Atypical Types

v 1.0

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Slides online at:

http://pic.blog.plove

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Good AFTERNOON.

I am Mark Dominus.

Thank you for inviting me to NASHVILLE.

It is a real honor to be speaking here at OOPSLA.

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Shameful confession

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In the programming community, we see a lot of holy wars.

Some of these are merely matters of personal preference.

They go on forever.

For example, should one use `vi` or `emacs`?

It can be easy to forget that other arguments are eventually resolved.

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For example, structured programming, or `goto`?

This one is finished now.

The bodies of the `goto` supporters are buried pretty deep.

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Before that, there was a holy war about high-level languages vs. assembly language.

I caught the tail end of it when I began programming in the 1970's.

"High-level languages are inefficient," said the assembly language proponents.

And they were right.

They lost anyway.

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Manual memory allocation vs. automatic garbage collection.

I didn't expect to see this resolved as soon as it was.

But the advent of Java ended *that* discussison.

Right or wrong, garbage collection has won.

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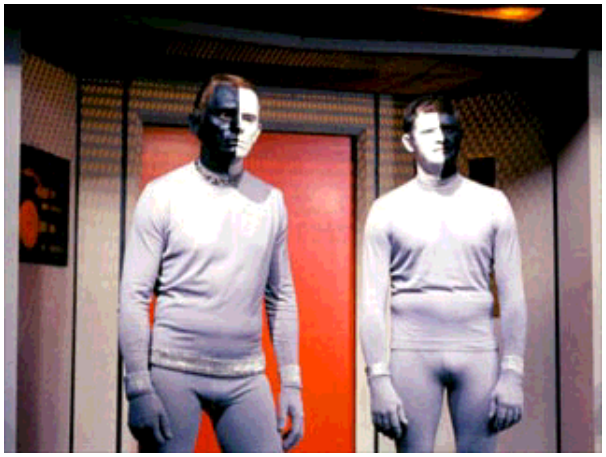
One of these discussions that is still going on concerns strong vs. weak type systems.

C and Pascal programmers used to argue a lot about this in the 1980's.

Which is kind of funny, since C and Pascal have almost exactly the same type system.



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In 1999 ago I gave a talk on this topic.

1999 title: "Strong Typing Doesn’t Have to Suck."

(It was an audience of Perl programmers.)

For Perl programmers, any kind of automatic check is a hard sell.

Perl’s motto is "Enough rope".

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I said the question was still open.

In 1999, there was no well-known static type system that did not suck.

(I discussed SML, an academic research language.)

At the time, Java's type system was a craptastic throwback to the 1970's.

In 2008, I think Java 5.0 is a persuasive argument in favor of static typing.

Let's look at the history a bit.

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Why Types?

Sherman, set the WABAC machine for 1955!

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- I think this idea first appeared in COBOL
- It’s a pretty good idea anyway

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Early Type Systems: FORTRAN

(This is Fortran 77, but early Fortran was similar.)

- `INTEGER`
  - `INTEGER*2`, `INTEGER*4`, `INTEGER*8`
- `LOGICAL` (Fortran jargon for ‘boolean’)
  - `LOGICAL*1` (synonym: `BYTE`), `LOGICAL*2`, `LOGICAL*4`, `LOGICAL*8`
- `REAL`
  - `REAL*4`, `REAL*8` (synonym: `DOUBLE PRECISION`), `REAL*16`
- `COMPLEX`
  - `COMPLEX*8`, `COMPLEX*16` (synonym: `DOUBLE COMPLEX`), `COMPLEX*32`

Now if you write:

```
INTEGER I
REAL R,S

R = I + S
```

then the compiler can automatically generate the correct instructions

- **Static** type checking

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Early Type Systems: FORTRAN

- Side note: Declaration is optional, defaults to:
  - `INTEGER` for variables that begin with `I`, `J`, `K`, `L`, `M`, `N`
  - `REAL` for other variables
- Array types also:

```
INTEGER A(10)
```

- Functions have types:

```
FUNCTION F(X)
INTEGER F, X
F = X+1
RETURN

N = F(37)
```

- **Static** type checking
- *Expressions* have types, determined at *compile time*

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Early Type Systems: Lisp

- **Dynamic** type checking
- *Values*, not expressions, are tagged with types
- Operations generate type errors at *run time*

```
(+ 1 2)
        3

(+ 1 2.0)
        3.0

(+ 1 "eels")
        Error in +: "eels" is not a number.
```

