PThreads in a Nutshell

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CS 499: Spring 2016 GMU

Logistics

Today

- POSIX Threads Briefly

Reading

- Grama 7.1-9 (PThreads)
- POSIX Threads Programming Tutorial

HW4 Upcoming

- Post ~~over the weekend~~ soon
- Due in last week of class
- OpenMP Password Cracking
- PThreads Version
- Exploration of alternative programming models
- Maybe a sorting routine. . .

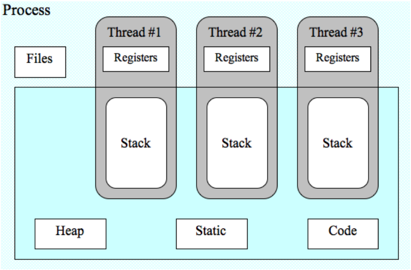
Threaded Programming

- OpenMP provided threads via directives (`#pragma omp`)
- Thread creation, execution, and cleanup all automated
- PThreads is lower-level, similar to `fork()` / `waitpid()` of IPC programming

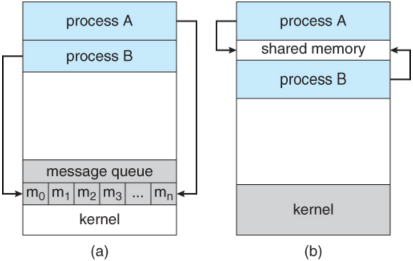
Threads vs IPC

You can mix IPC/Threads if you hate yourself enough.

Threads in PThreads	Process in IPC
Fast startup	Longer startup
Memory shared by default	Must share memory explicitly
Little protection between threads	Good protection between processes
`pthread_create() /join()`	`fork() / waitpid()`
Queues, Semaphores, Mutexes, CondVars	Queues, Semaphores, Shared Mem



Source



Source

Thread Creation

```
#include <pthread.h>
int pthread_create(pthread_t *thread,
                   const pthread_attr_t *attr,
                   void *(*start_routine) (void *),
                   void *arg);

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

- Start a thread running function `start_routine`
- `attr` may be `NULL` for default attributes
- Pass arguments `arg` to the function
- Wait for thread to finish, put return in `retval`

Minimal Example

```
// Minimal example of starting a pthread, passing a
// parameter to the thread function, then waiting for it to
// finish
#include <pthread.h>
#include <stdio.h>

void *fx(void *param){
  int p=(int) param;
  p = p*2;
  return (void *) p;
}

int main(){
  pthread_t thread_1;
  pthread_create(&thread_1, NULL, fx, (void *) 42);
  int xres;
  pthread_join(thread_1, (void **) &xres);
  printf("result is: %d\n",xres);
  return 0;
}
```

Compilation

```
> gcc pthreads_minimal_example.c -lpthread
pthreads_minimal_example.c: In function 'fx':
pthreads_minimal_example.c:7:9: warning:
 cast from pointer to integer of different
 size [-Wpointer-to-int-cast]
   int p=(int) param;
         ^
pthreads_minimal_example.c:9:10: warning:
 cast to pointer from integer of different
 size [-Wint-to-pointer-cast]
   return (void *) p;
          ^
> a.out
result is: 84
```

Things to Ask

- How much compiler support do you get with pthreads?
- How does one pass multiple arguments to a function?
- What does the parent thread do on creating a child thread?
- If multiple children are spawned, which execute?

Exercise: A Slice of the Pi

- Recall Monte-Carlo estimation of π
- Serial code: http://cs.gmu.edu/~kauffman/cs499/picalc.c
- Convert serial version to use PThreads
- How to determine # of threads, thread id
- What info to communicate threads
- How to accumulate results

```
main(){
  unsigned int rstate = 123456789;
  int npoints = atoi(argv[1]);
  int total_hits=0;
  for (int i = 0; i < npoints; i++) {
    double x = ((double) rand_r(&rstate)) / ((double) RAND_MAX);
    double y = ((double) rand_r(&rstate)) / ((double) RAND_MAX);
    if (x*x + y*y <= 1.0){
      total_hits++;
    }
  }
  double pi_est = ((double)total_hits) / npoints * 4.0;
}
```

Speedup!

- Recall that this problem is almost embarassingly parallel
- Very little communication/coordination required
- Speedup follows

4-proc desktop

