GPU Microarchitecture Note Set 1a—Parallelism

Parallel Computation

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Parallel Computation Idea:

One computer takes t seconds to run a program, which is not fast enough ...

... so try to use n computers to get the program to run in t/n seconds ...

... choose n to fit your performance goal and budget.

Easier said than done.

Example:

Suppose 1 computer takes 1 hour to run program A.

Convert A to a parallel program, A_p.

We hope that A_p will run in $\frac{1}{2}$ hour on a system that costs twice as much.

We hope that A_p will run in 1 minute on a system that costs 60 times as much.

We hope that A_p will run in 1 nanosecond on a system that costs 60×10^9 times as much.

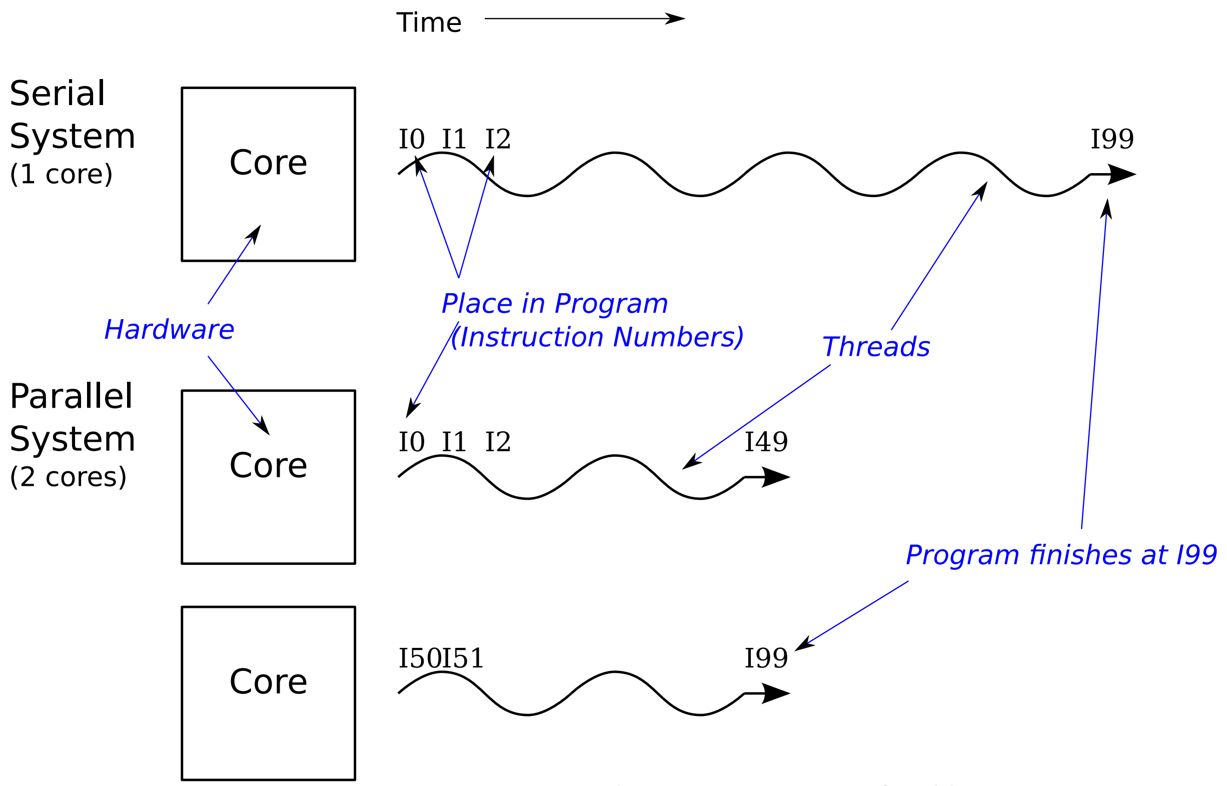
Parallel Computation:

The use of multiple processor cores to speed the execution of a program.

