CS252 – Final 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**
2. **Readability**
3. **Learnability**
4. **Safety** (e.g. security and can errors be caught at compile time)
5. **Machine independence**
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-core "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.**
  - **A function call 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 in the list except the last one
  - `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 infinite list containing only `m`

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]

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

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]
```

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
```

Reasons for a Large Number of Programming Languages

- **Different domains**
- **Different design choices**

Recursion

- `:t` or `:type` – Gets the type of a variable or function.

Example:

```
> :type 'A'
'A' :: Char
> :t "Hello"
"Hello" :: [Char]
```

Haskell's Base Typeclasses

- `Ord` – Can be ordered
- `Eq` – Can perform equality check
- `Show` – Can convert to String
- `Read` – Can convert from String
- `Enum` – Sequentially Ordered
- `Bounded` – Has upper and lower bound.

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 ::=`
`  true`
`| false`
`| if e`
`  then e`
`  else e`
	***Expressions*:**
	constant true
	constant false
	conditional

`v ::=`
`  true`
`| false`
	***Values*:**
	constant true
	constant false

Formal Semantic Styles

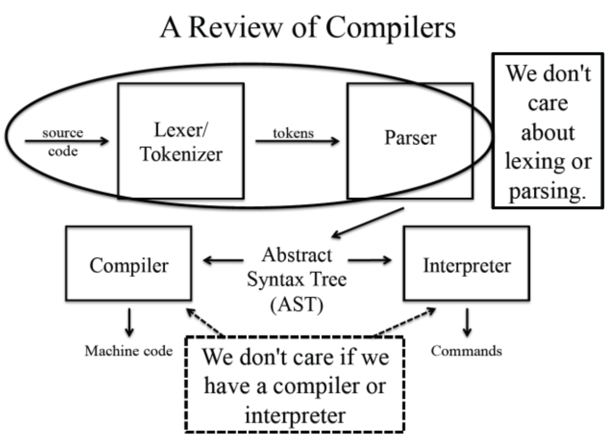
- **Operational** – **Specify how expressions should be evaluated.**
  - Big-Step ("Natural")
  - Small-Step ("structural")
- **Axiomatic**
- **Denotational**

Big Step Operational Semantics

- **Evaluates every expression to a value**
- $\Downarrow$: "***Evaluates to***" symbol in Big-Step operational semantics.
- **Example Formatting:**

$$e \Downarrow v$$

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



Small-Step Operational Semantics

- Evaluate an expression until it is in ***normal form***
- **Normal Form** – Any form that cannot be evaluated further.
- $\rightarrow$: "***Evaluates to***" symbol in small step operational semantics. **Example:**

$$e \rightarrow e' \rightarrow e'' \rightarrow v$$

- $\rightarrow^*$: 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`" with "`E-If`"

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."
```

Lab #02 Review

Bool Expression Type

```
> data BoolExp = BTrue
>        | BFalse
>        | Bif BoolExp BoolExp BoolExp
>        | B0
>        | Bsucc BoolExp
>        | Bpred BoolExp
>   deriving Show
```

BoolVal Type

```
> data BoolVal  = BVTrue
>               | BVFalse
>               | BVNum BVInt
>   deriving Show

> data BVInt = BV0
>              | BVSucc BVInt
>   deriving Show
```

Type Constructors: BoolExp, BoolVal, BVInt

***Non-nullary* Value Constructors:** BIf, Bsucc, Bpred, BVSucc, BVNum

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 no arguments to a function
- **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`

- 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]
```

`filter`

- 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]
```

foldl

- 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
```

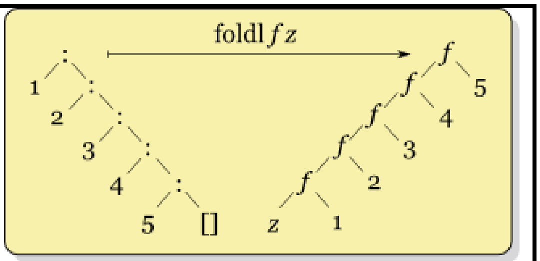
foldr

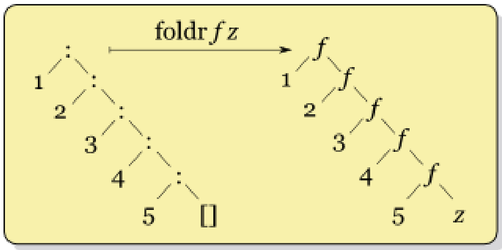
- Built in higher order function
- **Supports infinite lists.**
- "***Usually the right fold to use***"

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

Example:

```
> foldr (\x y -> x + y) 0 [1, 2, 3, 4]
-2 -- 1 – (2 – (3 – (4 – 0)))
```





Thunk – A delayed computation

Due to lazy evaluation, **foldl and foldr build thunks rather than calculate the results as they go.**

`foldl'`

- **`Data.List.foldl'`** evaluates its results eagerly (i.e. does not use **thunks**)
- **Good for large, but finite lists.**

`foldl` in terms of `foldr`

```
myFoldl' f acc x = foldr (flip f) acc (reverse x)
```

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"
- $\sigma[a \coloneqq v]$ – 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:

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

Reducible Expression (**Redex**) – Any expression that can be transformed (reduced) in one step.