```
> gcc picalc.c
> time a.out 100000000
npoints: 100000000
hits:    78541355
pi_est:  3.141654

real 2.35
user 2.27
sys 0.00

> gcc pthreads_picalc.c
> time -p a.out 100000000 2
npoints: 100000000
hits:    78539689
pi_est:  3.141588
real 1.36
user 2.53
sys 0.02
```

Timings on Zeus

```
zeus-1 [cs499]% gcc pthreads_picalc.c -lpthread -std=c99
zeus-1 [cs499]% time a.out 100000000 1
...
```

	Time (s)	
#threads	real	user
1	3.405	3.340
2	1.728	3.342
3	1.180	3.341
4	0.901	3.340
5	0.736	3.339
6	0.622	3.339
7	0.543	3.340
8	0.483	3.339
9	0.596	3.342
10	0.562	3.341

What kind of speedup are we getting here?

get_thread_id()???

> *As noted in other answers, pthreads does not define a platform-independent way to retrieve an integral thread ID. This answer* *http://stackoverflow.com/a/21206357/316487* *gives a non-portable way which works on many BSD-based platforms.*
> – *Bleater on Stack Overflow*

```
// Standard opaque object, non-printable??
pthread_t opaque = pthread_self();

// Non-portable, non-linux
pthread_id_np_t tid = pthread_getthreadid_np();

// Linux only
pid_t tid = syscall( __NR_gettid );
printf("Thread %d reporting for duty\n",tid);
```

Mutual Exclusion

- POSIX provides mutual exclusion via mutexes (mutices?), commonly referred to as locks.
- Good for thread synchronization, can also be used in IPC sync rather than semaphores/message queues

Basic pattern

```
Crate Lock variable
Initialize Lock
...
Obtain Lock
Execute critical section
Release Lock
...
Destroy Lock
```

Posix Calls

```
pthread_mutex_t lock;
pthread_mutex_init(&lock, NULL);
...
pthread_mutex_lock(&lock);
total_hits++;
pthread_mutex_unlock(&lock);
...
pthread_mutex_destroy(&lock);
```

Picalc with Locks

Adjust code to use global `total_hits`, protect updates using locking

https://cs.gmu.edu/~kauffman/cs499/pthreads_picalc.c

Timing with Locks

```
zeus-1 [cs499]% gcc pthreads_picalc_locking.c -lpthread -st
zeus-1 [cs499]% time -p a.out 100000000 1
```

	Locks			Lock-Free	
#threads	real	user	sys	real	user
1	7.05	6.98	0.00	3.405	3.340
2	27.62	22.15	28.73	1.728	3.342
3	25.65	22.60	40.07	1.180	3.341
4	34.32	29.41	94.90	0.901	3.340
5	43.65	33.26	162.76	0.736	3.339
6	41.32	29.15	194.13	0.622	3.339
7	34.66	23.72	197.91	0.543	3.340
8	30.68	20.00	200.10	0.483	3.339
9	29.11	19.21	197.84	0.596	3.342
10	28.49	18.51	197.57	0.562	3.341

Why are these numbers so much worse than the lock-free version?

Locks versus Condition Variables

- POSIX Mutexes use busy waiting - occupy CPU time while repeatedly trying to acquire the lock: *Spin Lock* or *Polling*
- Condition variables allow non-busy waiting

Recall the Semaphore

- Check an integer value atomically
- Increment / decrement that value
- If decrementing would drop below 0, *block*, wait to be notified of non-zero value
- Built-in wait queue to notify blocked processes of changes
- Blocking does not use CPU

CondVar ≈ Wait Queue

- Only the queue part of a semaphore

```
// Wait for signals
pthread_cond_wait(cv,mtx);
// Wake up waiting thread
pthread_cond_signal(cv);
```

- Required: External variable/variables to indicate state
- Required: Mutex to control access to those variables

Picalc with Condvars

