The pleasures and pain of advanced type systems

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Or: how I learned to stop worrying and love a good type error

Static types *work*

Static typing is *by far* the most widely used program verification technology in use today

- Lightweight (so programmers use them)
- Machine-checked (with every compilation)
- Ubiquitous (so programmers can't avoid them)

Why do types work?

- Type errors identify bugs!
  - True + ‘c’
  - Memory & control-flow safety
- Types *specify* code. They say (to people) what functions do

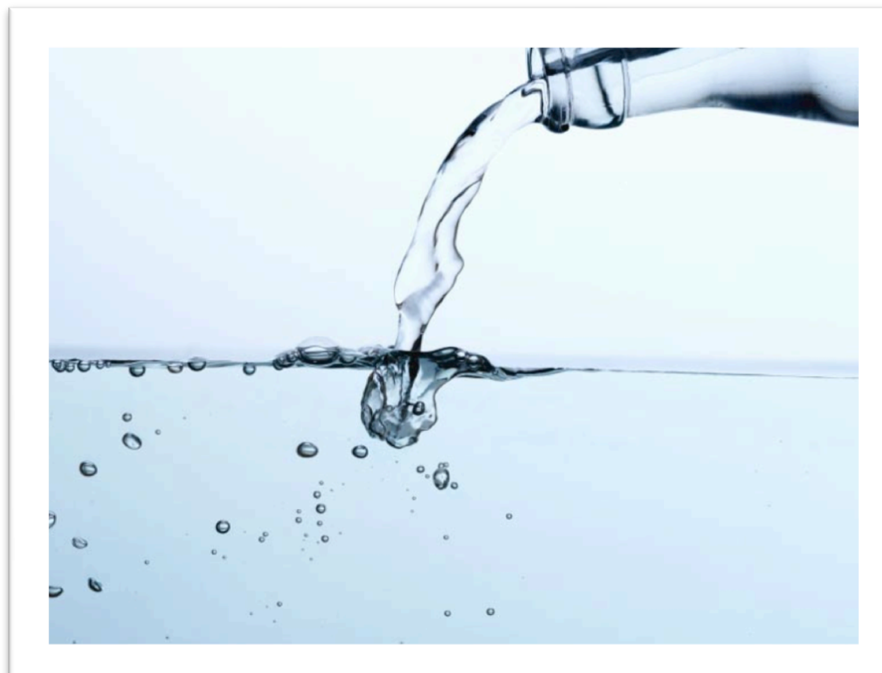
```
foozle :: Gizmo -> Gadget -> Contraption
```

- Types support interactive program development (Intellisense,Eclipse)
- Types support software maintenance (the **most important** benefit, seldom mentioned)

