Levels of Control Flow:

- 1. Within expressions
- 2. Among program units
- 3. Among program statements

Evolution:

- FORTRAN I control statements were based directly on IBM 704 hardware
- Much research and argument in the1960s about the issue
 - One important result: It was proven that all flowcharts can be coded with only two-way selection and pretest logical loops
- Def: A *control structure* is a control statement and the statements whose execution it controls

Overall Design Question:

What control statements should a language have, beyond selection and pretest logical loops?

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Compound statements - introduced by ALGOL 60 in the form of begin...end

A *block* is a compound statement that can define a new scope (with local variables)

Selection Statements

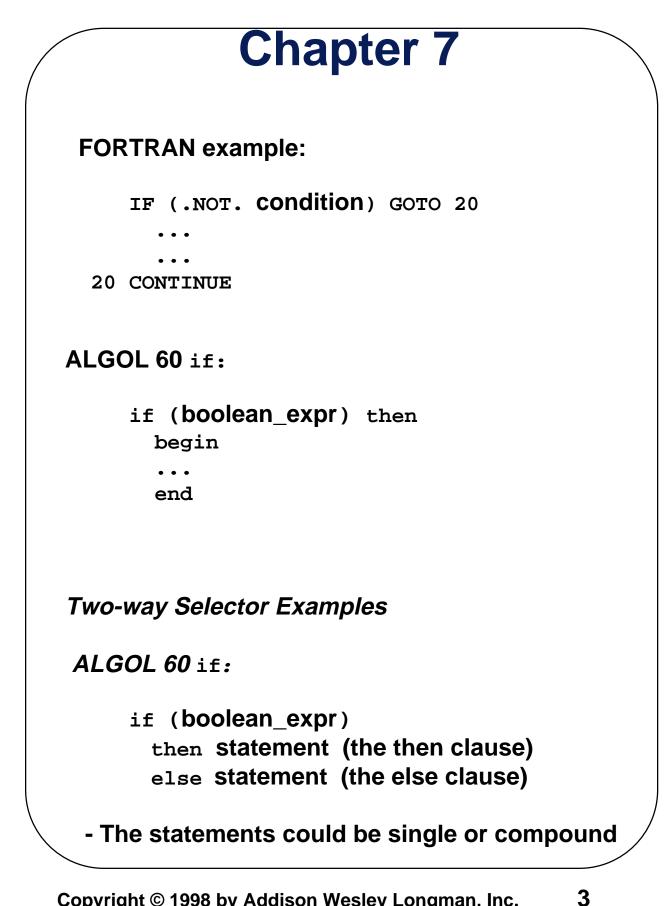
Design Issues:

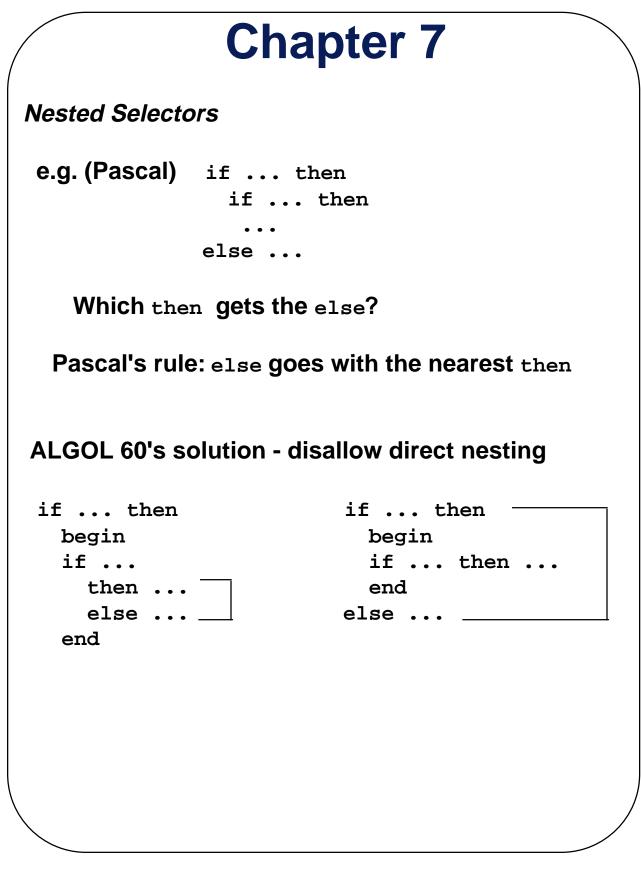
- 1. What is the form and type of the control expression?
- 2. What is the selectable segment form (single statement, statement sequence, compound statement)?
- 3. How should the meaning of nested selectors be specified?

