Motivation

- Most modern applications are multithreaded
- Threads run within ~~application~~ a process
- Multiple tasks with the application can be implemented by separate threads
  - Update display
  - Fetch data
  - Spell checking
  - Answer a network request

Motivation

Motivation

- Process creation is heavy-weight while thread creation is light-weight
- Can simplify code, increase efficiency
- Kernels are generally multithreaded

Processes Vs. Threads

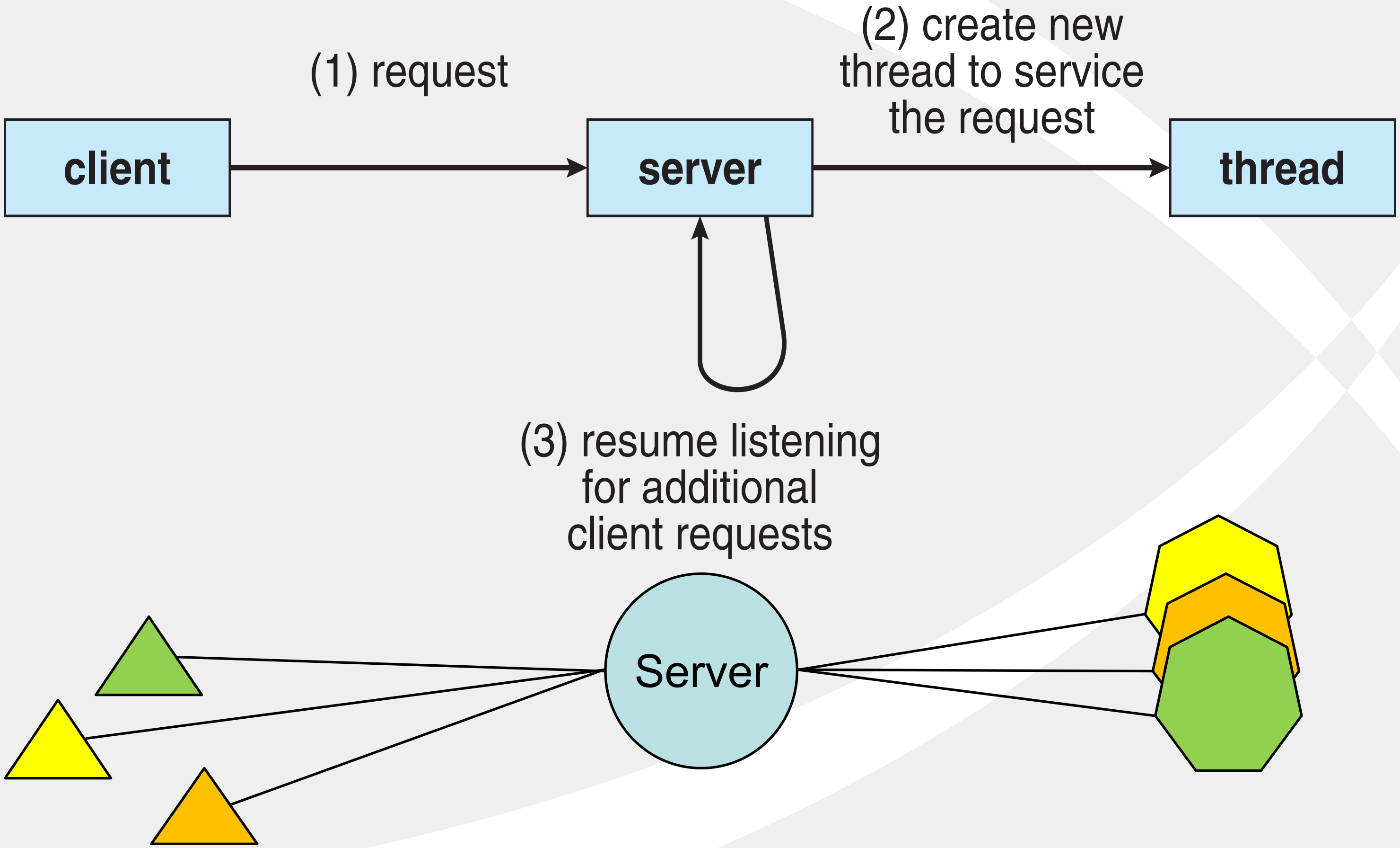
Processes

- Create a new address space at creation
- Allocate resources at creation
- Need IPC to share data
- Deeper isolation for security and fault tolerance

Threads

- Same address space
- Quicker creation times – actual times depend on kernel versus user threads
- Sharing through shared memory
- Fault sharing between all threads within a process