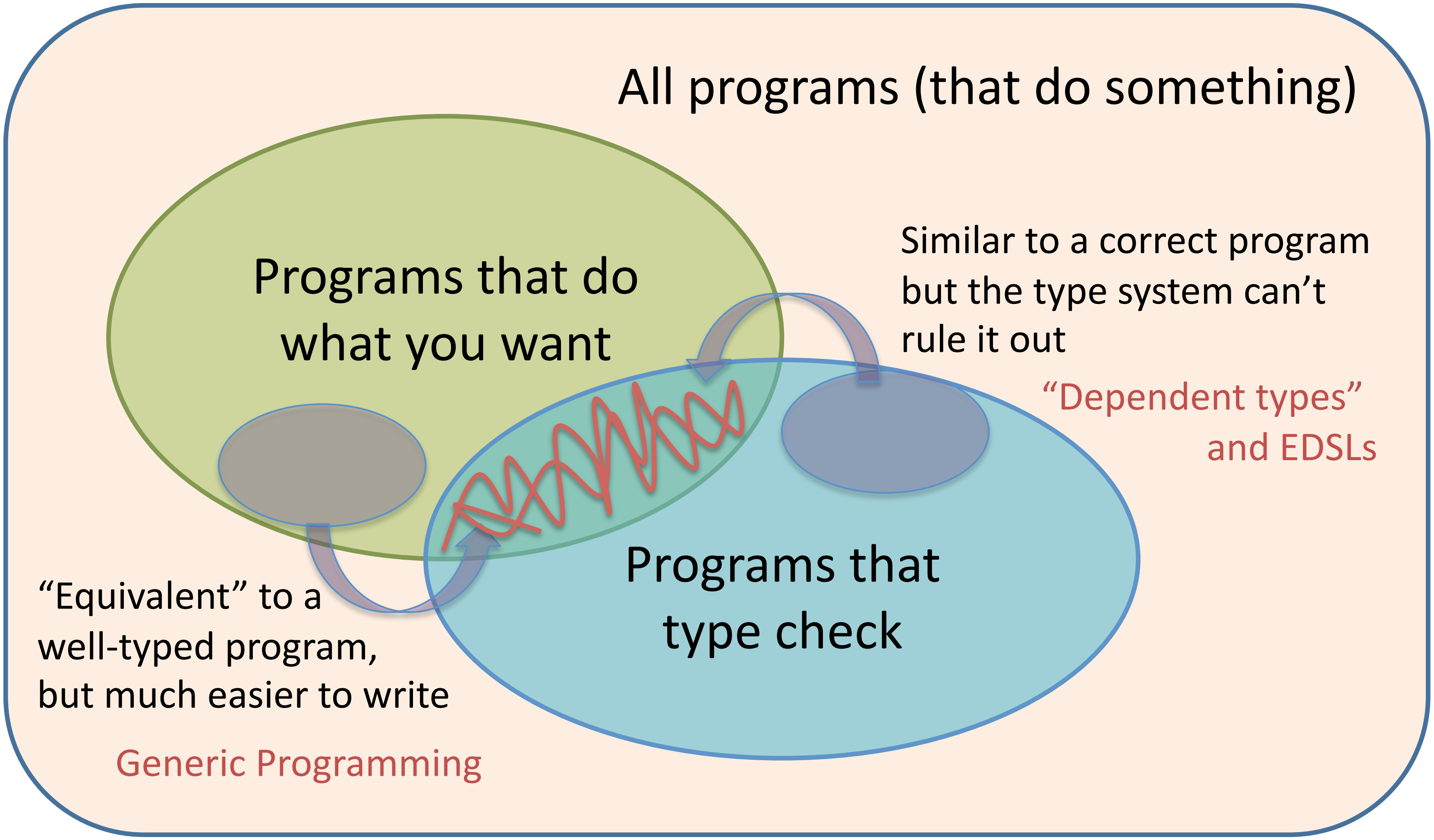
Haskell's advanced type system

Types work better for pure code

```
f :: [a] -> [a]
```

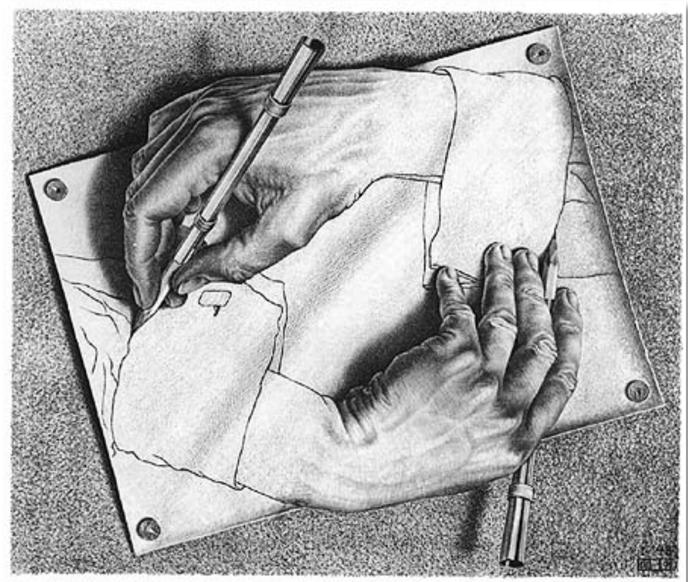


Type system ~~Pain~~ Pleasure



Haskell Metaprogramming

```
data Expr =
   | CB Bool
   | CI Int
   | If Expr Expr Expr
   | BinOp Op Expr Expr
   | …
   | …
  deriving (Eq, Ord, Show, Read)
```



