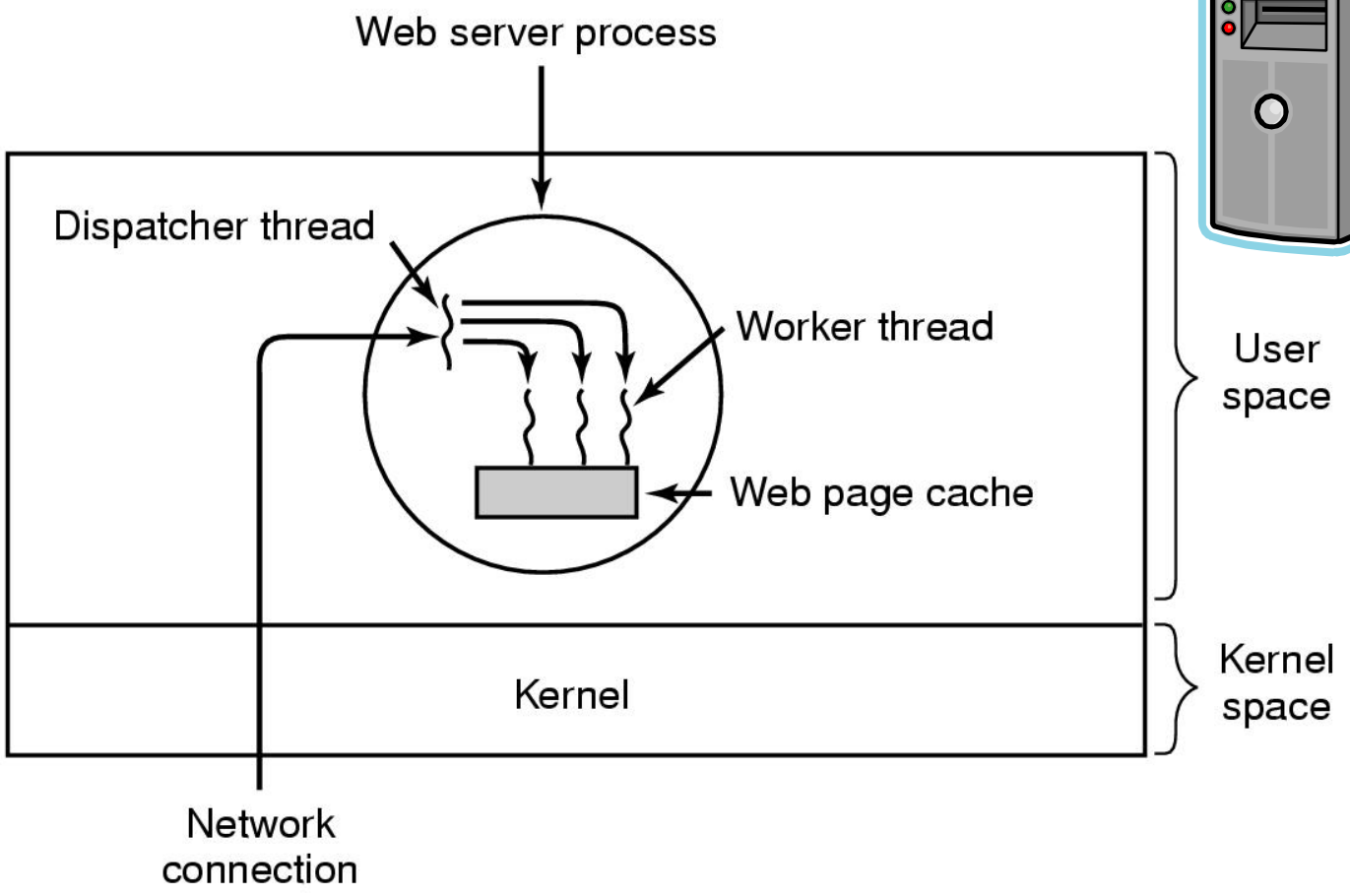
Per Process Items	Per Thread Items
Address space Global variables Open files Child processes Pending alarms Signals and signal handlers Accounting information	Program counter Registers state Stack

- Each thread executes separately
- Threads in the same process share many resources
- No protection among threads!!

