Reconciling OO and Haskell-Style Overloading

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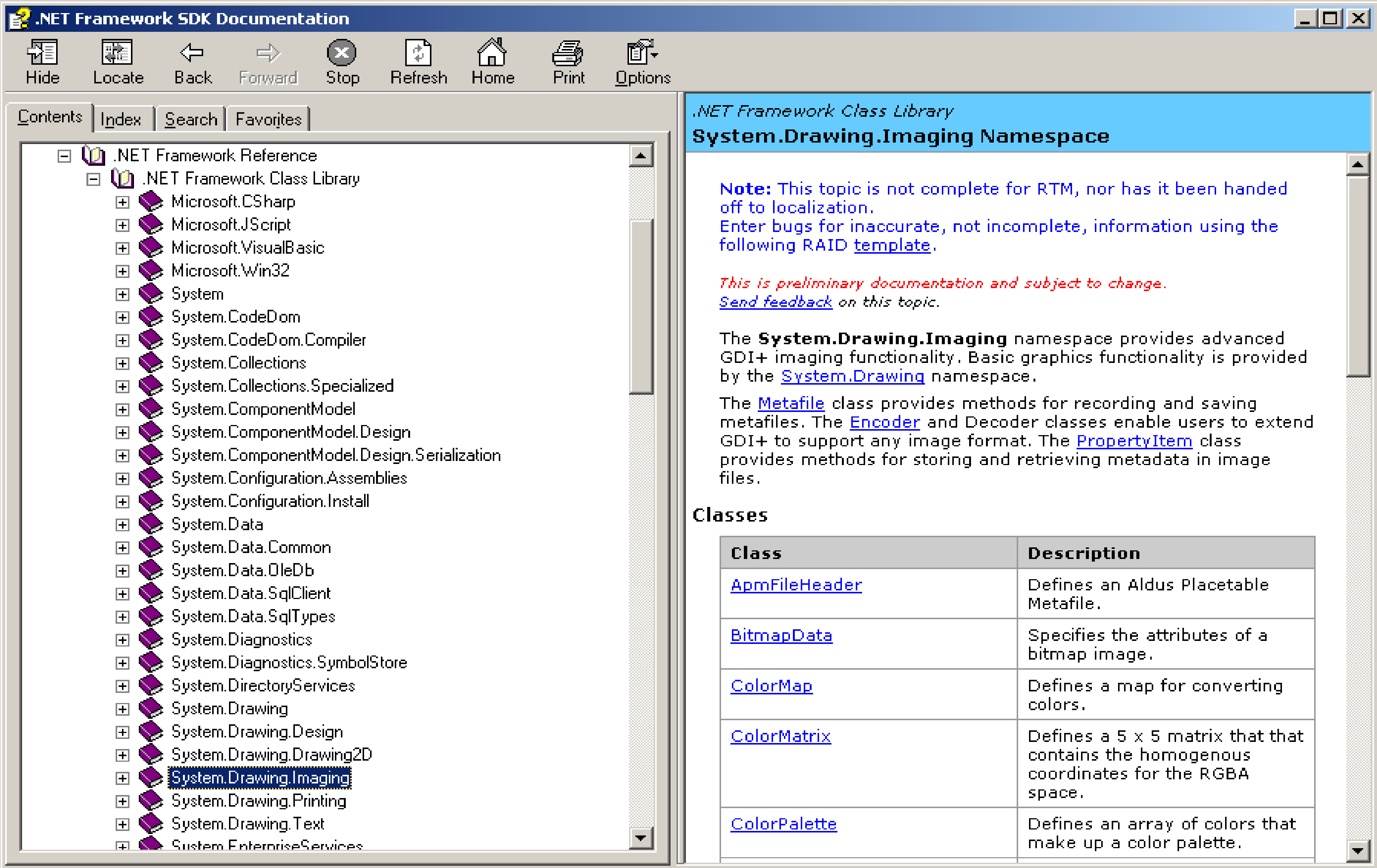
It's an OO World



Basic FFI

C#	Haskell

`class A {`
`  static int m(int, char);`
`}`
	`m :: Int -> Char -> IO Int`

- Marshal C# base types to/from Haskell types
- Design decisions yet to make:
  - Unboxing? (Probably ignore)
  - Byrefs? (Probably copy in, copy out)
  - Null Pointers? (Probably use `Maybe`)
  - Purity? Non-null? (Need standard C# type annotations)

Novelty 1: Subtyping

C#	Haskell

`class A {`
`  int m(char);`
`}`
`class B : A, I { … }`
	`m :: Char -> A -> IO Int`

- `a :: A, b :: B`

- `a # m '1' :: IO Int`
- `b # m '1' :: IO Int`

`(#) :: a -> (a -> b) -> b`

ding in this talk. In
derived class.)

