Control Flow ลำดับ execute

Ordering of what should be done in program execution

- Sequencing: implicit ordering from top to bottom
- Selection: choice is made among two or more statements
- Iteration: program fragment executed repeatedly
- Procedural abstraction: collection of control constructs encapsulated in a single unit
- Recursion: self-referential subroutines

อนุประโยคที่มี value

Expression

ส่วนที่เล็กสุดของ execution

Expression produces a value, i.e. literal constant, named variable, constant, or operator (or function) applied to operands (or arguments)

A language may specify the location of function name.

- Prefix: before arguments, e.g. (*(+ 1 3) 2) in Lisp
- Infix: among arguments, e.g. 1+3 in most imperative languages
- Postfix: after arguments, e.g. post-increment/decrement (++ and--) in C and its descendants

Most imperative languages use infix notation for binary operators, and prefix notation for many operators and other functions.

Precedence and Associativity

When operators are written in infix notation without parentheses, ambiguity arises as to what is an operand of what, e.g.

a+b*c**d**e/f should be evaluated as

((((a+b)*c)**d)**e)/f or

a+(((b*c)**d)**(e/f)) or

a+((b*(c**(d**e)))/f) ?

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Precedence says that certain operators, in the absence of parentheses, group more tightly than other operators, e.g.

a-b*c is a-(b*c)

Associativity says sequences of operators of equal precedence, in the absence of parentheses, group to the left or to the right, e.g.

Precedence

Operators at the top group most tightly.

In most languages, multiplication and division group more tightly than addition and subtraction.

Fortran	Pascal	C	Ada
		++, -- (post-inc., dec.)	
**	not	++, -- (pre-inc., dec.), +, - (unary), &, * (address, contents of), !, ~ (logical, bit-wise not)	abs (absolute value), not, **
*, /	*, /, div, mod, and	* (binary), /, % (modulo division)	*, /, mod, rem
+, - (unary and binary)	+, - (unary and binary), or	+, - (binary)	+, - (unary)
		<<, >> (left and right bit shift)	+, - (binary), & (concatenation)
.eq., .ne., .lt., .le., .gt., .ge. (comparisons)	<, <=, >, >=, =, <>, IN	<, <=, >, >= (inequality tests)	=, /= , <, <=, >, >=
.not.		==, != (equality tests)	
		& (bit-wise and)	
		^ (bit-wise exclusive or)	
		| (bit-wise inclusive or)	
.and.		&& (logical and)	and, or, xor (logical operators)
.or.		|| (logical or)	
.eqv., .neqv. (logical comparisons)		?: (if…then…else)	
		=, +=, -=, *=, /=, %=, >>=, <<=, &=, ^=, |= (assignment)	
		, (sequencing)	

Associativity

Basic arithmetic operators almost always associate left-to-right.

9-3-2 is 4, not 8 because (9-3)-2

Exponentiation usually associates right-to-left.

4**3**2 is 4**(3**2)

Assignment associates right-to-left.

a = b = a+c is (a+c) assigned to b, then the same value assigned to a

Exercise: Precedence and Associativity

Given the precedence table and associativity rules in the previous slides,

- Apply parentheses to the expression to show how operands are grouped to operators and
- Give the result of the expression
- Where a = 1, b = 2, c = 3, d = 2, e = 2, f = 3

Fortran a + b * c ** d ** e / f result is

Pascal a < b and c < d result is error

C (a < b) && (c < d) result is

Evaluation Order within Expression (1)

Precedence and associativity **do not** specify the order in which the operands of a given operator are evaluated, e.g.

Precedence and associativity say a - f(b) - c * d is (a - f(b)) - (c * d)

Which one is evaluated first, (a - f(b)) or (c * d) ?

Similarly, in f(a, g(b), h(c)) , what is the order in which the arguments will be evaluated?

But evaluation order is important.

- Impact on expression result via side effect
  - *What if f(b) modifies c and/or d?*
  - *What if g(b) modifies a and/or c?*
- Impact on code improvement
  - *In a*b + f(c), for example, it might be desirable to call f first, because the product a*b stored in a register would need to be saved (on stack) during the call to f (i.e. run time cost) as f might want to use all registers.*

Evaluation Order within Expression (2)

As for code improvement, most languages then leave the order of evaluation undefined, i.e. compiler can choose whatever order that results in faster code.

Be careful when writing expression in which side effect of evaluating one operand or argument can affect the value of another, e.g. use parentheses to impose ordering.