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Static Typing in ALGOL-based languages

- ALGOL (1960), Pascal (1968), C (1971)
- These are all very similar
- Attempt to extend type system beyond scalars
- `array of` *type*
- `pointer to` *type* (‘reference’ in ALGOL)
- `set of` *type* (Pascal only)
- `record of` *types* (`struct` in C)
- `function returning` *type*
- And arbitrary compositions of these operations:

```
/* This is why we love C */
int *((*murgatroyd[17])(void *));
```

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Typing: Hard to Get Right

- Goal: Compile-time checking of program soundness
- Pitfalls
  - False negative: Ignore real errors
  - False positive: Report spurious errors

Pascal Examples

```
var     s : array [1..10] of character;
s := 'hello';                       { You wish }

{----Thank you sir and may I have another! ----------}

type string = array [1..40] of character;
procedure error (c: string)
begin
   write('ERROR: ');
   write(c);
   writeln('');
end;

error('File not found');  { In your dreams }
error('File not found                          ');  { You have to d
error('Please just kill me Mr. Wirth           ');
```

Wirth agrees that this was a bad move.

And almost every commercial implementation of Pascal fixed this problem.

Not all these fixes were mututally compatible.

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Typing: Hard to Get Right

Pascal is pretty much dead, so let's have a...

C Example

```
#include <stdio.h>

int main(void)
{
  unsigned char *c;
  float f = 10;

  for (c = (char *)&f;
       c < sizeof(float) + (char *)&f;
       c++) {
    printf("%u ",  *c);
  }
  putchar('\n');

  return 0;
}
```

```
float.c: In function 'main':
float.c:9: warning: comparison of distinct pointer types lacks a
```

- The warning is spurious

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C Example

- The whole program was one giant type violation
  - But the compiler didn’t care

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Typing in Pascal and C is a Failure

Many spurious errors

- So programmers ignore them

Proliferation of type-defeating features:

- Casts (C) `(char *)(&f)`
- Automatic conversions (C)

```
int i;
i = 1.42857;          /* Silently truncated to 1 */
```

- Variadic functions (C)
- Union types (C and Pascal both)

```
var u: case tag: integer of
         0: (intval: integer);
         1: (realval: real);
         2: (stringval: array [1..20] of character);
         3: (boolval: boolean);
       end;
    r : real;

u.intval = 1428457;
r = u.realval;          { Gack }
```

- Abuse of the separate compilation facility (Pascal)

This proliferation is a sure sign of failure

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Coping With Failure

- Static typing, as implemented in C and Pascal, was not very technically successful
- Solution 1: Give up
  - Lisp
  - APL
  - AWK
  - Perl (*really* give up: `+(8/2)."."."0.0.0"`)

Hey, that worked pretty well!

- Solution 2: Try to do better
  - Haskell (and its precursors ISWIM, Miranda, ML, etc.)
  - Closely related: Java 5

This has *also* worked pretty well.

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1999 vs. Today

- In 1999, the Haskell type system was a hard sell
- Haskell was worked on by a bunch of funny-looking ivory-tower types:

Philip Wadler
(University of Edinburgh)

Martin Odersky
(EPFL)

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1999 vs. Today

Philip Wadler

Martin Odersky

- But these guys designed the Java 5 "generics" feature
- Which is directly derived from their experience with Haskell and related languages
  - Which they also designed
- The rest of this talk is about Haskell

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Static Typing that Works

We saw that typing in Pascal and C failed for several reasons:

- Too fine-grained (`character[12]` vs. `character[13]`)
- Spurious warnings ⇒ ignored warnings
- Too easy to violate (unions, casts)
- Too coarse-grained (`structs`)
- Inconvenient to use (explicit types everywhere)

These problems are surmountable!