```
int critical_occupied = 0;
pthread_mutex_t critical_mtx;
pthread_cond_t  critical_cv;
...;
double x = ((double) rand_r(&rstate)) / ((double) RAND_MAX);
double y = ((double) rand_r(&rstate)) / ((double) RAND_MAX);
if (x*x + y*y <= 1.0){

  // Enter the critical section
  pthread_mutex_lock(&critical_mtx);
  while(critical_occupied){
    pthread_cond_wait(&critical_cv, &critical_mtx);
  }
  critical_occupied = 1;
  pthread_mutex_unlock(&critical_mtx);

  // Update the state
  total_hits++;

  // Exit the critical section
  critical_occupied = 0;
  pthread_cond_signal(&critical_cv);
}
```

Timings

	Condvar			Mutex			Redux	
#Th	real	user	sys	real	user	sys	real	user
1	9.59	9.53	0.00	7.05	6.98	0.00	3.405	3.340
2	29.73	21.62	29.09	27.62	22.15	28.73	1.728	3.342
3	85.88	62.54	151.82	25.65	22.60	40.07	1.180	3.341
4	96.39	64.24	226.77	34.32	29.41	94.90	0.901	3.340
5	126.69	72.78	368.33	43.65	33.26	162.76	0.736	3.339
6	161.57	79.77	531.09	41.32	29.15	194.13	0.622	3.339
7	178.40	80.26	646.49	34.66	23.72	197.91	0.543	3.340
8	192.38	78.64	759.83	30.68	20.00	200.10	0.483	3.339
9	202.28	78.20	820.12	29.11	19.21	197.84	0.596	3.342
10	211.73	79.41	834.23	28.49	18.51	197.57	0.562	3.341

More Canonical Examples of Condition Variables

- Picalc is ill-suited for either Mutexes or Condition Variables to control access to the critical section of code.
- More canonical example of condvar is producer/consumer
- Examine `pthreads_producer_consumer.c`

John's Solution to Mutex Problems

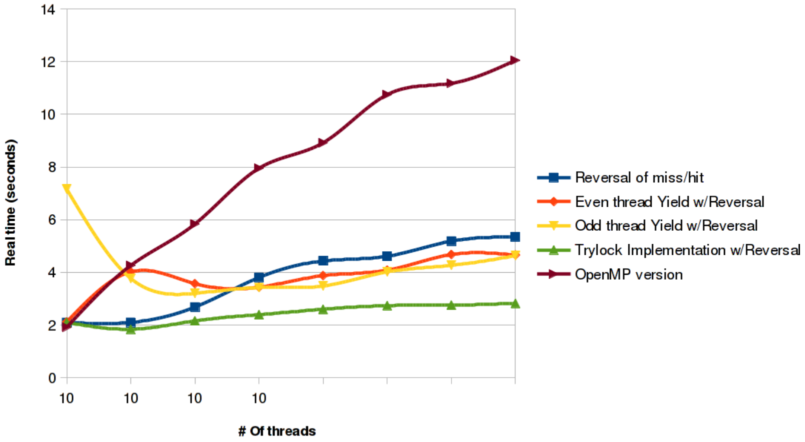
```
JohnMillerCards += 5;
```

- Tried several variants of `lock()`, `trylock()` schemes
- Found the following to be the most scalable

```
if (x*x + y*y > 1.0){
  if(pthread_mutex_trylock(&lock) == 0){
    total_miss++;
    pthread_mutex_unlock(&lock);
  }
  else{
    pthread_yield();
    pthread_mutex_lock(&lock);
    total_miss++;
    pthread_mutex_unlock(&lock);
  }
}
```

- Beats the OpenMP `critical` version for scaling

Scaling of John's Solutions



Take-Home

- PThreads provide threaded execution within a single program, shared memory
- Primary capability: spawn threads starting different functions
- Provide basic coordination mechanisms for mutual exclusion
- Did not cover large swaths of other facilities (message queues, thread priority and cancellation, etc.) but these exist and should be investigated should the need arise