CS252 – Midterm Exam Study Guide
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Lecture #01 – General Introduction

Reasons for Different Programming Languages
1. **Different domains** (e.g. web, security, bioinformatics)
2. **Legacy code and libraries**
3. **Personal preference**

Programming Language Design Choices
1. **Flexibility**
2. **Type safety**
3. **Performance**
4. **Build Time**
5. **Concurrency**

Features of Good Programming Languages

1. **Simplicity**	4. **Safety** (e.g. security and can errors be caught at compile time)
2. **Readability**	5. **Machine independence**
3. **Learnability**	6. **Efficiency**

Goals almost always conflict

Conflict: Type Systems
- **Advantage:** Prevents bad programs.
- **Disadvantage:** Reduces programmer flexibility.

Blub Paradox: Why do I need advanced programming language techniques (e.g. monads, closures, type inference, etc.)? My language does not have it, and it works just fine.

Current Programming Language Issues
- **Multi-code "explosion"**
- **Big Data**
- **Mobile Devices**

Advantages of Web and Scripting Languages
- **Examples:** Perl, Python, Ruby, PHP, JavaScript
- **Highly flexible**
- **Dynamic typing**
- **Easy to get started**
- **Minimal typing** (i.e. type systems)

Major Programming Language Research Contributions
- **Garbage collection**
- *Sound* **type systems**
- **Concurrency tools**
- **Closures**

Programs that Manipulate Other Programs
- **Compilers & interpreters**
- **JavaScript rewriting**
- **Instrumentation**
- **Program Analyzers**
- **IDEs**

Formal Semantics
- Used to **share information** *unambiguously*
- **Can formally prove a language supports a given property**
- *Crisply define how a language works*

Types of Formal Semantics
- **Operational**
  - Big Step "*natural*"
  - Small Step "*structural*"
- **Axiomatic**
- **Denotational**

Haskell

- **Purely functional** – Define "*what stuff is*"
- **No side effects**
- **Referential transparency** – **A function with the same input parameters will always have the same result**.
  - **An expression can be replaced with its value and nothing will change**.
- **Supports type inference**.

Duck Typing – Suitability of an object for some function is determined not by its type but by presence of certain methods and properties.
- **More flexible** but **less safe**.
- **Supported by Haskell**
- **Common in scripting languages** (e.g. Python, Ruby)

Side Effects in Haskell
- Generally not supported.
- **Example of Support Side Effects**: File IO
- Functions that do have side effects must be separated from other functions.

Lazy Evaluation
- **Results are not calculated until they are needed**
- **Allows for the representation of infinite data structures**

Lecture #02 – Introduction to Haskell

Key Traits of Haskell
1. **Purely functional**
2. **Lazy evaluation**
3. **Statically typed**
4. **Type Inference**
5. **Fully curried functions**

ghci – Interactive Haskell.

let – Keyword required in ghci to set a variable value. **Example**:
```
> let f x = x + 1
> f 3
4
```

Run Haskell from Command Line
Use **runhaskell** keyword. Example:
```
> runhaskell <FileName>.hs
```

Hello World in Haskell
```
main :: IO ()
main = do
    putStrLn "Hello World"
```

Primitive Classes in Haskell
1. **Int** – **Bounded** Integers
2. **Integer** – **Unbounded**
3. **Float**
4. **Double**
5. **Bool**
6. **Char**

Lists
- **Base 0**
- Comma separated in square brackets
- **Operators**
  - **:** Prepend
  - **++** Concatenate
  - **!!** Get element a specific index
  - **head** First element in list
  - **tail** All elements after head
- **last** Last element in the list
- **init** All elements except the last
- **take n** Take first n elements from a list
- **replicate l m** Create a list of length l containing only m
- **repeat m** Create an in

Ranges
- Can be infinite or bounded
- Use the "**..**" notation. **Examples**:
```
> [1..4]
[1, 2, 3, 4]

> [1,2..6]
[1, 2, 3, 4, 5, 6]

> [1,3..10]
[1, 3, 5, 7, 9]
```

Hello World in Haskell
```
main :: IO ()
main = do
    putStrLn "Hello World"
```

List Examples
```
> putStrLn $ "Hello " ++ "World"
"Hello World"

> let s = bra in s !! 2 : s ++ 'c' : last s : 'd' : s
"abracadabra"
```

Infinite List Example
```
> let even = [2,4..]
> take 5 even
    [2, 4, 6, 8, 10]
```

<table>
<tr><th colspan="2">List Comprehension</th><th>A Simple Function</th><th rowspan="2">Pattern Matching</th></tr>
</table>

List Comprehension
- **Based off set notation.**
- **Supports filtering** as shown in second example
- If **multiple variables** (e.g. a, b, c) are specified, **iterates through them like nested for loops**.
- Uses the **pipe (|)** operator. **Examples:**

```
> [ 2*x | x <- [1..5]]
[2, 4, 6, 8, 10]
```

```
> [(a, b, c) | a <- [1..10], b <-[1..10],
         c <- [1..10], a^2 + b ^2 == c^2]

  [(3, 4, 5), (4, 3, 5), (6, 8, 10), (8, 6, 10)]
```

A Simple Function
```
> let inc x = x + 1
> inc 3
4

> inc 4.5
5.5

> inc (-5) -- Negative
-4
```

Type Signature
- Uses symbols "**::**" and "**->**"
- **Example:**
```
inc :: Int -> Int
inc x = x + 1
```