Multithreaded Server Architecture



Benefits

- **Responsiveness –** may allow continued execution if part of process is blocked, especially important for user interfaces
- **Resource Sharing –** threads share resources of process, easier than shared memory or message passing
- **Economy –** cheaper than process creation, thread switching lower overhead than context switching
- **Scalability –** process can take advantage of multiprocessor architectures

Multicore Programming

- **Multicore** or **multiprocessor** systems putting pressure on programmers, challenges include:
  - **Dividing activities**
  - **Balance**
  - **Data splitting**
  - **Data dependency**
  - **Testing and debugging**

Multicore Programming

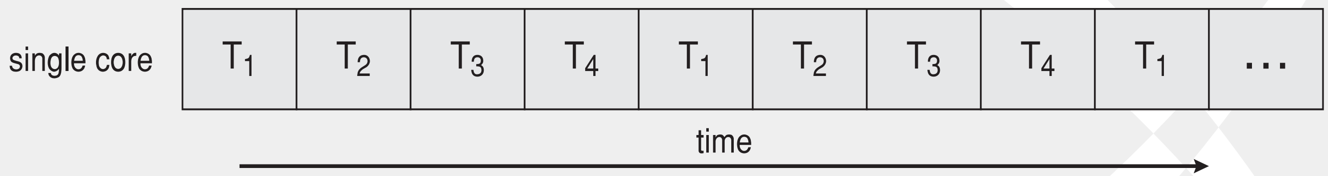
- ***Parallelism*** implies a system can perform more than one task simultaneously
- ***Concurrency*** supports more than one task making progress
  - Single processor / core, scheduler providing concurrency

Multicore Programming…

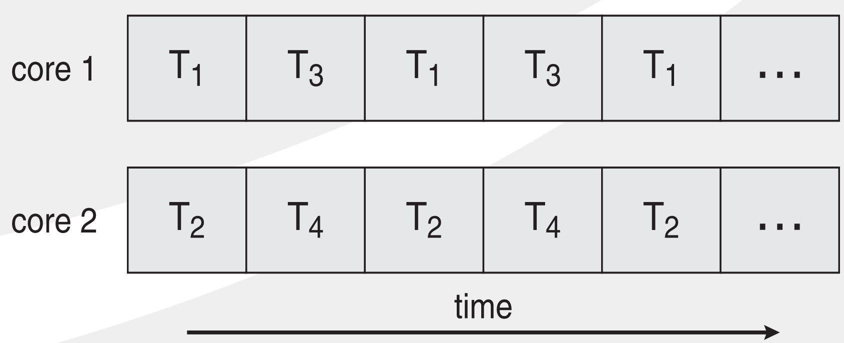
- Types of parallelism
  - **Data parallelism** – distributes subsets of the same data across multiple cores, same operation on each
  - **Task parallelism** – distributing threads across cores, each thread performing unique operation

Concurrency vs. Parallelism

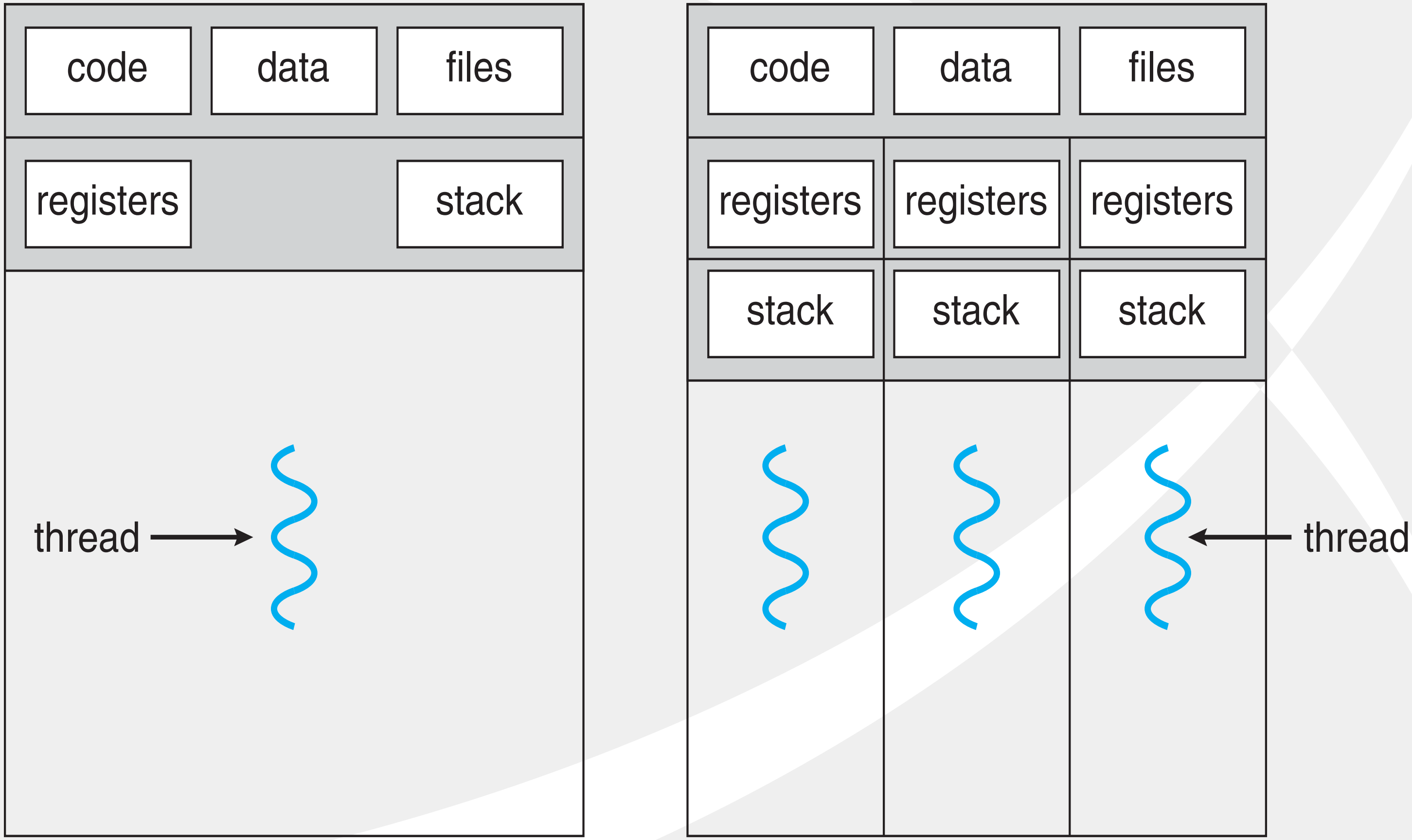
- Concurrent execution on single-core system:



- Parallelism on a multi-core system:



Single and Multithreaded Processes



single-threaded process

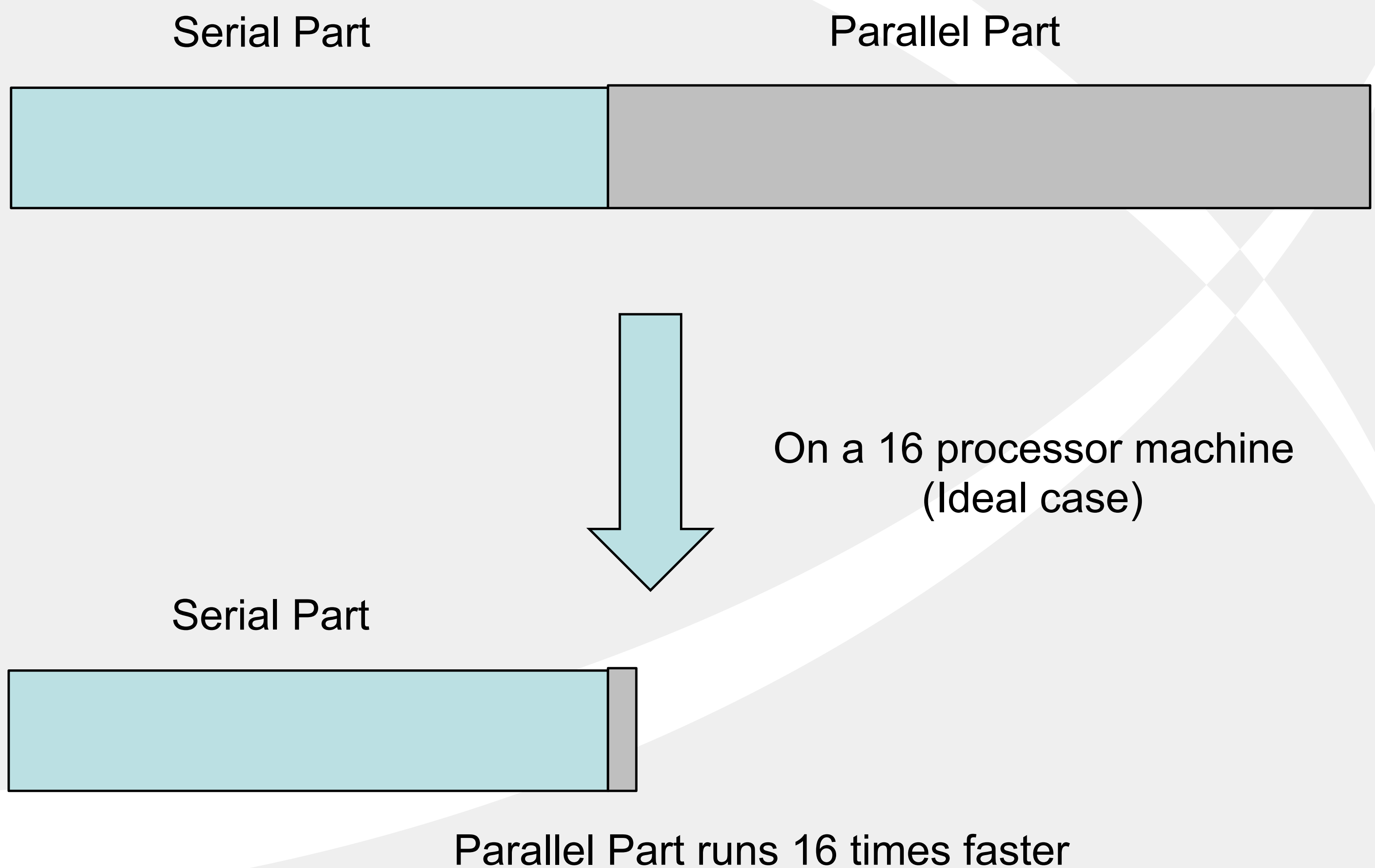
multithreaded process

Amdahl's Law

- Identifies performance gains from adding additional cores to an application that has both serial and parallel components
- *S* is serial portion
- *N* processing cores

$$speedup \le \frac{1}{S + \frac{(1-S)}{N}}$$

Amdhal's Law…


Serial Part
Parallel Part
On a 16 processor machine
(Ideal case)
Serial Part
Parallel Part runs 16 times faster

Amdahl's Law…

Serial time = T
Parallel time = (0.75/2 + .25)T

Speedup = 1/(0.375 + 0.25)
= 1.6

- That is, if application serial, moving from 1 speedup of 1.6 times
- As *N* approaches infinity, speedup approaches 1 / *S*

Resulting improvement from an enhancement is "limited" by the fraction of the task that can be improved