A *parallel program* consists of multiple *threads* that will execute on a *parallel system* consisting multiple *cores*.

The goal is to lower execution time by using multiple cores.

Realizing this goal is often frustrated by the difficulty of parallel programming.



Definitions

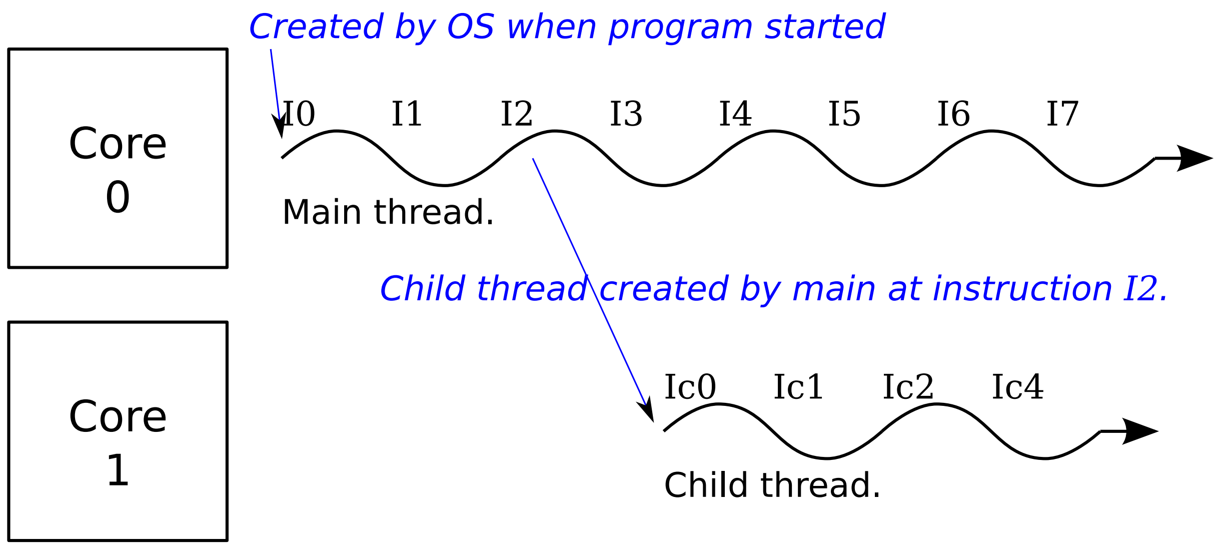
Thread:

A path through the program defined by the programmer, compiler, or some piece of support software.

The first program you wrote probably consisted of a single thread.

Programs start with a single thread . . .
. . . and can create additional threads as needed.

A program with multiple threads is a parallel program.


Created by OS when program started
Core 0
I0 I1 I2 I3 I4 I5 I6 I7
Main thread.
Child thread created by main at instruction I2.
Core 1
Ic0 Ic1 Ic2 Ic4
Child thread.

