Callability Control

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Conventions

We will consider C♯ (or any other .Net or JVM language), since it:

- is statically-typed,
- supports named/identifiable functions (e.g. static/instance methods and constructors),
- supports dynamic dispatch (with interfaces, virtual methods, etc.),
- supports dynamic code loading, and
- supports dynamic function lookup and invocation (with reflection).

For brevity I will omit accessibility modifiers and allow free standing static functions.

The Problem

1. What *could* this function do?

   ```
   static void M1() { Sign(0); }
   ```

2. What about this, what *could* it do?

   ```
   interface I { void Run(); }
   static void M2(I x) { x.Run(); }
   ```

3. How about this?

   ```
   static void M3(String url) {
     // Load code (possibly from the internet)
     Assembly code = Assembly.LoadFrom(url);
     code.GetMethod("M").Invoke(null, null); } // dynamically invoke M()
   ```

Callability

- *Callability* is the *ability* to *call* a function.
- A function's callability is the set of things it can call.

Restatement of the Problem:

1. What is the callability of `Sign`? (Where `Sign` is a static method.)
2. What is the callability of `x.Run`? (Where `x` is of an interface type `I`.)
3. What is the callability of `M`? (Where `M` was a dynamically loaded static method.)

The Callability Rules

$f \rightsquigarrow g$, i.e. a function f *can-call* a function g, iff:

1. $g \in \mathit{Calls}(f) \Rightarrow f \rightsquigarrow g$, i.e. f is annotated with calls[… , g, …].

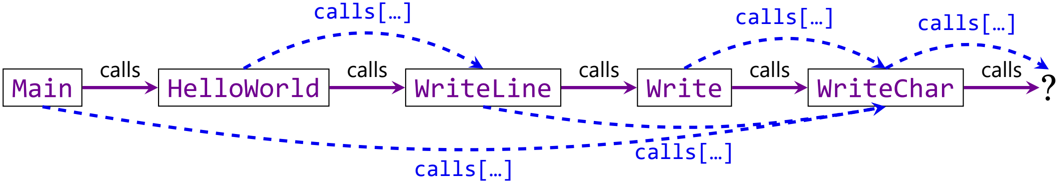
   Example:
   ```
   static void Write(String s) calls[WriteChar] {
     foreach (Char c in s) WriteChar(c); }
   ```

2. $(\forall h \in \mathit{Calls}(g) \bullet f \rightsquigarrow h) \Rightarrow f \rightsquigarrow g$, i.e. if f can call every function in the calls[…] annotation of g.

   Example:
   ```
   static void WriteLine(String s) calls[WriteChar] {
     Write(s + "\n"); }
   ```

The previous rules apply transitively, and always allow for recursive calls.

Example:
```
static void HelloWorld() calls[WriteLine] {
  WriteLine("Hello World!"); }
static void Main(String[] args) calls[WriteChar] {
  HelloWorld(); }
```



Primitive Operations

To simplify things we will assume that the language provides only two intrinsic functions, `Unrestricted` and `Restricted`.

1. `Unrestricted` can be called by any function:

   ```
   static Object Unrestricted(String op, params Object[] args)
     calls[];
   ```

   Example: `Unrestricted("Add", 1, 2); // Returns 3`

2. `Restricted` can only be directly called by functions that contain `Restricted` in their `calls`:

   ```
   static Object Restricted(String op, params Object[] args)
     calls[Restricted];
   ```

   Example:
   ```
   static void WriteChar(Char c) calls[Restricted] {
       Restricted("CCall", "putchar", c); }
   ```

How to Solve Problem 1 (Static Dispatch)

What can `Sign(0)` do?

1. (indirectly) perform only `Unrestricted` operations:

   ```
   static Int32 Sign(Int32 x) calls[] {…}
   ```

2. also (indirectly) perform *some* `Restricted` operations:

   ```
   static Int32 Sign(Int32 x) calls[WriteLine] {…}
   ```

3. also (indirectly) perform *any* `Restricted` operation:

   ```
   static Int32 Sign(Int32 x) calls[Restricted] {…}
   ```

How to Solve Problem 2 (Dynamic Dispatch)

What can `x.Run()` do?

```
interface I { void Run() calls[]; }
```

Callability Generics

Consider this:

```
  interface I<'a> { void Run() calls['a]; }
```

Example:

```
class HelloWorld: I<[WriteLine]> {
        void I.Run() calls[WriteLine] { WriteLine("Hello World!"); }}
```

Now to answer the question: what can `x.Run()` do?

1. Only perform `Unrestricted` operations:
   ```
   static void M2(I<[]> x) calls[] { x.Run(); }
   ```
2. Also print lines to standard-output:
   ```
   static void M2(I<[WriteLine]> x) calls[WriteLine] { x.Run(); }
   ```
3. Perform any `Restricted` operation:
   ```
   static void M2(I<[Restricted]> x) calls[Restricted] { x.Run(); }
   ```
4. Defer the decision to the caller of `M2`:
   ```
   static void M2<'a>(I<['a]> x) calls['a] { x.Run(); }
   ```

How to Solve Problem 3 (Dynamic Code Loading & Invocation)

In C♯ to dynamically invoke a static or instance method, you simply write:

```
methodInfo.Invoke(receiver, args)
```

For our system to be sound, we could declare `Invoke` like this:

```
/// Represents a method m
class MethodInfo {
  …
  /// Throws an exception if Invoke<'a> ↝̸ m,
  /// otherwise calls receiver.m(args)
  Object Invoke<'a>(Object receiver, Object[] args) calls['a] { … }
  … }
```

```
static void M3(String url) {
  // Load code (possibly from the internet)
  Assembly code = Assembly.LoadFrom(url);
  // call M(), but only if it can only perform Unrestricted operations
  code.GetMethod("M").Invoke<[]>(null, null); }
```

Conclusion

1. No need to look at the body of methods to determine what they can do.
2. No need to look at *every* piece of code we are compiling with.
3. Our reasoning is static and consistently sound.

Future Work

- Make our annotations less verbose:
  - Infer `calls` annotations?
  - Have a `cant-call` annotation?
  - Support wild-cards?
  - Allow named groups of functions?
- Improve support for dynamic code loading:
  - Allow calling newly loaded functions, even if they have themselves in their `calls` annotation.
- Formalise the reasoning properties we want from our system:
  - Reason in the presence of unsafe operations (like executing arbitrary machine code).
  - Prove them!