Code Shape III
Booleans, Relationals, & Control flow

EaC section 7.4 & 7.8

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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 → r_1

if ($l < r$)
stmt$_1$
else
stmt$_2$
	becomes	cmp_LT r_l, r_r → r_1
		cbr r_1 → stmt$_1$, stmt$_2$

conditional branch

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:

$x < y$ becomes cmp r_x, r_y → cc_1

cbr_LT cc_1 → L_T, L_F

L_T: loadI 1 → r_2

br → L_E

L_F: loadI 0 → r_2

L_E: … other stmts …

This “positional representation” is much more complex

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:

$x < y$ becomes

$\text{cmp } r_x, r_y \rightarrow cc_1$
$\text{cbr\_LT } cc_1 \rightarrow L_T, L_F$
L_T: $\text{loadI } 1 \rightarrow r_2$
$\text{br} \rightarrow L_E$
L_F: $\text{loadI } 0 \rightarrow r_2$
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 $\leftarrow$ c + d
  else a $\leftarrow$ 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	

Boolean & Relational Values

Conditional move & predication both simplify this code

Example
if $(x < y)$
then $a \leftarrow c + d$
else $a \leftarrow e + f$

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_<	$cc_1, r_1, r_2 \Rightarrow r_a$			

Both versions avoid the branches

Both are shorter than CCs 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

	comp	$r_a,r_b \Rightarrow cc_1$	
	cbr_LT	cc_1	$\rightarrow L_1,L_2$
L_1:	comp	$r_c,r_d \Rightarrow cc_2$	
	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		

Boolean Compare

cmp_LT	$r_a,r_b \Rightarrow r_1$
cmp_LT	$r_c,r_d \Rightarrow r_2$
and	$r_1,r_2 \Rightarrow r_x$

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 $r_a, r_b \Rightarrow cc_1$ i2i_< $cc_1, r_T, r_F \Rightarrow r_1$ comp $r_c, r_d \Rightarrow cc_2$ i2i_< $cc_2, r_T, r_F \Rightarrow r_2$ and $r_1, r_2 \Rightarrow r_x$	cmp_LT $r_a, r_b \Rightarrow r_1$ cmp_LT $r_c, r_d \Rightarrow r_2$ and $r_1, r_2 \Rightarrow r_x$

Conditional move is worse than Boolean compares

Predication is identical to Boolean compares

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 case base complicates the predicates and makes branches attractive