Novelty 2: Overloading

C#	Haskell

`class A {`
`  int m(char);`
`  int m(int);`
`}`
	`m :: Char -> A -> IO Int`
	`m :: Int -> A -> IO Int`

- `a :: A`

- `a # m '1' :: IO Int   -- call first m`
- `a # m 1 :: IO Int     -- call second m`

- (This doesn't seem so bad, give Haskell already has type-based overloading)

Novelty 3: "Overlapping" Methods

C#	Haskell

`class C { … }`
`class D : C { … }`
`class A {`
`  int m(C);`
`  int m(D);`
`}`
	`m :: C -> A -> IO Int`
	`m :: D -> A -> IO Int`

```
a :: A, c :: C, d :: D

a # m c :: IO Int  -- call first m
a # m d :: IO Int  -- call second m
```

- (Since both `m`'s match second call, this seems well outside of Haskell's system)

Objectives

- Account for these novelties in a way which:
  - is as natural as C#: no name mangling or explicit coercions
  - blends with existing constrained polymorphism and class constraints framework

- Non objectives:
  - Extend Haskell to be a "calculus of objects"
    - in particular, internalizing virtual methods
  - be as natural as C# for constructing new classes
  - (The MLj approach would probably be the best were these to be the objectives)

Constrained Polymorphism in 1 Slide

- Classes: `class D a => C a where a -> a`
- Constraints: `C τ`

  true if type τ is a member of type class `C`
- Witnesses: `instance C Int = t`

  `C Int` is true, and witnessed by the pair

  `(W, t)`

  where `W` is a witness for `D Int`

  and `t :: Int -> Int`

- Type inference propagates constraints at compile-time
- Dictionary transformation causes witnesses to be propagated at run-time

Obvious Non-starter

- Can't just encode C# class as Haskell class:
  - Will reject C# class with overloaded methods (Haskell method names must be unique within class)
  - Will reject C# classes sharing the same method name (Haskell method names must be unique across all classes)
  - Too much witness passing:

    ```
    f :: A a => a -> IO Int
    ```

    Each call to f passes bogus dictionary of methods for `a`

Subtyping: Attempt

- Simulate subtyping constraints using classes:

C#	Haskell

`class A {`
`  int m(char);`
`}`
`class B : A, I`
`  { … }`
	`newtype A = ObjRef`
	`newtype B = ObjRef`
	
	`class BelowA a`
	`instance BelowA A`
	`instance BelowA B`
	
	`class (BelowA a, BelowI a) =>`
	`        BelowB a`
	`instance BelowB B`
	
	`m :: BelowA a => Char -> a -> IO Int`

Subtyping: Attempt

- ☺ No witness passing required
- ☺ Works for multiple inheritance
- ☺ `AboveA` may be defined analogously
- ☺ Captures transitivity

```
m :: BelowA a => Char -> a -> IO Int
n :: BelowB a => Char -> a -> IO Int
f :: BelowB a => a -> IO Int
f x = do i <- x # m '1'
         j <- x # n '2'
         return i + j
```

Subtyping: Attempt

- ☹ Quadratic growth in instance declarations
- ☹ Almost no subtype simplifications possible

```
(AboveA a, BelowA a) => a -> a
```

instead of `A -> A`

```
(AboveA a, BelowB a) => a -> a
```

instead of type error

Subtyping: Solution

- Add a new subtype constraint

  `t :<: u` "type `t` is a subtype of type `u`"

- Subtype constraints only appear on
  - imported methods
  - `coerce :: a :<: b => a -> b`
  - (possibly) functions using the above

- Subtypes only introduced by `newtype` declarations

  `newtype A :<: B`$_1$`, ..., B`$_n$` = ObjRef`

Subtyping: Solution

C#	Haskell

`class A {`
`  int m(char);`
`}`
`class B : A, I`
`  { … }`
	`newtype A = ObjRef`
	`newtype B :<: A, I = ObjRef`
	
	`m :: a :<: A => Char -> a -> IO Int`

- `a :: A, b :: B`
- `a # m '1' :: IO Int`
- `b # m '1' :: IO Int`
- `f :: a :<: A => a -> IO Int`
  `f x = x # m '1'`

Subtyping: Quirks

- For convenience, rules for structural subtyping builtin
- Subtyping is **not** implicit on every application
- Hence, maximization & minimization simplification rules not applicable