Pattern Matching
- Used to handle different input data
- Guard uses the pipe (|) operator
- Example:
```
inc :: Int -> Int
inc x
  | x < 0 = error "invalid x"
inc x = x + 1
```
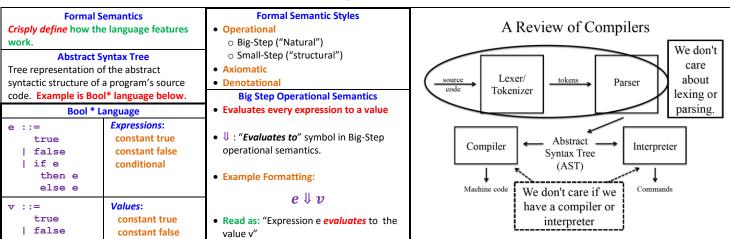
Recursion
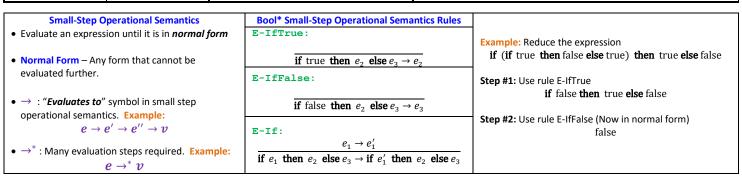- **Base Case** – Says when recursion should stop.
- **Recursive Step** – Calls the function with a *smaller version* of the problem

Example:
```
addNum :: [Int] -> Int
addNum [] = 0
addNum (x:xs) = x + addNum xs
```

Lab #01 – Max Number
```
> maxNum :: [Int] -> Int
> maxNum [] = error "Invalid Input"
> maxNum [x] = x
> maxNum (x:xs) = if x > maxXs then x else maxXs
>    where maxXs = maxNum xs
```

Lecture #03 – Operational Semantics

Formal Semantics
Crisply define **how the language features work**.

Abstract Syntax Tree
Tree representation of the abstract syntactic structure of a program's source code. **Example is Bool* language below**.

Bool * Language

e ::=	Expressions:
true	constant true
	false	constant false
	if e	conditional
then e	
else e	
v ::=	Values:
true	constant true
	false	constant false

Formal Semantic Styles
- **Operational**
  - Big-Step ("Natural")
  - Small-Step ("structural")
- **Axiomatic**
- **Denotational**

Big Step Operational Semantics
- **Evaluates every expression to a value**

- ⇓ : "**Evaluates to**" symbol in Big-Step operational semantics.

- **Example Formatting:**

$$e \Downarrow v$$

- **Read as:** "Expression e **evaluates** to the value v"

A Review of Compilers

We don't care about lexing or parsing.

We don't care if we have a compiler or interpreter

Small-Step Operational Semantics
- Evaluate an expression until it is in *normal form*

- **Normal Form** – Any form that cannot be evaluated further.

- → : "**Evaluates to**" symbol in small step operational semantics. **Example:**
  $$e \rightarrow e' \rightarrow e'' \rightarrow v$$

- →* : Many evaluation steps required. **Example:**
  $$e \rightarrow^* v$$

Bool* Small-Step Operational Semantics Rules

E-IfTrue:

$$\frac{}{\text{if true then } e_2 \text{ else } e_3 \rightarrow e_2}$$

E-IfFalse:

$$\frac{}{\text{if false then } e_2 \text{ else } e_3 \rightarrow e_3}$$

E-If:

$$\frac{e_1 \rightarrow e_1'}{\text{if } e_1 \text{ then } e_2 \text{ else } e_3 \rightarrow \text{if } e_1' \text{ then } e_2 \text{ else } e_3}$$

Example: Reduce the expression
  if (if true then false else true) then true else false

Step #1: Use rule E-IfTrue
  if false then true else false

Step #2: Use rule E-IfFalse (Now in normal form)
  false

Bool* Extension: Numbers

- `0` : The Number "0"
- `succ 0` : Represents "1"
- `succ succ 0` : Represents "2"
- `pred n` : Gets the predecessor of "*n*"

Extended Bool * Language
```
e ::=
    true
    | false
    | if e then e else e
    | 0
    | succ e
    | pred e
v ::= true | false
    | IntV

IntV ::= 0 | succ IntV
```

Literate Haskell

- **File Extension:** ".lhs"

- **Code lines begin with ">"**

- **All other lines are comments**.

- "Essentially swaps code with comments."

Case Statement in Haskell

- **Keywords:** case, of, otherwise
- **Operator:** ->

Example:

```
case x of
   val1 ->  "Value 1"
   val2 -> "Value 2"
   otherwise -> "Everything else."
```

Bool Expression Type	BoolVal Type	
| ```
> data BoolExp = BTrue
>        | BFalse
>        | Bif BoolExp BoolExp BoolExp
>        | B0
>        | Bsucc BoolExp
>        | Bpred BoolExp
>    deriving Show
``` | ```
> data BoolVal = BVTrue
>             | BVFalse
>             | BVNum BVInt
>    deriving Show

> data BVInt = BV0
>           | BVSucc BVInt
>    deriving Show
``` | **Type Constructors:** BoolExp, BoolVal, BVInt<br><br>***Non-nullary* Value Constructors:** Bif, Bsucc, Bpred, BVSucc, BVNum<br><br>**Note:** Even constants like B0, BTrue, BFalse, BVTrue, and BVFalse are nullary value constructors (since they take no arguments) |

Lecture #04 – Higher Order Functions

Lambda
- Analogous to anonymous classes in Java.
- Based off Lambda calculus
- **Example**:

```
> (\x -> x + 1) 1
2
>(\x y -> x + y) 2 3
5
```

Function Composition

- Uses the **period** (.)
- **f(g(x))** can be rewritten **(f . g) x**

Point-Free Style
- Pass function arguments no arguments. Example:

```
> let inc = (+1) – No args
> inc 3
4
```

Example: Lambda with Function Composition
```
> let f = (\x -> x – 5)
         . (\y -> y * 2)
> f 7
9

> let f = (\x y -> x – y)
        . (\z -> z * (-1))
> f 3 4
-7
```

Iterative vs. Recursive
- **Iterative tends to be more efficient than recursive.**
- **Compiler can optimize tail recursive function.**

Tail Recursive Function – The recursive call is the last step performed before returning a value.

Not Tail Recursive

```
public int factorial(int n) {
  if (n==1) return 1;
  else {
    return n * factorial(n-1);
  }
}
```

Last step is the multiplication so not tail recursive.

Tail Recursive Factorial

```
public int factorialAcc(int n, int acc)
{
  if (n==1) return acc;
  else {
    return factorialAcc(n-1, n*acc);
  }
}
```

Tail recursive code often uses the accumulator pattern like above.

