DYNAMIC SCHEDULING

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Overview

- Announcement
  - Homework 3 will be uploaded tonight

- This lecture
  - Dynamic scheduling
    - Forming data flow graph on the fly
  - Register renaming
    - Removing false data dependence
    - Architectural vs. physical registers
Goal: exploiting more ILP by avoiding stall cycles

Branch prediction can avoid the stall cycles in the frontend
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  - More instructions are sent to the pipeline
Goal: exploiting more ILP by avoiding stall cycles

- Branch prediction can avoid the stall cycles in the frontend
  - More instructions are sent to the pipeline

- Instruction scheduling can remove unnecessary stall cycles in the execution/memory stage
  - Static scheduling
    - Complex software (compiler)
    - Unable to resolve all data hazards (no access to runtime details)
  - Dynamic scheduling
    - Completely done in hardware
Dynamic Scheduling

Key idea: creating an instruction schedule based on runtime information

Hardware managed instruction reordering

Assembly code:

DIV F1, F2, F3  ▶️ Long latency operation
ADD F4, F1, F5  ▶️ Dependent instruction
SUB F6, F5, F7  ▶️ Independent instruction

Out-of-order execution?
Dynamic Scheduling

- **Key idea:** creating an instruction schedule based on runtime information
  - Hardware managed instruction reordering
  - Instructions are executed in data flow order

Program code

```
ADDI  R1, R0, #1
ADDI  R2, R0, #4
ADD   R3, R3, R2
ADD   R2, R2, #1
BNEQ R2, R1, next
BNEQ R2, R0, loop
ADD   R4, R4, R3
BNEQ R2, R0, loop
```

How to form data flow graph on the fly?
Register Renaming

- Eliminating WAR and WAW hazards
  - Change the mapping between architectural registers and physical storage locations

WAR and WAW hazards can be removed using more registers
Register Renaming

- Eliminating WAR and WAW hazards
  1. allocate a free physical location for the new register
  2. find the most recently allocated location for the register

DIV  F1, F2, F3
ADD  F4, F1, F5
SUB  F5, F6, F7
ADD  F4, F5, F8

DIV  P12, P11, P13
Register Renaming

- Eliminating WAR and WAW hazards
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Register Renaming

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### Architectural Registers

| DIV   | F1, F2, F3 |
| ADD   | F4, F1, F5 |
| SUB   | F5, F6, F7 |
| ADD   | F4, F5, F8 |

### Physical Locations

| DIV   | P12, P11, P13 |
| ADD   | P14, P12, P15 |
| SUB   | P19, P17, P13 |

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