# Class 11: Parsing in Haskell

(guest lecture)

April 4

# What is a parser?

```
type Parser :: String → StructuredObject
```

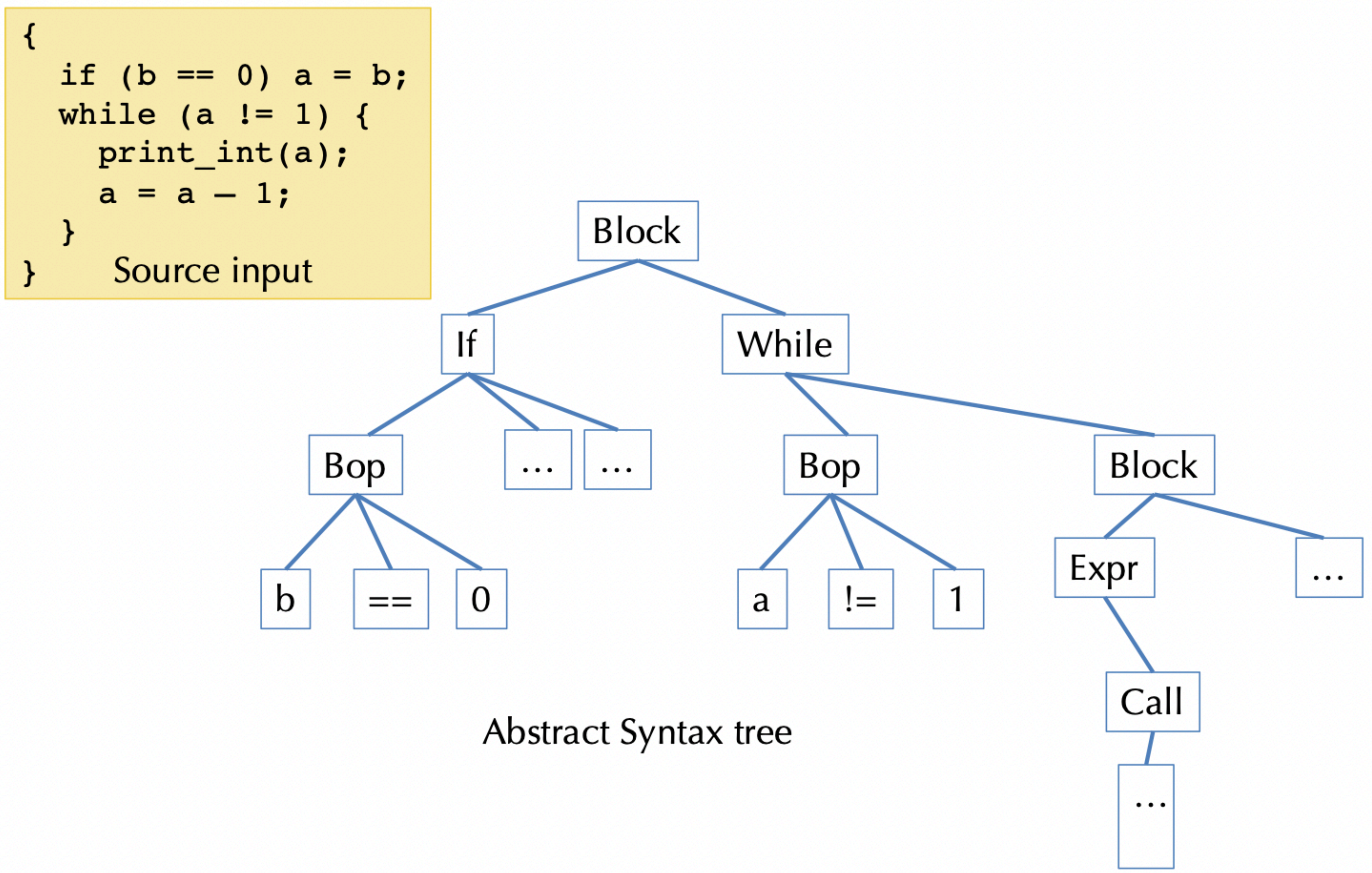



Diagram by Steve Zdancewic (CIS 3410)

# Why do parsers matter?

Parsing is a fundamental aspect of many system programming tasks:

**CIS 2400 / 3410:** Compilers (parse programs)

**CIS 3800:** Operating Systems (parse terminal input)

**CIS 5530:** Networks (parsing packets)

Haskell makes writing parsers simple (& fun!)