Example: Redex

if true **then** (**if** true **then** false **else** false) else true

This reduces to "**if** true **then** false **else** false"

Example: Not a Redex

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 (redexs). **Example:**

EC-IfFalse:

$C[\text{if false then } e_2 \text{ else } e_3] \rightarrow C[e_3]$

Context Syntax

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

Data.Map

- **Library:** import Data.Map as **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`.**
  - **`Map.member k m`** – Returns true if k is in map "m" and false otherwise.

Precondition – Text above the line in a rule.

Context Rule for Binary Op:

$$\frac{v_3 = v_1 \text{ op } v_2}{C[v_1 \text{ op } v_2] \rightarrow C[v_3]}$$

How to Read a Small Step Semantic Rule: "Given <*Precondition*>, then <*LeftSideArrow*> evaluates to <*RightSideArrow*>."

Lecture #06 – LaTeX

TeX

- Created by Donald Knuth
- **Domain specific language for typesetting documents**.
- Precisely controls the interface of content.
- Type of **Literate Programming** – **Logic is in natural language and code is interspersed**. “***Mark code instead of marking comments.***”

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
- Can be used to provide context.
- **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`”**

- **`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.

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.

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

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

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

Explanation: A Tree requires one type parameter (e.g. `Int`) 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 typeclass 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/Monad commands together. **Syntactic sugar for bind ">>="**
- **<-** Extracts data out of an IO/Monad "Box"
- `return` – Places data into an IO/Monad "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 <*>`. It should be based off Applicative Functor Law #1.

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`

```
import Control.Applicative

main = do
        a <- (++) <$> getLine <*> getLine
        putStrLn a
```

`liftA2`

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`

```
> (:) <$> Just 3 <*> Just [4]
Just [3, 4]
> liftA2 (:) (Just 3) (Just [4])
Just [3, 4]
```

Applicative Functor Definition

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)
```

Example: Implement `applyMaybe` that applies a function to a `Maybe`

```
applyMaybe :: Maybe a -> (a -> Maybe b)
             -> (Maybe b)

applyMaybe Nothing _ = Nothing
applyMaybe (Just x) f = Just (f x)
```

Chaining `applyMaybe`

```
> (Just 3) `applyMaybe` (\x -> Just (x*2))
           `applyMaybe` (\y -> Just (y-1))
Just 5

> (Just 3) `applyMaybe` (\_ -> Nothing)
           `applyMaybe` (\y -> Just (y-1))
Nothing
```

Additional Names for Monoids

- “Programmable Semicolons”
- “Applicative Functors you can chain.”

Monad Typeclass Definition

```
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
```

Example a Robot Moving Towards a Goal (Not Failure)

```
--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)
```

`Maybe` as an Instance of the Monad Typeclass

```
instance Monad Maybe where

     return = Just

     (>>=) Nothing  _ = Nothing
     (>>=) (Just x) f = f x

     fail _           = Nothing
```

Example a Robot Moving Towards a Goal (with Failure)

```
-- 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”

```
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"))
```

Integer Division with Bind with “do”

```
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"
```

Integer Division with Bind with “do” and return

```
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

```
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.

Example Use of `List` as a Monad

```
listOfTuples :: [(Int, Char)]
listOfTuples = do
                   n <- [1, 2]
                   ch <- ['a', 'b']
                   return (n, ch)
> listOfTuples
[(1,'a'), (1,'b'), (2,'a'), (2, 'b')]
```

Combining a `Maybe` and a `List` Monad

```
> 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 popular type of LR parsers.
  - **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

```haskell
import Text.ParserCombinators.Parsec

num :: GenParser st String
num = many1 digit

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

```haskell
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 `<?>`

```haskell
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.

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

Verbose Approach

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

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

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

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

cellContent :: GenParser Char st String
cellContent = many $ noneOf “,\n” -- Two characters

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

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

Concise Approach

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

csvFile = line `sepBy` eol

line = cell `sepBy` string ","

cell = many (noneOf "\n")

eol = try (string "\n\r") -- Try more complex case first
   <|> string "\n"
   <?> "end of line"

main = do
       args <- getArgs
       p <- parseFromFile csvFile (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
7
> 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.