User vs. Kernel Threads

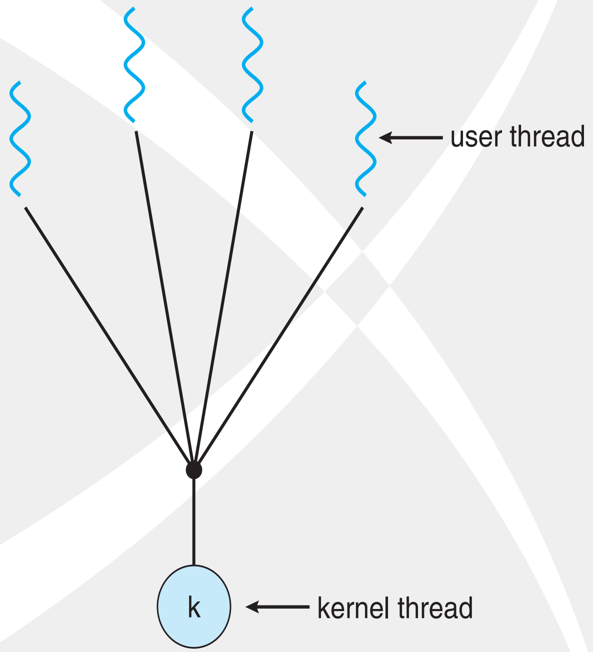
- **User threads** - management done by user-level threads library
- Three primary thread libraries:
  - POSIX **Pthreads**
  - Windows threads
  - Java threads
- **Kernel threads** - Supported by the Kernel
- Examples – virtually all general purpose operating systems, including: Windows, Solaris, Linux

Multithreading Models

- Many-to-One
- One-to-One
- Many-to-Many

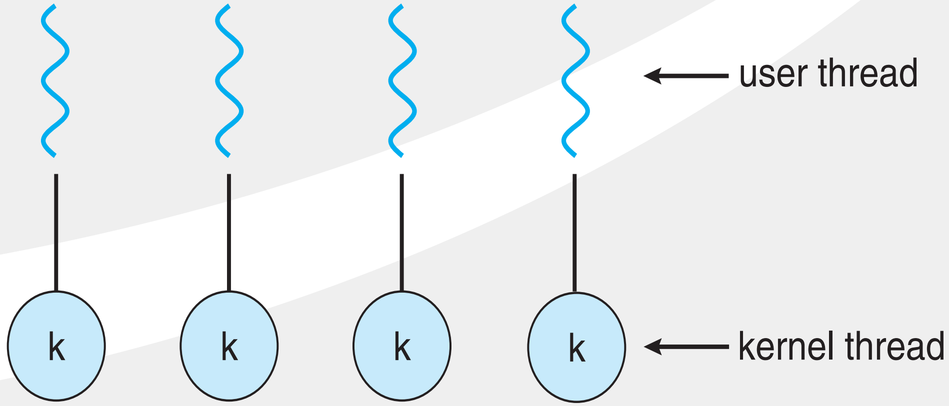
Many-to-One

- Many user-level threads mapped to single kernel thread
- One thread blocking causes all to block
- Multiple threads may not run in parallel on multicore system because only one may be in kernel at a time
- Few systems currently use this model
- Examples: **Solaris Green Threads, GNU Portable Threads**