But Java and C# require left-to-right evaluation (i.e. cleaner semantics over run time cost).

Exercise: Precedence, Associativity, Evaluation Order

Given the precedence table and associativity rules in the previous slides, and evaluation order within expression is left to right, what is the result of this C program?

```
int give2() { printf("two\n"); return 2; }
int give3() { printf("three\n"); return 3; }
int give4() { printf("four\n"); return 4; }

int main() {
printf("%d\n", give4() + give2() * give3() - give4() / give2());
return 0;
}
```

four
two
three
four
two
8

Assignment

In imperative language, assignment provides the means to make the changes to the values of variable in memory.

Assignment takes two arguments.

- A **value**
- A **reference to a variable** into which the value should be placed.

Assignment has a side effect, i.e. it changes the value of a variable, thereby affecting the result of any later computation in which the variable appears.

ตัวแปรเปลี่ยนค่า

```c
//C
int max(int x, int y) {
   if (x > y) {return x;} else {return y;}
}
int main()
{   int a, b;
   a = 1; b = 2;
   printf("max is %d\n", max(a, b)); //max is 2
   a = 3;
   printf("max is %d\n", max(a, b)); //max is 3
   return 0;
}
```

```
--Haskell has no assignment and no side effect
a, b :: Int
a = 1
b = 2
max a b
--2
max a b
--2
```

var ไม่มีการเปลี่ยนค่า

Semantics of Assignment (1)

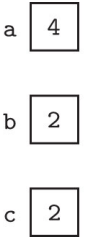
In **value model of variables**, a variable is a named container for a value (e.g. Pascal, C, Java's built-in type, PHP).

A variable has two interpretations when used with assignment.

- **l-value** refers to expression that denotes location.
- **r-value** refers to expression that denotes value.

a = b

```
//C
b = 2;          // l-value of b is used
c = b;          // r-value of b is used, l-value of c is used
a = b+c;        // r-values of b and c are used, l-value of a is used
```

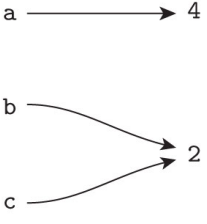


Semantics of Assignment (2)

In **reference model of variables**, a variable is a named reference to a value (e.g. Clu, Lisp, Haskell, Smalltalk, Java's user-defined type (class), Python, Ruby).

- Every variable is an **l-value**.
- When a variable appears where an **r-value** is expected, it must **be dereferenced** to obtain the value to which it refers (automatic in most languages).

```
%Clu
b := 2;          % l-value of b is used
c := b;          % l-value of b is dereferenced, l-value of c is used
a := b+c;        % l-values of b and c are dereferenced, l-value of a is used
                 % 2 and 4 are immutable values at some locations to which any variables can refer
```



Short-Circuit Evaluation

Consider these logical expressions,

(a < b) and (b < c)

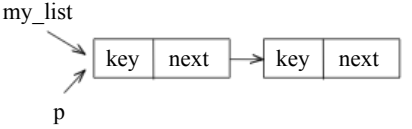
(a > b) or (b > c)

When the overall value of these expressions can be determined from the first half of the computation, compiler will generate code that skips the second half.

This saves time.

Short-Circuit Changes Semantics of Boolean Expressions

An example of a search for an element in a list.



C short-circuits its logical operators.

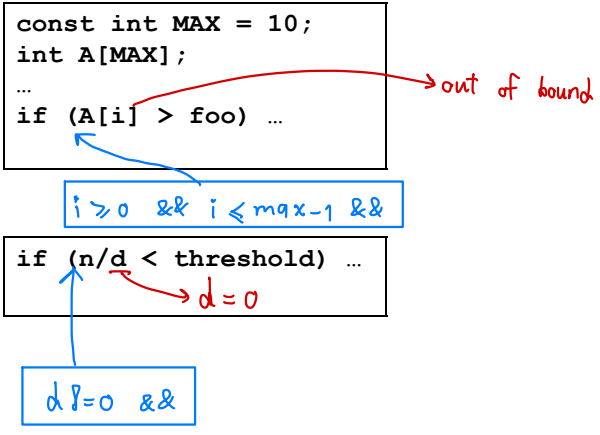
```
//C
p = my_list;
while (p && p->key != val)
 p = p->next;
```

Pascal does not short-circuit. Both <> will be evaluated before and, so run-time semantic error if p is nil (unsuccessful search).

```
(* Pascal *)
p := my_list;
while (p <> nil) and (p^.key <> val) do (*ouch!*)
 p := p^.next;
```

Exercise: Short-Circuit

How can we use short-circuit evaluation to make the following code safer?



