Subroutines and Control Abstraction

CSE 307 – Principles of Programming Languages

Stony Brook University

http://www.cs.stonybrook.edu/~cse307

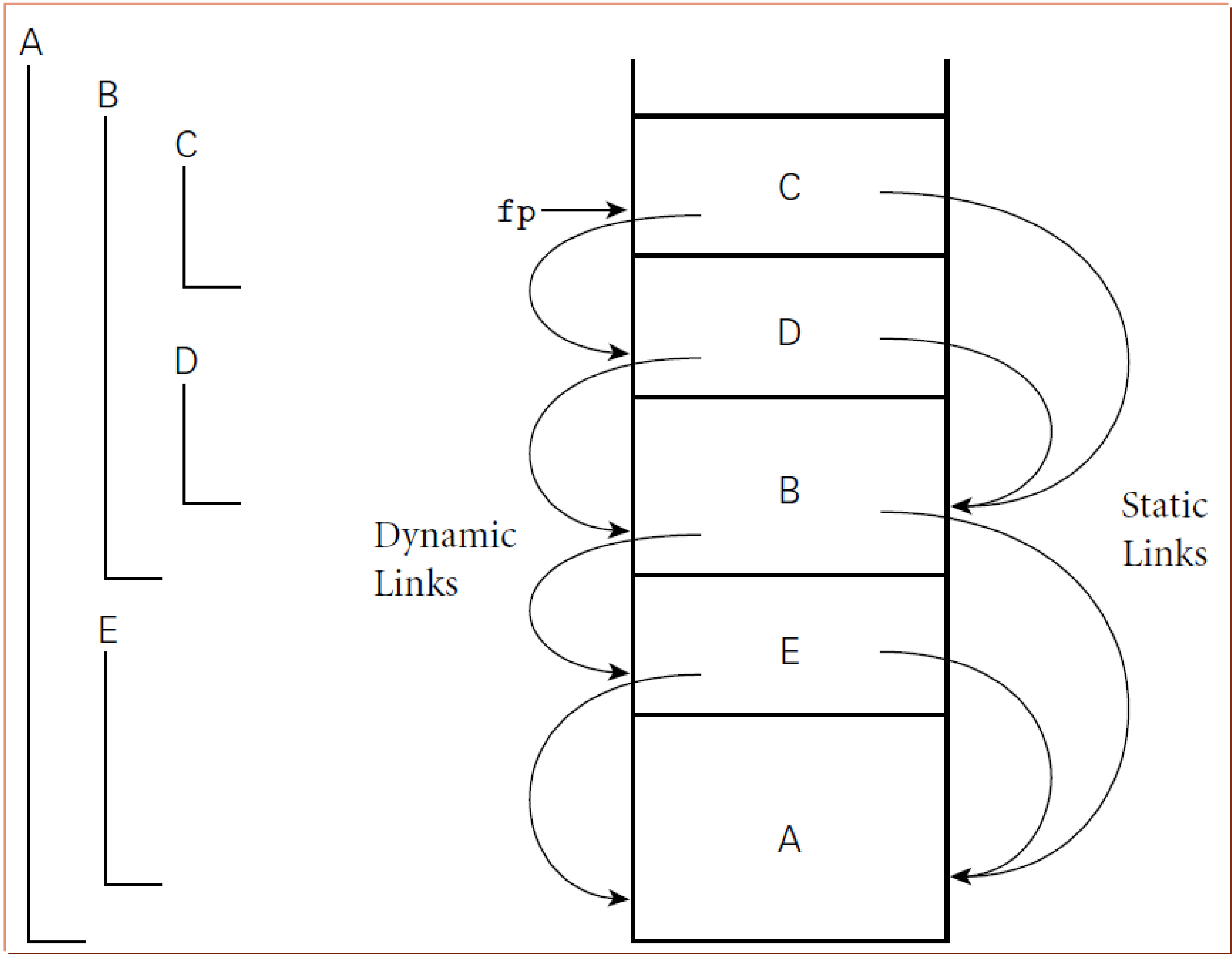
Subroutines

- Why use subroutines?
  - Give a name to a task.
  - We no longer care how the task is done.
- The subroutine call is an expression:
  - Subroutines take arguments (in the formal parameters)
  - Values are placed into variables (actual parameters/arguments)
  - A value is (usually) returned.

