CS558 Programming Languages

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Lecture 4b

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Procedures and Functions

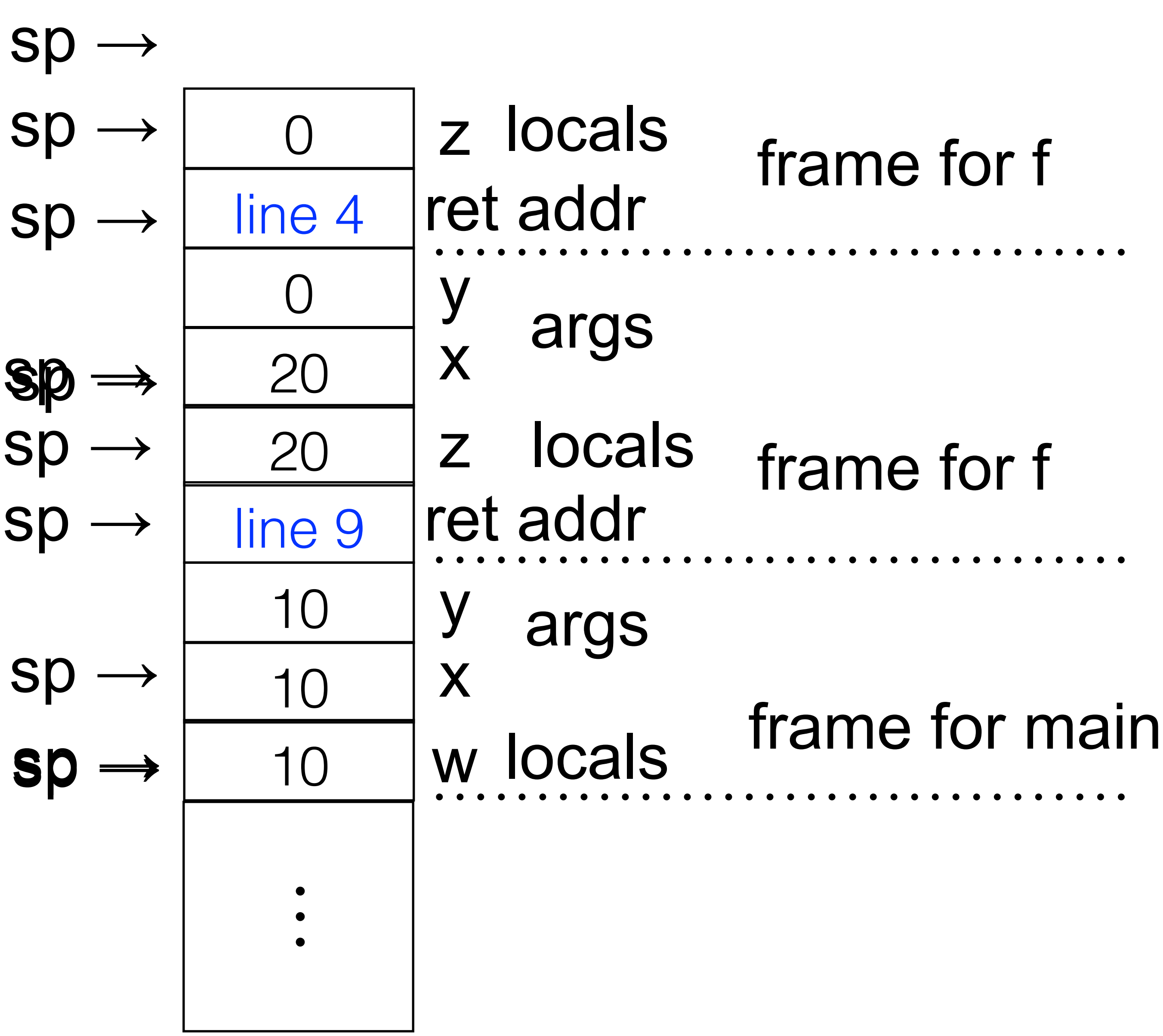
- Procedures have long history as essential programming tool
- Low-level view: subroutines let us avoid duplicating frequently-used code
- Higher-level view: procedural abstraction lets us divide programs into components with hidden internals
- Procedural abstractions are parameterized over values and (sometimes) types
- A function is just a procedure that returns a result (or, conversely, a procedure is just a function whose result we don’t care about).

