Pthreads Basics

Parallel Computing

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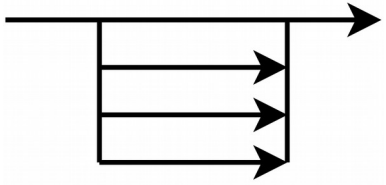
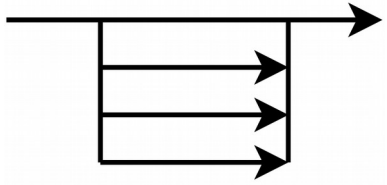




POSIX Threads

POSIX: Portable Operating System Interface

- IEEE standards defining API of software for UNIX-like operating systems

POSIX threads (Pthreads)

- standard approved 1995, amendments
- functions for
  - creating threads
  - synchronizing threads
  - thread interaction
- *opaque* data types for
  - thread identifiers
  - synchronization constructs
  - attributes
  - ...
- header file `pthread.h`
- compilation: `gcc -pthread -o prog prog.c`

References:

- D. R. Butenhof, *Programming with POSIX Threads*, Addison-Wesley, 1997
- http://opengroup.org/onlinepubs/007908799/xsh/pthread.h.html

(P)Threads in Linux

How can a thread-library be implemented?

Abstraction levels:

- threads: created by a user program
- kernel entity: “process”, scheduled by operating system
- processor: physical device, gets assigned kernel entities by scheduler

Design decision: how to map threads to kernel entities?

M-to-1:

- all threads of process mapped to one kernel entity
- fast scheduling (in library), but no parallelism

M-to-N:

- threads of process mapped to different kernel entities
- two-level scheduling (library and kernel) incurs overhead, but allows parallelism

1-to-1:

- each thread mapped to one kernel entity
- scheduling in kernel, less overhead than in M-to-N case, allows parallelism
- used in most modern Linux systems: *Native POSIX Threads Library (NPTL)*

Pthread Lifecycle: States

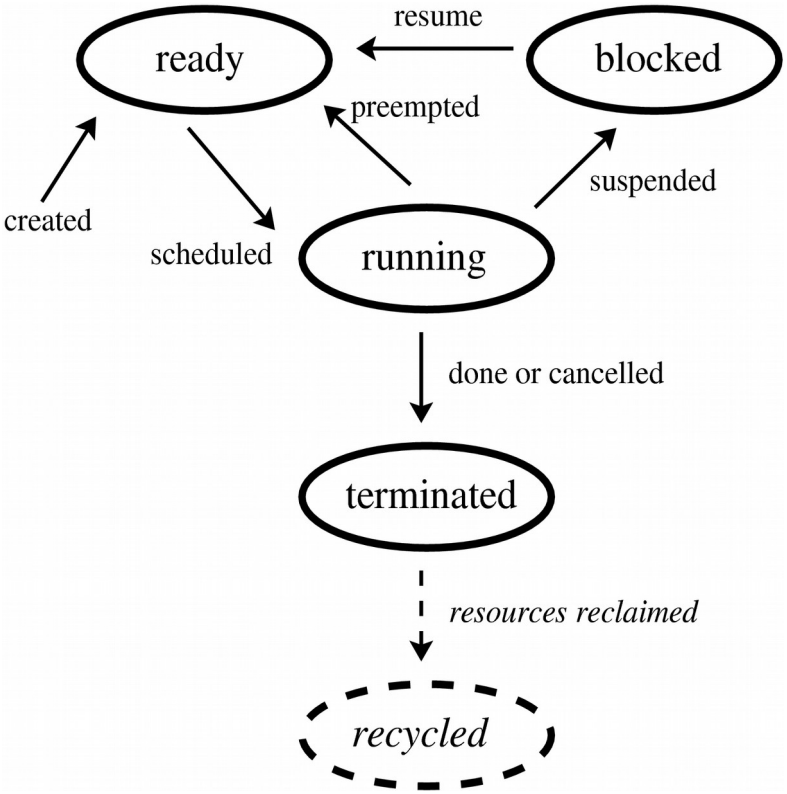
Ready
- able to run, waiting for processor

Running
- on multiprocessor possibly more than one at a time

Blocked
- thread is waiting for a shared resource

Terminated
- system resources partially released
- but not yet fully cleaned up
  - thread's own memory is obsolete
  - can still return value