# How do we define a Parser type in Haskell?

# Defining the `Parser` type

## A `Parser` is a function:

```
type Parser :: String → StructuredObject
```

## A `Parser` doesn't need to consume all of its input:

```
type Parser = String → (StructuredObject, String)
```

remainder of input

A `Parser` should be polymorphic
over the type of structured object that it returns:

```
type Parser a = String → (a, String)
```

structured
object

# A `Parser` should be able to fail (not all strings are parseable!)

```
type Parser a = String → Maybe (a, String)
```

possibility of getting `Nothing`

How do we separate what a `Parser` *is*
from what a `Parser` *does*?

we use ***records***!

# Crash course on Haskell records

# Motivation: how do we give *names* to the arguments of data constructors?

# Record example

```
data Student = MkStudent {
  name :: String,
  age :: Int
}
```

record type definition

constructor for
the record type

```haskell
data Student = MkStudent {
  name :: String,
  age :: Int
}
```

```
ghci> :t MkStudent
MkStudent :: String → Int → Student
```

name age

# Example: defining a record

```
MkStudent :: String → Int → Student
data Student = MkStudent { name :: String, age :: Int }

ernest :: Student
ernest = MkStudent { name = "Ernest", age = 22 }

— alternative syntax (order matters!)
ernest :: Student
ernest = MkStudent "Ernest" 22
```

# Each record field defines a *selector*

```haskell
ernest :: Student
ernest = MkStudent { name = "Ernest", age = 22 }
```

```
ghci> name ernest
“Ernest”
```

```haskell
name :: Student → String
```

```
ghci> age ernest
22
```

```haskell
age :: Student → Int
```

# Defining the `Parser` type

# Recall our working type definition for a `Parser` :

```
type Parser a = String → Maybe (a, String)
```

**Let’s package this into a record**

# Separating values of type `Parser a` from their parsing functionality:

```
newtype Parser a =
  P { doParse :: String → Maybe (a, String) }
```

**actual function that does the parsing**

```
ghci> :t P
P :: (String → Maybe (a, String)) → Parser a
```

the `doParse` function

the constructor P takes in a function called `doParse` & returns a `Parser`

## The `doParse` field in the record defines a record selector:

```
newtype Parser a =
  P { doParse :: String → Maybe (a, String) }
```

```
ghci> :t doParse
doParse :: Parser a → (String → Maybe (a, String))
```

The `doParse` record selector takes a `Parser` & returns the underlying function

# Simple parsers

# Parsing one single Char

```
get :: Parser Char
get = P $ \s →
  case s of
    (c : cs) → Just (c, cs)
    [] → Nothing
```

the stuff after $ is the `doParse` function associated with this parser

(in Haskell, you can use $ to avoid using parentheses)

```haskell
get :: Parser Char
get = P $ \s →
  case s of
    (c : cs) → Just (c, cs)
    [] → Nothing
```

`s :: String = [Char]`

`P :: (String → Maybe (Char, String)) → Parser Char`

# Exercise: parsing one single digit

```
oneDigit :: Parser Int
```

# Exercise solution: Parsing a single digit

```
oneDigit :: Parser Int
oneDigit = P $ \s →
  case s of
    (c : cs) → do
      i ← readMaybe [c]
      return (i, cs)
    [] → Nothing
```

# Exercise solution: Parsing a single digit

```
oneDigit :: Parser Int
oneDigit = P $ \s →
  case s of
    (c : cs) → do
      i ← readMaybe [c]
      return (i, cs)
    [] → Nothing
```

`s :: String = [Char]`

**What if instead of `Parsers` for Ints / Chars, we want to build a `Parser` for a function?**

# Parsing the sign of integers

```
oneOp :: Parser (Int → Int)
oneOp = P $ \s →
  case s of
    ('-' : cs) → Just (negate, cs)
    ('+' : cs) → Just (id, cs)
    _ → Nothing
```

```haskell
oneOp :: Parser (Int → Int)
oneOp = P $ \s →
  case s of
    ('-' : cs) → Just (negate, cs)
    ('+' : cs) → Just (id, cs)
    _ → Nothing
```