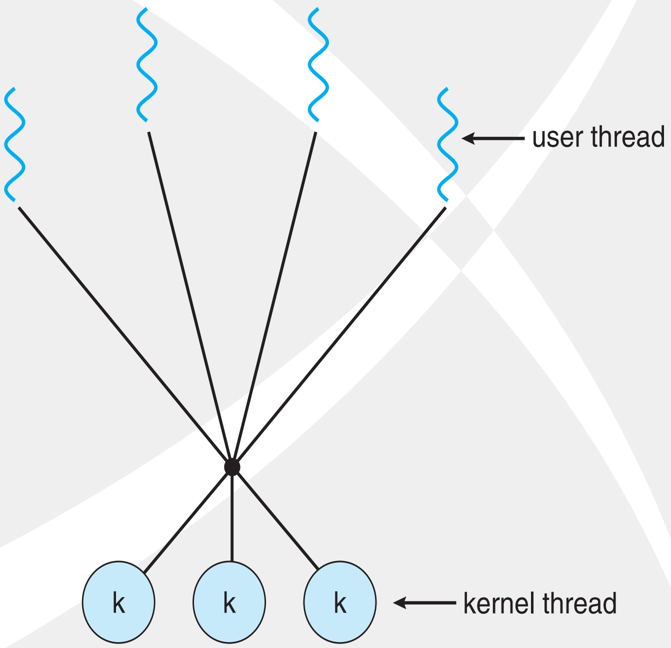
One-to-One

- Each user-level thread maps to kernel thread
- Creating a user-level thread creates a kernel thread
- More concurrency than many-to-one
- Number of threads per process sometimes restricted due to overhead
- Examples: **Windows, Linux, Solaris 9 and later**



Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads
- Allows the operating system to create a sufficient number of kernel threads
- Solaris prior to version 9
- Windows with the *ThreadFiber* package

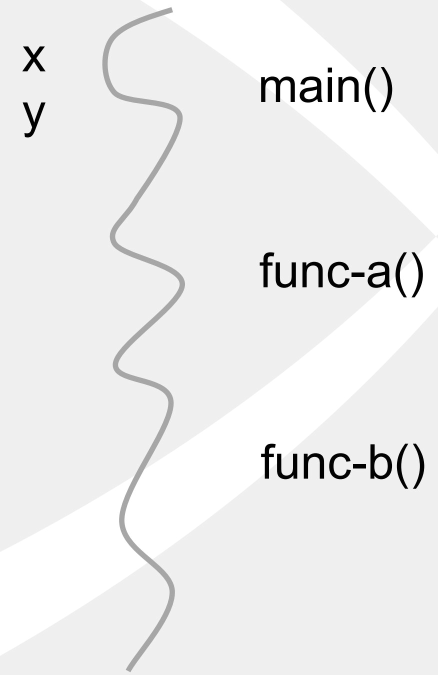


Thread Libraries

- **Thread library** provides programmer with API for creating and managing threads
- Two primary ways of implementing
  - Library entirely in user space
  - Kernel-level library supported by the OS

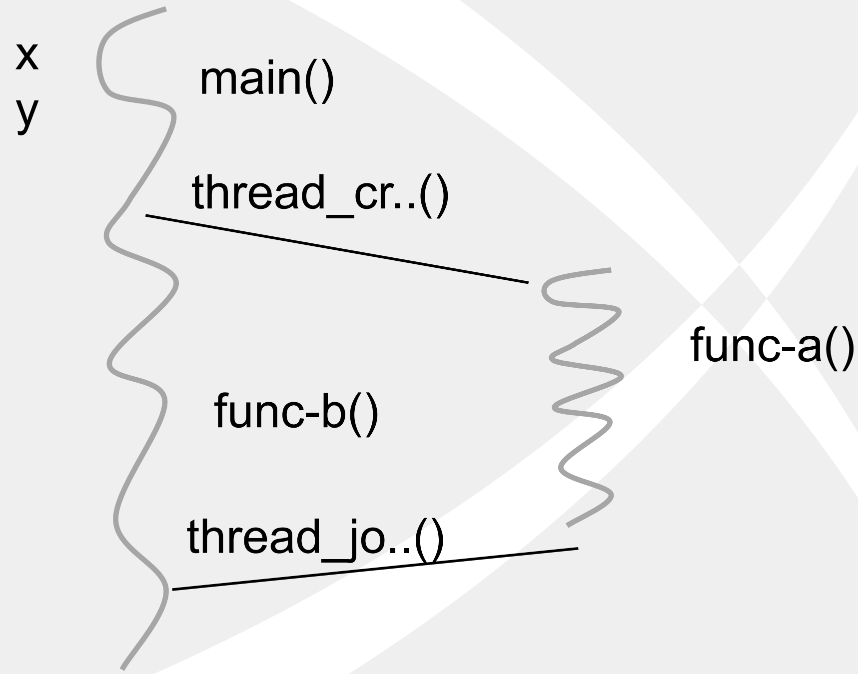
Threads: Concept

```
int x = 10;
int y = 20;

void func-a() {
        x = x +10;
        y = y – 10;
}

func-b() {
        printf(“a = %d”, a);
        printf(“b = %d\n”, b);
}

main() {
        func-a();
        func-b();
}
```



