CSCE 313-200
Introduction to Computer Systems
Spring 2024

Threads

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Updates

- Quiz 2 next Monday
  - The last two lectures (OS concepts, processes)
  - Understanding of homework
- Common issues in hw1p1
  - Not waiting for CC.exe to exit
  - Printing room with %X instead of %llX
  - Not handling CC errors in ResponseCC::status
- Make sure to check for API errors
  - Catches bugs sooner, simplifies debugging

Chapter 4: Roadmap

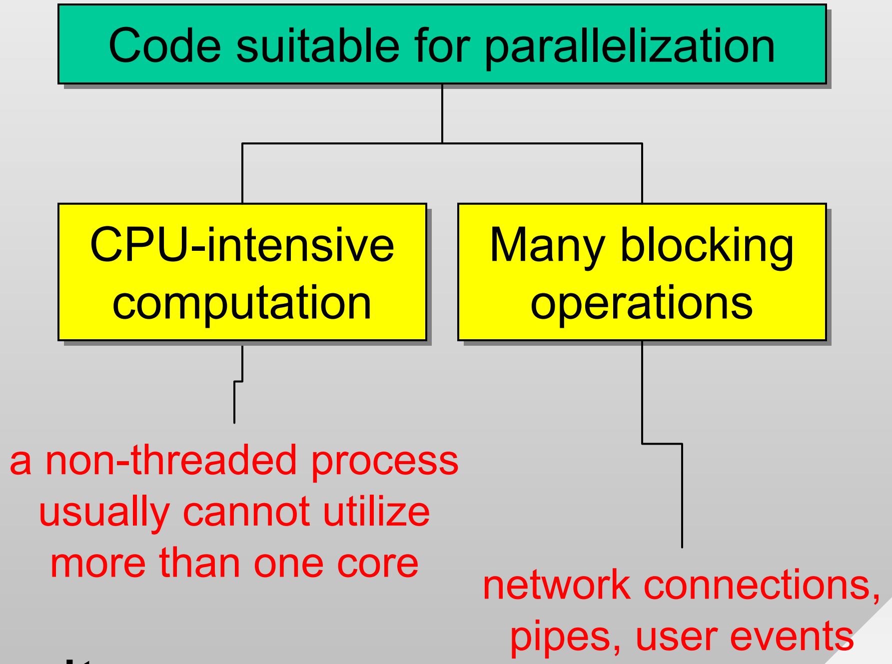
- 4.1 Processes and threads
- 4.2 SMP
- 4.3 Micro-kernels
- 4.4 Windows threads
- 4.5 Solaris threads
- 4.6 Linux threads

Part II

Chapter 3: Processes
Chapter 4: Threads
Chapter 5: Concurrency
Chapter 6: Deadlocks

