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Systems Programming – Part 2
Concurrent Systems Programming

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Topics of Part 2 of SP(GA)

- **Intro to Concurrency (with Processes and Threads)**
  - **Intro to POSIX Threads**
- Process/Thread Synchronisation
- More on Process Management (from an OS Perspective)
- Concurrency Beyond Threads & Limits of Scalability
- Virtual Memory & Levels of Storage

Intro to POSIX Threads

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Thread Implementations

- There are thread implementations in almost all programming languages; we will look at the C **pthread** library

- Many threading implementations are conceptually quite similar, and realise a particular thread lifecycle:
  - A thread is **created**: starts executing a specified function, with some arguments, and is given an identifier
  - A thread can **wait** for another thread to terminate
  - A thread can **cancel** another thread
  - A thread **terminates** either by calling exit or when its main function ends
  - **Communication** between threads happens through modifying the state of **shared variables**

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POSIX Threads

- Part of the **POSIX specification** collection, defining an API for thread creation and management (***pthread.h***)
- Implementations for all **Unix-alike operating systems** available
  - Utilization of kernel- or user-mode threads depends on implementation
- Groups of functionality (pthread_ function prefix)
  - **Thread management**: Start, wait for termination, ...
  - **Synchronization means**: Mutexes, condition variables, read/write locks, barriers
- Semaphore API is a separate POSIX specification (sem_ prefix)

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POSIX Threads

- POSIX Threads is the most used threading implementation for C
- To use it we need to *#include <pthread.h>* and specify a compiler flag (*–lpthread)*

```c
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>
#include <assert.h>

void * PrintHelloWorld(void*) {
  printf("Hello World from a thread!\n");
  return NULL;
}
```

```c
int main() {
  pthread_t thread;
  int error = pthread_create(&thread,
    NULL, PrintHelloWorld, NULL);
  assert(error == 0);
  printf("Created thread\n");
  error = pthread_join(thread, NULL);
  assert(error == 0);
}

clang -Wall -Werror program.c -lpthread -o program
```

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POSIX Threads

- *pthread_create()*
  - Create a new thread in the same process, with a given routine and argument

- *pthread_exit(), pthread_cancel()*
  - Terminate a thread from inside (→ exit) or outside (→ cancel) of the thread

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Creating POSIX Threads

- Threads are created with the *pthread_create* function

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

- It takes four arguments:
  1. **A thread** identifier, which is a pointer to a memory location of type *pthread_t*
  2. Thread attributes which set properties such as scheduling policies or stack size (and passing *NULL* results in default attributes)
  3. A **function pointer** to the ***start_routine***
     This function takes a single argument of type *void** and returns a value of type *void**
  4. The **argument** that is passed **to *start_routine*** *(a pointer)*
- It returns 0 if the thread is created successfully or, else, a non-zero error code
- **Passing pointers to and from start_routine allows the passing of arbitrary data**
- It requires care to ensure that the memory locations pointed to have appropriate lifetimes

Passing an argument to a thread

```c
#include <pthread.h>
#include <stdio.h>
#include <stdlib.h>
#define NUM_THREADS 5

void *PrintHello(void *threadid)
{
  long tid;
  tid = (long)threadid;
  printf("Hello World! It's me, thread #%ld!\n", tid);
  pthread_exit(NULL);
}

int main(int argc, char *argv[])
{
  pthread_t threads[NUM_THREADS];
  int rc;
  long t;
  for(t=0;t<NUM_THREADS;t++){
    printf("In main: creating thread %ld\n", t);
    rc = pthread_create(&threads[t], NULL, PrintHello, (void *)t);
    if (rc){
      printf("ERROR; return code from pthread_create() is %d\n", rc);
      exit(-1);
    }
  }
  pthread_exit(NULL);
}
```

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Waiting for Other Threads

- *pthread_join()*
  - Blocks the caller until the specified thread terminates
  - Only one joining thread per target is allowed
  - If the thread gave an exit code to *pthread_exit()*, it can be determined here

