Procedure Parameter Passing

TYPE IARRAY IS ARRAY OF INTEGER;
PROCEDURE f(x:INTEGER,y:INTEGER) IS ...
PROCEDURE g(z:IARRAY,q:IARRAY) IS ...
VAR a: IARRAY, w: INTEGER
f(3,w); ... g(a,a); ... f(17+5,a[3]);

- Do we pass addresses (l-values) or contents (r-values) of variables?
- How do we pass actual values that aren’t variables?
- What does it mean to pass an aggregate value like an array?

Call-by-Value (i.e., r-value)

- Each actual argument is evaluated to a value before call.
- On entry, value is bound to formal parameter just like a local variable.
- Updating formal parameter doesn’t affect actuals in calling procedure.

```c
double hyp(double a,double b) {
    a = a * a;
    b = b * b;
    return sqrt(a+b);
}
```

- Simple; easy to understand!
- Implement by copying.

Problems with Call-by-Value

- Can be inefficient if value is large.

Example (C): Calls to dotp copy 20 doubles:

```c
typedef struct {double a1,a2,...,a10;} vector;

double dotp(vector v, vector w) {
    return v.a1 * w.a1 + v.a2 * w.a2 + ...
        + v.a10 * w.a10;
}
vector v1,v2;
double d = dotp(v1,v2);
```

- Cannot affect calling environment directly. (Often a good thing, but not always!)

Example: calls to swap have no effect:

```c
void swap(int i,int j) {
    int t;
    t = i ; i = j; j = t;
}
```

- Can at best return only one result (as a value), though this might be a record.
Call-by-Reference (i.e., l-value)

- Pass the address (l-value) of each actual parameter.
- On entry, the formal is bound to the address, which must be dereferenced to get value, but can also be updated.
- If actual argument doesn’t have an l-value (e.g., “2 + 3”), either:
  - Evaluate it into a temporary location and pass address of temporary, or
  - Treat as an error.
- Now swap, etc., work fine!
- Accesses are slower.
- Lots of opportunity for aliasing problems, e.g.,

  ```
  PROCEDURE matmult(a,b,c: MATRIX) ...
  (* sets c := a * b *)
  matmult(a,b,a) (* oops! *)
  ```

- Call-by-value-result (a.k.a. copy-restore) addresses this problem, but has other drawbacks.

C/C++ Records and Arrays

In ANSI C/C++, record (struct or class) r-values are the actual contents.

To avoid copying C structures, must use pointers:

```c
typedef struct {double a1,a2,...,a10;} vector;
double dotp(vector *v, vector *w) {
    return v->a1 * w->a1 + v->a2 * w->a2 + ...
           + v->a10 * w->a10;
}
vector v1,v2;
double d1 = dotp(&v1,&v2);
```

On the other hand, C/C++ array r-values are pointers to the contents. In this example, no doubles are copied on call:

```c
typedef double vector[10];
double dotp(vector v, vector w) {
    double d = 0.0; int i;
    for (i = 0; i < 10; i++)
        d += v[i] * w[i];
    return d;
}
vector v1,v2;
double d1 = dotp(v1,v2);
```

Complex and Simple Solutions

- C++ supports both cbr parameters and explicit pointers:

  ```c
  swap(int &a, int *b) {
      int t;
      t = *a; *a = *b; *b = t;
  }
  ...
  swap(a[p],&a[q]);
  ```

  Mixing explicit and implicit pointers can be very confusing!

- In Java, ML, and PCAT, r-values of both records (objects) and arrays are pointers to the actual contents, which are held in the heap. These languages have only call-by-value, but this doesn’t actually cause copying, even for record or array values.
- Approach is made more feasible because programmer doesn’t have to worry about lifetime of heap data, due to automatic garbage collection.
- Clever compilers can decide whether smallish objects should be heap-allocated or manipulated directly.

Hybrid Methods

How might we combine the simplicity of call-by-value with the efficiency of call-by-reference, especially for large values like records and arrays?

Answer depends on what a record or array r-value is in a particular language. (This is also important for the semantics of assignment, of course.)

- In Pascal, Ada, and similar languages, r-values of both arrays and records are the actual contents. So passing a record or array by value means copying the contents, whereas passing by reference doesn’t. These languages let the programmer specify (in the procedure header) the method to use on each parameter.
- C always uses call-by-value, but programmers can take the l-value of a variable explicitly, and pass that to obtain cbr-like behavior:

  ```c
  swap(int *a, int *b) {
      int t;
      t = *a; *a = *b; *b = t;
  }
  swap(&a[p],&a[q]);
  ```

  Of course, it is the programmer’s responsibility to make sure that the l-value remains valid (especially when it is returned from a function).
Substitution

- Can often get the effect we want using substitution, i.e., macro-expansion, e.g. (in C):

  ```c
  #define swap(x,y) {int t; t = x; x = y; y = t;
  ...
  swap(a[p],a[q]);
  ```

- BUT blind substitution is dangerous because of possible “variable capture,” e.g.,

  ```c
  swap(a[t],a[q])
  ```

  expands to

  ```c
  (int t; t = a[t]; a[t] = a[q]; a[q] = t;)
  ```

  Here “t is captured” by the declaration in the macro, and is undefined at its first use.

- Really want “substitution with renaming where necessary” = Algol-60’s call-by-Name facility.

- Flexible, but potentially very confusing, and inefficient to implement.

- If language has no updatable variables (as in “pure” functional languages), substitution gives a beautifully simple semantics for procedure calls.