POSIX threads

CS 241

February 17, 2012

Recall: Why threads over processes?

Creating a new process can be expensive

- Time
  - A call into the operating system is needed
  - Context-switching involves the operating system
- Memory
  - The entire process must be replicated
- The cost of inter-process communication and synchronization of shared data
  - May involve calls into the operation system kernel

Threads can be created without replicating an entire process

- Creating a thread is done in user space rather than kernel

Shared virtual address space

POSIX threads

Early on

- Each OS had it's own thread library/API
- Difficult to write multithreaded programs
  - Learn a new API with each new OS
  - Modify code with each port to a new OS

So later…

- POSIX (IEEE 1003.1c-1995) provided a standard known as pthreads

The pthreads API

Thread management

- Creating, detaching, joining, etc. Set/query thread attributes

today

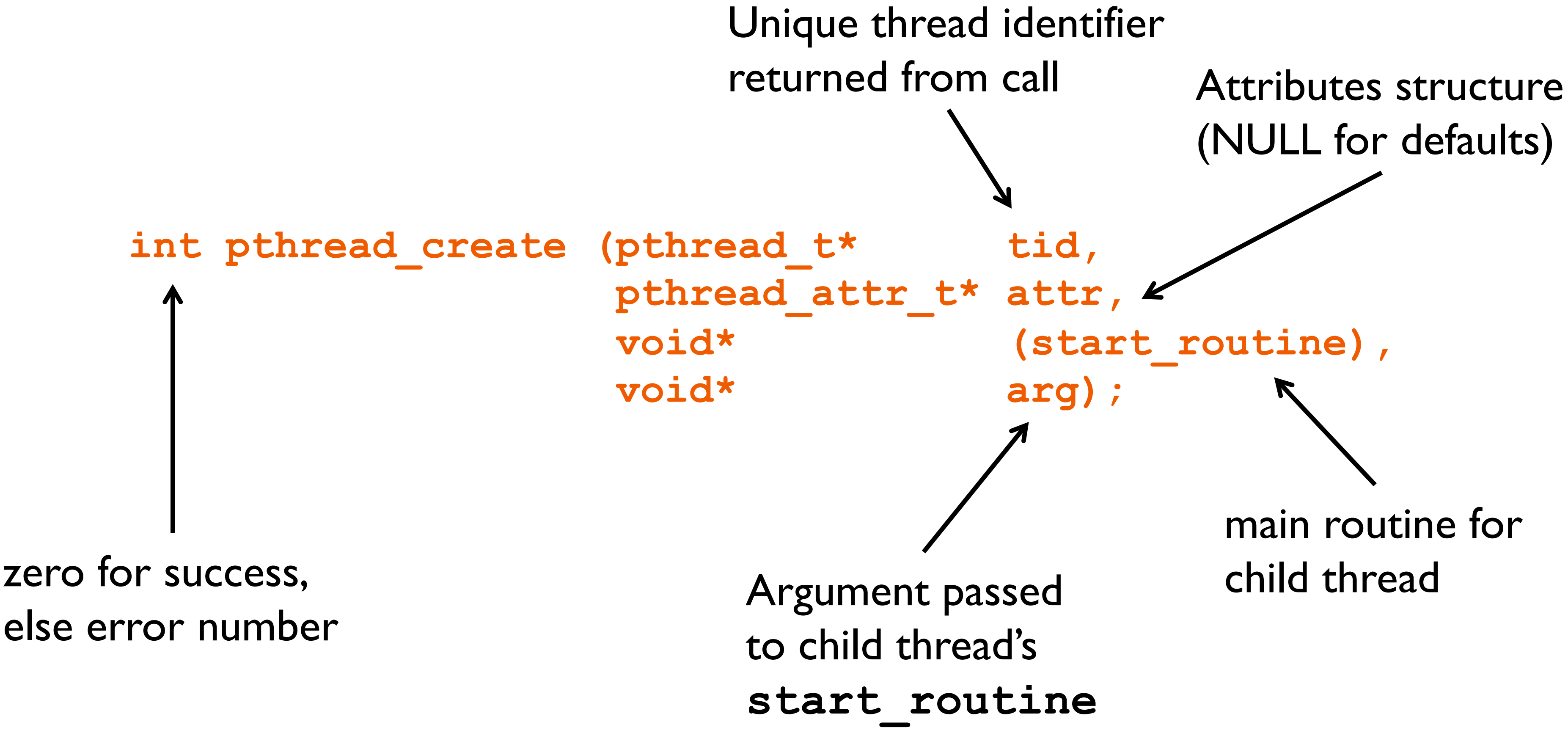
Mutexes

- Synchronization

Condition variables

- Communications between threads that share a mutex

Creating a Thread



```
int pthread_create (pthread_t*         tid,
                    pthread_attr_t* attr,
                    void*             (start_routine),
                    void*             arg);
```