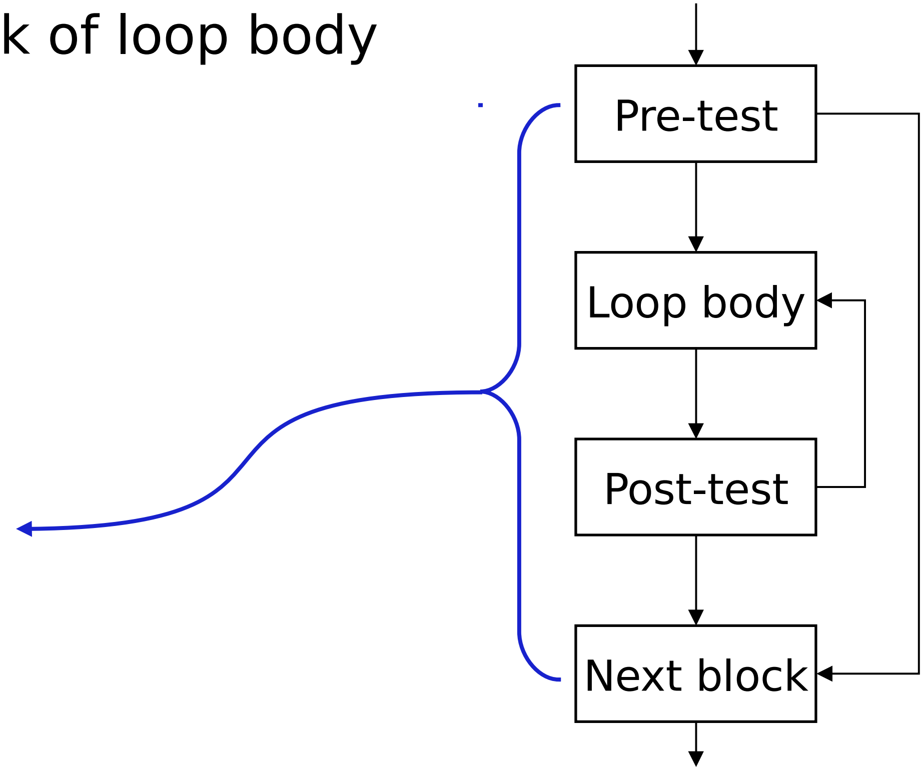
Control Flow

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

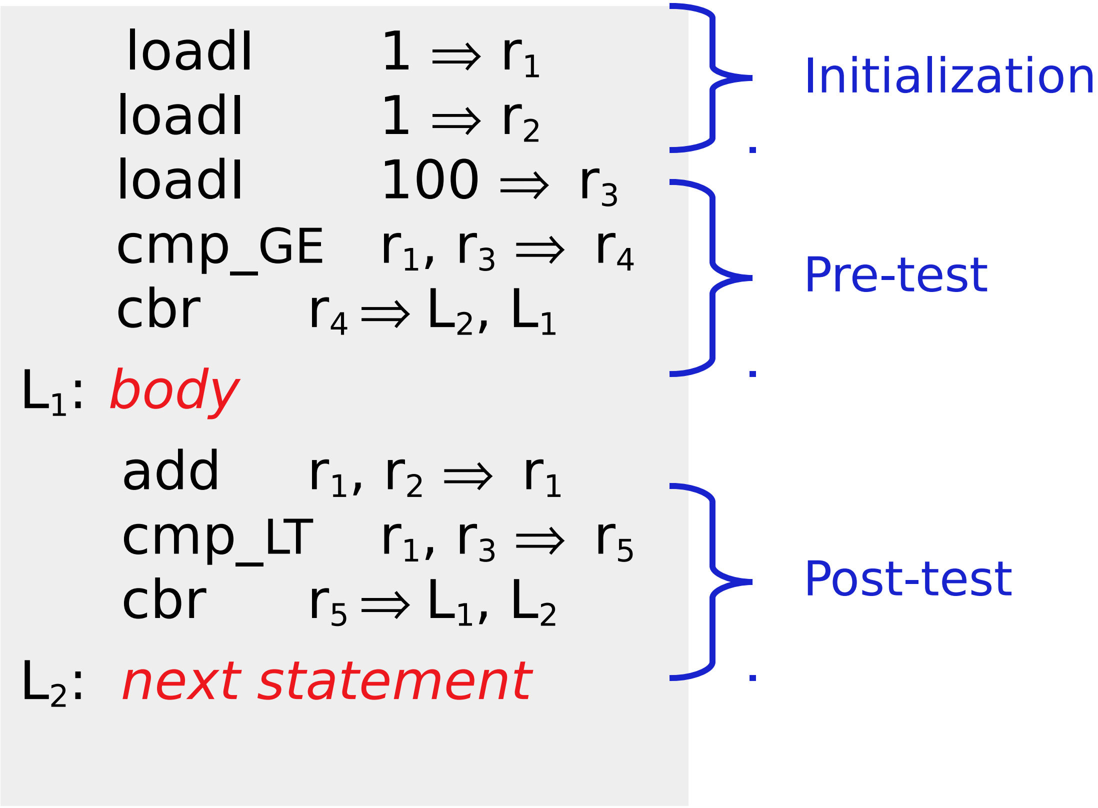
while, for, do, & until all fit this basic model



Loop Implementation Code

for (i = 1; i< 100; i++) { *body* }

next statement



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

Break statements

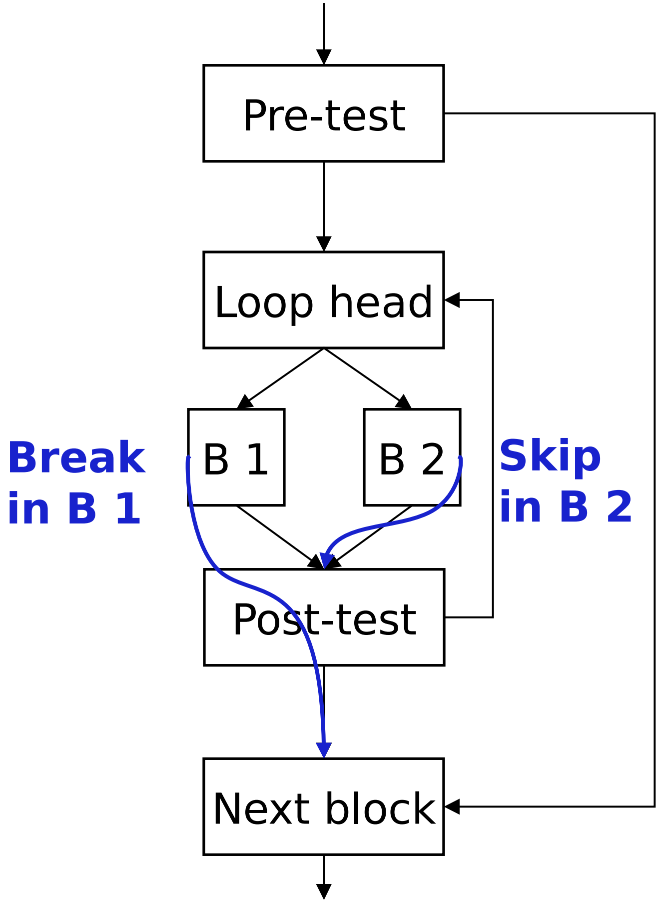
Many modern programming languages include a break

- 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

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)

Surprisingly many compilers do this for all cases!