**What if we want to build a `Parser` that parses *only* when a condition is satisfied?**

# Conditional parsing

```
satisfy :: (Char → Bool) → Parser Char
satisfy f = P $ \s → do
  (c, cs) ← doParse get s
  guard (f c)
  return (c, cs)
```

here, we're using the Maybe monad

# `Parser` is a monad

## Parser is a Monad

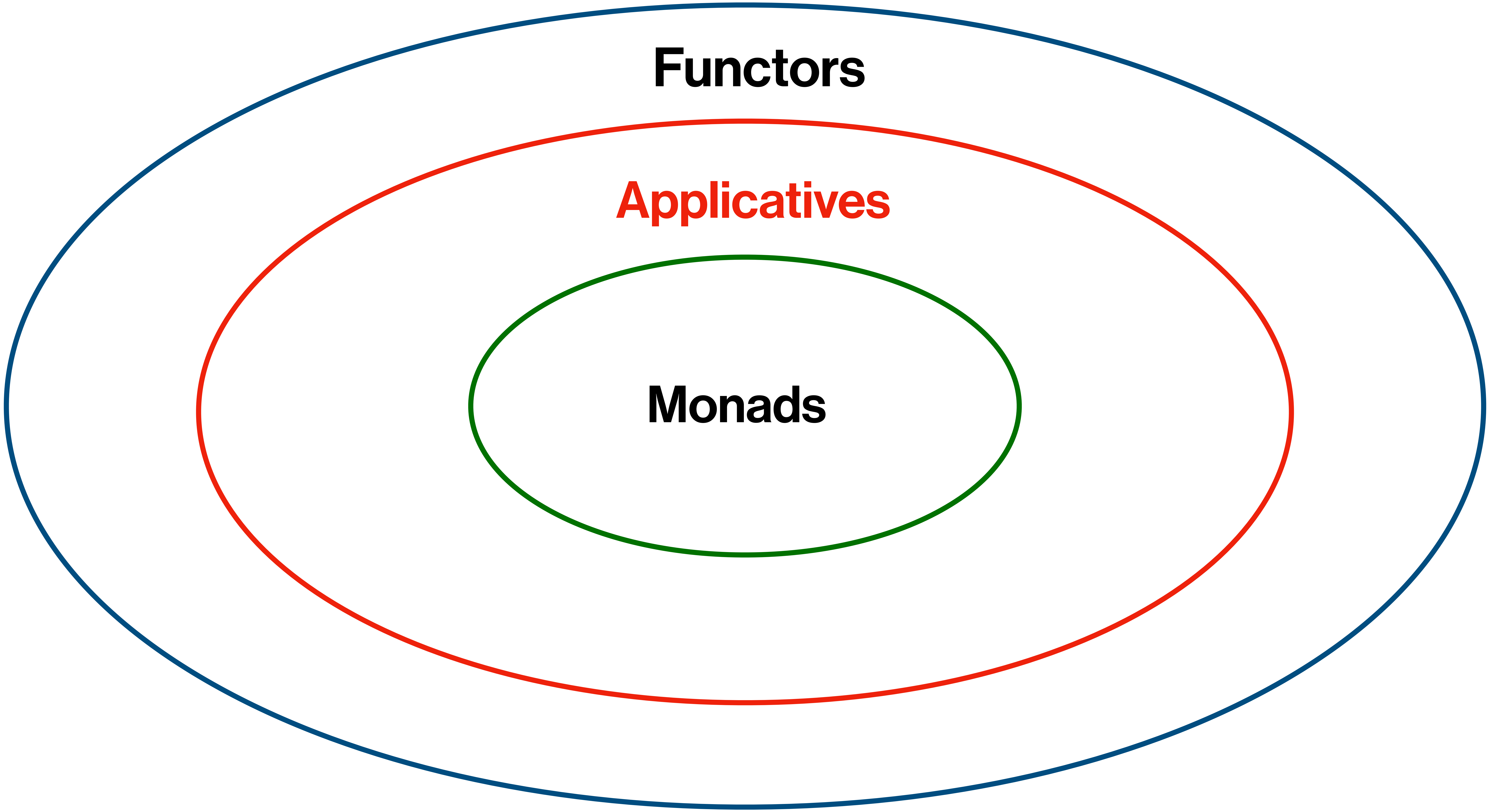
```
instance Monad Parser where
  return :: a → Parser a
  return a = P $ \s → Just (a, s)

  (>>=) :: Parser a → (a → Parser b) → Parser b
  p >>= k = P $ \s → do
    (a, s') ← doParse p s
    doParse (k a) s'
```

**As it turns out,
there’s a generalisation of Monads that is
more useful for parsing!**

# Detour: `Applicative` functors

(or, how to compose parsers)

# Monad $\subsetneq$ Applicative $\subsetneq$ Functor



Recall the Functor typeclass:

```
class Functor f where
  fmap :: (a → b) → f a → f b
```

If you give me:

a "container" of a's

& a function from a → b

I can give you:

a "container" of b's

```haskell
class Functor f where
  fmap :: (a → b) → f a → f b
```

What if the `a → b` function itself is contained inside a Functor?