Automatic definition of equality, ordering, serialization functions

Generic Programming

```
deriving (Eq, …, Generic)
```

- Enables user-defined generic traversals
  - Operations defined over representations of the type structure, in a type-preserving way
  - Eliminates boilerplate code. Aids development & refactoring

- Examples:

```
children (BinOp Plus e1 e2) == [e1; e2]
freevars (BinOp Plus (Var "x") (Var "y")) ==
    ["x"; "y"]
freshen (If (Var "x") (Var "y") (Var "z")) ==
    (If (Var "x0") (Var "y0") (Var "z0"))
arbitrary / shrink
```

for random test generation

Dependent types, aka GADTs

```
data Expr a where
  CB    :: Bool -> Expr Bool
  CI    :: Int -> Expr Int
  If    :: Expr Bool -> Expr a
        -> Expr a -> Expr a
  BinOp :: Op (a -> b -> c)
        -> Expr a -> Expr b -> Expr c

t = If (CI 3) (CI 4) (CI 5)
```

Doesn't type check now

Embedded Domain Specific Language

- Why define a DSL?
  - Specialize your development environment for your application
  - Reduced language, so fewer “wrong” program typecheck
- Why Embedded in Haskell?
  - Building a programming language is hard!
  - Dependent types can constrain embedded language, application-specific type checking

Ivory EDSL

- Low-level safe C-like language for safe systems programming
- DARPA research program for vehicle security
- Deeply embedded in Haskell, generates C, linked with RTOS and loaded onto quadcopter

| galois |

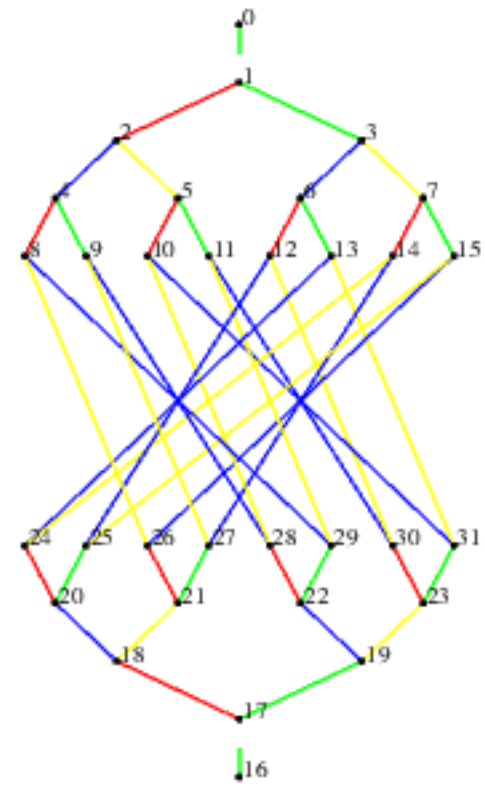
http://smaccmpilot.org/

```haskell
-- | Convert an array of four 8-bit integers
  into a 32-bit integer.
test2 :: Def ('[Ref s (Array 4 (Stored Uint8))]
                :-> Uint32)
test2 = proc "test2" $ \arr -> body $ do
  a <- deref (arr ! 0)
  b <- deref (arr ! 1)
  c <- deref (arr ! 2)
  d <- deref (arr ! 3)
  ret $ ((safeCast a) `iShiftL` 24) .|
        ((safeCast b) `iShiftL` 16) .|
        ((safeCast c) `iShiftL` 8)  .|
        ((safeCast d) `iShiftL` 0)
```

Quipper EDSL

- Embedded, scalable functional language for quantum computing
  - circuit description language
  - automatic synthesis of reversible quantum circuits

