Code Shape IV
Booleans, Relationals, & Control flow

COMP 412
Fall 2005

Boolean & Relational Values

How should the compiler represent them?

- Answer depends on the target machine

Two classic approaches

- Numerical representation
- Positional (implicit) representation

Correct choice depends on both context and ISA

Boolean & Relational Values

Numerical representation

- Assign values to TRUE and FALSE
- Use hardware AND, OR, and NOT operations
- Use comparison to get a boolean from a relational expression

Examples

x < y	***becomes***	**cmp_LT $r_x, r_y \Rightarrow r_1$**
if (x < y) **then $stmt_1$** **else $stmt_2$**	***becomes***	**cmp_LT $r_x, r_y \Rightarrow r_1$** **cbr $r1 \rightarrow \_stmt_1, \_stmt_2$**

Boolean & Relational Values

What if the ISA uses a condition code?

- Must use a conditional branch to interpret result of compare
- Necessitates branches in the evaluation

Example:

			cmp	$r_x, r_y \Rightarrow cc_1$
			cbr_LT	$cc_1 \rightarrow L_T, L_F$
$x < y$	***becomes***	L_T:	**loadI**	$1 \Rightarrow r_2$
			br	$\rightarrow L_E$
		L_F:	**loadI**	$0 \Rightarrow r_2$
		L_E:	**…other stmts…**	

This "positional representation" is much more complex

Boolean & Relational Values

Editorial comment: (KDC)
This is an evil, seductive idea

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Example:

x < y ***becomes***

	cmp	$r_x, r_y \Rightarrow cc_1$
	cbr_LT	$cc_1 \rightarrow L_T, L_F$
L_T:	**loadI**	$1 \Rightarrow r_2$
	br	$\rightarrow L_E$
L_F:	**loadI**	$0 \Rightarrow r_2$
L_E:	**...other stmts...**	

Condition codes

- are an architect's hack
- allow ISA to avoid some comparisons
- complicates code for simple cases

This "positional representation" is much more complex

Boolean & Relational Values

The last example actually encodes result in the PC

If result is used to control an operation, this may be enough

Example
if (x < y)
then a ← c + d
else a ← e + f

Variations on the ILOC Branch Structure

	Straight Condition Codes			*Boolean Compares*	
	comp	$r_x, r_y \Rightarrow cc_1$		cmp_LT	$r_x, r_y \Rightarrow r_1$
	cbr_LT	$cc_1 \rightarrow L_1, L_2$		cbr	$r_1 \rightarrow L_1, L_2$
L_1:	add	$r_c, r_d \Rightarrow r_a$	L_1:	add	$r_c, r_d \Rightarrow r_a$
	br	$\rightarrow L_{OUT}$		br	$\rightarrow L_{OUT}$
L_2:	add	$r_e, r_f \Rightarrow r_a$	L_2:	add	$r_e, r_f \Rightarrow r_a$
	br	$\rightarrow L_{OUT}$		br	$\rightarrow L_{OUT}$
L_{OUT}:	nop		L_{OUT}:	nop	

Condition code version does not directly produce (x < y)

Boolean version does

Still, there is no significant difference in the code produced

Boolean & Relational Values

Conditional move & predication both simplify this code

Example
if (x < y)
then a ← c + d
else a ← e + f

Other Architectural Variations				
Conditional Move		***Predicated Execution***		
comp	$r_x, r_y \Rightarrow cc_1$		cmp_LT	$r_x, r_y \Rightarrow r_1$
add	$r_c, r_d \Rightarrow r_1$	(r_1)?	add	$r_c, r_d \Rightarrow r_a$
add	$r_e, r_f \Rightarrow r_2$	$(\neg r_1)$?	add	$r_e, r_f \Rightarrow r_a$
i2i_<	$cc_1, r_1, r_2 \Rightarrow r_a$			

This may not be realistic

Both versions avoid the branches

Both are shorter than cond'n codes or Boolean-valued compare

Are they better?