Thread Usage: Word Processor



Thread Usage: Web Server



Summary: Creating Threads

- Initially, **`main()`** has a single thread
  - All other threads must be explicitly created
- **`pthread_create()`** ➔ new executable thread
  - Can be called any number of times from anywhere
- Maximum number of threads is implementation dependent
- Question:
  - After a thread has been created, how do you know when it will be scheduled to run by the operating system?
  - Answer: It is up to the operating system
    - Note: Good coding should not require knowledge of scheduling

Pthread_exit

```
void pthread_exit(void *value_ptr);
```

Common uses:

value_ptr is often a pointer to a malloc'd struct (memory must be free'd by joining thread)

Pass a pointer to heap not to the stack!!!

Thread Exit: pthread_exit or return?

- When a thread is done, it can return from its first function (the one used by pthread_create) or it can call pthread_exit

- An implicit call to pthread_exit() is made when a thread other than main() returns from the start routine that was used to create it. The function's return value shall serve as the thread's exit status.

pthreads Attributes

- Attributes
  - Data structure `pthread_attr_t`
  - Set of choices for a thread
  - Passed in thread creation routine
- Choices
  - Scheduling options (more later on scheduling)
  - Detached state
    - Detached
      - Main thread does not wait for created threads to terminate
    - Joinable
      - Main thread waits for created thread to terminate
      - Useful if created thread returns a value

pthreads Attributes

- Initialize an attributes structure to the default values
  - `int pthread_attr_init (pthread_attr_t* attr);`
- Set the detached state value in an attributes structure
  - `int pthread_attr_setdetachedstate (pthread_attr_t* attr, int value);`
  - Value
    - **PTHREAD_CREATE_DETACHED**
    - **PTHREAD_CREATE_JOINABLE**

Waiting for Threads: `pthread_join()`

```
int pthread_join(pthread_t thread, void** retval);
```

- Note
  - You cannot call `pthread_join()` on a detached thread,
  - Detaching means you are NOT interested in knowing about the thread's exit
- Set `pthread_attr` to joinable before calling `pthread_create()`

➔ This is the default option!

```
pthread_attr_init(&attr);
pthread_attr_setdetachstate(&attr,
    PTHREAD_CREATE_JOINABLE);
```


Example: pthread_create()

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
void *snow(void *data) {
    printf("Main thread said:%s\n", (char *) data);
    pthread_exit(NULL);
}
int main(int argc, char *argv[]) {
    pthread_t mythread;
    int result;
    char *data = "Let it snow.";
    result = pthread_create(&mythread, NULL, snow, (void *) data);
    printf("pthread_create() returned %d\n", result);
    if(result)
        exit(1);
    pthread_exit(NULL);
}
```


Example 1: process vs. thread

```
#include <stdio.h>
#include <unistd.h>
#include <sys/wait.h>

int x = 1;
void *func(void *p){
  x = x + 10;
  printf("child's x is %d\n", x);
  return NULL;
}

int main(int argc, char** argv) {
  if (fork() == 0)
    func(NULL);
  else {
    wait(NULL);
    printf("parent's x is %d\n", x);
  }
}
```


Example 2: process vs. thread

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

int x = 1;

void *func(void *p){
  x = x + 10;
  printf("func thread's x is %d\n", x);
  pthread_exit(NULL);
}

int main(int argc, char** argv) {
  pthread_t tid;

  pthread_create(&tid, NULL, func, NULL);
  pthread_join(tid, NULL);
  printf("main thread's x is %d\n", x);
}
```


Returning data through `pthread_join()`

```
void *thread(void *vargp) {
    int *value = (int *)malloc(sizeof(int));
    *value = 84;
    pthread_exit(value);
}

int main() {
    int i; pthread_t tid; void *vptr_return;

    pthread_create(&tid, NULL, thread, NULL);
    pthread_join(tid, &vptr_return);
    i = *((int *)vptr_return);
    free(vptr_return);
    printf("%d\n",i);
}
```