Unique thread identifier returned from call

Attributes structure (NULL for defaults)

zero for success, else error number

Argument passed to child thread’s **`start_routine`**

main routine for child thread

Creating a Thread

`pthread_create()` takes a pointer to a function as one of its arguments

- start_routine is called with the argument specified by arg
- start_routine can only have one parameter of type void *
- Complex parameters can be passed by creating a structure and passing the address of the structure
- The structure shouldn't be a local variable

Example: pthread_create()

```
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
void *snow(void *data) {
   printf("Let it snow ... %s\n", 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, data);
   printf("pthread_create() returned %d\n", result);
   if(result)
      exit (1);
   pthread_exit(NULL);
}
```

Thread vs. Process Creation

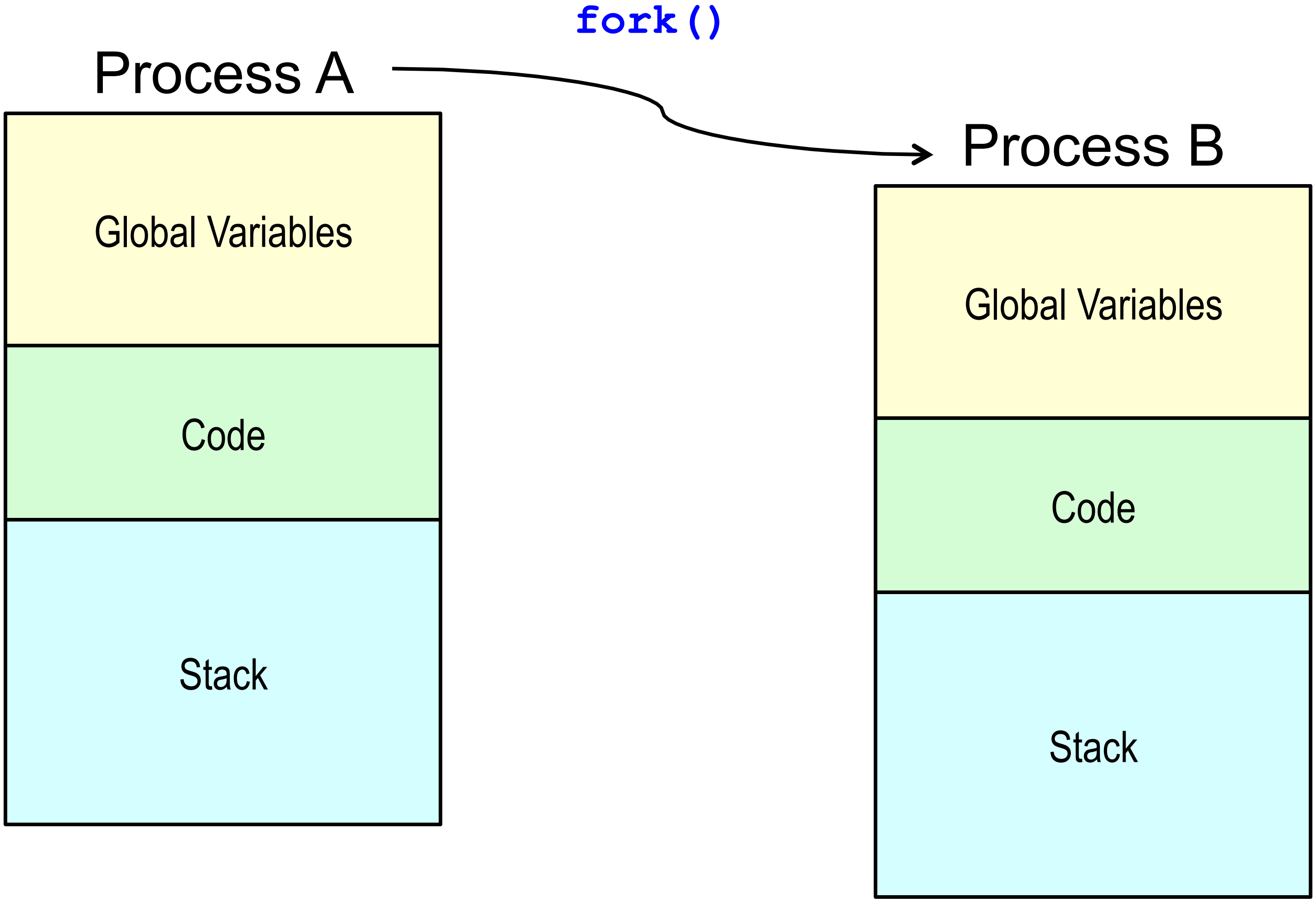
`fork()`

- Two separate processes with independent destinies
- Start from same position as parent (clone)
- Independent memory space for each process

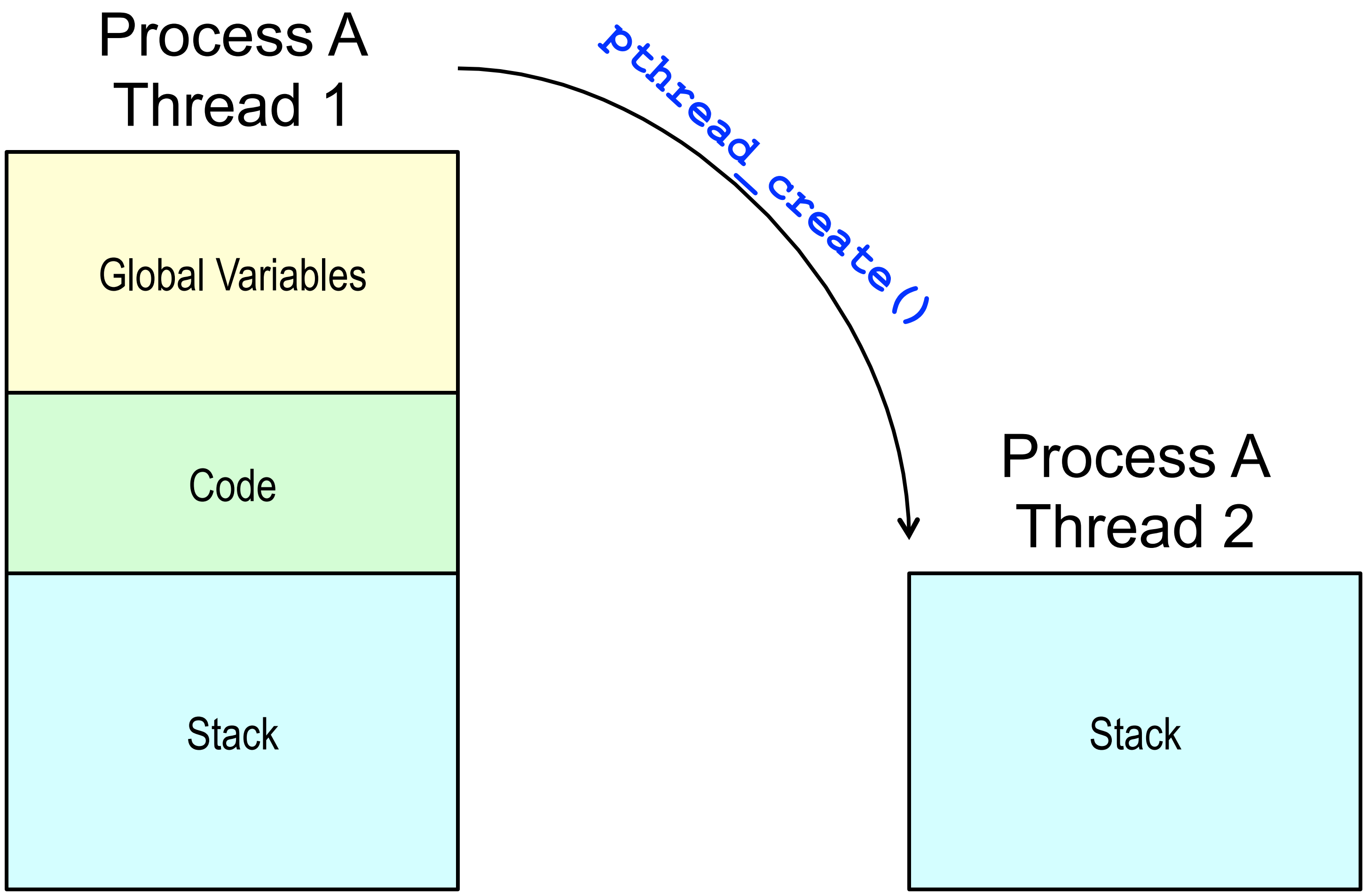
`pthread_create()`

- Two separate threads with independent destinies
- Start from a function
- Share memory

fork()


fork()
Process A
Global Variables
Code
Stack
Process B
Global Variables
Code
Stack

pthread_create()



Process A
Thread 1

Global Variables

Code

Stack

pthread_create()

Process A
Thread 2

Stack

Possible output?