  `(A :<: a, b :<: B) => b -> a`

  cannot be reduced to `B -> A`
- We only assume newtypes form a poset, **not** a lattice or upwards-closed semi-lattice
- Hence, no $\perp$ or T types

Subtyping: Quirks

- The subtype poset is downward extensible
- Hence glb rules are not applicable

```
newtype A
newtype B
newtype C :<: A, B
(a :<: A, a :<: B) => a -> a
```

cannot be reduced to

```
a :<: C => a -> a
```

since another module may add

```
newtype D :<: A, B
```

- lub rules ok

Overloading: Attempt

- Encode OO overloading as degenerate Haskell type-class overloading

C#	Haskell

class A {
  int m(char);
  int m(int);
}
	class Has_m a where
	  m :: a
	
	instance a :<: A =>
	  Has_m (Char -> a -> IO Int)
	    where m = {- call first m -}
	
	instance a :<: A =>
	  Has_m (Int -> a -> IO Int)
	    where m = {- call second m -}

Overloading: Attempt

- ☹ Type inference won't commit to return type:

```
a :: A
a # m '1' :: Has_m (Char -> A -> b) => b
```

- ☹ Type inference won't report error eagerly:

```
a # m True :: Has_m (Bool -> A -> b) => b
```

- ☹ Type inference won't commit to a method:

```
instance a :<: A =>
  Has_m ((Int, Int) -> a -> IO Int)
a # m (x,y) :: Has_m ((b,c) -> A -> d) => d
```

Overloading: Attempt

- These problems are a consequence of the openness of instance declarations:
  - simplifier must assume `Has_m` could be extended in another module
  - hence `Has_m` constraints will propagate within type schemes until become ground
- But, we want most/all method overloading to be resolved before generalization based on which methods are visible now

Overloading: Solution

- Introduce notion of `closed` class
- If simplifier sees a class constraint for a closed class, it may assume all instance declarations are in scope
- This allows more aggressive simplification: improvement and early failure

- `Has_m` classes are declared `closed`
- Constraint syntactic sugar

```
m :: t
```

for

```
Has_m t
```

Overloading: Solution

C#	Haskell

`class A {`
`  int m(char);`
`  int m(int);`
`}`
	`class closed m :: a where`
	`  m :: a`
	
	`instance a :<: A =>`
	`  m :: Char -> a -> IO Int`
	`    where m = {- call first m -}`
	
	`instance a :<: A =>`
	`  m :: Int -> a -> IO Int`
	`    where m = {- call second m -}`

Overloading: Solution

- ☺ Only one method on `A` with `Char` argument possible, so commit:

```
a :: A
a # m '1' :: IO Int
```

- ☺ No methods on `A` with `Bool` argument possible, so reject:

```
a # m True
error: cannot satisfy m :: Bool -> A -> c
```

- ☺ Only one method on `A` with pair argument, so commit:

```
instance a :<: A =>
  m :: (Int, Int) -> a -> IO Int
a # m (x, y) :: IO Int
```

  (and `x :: Int, y :: Int`)

Overloading: Solution

☺ A little more subtle: still don't know which method, but know result must be `IO Int`

```
a :: A
f :: (m :: a -> A -> IO Int) =>
         a -> IO Int
f x = a # m x
```

- (Deferring method constraints seems reminiscent of virtual methods. We shall return to this)

Simplification for Closed Class Constraints

Given constraint $C\ \tau$ for closed class C:

- Step 1: Collect all "candidate" instances

  $\forall\ \alpha\ .\ \Phi \Rightarrow C\ \upsilon$

  such that there exists a θ such that

  $\theta\ [\alpha \mapsto \beta]\ (C\ \upsilon) = \theta\ (C\ \tau)$

  and $\theta\ [\alpha \mapsto \beta]\ \Phi$ (may be) satisfiable

- Step 2: Calculate least-common generalization, τ', of all

  $\theta\ [\alpha \mapsto \beta]\ \upsilon$

- Step 3: Unify τ with τ'
- Step 4: If only one candidate, use it to construct witness for $C\ \tau'$

Overlapping Overloading: Attempt

- Overlapping methods become overlapping instances

C#	Haskell

`class C { … }`
`class D : C { … }`
`class A {`
`  int m(C);`
`  int m(D);`
`}`
	`class closed m :: a where`
	`  m :: a`
	
	`instance (a :<: A, b :<: C) =>`
	`  m :: b -> a -> IO Int`
	`instance (a :<: A, b :<: D) =>`
	`  m :: b -> a -> IO Int`