- Joint project between Dalhousie, Penn, IAS



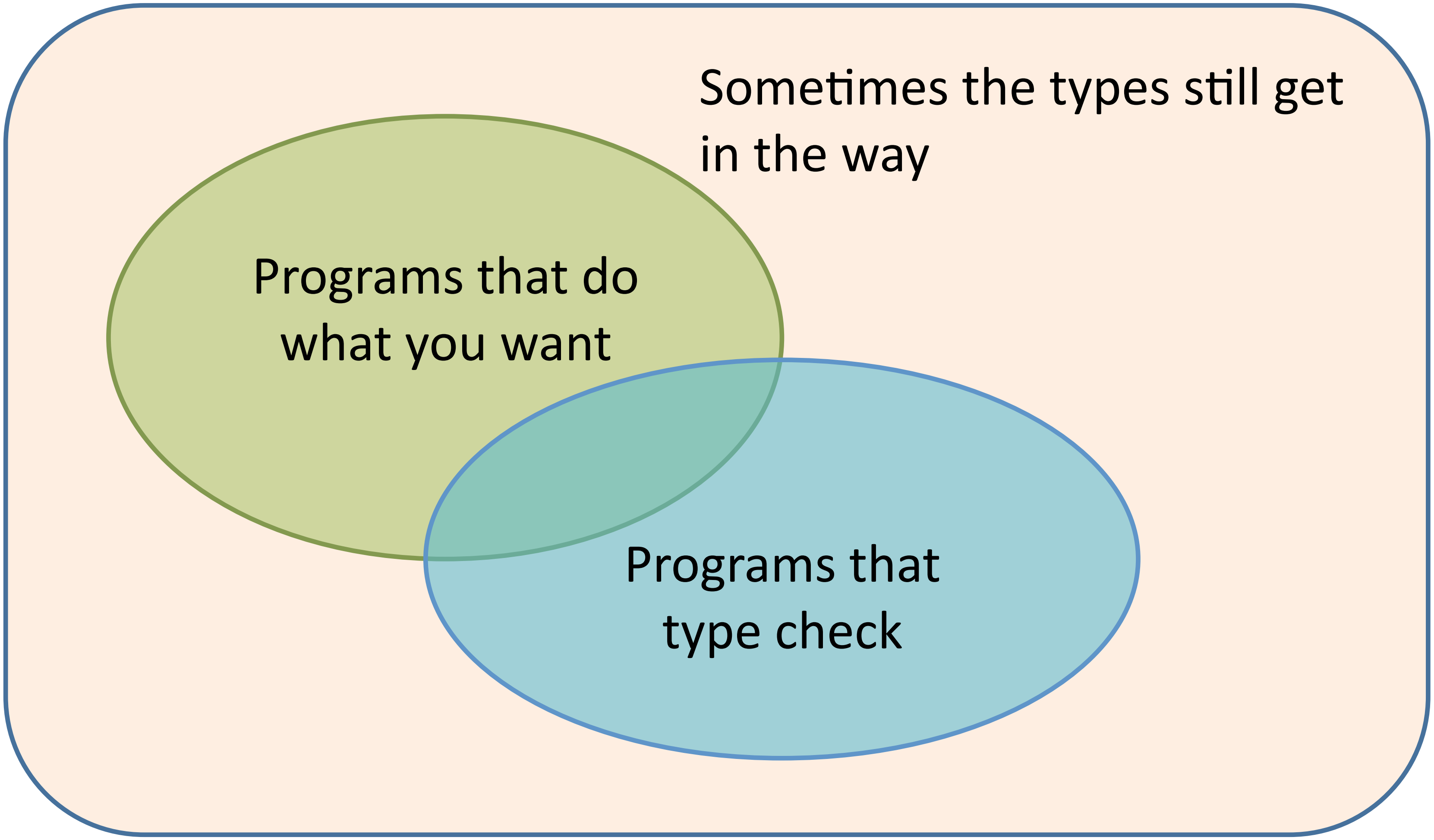
http://www.mathstat.dal.ca/~selinger/quipper/