Tail Recursion in Haskell

```
fact' :: Int -> Int -> Int
fact' 0 acc = acc
fact' n acc = fact' (n - 1) (n * acc)
```

Higher Order Functions

Functions in Functional Programming

- **Functional languages treat programs as mathematical functions**.

- **Mathematical Definition of a Function**: A function f is a rule that associates to each x from some set X of values a unique y from a set of Y values.

$$(x \in X \wedge y \in Y) \rightarrow y = f(x)$$

- f – Name of the function
- x – Independent variable
- y – Dependent variable
- X – Domain
- Y – Range

Qualities of Functional Programming

- **Functions clearly distinguish**:
  - Incoming values (**parameters**)
  - Outgoing Values (**results**)

- **No (re)assignment**

- **No loops**

- **Return values depend only on input parameters**

- *Functions are first class values*; this means they can:
  - Passed as arguments to a function
  - Be returned from a function
  - Construct new functions dynamically

Higher Order Function

Any function that **takes a function as a parameter *or* returns a function as a result**.

Function Currying
Transform a function with multiple arguments into multiple functions that each take exactly one argument.

Named after Haskell Brooks Curry.

Currying Example
```
addNums :: Num a => a -> a -> a
```

addNums is a **function that takes in a number and returns a function that takes in another number**.

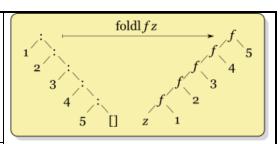| map	foldl	

• Built in Haskell higher order function
• **Applies a function to all elements of a list.**
 	
`map :: (a -> b) -> [a] -> [b]`
 	
`> map (+1) [1, 2, 3]`
`[2, 3, 4]`
	• Built in higher order function
	• **Does not support infinite lists**.
	• **Should only be used for special cases**.
	
	`foldl :: (b -> a -> b) -> b -> a -> b`
	
	Example:
	`> foldl (\x y -> x - y) 0 [1, 2, 3, 4]`
	`-10 -- (((0-1) - 2) - 3) - 4`	

filter	foldr	

• Built in Haskell higher order function
• **Removes all elements from a list that do not satisfy (i.e. make true) some predicate**.
 	
`filter :: (a -> Bool) -> [a] -> [a]`
 	
`> filter (>2) [1, 2, 3, 4]`
`[3, 4]`
	• Built in higher order function
	• **Supports infinite lists**.
	• "***Usually the right fold to use***"
	
	`foldr :: (b -> a -> a) -> a -> b -> a`
	
	Example:
	`> foldl (\x y -> x + y) 0 [1, 2, 3, 4]`
	`-2 -- 1 - (2 - (3 - (4 - 0)))`	

	foldl'	
Thunk – A delayed computation Due to lazy evaluation, **foldl and foldr build thunks rather than calculate the results as they go**.	• `Data.list.foldl'` evaluates its results eagerly (i.e. does not use thunks) • **Good for large, but finite lists.**	

Lecture #05 – Small-Step Operational Semantics

WHILE Language
• Unlike the Bool* language, **WHILE supports mutable references**.

e ::= a	Variable/addresses
| v	Values
| a:=e	Assignment
| e;e	Sequence
| e op e	Binary Operations
| if e then e else e	Conditional
| while (e) e	While Loops
v ::= i	Integers
| b	Boolean
op ::= + | - | * | / | >= | > | <= | <	

Small Step Semantics with State
• Since the WHILE language supports mutable references, the grammar must be updated to support it.

While Relation:
$$e, \sigma \rightarrow e', \sigma'$$

• σ – Store. **Maps *references* to values.**

Example Operations:
• $\sigma(a)$ – Retrieves the value at address "a"
• $\sigma[a := v]$ – Identical to the original store with the exception that it now stores the value v at address "a"

Evaluation Order Rules
• **Tend to be repetitive and clutter the semantics.**
• **Context based rules tend to represent the same information as evaluation order rules but more concisely.**

Reduction Rule
Rewrites the expression. Example:
E-IfFalse:
`if false then e2 else e3 → e3`

Context Rule
Specify the order for evaluating expressions. Example:

E-If:
$$\frac{e_1 \rightarrow e_1'}{\text{if } e_1 \text{ then } e_2 \text{ else } e_3 \rightarrow \text{if } e_1' \text{ then } e_2 \text{ else } e_3}$$

Reducible Expression (Redex)	Example: Redex	Example: Not a Redex
Reducible Expression (**Redex**) – Any expression that can be transformed (reduced) in one step.	**if** true **then** (**if** true **then** false **else** false) **else** true This reduces to "**if** true **then** false **else** false"	**if** (**if** true **then** false **else** false) **then** true **else** true Not a redex as expression "**if** true **then** false **else** false" must be evaluated first.

Evaluation Contexts
• **Alternative to evaluation order rules.**
• **Marker** (•) / **hole** indicate the **next place for evaluation** (i.e. where we will do the work).

Example:
  C[r]
  = **if** (**if** true **then** false **else** false) **then** true **else** true

    r = **if** true **then** false **else** false

    C = **if** • **then** true **else** true

C[r] is the original expression.

Rewriting Evaluation Order Rules
Context based rules only apply to reducible expressions (redexes). **Example**:

EC-IfFalse:
  C[if false **then** e₂ **else** e₃] → C[e₃]

Context Syntax

```
C ::= •
    | if C then e else e
    | C op e
    | v op C
    | ...
```

Data.Map
• **Library:** Data.Map
• **Immutable**
• **Example Methods**:
  ○ `Map.empty` – Creates and returns an empty map

  ○ `Map.insert k v m` – Inserts a value "**v**" at key "**k**" into map "**m**". **Returns a new, updated map.**

  ○ `Map.lookup k m` – Returns the value at key "**k**" in map "**m**". **Wrapped in a maybe.**

Precondition – Text above the line in a rule.	**Context Rule for Binary Op:** $\dfrac{v_3 = v_1 \text{ op } v_2}{C[v_1 \text{ op } v_2] \rightarrow C[v_3]}$	**How to Read a Small Step Semantic Rule**: "Given *<Precondition>*, then *<LeftSideArrow>* evaluates to *<RightSideArrow>*."