Overlapping Overloading: Attempt

- ☹ Overlapping instances are illegal in standard Haskell
- ☹ GHC/Hugs support them, but (as usual for Haskell...) without any formal description, and inconsistently (even between versions)
- ☺ Could be made to work if only one candidate:

```
a :: A, c :: C
a # m c     -- only first m possible
```

- ☹ But still fails with multiple candidates:

```
a :: A, d :: D
a # m d :: (m :: D -> A -> IO Int) => IO Int
              -- should choose second m
```

Overlapping Overloading: Solution

- Classes declared as `closed` (or `overlap`) may have arbitrarily overlapping instances
- Solve class constraints as before, but if multiple candidates, may choose least under (an approximation of) the instantiation ordering ≤
- Eg:

```
∀ a b . (a :<: A, b :<: D) => m :: b -> a -> IO Int
                         ≤
∀ a b . (a :<: A, b :<: C) => m :: b -> a -> IO Int
```

since from `a :<: A, b :<: D`

we may derive `a :<: A, b :<: C`

Overlapping Overloading: Solution

- More formally, $\leq$ is defined by entailment:

$$\frac{\forall\, \beta\,.\,\Xi \Rightarrow C\,\tau\,,\,[\alpha \to \alpha']\,\Phi \;|\!-^{e}\; [\alpha \to \alpha']\,C\,\upsilon}{\forall\, \alpha\,.\,\Phi \Rightarrow C\,\upsilon \leq \forall\, \beta\,.\,\Xi \Rightarrow C\,\tau}$$

- However, it is implemented by simplification:

$$\frac{\begin{array}{c} <\forall\, \beta\,.\,\Xi \Rightarrow C\,\tau\,,\,[\alpha \to \alpha']\,\Phi,\, C\,\upsilon > \\ \to^{*} <\forall\, \beta\,.\,\Xi \Rightarrow C\,\tau\,,\,[\alpha \to \alpha']\,\Phi > \end{array}}{\forall\, \alpha\,.\,\Phi \Rightarrow C\,\upsilon \leq \forall\, \beta\,.\,\Xi \Rightarrow C\,\tau}$$

Overlapping Overloading: Incompleteness

- Constraint simplifier is deliberately incomplete w.r.t. constraint entailment for overlapping instances:
  - Only consider one class constraint at a time:

```
instance m :: Int -> Int
instance m :: Bool -> Int
instance n :: Int -> Int
instance n :: Char -> Int
f x = m x + n x
```

  Valid typing is `f :: Int -> Int`

  But inferred type is

```
f :: (m :: a -> Int, n :: a -> Int) =>
         a -> Int
```

Overlapping Overloading: Incompleteness

- Don't fully exploit unsatisfiability

```
class closed C a where ...
class closed D a where ...
instance C Int

instance C a => m :: a -> IO Int
instance D a => m :: a -> IO Int
f x = m x
```

Valid typing is `f :: Int -> IO Int`

But inferred type is

```
f :: (m :: a -> IO Int) => a -> IO Int
```

Virtual Methods vs Member Constraints

C#	Haskell
`class A {`	`newtype A`
`  virtual int m();`	`newtype B :<: A`
`}`	`instance m :: A -> IO Int`
`class B : A {`	`instance m :: B -> IO Int`
`  virtual int m();`	
`}`	
`int f(A, A);`	`=>`
`f (x, y) {`	`nt`
`  int i, j;`	`x y = do i <- x # m`
	`j <- y # m`
	`return i + j`
`}`	

Dispatch based on dynamic type of x

Call m passed as implicit argument

Virtual Methods vs Member Constraints

- Can we simulate OO references using existentials? Not quite:

```
data Sub a = forall b . b :<: a => Sub b
newtype A
newtype B :<: A
instance m :: A -> IO Int
instance m :: B -> IO Int
f = do a :: A <- new
       b :: B <- new
       list :: Sub A = [Sub a, Sub b]
       return (map (\Sub a -> m a) list)
error: constraint m :: a -> b escapes scope
of existentially quantified variable a
```

But, as stands, system cannot determine `m` from subtype constraint passed captured in `Sub`

