

COMPUTATIONAL MATH, SCIENCE AND ENGINEERING DEPARTMENT

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Threads 1

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8576 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000

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CMSE 822, FS21, W.F. Punch

Outline

- what are threads and processes
- how to make a thread
- how to synchronize threads
- how to communicate between threads.



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Process

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8448 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000

8512 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000

8576 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000

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What's a process?

The class definition of a process is a program *in execution*. It has

- a virtual address space
- hardware context (registers, stack, file handles, etc.)
- O.S. info about priority, other resources being used



Processes

- Reality: each CPU can only run one program at a time
- Fiction to user: many people getting short (~ 10 - 100 ms) time slices
 - pseudo-parallelism \rightarrow *multiprogramming*
 - modeled as sequential processes
 - *context switch*



Context Switch?

Processes get a fairshare of the CPU.
Need to context switch, move one
process off and another on the CPU

- What's involved in doing such a switch (do you imagine)



Time and latency

<https://eli.thegreenplace.net/2018/measuring-context-switching-and-memory-overheads-for-linux-threads/>

Maybe 2 μ s to switch (4000 clock ticks)

What's the latency here?



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Thread

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7040 673A004C 61726765 7374206C 6F6E673A 0053697A 65206F66 206C6F6E 67206C6F 6E672069 6E743A00 53697A65 206F6620 666C6F61 743A0053 6D616C6C 65737420
7104 666C6F61 743A004C 61726765 73742066 6C6F6174 3A004469 67697473 20696E20 6D617469 737612C2 20666C6F 61743A00 53697A65 206F6620 646F7562 6C653A00
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8320 29190000 01000000 9E1A0000 01000000 A31A0000 01000000 B21A0000 01000000 BC1A0000 01000000 C11A0000 01000000 D01A0000 01000000 E01A0000 01000000
8384 DA1A0000 01000000 E41A0000 01000000 EE1A0000 01000000 F81A0000 01000000 14190000 01000000 00000000 00000000 00000000 00000000 00000000 00000000
8448 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
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8576 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000

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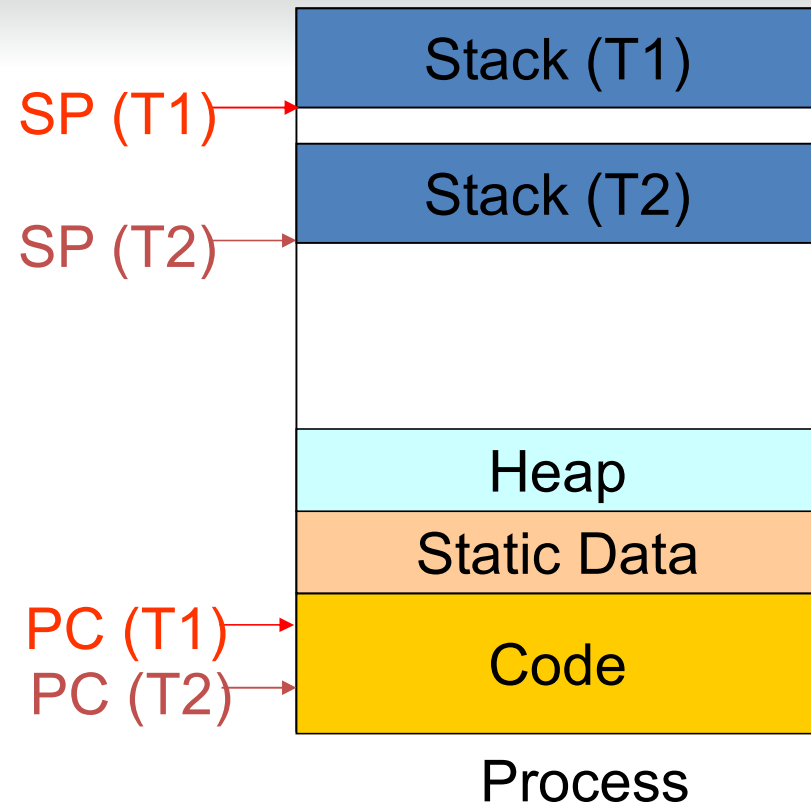
Threads

- process: address space + single thread of control
- sometimes want multiple threads of control (flow) in same address space
- quasi-parallel
- threads separate resource grouping & execution
- thread: program counter, registers, stack
- also called lightweight processes
- multithreading: avoid blocking when waiting for resources
 - multiple services running in parallel
- state: running, blocked, ready, terminated



What is a Thread?