Review Of Stack Layout

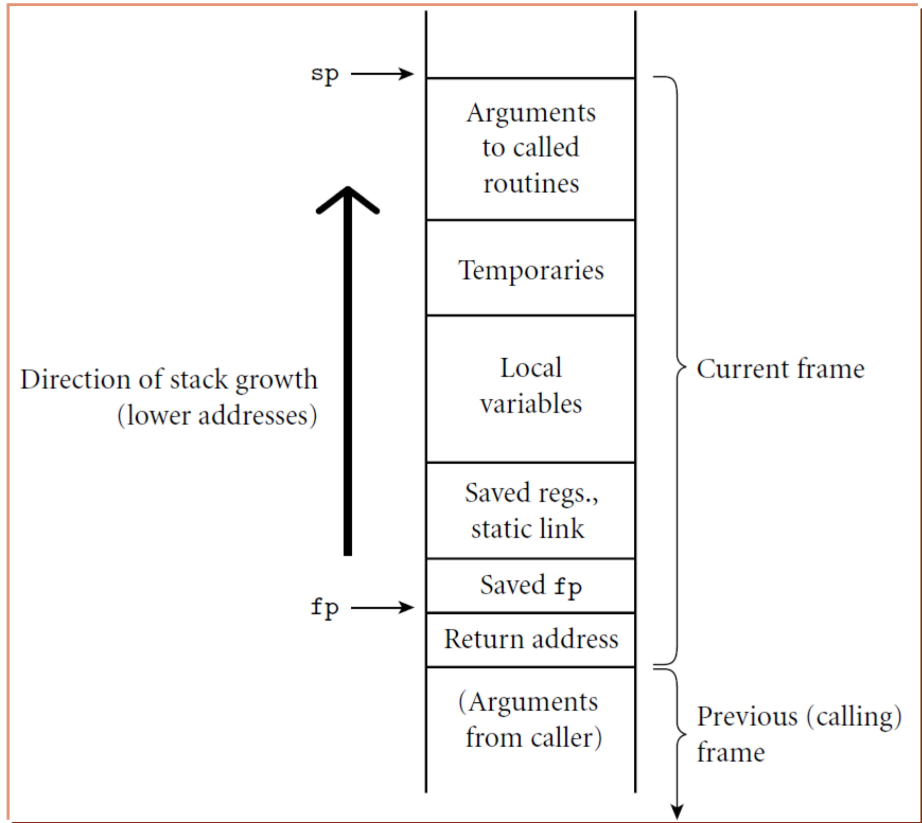
- Allocation strategies:
  - Static
    - Code, Globals
    - Explicit constants (including strings, sets, other aggregates)
    - Small scalars may be stored in the instructions themselves
  - Stack
    - parameters
    - local variables
    - temporaries
    - bookkeeping information
  - Heap
    - dynamic allocation

Review Of Stack Layout



Review Of Stack Layout

- Contents of a stack frame:
  - bookkeeping
    - return Program Counter (PC)
    - saved registers
    - line number
    - static link
  - arguments and returns
  - local variables
  - temporaries



Calling Sequences

- Maintenance of stack is responsibility of *calling sequence* and subroutine *prolog* and *epilog*
  - space is saved by putting as much in the prolog and epilog as possible
  - time may be saved by putting stuff in the caller instead, where more information may be known

Calling Sequences

- Common strategy is to divide registers into caller-saves and callee-saves sets
  - caller uses the "callee-saves" registers first
  - "caller-saves" registers if necessary
- Local variables and arguments are assigned fixed OFFSETS from the stack pointer or frame pointer at compile time
  - some storage layouts use a separate arguments pointer

Parameter Passing

- Modes of passing parameters:
  - Call by value: make a copy of the parameter.
  - Call by reference: allows the function to change the parameter
    - out-parameters
  - Call by sharing: requires parameter to be a reference itself.
    - Makes copy of reference that initially refers to the same object.
    - E.g., Python, Java Objects.