(Recycled)
- all system resources fully cleaned up
- controlled by the operating system



Pthread Creation

`int pthread_create(arg0, arg1, arg2, arg3)`

- `arg0: pthread_t *tid_ptr`
  - where to store thread ID of type `pthread_t`
- `arg1: const pthread_att_t *attr`
  - may set certain attributes at startup
  - ignored for the moment: always pass `NULL` → set default attributes
- `arg2: void *(*start)(void *)`
  - pointer to thread's startup function
  - takes exactly one `void*` as argument
- `arg3: void *arg`
  - actual parameter of thread's startup function
- returns zero on success, else error code

thread ID is stored in `*tid_ptr`

- `pthread_t pthread_self()` returns ID of current thread
- `int pthread_equal(pthread_t tid1, pthread_t tid2)` compares IDs

Example: `helloworld`

`main`-Thread

Process creates thread which executes `main`-function → "`main`-thread"

`main`-thread behaves slightly differently from ordinary threads:

- termination of `main`-thread by returning from `main` causes process to terminate
  - all threads of process terminate
  - Example: `helloworld`
- calling `pthread_exit(...)` in `main`-thread causes process to continue
  - all created threads continue
  - recall lifecycle: `main`-thread terminates → resources partially released
    - Attention: stack may be released!
  - memory errors: dereferencing pointers into `main`-thread's (released) stack
  - Example: `helloworld_buggy`

Pthread Termination

generally: thread terminates if startup function returns

`int pthread_exit(void *value_ptr)`

- causes thread to terminate (special semantics in `main`-thread)
- implicitly called if thread's startup function returns (except in `main`-thread)
- `value_ptr` is the thread's return value (see `pthread_join(...)`)

`int pthread_detach(pthread_t tid)`

- resources of `tid` can be reclaimed after `tid` has terminated
- default: not detached
- any thread can detach any thread (including itself)

`int pthread_join(pthread_t tid, void **value)`

- returns when `tid` has terminated (or already terminated), caller blocks
- optionally stores `tid`'s return value in `*value`
  - return value from calling `pthread_exit(...)` or returning from startup function
- joined thread will be implicitly detached
- detached threads can not be joined

Pthread Termination - Examples

- Example: `helloworld_join`
- Returning values from threads
  - returning values from threads via `pthread_join(...)`
    - example: `returnval`
    - but: waiting for termination often not needed
    - good practice to release system resources as early as possible
  - alternative to `pthread_join(...)`: custom return mechanism
    - threads store their return values on the heap
    - Example: `returnval_heap`
      - problem: need to notify main-thread somehow that all threads have written results
  - error: joining a detached thread
    - resources are (may be or not) already released
    - join should fail
    - Example: `returnval_buggy`
  - error: returning pointer to local variable
    - Example: `returnval_buggy`

Pthread Lifecycle Revisited (1/2)

Creation

- process creation → `main`-thread creation
- `pthread_create(...)`: new threads are ready
  - no synchronization between `pthread_create(...)` and new thread's execution

Startup

- `main`-thread's `main` function called after process creation
- newly created threads execute startup function

Running

- ready threads are eligible to acquire processor → will be running
- scheduler assigns timeslice to ready thread → threads will be preempted
- switching threads → context (registers, stack, pc) must be saved

Blocking

- running threads may block, e.g. to wait for shared resource
- blocking threads become ready (not running) again

Pthread Lifecycle Revisited (2/2)

Termination

- generally: when thread returns from startup function
- `pthread_exit`
- can also explicitly be cancelled by `pthread_cancel(...)`
- (optional cleanup handlers are called)
- only thread's ID and return value remain valid, other resources might be released
- terminated threads can still be joined or detached
  - joined threads will be implicitly detached, i.e. all its system resources will be released

Recycling

- occurs immediately for terminated, detached threads → all resources released

Creating and Using Threads: Pitfalls

- Sharing pointers into stack memory of threads
  - perfectly alright, but handle with care
    - passing arguments
    - returning values
- Resources of terminated, non-detached threads can not fully be released
  - large number of threads → performance problems?
  - should join or detach threads
- Relying on the speed/order of individual threads
  - do not make any assumptions!
  - need mechanism to notify threads that certain conditions are true
    - example: `returnval_heap`
  - must prevent threads from modifying shared data concurrently
    - example: `sum`
- → Synchronization