Functor Definitions

Lists

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

Maybe

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

IO

```
instance Functor IO where
  fmap f a = do
             x <- a
             return (f x)
```

Applicative Functor Definitions

Lists

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

Maybe

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

IO

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

Monad Definitions

Lists

```
instance Monad [] where
 return x = [x]
 (>>=) xs f = concat $ map f x
 fail  _   = []
```

Maybe

```
instance Monad Maybe where
  return x  = Just x
  (>>=) Nothing  _ = Nothing
  (>>=) (Just x) f = f x
  fail  _    = Nothing
```

IO

```
instance Monad IO where
   (>>=) a f = do
               x <- a
               f x
   fail s = ioerror (userError s)
```

Lecture #12 – Introduction to JavaScript

JavaScript

- Developed at Netscape by Brendan Eichs in 10 days
- Originally named "Mocha"
- Syntax similar to Java

Multi-paradigm JavaScript

Supported programming paradigms:

- Imperative
- Functional
- Object-Oriented (**through prototypes**)

Where JavaScript is Run

- **Client Side Versions**
    - Runs on user machine
- **Server-side Versions**
    - JVM: **Rhino** & **Nashorn**
    - **Node.js**

Example: Imperative JavaScript

```
function addList(list){
  var = i, sum = 0;
  for( i = 0; i < list.length ; i++){
    sum += list[i];
  }
  return sum;
}
```

Example: Functional JavaScript

```
function addList(list){
  if(list.length == 0){
    return 0;
  }

  return list[0]
        + addList(list.slice(1));
}
```

`slice(begin[, end])` – Takes a subset of an array from the "`begin`" index to the "`end`" (exclusive). If no "`end`" is specified, it takes all elements to the end of the list.

Example: Object-Oriented JavaScript

```
function Adder(amount){
  this.amount = amount;
}
Adder.prototype.add = function(x){
                   return this.amount + x;
              }
var myAdder = new Adder(1)
var y = myAdder.add(7)
```

`Adder` – Name of a new constructor. **Convention is to start constructors with a capital letter**.

`this` – Not optional in JavaScript.

Example: Quirks of JavaScript

```
var x = 42; // Create with var
y = 7; // No error without var
function add(a, b){
  return a + b;
}
function noReturnAdd(a, b){
  a + b;
}

// c is "undefined" since no return
var c = noReturnAdd(x, y)

//Lambda Function
var myLambda = function(x){return x * x;}
```

Printing to the Console in JavaScript

- **Standard Approach:**

  `console.log("…")`

    - Not supported by all implementations.
- JVM-based JavaScript Approach: `print`
- Solution to Support a Single Interface: `var print = console.log`

Closures

- Functions whose inner variables refer to independent (free) variables.

Example: Closure in JavaScript

```
var getNextInt = function (){
  var nextInt = 0;
  return function(){
           return nextInt++;
       }
}(); // Double paren to run the func
console.log(getNextInt()); // print "0"
console.log(getNextInt()); // print "1"
console.log(getNextInt()); // print "2"
```

Node.js

- JavaScript runtime environment and library **designed to run outside the browser**.
- Based off Google's V8 engine.
- `npm` – Package manager to get new packages.

Callback Function

- Functions in JavaScript are first class objects of type "Object".
- Not executed immediately.

JavaScript supports both "`null`" and "`undefined`"

Reading from a File with Callbacks in Node.js

```
var fs = require('fs')
fs.readFile('myFile.txt',
    function(err, data){
      if(err)
        throw err;
      else
        console.log("" + data);
    }
}
console.log("All done")
```

"`All done`" prints before the file contents due to callbacks.

`require` – Includes the JavaScript package "`fs`"

Synchronous File IO in Node

```
var fs = require('fs')
var data =
fs.readFileSync('myFile.txt');
console.log("All done")
```

To eliminate callbacks, most function names can be appended with "`Sync`"

Undeclared Object Fields

Any undeclared object fields or uninstantiated variables are undefined.

```
var y; // Uninstantiated

// Both print 'undefined'
console.log(y)
console.log(myDog.name)
```

Creating a JavaScript Object

```
var myDog = {age : 3,
             weight: 100}
```

Every object is a map.

Adding a Field to a JavaScript Object

```
myDog['height'] = 45 // Add a new height field
                     // Note the single quotes
```

Adding a Function to a JavaScript Object's Prototype

```
myDog.speak = function(){ console.log("Grr"); }
```

Delete a Function from a JavaScript Object's Prototype

```
delete myDog.speak
```

Prototypes

Object Prototypes

JavaScript prototypes are just like any other object.

```
var dogPrototype = {
    speak: function(){
      console.log("bark!");
    }
}
```

Defining an Object's Prototype

```
var rex = { name: "Rex",
            __proto__ : dogPrototype}
```

Prototypical Inheritance: If an object does not have a method of field, JavaScript looks to the object's `__proto__` object.