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Waiting for Other Threads

- To wait for another thread to terminate we use *pthread_join*

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

- It takes two arguments:
  1. A thread identifier (the thread we want to wait for)
  2. A **pointer** to a **memory location** of type void*

     The return value of the *start_routine* (== a generic pointer), as passed to *pthread_create,* will be copied to this location

- It returns 0 on success and, otherwise, a non-zero error code

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Waiting for Another Thread

- Example of returning a single int value from a thread:

```
int* return_value;

int error = pthread_join(thread, (void**)&return_value);

assert(error == 0);

if (return_value) {
  printf("return_value: \n", *return_value);
}

// maybe: free(return_value);
```

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Waiting for Another Thread

```
void *thread_func(void *args) {
  /* ... */

  /* Allocate heap space for this thread's results */
  struct results *results = calloc(sizeof (struct results), 1);

  /* ... populate results struct ... */

  /* Return the pointer to results */
  pthread_exit(results);
}
```

```
struct results *results;

int error = pthread_join(thread, (void**)&results);

assert(error == 0);

/* make use of results, but then also free(results)
at some point */
```

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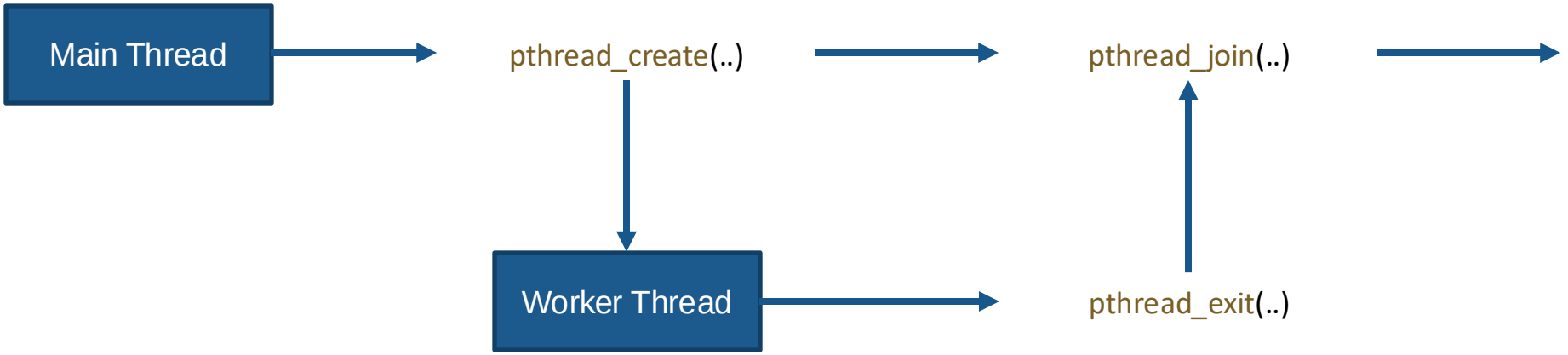
Forking and Joining Threads



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To Do Now

Completing this activity will support your understanding of the material today (before we have real lab time tomorrow!)

In the "Lecture 2.2 files" folder on Moodle

- Review the code for *pthread_hello_world.c*
- Compile it and run it – don't forget the "-lpthread" flag for clang (see Slide 5 for an example)
- Add another print statement "Last thread about to die" just before the main thread terminates

(Optional) Recommended Reading

- Blaise Barney, Lawrence Livermore National Laboratory, UCRL-MI-133316, POSIX Threads Programming, https://hpc-tutorials.llnl.gov/posix/, Section 5 for today and later Section 7

- Videos
  - Programming with Threads, Jacob Sorber, https://www.youtube.com/playlist?list=PL9IEJIKnBJjFZxuqyJ9JqVYmuFZHr7CFM
  - Unix Threads in C, CodeVault, https://www.youtube.com/playlist?list=PLfqABt5AS4FmuQf70psXrsMLEDQXNkLq2