Lecture #06 – LaTeX

TeX
- Created by Donald Knuth
- Precisely controls the interface of content.
- Type of **Literate Programming** – Logic is in natural language and code is interspersed.

LaTeX
- Developed by Leslie Lamport. Derives from TeX.
- Type of **Domain Specific Language** (DSL) – A **computer language that is specialized for a particular application domain**.
- Enforces **separation of concerns** – Design principle for **separating a computer program into different sections, such that each section addresses a separate concern**.
  - ○ **Example:** LaTeX separates formatting from content.
- **Literate Programming**

Specify Document Type
```
\documentclass{article}
```

Specify Title Block Content
```
\title{Hello World!}
```

Start Document
```
\begin{document}
```

Generate Title from Title Information
```
\title{Hello World!}
```

Close the Document
```
\end{document}
```

Cross-Reference
```
\ref{<referenceName>}
```

Reference a Bibliography Citation
```
\cite{<citationName>}
```

Create a Reference
```
\label{<referenceName>}
```

Create a Bibliography
```
\bibliography{<bibFileName>}
```

Create a List
```
\begin{itemize}
\item Text for #1
\item Text for #2
   \end{itemize}
```

Create Section with Label
```
\section{Section #1}
   \label{sec:one}
```

Create Subsection with Label
```
\subsection{<SubsectionName>}
   \label{sec:<refName>}
```

Use of Tilde (~)
Creates an undividable space so the text
"`Section~\ref{sec:one}`" will appear on one line

BibTeX
- **References are tedious to reformat and renumber.**
- Reference details shorted in a "*.**bib**" file.

Create a Bibliography
```
\bibliography{biblio}
```

BibTeX filename for the example would be "**biblio.bib**"

Define Bibliography Style
```
\bibliographystyle{plainurl}
```

BibTeX Article Reference Example
```
@article{citationName,
   author = {Donald Knuth},
   title = {Literate Programming},
   journal = {},
   year = {1984},
   volume = {27},
   number = {2},
   pages = {97–111},
}
```

Lecture #07 – Types and Typeclasses

Maybe Type
- **Example of an algebraic data type**
- Enables behavior similar to **null** in Java
- **Used when:**
  - ○ **A function may not return a value**
  - ○ **A caller may not pass an argument**
- **Definition:**
```
data Maybe a = Nothing
             | Just a
```

Maybe "Divide" Example
```
divide :: Int -> Int -> Maybe Int
divide _ 0 = Nothing
divide x y = Just $ x `div` y

> divide 5 2
2
> divide 4 0
Nothing
```
DO NOT FORGET THE Just IN CORRECT SOLUTION

Maybe Map Example
```
import Data.Map

m = Map.empty
m' = Map.insert "a" 42 m
case (Map.lookup "a") of
   Nothing -> error "Element not in map"
   Just x -> putStrLn $ show x
```
Since element may not be in the map, you need to use a maybe

Algebraic Data Type
- A **composite data type** (i.e. **a type made from other types**).
- **Created via the Keyword: data**
- **Examples:** Either, Maybe, Tree

Example Algebraic Data Type
```
data Tree k = EmptyTree
            | Node (Tree k) (Tree k) val
            deriving (Show)
```

k – Type parameter. **Specifies a type not a value.**

Node: **Value Constructor that creates values of type** "`Tree k`"

Partially Applying a Value Constructor
- Value constructors can be partially applied similar to functions. **Example:**
```
> let leaf = Node EmptyTree EmptyTree

> Node (leaf 3) (leaf 7) 5
```
This creates a three node tree with value 5 at the root and values 3 and 7 at the leaves.

- **Tree** and **Tree Int** have no types since they themselves form a **concrete type**.
- **Node** does have a type:
```
> :t Node
Node :: (Tree k) -> (Tree k) -> k -> (Tree k)
```

Explanation: **To make a complete Node object, you pass it two objects of type "Tree k" and another object of type "k" and that returns a "Tree k" object.**

Type of the "+" Operator
```
> :t (+)
(+) :: (Num a) => a -> a -> a
```

Explanation: The plus sign takes two numbers of type "**a**" and returns an object of type "**a**".

Type of a Number
```
> :t 3
3 :: (Num a) => a
```

Explanation: Since "3" has no explicit type, it can for now be any type that satisfies the "Num" type class.

Kinds			Typeclasses

Kinds

- "*The type of types*".
- Concrete types have a kind of "**"
- Keyword :k, :kind
- Example:

```
> :k Tree
Tree :: * -> *
```

Explanation: A Tree requires one type parameter to be made a concrete type.

String Kind
```
> :kind String
String :: *
```

Map Kind
```
> :k Map
Map :: * -> * -> *
```

Maybe Kind
```
> :k Maybe
Map :: * -> *
```

Map String Kind
```
> :kind (Map String)
(Map String) :: * -> *
```

Explanation: Map String is has one of the two type parameters filled so it has one less asterisk.

Typeclasses

- **Similar to interfaces in Java**.
  - Like a contract.
  - **Implementation details can be included in typeclass definition**.

- No relation to classes in object-oriented programming.
  - **Example**: Do not have any data associated with them.

- **Simplify polymorphism**.

Example: **Eq** Typeclass

```
class Eq a where
    (==) :: a -> a -> Bool
    (/=) :: a -> a -> Bool
    x == y = not (x /= y)
    x /= y = not (x == y)
```

The last two lines in the type class definition allow the developer to program either (==) or (/=) but not necessarily both.

Example: Make **Maybe** an Instance of **Eq**

```
instance (Eq a) => Eq (Maybe a) of
    (==) Nothing Nothing  = true
    (==) (Just x) (Just y) = x == y
    (==) _        _        = false
```

Need to ensure type "a" supports "Eq" so add that as a **class constraint**.

Class Constraint
- **Operator**: =>
- Ensures that a type parameter satisfies some type class requirement.