`Applicative` functors

= “functors with application”

```haskell
class Functor f ⇒ Applicative f where
      pure    :: a → f a
      (<*>)   :: f (a → b) → f a → f b
```

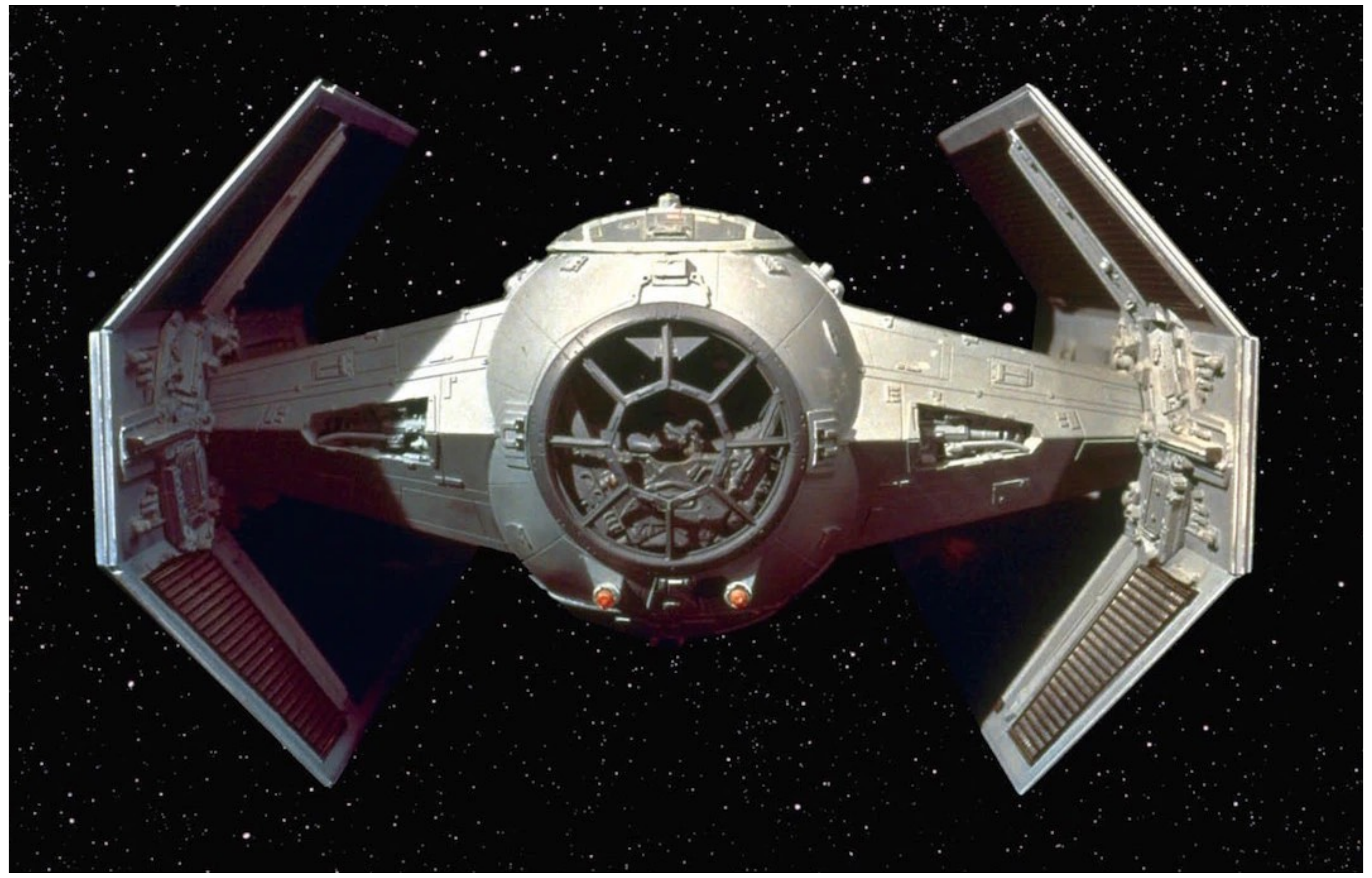
## Inject a value into the `Applicative` type

```
pure :: Applicative f ⇒ a → f a
```

analogous to `return` for Monads

# Contextual application of functions

```
(<*>) :: Applicative f ⇒ f (a → b) → f a → f b
```



TIE fighter from Star Wars

**<*>**

"tie fighter"