Single-Way Examples

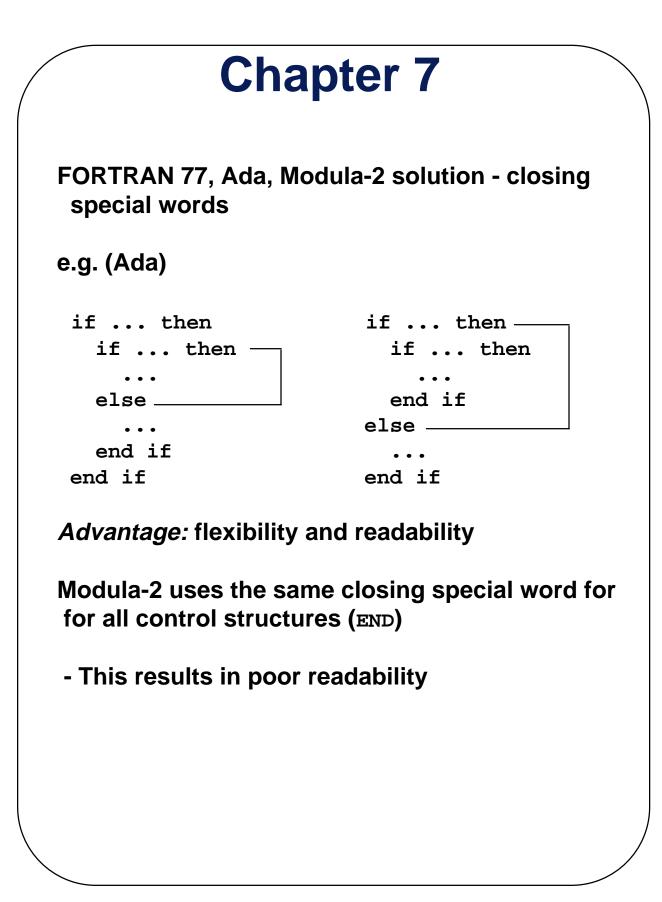
FORTRAN IF: IF (boolean_expr) statement

Problem: can select only a single statement; to select more, a goto must be used, as in the following example





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Multiple Selection Constructs

Design Issues:

- 1. What is the form and type of the control expression?
- 2. What segments are selectable (single, compound, sequential)?
- 3. Is the entire construct encapsulated?
- 4. Is execution flow through the structure restricted to include just a single selectable segment?
- 5. What is done about unrepresented expression values?

Early Multiple Selectors:

1. FORTRAN arithmetic IF (a three-way selector) IF (arithmetic expression) N1, N2, N3

Bad aspects:

- Not encapsulated (selectable segments could be anywhere)
- Segments require GOTOS

2. FORTRAN computed GOTO and assigned GOTO

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Modern Multiple Selectors
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1. Pascal case (from Hoare's contribution to ALGOL W)