Unlimited possiblities

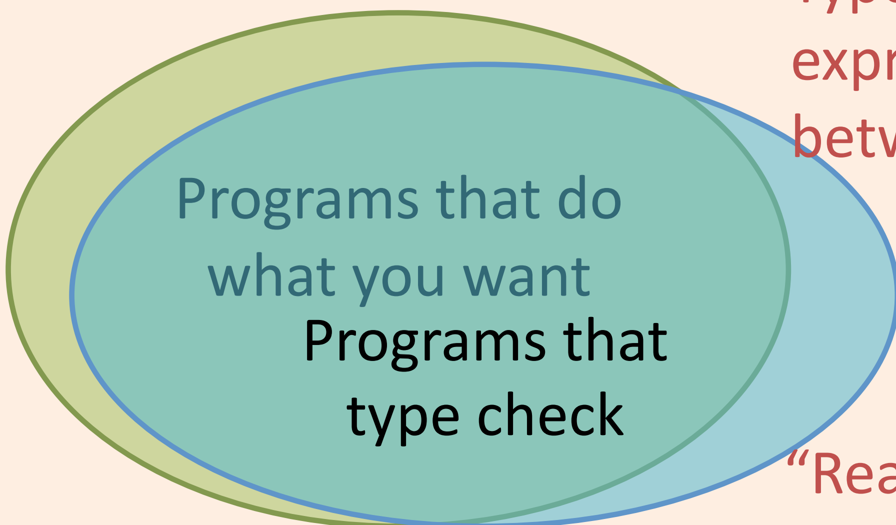
```
import BASIC
main = runBASIC $ do
  10  LET X =: 1
  20  PRINT "Hello BASIC world!"
  30  LET X =: X + 1
  40  IF X <> 11 THEN 20
  50  END
```

