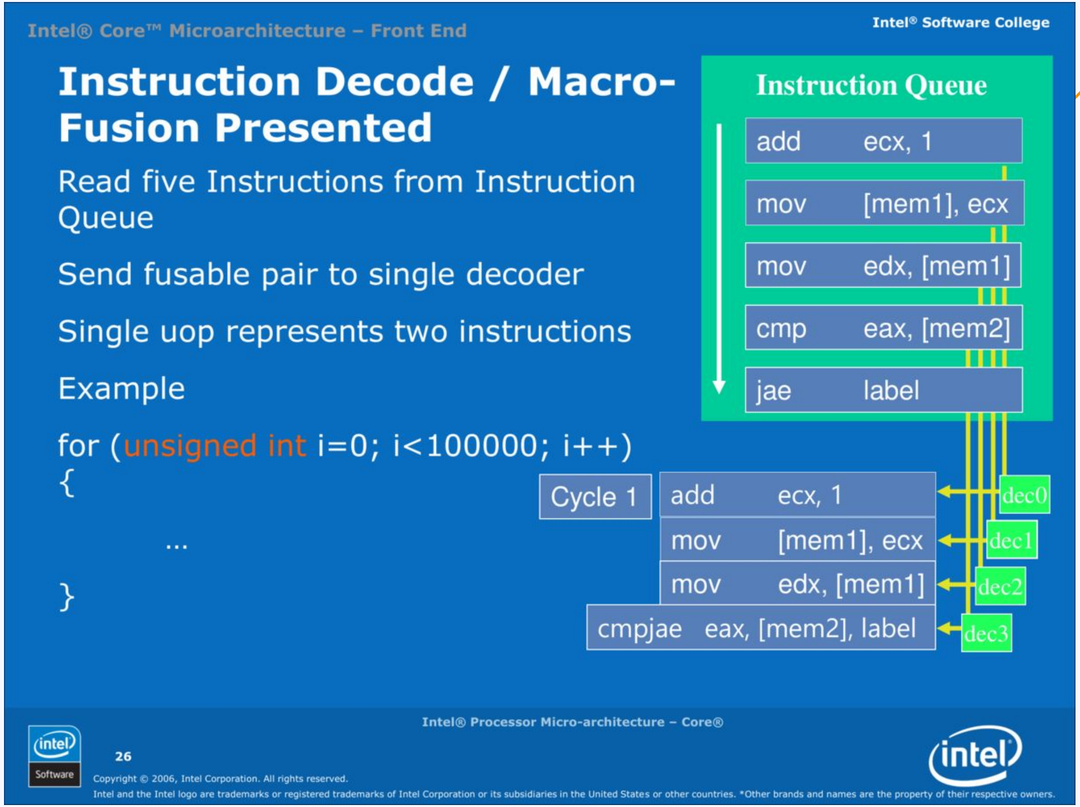
Compiler-supported ILP

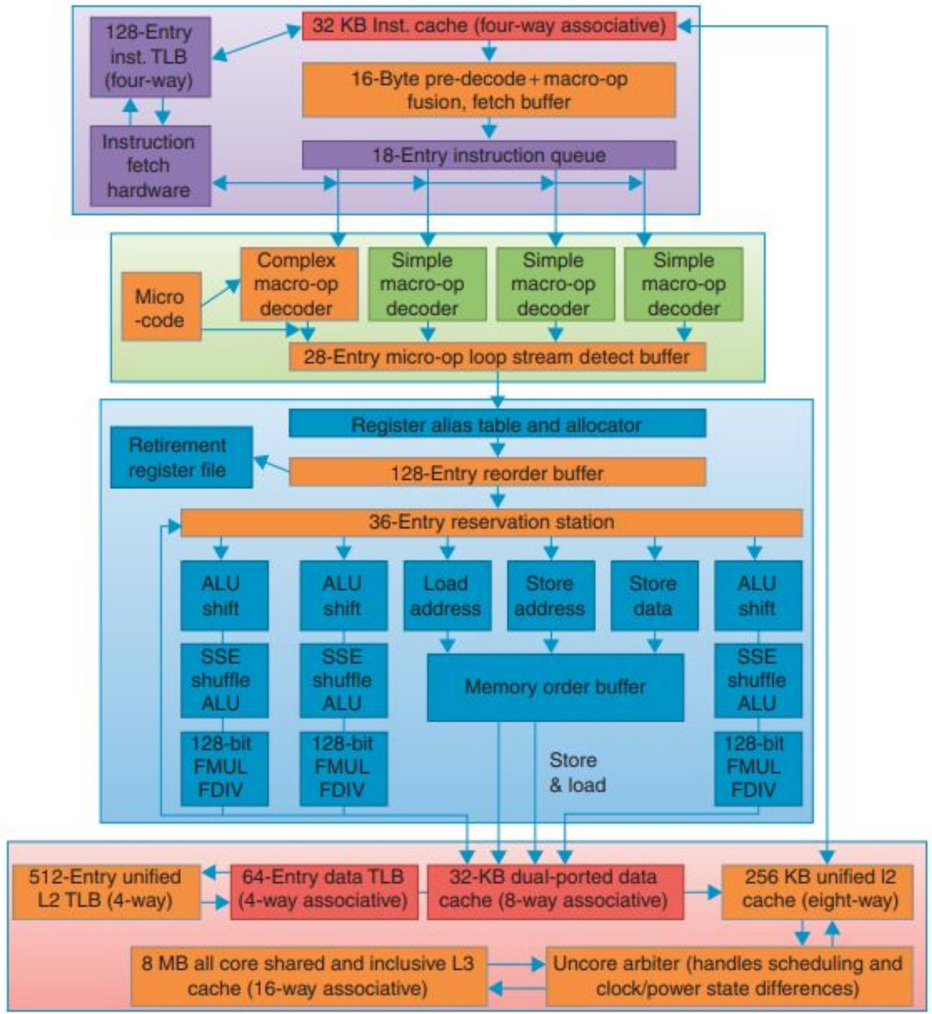