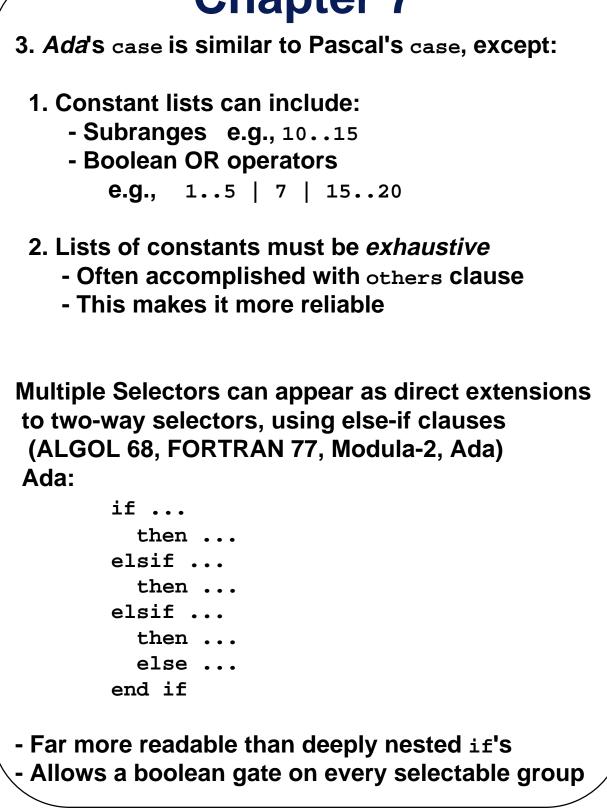
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case expression of
constant_list_1 : statement_1;
...
constant_list_n : statement_n
end
```

Design choices:

- 1. Expression is any ordinal type (int, boolean, char, enum)
- 2. Segments can be single or compound
- 3. Construct is encapsulated
- 4. Only one segment can be executed per execution of the construct
- 5. In Wirth's Pascal, result of an unrepresented control expression value is undefined (In 1984 ISO Standard, it is a runtime error)
 - Many dialects now have otherwise or else clause

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Chapter 7 2. The C and C++ switch switch (expression) { constant_expression_1 : statement_1; constant_expression_n : statement_n; [default: statement_n+1] **Design Choices:** (for switch) 1. Control expression can be only an integer type 2. Selectable segments can be statement sequences, blocks, or compound statements 3. Construct is encapsulated 4. Any number of segments can be executed in one execution of the construct (there is no implicit branch at the end of selectable segments) 5. default clause is for unrepresented values (if there is no default, the whole statement does nothing) - Design choice 4 is a trade-off between reliability and flexibility (convenience) - To avoid it, the programmer must supply a break statement for each segment



Iterative Statements

 The repeated execution of a statement or compound statement is accomplished either by iteration or recursion; here we look at iteration, because recursion is unit-level control

General design Issues for iteration control statements:

- 1. How is iteration controlled?
- 2. Where is the control mechanism in the loop?

Counter-Controlled Loops

Design Issues:

- 1. What is the type and scope of the loop var?
- 2. What is the value of the loop var at loop termination?
- 3. Should it be legal for the loop var or loop parameters to be changed in the loop body, and if so, does the change affect loop control?
- 4. Should the loop parameters be evaluated only once, or once for every iteration?

1. FORTRAN 77 and 90

- Syntax: DO label var = start, finish [, stepsize]

- Stepsize can be any value but zero

- Parameters can be expressions

- Design choices:

- 1. Loop var can be integer, real, or double
- 2. Loop var always has its last value
- The loop var cannot be changed in the loop, but the parameters can; because they are evaluated only once, it does not affect loop control
- 4. Loop parameters are evaluated only once

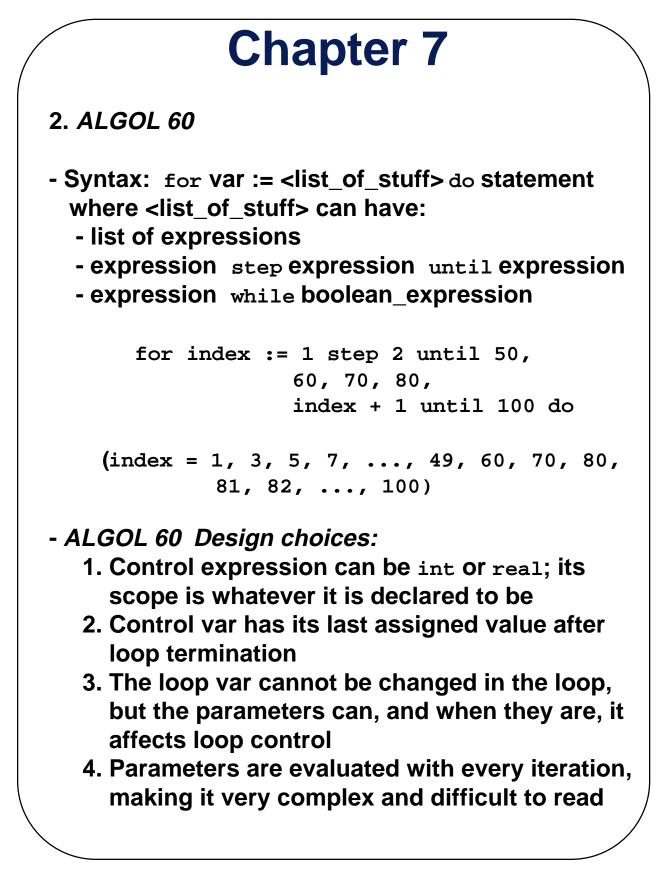
FORTRAN 90's Other DO

- Syntax:

[name:] DO variable = initial, terminal [, stepsize]

END DO [name]

- Loop var must be an INTEGER



Chapter 7
3. Pascal
 Syntax: for variable := initial (to downto) final do statement
 Design Choices: 1. Loop var must be an ordinal type of usual scop 2. After normal termination, loop var is undefined 3. The loop var cannot be changed in the loop; the loop parameters can be changed, but they are evaluated just once, so it does not affect loop control 4. Just once
4. Ada
- Syntax:
for var in [reverse] discrete_range loop
end loop

Chapter 7 Ada Design choices: 1. Type of the loop var is that of the discrete range; its scope is the loop body (it is implicitly declared) 2. The loop var does not exist outside the loop 3. The loop var cannot be changed in the loop, but the discrete range can; it does not affect loop control 4. The discrete range is evaluated just once 5. C - Syntax: for ([expr_1]; [expr_2]; [expr_3]) statement - The expressions can be whole statements, or even statement sequences, with the statements separated by commas - The value of a multiple-statement expression is the value of the last statement in the expression e.g., for (i = 0, j = 10; j == i; i++)...

 If the second expression is absent, it is an infinite loop

C Design Choices:

- 1. There is no explicit loop var
- 2. Irrelevant
- 3. Everything can be changed in the loop
- 4. Pretest
- 5. The first expression is evaluated once, but the other two are evaluated with each iteration
- This loop statement is the most flexible
- 6. C++
 - Differs from C in two ways:
 - 1. The control expression can also be Boolean
 - 2. The initial expression can include variable definitions (scope is from the definition to the end of the function in which it is defined)

