Subprograms

Parameters that are subroutines

- In some situations, subroutine names can be sent as parameters to other subroutines
- Only the transmission of computation is necessary, which could be done by passing a functional pointer

Two complications with subroutine parameters

- Are parameters type checked?
  - Early Pascal and FORTRAN 77 do not type check
  - Later versions of Pascal, Modula-2, and FORTRAN 90 do
  - C and C++ do

Two complications with subroutine parameters (cont’d)

- What referencing environment should be used for executing the passed subroutine?
  - The environment of the call statement that enacts the passed subroutine (shallow binding)
  - The environment of the definition of the subroutine (deep binding)
  - The environment of the call statement that passed it as an actual parameter (ad hoc binding)

An Example

- For shallow binding, the referencing environment of sub2 is sub4
- For deep binding, the referencing environment of sub2 is sub1
- For ad hoc binding, the referencing environment of sub2 is sub3

What is the output of alert(x)?

- Shallow binding?
- Deep binding?
- Ad hoc binding?
Referencing Environment for Subroutine Parameters

- Deep binding and ad hoc binding can be the same when a subroutine is declared and passed by the same subroutine.
- In reality, ad hoc binding has never been used.
- Static-scoped languages usually use deep binding.
- Dynamic-scoped languages usually use shallow binding.

Design Issues for Functions

- Are side effects allowed?
  - Ada requires in-mode parameters, and does not allow any side effect.
  - Most languages support two-way parameters, and thus allow functions to cause side effects.

Overloaded Subroutine

- A subroutine that has the same name as another subroutine in the same referencing environment, but its number, order, or types of parameters must be different.
  - E.g., void fun(float);
  - C++ and Ada have overloaded subroutines built-in, and users can write their own overloaded subroutines.

Generic Subroutine

- A generic or polymorphic subroutine takes parameters of different types on different activations.
  - An example in C++
    ```cpp
    template<class Type>
    Type max(Type first, Type second) {
      return first > second ? first : second;
    }
    int a, b, c;
    char d, e, f;
    ...
    c = max(a, b);
    f = max(d, e);
    ```

An Example

- In static-scoped languages, Receiver is not always visible to Sent, so deep binding is natural.
- In dynamic-scoped languages, it is natural for Sent to have access to variables in Receiver, so shallow binding is appropriate.

Design Issues for Functions

- What types of values can be returned?
  - FORTRAN, Pascal, and Modula-2: only simple types.
  - C: any type except functions and arrays.
  - Ada: any type (but subroutines are not types).
  - JavaScript: functions can be returned.
  - Python, Ruby, and functional languages: methods are objects that can be treated as any other object.

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Generic Subroutine

- Overloaded subroutines provide a particular kind of polymorphism called **ad hoc polymorphism**
  - Overloaded subroutines need not behave similarly
- Parametric polymorphism is provided by a subroutine that takes generic parameters to describe the types of parameters
- Parametric polymorphic subroutines are often called generic subroutines

Coroutine

- A special kind of subroutine. Rather than the master-slave relationship, the caller and callee coroutines are on a more equal basis
- A coroutine is a subroutine that has multiple entry points, which are controlled by coroutines themselves

Coroutine

- The first execution of a coroutine begins at its beginning, but all subsequent executions often begin at points other than the beginning
- Therefore, the invocation of a coroutine is named a **resume**
- Typically, coroutines repeatedly resume each other, possibly forever
- Their executions interleave, but do not overlap

An Example

```cpp
sub co1() {
    ...
    resume(co2);
    ...
    resume(co3);
}
```

- The first time co1 is resumed, its execution begins at the first statement, and executes down to resume(co2) (with the statement included)
- The next time co1 is resumed, its execution begins at the first statement after resume(co2)
- The third time co1 is resumed, its execution begins at the first statement after resume(co3)

Coroutine

- The interleaved execution sequence is related to the way multiprogramming operating systems work
  - Although there may be one processor, all of the executing programs in such a system appear to run concurrently while sharing the processor
  - This is called **quasi-concurrency**
- Coroutines provide quasi-concurrent execution of program units