Shared code

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

fork version

```
main(...) {
    fork();
    func(NULL);
}
```

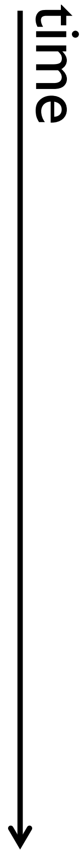
threads version

```
main(...) {
   pthread_t tid;
   pthread_create(&tid,NULL,
                  func,NULL);
   func(NULL);
}
```

Possible output: threads version, #1

```
int x = 1;

void* func(void* p){
    x = x + 1;
    printf("x is %d\n”, x);
    return NULL;
}
```

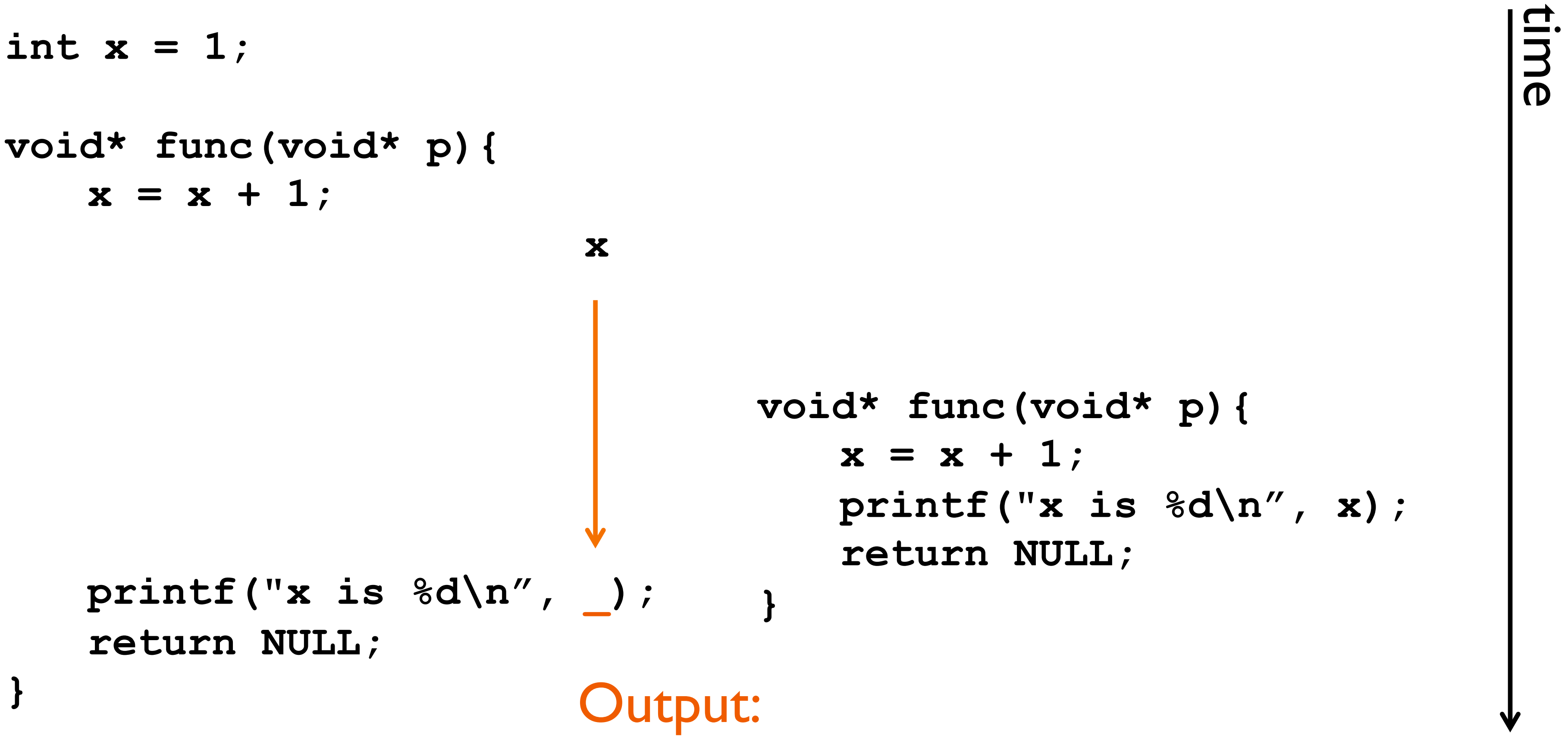
```
                                    void* func(void* p){
                                        x = x + 1;
                                        printf("x is %d\n”, x);
                                        return NULL;
                                    }
```