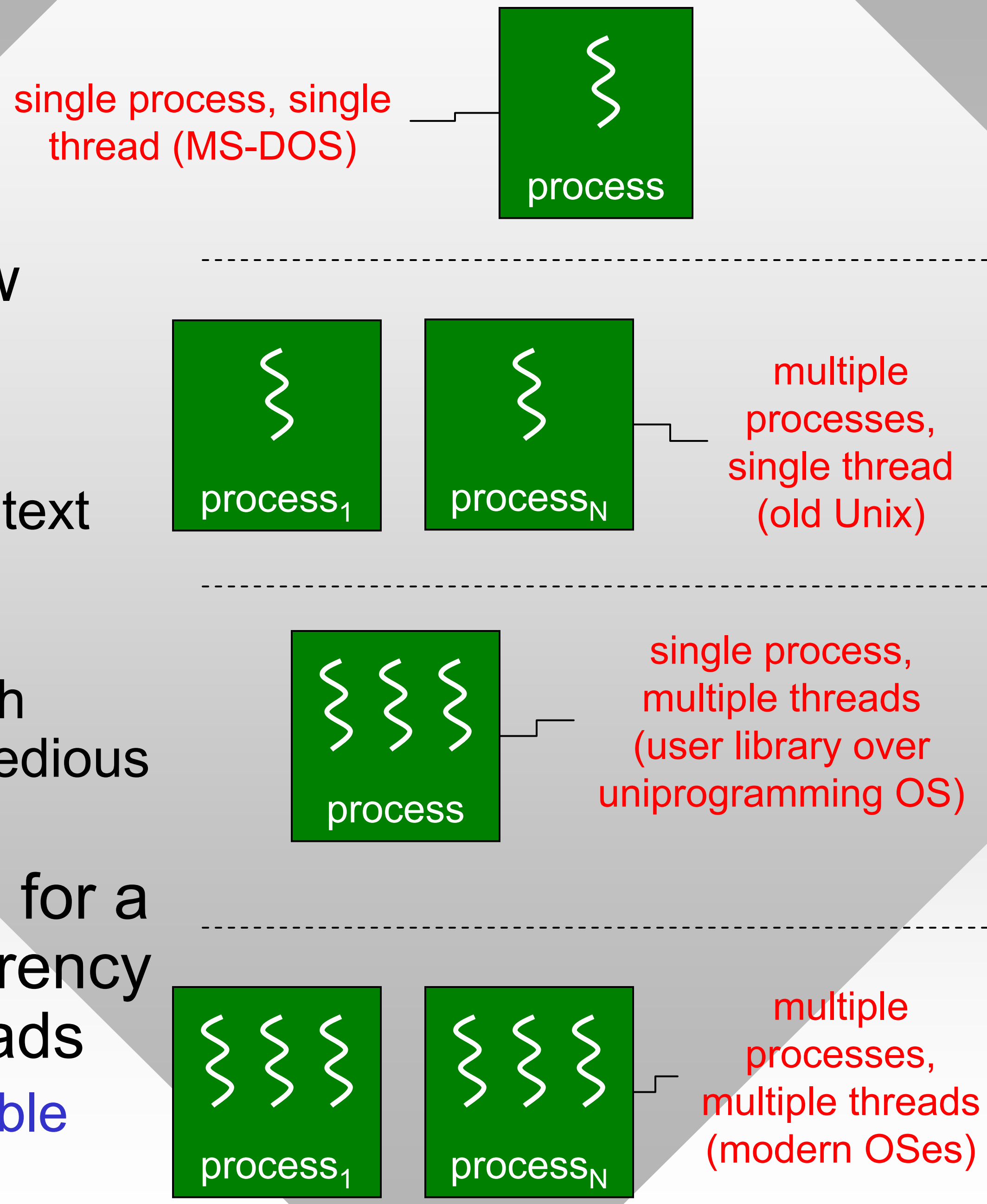
Motivation

- Why parallelize a single program?
- Two main reasons
  - Take advantage of multi-core CPU capacity
  - Perform many concurrent blocking operations quickly
- While non-blocking I/O helps with the second issue, it doesn't solve the first one
  - Also makes code more complex

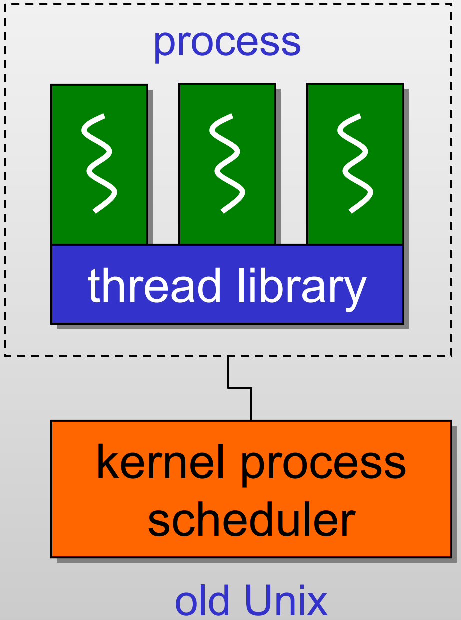


Taxonomy

- Why not create a new process then?
- Two main issues:
  - Frequent process context switch is expensive
  - Data sharing may be inefficient (i.e., through kernel) and possibly tedious to program
- Thus, there is a need for a simpler/faster concurrency model that uses threads
  - Thread is a dispatchable unit of work within a process