- Execution context
 - Program counter (PC)
 - Stack pointer (SP)
 - Data registers



Why threads?

- Parallel execution
- Shared resources → faster communication without serialization
- faster to suspend if some are I/O-bound → overlap computation and I/O
- easy porting to multiple CPUs



Thread variants

- POSIX (pthreads)
- Java threads
- Windows threads



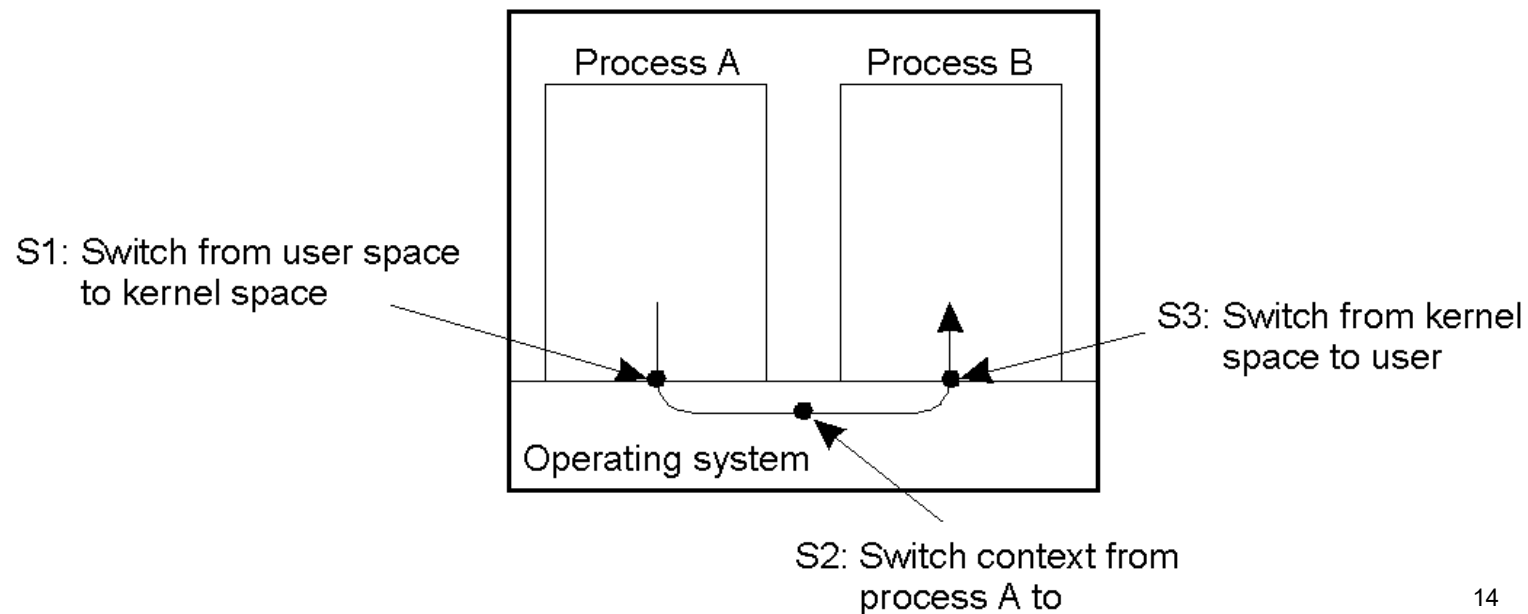
Process vs. Thread (1)

- Process: unit of allocation
 - Resources, privileges, etc
- Thread: unit of execution
 - PC, SP, registers
- Each process has one or more threads
- Each thread belong to one process



Process vs. Thread (2)

- Processes
 - Inter-process communication is expensive: need to context switch
 - Secure: one process cannot corrupt another process



Process vs. Thread (3)

- Threads
 - Inter-thread communication cheap: can use process memory and may not need to context switch
 - Not secure: a thread can write the memory used by another thread



