Exploiting More ILP

- ILP = __________________ __________________ (parallelism within a single program)
- How can we exploit more ILP?
  1. ________________
     (Split execution into many stages)
  2. ________________
     (Start executing more than one instruction each cycle)

Multi-processing in SOME form... (chapter 6)

1. Multi-processors – multiple CPUs in a system
2. Multi-core – multiple CPUs on a single chip
3. Clusters – machines on a network working together

Idea: create powerful computers by connecting many smaller ones

- good news: works for timesharing (better than supercomputer)
- bad news: its really hard to write good concurrent programs many commercial failures

Multiple Issue Processors

- Key metric: CPI \( \rightarrow \) IPC
- Key questions:
  1. What set of instructions can be issued together?
  2. Who decides which instructions to issue together?
     - Static multiple issue
     - Dynamic multiple issue
Who? When? Why?

• “For over a decade prophets have voiced the contention that the organization of a single computer has reached its limits and that truly significant advances can be made only by interconnection of a multiplicity of computers in such a manner as to permit cooperative solution.... Demonstration is made of the continued validity of the single processor approach...”

• “...it appears that the long-term direction will be to use increased silicon to build multiple processors on a single chip.”

Multiprocessor/core: How do processors SHARE data?

1. Shared variables in memory
   - Symmetric Multiprocessor
   - Uniform Memory Access
   - Non-Uniform Memory Access

2. Send explicit messages between processors

Flynn’s Taxonomy of multiprocessors(1966)

1. Single instruction stream, single data stream
2. Single instruction stream, multiple data streams
3. Multiple instruction streams, single data stream
4. Multiple instruction streams, multiple data streams
Example Multi-Core Systems (part 1)

- 2 × quad-core Intel Xeon e5345 (Clovertown)
- 2 × quad-core AMD Opteron X4 2356 (Barcelona)

Example Multi-Core Systems (part 2)

- 2 × oct-core Sun UltraSPARC T2 S140 (Niagara 2)
- 2 × oct-core IBM Cell QS20

Clusters

- Constructed from whole computers
- Independent, scalable networks
- Strengths:
  - Many applications amenable to loosely coupled machines
  - Exploit local area networks
  - Cost effective / Easy to expand
- Weaknesses:
  - Administration costs not necessarily lower
  - Connected using I/O bus
- Highly available due to separation of memories
- Approach taken by Google etc.

A Whirlwind tour of Chip Multiprocessors and Multithreading

Slides from Joel Emer’s talk at Microprocessor Forum
**Instruction Issue**

Reduced function unit utilization due to….

**Superscalar Issue**

Superscalar leads to more performance, but lower utilization.

**Chip Multiprocessor**

Limited utilization when only running one thread.

**Fine Grained Multithreading**

Intra-thread dependencies still limit performance.
Simultaneous Multithreading

Maximum utilization of function units by independent operations

Concluding Remarks

- Goal: higher performance by using multiple processors / cores
- Difficulties
  - Developing parallel software
  - Devising appropriate architectures
- Many reasons for optimism
  - Changing software and application environment
  - Chip-level multiprocessors with lower latency, higher bandwidth interconnect
- An ongoing challenge!