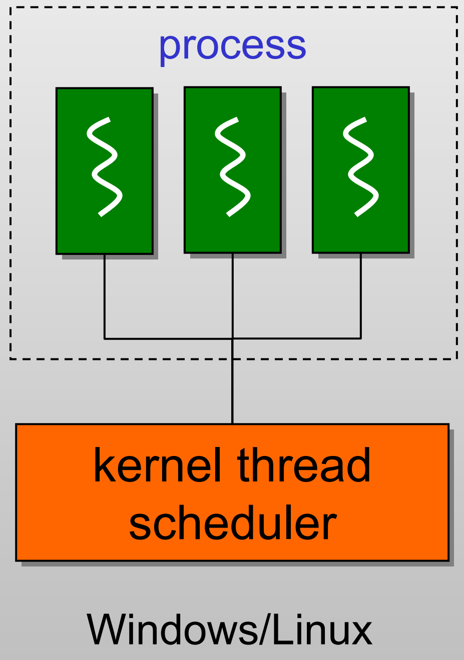
How to Implement Threads



- Historically, threads didn't exist in multi-tasked OSes
  - Users wrote special libraries to emulate threads
  - OS scheduled the process, then library scheduled threads
- Benefits of User-Level Threads (ULT):
  - Thread switch completely in user mode (i.e., fast)
  - Control over scheduler and its policy
  - Portability of code (no dependency on OS APIs)
- Problems:
  - When kernel APIs block, the entire process is blocked
  - No ability to run concurrently on multiple CPUs

How to Implement Threads

- Later, OSes became thread-aware and offered Kernel-Level Threads (KLT)
  - Another term is Light Weight Processes (LWT)
- Benefits of KLT:
  - Multi-CPU usage by the same program, non-blocking I/O
- Drawbacks compared to ULT:
  - Requires kernel mode switch after each slice (higher latency)
  - Less flexibility with scheduling



Performance

- How expensive is context switch?
  - Traditional numbers suggest ULT switch is 10x faster than KLT, which is 4-5x faster than process switch
- Windows benchmark agrees with the last ratio
  - ULT rarely used on Windows, no performance results readily available

delay in microsec

Operation	ULT	KLT	Process
Create	34	948	11,300
Event wait + switch	37	441	1,840

old VAX Unix

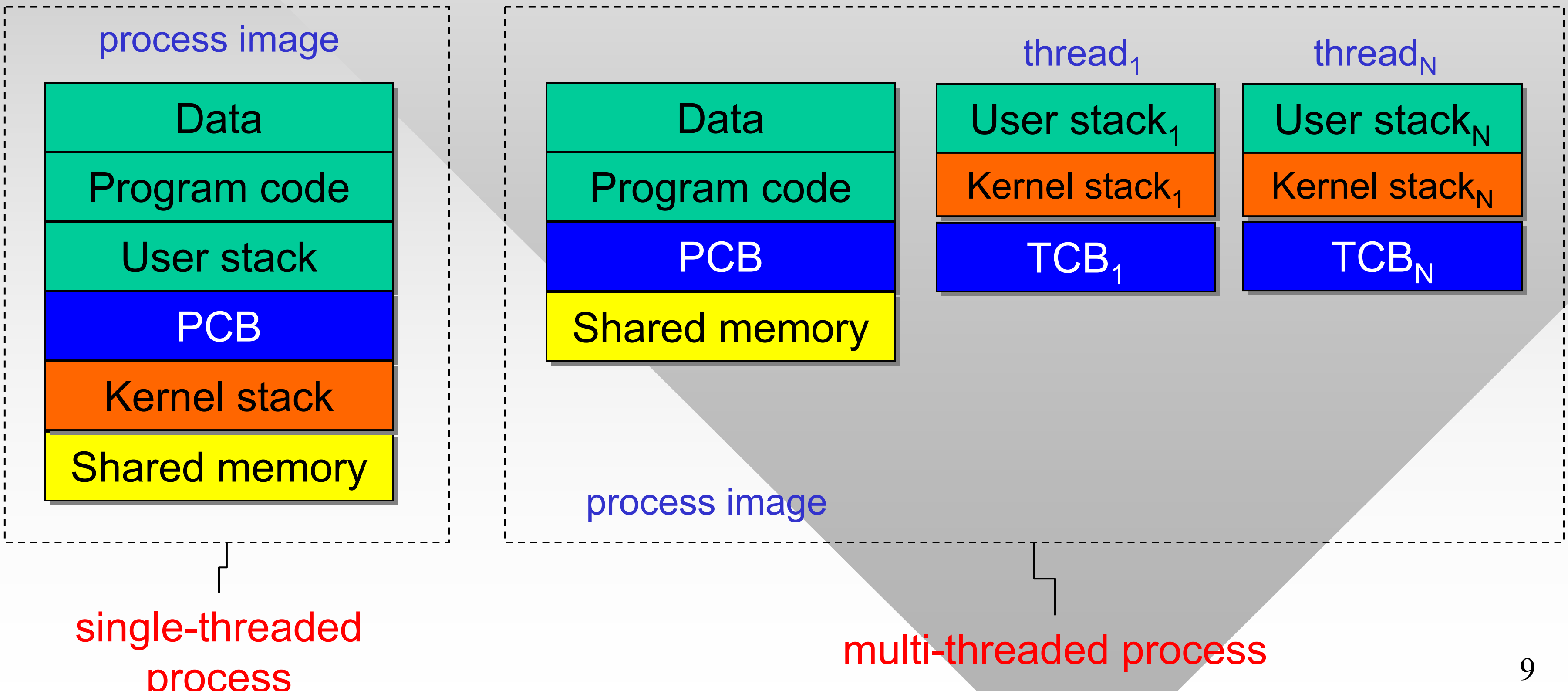
Operation	ULT	KLT	Process
Event wait + switch		0.44	2.2