Thread Argument Passing

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#define NUM_THREADS    8

char *messages[NUM_THREADS];

void *PrintHello(void *threadid) {
   int *id_ptr, taskid;

   sleep(1);
   id_ptr = (int *) threadid;
   taskid = *id_ptr;
   printf("Thread %d: %s\n", taskid, messages[taskid]);
   pthread_exit(NULL);
}
```


Thread Argument Passing

```
int main(int argc, char *argv[]) {

    pthread_t threads[NUM_THREADS];
    int *taskids[NUM_THREADS];
    int rc, t;

    messages[0] = "English: Hello World!";
    messages[1] = "French: Bonjour, le monde!";
    messages[2] = "Spanish: Hola el mundo!";
    messages[3] = "Klingon: Nuq neH!";
    messages[4] = "German: Guten Tag, Welt!";
    messages[5] = "Russian: Zdravstvytye, mir!";
    messages[6] = "Japanese: Sekai e konnichiwa!";
    messages[7] = ”Italian: Ciao Mondo!";
```


Thread Argument Passing

```
    for(t=0;t<NUM_THREADS;t++) {
       taskids[t] = (int *) malloc(sizeof(int));
       *taskids[t] = t;
       printf("Creating thread %d\n", t);
       rc = pthread_create(&threads[t], NULL, PrintHello,
                           (void *) taskids[t]);
       if (rc) {
               printf("ERR; pthread_create() ret = %d\n", rc);
           exit(-1);
       }
    }
    pthread_exit(NULL);
}
```


Thread Argument Passing

```
    for(t=0;t<NUM_THR
        taskids[t] =
        *taskids[t] =
        printf("Creat
        rc = pthread_
        if (rc) {
                printf
            exit(-1);
        }
    }
    pthread_exit(NULL
}
```

```
Creating thread 0
Creating thread 1
Creating thread 2
Creating thread 3
Creating thread 4
Creating thread 5
Creating thread 6
Creating thread 7
Thread 0: English: Hello World!
Thread 1: French: Bonjour, le monde!
Thread 2: Spanish: Hola el mundo!
Thread 3: Klingon: Nuq neH!
Thread 4: German: Guten Tag, Welt!
Thread 5: Russian: Zdravstvytye, mir!
Thread 6: Japanese: Sekai e konnichiwa!
Thread 7: Italian: Ciao Mondo!
```


Passing Complex Arguments

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#define NUM_THREADS    8

char *messages[NUM_THREADS];

struct thread_data {
   int  thread_id;
   int  sum;
   char *message;
};

struct thread_data thread_data_array[NUM_THREADS];
```


Passing Complex Arguments

```
void *PrintHello(void *threadarg) {
    int taskid, sum;
    char *hello_msg;
    struct thread_data *my_data;

    sleep(1);
    my_data = (struct thread_data *) threadarg;
    taskid = my_data->thread_id;
    sum = my_data->sum;
    hello_msg = my_data->message;
    printf("Thread %d: %s  Sum=%d\n", taskid, hello_msg, sum);
    pthread_exit(NULL);
}
```


Passing Complex Arguments

```
int main(int argc, char *argv[]) {

    pthread_t threads[NUM_THREADS];
    int rc, t, sum;

    sum=0;
    messages[0] = "English: Hello World!";
    messages[1] = "French: Bonjour, le monde!";
    messages[2] = "Spanish: Hola el mundo!";
    messages[3] = "Klingon: Nuq neH!";
    messages[4] = "German: Guten Tag, Welt!";
    messages[5] = "Russian: Zdravstvytye, mir!";
    messages[6] = "Japanese: Sekai e konnichiwa!";
    messages[7] = ”Italian: Ciao Mondo!";
```


