**Call by Name and Lazy Evaluation**

Call by name has much of the flavor of *lazy evaluation*. With lazy evaluation, you don't compute a value but rather a *suspension*—a function that will provide a value when called. This can be useful when we need to control how much of a computation is actually performed.

Consider an infinite list of integers. Mathematically it is represented as:

\[ 1, 2, 3, \ldots \]

How do we compute a data structure that represents an infinite list?

The obvious computation

```java
infList(int start) {
    return list(start, infList(start+1));
}
```

doesn't work. (Why?)

A less obvious implementation, using suspensions, *does* work:

```java
infList(int start) {
    return list(start, function() {
        return infList(start+1);
    });
}
```

Now, whenever we are given an infinite list, we get two things: the first integer in the list and a suspension function. When called, this function will give you the rest of the infinite list (again, one more value and another suspension function).

The whole list is there, but only as much as you care to access is actually computed.

**Eager Parameter Evaluation**

Sometimes we want parameters evaluated *eagerly*—as soon as they are known.

Consider a sorting routine that breaks an array in half, sorts each half, and then merges together the two sorted halves (this is a *merge sort*).

In outline form it is:

```java
sort(inputArray) {
    ...
    merge(sort(leftHalf(inputArray)),
         sort(rightHalf(inputArray)));
}
```

This definition lends itself nicely to parallel evaluation: The two halves of an input array can be sorted in parallel. Each of these two halves can
again be split in two, allowing parallel sorting of four quarter-sized arrays, then leading to 8 sorts of 1/8 sized arrays, etc.

But, to make this all work, the two parameters to merge must be evaluated *eagerly*, rather than in sequence.

**Type Equivalence**

Programming languages use types to describe the values a data object may hold and the operations that may be performed.

By checking the types of values, potential errors in expressions, assignments and calls may be automatically detected. For example, type checking tells us that

\[ 123 + "123" \]

is illegal because addition is not defined for an integer, string combination.

Type checking is usually done at compile-time; this is *static typing*.

Type-checking may also be done at run-time; this is *dynamic typing*.

A program is *type-safe* if it is impossible to apply an operation to a value of the wrong type. In a type-safe language, plus is never told to add an integer to a string, because its definition does not allow that combination of operands. In type-safe programs an operator can still see an illegal value (e.g., a division by zero), but it can’t see operands of the wrong type.

A *strongly-typed* programming language forbids the execution of type-unsafe programs.

*Weakly-typed* programming languages allow the execution of potentially type-unsafe programs.

The question reduces to whether the programming language allows programmers to “break” the type rules, either knowingly or unknowingly.

Java is strongly typed; type errors preclude execution. C and C++ are weakly typed; you can break the rules if you wish. For example:

```c
int i; int* p;
p = (int *) i * i;
```

Now `p` may be used as an integer pointer though multiplication need not produce valid integer pointers.

If we are going to do type checking in a program, we must decide whether two types, T1 and T2 are equivalent; that is, whether they be used interchangeably.
There are two major approaches to type equivalence:

**Name Equivalence:**

Two types are equivalent if and only if they refer to exactly the same type declaration.

For example,

```plaintext
type PackerSalaries = int[100];
type AssemblySizes = int[100];
PackerSalaries salary;
AssemblySizes size;
```

Is

```
sal = size;
```

allowed?

Using name equivalence, no. That is, `salary` \(\not\equiv\,_{N}\,\) `size` since these two variables have different type declarations (that happen to be identical in structure).

Formally, we define \(\equiv\,_{N}\) (name type equivalence) as:

(a) \(T \equiv\,_{N}\, T\)

(b) Given the declaration

```
Type T1 = T2;
```

\(T1 \equiv\,_{N}\, T2\)

We treat anonymous types (types not given a name) as an abbreviation for an implicit declaration of a new and unique type name.

Thus

```
int A[10];
```

is an abbreviation for

```
Type Tnew = int[10];
Tnew A;
```

**Structural Equivalence**

An alternative notion of type equivalence is structural equivalence (denoted \(\equiv\,_{S}\)).

Roughly, two types are structurally equivalent if the two types have the same definition, independent of where the definitions are located. That is, the two types have the same definitional structure.

Formally,

(a) \(T \equiv\,_{S}\, T\)

(b) Given the declaration

```
Type T = Q;
```

\(T \equiv\,_{S}\, Q\)

(c) If \(T\) and \(Q\) are defined using the same type constructor and corresponding parameters in the

```plaintext
two definitions are equal or structurally equivalent then \(T \equiv\,_{S}\, Q\)
```

Returning to our previous example,

```plaintext
type PackerSalaries = int[100];
type AssemblySizes = int[100];
PackerSalaries salary;
AssemblySizes size;
```

\(salary \equiv\,_{S}\, size\) since both are arrays and 100=100 and int \(\equiv\,_{S}\, int\).
Which notion of Equivalence do Programming Languages Use?

C and C++ use structural equivalence except for structs and classes (where name equivalence is used). For arrays, size is ignored.

Java uses structural equivalence for scalars. For arrays, it requires name equivalence for the component type, ignoring size. For classes it uses name equivalence except that a subtype may be used where a parent type is expected. Thus given

```c
void subr(Object O) { ... };
```

the call

```c
subr(new Integer(100));
```

is OK since `Integer` is a subclass of `Object`.

Automatic Type Conversions

C, C++ and Java also allow various kinds of automatic type conversions.

In C, C++ and Java, a `float` will be automatically created from an `int`:

```c
float f = 10; // No type error
```

Also, an integer type (`char, short, int, long`) will be widened:

```c
int i = 'x';
```

In C and C++ (but not Java), an integer value can also be narrowed, possibly with the loss of significant bits:

```c
char c = 1000000;
```