Procedure Activation Data

- Each invocation of procedure is specialized by associated activation data, such as
  - the actual values corresponding to the formal parameters of the procedure
  - locations allocated for the values of local variables
  - the return address in the caller
- Activation data lives from the time procedure is called until the time it returns
- If one procedure calls another, directly or indirectly, their activation data must be kept separate, because lifetimes overlap
  - In particular, each recursive invocation needs new activation data

Activation Stacks

- In most languages, activation data can be stored in frames, which are pushed and popped on the stack




```
1  int f(int x, int y){
2      int z = y+y;
3      if (z > 0)
4          z = f(z,0);
5      return z+y;
6  }
7  void main() {
8      int w = 10;
9      w = f(w,w);
10 }
```

C

Calling conventions

- In compiled language implementations, we want to be able to generate the code for procedures separately from the code for their applications
  - e.g. procedure may live in a pre-compiled library
- Requires a calling convention between caller and callee
  - e.g. caller places parameter values on the stack in a fixed order, and callee looks for them there
  - In an interpreter, where caller and callee are visible at the same time, it is easy to be imprecise about this, but we will try to build a careful model in the labs

Procedure Parameter Passing

- When we apply a function in an imperative language, the formal parameters get bound to locations containing values
  - How is this done and which locations are used?
  - Do we pass addresses or contents of variables from the caller?
  - How do we pass actual values that aren’t variables?
  - What does it mean to pass a large value like an array?
- Two main approaches: call-by-value(CBV) and call-by-reference (CBR).
  - Also call-by-name/need(CBN).

Call-by-value

- Each actual parameter is evaluated to a value before call
- On entry to function, each formal parameter is bound to a freshly-allocated location, and the actual parameter value is copied into that location
  - Much like processing declaration and initialization of a local variable
- Semantics are just like assignment of actual expression to formal parameter
- Simple; easy to understand!

Issues with call-by-value

- Updating a formal parameter doesn't affect actuals in the caller.

- Usually a good thing!

- But sometimes not what we want

```
void swap(int i,int j) {
  int t;
  t = i ; i = j; j = t;
}
...
swap(a[p],a[q]);
```

call has no effect on `a`

C

More issues

- Can be inefficient for large unboxed values, e.g. C `structs` (records):

```
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);
```

C

Call to `dotp` copies 20 doubles

Call-by-reference

- Pass a pointer to the existing location of each actual parameter

- Within function, references to formal parameter are indirected through this pointer — so parameter can be dereferenced to get the value, but can also be updated

- If actual argument doesn't have a location (e.g. is an expression `(x+3)`) then either

    - evaluate it into a temporary location and pass address of temporary,or

    - treat as an error

Issues with Call-by-reference

- Now procedures like `swap` work fine!
- Can also return values from procedure by assigning to parameters
- Lots of opportunity for aliasing problems, e.g.

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

matmult(a,b,a) (* oops! *)
```

overwrites parts of argument as it computes result

Hybrid methods

- In Pascal, Ada, and C++, programmer can specify (in the procedure header) for each parameter whether to use CBV or CBR

- C always uses CBV, but programmers can take the address of a variable explicitly, and pass that to obtain CBR-like behavior:

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

Values can be References

- In many modern languages, like Java or Python, both records (objects) and arrays are always boxed, so values of these types are already pointers (or references)

- Thus, even if the language uses CBV, the values that are passed are actually references: calls don't cause any actual copying of the large values

- But it is a mistake (which some otherwise good authors make) to say that these languages use "call-by-reference" (If they did, they would be passing a reference to the reference!)

Substitution and macros

- One simple way to give semantics to procedure calls is say they behave “as if” the procedure body were textually substituted for the call, substituting actual parameters for formal ones.

- This is very similar to macro-expansion, which really does this substitution (statically)

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

C

expands to

```
{int t; t = a[p]; a[p] = a[q]; a[q] = t;}
```

Avoiding capture

- Blind substitution is dangerous!

```
#define swap(x,y) {int t;t = x;x = y;y = t;}
```

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

expands to

```
{int t; t = a[t]; a[t] = a[q]; a[q] = t;}
```

Nonsense!

We say that `t` has been captured by the declaration in the macro block

Call-by-name (CBN)

- One solution is to note that names of local variables are not important, e.g. we can rename to

```
{int u; u = a[t]; a[t] = a[q]; a[q] = u;}
```

- Call-by-name can be thought of as “substitution with renaming where necessary”

- On real machines, CBN is implemented by passing to the function the AST for actual argument + values of its free variables

- This makes CBN much less efficient to implement than CBV or CBR. (We may see more later.)

Call-by-need

- A very useful feature of call-by-name is that arguments are evaluated only if needed

```
foo x y = if x > 0 then x else y

foo 1 (factorial 1000000)
```

avoids expensive computation

Haskell

- As a further refinement, “pure” functional languages typically use call-by-need (or lazy) evaluation, in which arguments are evaluated at most once:

```
foo x y = if x > 0 then x else y * y

foo (-1) (factorial 1000000)
```

avoids expensive recomputation