Class Information

- Seventh homework has been posted.

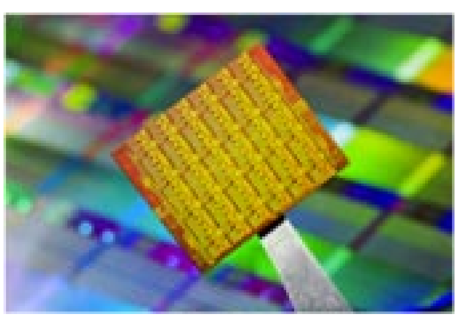
Programming with Concurrency

Why do we care about concurrency?

- Today, concurrency is nearly everywhere (peta-flops supercomputers to high-end smart phones).
- Necessary to keep "Moore's Law" alive due to power/heat dissipation limits.
- Some form of parallel programming will be required, i.e., automatic tools have not been able to hide all aspects of concurrency.

$\Rightarrow$

$\boxed{\text{Need to understand the basics of parallel programming}}$



Programming with Concurrency

Two ways of thinking about concurrency?

data-centric view: partition the data that can be worked on in parallel (data-level parallelism);

⇒ your work is determined by the data that you are assigned to work on.

task-centric view: partition the work that can be done concurrently (task-level parallelism);

⇒ your data is determined by the work that you have to do

What tasks have "to travel" to what data (data-centric) or what data has "to travel" to what tasks (task-centric) are symmetric problems.

Programming with Concurrency

Task-level parallelism can be performed at different levels:

1. **Instruction-level** parallelism (ILP) – typically exploited by hardware or compiler
2. **Loop-level parallelism** – single loop iterations are considered individual tasks
3. **Procedure-level** parallelsim – different procedures may be executed concurrently
4. **Process-level** parallelism – different programs may be executed concurrently

Will concurrentrate on loop-level parallelism

Loop-level Parallelism

We will concentrate on compilation issues for compiling **scientific codes**. Some of the basic ideas can be applied to other application domains as well. Typically, scientific codes

- Use arrays as their main data structures.
- Have loops that contain most of the computation in the program.

As a result, advanced optimizing transformations concentrate on **loop level optimizations**. Most loop level optimizations are **source–to–source**, i.e., reshape loops at the source level.

We will talk about briefly about

- Dependence analysis
- Vectorization
- Parallelization

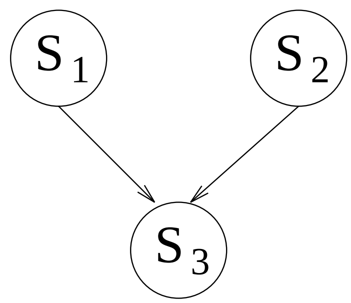
Dependence — Overview

dependence relation: Describes all *statement–to–statement execution orderings* for a sequential program that must be preserved if the meaning of the program is to remain the same.

There are two sources of dependences:

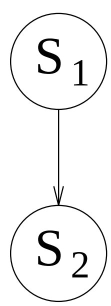
<u>data dependence</u>

```
S1  pi = 3.14
S2  r = 5.0
S3  area = pi * r**2
```



<u>control dependence</u>

```
S1  if (t .ne.  0.0) then
S2     a = a/t
    endif
```



How to preserve the meaning of these programs?

Execute the statements in an order that preserves the original *load/store* order.

Dependence — Basics

Theorem

Any reordering transformation that preserves every dependence (i.e., visits first the source, and then the sink of the dependence) in a program preserves the meaning of that program.

□

Note: Dependence starts with the notion of a sequential execution, i.e., starts with a sequential program.

Dependence — Overview

Definition — There is a data dependence from statement S_1 to statement S_2 ($S_1 \delta S_2$) if

1. Both statements access the same memory location, and
2. There is a run–time execution path from S_1 to S_2.

Data dependence classification

"S_2 depends on S_1" — $S_1 \delta S_2$

true (flow) dependence

occurs when S_1 writes a memory location that S_2 later reads

anti dependence

occurs when S_1 reads a memory location that S_2 later writes

output dependence

occurs when S_1 writes a memory location that S_2 later writes

input dependence

occurs when S_1 reads a memory location that S_2 later reads. Note: Input dependences do not restrict statement (*load/store*) order!

Dependence — Where do we need it?

We restrict our discussion to data dependence for scalar and subscripted variables (no pointers and no control dependence).

Examples:

```
do I = 1, 100
  do J = 1, 100
    A(I,J) = A(I,J) + 1
  enddo
enddo
```

```
do I = 1, 99
   do J = 1, 100
      A(I,J) = A(I+1,J) + 1
   enddo
enddo
```

<u>vectorization</u>

```
A(1:100:1,1:100:1) = A(1:100:1,1:100:1) + 1
A(1:99,1:100) = A(2:100,1:100) + 1
```

<u>parallelization</u>

```
doall I = 1, 100
  doall J = 1, 100
    A(I,J) = A(I,J) + 1
  enddo
  implicit barrier sync.
enddo
implicit barrier sync.
```

```
do I = 1, 99
   doall J = 1, 100
      A(I,J) = A(I+1,J) + 1
   enddo
   implicit barrier sync.
enddo
```