Sequencing

It is the principal means of controlling the order in which side effects occur.

When one statement follows another, the first statement executes before the second.

Sequence of statements can be enclosed as a compound statement (block), e.g. begin…end or {…}.

Selection

Most languages employ variant of if ... then … else ...

if *condition* then *statement*
else if *condition* then *statement*
else if *condition* then *statement*
…
else *statement*

Short-Circuited Condition in Selection

In languages with short-circuit, compilers generate target code which evaluates the conditions for branching control to various locations without having to store any boolean values.

```
if ((A > B) and (C > D)) or (E ≠ F) then
   then_clause
else
   else_clause
```

```
      r1 := A
      r2 := B
      if r1 <= r2 goto L4
      r1 := C
      r2 := D
      if r1 > r2 goto L1
L4:   r1 := E
      r2 := F
      if r1 = r2 goto L2
L1:   then_clause
      goto L3
L2:   else_clause
L3:
```

Nested If

Compilers generate target code which tests each expression sequentially.

```
--Ada

i := …  -- calculate tested expression
if i = 1 then
 clause_A
elsif i = 2 or i = 7 then
 clause_B
elsif i in 3..5 then
 clause_C
elsif i = 10 then
 clause_D
else
 clause_E
end if;
```

```
    r1 := ...                    -- calculate tested expression
    if r1 ≠  1 goto L1
    clause_A
    goto L6
L1: if r1 = 2 goto L2
    if r1 ≠  7 goto L3
L2: clause_B
    goto L6
L3: if r1 < 3 goto L4
    if r1 > 5 goto L4
    clause_C
    goto L6
L4: if r1 ≠  10 goto L5
    clause_D
    goto L6
L5: clause_E
L6:
```

Case/Switch Statements

Less verbose syntactically than nested if but the principal motivation is to facilitate the generation of efficient target code.

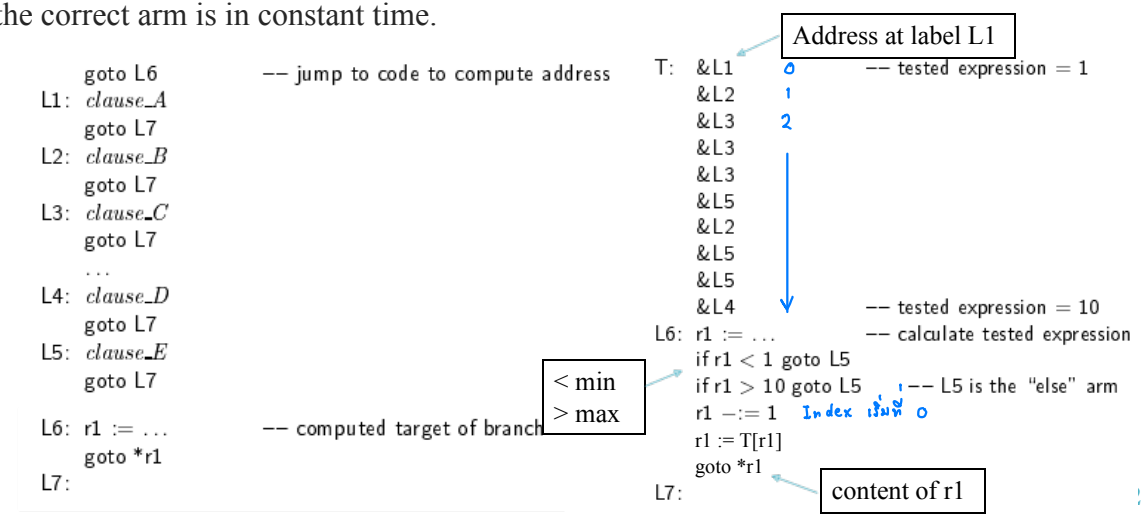
```
--Ada with case labels and arms

case …  --calculate tested expression
is
 when 1       => clause_A
 when 2 | 7   => clause_B
 when 3..5    => clause_C
 when 10      => clause_D
 when others => clause_E
end case;
```

```
-- General form

   goto L6  --jump to code to compute address
L1: clause_A
   goto L7
L2: clause_B
   goto L7
L3: clause_C
   goto L7
   ...
L4: clause_D
   goto L7
L5: clause_E
   goto L7

L6: r1 := ...  --computed target of branch
   goto *r1
L7:
```

Case/Switch Implementation Example

Code at label T is an array of addresses (called jump table). Each entry is for each value from the lowest to the highest value of the case labels.

