THE UNIVERSITY OF WARWICK

High Performance Computing

Models of Parallel Programming

Dr Ligang He

Models of Parallel Programming

Different approaches for programming on parallel and distributed computing systems include:

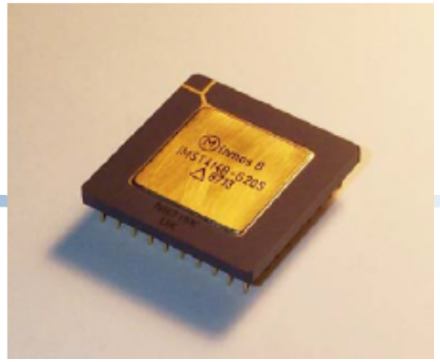
- Dedicated languages designed specifically for parallel computers
- Smart compilers, which automatically parallelise sequential codes
- Data parallelism: multiple processors run the same operation on different elements of a data structure
- Task parallelism: multiple processors run different operations

- Two classes of parallelism according to computer architecture

- Shared memory: processors share a common address space
- distributed memory: the memory in each processor has its own address space

Specially Designed Language

Occam



Occam is a concurrent programming language

Occam is an executable implementation of Communicating Sequential Processes (CSP) theory

CSP: a mathematical theory for describing the interactions of tasks in a concurrent system

Can theoretically prove if the program written in Occam is correct

Occam is specially designed to make full use of the features of a custom-designed computer system, which is built with the *transputer* (transistor computer) chips, developed by INMOS

Transputer is the first microprocessor specially designed for parallel computing

A number of transputer chips are wired to form a complete computer system (no bus, RAM or OS)

In Occam, the processes communicate through channels

Channel can be regarded as the message passing mechanism within a computer

Occam

Sequential execution:

```
SEQ
   x := x + 1
   y := x * x
```


Parallel execution:

```
PAR
   p()
   q()
```

Communication between processes:

```
ProcessA ! Channel_var
ProcessB ? Channel_var
```

Occam

The Occam language was not popular

- **Poor portability**
- **Transputer chip is very expensive**

For more information:

Occam 2 reference manual

www.wotug.org/occam/documentation/oc21refman.pdf

Occam archive

http://vl.fmnet.info/occam/

Transputer

http://en.wikipedia.org/wiki/INMOS_Transputer

Dedicated languages

In general dedicated languages are going to do a better job

1. **Designed with the hardware architecture**
2. **Structure of the language reflects the nature of parallelism**

However

1. **Niche languages are not generally popular**
2. **It's hard to port existing code**

Much better to modify and extend an existing language to include parallelism, because

1. **Better audience**
2. **Only need to learn new constructs or API, not a new language**
3. **Porting is a lot easier**

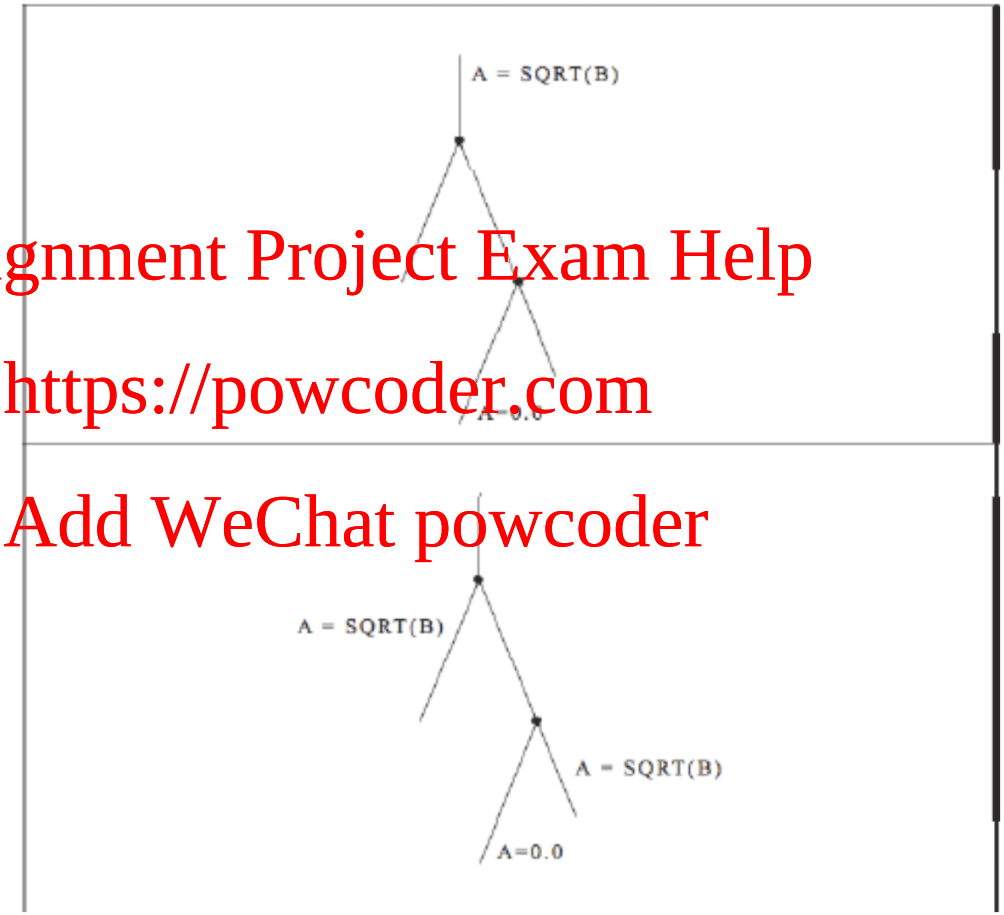
Compiler Approach

Compiler Approach

- Automatically parallelize the sequential codes
- Very conservative
- Re-implementing the code in an more efficient way
- Can remove the dependency if possible