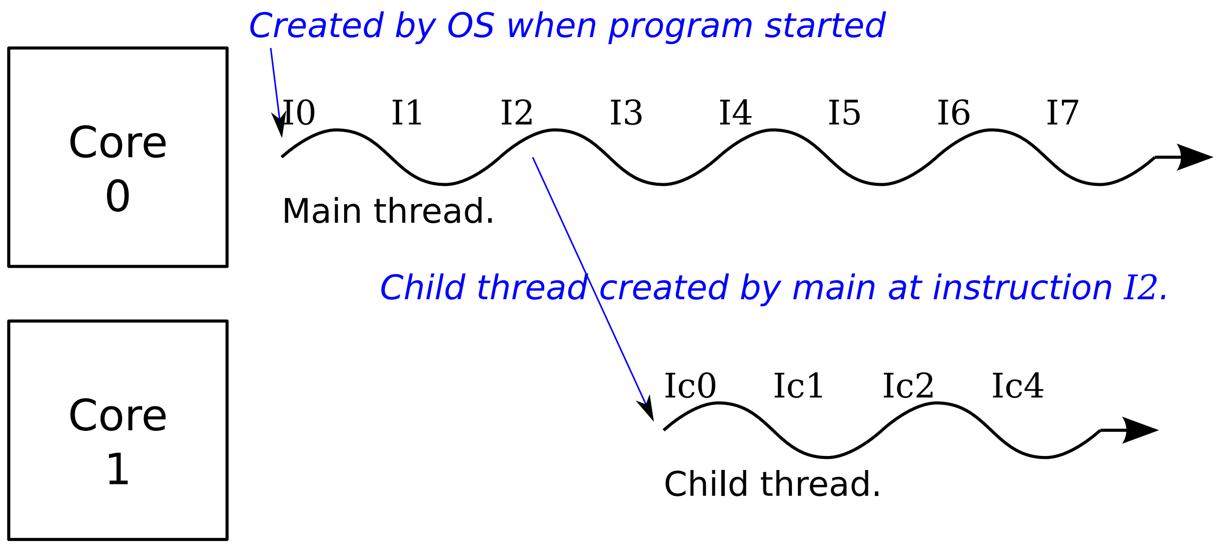
Thread Spawn Example

Pseudocode with *ad-hoc* instruction labels:

```
void main()
 I0: a = 1;
 I1: b = 9;
 I2: thread_create(my_child);
 I3: c = a + b;
 ...
```

```
void my_child()
 Ic0: x = 7;
 Ic1: y = 9;
 Ic2: z = x + y;
 ...
```

Execution timing: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Core:
Hardware needed to execute a thread.

Sometimes called a CPU (central processing unit).

A core has:

Hardware to fetch instructions.

Functional units to perform arithmetic operations.

Register files to hold intermediate (working, temporary) data values.

Hardware to decode and orchestrate instruction execution.

Execution of Multithreaded Programs

Consider a system with c cores and a program with r threads.

Typically the OS will distribute the r threads evenly over the c cores.

If $c < r$ then $c - r$ cores will sit idle.

If $c > r$ then a core may have more than on thread assigned.

Computation of Speedup Parallel System

Consider

A parallel program that can spawn any number of threads, as needed.

A computer consisting of c cores.

Let $t(1)$ denote the execution time on 1 core.

Its value is determined by the single-thread performance of the core.

Let $t(c)$ denote the execution time on c cores.

Its value is determined by the parallel program and by $t(1)$.

Speedup:

[of a parallel program on parallel system]. The ratio of execution time on one core to the time on the entire system.

Using the notation above:

$$S = \frac{t(1)}{t(c)}.$$

For example:

A program runs in $10\,\mathrm{s}$ *on one core and* $3\,\mathrm{s}$ *on 5 cores.*

The speedup is then $S = \frac{10\,\mathrm{s}}{3\,\mathrm{s}} = 3.33$.

Speedup Special Cases

Speedup Case: *Linear Speedup*— $S = c$.

This occurs when $t(c) = t(1)/c$.

This indicates no duplication of effort by threads, no time lost to communication.

There are some programs with linear speedup...
... but for many others the speedup is lower.

Example:

A program runs in $10\,\mathrm{s}$ *on one core and is to be run on 5 cores. What would its run time be if it achieves linear speedup?*

To achieve linear speedup it would need to run in $10\,\mathrm{s}/5 = 2\,\mathrm{s}$.

Speedup Special Cases

Speedup Case: *No Speedup*— $S = 1$.

This occurs when $t(c) = t(1)$.

This might be the programmer's fault ...
... or an inherent property of the problem.

Speedup Special Cases

Speedup Case: *Serial Limiter*— $S = c/(cf + 1 - f)$

This is sometimes referred to as *Amdahl's Law*.

This applies to a program that can be split into two parts...
... a part with linear speedup...
... and a part with no speedup (the *serial* portion).

Symbol f is the fraction of the program with linear speedup.

When $f = 0$, all of the program enjoys linear speedup;...
... when $f = 1$, no part of the program can be parallelized.