Macro-op fusion

<u>*source*</u>



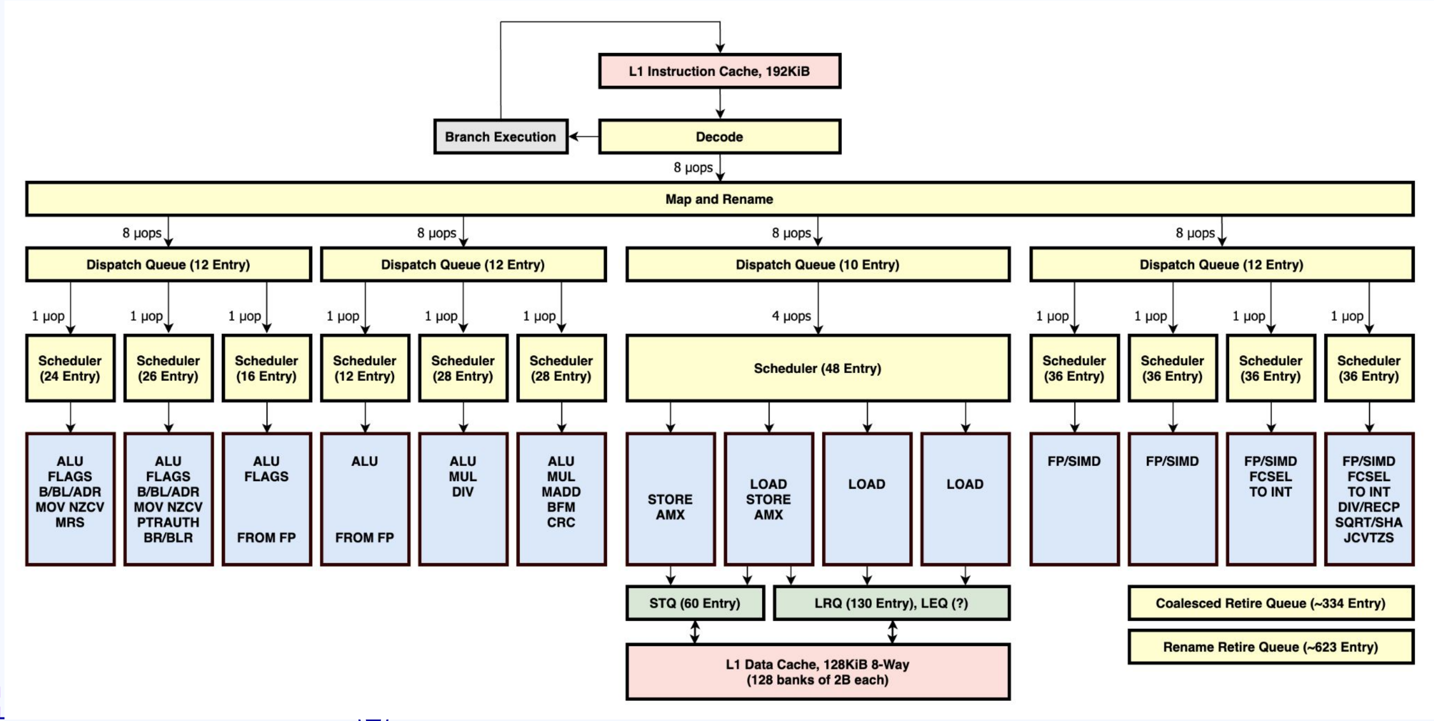
Intel Core i7 (H&P fig. 3.41)