Parameter Passing

```
def f(a):
   a += 1
x = 0
f(x)
print(x)
```

- value: 0
- reference: 1
- sharing: 0

Parameter Passing

```
def f(a):
    a.foo = 1
x = object()
x.foo = 0
f(x)
print x.foo
```

- value: 0
- reference: 1
- sharing: 1

Parameter Passing

```
z = object()
z.foo = 1
def f(a):
    a = z
x = object()
x.foo = 0
f(x)
print x.foo
```

- value: 0
- reference: 1
- sharing: 0

Parameter Passing

- Call-by-value:
  - Can't have aliasing between parameters.
  - Can be expensive to implement (e.g., copying large objects).
  - Can't change a parameter, except by returning a new copy.
- Call-by-reference:
  - No copying objects.
  - Out-parameters (i.e., the procedure returns values through its parameters).
  - Good: More flexibility.
  - Bad: Can be confusing when arguments change.

Parameter Passing

- C/C++: functions
  - parameters passed by value (C)
  - parameters passed by reference can be simulated with pointers (C)
    - void proc(int* x,int y){*x = *x+y } …
    - proc(&a,b);
  - or directly passed by reference (C++)
    - void proc(int& x, int y) {x = x + y }
    - proc(a,b);

Parameter Passing

- Call-by-sharing.
  - No copying of large objects.
  - No implicit out parameters.
    - Can change objects, but not arguments.

Parameter Passing

- Other fun tricks with parameters:
  - ***<u>Named parameters (pass-by-name)</u>***: the values are passed by ***associating*** each one with a ***parameter name***. E.g.,in Objective-C:

```
[window addNewControlWithTitle:@"Title"
        xPosition:20
        yPosition:50
            width:100
           height:50
       drawingNow:YES];
```

Parameter Passing

- Other fun tricks with parameters:
  - ***Default parameters***: default values are provided to the function
    - C++ example:

```
void PrintValues(int nValue1, int nValue2=10){
   using namespace std;
   cout << "1st value: " << nValue1 << endl;
   cout << "2nd value: " << nValue2 << endl;
}
int main(){
   PrintValues(1); // nValue2 will use default parameter of 10
   PrintValues(3, 4); // override default value for nValue2
}
```

Parameter Passing

- Other fun tricks with parameters:
  - ***Variadic functions***: functions of indefinite arities
    - C, Objective-C and C++:

```
double average(int count, ...){
   va_list ap;    int j;   double tot = 0;
   va_start(ap, count); //Requires the last fixed parameter (to get the address)
   for(j=0; j<count; j++)
      tot+=va_arg(ap, double); //Requires the type to cast to.
                               // Also increments ap to the next argument.
   va_end(ap);
   return tot/count;
}
```

Parameter Passing

- Other fun tricks with parameters:
  - ***Pass-by-name in ALGOL 60***:
    - the body of a function is interpreted at call time after textually substituting the actual parameters into the function body.
    - In this sense the evaluation method is similar to that of C preprocessor macros.
    - By substituting the actual parameters into the function body, the function body can both read and write the given parameters. In this sense the evaluation method is similar to pass-by-reference.
      - The difference is that since with pass-by-name the parameter is *evaluated* inside the function, a parameter such as a[i] depends on the current value of i inside the function, rather than referring to the value of a[i] before the function was called.
    - **Pass-By-Name Security Problem** (see next slide)

Parameter Passing

- ***<u>Pass-by-name in ALGOL 60:</u>***
  - **Pass-By-Name Security Problem**:

```
procedure swap (a, b);
integer a, b, temp;
begin
  temp := a;
  a := b;
  b:= temp
end;
```

Call swap(i, x[i]):   temp := i;   i := x[i];   x[i] :=

Before call:	i = 2	x[2] = 5	
After call:	i = 5	x[2] = 5	x[5] = 2

Swap doesn't work!

