ACM/CS 114
Parallel algorithms for scientific applications

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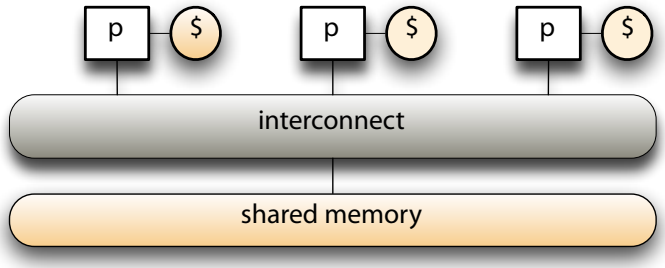
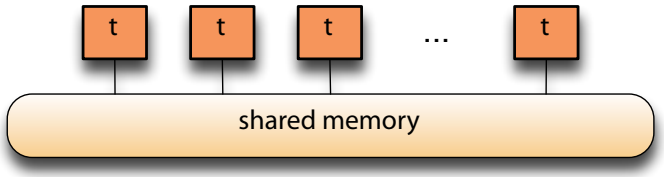
Threads and shared memory parallelism

- recall the shared memory architecture



  - processors are connected to a memory pool with a global address space
  - processors have their own cache but no private memory
- model is relevant for *threads*
  - lightweight processes that can be scheduled independently, but share many OS resources
    - CPU
    - memory
    - but also file descriptors, process environment, etc.
  - supported by most modern operating systems



Processes and threads

- in most operating systems, a process has
  - process id and group id, user id and group id
  - environment variables
  - working directory
  - scheduling information
  - registers, stack, heap, instruction stream
  - file descriptors, signal handlers, other process dependent structures
- threads
  - share many of the per-process properties
    - they are lightweight since they incur low overhead
  - have their own copy of
    - registers, stack, instruction stream
    - scheduling information
- threads are important programming constructs
  - every vendor supports a proprietary interface
  - *pthreads*, the POSIX standard API specification brought portability
  - standardized creation, management, synchronization

The pthreads API

- threads require support from the compiler, the linker, the loader, and the OS kernel
  - thread safety
- special command line argument to most compliant compilers
  - changes the instruction strategy
  - adds the pthread runtime library to the link line
  - links against the thread safe runtime
- naming conventions

Prefix	Functional group
`pthread_`	access to the threads, and some miscellaneous routines
`pthread_attr_`	thread attribute objects
`pthread_mutex_`	mutexes
`pthread_mutexattr_`	mutex attribute objects
`pthread_cond_`	condition variables
`pthread_condattr_`	condition variable attribute objects
`pthread_key_`	thread-specific data keys
`pthread_rwlock_`	read/write locks
`pthread_barrier_`	synchronization barriers

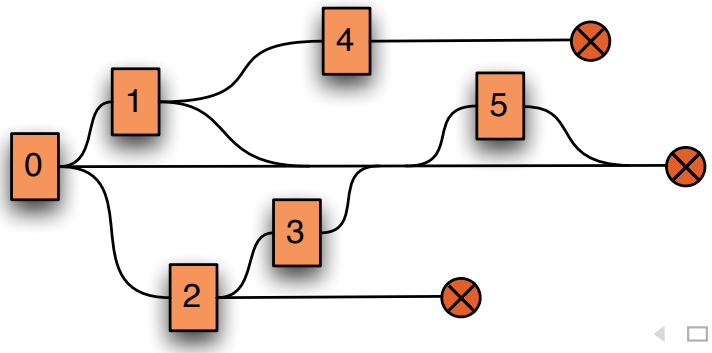
- the standard specifies the API for `C` only; `FORTRAN` support varies
  - must include `pthread.h`
- lots of good books; see **`http://acm114.caltech.edu/references`**

Creating threads

- create threads by calling

```
1 int pthread_create(
2    pthread_t* id, const pthread_attr_t* attr,
3    void* (*startup)(void*), void* arg);
```

- initially a process has one thread; every other thread must be explicitly created by calling `pthread_create` and passing
  - `id`: the location where a unique thread identifier will be stored
  - `attr`: an opaque attribute object with thread initialization options
  - `startup`: a pointer to a `C` function that will be executed by the thread once it gets scheduled
  - `arg`: user defined data to be passed to `startup`; may be `NULL`
- once scheduled, threads are first class citizens
- the maximum number of threads per process depends on the implementation



Terminating threads

- several ways to terminate a thread
  - the thread returns from `main`
  - the thread explicitly calls `pthread_exit`
  - the thread is killed when another thread calls `pthread_cancel`
  - the process terminates due to some system call, e.g. `exit`, `exec`, etc.
- use `pthread_exit` to kill a thread when it is no longer needed

```
1 int pthread_exit(void * status);
```

- if `main` finishes and any threads remain
  - they get killed unless `main` has called `pthread_exit`
  - otherwise they continue to run
- thread routines do not have to call `pthread_exit` unless they intend to pass their termination status to their creator
- `pthread_exit` does not perform any process cleanup: it doesn't flush/close files, release other resources, signal the process parent, etc.

Hello world

```
1  #include <pthread.h>
2  #include <stdio.h>
3  #define THREADS 10
4
5  void* hello(void* threadID) {
6     long id = (long) threadID;
7     printf("hello from %02ld/%0d\n", id, THREADS);
8     pthread_exit(NULL);
9     return NULL;
10 }
11
12 int main(int argc, char* argv[]) {
13    long id;
14    int status;
15    pthread_t threads[THREADS];
16
17    for (id=0; id<THREADS; id++) {
18       printf("creating thread %02ld\n", id);
19       status = pthread_create(&threads[id], NULL, hello, (void*) id);
20       if (status) {
21          printf("error %d in pthread_create\n", status);
22       }
23    }
24
25    pthread_exit(NULL);
26    return 0;
27 }
```