AMD Phenom II X6 2.8 GHz

- While these latencies are small, they do increase as the # of threads/processes in the ready state rises

Kernel Threads

- Difference from the single-threaded model
  - Threads have separate stacks and execution context called Thread Control Block (TCB), but share all virtual memory



Kernel Threads

- OS still enforces separation between processes
  - However, threads are not protected from each other
  - Buffer overflow in one thread may wipe out data of other threads in the same process
- Process owns
  - Virtual address space and shared memory
  - Security attributes of all objects (e.g., open files)
- Threads own
  - TCB that includes thread state (e.g., blocked, running, ready), thread context (registers), scheduler priorities and its auxiliary info, pending wait events
  - Execution stack (user and kernel)

Using Threads

```
typedef DWORD
(__stdcall *LPTHREAD_START_ROUTINE)
( [in] LPVOID lpThreadParameter );
```

- In Windows:

```
HANDLE WINAPI CreateThread (
  __in_opt   LPSECURITY_ATTRIBUTES lpThreadAttributes,
  __in       SIZE_T dwStackSize,
  __in       LPTHREAD_START_ROUTINE lpStartAddress,
  __in_opt   LPVOID lpParameter,
  __in       DWORD dwCreationFlags,
  __out_opt  LPDWORD lpThreadId );
```

- Security = NULL, stacksize = 0 (default), flags = 0
- Must provide the address of start function
  - Thread executes from that address
  - Current thread continues as normal
- Definition of a thread function:

```
DWORD __stdcall MyThread (LPVOID lpThreadParameter);
```

Using Threads

```
DWORD __stdcall ThreadStarter (LPVOID p) {
  ThreadParams *t = (ThreadParams*) p;
  t->me->Run (t->threadID);
  return 0;
}
```

```
class MyExample {
public:
  int     count;
  void    Run (int threadID);
};
```

```
class ThreadParams {
public:
  MyExample* me;
  int        threadID;
};
```

```
#define THREADS_TO_RUN        100
void main (void) {
  HANDLE thread [THREADS_TO_RUN];       // stores thread handles
  ThreadParams t [THREADS_TO_RUN];      // parameters passed to threads
  MyExample me;   me.count = 0;

  for (int i = 0; i < THREADS_TO_RUN; i++) {      // start a bunch of threads
    t[i].threadID = i;                            // assign seq # to this thread
    t[i].me = &me;  // must pass a pointer to shared variables/classes
    // run thread with default stack size
    if ((thread [i] = CreateThread (NULL, 0, ThreadStarter, t + i, 0, NULL)) == NULL) {
      printf (“failed to create thread %d, error %d\n", i, GetLastError());
      exit (-1);
    }
  }
  for (int i = 0; i < THREADS_TO_RUN; i++) { // now hang here waiting for threads to quit
    WaitForSingleObject (thread [i], INFINITE);
    CloseHandle (thread[i]);
  }
  printf (“result = %d\n”, me.count);
}
```

Using Threads

```
void MyExample::Run (int threadID)
{
   Sleep (100);
   count ++;
   printf ("Thread %d finished\n", threadID);
}
```

- Try to encapsulate all functionality inside your class member functions
- Local variables are never shared (they stay in thread stack)

```
void MyExample::Run (int threadID)
{
   int a = 4;        // local
   Sleep (100);
   a += 70;
}
```

- Global and static variables
  - Shared between threads, but they are considered bad style and thus not recommended

```
int b = 3;            // global
void MyExample::Run (int threadID)
{
  static int a = 4; // static
  a += 70;
  b += 70;
}
```

- Heap-allocated blocks
  - Normally not shared unless you provide a common pointer to multiple threads and they dereference it