Parameter Passing

- *<u>Pass by Value-Returned (or value-result)</u>*: pass a value-returned parameter by address (just like pass by reference parameters), but, upon entry, the procedure makes a temporary copy of this parameter and uses the copy while the procedure is executing.
  - When the procedure finishes, it copies the temporary copy back to the original parameter.
  - In some instances, pass by value-returned is more efficient than pass by reference, in others it is less efficient:
    - If a procedure only references the parameter a couple of times, copying the parameter's data is expensive.
    - If the procedure uses this parameter often, the procedure amortizes the fixed cost of copying the data over many inexpensive accesses to the local copy.

Parameter Passing

- ***Pass by Result***: almost identical to pass by value-returned: the procedure uses a local copy of the variable and then stores the result through the pointer when returning.
  - The difference between pass by value-returned and pass by result is that when passing parameters by result you do not copy the data upon entering the procedure.
  - Pass by result parameters are for returning values, not passing data to the procedure. Therefore, pass by result is slightly more efficient than pass by value-returned since you save the cost of copying the data into the local variable.

Returning from a Function

- Different ways of returning a value from a function.
  - Return statement.
    - Statements -are- expressions.
  - Assigning to the function name. (Pascal, Fortran, Algol)
    - This interacts poorly w/ scoping and recursion
  - Special return location.
    - Eiffel calls it Result.
    - Means we don't have to allocate a variable to store the result in.

Generic Subroutines and Modules

- Generic modules or classes are particularly valuable for creating containers: data abstractions that hold a collection of objects
  - When defining a function, we don't need to give all the types
- Generic subroutines (methods) are needed in generic modules (classes), and may also be useful in their own right

Generic Subroutines and Modules

- Implementation of generic programming:
  - One approach is implicit *parametric polymorphism*:
    - Dynamic typing.
    - Just try running the code.
      - No checking at compile time - not type safe.
    - **Python approach**.
  - An alternative is to have a function that has parameterized types
    - Generic classes and methods
    - Can be static typed checked
    - **Java approach**

```
boolean <T> allEqual(T a, T b, T c) {
    return a.equals(b) && b.equals(c);
}
```

Generic Subroutines and Modules

- Parameterized types: Two implementation approaches:
- C++:
  - generates new code for each type:
    - linker can help with that
    - allows specialization
    - can make the code bigger
    - can use types in the function: new T();
    - Templates can cause horrible error messages
- Java
  - type erasure:
    - Replace all type parameters in generic types with their bounds,
    - Only one instance of the code,
    - Can't do operations involving the type.

Generic Subroutines and Modules

```
class DefaultDict <T> {
    T get(k) {
        if (! this.hasKey(k)) {
            this.put(k, new T());
        }
        return super.get(k);
    }
}
```

- We need to specify which operations a type parameter must support.
- C++:
  - look at the operations used, derive it from that.
    - example above: needs to be creatable, needs to be insertable into it
- Java:
  - specify which class inherits from (Object by default).

Generic Subroutines and Modules

- Generics are better than macros:
  - E.g., take the macro:

```
#define min(a, b) (a < b) ? a : b
```

  - Problem: min(a++, b++)
    - Variables a++ or b++ evaluated more than once
  - C++ generic:

```
template <class T>
T min(T a, T b) {
  return (a < b ) ? a : b;
}
```

    - Far fewer problems: variables evaluated only once.

Exception Handling

- What is an exception?
  - a hardware-detected run-time error or unusual condition detected by software
- Examples
  - arithmetic overflow
  - end-of-file on input
  - wrong type for input data
  - user-defined conditions, not necessarily errors

Exception Handling

- What is an exception handler?
  - code executed when exception occurs
  - may need a different handler for each type of exception
- Why design in exception handling facilities?
  - allow user to explicitly handle errors in a uniform manner
  - allow user to handle errors without having to check these conditions
  - explicitly in the program everywhere they might occur