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The Haskell Programming Language

- Extremely expressive and fine-grained type system
- Many fascinating and powerful features that I will not discuss today
- Originally a research language
- Solves the type problems of C and Pascal

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Types in Haskell

Scalars

```
17          Integer
17.3        Float
'x'         Char
True        Bool
```

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Types in Haskell

Tuples

```
(17, 'x')                    (Integer, Char)
(12.5, 13.5, 9)              (Float, Float, Int)
(True, False, True)          (Bool, Bool, Bool)
```

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Types in Haskell

Lists

```
[True, False, True]              [Bool]
[True, False, True, False]       [Bool]
[1,2,3,4,5]                      [Integer]
['O', 'O', 'P', 'S', 'L', 'A']   [Char]
"OOPSLA"                         [Char]
```

- `String` is accepted as a synonym for `[Char]`
- Types like `[Integer]` this should remind you of Java types like `List<Integer>` etc.
- Just as Java has `List<List<Integer>>`, Haskell has `[[Integer]]`

```
[ [1,2,3], [4,6], [0,233] ]      [[Integer]]
[ "I", "like", "pie" ]           [[Char]]
[17, "foo"]                      Error
```

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Types in Haskell

Polymorphism

```
[]                                  [a]
[ [1,2,3], [], [] ]                 [[Integer]]
[ ['p', 'i', 'e'], [], [] ]         [[Char]]

([], [])                            ([a], [b])
```

(Better examples coming up shortly.)

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Types in Haskell

Type composition

```
[ (True, [1, 2, 3]),
  (False, []),
  (False, [4, 5])
]
```

```
[ (Bool, [Integer]) ]
```

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Types in Haskell

Function types

```
not                             Bool -> Bool
words                           String -> [String]
unwords                         [String] -> String

length                          [a] -> Int
reverse                         [a] -> [a]

head                            [a] -> a
tail                            [a] -> [a]
:                               a -> [a] -> [a]
```

- `:` is the "cons" operation
  - `[1,2,3]` is shorthand for `1:2:3:[]`

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Overloading

- *Type classes* are something like object classes in Java
- Several different types might be instances of the same class
  - This means they must support some basic set of operations
- For example, any type `t` might be an instance of the `Show` class
  - If so, there must be a function `show` of type `t -> String`
  - The Haskell standard library makes all the standard types instances of `Show`
  - So for example:

```
show 137                yields    "137"
show True               yields    "True"
show "Foo"              yields    "\"Foo\""
```

- If you define your own type, you can define a `show` method
  - And you can declare your type to be an instance of `Show`
- Notation:

```
Show Integer            ("Integer is an instance of Show")
Show Bool               ("Bool is an instance of Show")
Show [Char]             ("[Char] is an instance of Show")
```

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Overloading

- The `show` function itself has this type:

```
(Show a) => a -> String
```

- That is, it takes an argument of type `a` and returns a `String`
  - But only if `a` is an instance of `Show`
  - The `(Show a)` is called a *context*
- The `show` function for `Bool` has type `Bool -> String`

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Overloading

- Numeric operations are similarly overloaded
- The type of `+` is

```
(Num a) =>  a -> a -> a
```

- So you can add two `Integer` arguments and get another `Integer`
- Add two `Float` arguments and get another `Float`
- Define your own `Vector` type
  - Declare that it's an instance of `Num`
  - Define `+` (and `*`, etc.) operations on it
  - And then add two `Vector` arguments and get another `Vector`
  - But if you mess up and add a `Vector` to an `Integer` you'll get a compile-time error

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Overloaded constants

- Constants like 163 are taken to be shorthand for

```
fromInteger 163
```

- Where `fromInteger` has type

```
(Num a) => Integer -> a
```

- So you can use "`163`" as a constant of any numeric type
  - As long as that type defines an appropriate `fromInteger` function

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Overloaded constants

- In particular, this works:

```
163 + 13.5
```

- 163 gets the same type as 13.5 here
  - An appropriate value is manufactured by an appropriate version of `fromInteger`
- No nonsense like this:

```
double fahrenheit = 98.6;
double celsius1 = 5/9 * (fahrenheit - 32);
double celsius2 = (fahrenheit - 32) * 5/9;

printf("%.1f\n%.1f\n", celsius1, celsius2);

/* This is why we love C */
```

```
0.0
37.0
```

- A constant like `163` actually has this type:

```
(Num a) => a
```

- "Any type `a`, as long as it's an instance of `Num`."

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Overloading

- Early versions of this type system had problems with equality
- What's the type of ==?
- Something like `a -> a -> Bool`
  - *Except* that `a` must not be a function type
- Haskell solves this problem:
  - `(Eq a) => a -> a -> Bool`
  - And function types are not instances of `Eq`
- Similarly, ordered types should be declared instances of `Ord`
  - Values can be compared with <, >, etc.

