

Classes for the Masses (Extended Abstract)

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ABSTRACT

Type classes are an immensely popular and productive feature of Haskell. They have since been adopted in, and adapted to, numerous other languages, including theorem provers. This talk will sketch that type classes have a natural and efficient representation in .NET. This paves the way for the extension of F# and other .NET languages with Haskell style type classes. The representation is type preserving and promises easy and safe cross-language inter-operation. We are currently, and rapidly, extending the open source C# compiler and language service, Roslyn, with support for type classes but intend to do the same for F# once that work has been completed.

1. INTRODUCTION

Haskell's *type classes* [8, 9] are a powerful abstraction mechanism for describing generic algorithms applicable to types that have different representations but common interfaces. A *type class* is a predicate on types that specifies a set of required operations by their type signatures. A type may be declared to be an *instance* of a type class, and must supply an implementation for each of the class' operations. Type classes may be arranged hierarchically, permitting subsumption and inheritance. A default method may also be associated with an operation allowing its implementations to be omitted.

Many modern language have adopted features inspired by type classes, with different implementation techniques. Scala has *implicit*s [7], implicit method arguments denoting dictionaries, that are inferred by the compiler but represented, at run-time, as additional heap-allocated arguments to methods (with commensurate overhead). C++ came very close to adopting *concepts* [5], a rather different compile-time template mechanism, directly inspired by Haskell's type classes but emphasize compile-time code specialization. Rust has *traits* [3] and Swift has *protocols* [4].

Contribution We describe a simple encoding that allows us to add type classes to any .NET language, allowing interoperable definitions of type classes. Our encoding relies on the CLR's distinctive approach to representing and compiling generic code [6, 10]. Unlike, for example, the JVM, the CLR byte-code format is fully generic (all source level type information, including class and method type parameters, are represented in the metadata and virtual instruction set). Parameterized code is JIT-compiled to type passing code, with type parameters having run-time representations as (second-order) values. The JIT compiler uses the refined types to generate specialized memory representations (for

instantiated generic types) and specialized (and thus more efficient) code for generic methods. For example, scalar types and compounds of scalars called structs have natural unboxed representations familiar to C(++) programmers; generic array manipulating code will manipulate array elements without boxing when instantiated at scalar types. This run-time specialization allows the JIT to avoid the uniform (i.e. lowest-common-denominator) representations adopted by many implementations of ML, Haskell, the JVM and most dynamic languages.

Haskell compilers typically compile type classes using the so-called *dictionary translation*. The translation, guided by source types, inserts terms that justify type class constraints. These terms, or witnesses, are records of functions that provide implementations for all of the constraint's methods. Although similar to object-oriented virtual method tables, witness are not attached to objects, but passed separately as function arguments. Because type classes are resolved statically, aggressive inlining can remove most, but not all, indirection through witness parameters. This leads to efficient code with few indirect calls and leaner representations of values than full-blown objects. Objects, in contrast, must lug their method-tables wherever they go.

Given the obvious similarity between type passing and dictionary passing, it is perhaps not surprising that type passing forms an excellent implementation technique for Haskell's dictionary passing. This talk will give an overview of the technique that we are applying to provide efficient, interoperable type class implementations to both C# and F#.

2. THE REPRESENTATION

This section sketches our representation of the Haskell'98 type classes on .NET by example. For each example, we give the Haskell code, underlying .NET code in vanilla C#, and proposed F# syntax. We use vanilla C# as a more readable proxy for .NET intermediate bytecode and metadata.

2.1 Haskell Type Classes

A Haskell type class, for example:

```
class Eq a where
  (==) :: a -> a -> Bool
```

Is naturally represented in C# as:

```
interface Eq<A> {
    bool Equals(A a, A b);
}
```

For new F# syntax we adopt the keyword `concept` (`class` is already taken):

```
concept Eq 'a where
    (==): 'a -> 'a -> bool
```

2.2 Haskell Overloads

The Haskell declaration of class `Eq` `a` implicitly declares the overloaded operations induced by class' members.

```
(==) :: (Eq a) => a -> a -> Bool
```

Observe that the overload operation has a more general constrained type `(Eq q) =>...`

This generic operation can be represent in C# by the method:

```
public static bool Equals<A,EqA>(A a, A b)
    where EqA : struct, Eq<A> {
    return default(EqA).Equals(a, b); }
```

This method has not one, but *two*, type parameters. The first, `A`, is just the type parameter from the declaration. The second, `EqA`, is a type parameter that is constrained to be a struct and witnesses the constraint that `A` supports interface `Eq<A>`.