Passing Complex Arguments

```
    for(t=0;t<NUM_THREADS;t++) {
        sum = sum + t;
        thread_data_array[t].thread_id = t;
        thread_data_array[t].sum = sum;
        thread_data_array[t].message = messages[t];
        printf("Creating thread %d\n", t);
        rc = pthread_create(&threads[t], NULL, PrintHello,
                            (void *) &thread_data_array[t]);
        if (rc) {
            printf("ERR; pthread_create() ret = %d\n", rc);
            exit(-1);
        }
    }
    pthread_exit(NULL);
}
```


Passing Complex Arguments

```
    for(t=0;t<NUM_THREADS;t++) {
        sum = sum + t;
        thread_data_array[t].thread_id = t;
        thread_data_array[t].sum = sum;
        rc = pthread_create(&threads[t], NULL, PrintHello,
                            (void *) taskids[t]);
        rc = pthread_create(&threads[t], NULL, PrintHello,
                            (void *) &thread_data_array[t]);
        if (rc) {
            printf("ERR; pthread_create() ret = %d\n", rc);
            exit(-1);
        }
    }
    pthread_exit(NULL);
}
```


Passing Complex Arguments

```
    for(t=0;t<NU
        sum = su
        thread_da
        thread_da
        thread_da
        printf("C
        rc = pthr

        if (rc)
            print
            exit
        }
    }
    pthread_exit(NULL);
}
```

```
Creating thread 0
Creating thread 1
Creating thread 2
Creating thread 3
Creating thread 4
Creating thread 5
Creating thread 6
Creating thread 7
Thread 0: English: Hello World!  Sum=0
Thread 1: French: Bonjour, le monde!  Sum=1
Thread 2: Spanish: Hola el mundo!  Sum=3
Thread 3: Klingon: Nuq neH!  Sum=6
Thread 4: German: Guten Tag, Welt!  Sum=10
Thread 5: Russian: Zdravstvytye, mir!  Sum=15
Thread 6: Japan: Sekai e konnichiwa!  Sum=21
Thread 7: Italian: Ciao Mondo!  Sum=28
```


Incorrect Argument Passing

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#define NUM_THREADS    8

void *PrintHello(void *threadid)
{
    int *id_ptr, taskid;
    sleep(1);
    id_ptr = (int *) threadid;
    taskid = *id_ptr;
    printf("Hello from thread %d\n", taskid);
    pthread_exit(NULL);
}
```


Incorrect Argument Passing

```
int main(int argc, char *argv[]) {
    pthread_t threads[NUM_THREADS];
    int rc, t;

    for(t=0;t<NUM_THREADS;t++) {
        printf("Creating thread %d\n", t);
        rc = pthread_create(&threads[t], NULL, PrintHello,
                            (void *) &t);
        if (rc) {
            printf("ERR; pthread_create() ret = %d\n", rc);
            exit(-1);
        }
    }
    pthread_exit(NULL);
}
```

The loop that creates threads modifies the content of the variable passed by address, before the created threads can access it.

Incorrectly returning data through `pthread_join()`

What will happen here?

```
void *thread(void *vargp) {
    exit(42);
}

int main() {
    int i;
    pthread_t tid;

    pthread_create(&tid, NULL, thread, NULL);
    pthread_join(tid, (void **)&i);
    printf("%d\n",i);
}
```


Incorrectly returning data through `pthread_join()`

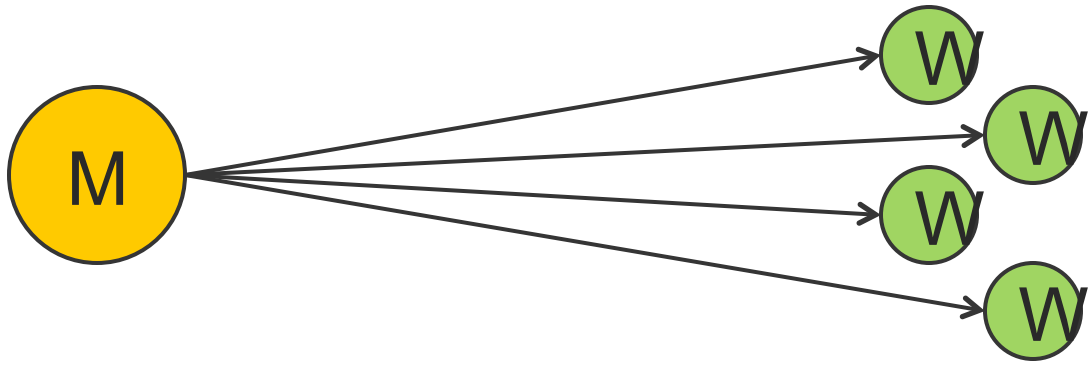
What will happen here?