Add a Special “speak” Method to Rex

```
rex.speak = function(){
                console.log(“Grr”);
            };
rex.speak(); // Prints “Grr”

delete rex.speak;
// Prints “Bark!” from __proto__
rex.speak();

delete rex.speak; // Does nothing
rex.speak(); // Prints “Bark!”
```

Unspecified Function Arguments: In JavaScript, any unspecified function argument **defaults to** “**undefined**”.

Effect of the “new” Keyword

```
function Cat(name, breed){
  var this = {}; // Add when new is used
  this.prototype = Cat.prototype; // Also comes from new
  this.name = name;
  this.breed = breed;
  this.speak = function(){console.log("meow");};
  return this; // Also comes from new
}
```

No “return” in a Function

```
function noReturnAdd(x, y){
  x + y; // without "return"
}

// c is “undefined” since no return
var c = noReturnAdd(x, y)
console.log(c); // Prints "undefined"
```

Top Prototypes

`Object.prototype` – Top of all object prototypes

`Function.prototype` – Top of all function prototypes.

Iterating Using “forEach”

```
var arr = [1, 2, 3];
// Print each element in array
arr.forEach(function(val){
             console.log(val);
           });
```

Note: This uses parentheses not curly brackets.

require

- Used to **import an external module** in **Node.js**
- Can be stored in a variable. **Example**:

```
var net = require('net');
```

Running from the Command Line

- Use the keyword “`node`” for Node.js. **Example**:

```
$ node my_program.js
```

Example: Create an Object with a Factory Method

```
var Droid = {
  speak: function() {
            console.log("I am "
                        + this.name);
         },
  create: function(name) {
            var clone = Object.create(this);
            clone.name = name;
            return clone;
         }
};
```

Example: Currying in JavaScript

```
Function.prototype.curry = function(){
  // Take slice from the Array class' prototype
  var slice = Array.prototype.slice;
  // Convert arguments to an array
  var args = slice.apply(arguments);
  var that = this;
  return function(){
    return that.apply(null,
                      args.concat(slice.apply(arguments));
  };
};
function add(x, y){
  return x + y;
}
var addOne = add.curry(1);
console.log(addOne(3)); // Prints "4"
```

Lecture #13 – Lambda Calculus

Expressions

```
e ::= x        (Variables, immutable)
    | λ x.e    (Lambda abstraction)
    | e e      (Function application)
```

Note: Lambda (λ) is simply a function.

```
v ::= (λ x.e)    (Lambda abstraction)
```

Function Application

Given a function where `E` is a **complex expression**:

$$\lambda(x.E)v$$

Then:

$$\lambda(x.E)v \rightarrow E[x \vdash> v]$$

Hence, “v” replaces “x” in “E”.

Lambda Calculus is a simple, Turing complete language. Hence it is equal in power to a Turing Machine.

Lambda calculus stops evaluating when the result is in **normal form**.

Small-Step Evaluation Order Rules for Lambda Calculus

Rule: SS-E1	**Rule: SS-E2**	**Rule: SS-Lambda Context**	**Optional Rule: Lazy SS-Lambda Context**
$\dfrac{e_1 \rightarrow e_1'}{e_1\ e_2 \rightarrow e_1'\ e_2}$	$\dfrac{e_2 \rightarrow e_2'}{(\lambda x.e)\ e_2 \rightarrow (\lambda x.e)\ e_2{}'}$	$(\lambda x.e)\ v \rightarrow e[x \vdash> v]$	$(\lambda x.e)\ e_2 \rightarrow e[x \vdash> e_2]$

Evaluation Strategies

Strict Evaluation Strategies		Lazy Evaluation Strategies	
Call by Value: Pass a **copy** of a parameter	**Call by Reference: Implicit reference** (e.g., pointer) to the parameter is passed.	**Call By Name: Re-evaluate the argument each time** it is used.	**Call by Need: Memoizes parameter value** after first use.

Language Equivalents of $(\lambda x.e)$		True and False in Lambda Calculus	
JavaScript: `function(x){return e;}`	**Haskell:** `(\x -> e)`	**True in Lambda Calculus:** $getFirstParam = tru = (\lambda x.\lambda y.x)$ **Note:** This returns the ***first*** parameter in the pair of values.	**True in Lambda Calculus:** $getSecondParam = fls = (\lambda x.\lambda y.y)$ **Note:** This returns the ***second*** parameter in the pair of values.