Source: *Haskell Programming from First Principles*
(Chris Allen & Julie Moronuki)

## `Parser` is an `Applicative`

```haskell
instance Applicative Parser where
  pure :: a → Parser a
  pure a = P $ \s → Just (a, s)

  (<*>) :: Parser (a → b) → Parser a → Parser b
  p1 <*> p2 = P $ \s → do
    (f, s') ← doParse p1 s
    (x, s'') ← doParse p2 s'
    return (f x, s'')
```

# Composing parsers

```
(<*>) :: Parser (a → b) → Parser a → Parser b
p1 <*> p2 = P $ \s → do
```

# Composing parsers

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1. Use parser `p1` to extract a function `f`

# Composing parsers

```
(<*>) :: Parser (a → b) → Parser a → Parser b
p1 <*> p2 = P $ \s → do
  (f, s') ← doParse p1 s
  (x, s'') ← doParse p2 s'
```

1. Use parser **p1** to extract a function **f**
2. Using the remaining input **s'**, use parser **p2** to extract a value **x**

# Composing parsers

```
(<*>) :: Parser (a → b) → Parser a → Parser b
p1 <*> p2 = P $ \s → do
  (f, s') ← doParse p1 s
  (x, s'') ← doParse p2 s'
  return (f x, s'')
```

1. Use parser p1 to extract a function f
2. Using the remaining input s', use parser p2 to extract a value x
3. Apply f to x, and return s'' (the new remainder of the input)

# Example: parsing signed digits

```
oneOp :: Parser (Int → Int)
```

parses + and -

```
oneDigit :: Parser Int
```

parses digits

```
signedDigit :: Parser Int
signedDigit = oneOp <*> oneDigit
                (<*>) :: Parser (a → b) → Parser a → Parser b
```

# Monad vs Applicative

# Monads vs Applicatives

**Monads**

```
(>>=) :: Parser a → (a → Parser b) → Parser b
```

**Applicatives**

```
(<*>) :: Parser (a → b) → Parser a → Parser b
```

# Monads vs Applicatives

## Monads

```
(>>=) :: Parser a → (a → Parser b) → Parser b
```

the result of the 1st parser gets to
influence how the 2nd parser behaves

## Applicatives

```
(<*>) :: Parser (a → b) → Parser a → Parser b
```

the results of the 1st parser are not visible

need to declare beforehand how the parsed objects will be combined
(the structure of the computation remains fixed throughout)

**Conor McBride, originator of the Applicative typeclass:**

"Applicative computations come from the 1960s: you choose all things you're going to compute today and you collect your line-printer output in the morning; **you can't look at the output of one computation and use it to choose a later computation**."

"Monadic computations come from the 1970s: you sit at your teletype, and **you get to see the response to your previous command before you choose your next command**"

(CIS 5520 discussion)

Monads are more powerful than Applicatives,
but we don't need the full monadic structure for parsing!

