Threads in C

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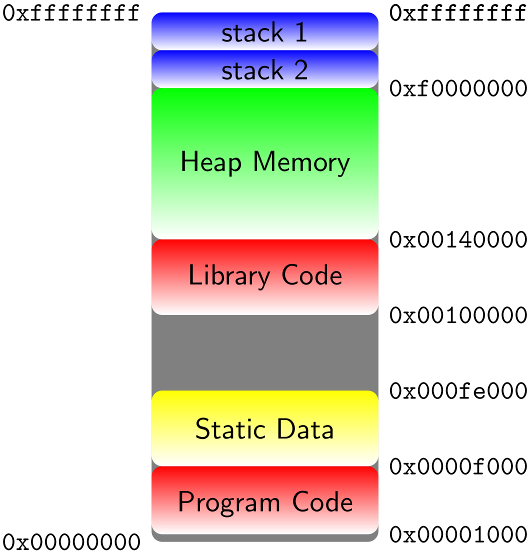
The Basic C Model

- One computer
- One process
- One thread
- One stack

Multithreaded Memory Layout (Again)



Thread APIs

- Threads are not part of C99
- They are part of C1X, but there are currently no implementations of C1X
- On UNIX-like platforms, the POSIX Thread APIs are portable
- Other platforms there are different APIs

Creating Threads

```
pthread_t thread;
pthread_create(&thread, NULL, start_function,
    arg);
```

- Creates a new stack
- Registers it for scheduling
- Sets instruction pointer in new thread to `start_function`

Combining Threads

```
void *ret;
pthread_join(thread, &ret);
```

- Waits for `thread` to finish
- Sets `ret` to the return value from the thread start function

Aside: Function Pointers

```
void example(void) { printf("Stuff goes here\n")
    ; }
void user(void)
{
    // Call example
    example();
    // Store a pointer to example:
    void (*funcPtr)(void) = example;
    // Call example via the function pointer
    funcPtr();
}
```

Thread Overhead

- Creating the stack
- Copying all of the thread-local variables
- Context switching if number of threads exceeds number of cores
- Synchronisation costs (including implicit cache coherency cost)

Sometimes adding threads makes things slower!

Example: Parallel Quicksort

- Recursive sorting algorithm
- Perform sub-sorts in a new thread

Revision: Quicksort

1. Pick pivot point
2. Split array into ‘values lower than pivot’ and ‘values greater than pivot’
3. Recursively sort each sub-array.

Serial Quicksort

```
void quicksort(int *array, int left, int right)
{
    if (right > left)
    {
        int pivotIndex = left + (right - left)/2;
        pivotIndex = partition(array, left, right,
            pivotIndex);
        quicksort(array, left, pivotIndex-1);
        quicksort(array, pivotIndex+1, right);
    }
}
```

Making it Parallel

- Partition can't (easily) be done in parallel
- Recursive calls can

Recursive Quicksort

```
void quicksort(int *array, int left, int right)
{
  if (right > left)
  {
    int pivotIndex = left + (right - left)/2;
    pivotIndex = partition(array, left, right,
        pivotIndex);
    struct qsort_starter arg = {array, left,
        pivotIndex-2};
    pthread_t thread;
    // Create a new thread for one subsort
    pthread_create(&thread, 0, qsthread, &arg);
    quicksort(array, pivotIndex+1, right);
    // Wait for both to finish
    pthread_join(thread, NULL);
  }
}
```

Why The Structure?

```
struct qsort_starter
{
  int *array;
  int left;
  int right;
};
void* qsthreadthread(void *init)
{
  struct qsort_starter *start = init;
  quicksort(start->array, start->left, start->
      right);
  return NULL;
}
```

- Thread function only takes one (`void*`) argument
- If we want to pass more than one, we must pass a struct pointer

Is this Safe?

```
struct qsort_starter arg = {array, left,
    pivotIndex-2};
pthread_t thread;
// Create a new thread for one subsort
pthread_create(&thread, 0, qsthread, &arg);
```

- Usually not - passing stack allocation to another thread
- Safe here because of the `pthread_join()` call.

Testing Speedup

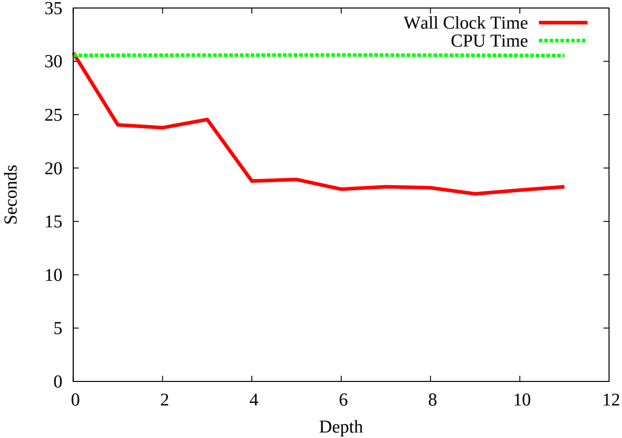
```
$ time ./a.out
real    0m30.792s
user    0m30.552s
sys     0m0.222s
```

real (a.k.a wall clock time) - elapsed time from start to finish

user CPU time scheduled to the process

sys CPU time scheduled to the kernel to handle system calls for the process

Multithreading Performance



Speedup

$$S_p = \frac{T_1}{T_p}$$

T_1 time for sequential algorithm

T_p time for parallel algorithm with p processors

S_p speedup with p processors

Wall clock time, not CPU time!

Efficiency

$$E_p = \frac{S_p}{p}$$

- More useful metric
- Can compare E_p values independently of p

Parallel Quicksort Speedup

Threads	p	T_p	S_p	E_p
1	1	30.792	1	1
2	2	24.044	1.28	0.64
4	2	23.780	1.29	0.65
8	2	24.548	1.25	0.63
16	2	18.784	1.63	0.82

- Linear speedup: $S_p = p, E_p = 1$
- Superlinear speedup (very rare!) $E_p > 1$

Why Sublinear?

- The partition step is serial
- Uneven workload distribution between threads (e.g. one thread sorting 998 elements, one sorting 2)

Amdahl's Law

- Maximum speedup of a program is limited by the sequential portion
- For quicksort, this is the partition step
- Absolute best case, with infinite processors, is $O(n)$ for quicksort

Parallel Quicksort is Easy

- No data sharing between threads
- No communication between threads, except on exit
- Concurrent parts could be in separate processes
- Threads just eliminate some copying overhead

Questions?