Kind of Typeclasses

```
> :k Eq
Eq :: * -> Constraint
```

```
> :k Num
Num :: * -> Constraint
```

Note: **Typeclasses are a class constaint (not a type) so their kind is different**.

Lecture #08 – Functors

Functor Type Class Definition

```
class Functor f where
    fmap :: (a -> b) -> f a -> f b
```

This is very similar to the definition of the higher order function "map"

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

Functor – **Something that can be mapped over**.
- Handles things "inside a box"

Example: List ([]) as an Instance of **Functor**

```
instance Functor [] where
    fmap = map
```

Explanation: map is a specialized version of fmap for lists.

Examples: map and fmap on Lists

```
> map (+1) [1, 2, 3]
[2, 3, 4]
```

```
> fmap (+1) [1, 2, 3]
[2, 3, 4]
```

```
> fmap (+1) []
[]
```

Examples: fmap on Maybes

```
> fmap (+1) (Just 3)
Just 4
```

```
> fmap (+1) Nothing
Nothing
```

Example: **Maybe** as an Instance of **Functor**

```
instance Functor Maybe where
    fmap _ Nothing = Nothing
    fmap f (Just x) = Just (f x)
```

DO NOT FORGET THE Just IN VALID SOLUTION

Either Algebraic Data Type

```
data Either a b = Left a
                | Right b
    deriving (Eq,Ord,Read,Show)
```

- **Left** – **Error type that is not mappable**.

- **Right** – **Expected type**

Example: **Either** as an Instance of **Functor**

```
instance Functor (Either a) where
    fmap _ (Left x) = Left x
    fmap f (Right y) = Right (f y)
```

```
> fmap (+1) Leftt 20
20 -- No Change
```

```
> fmap (+1) Right 20
21 -- Changed
```

IO in Haskell

- Haskell avoids side effects but they are inevitable in real programs.

- **Monads**
  - Related to Functors
  - Compartmentalize side effects.

- **()**
  - Unit type in Haskell

Type Signature of the main Function in Haskell
```
main :: IO ()
```

Hello World in Haskell
```
main = putStrLn "Hello World"
```

Type Signature of getLine
```
getLine :: IO String
```

- **do** – Allows for the chaining of multiple IO commands together

- **<-** Extracts data out of an "IO Box"

- **return** – Places data into an "IO Box"

do Example

```
main = do
    line <- getLine
    if null line -- Checks for empty str
        then return ()
        else putStrLn $ reverseWords line


reverseWords :: String -> String
reverseWords = unwords .
               map reverse . words
```

return in Haskell
- **Unrelated to "return" in other languages**

- **Better described as "wrap" or "box"**

Summary:
return – Boxes an IO (**since IO is a monad**)

<- Unboxes an IO

Type of the Unit Type ()
- Base type

```
> :t ()
() :: ()
```

Type of return
```
> :t (return ())
(return ()) :: Monad m => m ()
```

Monad is a **typeclass**.

Using IO as a Functor

```
main = do
        line <- fmap (++"!!!") getLine
        putStrLn line
```

Explanation: This function takes a string input from standard in and appends "!!!" at which point it prints it to the console.

Definition of IO as a Functor

```
instance Functor IO where
    fmap f action = do
                    result <- action
                    return (f result)
```

Explanation: The action object is taken out of the IO box, the function "f" applied to it, and then returned to the IO box.

id Function

- **Takes one input parameter and returns that input parameter unmodified. Examples:**

```
> id 3
3

> id "Hello World"
"Hello World"
```

Functor Laws

Functor Law #1: If we map the id function over a Functor, the Functor that we get back should be the same as the original Functor.

Examples:
```
> fmap id (Just 3)
Just 3
> fmap id Nothing
Nothing
> fmap id [1, 2, 3]
[1, 2, 3]
```

Functor Law #2: Composing two functions and then mapping the resulting (composed) function over a Functor should be the same as first mapping one function over the Functor and then mapping the other one.

Law #2 Written Formally
```
fmap (f . g) = fmap f . fmap g
```

The Functor laws are NOT enforced. They are good practice that makes the code easier to reason about.

Lecture #09 – Applicative Functors

Functor – **Something that can be mapped over. Allow you to map functions over different data types. Examples:**
- **Maybe**
- **Either**
- **IO**
- **Lists**
- **<*>**

Functors return boxed up values.

Functor Example

```
> fmap (+1) [1, 2, 3]
[2, 3, 4]

> let x = fmap (+) [1, 2, 3]
```

Explanation: In this case **x** is:
```
[(1+), (2+), (3+)]
```

Applicative Functor
- Requires the importing of a special library as shown below:

```
import Control.Applicative
```

Functions in Applicative Typeclass:
- **pure** – Wraps/boxes a value
- **<*>** - Infix version of **fmap**. Is itself a Functor.

Example Uses of pure
```
> pure 7
7

> pure 7 :: Maybe Int
Just 7

> pure 7 :: [Int]
[7]
```

Type Class Definition of Applicative

```
class (Functor f) => Applicative f where
    pure :: a -> f a
    <*> :: f (a -> b) -> f a -> f b
```

Only difference between <*> and fmap is that the function in <*> is boxed while it is not in fmap (see the green f).

Make Maybe an Instance of Applicative

```
instance Applicative Maybe where
    pure = Just
    Nothing <*> _ = Nothing
    (Just f) <*> x = fmap f x
```

Explanation: pure simply wraps the value in **Just**. No need to explicitly check if "**x**" is maybe as **fmap** will do that for you.

Examples of Applicative Maybe

```
> Just (+3) <*> Just 4
Just 7
> pure (+3) <*> Just 4
Just 7
> pure (+) <*> Just 3 <*> Just 4
Just 7
> (+) <$> Just 3 <*> Just 4
Just 7
```

Explanation: x <$> is fmap as an infix operator. It is NOT necessarily the same as pure x <*>

Making [] an Instance of Applicative

```
instance Applicative [] where
    pure x = [x]
    fs <*> xs = [f x | f <- fs, x <- xs]
```

Explanation: The function is actually a list of functions so list comprehension is needed.