L6 checks boundary and fetches corresponding entry from the table and branches to it. So finding the correct arm is in constant time.



Exercise: Case/Switch Implementation

What is the problem with jump table implementation in the previous slide?

ถ้า range data กว้าง ขี้ใหญ่ไป

What do you think a compiler should do about it?

Switch Statement with Fall-Through

Found in C and retained in C++, Java.

- Each possible value for tested expression must have its own label.
- A label with empty arm falls through into the code of subsequent label.
- To get out of a switch, a break statement must be used at the end of an arm, rather than falling through into the next.

```
switch (… /*tested expression */) {
 case 1: clause_A;
         break;
 case 2:
 case 7: clause_B;
         break;
 case 3:
 case 4:
 case 5: clause_C;
      break;
 case 10: clause_D;
       break;
 default: clause_E;
       break; }
```

Iteration

In most languages, iteration takes the form of loops.

An enumeration controlled loop executes over values in a given finite set.

A logically controlled loop executes until some boolean condition changes value.

An iterator iterates over elements of any well-defined set (collection).

Enumeration-Controlled Loop

Test for empty bounds first, i.e. test terminating condition before the first iteration.

```
(* Modula-2: enumeration-controlled *)
  FOR i := first TO last BY step DO
   …
  END
  /* C: combination of enumeration- and logically-controlled
  */
  for (i = first; i <= last; i += step) {
   …
  }
```

```
        r1 := first
        r2 := step
        r3 := last
        goto L2
L1:     ...                     -- loop body; use r1 for i
        r1 := r1 + r2
L2:     if r1 <= r3 goto L1
```

Logically Controlled Loop

Pre-test loop: Loop body may not be executed

```
while condition do statement
```

Post-test loop: Loop body is executed at least once.

```
//C
do {
 line = read_line(stdin);
} while line[0] != '$';
```

Mid-test loop: A special statement is nested inside a test for terminating condition.

```
//C
for (;;) {
 line = read_line(stdin);
 if (all_blanks(line)) break;
 consume_line(line);
}
```

Iterator (1)

True iterator (e.g. Clu, Python, Ruby, C#)

- Any container abstraction provides an iterator that enumerates its items.

```
#Python
#Iterator goes unseen as it is implicitly used
for i in [1, 2, 3]:
 print(i)
...
1
2
3

#range(first, last, step) is a built-in iterator.
#It yields integers in the range in increments of step, but not including last.
#It is a function but, when called each time, continues where it last left off, giving next integer.

my_list = [‘one’, ‘two’, ‘three’, ‘four’, ‘five’]
my_list_len = len(my_list)
for i in range(0, my_list_len, 2):
 print(my_list[i])
...
one
three
five
```

Iterator (2)

Iterator as an ordinary object (e.g. C++, Java, Ada, Python).

- Provides methods for initialization, generation of the next index value, and testing for completion.

```
//Java
ArrayList al = new ArrayList();
//add elements to the array list
al.add("C");
al.add("A");
al.add("E");

//use iterator to display contents of al
System.out.print("Contents of al: ");
Iterator itr = al.iterator();

while(itr.hasNext()) {
 Object element = itr.next();
 System.out.print(element + " ");
}
…
Contents of al: C A E
```

Recursion → เปลือง memory

Functions calling themselves.

Functions calling other functions that call them back in turn.

Any iterative algorithm can be rewritten as a recursive algorithm and vice versa. Which to use in which circumstance is mainly a matter of taste.

Recursion and Iteration

	a	if a=b
gcd(a, b)	gcd(a-b, b)	if a>b
positive integers, a, b	gcd(a, b-a)	if b>a

```
//C
//Iteration, assume a, b > 0
   int gcd(int a, int b) {
    while (a != b) {
      if (a > b) a = a-b;
      else b = b-a;
    }
    return a;
   }
```

```
//C
//Recursion, assume a, b > 0
   int gcd(int a, int b) {
    if (a == b) return a;   //base case
    else if (a > b) return gcd (a-b, b);
         else return gcd(a, b-a);
   }
```