7. Java

- Differs from C++ in two ways:
 - 1. Control expression must be Boolean
 - 2. Scope of variables defined in the initial expression is only the loop body

Logically-Controlled Loops

- Design Issues:
 - 1. Pretest or postest?
 - 2. Should this be a special case of the counting loop statement (or a separate statement)?
- Language Examples:
- 1. Pascal has separate pretest and posttest logical loop statements (while-do and repeat-until)
- 2. C and C++ also have both, but the control expression for the posttest version is treated just like in the pretest case (while do and do while)
- 3 Java is like C, except the control expression must be Boolean (and the body can only be entered at the beginning--Java has no goto)
- 4. Ada has a pretest version, but no posttest
- 5. FORTRAN 77 and 90 have neither

Chapter 7 User-Located Loop Control Mechanisms - Design issues: 1. Should the conditional be part of the exit? 2. Should the mechanism be allowed in an already controlled loop? 3. Should control be transferable out of more than one loop? **Examples:** 1. Ada - conditional or unconditional; for any loop; any number of levels LOOP1: for ... loop while ... loop exit when ... LOOP2: end loop for ... loop exit LOOP1 when .. end loop LOOP2; end loop LOOP1;

Chapter 7 2. C, C++, and Java - break Unconditional; for any loop or switch; one level only (Java's can have a label) There is also has a continue statement for loops; it skips the remainder of this iteration, but does not exit the loop 3. FORTRAN 90 - EXTT Unconditional; for any loop, any number of levels FORTRAN 90 also has CYCLE, which has the same semantics as C's continue Iteration Based on Data Structures - Concept: use order and number of elements of some data structure to control iteration - Control mechanism is a call to a function that returns the next element in some chosen order, if there is one; else exit loop C's for can be used to build a user-defined iterator **e.g.** for (p=hdr; p; p=next(p)) { ... }

 Perl has a built-in iterator for arrays and hashes e.g.,

foreach \$name (@names) { print \$name }

Unconditional Branching

Problem: readability

 Some languages do not have them:e.g., Modula-2 and Java

Label forms:

- 1. Unsigned int constants: Pascal (with colon) FORTRAN (no colon)
- 2. Identifiers with colons: ALGOL 60, C
- 3. Identifiers in << ... >>: Ada
- 4. Variables as labels: PL/I
 - Can be assigned values and passed as parameters
 - Highly flexible, but make programs impossible to read and difficult to implement

Restrictions on Pascal's gotos:

A statement group is either a compound statement or the body of a repeat-until

The target of a goto cannot be a statement in a statement group that is not active

- Means the target can never be in a statement group that is at the same level or is nested more deeply than the one with the goto
- An important remaining problem: the target can be in any enclosing subprogram scope, as long as the statement is not in a statement group
 - This means that a goto can terminate any number of subprograms

Chapter 7 **Guarded Commands** (Dijkstra, 1975) *Purpose:* to support a new programming methodology (verification during program development) 1. Selection: if <boolean> -> <statement> [] <boolean> -> <statement> [] <boolean> -> <statement> fi -Semantics: when this construct is reached, - Evaluate all boolean expressions - If more than one are true, choose one nondeterministically - If none are true, it is a runtime error Idea: if the order of evaluation is not important, the program should not specify one See book examples (p. 319)!

2. Loops	do <boolean> -> <statement> [] <boolean> -> <statement> [] <boolean> -> <statement> od</statement></boolean></statement></boolean></statement></boolean>
 Evaluat If more nondet 	s: For each iteration: e all boolean expressions than one are true, choose one erministically; then start loop again are true, exit loop
See book e	example (p. 320)
program ve - Verificati - Verificati logical - Verificati	a between control statements and erification is intimate ion is impossible with gotos ion is possible with only selection and pretest loops ion is relatively simple with only d commands
beyond se	nclusion: Choice of control statements lection and logical pretest loops is a etween language size and writability