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Big Deal?

One big deal is that you do *not* need to declare types!

Let's consider everyone's favorite example:

```
int fact(int n) {
  if (n == 0) return 1;
  else return n * fact(n-1);
}
```

In Haskell, that looks almost the same:

```
fact 0 = 1
fact n = n * fact(n-1)
```

Hey, where did the `int`s go?

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Type inference

The compiler says to itself:

```
fact 0 = 1
fact n = n * fact(n-1)
```

"`0` has type `(Num a) => a`."

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Type inference

fact :: (Num *a*) => *a* -> *b*

"`0` has type `(Num a) => a`."

```
fact 0 = 1
fact n = n * fact(n-1)
```

"So `n` must have that type too."

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Type inference

fact :: (Num *a*) => *a* -> *b*
n :: (Num *a*) => *a*

"`0` has type `(Num a) => a`."

"So `n` must have that type too."

```
fact 0 = 1
fact n = n * fact(n-1)
```

"`n-1` checks out okay."

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Type inference

fact :: (Num *a*) => *a* -> *b*
n :: (Num *a*) => *a*

"*n* has type `(Num a) => a`."

```
fact 0 = 1
fact n = n * fact(n-1)
```

"`*` requires two arguments of the same type, both instances of `Num`."

"So `fact` must return `(Num a) => a` also."

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Type inference

fact :: (Num *a*) => *a* -> *a*
n :: (Num *a*) => *a*

"`fact` must return `(Num a) => a` also."

```
fact 0 = 1
fact n = n * fact(n-1)
```

"The return value of `1` is consistent with that."

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Type inference

fact :: (Num *a*) => *a* -> *a*
n :: (Num *a*) => *a*

```
fact 0 = 1
fact n = n * fact(n-1)
```

"Okay, everything checks out!"

- And if you ask it, it will *tell you* the type of `fact`:

```
fact :: (Num a) => a -> a
```

- If you ask for the factorial of an `Integer`, you get back an `Integer`
- If you ask for the factorial of a `Float`, you get back a `Float`
- If you ask for the factorial of a `String`, you get a compile-time error
  - Because `String` is not an instance of `Num`

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Haskell types are always correct

```
fact :: (Num a) => a -> a
```

- Ask the compiler to tell you the type of some function
- Is it what you expect?
  - Yes? Okay then!
  - If not, your program almost certainly has a bug.
    - A *real* bug, not a nonsense string-the-wrong-length bug

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Haskell types are always correct

- When there's a type error, you do not have to groan and pull out a bunch of casts
  - Or figure out to trick the compiler into accepting it anyway
  - Instead, you stop and ask yourself "What did I screw up this time?"
  - And when you figure it out, you say "Whew! Good thing I caught that."

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Type Inference Example 2

```
sumof []     = 0
sumof (h:t) = h + sumof t
```

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Type Inference

```
sumof []     = 0
sumof (h:t) = h + sumof t
```

"The argument is `[]`."

"That's some kind of list, say `[a]`."

"And let's say that the return type is `b` for now."

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Type Inference

sumof :: [*a*] -> *b*

"The argument has type `[a]`."

```
sumof []     = 0
sumof (h:t) = h + sumof t
```

"`h:t` is also a list, so that's okay."

"`h` must have type *a* and `t` must have type `[a]`."

```
h :: a
t :: [a]
```

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Type Inference

sumof :: [*a*] -> *b*
h :: *a*
t :: [*a*]

"`h` must have type `a` and `t` must have type `[a]`."

```
sumof []     = 0
sumof (h:t) = h + sumof t
```

"We're adding `h` to the return value of `sumof`."

"So the return value must be `a` also."

"And `+` is only defined for instances of `Num`, so `a` is such an instance

"So the return value is really of type (Num *a*) => *a*."

```
sumof :: (Num a) => [a] -> a
```

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Type Inference

sumof :: (Num *a*) => [*a*] -> *a*
h :: (Num *a*) => *a*
t :: (Num *a*) => [*a*]

"So the return value is really (Num *a*) => *a*."

```
sumof []     = 0
sumof (h:t) = h + sumof t
```

"That fits with the other return value of 0."

"And everything else checks out okay."