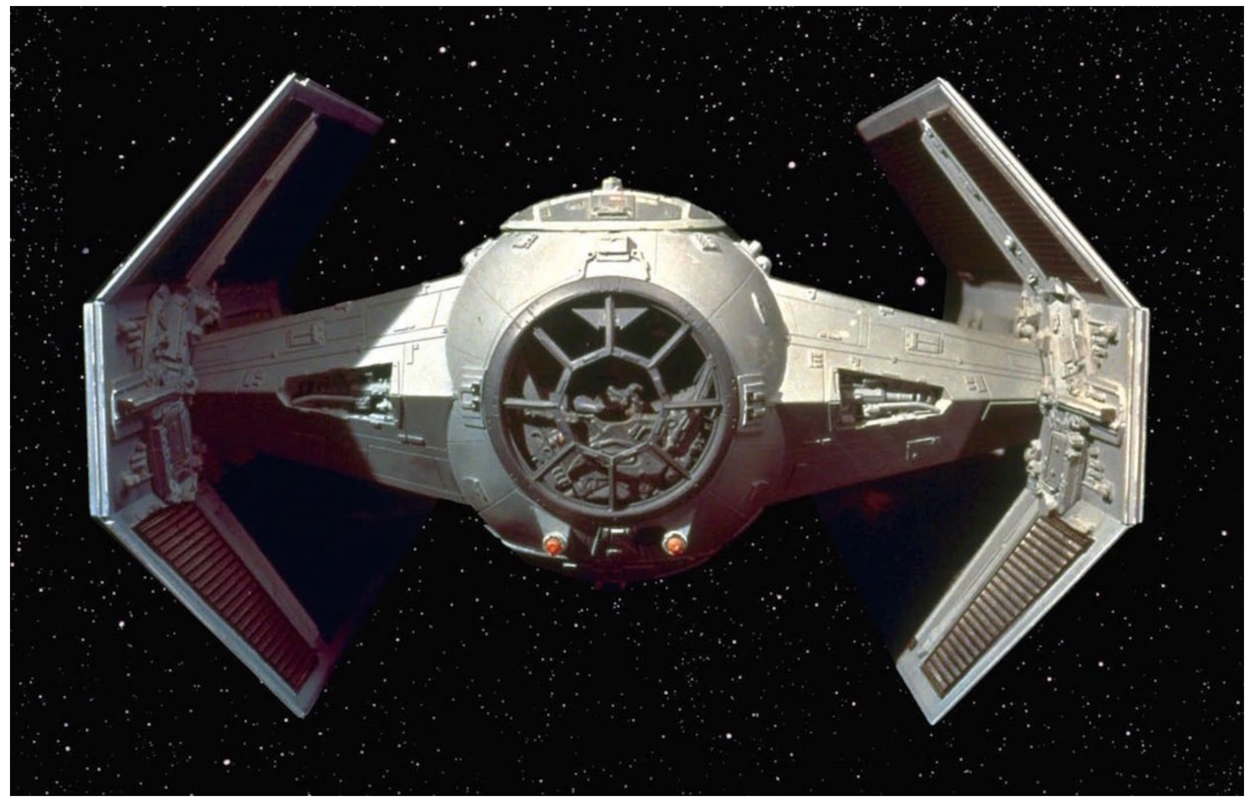
Defining Applicative operators alone is sufficient for parsers*

(in fact, we only give you an Applicative instance for Parser in this week's HW
— no Monad instance!)

*technically, parsers for any *context-free grammar*

# Applicative operators

# `Applicative` operators



TIE fighter from Star Wars

| | |
|---|---|
| `<*>` | "tie-fighter" |
| `<*` | "left tie" |
| `*>` | "right tie" |

Source: *Haskell Programming from First Principles*
(Chris Allen & Julie Moronuki)

```haskell
(<*) :: Applicative f => f a -> f b -> f a
```

result is discarded

keep the **1st** action's result

```haskell
(*>) :: Applicative f => f a -> f b -> f b
```

result is discarded

keep the **2nd** action's result

akin to >> for monads

## Exercise: using `*>` and `<*` to parse between parentheses

```
parenP :: Parser a → Parser a
```

# Example: parsing stuff within (...)

Parser for a specific char

```
char :: Char → Parser Char
```

```
parenP :: Parser a → Parser a
parenP p = char '(' *> p <* char ')'
```

parser for (

original
parser

parser for )

# Case study:
# Translating SQL to Pandas

# An automated tool for translating SQL queries into Pandas (joint work with Jason Hom)

https://github.com/homjason/sql-to-pandas

(Heavy usage of Applicative-based parsers for parsing SQL)

SQL

```
SELECT day, COUNT(total_bill) as num_bills
FROM tips_df
WHERE tip > 2
GROUP BY day
```