Using Threads

```
void MyExample::Run (int threadID)
{
   Sleep (100);
   count ++;
   printf ("Thread %d finished\n", threadID);
}
```

- Thread execution is non-deterministic
  - Threads can be interrupted at any time
  - Speed of execution may differ by any factor
- Make sure each thread gets its own copy of ThreadParams to avoid problems like this:

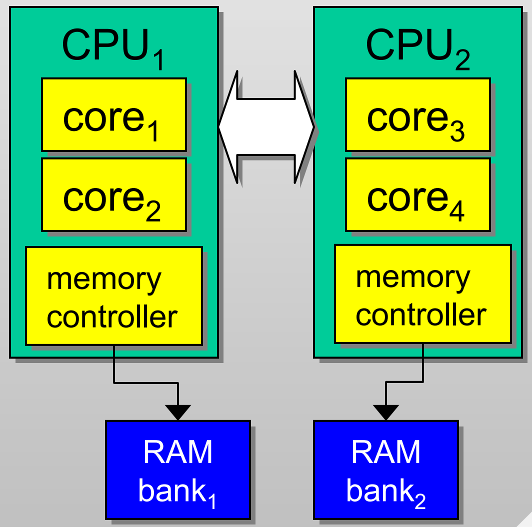
```
ThreadParams t;
t.me = &me;

for (int i = 0; i < THREADS_TO_RUN; i++) {        // start a bunch of threads
    t.threadID = i;                          // assign # to this thread
    if ((thread [i] = CreateThread (NULL, 0, ThreadStarter, &t, 0, NULL)) == NULL) {
      printf (“failed to create thread %d, error %d\n", i, GetLastError());
      exit (-1);
    }
}
```

all threads may get their threadID = THREADS_TO_RUN-1

Chapter 4: Roadmap

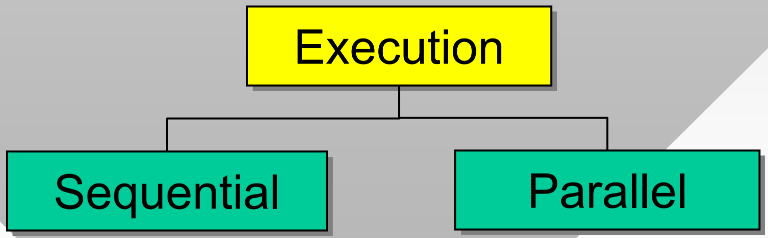
SMP

- SMP (Symmetric Multi-Processing)
  - Consists of multiple CPUs connected by bus (e.g., HyperTransport in AMD)
  - Each CPU contains multiple cores and dedicated memory controller
- SMP benefits:
  - Performance, ease of coding
  - Availability (e.g., failure of some CPUs does not have to crash the system)
  - Scalability (e.g., more CPUs can be added to an existing motherboard if it supports them)



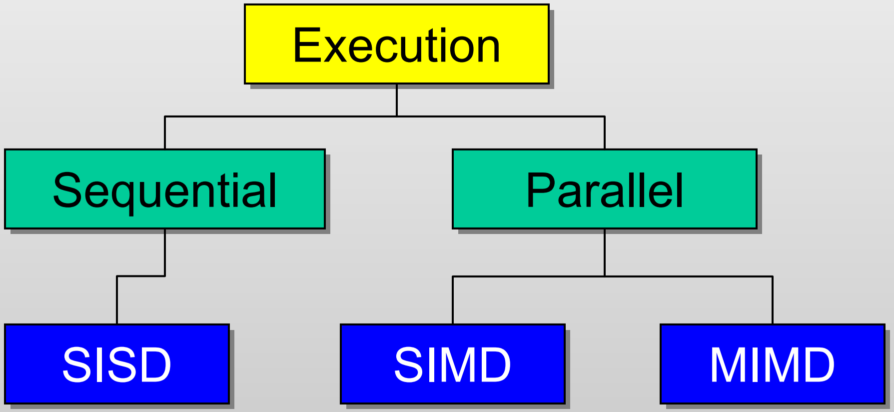
SMP

- CPU clock speed no longer scales due to insurmountable heat problems
  - Scaling cores is much easier at this stage
- Consumer-grade computers today
  - Intel Xeon w/112-cores, 8-CPU configurations (896 cores per motherboard), Intel Phi expansion card w/60 cores
  - CUDA (nVidia Titan) video cards with 5000+ cores
- Evolution of computer architecture:
  - Sequential computers had a single CPU
  - Traditional 1940s-1950s mainframes