Example Use of Applicative on Lists
```
> (*) <$> [1, 2, 3] <*> [1,0,0,1]
[1,0,0,1,2,0,0,2,3,0,0,3]

> pure 7
7   -- No change
> pure 7 :: [Int]
[7]
```

Definition of IO as an Instance of Applicative

```
instance Applicative IO where
    pure = return
    a <*> b = do
                f <- a
                x <- b
                return (f x)
```

Example of `Applicative IO`	`liftA2`

```import Control.Applicative```
 	
```main = do```
`      a <- (++) <$> getLine <*> getLine`
`      putStrLn a`
	A function that simplifies the application of a normal function to two Functors.
	
	```liftA2 :: (Applicative f) => (a -> b -> c) -> f a -> f b -> fc```
	```liftA2 f x y = f <$> a <*> b```

Example of `liftA2`		**Applicative Functor Definition**

```> (:) <$> Just 3 <*> Just [4]```
```Just [3, 4]```
```> liftA2 (:) (Just 3) (Just [4])```
```Just [3, 4]```
		A functor you can apply to other Functors.

Applicative Functor Laws

Law 1: `    pure f <*> x = fmap f x`	Law 2: `        pure id <*> v = v`	Law 3: `pure (.) <*> u <*> v <*> w = u <*> (v <*> w)`
Law 4: `  pure f <*> pure x = pure (f x)`	Law 5: `  u <*> pure y = pure ($y) <*> u`	Similar to Functor Laws, these are not strictly enforced but are good practice to make it easier to reason about the code.

Monoids

Monoid: An **associative** binary function and a value that acts as an **identity** with respect to that function.
 	
Examples
• x * 1   Identity of **Multiplication**
• lst ++ []   Identity of **Concatenation**
• x + 0   Identity of **Addition**
	Definition of Monoid Typeclass
	
	```class Monoid m where```
	`      mempty :: m`
	`      mappend :: m -> m -> m`
	`      mconcat :: [m] -> m`
	`      mconcat = foldr mappend mempty`	

Monoid Rules

Rule #1: `    mempty `mappend` x = x`	Rule #2: `    x `mappend` mempty = x`	Rule #3: `  (x `mappend` y) `mappend` z = x `mappend` (y `mappend` z)`

Lecture #10 – Monads

Functor – **Something that can be mapped over**.
Definition:
 	
```instance Functor f where```
`      fmap :: (a -> b) -> f a -> f b`
	Problem with Functors: Do not support chaining of multiple commands. **Example:**
	
	```> fmap (+) (Just 3) (Just 4)```
	
	Returns an error since it cannot resolve `(Just 3+)` and `(Just 4)`
		Applicative Functor: A **Functor that can be applied to other Functors**.
		
		```class (Functor f) => Applicative f where```
		`      (<*>) :: f (a -> b) -> f a -> f b`
		
		Requires library `Control.Applicative`

Even **with Applicative Functors, it is not possible to chain together multiple commands**. **Example:**
 	
```> Just (+3) <*> Just (+4) <*> Just (+5)```
Returns error
	Monads: Can chain through a series of functions.
	
	Key Operator:
	>>= (Bind)
		Example #1: Using Just
		```> (Just 3) >>= (\x -> Just (x + 4)) >>= (\y -> Just (y+5))```
		```12```
		
		Example #2: Using `return`
		```> (return 3) >>= (\x -> return (x + 4)) >>= (\y -> return (y+5))```
		```12```

Comparing <*> and >>=
 	
Functor:
`(<*>) :: Applicative f => f (a -> b) -> f a -> f b`
 	
Monad:
`(>>=) :: Monad m => m a -> (a -> m b) -> m b`
 	
Differences:
1. **Order of the arguments changed.**
2. **The function is boxed in Functor but not Monad**
3. **Monad function returns a boxed result.**
	Example of <$>, <*> and >>=
	
	```> (\x -> x + 1) <$> Just 3```
	```Just 4```
	
	```> Just (\x -> x + 1) <*> Just(3)```
	```Just 4```
	
	```> (Just 3) >>= (\x -> Just(x+1))```
	```Just 4```
		Example: Implement `applyMaybe` that applies a function to a `Maybe`
		
		```applyMaybe :: Maybe a -> (a -> b) -> (Maybe b)```
		```applyMaybe Nothing _ = Nothing```
		```applyMaybe (Just x) f = Just (f x)```

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Example: Implement **applyMaybe** that applies a function to a **Maybe**	Chaining applyMaybe	

`applyMaybe :: Maybe a -> (a -> Maybe b)`
`            -> (Maybe b)`
 	
`applyMaybe Nothing _ = Nothing`
`applyMaybe (Just x) f = Just (f x)`
	`> (Just 3) `applyMaybe` (\x -> Just (x*2))`
	`           `applyMaybe` (\y -> Just (y-1))`
	`Just 5`
	
	`> (Just 3) `applyMaybe` (\_ -> Nothing)`
	`           `applyMaybe` (\y -> Just (y-1))`
	`Nothing`	

Monad Typeclass Definition	Example a Robot Moving Towards a Goal (Not Failure)	

`class Monad m where`
`    return :: a -> m a`
`    (>>=) :: m a -> (a -> m b) -> m b`
 	
`    (>>) :: m a -> m b -> m b`
`    x >> y = x >>= (\_ -> y)  --Lamda`
 	
`    fail :: String -> m a`
`    fail msg = error msg`
	`--Location`
	`type Robot = (Int, Int)`
	
	`-- Functions`
	`up (x,y) = (x, y+1)`
	`down (x,y) = (x, y-1)`
	`left (x,y) = (x-1, y)`
	`right (x,y) = (x+1, y)`
		`-- Define Operator and start location`
		`x -: f = f x`
		`start = (0, 0)`
		
		`> start -: up -: right`
		`(1, 1)`
		
		`> start -: up -: left -: left -: right -: down`
		`(-1, 0)`

	Example a Robot Moving Towards a Goal (with Failure)	

