Programming Paradigms

- Imperative Programming – Fortran, C, Pascal
- Functional Programming – Lisp
- Object Oriented Programming – Simula, C++, Smalltalk
- Logic Programming - Prolog

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Parallel Programming

A misconception occurs that parallel programs are difficult to write as compared to sequential programmes. Consider the situations:

- ✓ Write a sequential programme and its multiple copies on a parallel computer. Parallelism remains transparent to the user.
- ✓ Write an Oracle application. Oracle is implicitly parallel. Run it on a parallel machine. Similarly parallel C and FORTRAN90.

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Parallel Programming

A parallel computer should be flexible and easy to use. This will depend upon its architecture and the way we write a parallel program on it.

Let us consider various Parallel Programming paradigms:

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Parallel Programming Paradigm

- Phase parallel
- Divide and conquer
- Pipeline
- Process farm
- Work pool
- Remark :

The parallel program consists of number of super steps, and each super step has two phases : *computation phase and interaction phase*

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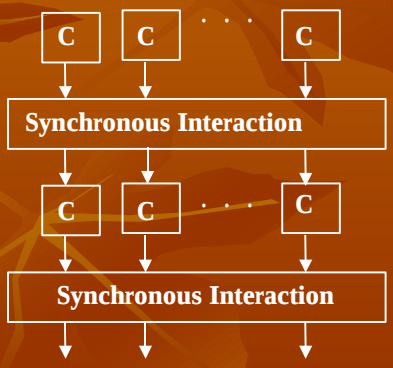
Phase Parallel Model



- The phase-parallel model offers a paradigm that is widely used in parallel programming.
- The parallel program consists of a number of supersteps, and each has two phases.
- In a computation phase, multiple processes each perform an independent computation *C*.
- In the subsequent interaction phase, the processes perform one or more synchronous interaction operations, such as a barrier or a blocking communication.
- Then next superstep is executed.

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Phase Parallel Model

This paradigm is also known as Loosely Synchronous Paradigm or the Agenda Paradigm.

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Phase Parallel Model Shortcomings

- Interaction is not overlapped with computation
- It is difficult to maintain balanced workload amongst processors.

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Phase Parallel Model

A special case of Phase-Parallel Paradigm is Synchronous Iteration Paradigm where the supersteps are a sequence of iterations in a loop.

Consider the example of computing x=f(x) where x is an n-dimensional vector.

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Synchronous Iteration Paradigm

```
parfor (i=0; i<n; i++)   //create n processes
                         //each executing a for loop
{
  for (j=0; j<N; j++)
    {
      x[i] = f_i(x);
      barrier;
    }
  }
```

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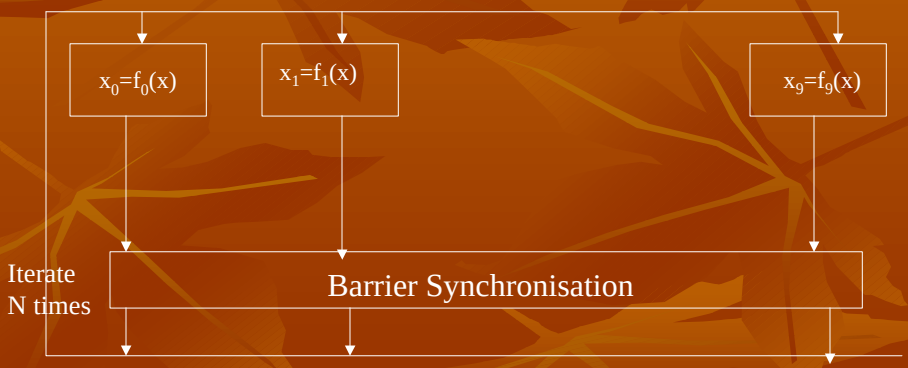
Synchronous Iteration Paradigm

For n = 9 we have



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Asynchronous Iteration Paradigm

```
parfor (i=0; i<n; i++)
{
  for (j=0; j<N; j++)
    x[i] = f_i(x);
  }
```

It allows a process to proceed to the next iteration, without waiting for the remaining processes to catch up.

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Asynchronous Iteration Paradigm

The above code could be indeterminate, because when a process is computing x[i] in the jth iteration, the x[i-1] value used could be computed by another process in iteration j-1.

However, under certain conditions, an asynchronous iteration algorithm will converge to the correct results and is faster than the synchronous iteration algorithm.

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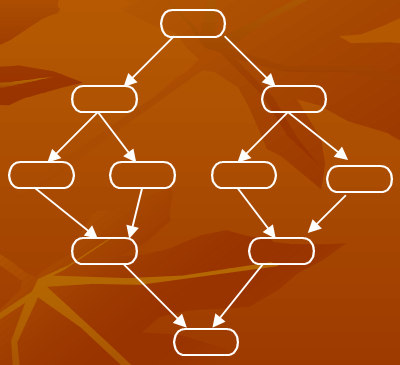
Divide and Conquer



- A parent process divides its workload into several smaller pieces and assigns them to a number of child processes.
- The child processes then compute their workload in parallel and the results are merged by the parent.
- The dividing and the merging procedures are done recursively.
- This paradigm is very natural for computations such as quick sort. Its disadvantage is the difficulty in achieving good load balance.