Coroutines

- Coroutines are execution contexts that exist concurrently, but that execute one at a time, and that transfer control to each other explicitly, by name
- Coroutines can be used to implement
  - iterators
  - threads
- Because they are concurrent (i.e., simultaneously started but not completed), coroutines cannot share a single stack

Coroutines

```
var q := new queue
coroutine produce
    loop
        while q is not full
            create some new items
            add the items to q
        yield to consume
coroutine consume
    loop
        while q is not empty
            remove some items from q
            use the items
        yield to produce
```

Coroutines

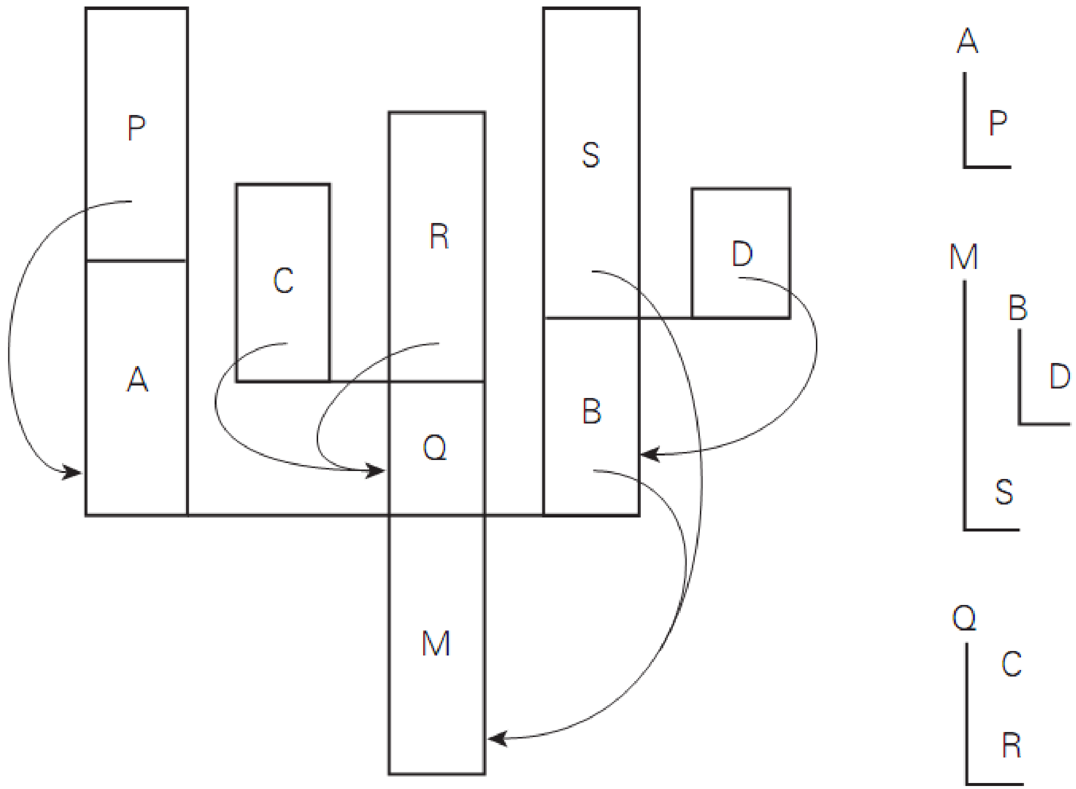


Figure 8.6 A cactus stack. Each branch to the side represents the creation of a coroutine (A, B, C, and D). The static nesting of blocks is shown at right. Static links are shown with arrows. Dynamic links are indicated simply by vertical arrangement: each routine has called the one above it. (Coroutine B, for example, was created by the main program, M. B in turn called subroutine S and created coroutine D.)

Summary

- Functional Abstraction:
  - Functions help us abstract the code:
    - by being able to give parts of the program meaningful name
    - by creating scopes in which data and control flow is controlled.
  - Learned about stack layouts:
    - Static link.
    - Dynamic link.
  - 3 main calling conventions.
    - Pass by value.
    - Pass by reference.
    - Pass by sharing.
  - Generics
    - Java
    - C++