Boolean & Relational Values

Consider the assignment $x \leftarrow a < b \wedge c < d$

VARIATIONS ON THE ILOC BRANCH STRUCTURE

Straight Condition Codes			***Boolean Compare***	
	comp	$r_a,r_b \Rightarrow cc_1$	cmp_LT	$r_a,r_b \Rightarrow r_1$
	cbr_LT	$cc_1 \rightarrow L_1,L_2$	cmp_LT	$r_c,r_d \Rightarrow r_2$
L_1:	comp	$r_c,r_d \Rightarrow cc_2$	and	$r_1,r_2 \Rightarrow r_x$
	cbr_LT	$cc_2 \rightarrow L_3,L_2$		
L_2:	loadI	$0 \Rightarrow r_x$		
	br	$\rightarrow L_{OUT}$		
L_3:	loadI	$1 \Rightarrow r_x$		
	br	$\rightarrow L_{OUT}$		
L_{OUT}:	nop			

Here, the boolean compare produces much better code

Boolean & Relational Values

Conditional move & predication help here, too

$x \leftarrow a < b \wedge c < d$

Other Architectural Variations			
Conditional Move		***Predicated Execution***	
comp	$r_a,r_b \Rightarrow cc_1$	**cmp_LT**	$r_a,r_b \Rightarrow r_1$
i2i_<	$cc_1,r_T,r_F \Rightarrow r_1$	**cmp_LT**	$r_c,r_d \Rightarrow r_2$
comp	$r_c,r_d \Rightarrow cc_2$	**and**	$r_1,r_2 \Rightarrow r_x$
i2i_<	$cc_2,r_T,r_F \Rightarrow r_2$		
and	$r_1,r_2 \Rightarrow r_x$		

Conditional move is worse than Boolean compares

Predication is identical to Boolean compares

The bottom line:

$\Rightarrow$ Context & hardware determine the appropriate choice

Control Flow

If-then-else

- Follow model for evaluating relationals & booleans with branches

Branching versus predication *(e.g., IA-64)*

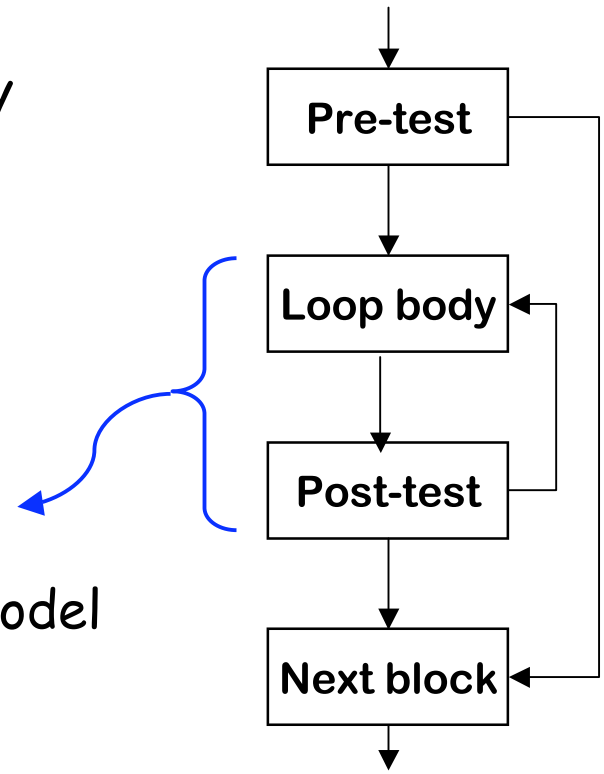
- Frequency of execution
  - Uneven distribution ⇒ do what it takes to speed common case
- Amount of code in each case
  - Unequal amounts means predication may waste issue slots
- Control flow inside the construct
  - Any branching activity within the construct complicates the predicates and makes branches attractive