Pre-decode??
Complex macro-op decoder??
Loop stream detect??



Firestorm (Apple M1)

Source (NOTE: reverse-engineered: might not be fully accurate)

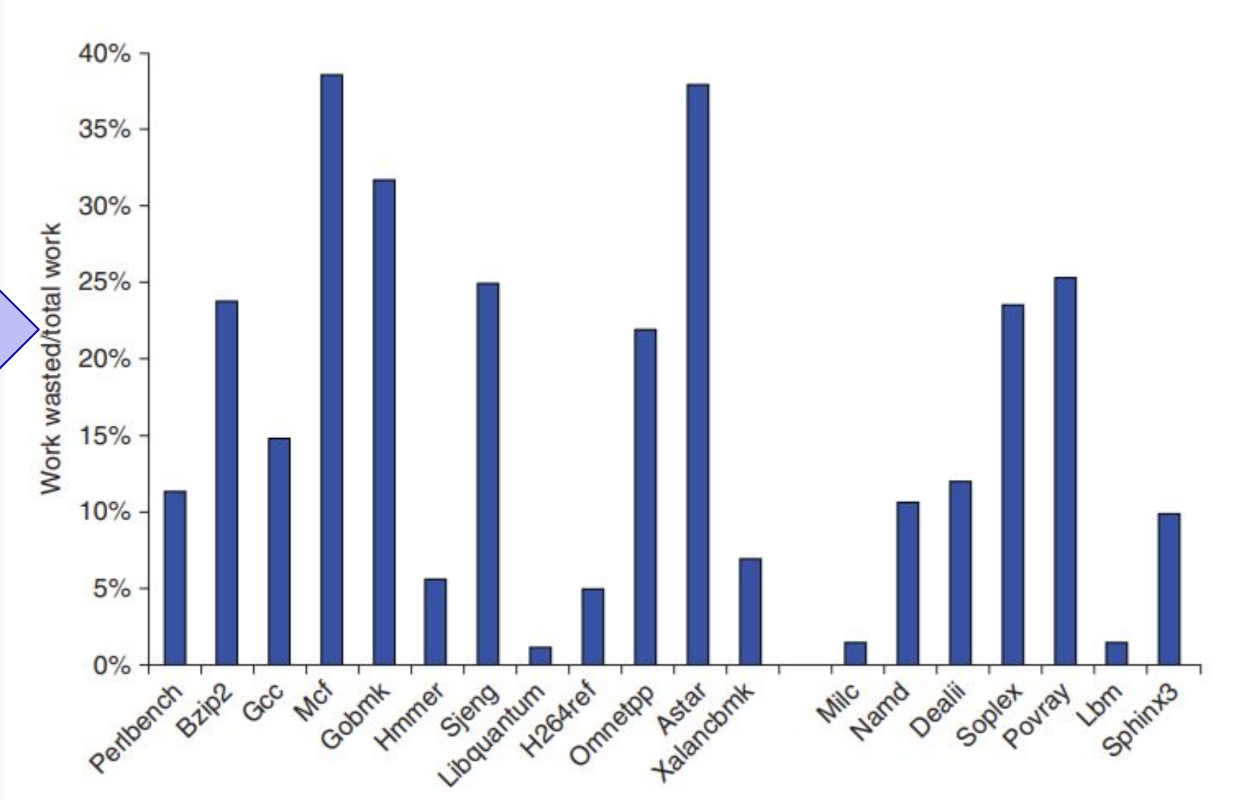


? ? ?

What performance metrics (beyond CPI) might become important in a speculative CPU?

H&P fig. 3.42

% of executed uops that were not committed



? ? ?