Benefits of Threads

- Less time to create a new thread than a process (maybe, OS dependent)
- Less time to terminate a thread than a process (ditto)
- Switching between threads takes less time than switching processes (yes!)
- Threads can communicate with each other via shared memory
 - without invoking the kernel

Threads

- Several actions that affect all of the threads in a process
 - The OS must manage these at the process level.
- Examples:
 - Suspending a process involves suspending all threads of the process
 - Termination of a process, terminates all threads within the process



Activities similar to Processes

- Threads have execution states and may synchronize with one another.
 - Similar to processes
- We look at these two aspects of thread functionality in turn.
 - Startup/execution
 - Synchronization



Concurrency vs. Parallel Processing

Concurrency means that multiple tasks are being processed at the same time. Not necessarily executing simultaneously

Parallel Processing means that multiple tasks are running at the same time (are executing on the CPU)



Why concurrent?

It is convenient to assign elements of execution to a thread even if that thread is not presently running.

Web browser has multiple threads, one associated with each tab (for example).
Maintains a state of execution!



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C++11 threads

```

5312 0000488B 15470B00 004889D6 4889C7E8 6E050000 488B1535 0B000048 89D64889 C7E85C05 0000488D 35790600 00488B05 140B0000 4889C7E8 7C050000 BE080000
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6464 4889E5B8 00000080 5DC35548 89E5B8FF FFFF7F5D C3554889 E5488B00 00000000 0000805D C3554889 E5488BFF FFFF7F5D C3554889 E58B0589 01000066
6528 0F6EC05D C3554889 E58B057D 01000066 0F6EC05D C3554889 E5488B00 00000000 00100066 480F6EC0 5DC35548 89E5488B FFFF7F5D FFFF7F5D 66480F6E C05DC355
6592 4889E548 B8000000 00000000 00B8A010 00004889 45F08955 F8DB6D0F 5DC35548 89E548C7 C0FFFFF7 FFB8FE7F 00004889 45F08955 F8DB6D0F 5DC35548 89E548C7 C0FFFFF7
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6720 0000FF25 40060000 FF254206 0000FF25 44060000 FF254606 0000FF25 48060000 FF254A06 0000FF25 4C060000 FF254E06 0000FF25 50060000 FF255206 0000FF25
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6848 00E9BEFF FFFF6861 000000E9 B4FFFFF7 68730000 00E9AAFF FFFF6885 000000E9 A0FFFFF7 68970000 00E996FF FFFF68B7 000000E9 8CFFFFF7 68F70000 00E982FF
6912 FFFF6800 00000000 FFFF77F7 FFFF77FF 53697A65 206F6620 73686F72 743A0053 6D616C6C 65737420 73686F72 743A004C 61726765 73742073 686F7274 3A005369
6976 7A05206F 6620696E 743A0053 6D616C6C 65737420 696E743A 0064C172 20696737A 3A005369 66206C6F 66E737A0 65737420 686F7274 3A005369
7040 673A004C 61726765 7374206C 6F6E673A 0053697A 65206F66 206C6F6E 67206C6F 6E672069 6E743A00 53697A65 206F6620 666C6F61 743A0053 6D616C6C 65737420
7104 666C6F61 743A004C 61726765 73742066 6C6F6174 3A004469 67697473 20696E20 6D617469 7376312C 20666C6F 61743A00 53697A65 206F6620 646F7562 6C653A00
7168 536D616C 6C657374 20646F75 626C653A 004C6172 67657374 20646F75 626C653A 00446967 69747320 696E206D 61746973 73612C20 646F7562 6C653A00 53697A65
7232 206F6620 6C6F6E67 20646F75 626C653A 00536D61 6C6C6E73 74206C6F 6E67206A 6F75626C 653A004C 61726765 7374206C 6F6E6720 646F7562 6C653A00 00000000
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7744 34000000 A4010000 3DFBFFFF FFFFFFFF 10000000 00000000 00040100 00000E10 86020403 00000000 06040B00 00000C07 08000000 00000000 34000000 DC010000
7808 15FBFFFF FFFFFFFF 15000000 00000000 00040100 00000E10 86020403 00000000 06041000 00000C07 08000000 00000000 00000000 14020000 F2FAFFFF FFFFFFFF
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8000 86020403 00000000 06041700 00000C07 08000000 00000000 34000000 BC020000 02FAFFFF FFFFFFFF 6A050000 00000000 00040100 00000E10 86020403 00000000
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8128 08000000 00000000 34000000 2C030000 44F9FFFF FFFFFFFF 15000000 00000000 00040100 00000E10 86020403 00000000 06041000 00000C07 08000000 00000000
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8256 BF190000 01000000 75190000 01000000 85190000 01000000 4A190000 01000000 3F190000 01000000 65190000 01000000 55190000 01000000 34190000 01000000
8320 29190000 01000000 0E1A0000 01000000 9E1A0000 01000000 A31A0000 01000000 B21A0000 01000000 BC1A0000 01000000 C61A0000 01000000 D01A0000 01000000
8384 DA1A0000 01000000 E41A0000 01000000 EE1A0000 01000000 F81A0000 01000000 14190000 01000000 00000000 00000000 00000000 00000000 00000000
8448 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
8512 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000
8576 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000 00000000