Output:

```
x is 2
x is 3
```

Possible output: threads version, #2



```
int x = 1;

void* func(void* p){
    x = x + 1;
```

```
void* func(void* p){
    x = x + 1;
    printf("x is %d\n”, x);
    return NULL;
}
```

```
    printf("x is %d\n”, _);
    return NULL;
}
```

Output:

```
x is 3
x is 2
```

Possible output: threads version, #3

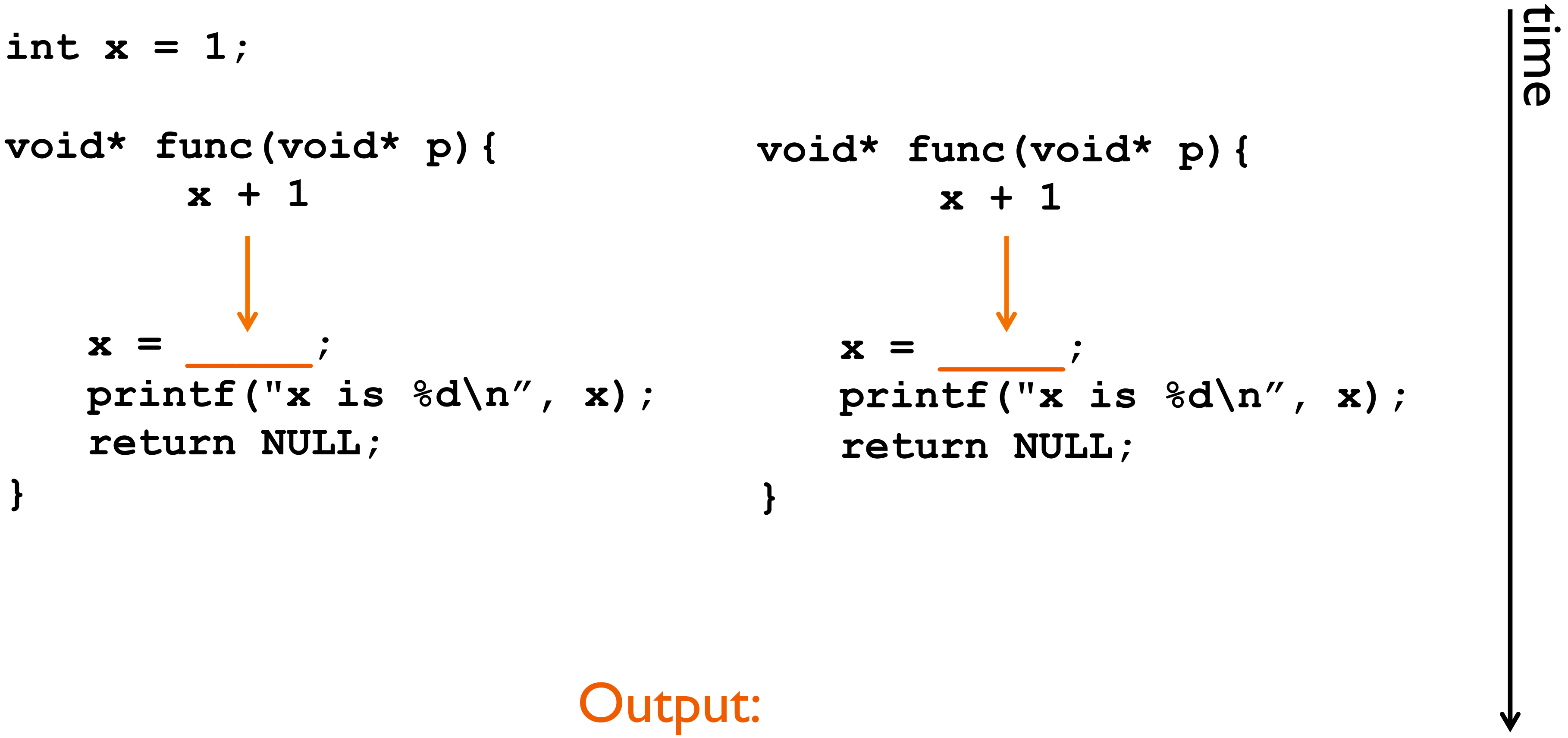
```
int x = 1;

void* func(void* p){
    x = x + 1;


    printf("x is %d\n”, x);
    return NULL;
}
```

```
void* func(void* p){

    x = x + 1;


    printf("x is %d\n”, x);
    return NULL;
}
```