http://augustss.blogspot.com/2009/02/regression-they-say-that-as-you-get.html

The pain of types



Current research



Type-level computation, expresses a relationship between types as a program

"Real" dependent types, which allow program values in types

Type *inference* in the presence of these advanced features

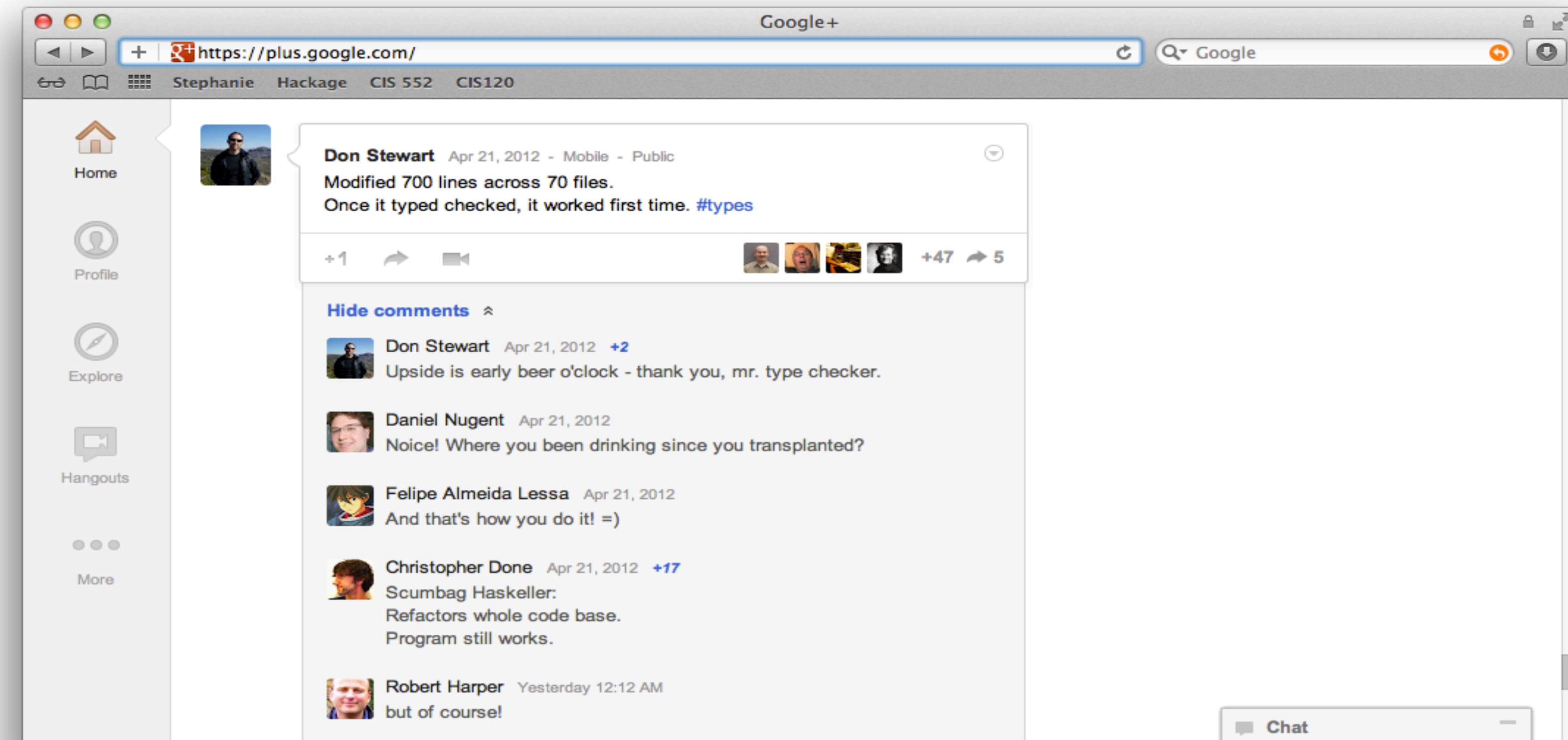
Type-level computation

```
-- Diatonic fifths, and their class (comments with the
   CMaj scale)
-- See http://en.wikipedia.org/wiki/Circle_progression

type family DiatV deg :: *
type instance DiatV I   = Imp -- V   -- G7  should be Dom
type instance DiatV V   = Imp -- II  -- Dm7 should be SDom
type instance DiatV II  = VI  -- Am7
type instance DiatV VI  = III -- Em7
type instance DiatV III = VII
  -- Bhdim7 can be explained by Dim rule
type instance DiatV VII = Imp -- IV
  -- FMaj7 should be SDom
type instance DiatV IV  = Imp -- I   -- CMaj7
```

http://hackage.haskell.org/package/HarmTrace-2.2.0

Not pain! Refactoring



Pain? Refactoring

- "Once it type checked…" heh, heh
- What about running tests *while* refactoring?

  … even if the program doesn't type check?

  … even if parts of the program haven't been written?

```
newVersionOfMyFunction ::  Widget -> Sprocket -> Assemblage
newVersionOfMyFunction = undefined
```

```
spaceman:~ sweirich$ ghci -fdefer-type-errors
GHCi, version 7.6.3: http://www.haskell.org/ghc/  :? for help
Prelude> let x = (True, 'a' && False)
<interactive>:2:16: Warning:
    Couldn't match expected type `Bool' with actual type `Char'
    In the first argument of `(&&)', namely 'a'
    In the expression: 'a' && False
    In the expression: (True, 'a' && False)
Prelude> :type x
x :: (Bool, Bool)
Prelude> fst x
True
Prelude> snd x
*** Exception: <interactive>:2:16:
    Couldn't match expected type `Bool' with actual type `Char'
    In the first argument of `(&&)', namely 'a'
    In the expression: 'a' && False
    In the expression: (True, 'a' && False)
(deferred type error)
```

Real Pain!

- Haskell is a research language, not supported by a major corporation
  - MSR will **not** invest more resources into it
- Open source (Yay!), fun for research (Yay!), but "infrastructure" things don't get done

Questions?

thanks!