Class Announcements

- Second project due Monday, April 17
- Midterms
  - Second midterm will be on April 11.

    Final (third midterm) exam on Thursday, May 4, noon - 3:00pm timeslot. Location: most likely this room.

    Any CONFLICTS with other classes?

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

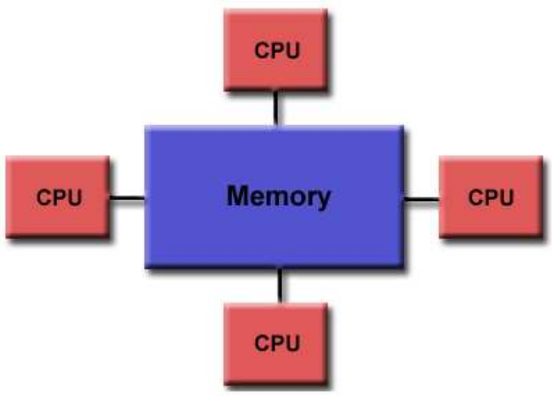
- Dependence analysis
- Vectorization
- Parallelization

Preview: Project and OpenMP

OpenMP

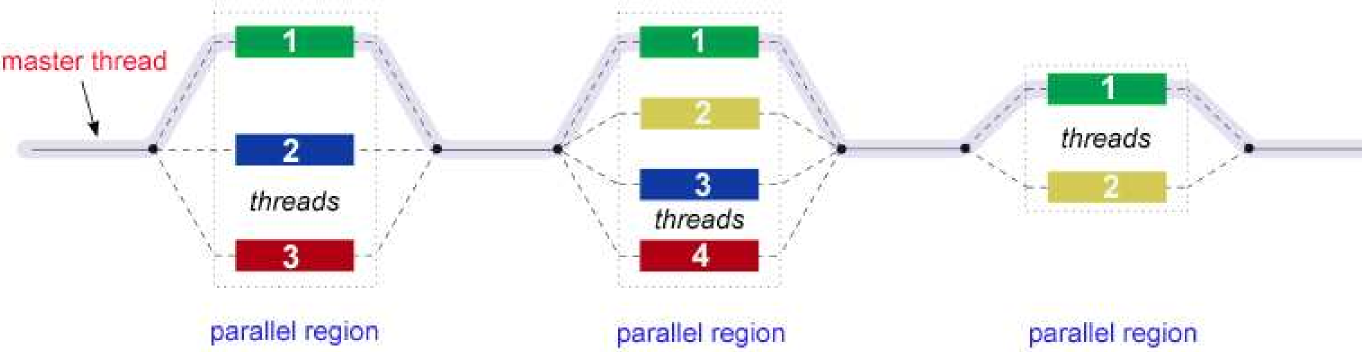
- Allows expression of parallelism at different levels: task and loop level
- Parallelization is done through pragmas.
- Look at the OpenMP documentation on our class web site.

Shared-Memory programming model programming

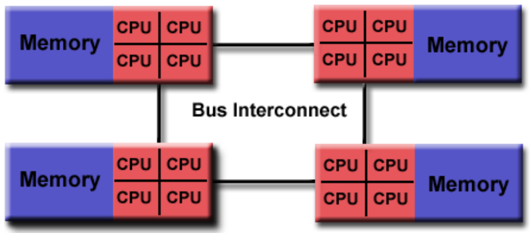


Shared Memory

Parallel Threads Execution Model



Distributed Memory



Project and OpenMP

Two important issues while specifying the parallel execution of a `for` loops:

- **safety** – parallel execution has to preserve all dependences
- **profitability** – benefits of parallel execution have to compensate for the overhead penalty

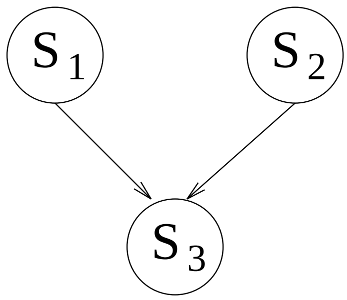
Dependence — Overview

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:

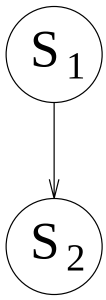
data dependence

S_1 `pi = 3.14`
S_2 `r = 5.0`
S_3 `area = pi * r**2`



control dependence

S_1 `if (t .ne.  0.0) then`
S_2 `   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`

Next Lecture

- Dependence testing
- Loop transformations
- Simple vectorization algorithm