Conditional in Lambda Calculus

$$test = \lambda cond\,.\ \lambda then\,.\ \lambda els.(cond\ then\ els)$$

Example #1:

$$test(tru\ tru\ fls)$$

$$\lambda cond\,.\ \lambda then\,.\ \lambda els.(cond\ then\ els)(tru\ tru\ fls)$$

$$\lambda then\,.\ \lambda els.(tru\ then\ els)(tru\ fls)$$

$$\lambda els.(tru\ tru\ els)(fls)$$

$$(tru\ tru\ fls)$$

$$(\lambda x.\lambda y.x)(tru\ fls)$$

$$(\lambda y.tru)(fls)$$

$$tru$$

Example #2:

$$test(fls\ tru\ fls)$$

$$\lambda cond\,.\ \lambda then\,.\ \lambda els.(cond\ then\ els)(fls\ tru\ fls)$$

$$\lambda then\,.\ \lambda els.(fls\ then\ els)(tru\ fls)$$

$$\lambda els.(fls\ tru\ els)(fls)$$

$$(fls\ tru\ fls)$$

$$\lambda x.\lambda y.y\ (tru\ fls)$$

$$\lambda y.y\ (fls)$$

$$fls$$

Boolean And

$$andd = \lambda b.\lambda c.(b\ c\ fls)$$

Pair

$$pair = \lambda f.\lambda s.\lambda b.(b\ f\ s)$$

Pair – A tuple-like data structure in Lambda Calculus.

Working with a Pair in Lambda Calculus

First Element in a Pair

$$first = \lambda p.(p\ tru)$$

Second Element in a Pair

$$second = \lambda p.(p\ fls)$$

Note #1: In the case of both $first$ and $second$, the term p must be a pair.

Note #2: Both of these rely on the tru or fls being substituted for the “b” in the $pair$ data structure in term selecting either the first or second element.

Church Encoding Numerals $zero = \lambda s.\lambda z.z$ $one = \lambda s.\lambda z.s\ z$ $two = \lambda s.\lambda z.s\ s\ z$ $three = \lambda s.\lambda z.s\ s\ s\ z$	**Successor Function** $scc = \lambda n.\lambda s.\lambda z.s(n\ z)$ **Example:** $one' = scc\ zero$ $two' = scc\ one' = scc(scc\ zero)$	**Plus in Lambda Calculus** $plus = \lambda m.\ \lambda n\ (\lambda s.\ \lambda z\ .\ m\ s\ (n\ s\ z))$ **Example:** Use church encoding numerals $plus\ three\ two \rightarrow^{*} \lambda s.\ \lambda z\ .(three\ s\ (two\ s\ z))$

Omega – Infinite Loop $Omega = (\lambda x\ .x\ x)\ (\lambda x\ .x\ x)$	**Fix Combinator** $fix = \lambda f.(\lambda x.f(\lambda y.x\ x\ y))\ (\lambda x.f(\lambda y.x\ x\ y))$ **Note:** Can be used to do factorial operations. **Usage:** $fix(g\ x) = g((fix\ g)x)$	

Lecture #14 – JavaScript Scoping

Example: First Class Function

```
function makeAdder(x){
  return function(y){
          return x + y;
        };
}
var addOne = makeAdder(1);
// Prints "11"
console.log(addOne(10));
```

Example: Function Application

```
function makeAdderList(arr){
  var i;
  var output = [];
  for(i  = 0; i < output.length; i++){
    // Need to create a new scope
    function(){
      // Can add to arr without append
      output[i] = function(y){
                     return arr[i] + y;
                   };
    }
  }
}
```

JavaScript lacks block scope for the closure to be right, must create the function inside another function.

Block Scope – The scope (i.e. visibility) of a variable is limited to a specific block (e.g., `for` loop, `if` statement, etc.).

- Unlike most languages, JavaScript does not have block scope.
- **To create a new scope, use an anonymous function.**

Variable Hoisting – All variable declarations (i.e., use of "`var`") are treated as if they are at the beginning of the function.

"`this`" in JavaScript

`this` – Refers to the scope where the function is called.

- **In Normal Function Calls** – `this` refers to the global "`this`"
- **Object Methods** – The object itself.
- **Constructor (using "`new`")** – The newly created object.
- **Exceptions: `apply`**, `call`, and `bind`. Inline event handles on DOM elements

Any time a new function is created, the other "this" is no longer in scope

Execution Context

Consists of three part:

- **A Variable Object** – **Container for variables and functions.**
- **Scope Chain** – Variable object plus **parent scopes**
- **Context Object** – `this`

Global Context

- **Top Level Context**
- Variable object is known as the "**global object**"
- `this` – Refers to the global object.

Any variable declared without `var` is added to the global context.