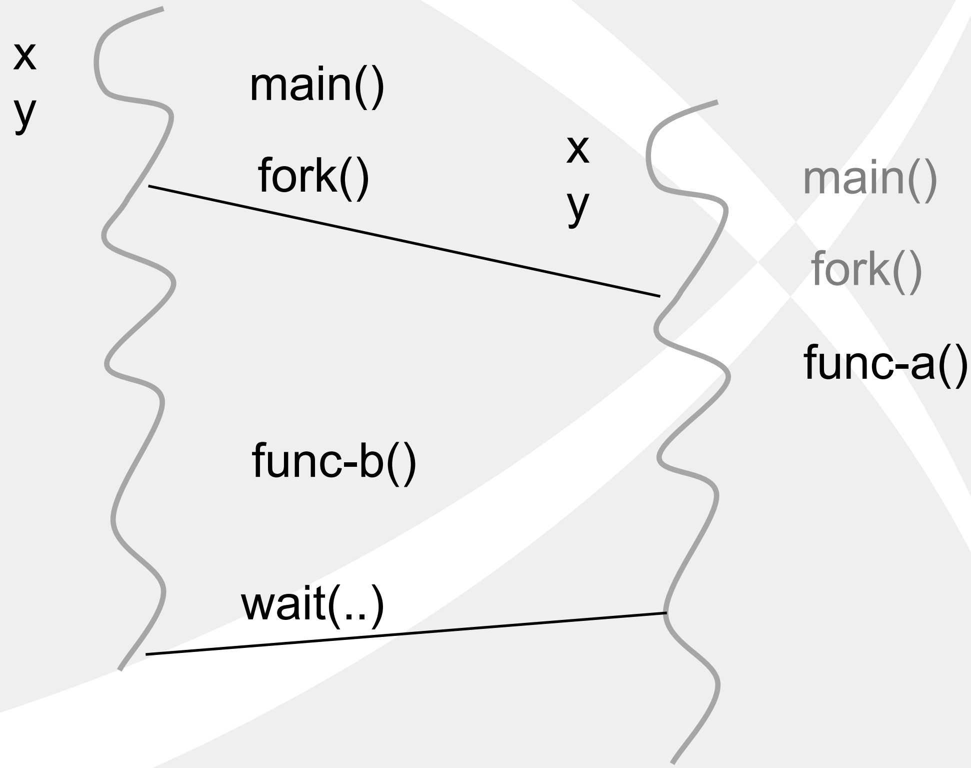
Threads: Concept

```
int x = 10;
int y = 20;

void func-a() {
        x = x +10;
        y = y – 10;
}

func-b() {
        printf(“a = %d”, a);
        printf(“b = %d\n”, b);
}

main() {
        thread_create_and_start(func-a());
        func-b();
        thread_join()
}
```