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Pipeline

- In pipeline paradigm, a number of processes form a virtual pipeline.
- A continuous data stream is fed into the pipeline, and the processes execute at different pipeline stages simultaneously in an overlapped fashion.

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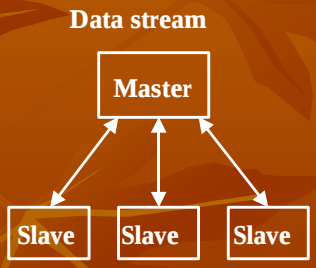
Process Farm



- This paradigm is also known as the master-slave paradigm.
- A master process executes the essentially sequential part of the parallel program and spawns a number of slave processes to execute the parallel workload.
- When a slave finishes its workload, it informs the master which assigns a new workload to the slave.
- This is a very simple paradigm, where the coordination is done by the master.

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Process Farm Disadvantage

The master can become a bottleneck.

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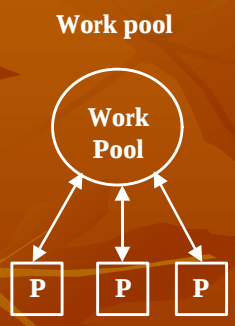
Work Pool



- This paradigm is often used in a shared variable model.
- A pool of works is realized in a global data structure.
- A number of processes are created. Initially, there may be just one piece of work in the pool.
- Any free process fetches a piece of work from the pool and executes it, producing zero, one, or more new work pieces put into the pool.
- The parallel program ends when the work pool becomes empty.
- This paradigm facilitates load balancing, as the workload is dynamically allocated to free processes.

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Work Pool

Implementing the work pool to allow efficient accesses by multiple processes is not easy especially in a message passing model. The work pool may be an unordered set, a queue or a priority queue.

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Programmability Issues

We define programmability as a combination of

- ✓ Structuredness
- ✓ Generality
- ✓ Portability

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Parallel Programming Models

Implicit parallelism

- If the programmer does not explicitly specify parallelism, but let the compiler and the run-time support system automatically exploit it.

Explicit Parallelism

- It means that parallelism is explicitly specified in the source code by the programming using special language constructs, complex directives, or library cells.

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Implicit Parallel Programming Models

Implicit Parallelism: Parallelizing Compilers

- Automatic parallelization of sequential programs
  - Dependency Analysis
  - Data dependency
  - Control dependency

Remark

Users belief is influenced by the currently disappointing performance of automatic tools (Implicit parallelism) and partly by a theoretical results obtained

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Implicit Parallel Programming Models

Effectiveness of Parallelizing Compilers

- **Question :**
  - **Are parallelizing compilers effective in generalizing efficient code from sequential programs?**
    - **Some performance studies indicate that may not be a effective**
    - **User direction and Run-Time Parallelization techniques are needed**

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Implicit Parallel Programming Models

Implicit Parallelism

- Bernstein's Theorem
  - It is difficult to decide whether two operations in an imperative sequential program can be executed in parallel
  - An implication of this theorem is that there is no automatic technique, compiler time or runtime that can exploit all parallelism in a sequential program

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Implicit Parallel Programming Models

To overcome this theoretical limitation, two solutions have been suggested

- The first solution is to abolish the imperative style altogether, and to use a programming language which makes parallelism recognition easier
- The second solution is to use explicit parallelism

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Explicit Parallel Programming Models

Three dominant parallel programming models are :

- Data-parallel model
- Message-passing model
- Shared-variable model

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Explicit Parallel Programming Models

Main Features	Data-Parallel	Message-Passing	Shared-Variable
Control flow (threading)	Single	Multiple	Multiple
Synchrony	Loosely synchronous	Asynchronous	Asynchronous
Address space	Single	Multiple	Multiple
Interaction	Implicit	Explicit	Explicit
Data allocation	Implicit or semiexplicit	Explicit	Implicit or semiexplicit

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Explicit Parallel Programming Models

Message – Passing

- Message passing has the following characteristics :
  - Multithreading
  - Asynchronous parallelism (MPI reduce)
  - Separate address spaces (Interaction by MPI/PVM)
  - Explicit interaction
  - Explicit allocation by user

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Explicit Parallel Programming Models

Message – Passing

- **Programs are multithreading and asynchronous requiring explicit synchronization**
- **More flexible than the data parallel model, but it still lacks support for the work pool paradigm.**
- **PVM and MPI can be used**
- **Message passing programs exploit large-grain parallelism**

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Explicit Parallel Programming Models

Shared Variable Model

- It has a single address space (Similar to data parallel)
- It is multithreading and asynchronous (Similar to message-passing model)
- Data resides in single shared address space, thus does not have to be explicitly allocated
- Workload can be either explicitly or implicitly allocated
- Communication is done implicitly through shared reads and writes of variables. However synchronization is explicit

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Explicit Parallel Programming Models

Shared variable model

- The shared-variable model assumes the existence of a single, shared address space where all shared data reside
- Programs are multithreading and asynchronous, requiring explicit synchronizations
- Efficient parallel programs that are loosely synchronous and have regular communication patterns, the shared variable approach is not easier than the message passing model

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Other Parallel Programming Models

- Functional programming
- Logic programming
- Computing by learning
- Object oriented programming

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