Re-implement the code in compilation

Before:



After:

Removing the dependency

Anti-dependency and output-dependency can be removed by renaming the variables

Dependency and Parallelism (revisit)

- Dependency: If instruction A must finish before instruction B can run, then B is dependent on A

- Two types of Dependency

  - Control dependency: waiting for the instruction which controls the execution flow to be completed

    - IF (X!=0) Then Y=1.0/X: Y=1.0/X has the control dependency on X!=0

  - Data dependency: dependency because of calculations or memory access

    - Flow dependency: A=X+Y; B=A+C;
    - Anti-dependency: B=A+C; A=X+Y;
    - Output dependency: A=2; X=A+1; A=5;

Removing the dependency

Anti-dependency and output-dependency can be removed by renaming the variables

Anti-dependency:

Before:

```
Y=2 * X
X= 5
```

After:

```
Y=2 * X
X1= 5
```

Output-dependency:

Before:

```
X=A/B
Y=X+2.0
X=D – E
```

After:

```
X=A/B
Y=X+2.0
X1=D – E
```

Examples of automatic parallelization by compiler

A compiler takes code written in a standard language (e.g. C or Fortran) and automatically compiles it to be run in parallel (e.g. by parallelizing loops)

Example 1:

```
DO I=1, N
    A(I)=A(I)+B(I)
ENDDO
```


Example 2:

```
DO I=2, N
   A(I)=A(I-1)+B(I)
ENDDO
```

Compiling the code:

```
f90 –O3 –autopar foo.f
```

Can this loop be parallelised?

Example 3:

```
DO I=2, N
        A(I)=2*B(I)
        C(I)=A(I)+C(I);

ENDDO
```

Features of the Compiler approach

- Can work fairly well for some regular problems
- Fully automatic (efficient) parallelisation is difficult, and unlikely to be efficient in general

Assisting Compiler

Programmers can assist the compiler by writing the code in a way that explicitly expresses the parallelism in the program

- **Usually done using directives (pseudo-comments that instruct the compiler where parallelism lies)**
- **During 1990s OpenMP emerged as a common set of directives for implementing various types of parallel execution and synchronization**
- **Add these to serial code (and ignored if targeting a single processor machine)**
- **Explicit parallelism: we are instructing the compiler what to do**
- **We cannot blame the compiler but ourselves if there is something wrong**

Examples of Assisting Compilers

Correct:

```
C$OMP PARALLEL
        DO I=1, N
                A(I)=A(I)+B(I)
        ENDDO
C$OMP END PARALLEL
```


Wrong:

```
C$OMP PARALLEL
        DO I=2, N
                A(I)=A(I-1)+B(I)
        ENDDO
C$OMP END PARALLEL
```

Compilers

For more information on this subject area see:

- Further reading in High Performance Compilers for Parallel Computing, Michael Wolfe
- Vectorizing C Compilers: how good are they? Lauren Smith, ACM/IEEE Conference on Supercomputing
- Parallelizing and Vectorizing Compilers, Eigenmann and Hoeflinger, (also on course web page)

Data Parallelism

Task parallelism vs. Data parallelism

Task parallelism:

```
if CPU="a" then
        do task “A”
else if CPU="b" then
        do task "B"
end if
```


Data parallelism:

```
d is an one-dimensional array
if CPU="a" then
        low_limit=1; upper_limit=50
else if CPU="b" then
        low_limit=51; upper_limit=100
end if
do i = low_limit , upper_limit
        Task on d(i)
end do
```

Data parallelism

- If we are applying the same operation to every element in an array (or list, set, tree, database or whatever) then we may be able to exploit data parallelism
- F90 and HPF provide the support for Data parallelism
- F90 and HPF allow scalar operations to be applied to arrays to support the data parallelism
  - adding two matrixes can be written as

A = B + C *! A, B, C are arrays*

which is equivalent to

```
do i = 1,m
    do j = 1,n
        A(i,j) = B(i,j) + C(i,j)
    enddo
enddo
```

The former expression is called explicit parallel statement while the latter expression called implicit parallel statements (the latter can be parallelised by the compiler if possible)

Data parallelism

A *data parallel* program is a sequence of explicitly and/or implicitly parallel statements

The compiler can partition the data into disjoint sub-domains, one per processor

Data placement is an essential part of data-parallelism, and if you get *the data locality* wrong, you will take a performance hit

Fortunatelly, compilers can achieve data partition, data allocation/placement, data communications

Data parallelism

A data-parallel programming is higher-level than the message passing-type approach

- programmer does not need to specify communication structures
- this is done by the compiler (inferred from the program and underlying computer architecture)

However,

- not all algorithms can be specified in data parallel terms
- if the program has irregular communication patterns then this will be compiled less efficiently

Examples of data parallel languages include F90 and HPF