- If you ask, it will say that the type is:

```
sumof :: (Num a) => [a] -> a
```

- If we had put `0.0` instead of 0, it would have deduced:

```
sumof :: (Fractional a) => [a] -> a
```

- (`Fractional` is a subclass of `Num`)
  - Among other things, it supports division
- If we had put `"Fred"` we would have gotten a type error
  - Because `String` is not an instance of `Num`

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Type Inference Example 3

```
map(f, []) = []
map(f, h:t) = f(h) : map(f, t)
```

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Type Inference

```
map(f, []) = []
map(f, h:t) = f(h) : map(f, t)
```

"`f` has some type, say *p*, and `[]` has some list type, say `[a]`."

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Type Inference

map :: (*p*, [*a*]) -> *q*
f :: *p*

"`[]` has some list type, say `[a]`."

```
map(f, []) = []
map(f, h:t) = f(h) : map(f, t)
```

"`h` must have type `a` and `t` must have type `[a]`."

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Type Inference

map :: (*p*, [*a*]) -> *q*
f :: *p*
h :: *a*
t :: [*a*]

"`h` must have type *`a`*."

```
map(f, []) = []
map(f, h:t) = f(h) : map(f, t)
```

"`f` is used as a function applied to `h`."

"So `f` must have type *`a -> b`* for some *`b`*."

"`f` must take an argument of type *`a`* and return a result of type *`b`*."

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Type Inference

map :: (*a* -> *b*, [*a*]) -> *q*
f :: *a* -> *b*
h :: *a*
t :: [*a*]

"`f` must take an argument of type *`a`* and return a result of type *`b`*."

```
map(f, []) = []
map(f, h:t) = f(h) : map(f, t)
```

"The result of `f` is consed to the result of `map`."

"So `map` must return *`[b]`*."

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Type Inference

map :: (*a* -> *b*, [*a*]) -> [*b*]
f :: *a* -> *b*
h :: *a*
t :: [*a*]

"`map` must return `[b]`."

```
map(f, []) =  []
map(f, h:t) = f(h) : [map(f, t)
```

"That fits with the return value in the other clause."

"Everything else checks out okay."

- If you ask the compiler, it will say that the type is:

```
map :: (a -> b, [a]) -> [b]
```

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Type Inference Example 3 Continued

```
map :: (a -> b, [a]) -> [b]
```

Normally `map` is defined as a *curried* function

Instead of this:

```
map(f, []) = []
map(f, h:t) = f(h) : map(f, t)
```

We write this:

```
map f []     = []
map f (h:t) = f(h) : map f t
```

And the type is:

```
map :: (a -> b) -> [a] -> [b]
```

Then for example:

```
length :: [a] -> Integer
map length ["I", "like", "pie"]
    [1, 4, 3]

length_all = map length

length_all :: [[a]] -> [Integer]
length_all ["I", "like", "pie"]
    [1, 4, 3]
```

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Life with Haskell

The Haskell type system has a lot of unspectacular successes.

Programming in Haskell is pleasant

- No type declarations—everything is automatic
- You get quite a few type errors (darn!)
- But *every error* indicates a real, *serious* problem
- Not like `lint` or C or Pascal.

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A Spectacular Example

Here's a *spectacular* example, due to Andrew R. Koenig.

We will write a merge sort function.

Strategy:

- Split list into two lists
- Sort each list separately
- Merge sorted lists together

We expect the type of this function to be

```
(Ord a) => [a] -> [a]
```

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Splitting

```
split [] = ([], [])
split [a] = ([a], [])
split (a:b:rest) = (a:a', b:b')
    where (a', b') = split rest


split :: [t] -> ([t], [t])
```

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Merging

```
merge [] ls = ls
merge ls [] = ls
merge (a:as) (b:bs) =
  if a <= b then a : merge as (b:bs)
  else           b : merge (a:as) bs

merge :: (Ord t) => [t] -> [t] -> [t]
```

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Merge Sort

```
sort [] = []
sort ls = merge (sort p) (sort q)
  where (p, q) = split ls
```

- If we ask Haskell for the type of `sort`, it says:

```
sort :: (Ord a) => [t] -> [a]
```

Huh??