Function Contexts

- **Activation** or **Variable Objects** which include:
  - **Arguments passed to the function**
  - **A special arguments object**
  - **Local variables**

`apply`, `bind`, `call` Example

```
x = 3;
function foo(y) {
   console.log(this.x + y);
}
foo(100); // Prints "103"

// Array passed for args
foo.apply(null, [100]);
// Update the context
foo.apply({x:4}, [100]);

// No array needed
foo.call({x:4}, 100);

// Create a new function
var bf = foo.bind({x:5});
bf(100);
```

- `apply` – Calls a function with the arguments passed as an array.
- `call` – Calls a function with the arguments passed in comma separated.
- `bind` – Used to create a new function with a custom context.

Lecture #14.5 – JSLint and TypeScript

Issues in JavaScript

- No block scope
- Forgetting `var` can lead to unexpected behavior since variables become global.
- Operator “==” is not transitive.
- Switch/case statements require “`break`”

JavaScript Automatically Inserts Semicolons

```
function makeObject() {
  return // Semicolon inserted here
  {
    madeBy: 'Austin Tech. Sys.'
  }
}
var o = makeObject();
console.log(o.madeBy); // error
```

Function "`parseInt`" can Yield Unexpected Results

```
// Drops the " tons"
console.log("what do you get? "
            + parseInt("16 tons"));

// Prints just "1" due to the "Oh"
parseInt("1O1");
```

Behavior of "`typeOf`"

`typeOf` – Returns a string. May yield unexpected results.

```
typeOf 5 // "number”
typeOf “hi” // “string”

typeOf NaN // “number”

typeOf null // “object”
```

Behavior of "`typeOfChar`"

`typeChar` – Returns a string. Classifies letters as “digits”.

```
typeOfChar "5" // “digit”

typeOfChar "q" // “digit”

// "Other character"
typeOfChar " "
```

JSLint

- A tool to write cleaner and safer JavaScript.
- Requires that `"use strict";` (with quotes and followed by semicolon) be added at the beginning of all functions.
- Performs static code analysis.
- **Helps catch common programming errors by requiring:**
  - Variables declared before they are used.
  - Semicolons are always used.
  - Double equals never used.
- Inspired by the “lint” tool from C

Benefits of Type Systems

- Tips for compilers
- Hints for IDEs
- Enforced documentation
- Prevent code with errors from running.

TypeScript

- Developed by Microsoft
- Static type checker for JavaScript.
- A new “superset” language of JavaScript with:
  - Type annotations
  - Classes
- Compiles to JavaScript

Function Type Annotations in TypeScript

```
function greet(person: string){
  console.log("Hello "
              + person);
}
var user : string = "Vlad";

// Prints "Hello Vlad”
greet(user);
```

Types in TypeScript

- `number` (`var pi : number = 3.14`)
- `boolean` (`var b : boolean = true`)
- `string` (`var greet : string = "hi"`)
- `array` (`var lst : number[] = [1, 2]`)
- `enum`
- `any` (`var a : any = 3; var b : any = "hi"`)
- `void`

TypeScript Class

```
class Employee{
  name : string;
  salary : number;

  constructor(name : string, salary : number){
    this.name = name;
    this.salary = salary;
  }
  display(){ console.log(this.name); }
}

var emp = new Employee('Jon', 50000);
emp.display();
```

TypeScript Function Example

```
function swap(arr : number[], i : number,
              j : number) {
  var tmp : number;
  tmp = arr[i]; arr[i] = arr[j]; arr[j] = tmp;
}
function sortAndGetLargest (arr : number[]) {
  var tmp : number;
  var i : number;
  var j : number;
  tmp = arr[0]; // largest elem
  for (i=0; i<arr.length; i++) {
    if (arr[i] > tmp) tmp = arr[i];
    for (j=i+1; j<arr.length; j++)
    if (arr[i] < arr[j]) swap(arr,i,j);
  }
  return tmp;
}
var largest = sortAndGetLargest([99,2,43,8,0,21]);
console.log(largest); // Prints 99
```

JSLint Requirements

- `++` - This should be replaced with “+= 1”
- `var` – Each var declaration should be on its own line and must be at the top of the function/file.
- Single line `if` and `for` statements still need curly brackets.

Lecture #15 – Event-Based Programming and Cryptocurrencies

JavaScript Embedded in HTML

Create a button on a website that prints “Hello” when clicked. **Inline event handlers are considered bad practice**.

```
<html>
  <input
    type='button'
    onclick='alert("Hello");'
    value='Say hi' />
</html>
```

Improved JavaScript in HTML

Give buttons an “`id`” and update its “`onclick`” method

```
<html>
  <input id='thebutton'
    type='button'
    value='Say hi' />

  <script type="text/javascript">
    var btn = document.
                   getElementById('thebutton');
    btn.onclick = function() {
                   alert('Groovy');
               };
  </script>
</html>
```

Adding an Event Listener

- If clicking a button should perform multiple functions, then an event listener should be used.

```
function sayGroovy(){
  console.log("Groovy");
}

// Add an "onclick" event listener
btn.addEventListener('click',
                     sayGroovy);

// Add another event listener
btn.addEventListener('click’,
          function(){
             console.log("Bogus”);
          });
```

Removing an Event Listener

- Event listeners can be **removed by function name**. **Example**:

```
btn.removeEventListener('click’,
                        sayGroovy);
```

Events in JavaScript

- **JavaScript is single threaded**.

