Pipelined Scheduling

- Allowing a resource/circuit to operate on multiple operations/data sets at the same time
  - Structural Pipelining
  - Functional Pipelining
Structural Pipelining

- Pipelined resources used
  - Multiplier, divider, …
  - Characterized by
    - Execution delay
    - Data introduction interval, DII
- Operations with NO data dependency
- Operations that DO NOT start in the same step
Structural Pipelining

- Known scheduling heuristics can be modified
  - Relax vertex selection criterion of list scheduling
Structural Pipelining

1 pipelined multiplier, DII = 1, latency = 2 cycles
1 non-pipelined alu, latency = 1 cycle

Operation Start Time
MUL ALU
{1} {2} 1
{3} {4} 2
{5} {6} 3

Schedule latency = 5 cycles
Without pipelining = 6 cycles
Functional Pipelining

• Hardware separated into stages
  – Source restarts before sink finishes
  – Data-introduction interval $\delta$
    • (input/specification dependent)
Degree of Pipelining

- $\delta$ determines resource requirement
  - Smaller $\delta$ means more overlap of operations, more resources needed
    - #of operations of type $k = N_k$
    - For a given $\delta$, LB on resource of type $k = \left\lceil \frac{N_k}{\delta} \right\rceil$
Pipelining and Concurrency

• Concurrent operations
  - Operations v and q are executing simultaneously at control step l if
    • \( \text{rem}(t_v/\delta) = \text{rem}(t_q/\delta) = l \)
  - Affects the design of the controller
Assume unit delay for all operations
For $\delta = 2$ we need
\[
\begin{bmatrix} 3 / 2 \end{bmatrix} = 2 \text{ multipliers}
\]
\[
\begin{bmatrix} 3 / 2 \end{bmatrix} = 2 \text{ ALUs}
\]
Scheduling in Presence of Loops

- Potential parallelism across loop iterations
- Sequential Execution
- Loop unfolding
  - Replication of iterations
- Loop folding
Loop Folding

- Number of iterations = n
- Latency of one iteration = $\lambda$
- Loop latency = $n\lambda$
- Fold loop iterations with $\delta < \lambda$
  - Pipeline the sequencing graph of the loop body
- Latency of folded loop = $n\delta + $ overhead
- Overhead = $\left\lceil \frac{\lambda}{\delta} \right\rceil - 1$