```
void *thread(void *vargp) {
    pthread_detach(pthread_self());
    pthread_exit((void*)42);
}

int main() {
    int i = 0;
    pthread_t tid;

    pthread_create(&tid, NULL, thread, NULL);
    pthread_join(tid, (void**)&i);
    printf("%d\n",i);
}
```


Common Ways to Structure Multi-threaded Code

- Manager/worker
  - Single thread (manager) assigns work to other threads (workers)
  - Manager handles all input and parcels out work

Manager/Worker Model



Manager:

```
create N workers
forever {
   get a request
   pick free worker
}
```

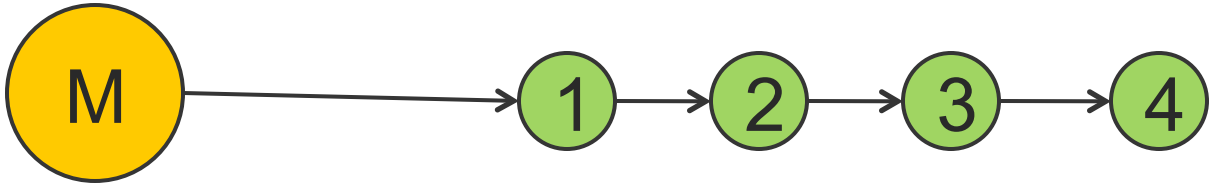
Worker:

```
forever {
   wait for request
   perform task
}
```


Common Ways to Structure Multi-threaded Code

- Pipeline
  - Task is broken into a series of sub-tasks
  - Each sub-task is handled by a different thread

Pipeline Model



Manager:

```
create N stages
forever {
    get a request
    pick 1st stage
}
```

Stage N:

```
forever {
    wait for request
    perform task
    pick stage n+1
}
```


Pthreads on GNU/Linux

- on GNU/Linux, threads are implemented as processes. Whenever you call pthread_create to create a new thread, Linux creates a new "light" process that runs that thread.

- Each thread maps to a kernel scheduling entity.

  ➔Scheduler handles pthreads as regular processes (you can assign a scheduling priority to each thread!)

- ptherad_t identifier is MEANINGFUL only in the process that created it and is not visible outside. So for instance, you cannot send a pthread_kill to a thread of another process.

pthread_t identifier

- More details for Linux:
  - pthread_self() will get you an identifier that is unique across your program, but not across your system. Although thread is a system object, the system is unaware of the identifier POSIX library allocated for the thread. On the contrary, Linux identifies threads with PID like number called TID: these numbers are system-wide.
  - each Thread in a process has different Thread ID and share same Process ID. if you are working with pthread library funtions, these funtions don't use these TIDs because these are kernel/OS level (**non-POSIX**) thread IDs.
  - In a single-threaded process, the Thread ID is equal to the Process ID (PID, as returned by getpid(2)). In a multithreaded process, all threads have the same PID, but each one has a unique TID.

pthread_t identifier

- More details for Linux:
  - Do you want to see your threads listed when invoking ps?
  - Try: ps –T

```
  PID   SPID TTY          TIME  CMD
 4932  4932 pts/1    00:00:00 xterm
 4935  4935 pts/3    00:00:00 bash
 4937  4937 pts/1    00:00:00 a.out
 4937  4938 pts/1    00:09:01 a.out
 4967  4967 pts/3    00:00:00 ps
```