An event must run to completion before the next event handler can run.

Event Emitter

- Import the “events” module using the syntax

```
         var ee =
  require('events').EventEmitter;
```

- Used to create event via the keyword “**on**”. **Example**:

```
ee.on('die', function(){
            console.log("Died");
         });
```

- Invoking (emitting) an event using the keyword “emit” **Example**:

```
setTimeout( function(){
             ee.emit('die');
           }, 100); // in ms
```

Create a TCP Server in Node.js Using Event Listeners

```
var net = require('net');
var eol = require('os').EOL;
var srvr = net.createServer();

// Add an event listener
srvr.on('connection', function(client) {
  client.write('Hello there!' + eol);
  client.end();
});
srvr.listen(9000);
```

`telnet` – Used to connect to a TCP server on the command line.

`127.0.0.1` – IP address of localhost

Cryptocurrencies

Types of Keys

- **Private Key**: Known only by the *owner*
- **Public Key**: Known by everyone

Digital Signature

- **Non-Repudiation** – **Involves associating actions or changes to a unique individual**.
  - **Solution in Cryptocurrency:** Digital signature.
- **Procedure:**
  - **Step #1**: Owner encrypts the message with his private key
  - **Step #2**: Use the public key to decrypt the message.
- **Analogy:** Enclosed Bulletin Board

Private Key Encryption

Used to transmit sensitive data to a specific recipient.

- **Procedure**:
  - **Step #1**: A user encrypts his data using the recipient’s public key.
  - **Step #2**: The intended recipient decrypts the data using his private key.
- **Analogy:** A public mailbox. Anyone can put letters in, but only the mailman has the key to open the box.

- `update` – Used to update the signature with the specified message contents. Each signature object can only be updated once.
- `hex` – Specifies that the output should be in hexadecimal format.
- `Sync` – Ensures that the file read is done immediately without relying on a callback.
- `SHA` – “Secure Hash Algorithm”
- `RSA` – Signature algorithm

Example: JavaScript Signer Example

```
var crypto = require('crypto');
var fs = require('fs');

// Constructor for a "Signer" object
function Signer(privKeyFile){
  this.privKey = fs.readFileSync(privKeyFile).toString('ascii');
}

// Add a "signMessage" function to the Signer prototype
Signer.prototype.signMessage = function(msgFileName){
    var msg = fs.readFileSync(msgFileName).toString('ascii');
    var sign = crypto.createSign('RSA-SHA256');

    return sign.update(msg).sign(this.privKey, 'hex');
}
```

Double Spending – **Spend the same funds in multiple places**.

Solutions to Prevent Double Spending:

- **Centralized Authority** – Disadvantages include that the central authority would charge a fee and not everyone trusts central authorities.
- **Decentralized Authority** – Broadcast transactions to everyone.

Ledger – Used to keep a **history of all transactions** and the funds held by all users.

Example: **JavaScript Verifier Example**

```
var crypto = require('crypto');
var fs = require('fs');

// Constructor for a "Verifier" object
function Verifier(publicKeyFile){
  this.publicKey = fs.readFileSync(privKeyFile).toString('ascii');
}

// Add a "verifySignature" function to the Verifier prototype
Verifier.prototype.verifySignature = function(msgFileName, signature){
    var msg = fs.readFileSync(msgFileName).toString('ascii');

    // Create a verifier
    var ver = crypto.createVerifier('RSA-SHA256').update(msg);

    // Verify signature matches the hash
    var legit = ver.verify(this.publicKey, signature, 'hex');
    return legit;
}
```

Bitcoin Mining

- **Block Chain** – Defines the transaction history.
  - **Used to prevent double spending.**

- **Proof of Work** – Verification of the block chain.

- Miners hash transaction details plus a "proof" (i.e. nonce)
  - **Reward**: New bitcoins are mined for the first to find a proof.

- **Cost to *Derive* a Proof:** 2^N where N is the number of the initial bits that must be "0" for the proof to be valid.
- **Cost to Verify a Proof:** A single hash

- Bitcoin protocol is designed to make mining more profitable than cheating.

