GPU Microarchitecture Note Set 1a—Parallelism

Parallel Computation Terminology

Parallel Computation

Parallel Computation Idea:

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

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

. . . choose c 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.

For $c = 2$, we hope that A_p will run in $\frac{1}{2}$ hour on a system that costs twice as much.

For $c = 60$, we hope that A_p will run in 1 minute on a system that costs 60 times as much.

For $c = 60 \times 10^9$, we hope that A_p will run in 1 nanosecond on a system that costs c times as much.

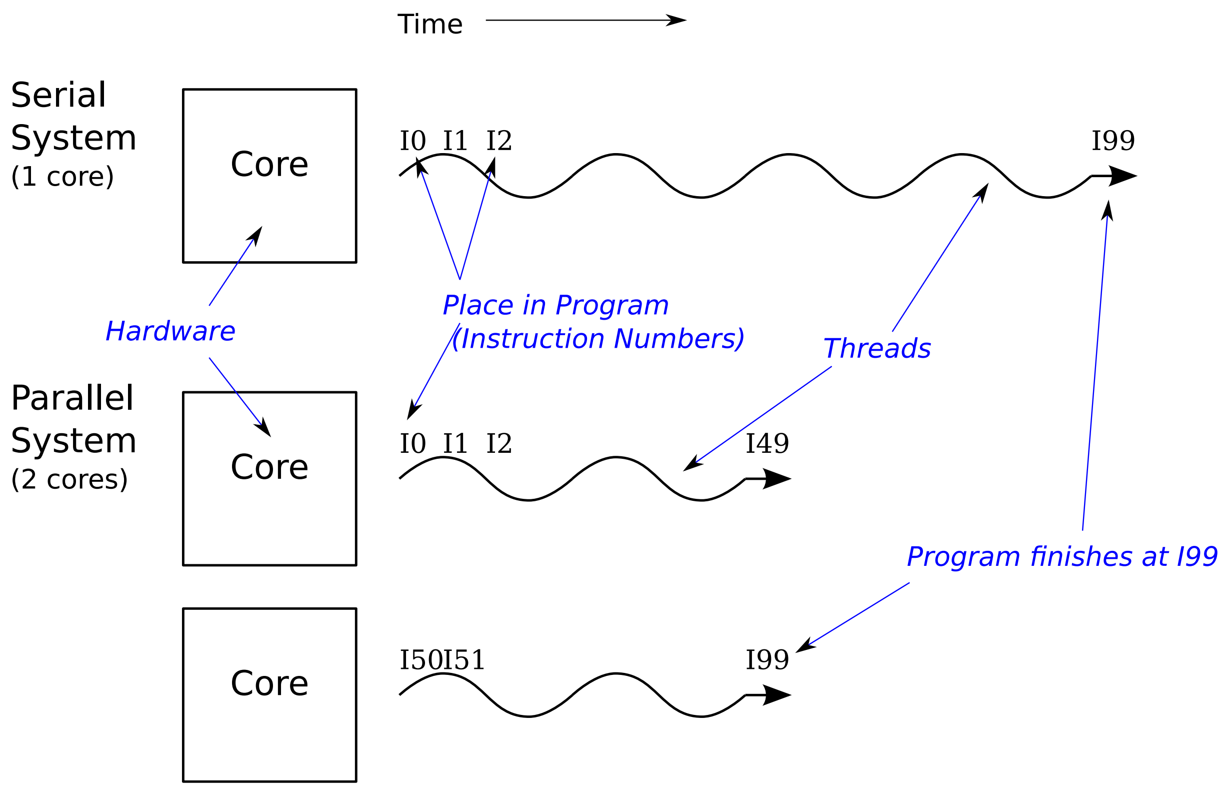
Parallel Computation:

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.