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Huh??

```
sort :: (Ord a) => [t] -> [a]
```

- This says that we could put in *any* kind of list `[t]`
  - It does not even have to be ordered
- And what we get out has nothing to do with what we put in
  - We could put in a list of `Integer` and get out a list of `String`
    - Which is impossible

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Huh??

```
sort :: (Ord a) => [t] -> [a]
```

- But this is *impossible*

One way the impossible can occur is if it never can occur

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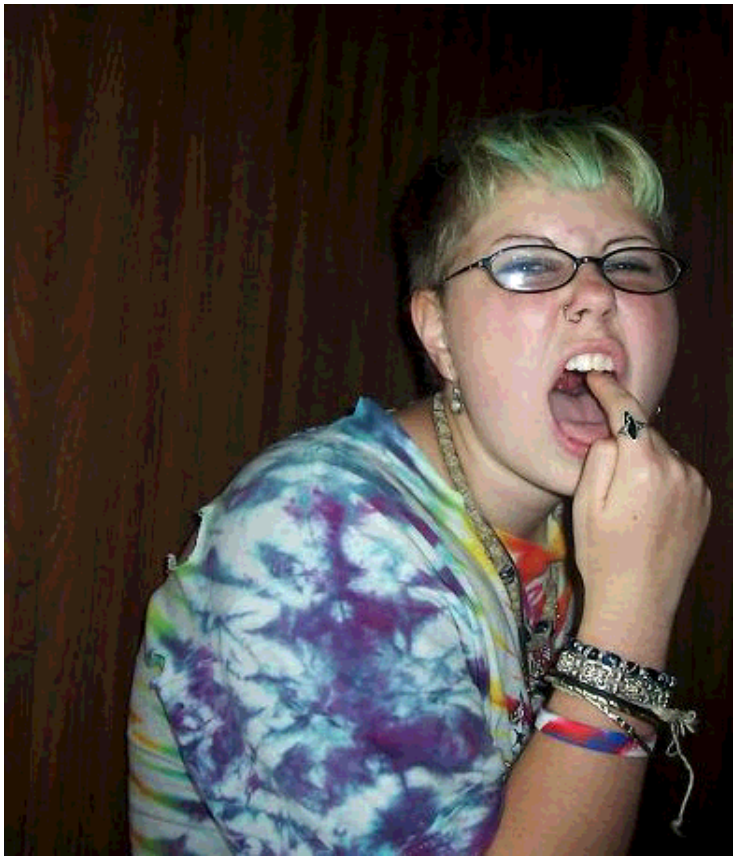

“Go out with you? Sure, when Arnold Schwarzenegger is elected president.”

“But he isn’t an American citizen.”

“Right!”

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Huh???

```
sort :: (Ord a) => [t] -> [a]
```

“Given a list of numbers, it could return a list of strings.”

“But it can’t possibly return a list of strings.”

“Right!”

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```
sort [] = []
sort ls = merge (sort p) (sort q)
  where (p, q) = split ls
```

In fact, this function has a bug.

- It never returns
  - (Except when the input is empty.)
  - (In which case it *does* return a list of type `[a]`)
- *Type checking* found an infinite loop bug!
- At compile time!!
- !!!!!!!!!!

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Where's the Bug?

```
sort [] = []
sort ls = merge (sort p) (sort q)
  where (p, q) = split ls
```

Suppose the function is trying to sort a one-element list `[x]`

It calls `split` and gets `([x], [])`

Then it tries to recursively sort the two parts

Sorting `[]` is okay.

Sorting `[x]` puts it into an infinite loop

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Solution: Add a clause

```
sort [] = []
sort [x] = [x]
sort ls = merge (sort p) (sort q)
  where (p, q) = split ls
```

The type is now:

```
sort :: (Ord a) => [a] -> [a]
```

as we expected it should be.

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Summary

Thank you!

They say to allot 3–5 minutes per slide

So I won’t pretend that there will be time for questions

(sorry)

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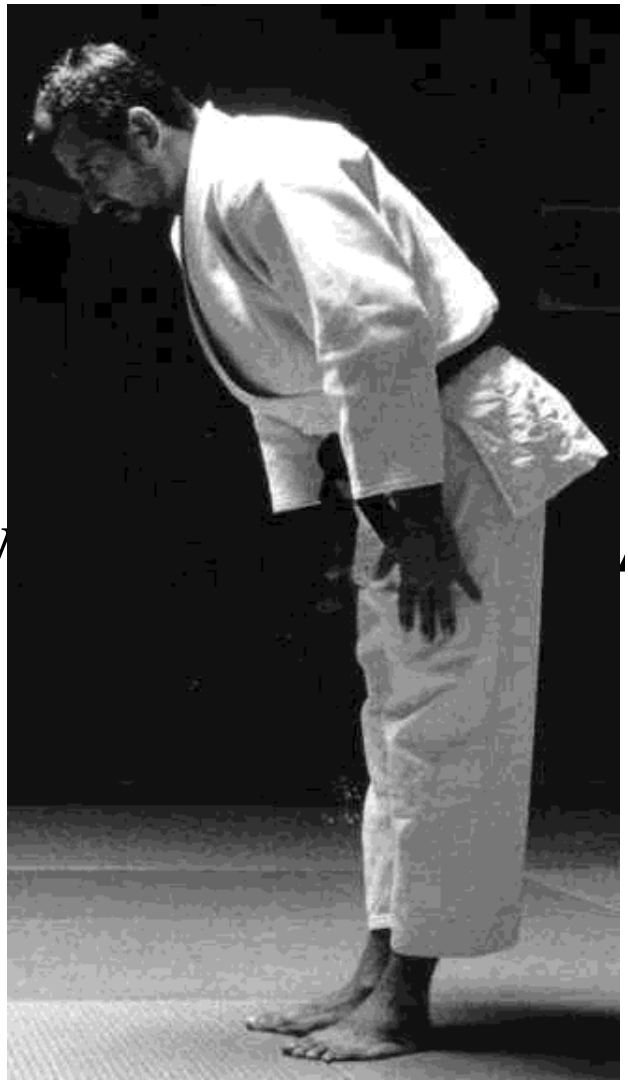