Output:

```
x is 3
x is 3
```

Possible output: threads version, #4



```
int x = 1;

void* func(void* p){
       x + 1


    x = _____;
    printf("x is %d\n”, x);
    return NULL;
}
```

```
void* func(void* p){
       x + 1


    x = _____;
    printf("x is %d\n”, x);
    return NULL;
}
```

Output:

```
x is 2
x is 2
```

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
- Correct coding should not require knowledge of scheduling
  - Later: How to accomplish that

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 the child threads to terminate
  - Joinable
    - Main thread waits for the child thread to terminate
    - Useful if child thread returns a value

pthreads Attributes

Initialize an attributes structure to the default values

- **`int pthread_attr_init (pthread_attr_t* attr);`**

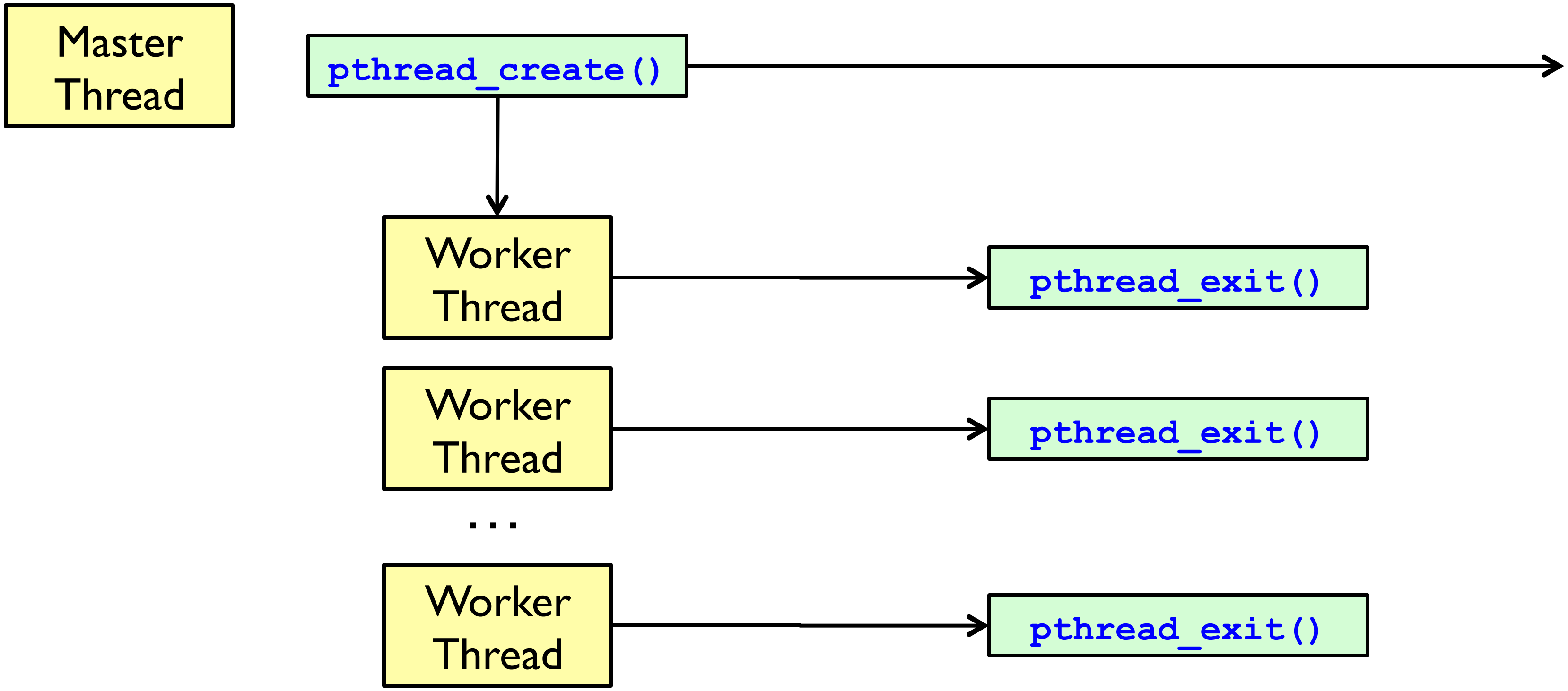
Set the detached state value in an attributes structure