Maybe as an Instance of the Monad Typeclass
 	
`instance Monad Maybe where`
 	
`    return = Just`
 	
`    (>>=) Nothing  _ = Nothing`
`    (>>=) (Just x) f = Just (f x)`
 	
`    fail _         = Nothing`
	`-- Once the goal is reached,`
	`-- the robot stops`
	`goal := Map.empty`
	`        -: (Map.insert (0, 2) True)`
	`        -: (Map.insert (-1, 3) True)`
	`        -: (Map.insert (-3, -8) True)`
	
	`moveTo :: Pos -> Maybe Pos`
	`moveTo p = if Map.member p goal`
	`             then Nothing`
	`             else Just p`
	
	`-- Since these are in bind, no need`
	`-- to handle Nothing. Bind handles it.`
	`up (x,y) = moveTo (x, y+1)`
	`down (x,y) = moveTo (x, y-1)`
	`left (x,y) = moveTo (x-1, y)`
	`right (x,y) = moveTo (x+1, y)`
		`start = (0, 0)`
		
		`> return start >>= up >>= left >>= left`
		`              >>= right >>= down`
		`Just (-1, 0)`
		
		`> return start >>= left  >>= left  >>= up`
		`              >>= up    >>= right >>= up`
		`              >>= right >>= right >>= down`
		`Nothing`
		
		Explanation: Reached one of the goals (-1, 3) at the red **up**

Integer Division Using Monads

Integer Division with Bind and No "do"	Integer Division with Bind with "do"	Integer Division with Bind with "do" and return

`mydiv :: Maybe Int -> Maybe Int -> Maybe Int`
`mydiv x y = x >>= (\numer ->`
`        y >>= (\denom ->`
`        if denom > 0`
`            then Just (div numer denom)`
`            else fail "Div by zero")`
	`mydiv :: Maybe Int -> Maybe Int -> Maybe Int`
	`mydiv x y = do`
	`        numer <- x`
	`        denom <- y`
	`        if denom > 0`
	`            then Just (div numer denom)`
	`            else fail "Div by 0"`
		`mydiv :: Maybe Int -> Maybe Int -> Maybe Int`
		`mydiv x y = do`
		`        numer <- x`
		`        denom <- y`
		`        if denom > 0`
		`            then return $ div numer denom`
		`            else fail "Div by 0"`

List Monad

Making **List** an Instance of Monad	Example Use of **List** as a Monad	Combining a **Maybe** and a **List** Monad

`instance Monad [] where`
`    return x = [x]`
`    (>>=) xs f = concat(map f xs)`
`    fail _    = []`
 	
Explnation: **concat** is needed here as **f** returns elements already in a list. As such, **concat** merges the individual lists (from each call to **f**) into a single list.
	`listOfTuples :: [(Int, Char)]`
	`listOfTuples = do`
	`            n <- [1, 2]`
	`            ch <- ['a', 'b']`
	`            return (n, ch)`
	`> listOfTuples`
	`[(1,'a'), (1,'b'), (2,'a'), (2, 'b')]`
		`> Just [2,3] >>= (\x -> Just( fmap (+1) x))`
		`[3, 4]`

Lecture #11 – Parsing Combinators

| Semantics: Enumerate **what a program means**. **Defined by the interpreter or compiler**.

Syntax: Enumerate **how a program Is structured**. **Defined by the lexer and parser**. | Compilation Flow
Step #1: Tokenizer/lexer generates a set of tokens.

Step #2: Parser turns the tokens into an abstract syntax tree.

Step #3: Compilers and interpreters convert the AST into machine code or commands respectively. | Lexer
Converts the characters of the program into words of the language.

Examples: Lex/Flex (C/C++). ANTLR & JavaCC (Java). Parsec (Haskell) |

Categories of Tokens
- **Reserved Words/Keywords**.
  - **Examples**: while, if, then, else

- **Literals/Constants**.
  - **Examples**: 123, "Hello World!"

- **Special symbols**.
  - **Examples**: ";", "=>", "&&"

- **Identifiers**.
  - **Examples**: "balance", "myFunction"

Parsing
- **Parser converts tokens to abstract syntax trees**.

- **Defined by context free grammars** (CFG)

- Types of Parsers:
  - **Bottom-up**/**Shift-Reduce** Parsers
  - **Top-down** parsers

Context Free Grammars
- Grammars specify the language.

- Specified in Backus-Naur form format. **Example**:

```
Expr -> Number
     |  Number + Expr
```

- **Terminal** – **Cannot be broken down** further.

- **Non-terminals** – **Can be broken down** further.

Example: "0", "1", "2", … , "9" are terminals but digit, number, and expression are not.

Example Grammar

```
expr -> expr + expr
     |   expr - expr
     |   ( expr )
     |   number

number -> number digit
       |  digit

digit -> 0 | 1 | 2 | … | 9
```

Bottom-Up / Shift-Reduce Parser
- **Shift** tokens onto a stack
- **Reduce** the stack to a non-terminal.

- **LR** – **L**eft to right, **R**ightmost derivation
- **LALR** – **L**ook-**A**head **LR** parsers are the most common type.
  - **Examples:** YACC/Bison

- **Fading from popularity**

Top-Down Parser
- **Non-terminals are expanded to match tokens**.

- **LL** – **L**eft to right, **L**eftmost derivation
- **LL(k) Parser** – Looks ahead up to *k* elements. **Examples**: Java CC, ANTLR

  - The higher the *k*, the more difficult language is to parse. *k* **can be arbitrary**.

  - *LL(1)* - Easy to parse using either LL or recursive descent parsers. **Many computer languages are designed to be LL(1)**.

Parser Combinator

Combine simpler parsers to make a more complex parser.

Example: Parsec

Useful Parsec Functions
- **many** – Parses **zero or more** occurrences of the given parser.
- **many1** – Parses **1 or more** occurrences of the given parser.

- **noneOf** – Anything but the specified value

- **spaces** – Whitespace characters

- **char** – The specific specified character
- **string** – The specific specified string.

- **sepBy** – Separate tokens by some token.