Control Flow

Loops

- Evaluate condition before loop (if needed)
- Evaluate condition after loop
- Branch back to the top (if needed)

Merges test with last block of loop body



while, for, do, & until all fit this basic model

Implementing Loops

```
for (i = 1; i< 100; i++) { body }
   next statement
```

loadI	$1 \Rightarrow r_1$	Initialization
loadI	$1 \Rightarrow r_2$	Initialization
loadI	$100 \Rightarrow r_3$	Pre-test
cmp_GE	$r_1, r_3 \Rightarrow r_4$	Pre-test
cbr	$r_4 \Rightarrow L_2, L_1$	Pre-test
L_1: *body*		
add	$r_1, r_2 \Rightarrow r_1$	Post-test
cmp_LT	$r_1, r_3 \Rightarrow r_5$	Post-test
cbr	$r_5 \Rightarrow L_1, L_2$	Post-test
L_2: *next statement*		

Break statements

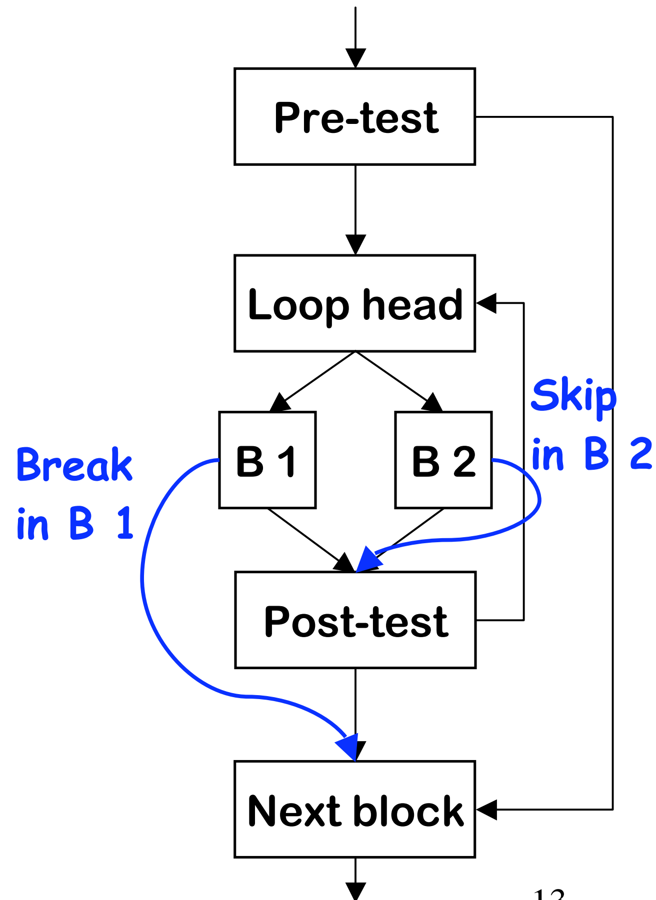
Many modern programming languages include a break

- Exits from the innermost control-flow statement
  - Out of the innermost loop
  - Out of a case statement

Translates into a jump

- Targets statement outside control-flow construct
- Creates multiple-exit construct
- Skip in loop goes to next iteration

Only make sense if loop has > 1 block



Control Flow

Case Statements

1 Evaluate the controlling expression

2 Branch to the selected case

3 Execute the code for that case

4 Branch to the statement after the case

Parts 1, 3, & 4 are well understood, part 2 is the key

Control Flow

Case Statements

1 Evaluate the controlling expression

2 Branch to the selected case

3 Execute the code for that case

4 Branch to the statement after the case (*use break*)

Parts 1, 3, & 4 are well understood, part 2 is the key

Surprisingly many compilers do this for all cases!

Strategies

- Linear search (nested if-then-else constructs)
- Build a table of case expressions & binary search it
- Directly compute an address (requires dense case set)