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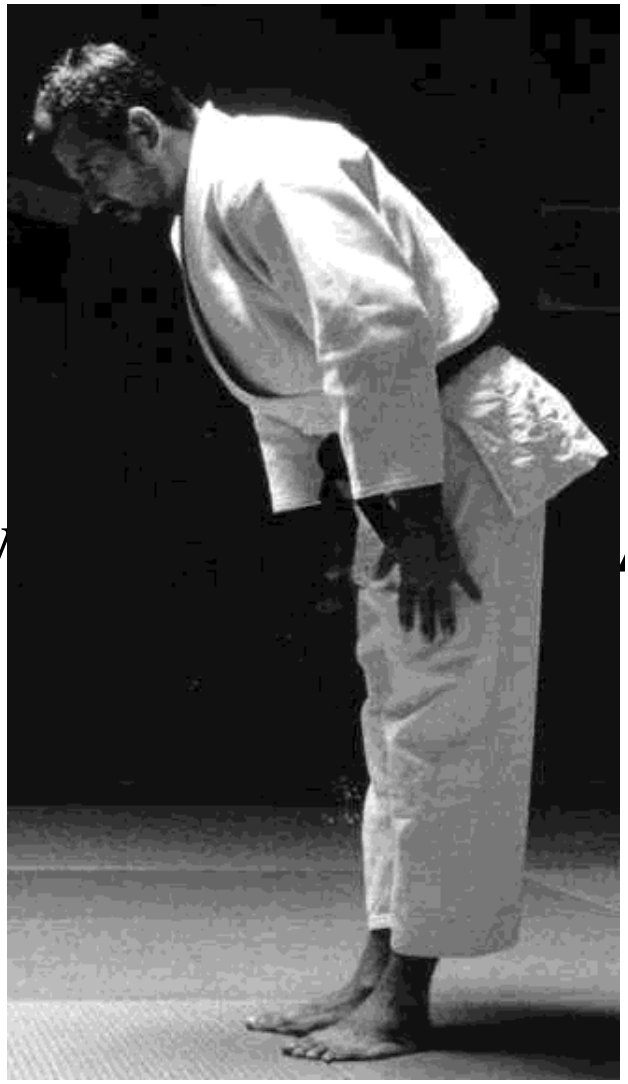

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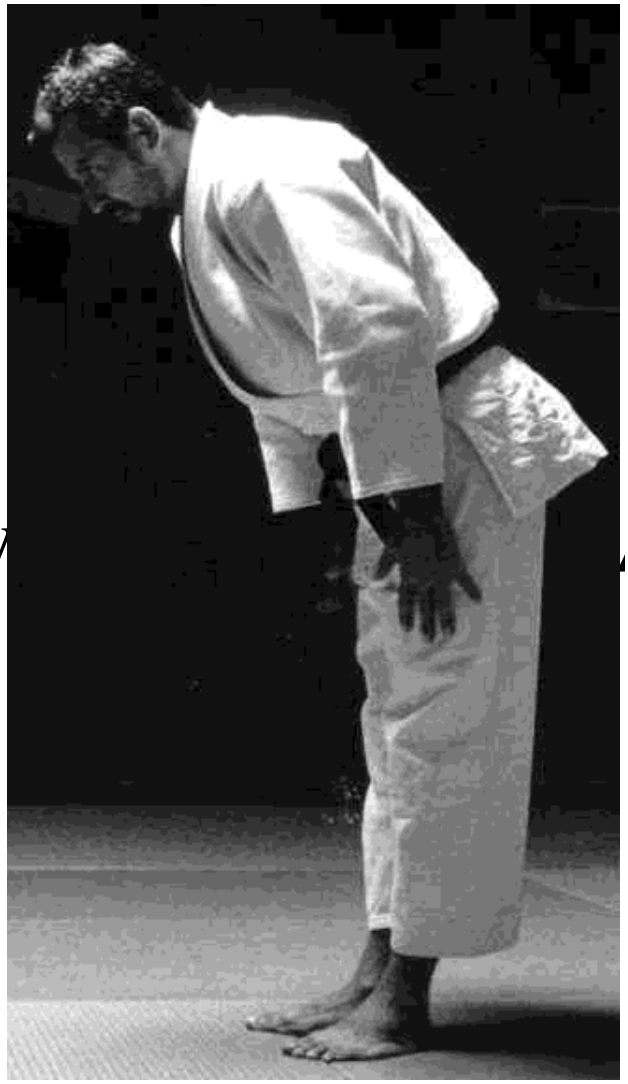

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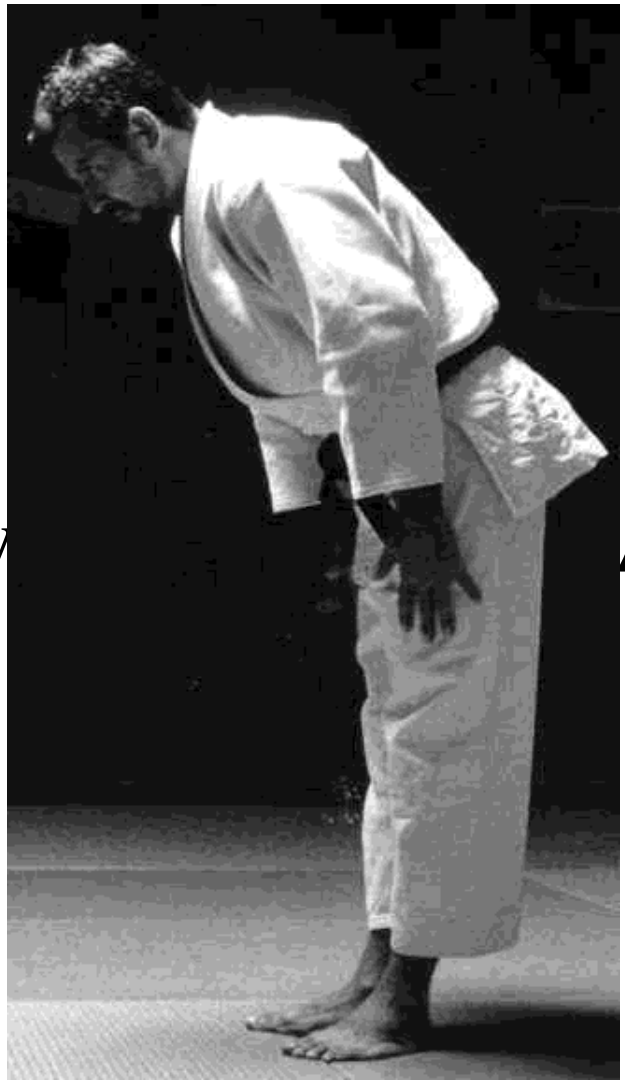

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