Example Parsec Code

```
import Text.ParserCombinators.Parsec

num :: GenParser st String
num = many1 digit

main = do
      print $ parse num "Hello" "42"
```

```
import Text.ParserCombinators.Parsec

num :: GenParser st Integer
num = do
      str <- many1 digit
      return $ read str

main = do
       print $ parse num "World" "42"
```

- **st** – "State." Always required for our purposes.
- **String**/**Integer** – Parser return type
- **many1** – Select one of more digits.
- **digit** – 0, 1, 2, 3, …, 9 (**terminal**)
- **num** – Parser entry function
- **"Hello"**/**"World"** – Debug string.
- **"42"** – String to parse.

Example with try, <|>, and <?>

```
eol =  try (string "\n")
   <|> string "\n\r"
   <?> "end of line"
```

- **try** – If an incomplete match is found, rewind.
- **<|>** – "Or" Operator for matching tokens.
- **<?>** – Otherwise with an accompanying error message.

Top-Down Parser
- Non-terminals are expanded to match tokens.
- **LL** – **L**eft to right, **L**eftmost derivation
- **LL(k) Parser** – Looks ahead up to *k* elements. **Examples**: Java CC, ANTLR

  - The higher the *k*, the more difficult language is to parse. *k* **can be arbitrary**.

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Parser Combinator

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- **noneOf** – Anything but the specified value

- **spaces** – Whitespace characters

- **char** – The specific specified character
- **string** – The specific specified string.

Practice Midterm and Review Notes

Question #1	Question #2	Question #3	Question #4	Question #5
a. **True**	a. **True**	a. **False** – Big step	a. **False** – Imperative	a. **True**
b. **False** – Lazy evaluation	b. **False** – Applicative functor	b. **True**	b. **True**	b. **False** – Typeclass
c. **False** – Lazy evaluation	c. **True**	c. **False** – Use store	c. **False**	c. **True**
d. **False** – Statically type	d. **True**	d. **True**	d. **True**	d. **False**
e. **True**	e. **True**	e. **False**	e. **True**	e. **False** – Algebraic data type

Haskell	**Purely Functional**	**Functional Languages**	**Operational Semantics**
• **Purely Functional** • **Lazy evaluation** • **Fully Curried Language** • **Statically Typed** • **Type Inference** – Via context, Haskell can deduce the type.	• **Referential Transparency** – A **function call** can be replaced with its equivalent value without affecting the program • **No (re)assignment** • **No loop** • **No side effects**	• **Functions are first class objects** meaning they can be passed to a function, returned from it, or created on the fly. • **Higher order function support**	• **Small Step** – Structural Semantics • **Big Step** – Natural Semantics • "**Get stuck**" – When a function is encountered that does not have an associated rule.

CSV Parser Example

```haskell
import Text.ParserCombinator.Parsec
import System.Environment

csvFile :: GenParser st [[String]]
csvFile = do
        arr <- many line
        char eof
        return arr

line :: GenParser st [String]
line = do
        result <- many1 cell
        char '\n'
        return result

cells :: GenParser st [String]
cells = do
        firstCell <- cellContents
        nextCells <- remainingCells
        return (firstCell:nextCells)

cellContent :: GenParser st String
cellContent = many $ noneOf ",\n" -- Two characters

remainingCells :: GenParser st [String]
remainingCells = do
                (char "," >> cells)
                <|> return []

main = do
        args <- getArgs
        p <- parseFromFile csvFile "example 1" (head args)
        case p of
            Left msg  -> error msg
            Right csv -> print csv
```

```haskell
import Text.ParserCombinator.Parsec
import System.Environment

csvFile = lines `sepBy` eol

line = cells `sepBy` string ","

cells = many (noneOf "\n")

eol = try (string "\n")
   <|> string "\n\r"
   <?> "end of line"

main = do
        args <- getArgs
        p <- parseFromFile csvFile "example 1" (head args)
        case p of
            Left msg  -> error msg
            Right csv -> print csv
```

Miscellaneous

Kind of Show and show
```
> :k Show
Show :: * -> Constraint
```

Type and Kind of show
```
> :k show
Error (A function not a type)
> :t show
show :: (Show a) => a -> String
```

Lambda and ADT Combined
```
> (\x -> Just (x+1)) 1
Just 2
```

Creating Type Alias
```
type String = [Char]
```

Allows for more readable code as developer can use a type name that makes more sense for a given application.

Example: `applyMaybe` that takes a `(Maybe a)` and applies to it a function that takes a normal **a** and returns a `(Maybe b)`

```
applyMaybe :: (Maybe a) -> (a -> Maybe b) -> (Maybe b)
applyMaybe Nothing _ = Nothing
applyMaybe (Just x) f = f x
```

Explanation: Since the function "**f**" already returns a Maybe, you do not need to re-box it. However, since it does not take a Maybe, you need to unbox the first input parameter.

Applying return to Items
```
> return 7
7return
> return 7 :: Maybe Int
Just 7
> return 7 :: [Int]
[7] -- Need Int or get an error
```

Conclusion: **Behavior for return is the same as pure**. Both put the object in the **minimum default context that still yields that value**.

List comprehension is syntactic sugar for using lists as monads.

Monads and Lambda

When trying to chain multiple functions together in a Monad, remember the Monad must return a **boxed value**. Hence, **Lambda often work well as they simplifying boxing**.

Applicative Typeclass – Allows you to use normal functions on values that have a context (i.e. are inside a Functor).

Monad: Given a value of type, **a**, in a context, **m**, apply a function that takes a normal value of type **a** and returns a value in the context **m**.

```
(>>=) :: (Monad m) => m a -> (a -> m b) -> m b
```

Monads are just applicative functors that support bind (**>>=**).

Key Difference: **Applicative functors support normal functions that take and return unboxed values while Monads return boxed values**.

return – Monad equivalent of "pure" for Applicative Functors.

Cannot use `fmap` in the definition of a `Monad` since `fmap` returns a boxed value while the function of the `Monad` returns a boxed value. Hence, if you used `fmap` with a `Monad`, you would return a double boxed value.