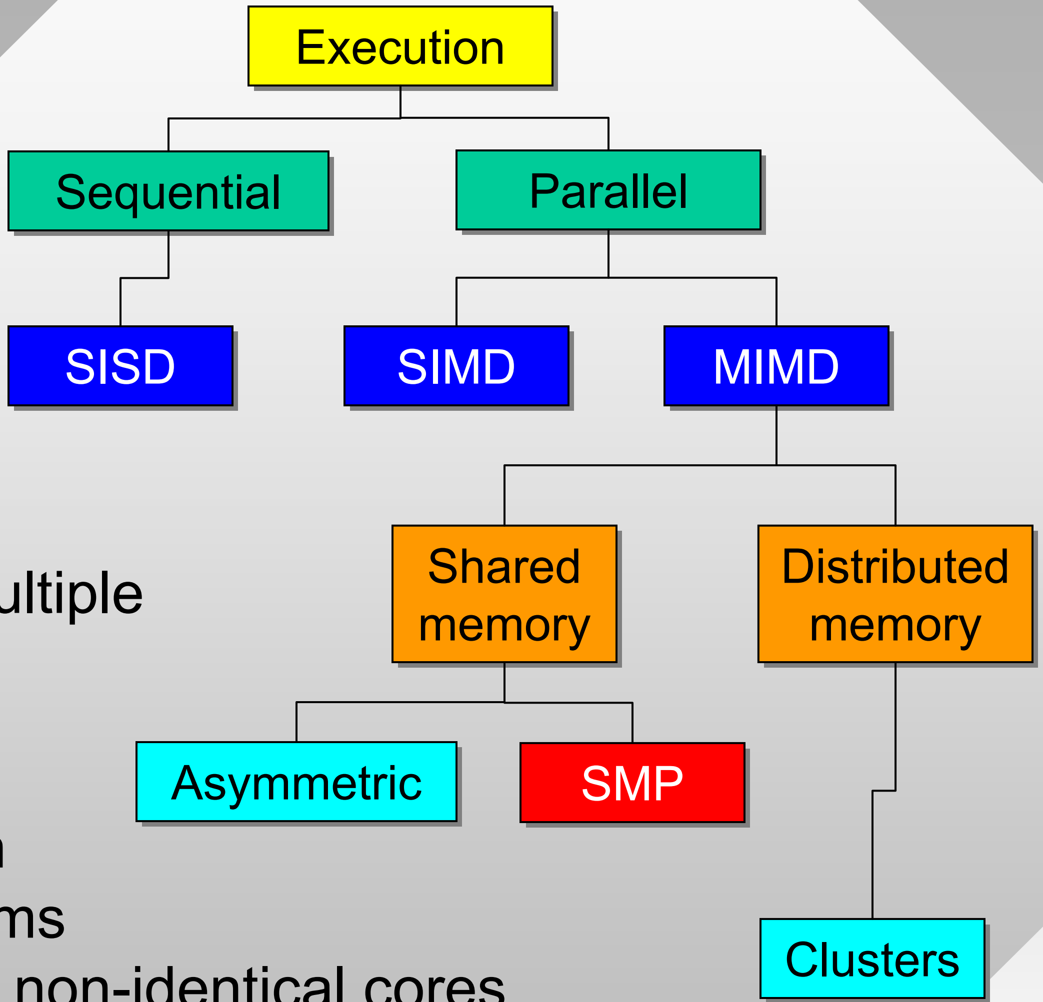


SMP

- Notation:
  - S = single, M = multiple
  - I = instruction, D = data
- Level 1
  - SISD: single core, no internal parallelism
  - SIMD: single core, can run the same instruction on multiple RAM locations in parallel (e.g., video cards, SSE, MMX, AVX)
  - MIMD: different instructions on different data (i.e., multiple cores)
  - MISD: rarely implemented



SMP



- Level 2:
  - Shared memory: single motherboard
  - Distributed memory: multiple computers
- Level 3:
  - Asymmetric: OS run on dedicated core, programs run everywhere else or non-identical cores
  - SMP: OS and programs share all cores (modern computers and kernels) ← this course
  - Clusters: racks of servers, possibly geographically distributed in datacenters

Wrap-up

- Cache coherence issues drastically affect consistency and performance when multiple threads modify the same RAM location