- **`int pthread_attr_setdetachstate (pthread_attr_t* attr, int value);`**
- **`value`** is one of
  - PTHREAD_CREATE_DETACHED (“zombie antidote”)
  - PTHREAD_CREATE_JOINABLE

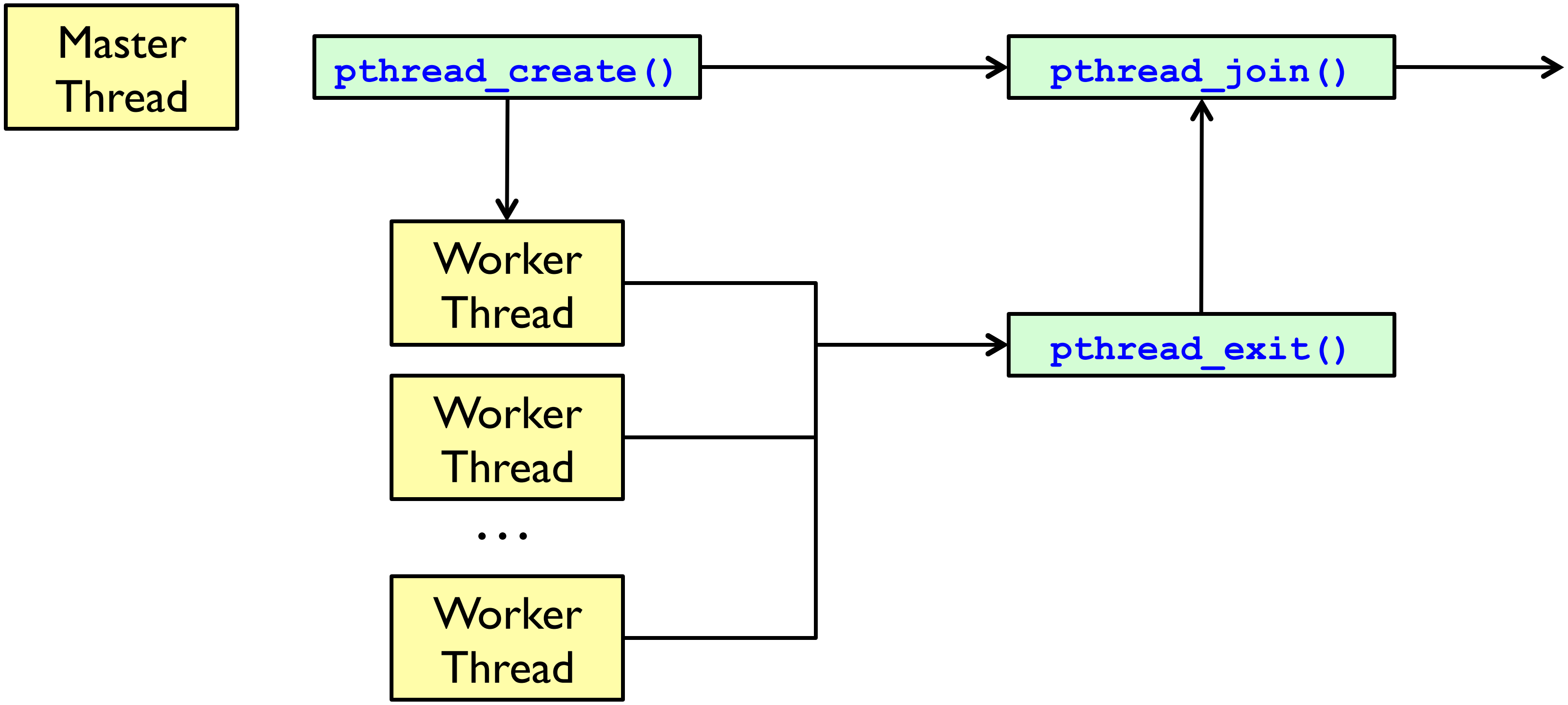
Can change your mind later

- joinable to detached via **`pthread_detach()`**
- but, nothing to go from detached to joinable

Detached Threads



Joined Threads



Master Thread

`pthread_create()`

`pthread_join()`

Worker Thread

Worker Thread

. . .