What effects would speculative execution have on the memory system?
(Hint: think protected access and/or caches)

Remember this question?

? ? ?

What else could we parallelize here?

```
for (int i = 0; i < 100; i++) {
    A[i] = A[i] + B[i];
}
```

A simpler example

```
addi t0, x0, 0   // t0/i = 0
addi t1, x0, 100 // t1 = 100
loop: bge t0, t1, end
slli t2, t0, 2   // t2 = t0/i * 4
add t2, a0, t2   // t2 = A + t2
lw t3, 0(t2)     // t3 = A[i]
add t3, t3, a1   // t3 = A[i] + c
sw t3, 0(t2)     // A[i] = A[i] +c
addi t0, t0, 1   // t0/i++
j loop
end: nop
```

```
for (int i = 0; i < 100; i++) {
    A[i] = A[i] + c;
}
```

Reduce # of computations in loop

```
addi t0, x0, 0    // t0/i = 0
addi t1, x0, 100 // t1 = 100
loop: bge t0, t1, end
slli t2, t0, 2    // t2 = t0/i * 4
add t2, a0, t2    // t2 = A + t2
lw t3, 0(t2)      // t3 = A[i]
add t3, t3, a1    // t3 = A[i] + c
sw t3, 0(t2)      // A[i] = A[i] +c
addi t0, t0, 1    // t0/i++
j loop
end: nop
```

```
addi t0, x0, 0    // t0/i = 0
addi t1, x0, 100 // t1 = 100
addi t2, a0, 0 // t2 = A
loop: bge t0, t1, end
lw t3, 0(t2)      // t3 = A[i]
add t3, t3, a1    // t3 = A[i] + c
sw t3, 0(t2)      // A[i] = A[i] +c
addi t2, t2, 4    // advance pointer
addi t0, t0, 1    // t0/i++
j loop
end: nop
```

Get rid of i

```
addi t0, x0, 0   // t0/i = 0
addi t1, x0, 100 // t1 = 100
addi t2, a0, 0 // t2 = A
loop: bge t0, t1, end
lw t3, 0(t2)     // t3 = A[i]
add t3, t3, a1   // t3 = A[i] + c
sw t3, 0(t2)     // A[i] = A[i] +c
addi t2, t2, 4   // advance pointer
addi t0, t0, 1   // t0/i++
j loop
end: nop
```

```
addi t2, a0, 0 // t2 = A
addi t1, a0, 400 // stop before A[100]
loop: bge t2, t1, end
lw t3, 0(t2)      // t3 = A[i]
add t3, t3, a1    // t3 = A[i] + c
sw t3, 0(t2)      // A[i] = A[i] +c
addi t2, t2, 4    // advance pointer
j loop
end: nop
```

? ? ?

What else could a compiler do?

```
addi t2, a0, 0 // t2 = A
addi t1, a0, 400 // stop before A[100]
loop: bge t2, t1, end
lw t3, 0(t2)      // t3 = A[i]
add t3, t3, a1    // t3 = A[i] + c
sw t3, 0(t2)      // A[i] = A[i] +c
addi t2, t2, 4    // advance pointer
j loop
end: nop
```

Loop unrolling

? ? ?

What if we don’t know the # of iterations through the loop at compile time?

```
int (i = 0; i < input_max; i++)
```

Dynamic loop size

```
for (int i = 0; i < input_max % 4; i++) {
     // do loop body
}
for (int j = input_max % 4; j < input_max; j += 4) {
   // unrolled loop body (4x)
}
```

? ? ?

Besides compiler complexity, what is a downside to loop unrolling?
(Could aggressive unrolling reduce performance?)

? ? ?

Could we unroll this loop?

```
for (int i = 0; i < 100; i++) {
    A[i + 1] = A[i] + C[i];
    B[i + 1] = B[i] + A[i + 1];
}
```

? ? ?