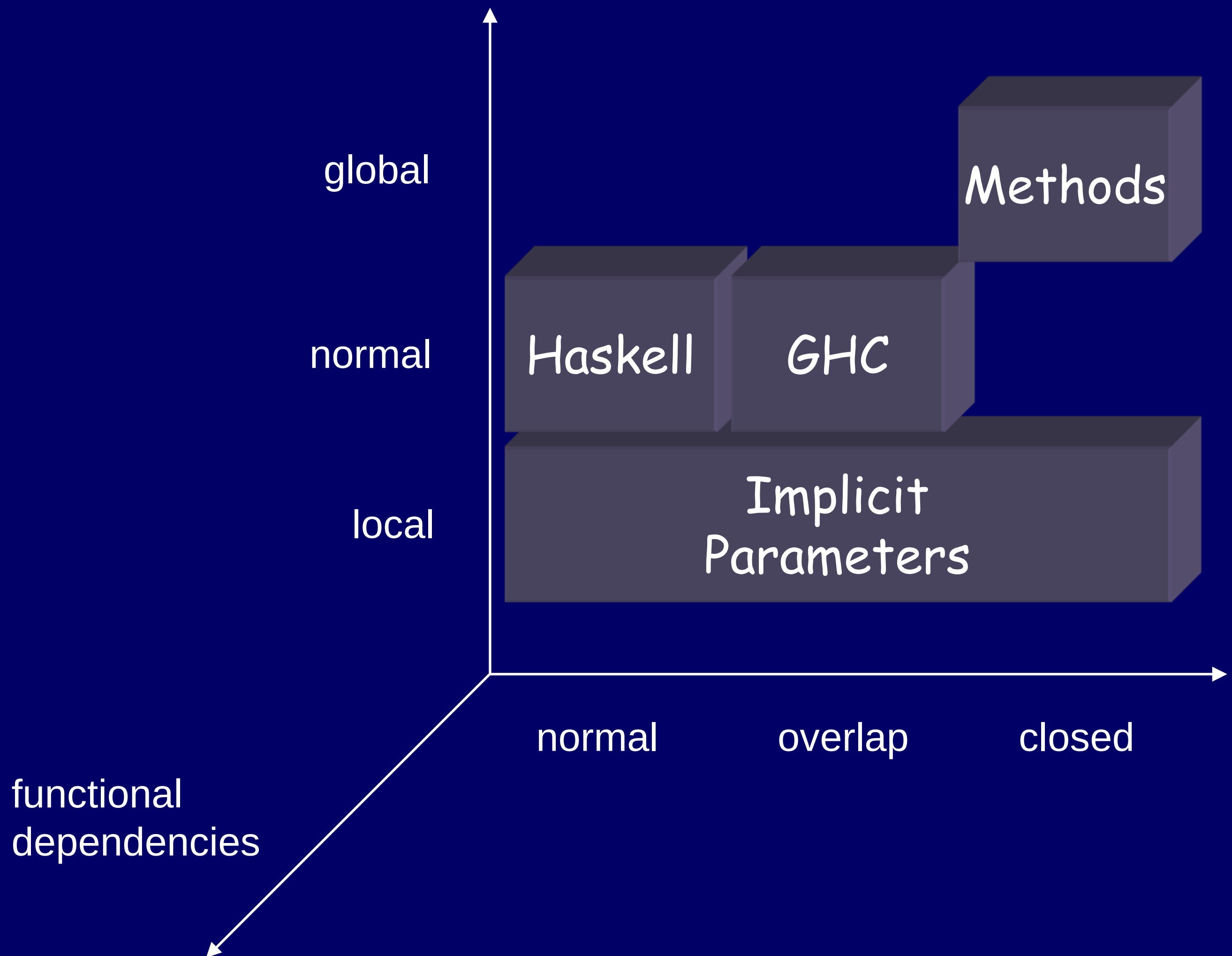
Virtual Methods vs Member Constraints

- Upshot: it rarely makes sense for a method constraint to escape into a type scheme
- If class C has `global` modifier, it is an error for C τ to appear in a scheme

```
class global closed m :: a
instance m :: A -> IO Int
instance m :: B -> IO Int
f x = x # m
error: constraint m :: a -> b cannot
  be generalized
```

Type Class Space

- Modifiers aren't as ad-hoc as may first appear:



Future Work

- About (finally...) to submit to Haskell or Babel Workshop
- Ulterior motive is to establish standard "calculus for type systems" including all the bells and whistles used in practice
- Simplifier defined quite abstractly...

  ... still work to be done in refining it to a good algorithm

  ... subtyping responsible for over half of complexity of simplifer
- Many small-scale FFI decisions to be made
- Simon & co about to start on implementation
- No formal properties shown as yet
- What about exporting Haskell as a .NET class?
- Can we further exploit nominal subtyping within Haskell?