Worker Thread

`pthread_exit()`

Waiting for Threads: pthread_join()

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

Suspends calling thread until target thread terminates

Returns

- 0 on success
- Error code on failure

Parameters

- **`thread`**: Target thread identifier
- **`retval`**: Value passed to **`pthread_exit()`** by the terminating thread is made available in the location referenced by **`retval`**

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 and return value

Set `pthread_attr` to joinable before creating thread

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

Returning data via pthread_join()

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

int main() {
   int i;
   pthread_t tid;

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

What is missing?

Returning data via pthread_join()

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

int main() {
    int i;
    pthread_t tid;

   /* Initialize and set thread detached attribute */
   pthread_attr_t attr;
   pthread_attr_init(&attr);
   pthread_attr_setdetachstate(&attr,
      PTHREAD_CREATE_JOINABLE);

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

Terminating Threads: pthread_exit()

```
int pthread_exit(void * retval);
```

Terminate the calling thread

Makes the value **`retval`** available to any successful join with the terminating thread

Returns

- **`pthread_exit()`** cannot return to its caller

Parameters

- **`retval`**: Pointer to data returned to joining thread

Note

- If **`main()`** exits before its threads via **`pthread_exit()`**, the other threads continue. Otherwise, they will be terminated when **`main()`** ends.

Termination example

```
#include <pthread.h>
#define NUM_THREADS 5


void *PrintHello(void *threadid) {
   printf("\n%d: Hello World!\n", threadid);
   pthread_exit(NULL);
}
```

Termination example

```
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, f, (void *)t);
      if (rc) {
         printf("ERROR; pthread_create() return code is %d\n”,
                rc);
         exit(-1);
      }
   }
}
```

Will all threads get a chance to execute?

```
pthread_exit(NULL);
```

Termination example

```
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, f, (void *)t);
        if (rc) {
            printf("ERROR; pthread_create() return code is %d\n”,
                   rc);
            exit(-1);
        }

    pthread_exit(NULL);
    }
}
```

Will all threads get a chance to execute before the parent exits?

```
for(t=0;t < NUM_THREADS;t++) {
    pthread_join(thread[t], NULL);
    printf(“Joined thread %d\n”,t);
}
```

pthread Error Handling

pthreads functions do not follow the usual Unix conventions

- Similarity
  - Returns 0 on success
- Differences
  - Returns error code on failure
  - Does not set errno
- What about errno?
  - Each thread has its own
  - Define _REENTRANT (-D_REENTRANT switch to compiler) when using pthreads

Thread Lifetime

A thread exists until...

- It returns from the function or calls pthread_exit()
- The whole process terminates
- The machine catches fire

So, your process terminates when…

Any thread calls exit();

The main thread returns

-
  ```
  main() {
    pthread_create();
    return 0;
  }
  ```

Segmentation fault

- `*(char*)0 = 0;`

There are no more threads left to run

Main points

A thread is the lightest unit of work that can be scheduled to run on the processor

To create a thread you

- Indicate which function the thread should execute
- Indicate the detach state of the thread

When a new thread is created

- It runs concurrently with the creating thread
- It shares common data space

Reference slides

Threads vs. Processes

Property	Processes created with fork	Threads of a process	Ordinary function calls
variables	Get copies of all variables	Share global variables	Share global variables
IDs	Get new process IDs	Share the same process ID but have unique thread ID	Share the same process ID (and thread ID)
Data/control	Must communicate explicitly, e.g., use pipes or small integer return value	May communicate with return value or carefully shared variables	May communicate with return value or shared variables
Parallelism (one CPU)	Concurrent	Concurrent	Sequential
Parallelism (multiple CPUs)	May be executed simultaneously	Kernel threads may be executed simultaneously	Sequential

Getting the current thread ID

You can retrieve the current thread ID

- pthread_t pthread_self(void);
- Returns currently executing thread’s ID