Could we unroll this loop?

```
for (int i = 0; i < 100; i++) {
    A[i] = A[i] + B[i];
    B[i + 1] = C[i] + D[i]
}
```

Detecting loop dependences

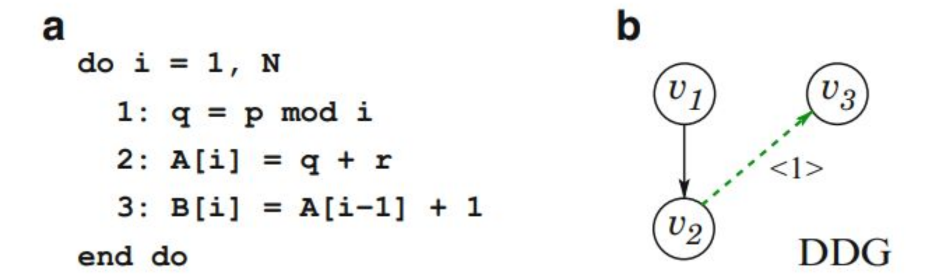


Figure 6.5 : Intra-iteration and loop carried dependences

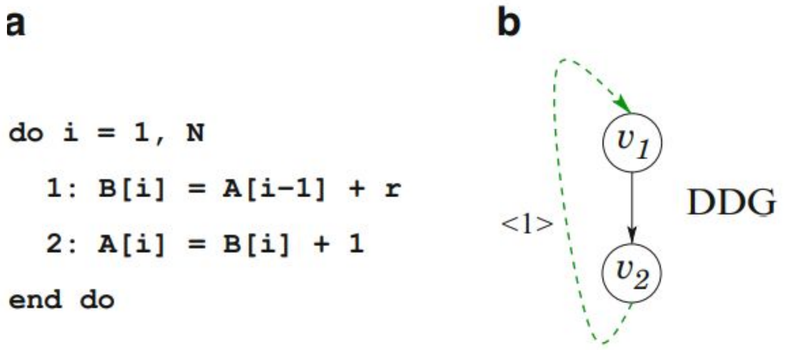


Figure 6.6 : Loop recurrences

From *Instruction Level Parallelism* by Aiken, Banerjee, Kejariwal, Nicolau

Other static ILP approaches

Software pipelining

- Pipeline dependent instructions within a loop

Global scheduling

- Move instructions across basic blocks

Trace scheduling

- Find a trace (common path through program) of multiple basic blocks
- Rearrange and parallelize instructions within trace
- Need "compensation code" in case branching into/out of trace

VLIW (Very Long Instruction Word)

Compiler packs instructions into one long instruction word

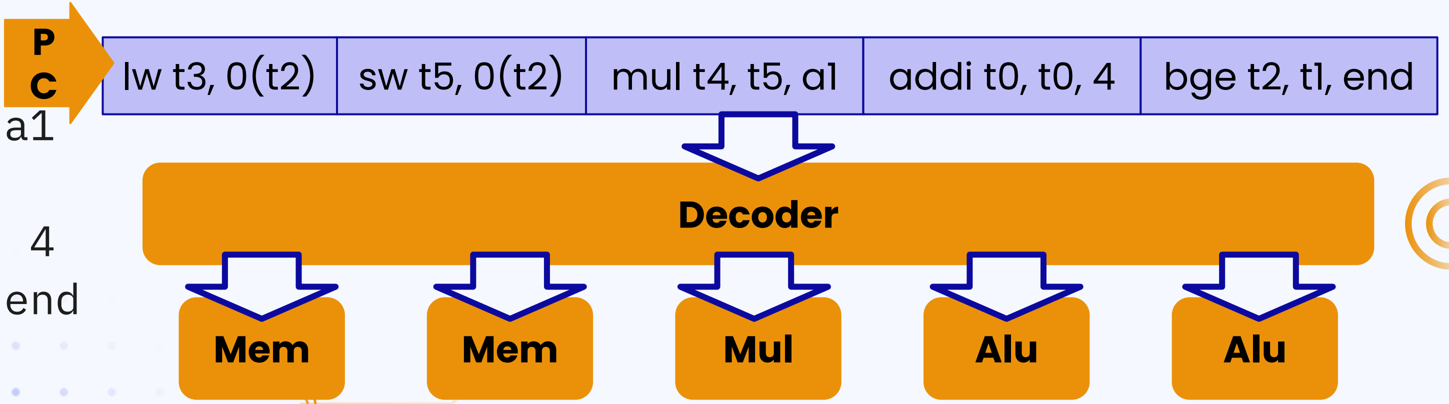
Early VLIW: no dependences between instructions, units operate in lockstep

Pairs with loop unrolling, trace scheduling

Pros:

Cons:

```
lw t3, 0(t2)
mul t4, t5, a1
sw t5, 0(t2)
addi t2, t2, 4
bge t6, t1, end
```



What tradeoffs do you see between dynamic and static ILP? Which do you like more? Can you imagine ways to combine them?