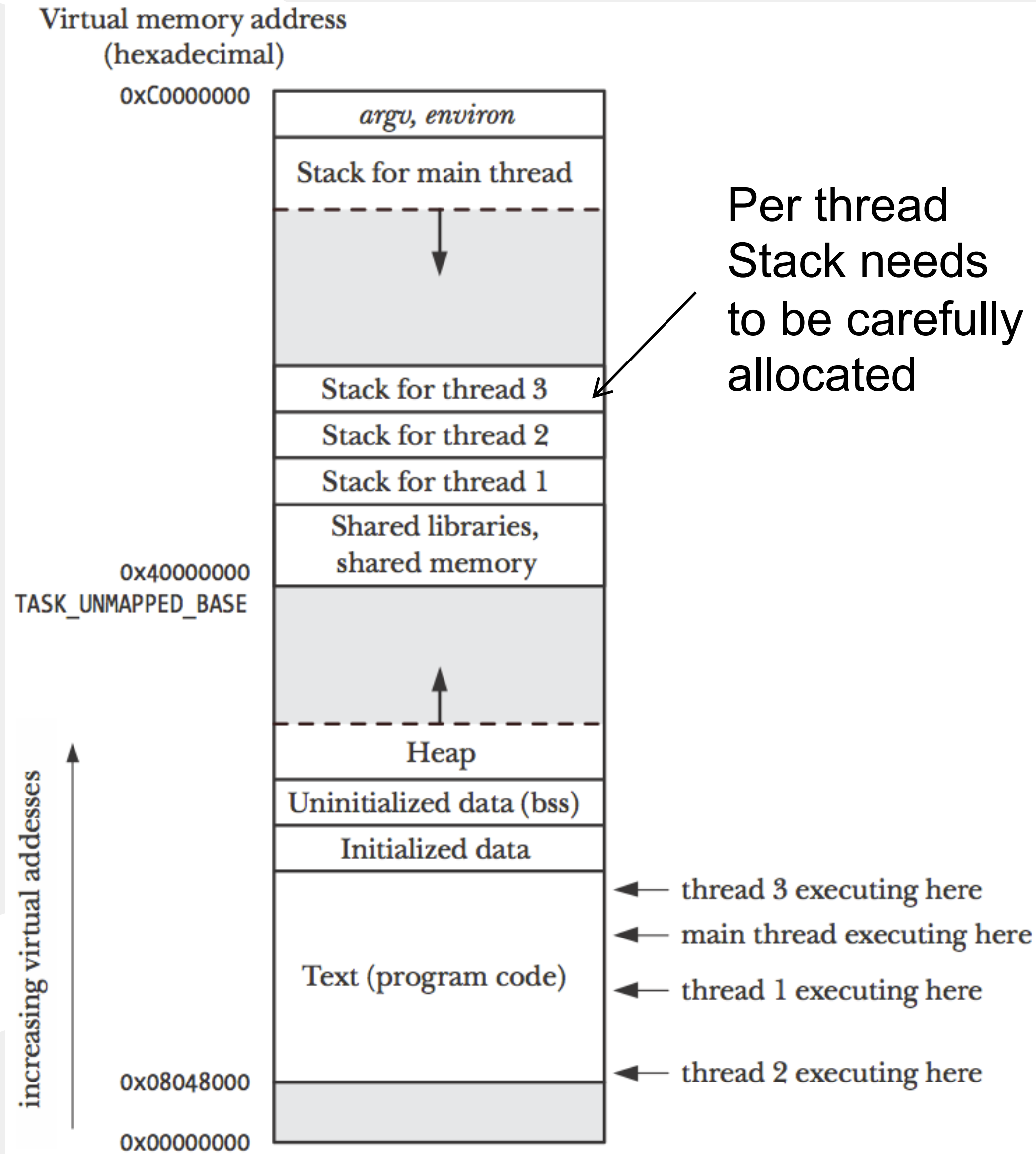
Threads versus Processes

```
int x = 10;
int y = 20;

void func-a() {
        x = x +10;
        y = y – 10;
}

func-b() {
        printf(“a = %d”, a);
        printf(“b = %d\n”, b);
}

main() {
        if (fork() == 0) func-a();
        func-b();
        wait(..)
}
```



Threads in Linux

- Four threads executing in Linux
  - Kernel level threads
  - Threads have specific stacks – thread local storage



Per thread Stack needs to be carefully allocated

Pthreads

- May be provided either as user-level or kernel-level
- A POSIX standard (IEEE 1003.1c) API for thread creation and synchronization
- ***Specification***, not ***implementation***
- API specifies behavior of the thread library, implementation is up to development of the library
- Common in UNIX operating systems (Solaris, Linux, Mac OS X)

Pthread Creation

- Process has the *main* thread at the beginning

```
#include <pthread.h>

int pthread_create(pthread_t *thread, const pthread_attr_t *attr,
                   void *(*start)(void *), void *arg);
```

Returns 0 on success, or a positive error number on error

- New thread continues with start() and main continues with the statement after

Pthread Termination

- A thread terminates for the following:
  - The start() function performs a return
  - Thread calls a pthread_exit() function
  - Thread is cancelled using pthread_cancel()
  - Any thread calls exit() or main thread returns

```
include <pthread.h>

void pthread_exit(void *retval);
```

Identities of Threads

- Each thread is uniquely identified by an ID
  - returned to the caller of pthread_create()
  - thread can obtain own ID using pthread_self()

```
include <pthread.h>

pthread_t pthread_self(void);
```

Returns the thread ID of the calling thread

- IDs allow checking if two threads are same

```
include <pthread.h>

int pthread_equal(pthread_t t1, pthread_t t2);
```