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Definitions

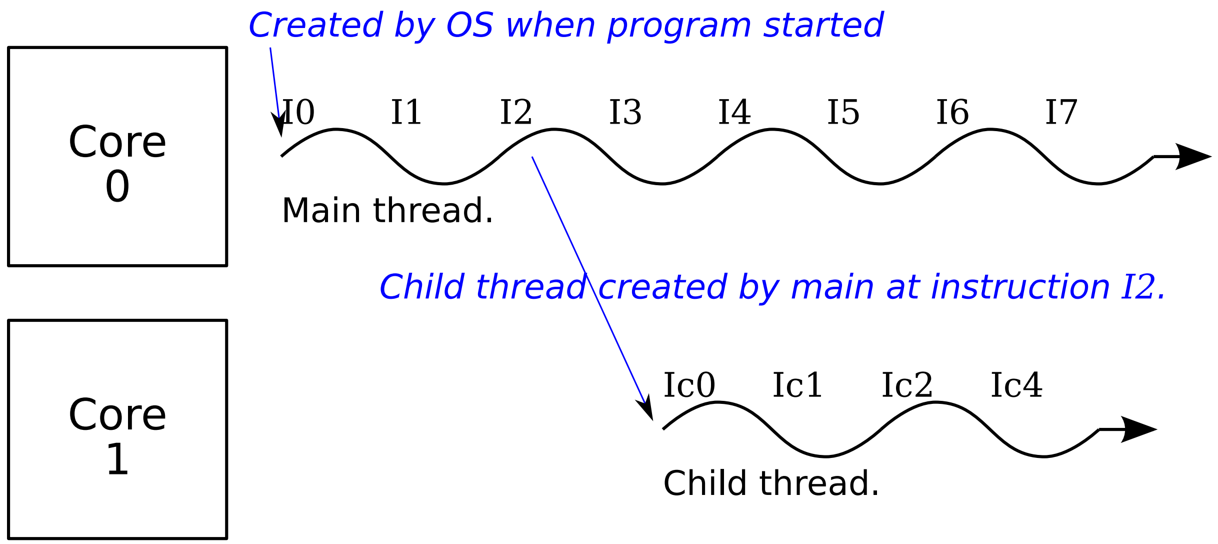
Thread:

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.



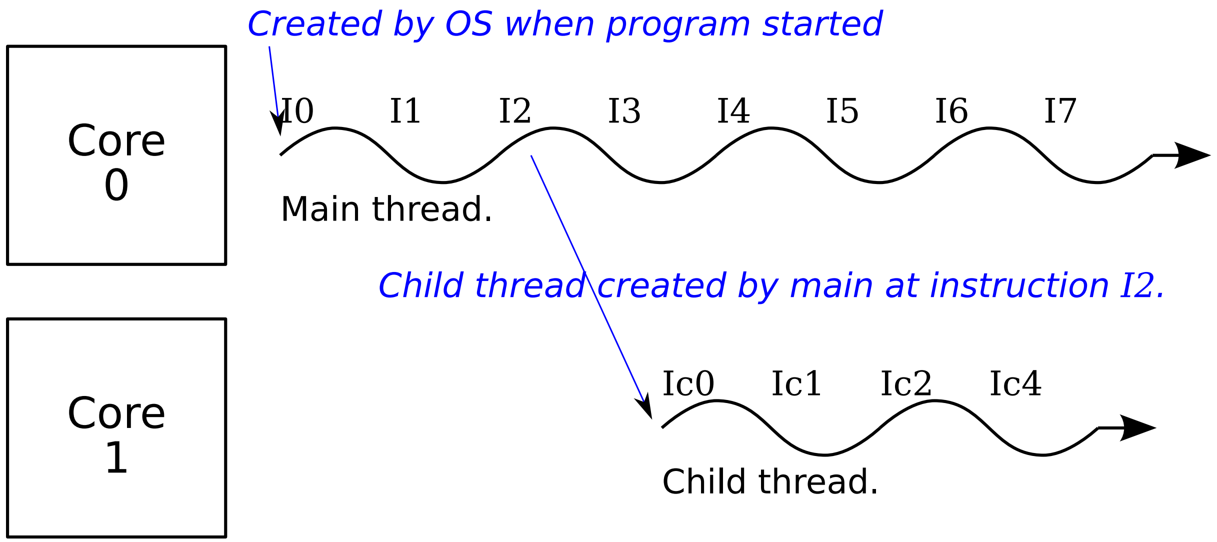
Thread Spawn Example

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:



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:

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

For example:

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

The speedup is then $S(5) = \frac{10\,\mathrm{s}}{3\,\mathrm{s}} = 3.33$.

Speedup Special Cases

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

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*— $S(c) = 1$.

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*— $S(c) = \frac{1}{f+(1-f)/c}$

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

Cannot parallelize $f \in [0,1]$ of program, f is *serial* portion.

E.g., for $f = 0.2$, can't parallelize 20% of program.

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).

$1 - f$ 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.