Pandas

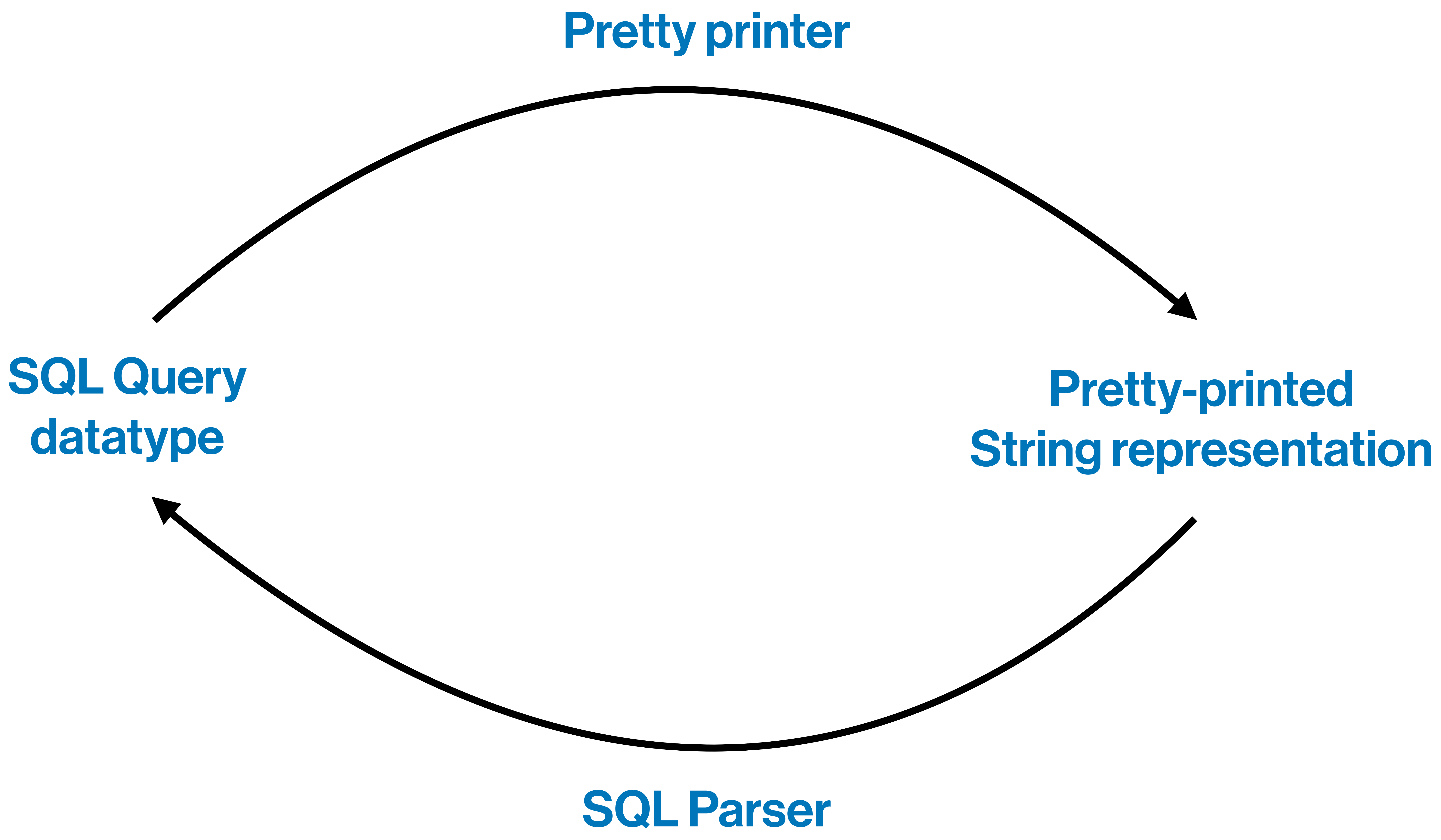
```
tips_df[tips_df["tip"] > 2]
    .groupby(by="day")
    .agg({"total_bill": "size"})
    .reset_index()
    .rename(columns={"total_bill": "num_bills"})
```

# Parsing a SQL query

```
queryP :: Parser Query
queryP = Query <$> selectExpP
     <*> fromExpP
     <*> ((Just <$> whereExpP) <|> pure Nothing)
     <*> ((Just <$> groupByP) <|> pure Nothing)
     <*> ((Just <$> orderByP) <|> pure Nothing)
     <*> ((Just <$> limitP) <|> pure Nothing)
```

(you'll see in the HW what the ( <|> ) operator does)

# Example QuickCheck round-trip property



## Example QuickCheck round-trip property

```haskell
prop_roundtrip :: Query → Bool
prop_roundtrip query =
  doParse queryParser (printQuery query) == Just (query, "")
```

fin

**Lecture adapted from:**

- **Stephanie Weirich's lectures for CIS 5520**
- **Brent Yorgey's lectures for CIS 1940 (Spring 2013)**