Returns nonzero value if *t1* and *t2* are equal, otherwise 0

Joining a Terminated Thread

- A thread can wait for another thread using the pthread_join() function

```
include <pthread.h>

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

Returns 0 on success, or a positive error number

- If a created thread is not *detached*, we ***must join*** with it, otherwise "zombie" thread will be created

Pthread Example

```
#include <pthread.h>
#include "tlpi_hdr.h"

static void *
threadFunc(void *arg)
{
    char *s = (char *) arg;

    printf("%s", s);

    return (void *) strlen(s);
}

int
main(int argc, char *argv[])
{
    pthread_t t1;
    void *res;
    int s;

    s = pthread_create(&t1, NULL, threadFunc, "Hello world\n");
    if (s != 0)
        errExitEN(s, "pthread_create");

    printf("Message from main()\n");
    s = pthread_join(t1, &res);
    if (s != 0)
        errExitEN(s, "pthread_join");

    printf("Thread returned %ld\n", (long) res);

    exit(EXIT_SUCCESS);
}
```

Detaching a Thread

- Default – a thread is joinable – another thread is going to retrieve the return state
- If no thread is interested in joining we need to detach the thread

```
#include <pthread.h>

int pthread_detach(pthread_t thread);
```

Returns 0 on success, or a positive error number

- It is not possible to join to a detached thread

Thread Attributes

- Attributes can be used to set properties of threads – such as detached

```
pthread_t thr;
pthread_attr_t attr;
int s;

s = pthread_attr_init(&attr);               /* Assigns default values */
if (s != 0)
    errExitEN(s, "pthread_attr_init");

s = pthread_attr_setdetachstate(&attr, PTHREAD_CREATE_DETACHED);
if (s != 0)
    errExitEN(s, "pthread_attr_setdetachstate");

s = pthread_create(&thr, &attr, threadFunc, (void *) 1);
if (s != 0)
    errExitEN(s, "pthread_create");
```

Protecting Shared Variables

- Advantage of threads – can share via global variables
- Must ensure multiple threads are not modifying the variables at the same time
- Use a pthread_mutex variable

```
#include <pthread.h>

int pthread_mutex_lock(pthread_mutex_t *mutex);
int pthread_mutex_unlock(pthread_mutex_t *mutex);
```

Both return 0 on success, or a positive error number

Example Program

```
#include <pthread.h>
#include "tlpi_hdr.h"

static int glob = 0;
static pthread_mutex_t mtx = PTHREAD_MUTEX_INITIALIZER;

static void *                    /* Loop 'arg' times increr
threadFunc(void *arg)
{
    int loops = *((int *) arg);
    int loc, j, s;

    for (j = 0; j < loops; j++) {
        s = pthread_mutex_lock(&mtx);
        if (s != 0)
            errExitEN(s, "pthread_mutex_lock");

        loc = glob;
        loc++;
        glob = loc;

        s = pthread_mutex_unlock(&mtx);
        if (s != 0)
            errExitEN(s, "pthread_mutex_unlock");
    }

    return NULL;
}
```

```
int
main(int argc, char *argv[])
{
    pthread_t t1, t2;
    int loops, s;

    loops = (argc > 1) ? getInt(argv[1], GN_GT_0, "num-loops")

    s = pthread_create(&t1, NULL, threadFunc, &loops);
    if (s != 0)
        errExitEN(s, "pthread_create");
    s = pthread_create(&t2, NULL, threadFunc, &loops);
    if (s != 0)
        errExitEN(s, "pthread_create");

    s = pthread_join(t1, NULL);
    if (s != 0)
        errExitEN(s, "pthread_join");
    s = pthread_join(t2, NULL);
    if (s != 0)
        errExitEN(s, "pthread_join");

    printf("glob = %d\n", glob);
    exit(EXIT_SUCCESS);
}
```

Thread Cancellation

- Terminating a thread before it has finished
- Thread to be canceled is **target thread**
- Two general approaches:
  - **Asynchronous cancellation** terminates the target thread immediately
  - **Deferred cancellation** allows the target thread to periodically check if it should be cancelled
- Pthread code to create and cancel a thread:

```
pthread_t tid;

/* create the thread */
pthread_create(&tid, 0, worker, NULL);

. . .

/* cancel the thread */
pthread_cancel(tid);
```

Thread Cancellation…

- Invoking thread cancellation requests cancellation, but actual cancellation depends on thread state

Mode	State	Type
Off	Disabled	–
Deferred	Enabled	Deferred
Asynchronous	Enabled	Asynchronous

- If thread has cancellation disabled, cancellation remains pending until thread enables it

Thread Cancellation…

- Default type is deferred
  - Cancellation only occurs when thread reaches **cancellation point**
    - I.e. `pthread_testcancel()`
    - Then **cleanup handler** is invoked
- On Linux systems, thread cancellation is handled through signals