The use of the `struct` constraint on `EqA` is significant and subtle. Structs are stack allocated so essentially free to create. Moreover, every struct, including type parameters `T` of kind struct, has a default (all-zero) value that is created by calling `default(T)`.

Invoking a method on a default value of reference type would simply raise a null-reference exception because the receiver is `null`. However, methods on structs (including interface methods) can always be properly invoked by calling the method on the struct's default value.

Thus an operation over some class can be represented as static generic method, parameterized by an additional dictionary type parameter (here `EqA`). Similarly, derived operations with type class constraints can be represented by generic methods with suitably constrained type parameters.

So a Haskell dictionary *value* corresponds to a C# dictionary *type*.

2.3 Haskell Instances

A Haskell instances declarations is represented by the declaration of an empty (field-less) .NET generic struct that implements the associated type class (itself an interface). This gives us a cheap representation of Haskell instances.

For example, the Haskell instance declaration:

```
instance Eq Integer where
    x == y = x 'integerEq' y
```

can be represented by the C# structure:

```
struct EqInt : Eq<int> {
    public bool Equals(int a, int b) { return a == b; }
}
```

For F#, we introduce the shorter `instance` declaration:

```
instance Eq int where
    Equals (a, b) = a = b
```

Note that the F# syntax, like Haskell, elides the name of the instance in the more explicit C# representation. In Haskell, instances are anonymous.

2.4 Derived Instances

This Haskell code defines, given an equality on (any) type `a`'s, an equality operation on lists of `a`.

```
instance (Eq a) => Eq ([a]) where
    nil == nil = true
    (a:as) == (b:bs) = (a == b) && (as == bs)
    _ == _ = false
```

We can represent such a Haskell parameterized instance as a *generic* struct:

```
struct EqList<A, EqA> : Eq<List<A>>
    where EqA : struct, Eq<A> {
    public bool Equals(List<A> a, List<A> b) {
        if (a.IsNull != b.IsNull) return true;
        else if (a.IsCons & b.IsCons)
            return default(EqA).Equals(a.Head,b.Head)
                && Equals(a.Tail,b.Tail);
        else false;
    }
}
```

This struct implements the interface `Eq<List<A>>`, but only when instantiated with a suitable type argument and witness for constraint `Eq<A>`. Notice that `EqList` has, once again, an additional type parameter witnessing `Eq<A>`. Instantiations of `EqList` construct witnesses for `Eq<List<A>>`.

For F# we adopt the more concise, nameless declaration:

```
instance Eq 'a => Eq (List 'a) where
    Equals(a,b) = match a,b with
    | [],[] -> true
    | (a::l,b::m) -> Equals(a,b) && Equals(l,m)
    | _,_ -> false
```

2.5 Other features

We do not have space to describe the representations of other features but suffice to say that we can encode: Haskell type class operations that themselves have constrained types in their signatures (using interface methods that are generic); Haskell type class hierarchies using interface inheritance; default operations using shared static methods; instances requiring polymorphic recursion, instances as data (to constrained term constructors) and multi-parameter type classes. Moreover, choosing to provide named witness rather than anonymous one allows us to support explicit as well as implicit instances. The only feature we cannot currently support is higher-kinded type classes (like `Monad`), but this is because .NET does not yet support higher kinds.

Much of the concision of Haskell comes not only from the declaration of type class hierarchies but from the implicit solution of constraints during type inference. For C#, we envision witness inference to be a mild generalization of type argument inference, with instantiations derived from the pervasive and locally assumed concept hierarchy. For F#, we hope to adapt Haskell's more elaborate techniques for not only solving but also implicitly propagating inferred type class constraints.

3. IMPLEMENTATION

We are currently prioritizing our efforts on our C# implementation of type classes [1], forked from Microsoft's open source Roslyn compiler [2], adopting a syntax loosely inspired by C++ concept proposal. However, we hope to turn our attention to F# over the second half of the summer.

4. REFERENCES

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