```

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two models in C++11

There are really two models in C++11:

- thread model
- async task model

The former is more standardized, the latter more "interesting" from a task view.



built atop a thread implementation

C++11 attempts to be more generic as it provides a model upon which different architectures can be utilized:

- pthreads for Unix
- ConcRT (concurrency runtime) windows



thread

```
#include<thread>
```

```
thread(callable object)
```

thread constructor *copies* the callable object to the local thread space and *starts* that separate thread by invoking the callable object



1.1

```
#include<iostream>
using std::cout; using std::endl;
#include<thread>
using std::thread;
```


```
void a_fun() {
    cout << "Hello World"<<endl;
}
```

```
int main() {
    thread thrd(a_fun);
    thrd.join();
}
```

argument is a
callable function



declare the
thread obj




either join
or detach



compiling

On linux:

```
g++ -pthread file_to_compile.cpp
```



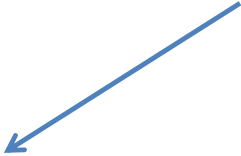
underlying implementation
being used to do the C++
threading model

1.2

```
#include<iostream>
using std::cout; using std::endl;
#include<thread>
using std::thread;

int main() {
    thread thrd(
        [] () {cout << "Hello World" << endl;}
    );
    thrd.join();
}
```

start thread
on lambda



1.3

```
#include<iostream>
using std::cout; using std::endl;
#include<thread>
using std::thread;
#include<string>
using std::string;
```

```
class MyClass{
private:
    string my_mesg_;
public:
```

```
    MyClass(string s) : my_mesg_(s) {};
```

constructor via
init list

```
    void operator() () {
        cout << my_mesg_ << endl;
    }
```

op() overload makes
and instance callable

```
};
```

```
int main(){
    MyClass mc("Hello World");
    thread thrd(mc);
    thrd.join();
}
```

invoke the
instance

What you cannot do

- As shown, you cannot return a value from a thread
 - you can change a reference passed in
 - we'll see other ways, but not this way
- You cannot ever copy a thread
 - if you pass one around, it has to be by reference or by a move.



join vs detach

The thread starts immediately and independently of the main thread.

The question is how they sync:

- `join`, caller waits at the join call for the thread to end
- `detach`, caller ignores the thread and each proceeds independently
 - often called a *daemon*



when to call

You only have to call join/detach before the thread object/var is destroyed:

- you can join/detach long after the thread has finished
- if you detach, the thread may run long after the thread object is detached and after the main ends



call once and done

If you have detached a thread, you can no longer communicate with it.

- but you can still sync with it (more later)

If you have joined a thread, you cannot join it again

`.joinable()` is a boolean that indicates whether you can join a thread



when does a thread end

- if the associated thread var is destroyed (goes out of scope)
 - at that point the destructor calls terminate, ending the thread.
- if the thread throws an exception
 - thread ends



what happens with exceptions

If the thread throws an exception and it is not handled, then the process halts.

If the main throws an exception before the thread is joined, the thread is destroyed and the thread terminated



exceptions are really tricky

We will see down the line that handling exceptions can be tricky.

The rule is basically "If something can go wrong it will" with concurrency.

We need to be extra careful.



beware detach

- if possible, only work with local/copied values. This avoids a thread trying to access destroyed values in another context
- if using globals, make sure they stay in scope until the thread ends
 - we'll see how to do this later