Attributes of a Good Hash Function

Role of a Hash Function: Compress arbitrary length inputs to small, fixed length outputs.	**One Way:** Given an output "y", it is infeasible to find an "x" such that: $h(x) = y$	**Collision Resistant**: It is infeasible to find any "x" and "y" such that: $h(x) == h(y)$	**Compression**	**Efficient**

Lecture #16 – Typed Arith

Benefits of Type Systems

- Tips for **compilers to make code more efficient**.
- Tips for **IDEs and other tools to make writing code easier**.
- **Enforced documentation**.
- **Prevent code with errors from running**.

Typing Rules

Format:

`e : T`

Meaning: Expression e falls into one of two categories:

1. **`e` evaluates to a value of type `T`**
2. **Goes into an infinite loop**.

The Typed Arith Language

```
e ::= true
    | false
    | 0
    | succ e
    | pred e
    | iszero e
    | if e then e else e

v ::= true
    | false
    | nv
n ::= 0
    | succ nv

T ::= Bool
    | Int
```

Good and Bad Typing Systems

- **Good type systems** prevent “bad” programs from running.
- **Bad type systems** prevent valid programs from running.
- **Typchecking** – In an expression “typechecks”, the expression is either:
  - A value
  - An evaluation rule reduces the expression to a different expression.

Type Safety = Progress + Preservation

Progress

A well typed expression does not “get stuck”

Formal Definition: Given that `e:T`, then either:

1. `e` is a value
2. There exists an `e'` such that `e -> e'`

Preservation

A well-type expression will not change its type during evaluation.

Formal Definition: Given that `e:T` and `e -> e'`, then:

`e':T`

Lecture #17 – Macros and Sweet.js

Macros

- Short for "*macroinstruction*"
- Rule specifies how an **input sequence maps** to a **replacement sequence**.

Macros in C

- Performed by a *preprocessor*
- **Rely on text substitution**.
- Embedded languages like PHP, Ruby, etc. use a similar approach.

Example: C Preprocessor Example

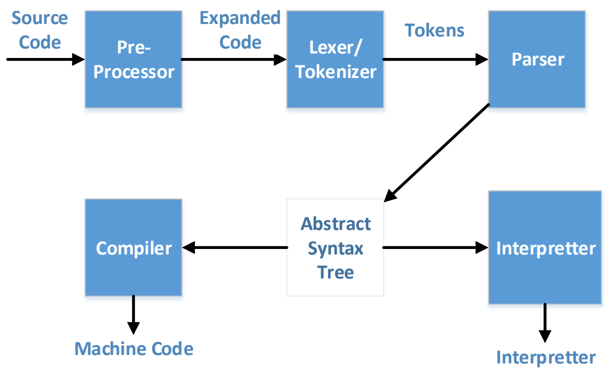
```
#define PI 3.14159
#define SWAP(a,b) {int tmp=a;a=b;b=tmp;}

int main(void){
  int x = 4, y=5, diam = 7;
  double circum = diam * PI;
  SWAP(x,y)
}
```

C Preprocessor Output

```
int main(void){
  int x = 4, y = 5, diam = 7;
  double circum = diam * 3.14159;
  {int tmp=x;x=y;y=tmp;}
}
```

Basic Compiler Structure with C-Style Macros



Problem with C Macros (Input)

```
// Macro should be on one line
#define SWAP(a,b) {int tmp=a;
                   a=b;
                   b=tmp;}

int main(void){
  int x = 4, tmp = 5;
  SWAP(x,tmp)
}
```

Problem with C Macros (Output)

```
int main(void){
  int x = 4, tmp = 5;
  { int tmp = x;
    a = tmp;
    tmp = tmp;
  }
}
```

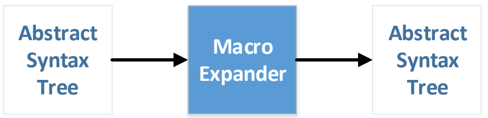
Hence, a **variable name collision** between the two variables named "`tmp`". This is known as "**inadvertent variable capture**"

Hygienic Macro – Any macro whose expansion is **guaranteed not to cause the accidental capture of identifiers**.

Syntactic Macros

- Derive from Lisp since Lisp programs are essentially one big AST.
- **Work at the level of abstract syntax trees**.
- Powerful by expensive.
- **Hygiene easier to address at the AST level**.
- Essentially a **source-to-source compiler**.

Basic Compiler Structure with Syntactic Macros



Macros in JavaScript

- **No standard macro system for JavaScript**
- Sweet.js has been gaining interest.
- Recently redesigned.

Sweet.js

- **Borrows concepts from Racket**.
- **Source-to-source compiler** (i.e., transpiler) for JavaScript.
- Examples of other JavaScript transpilers:
  - **TypeScript**
  - **CoffeeScript**
  - **Dart** (includes its own VM)
- Project backed by Mozilla

Invoking Sweet.js

- From command line:

```
$ sjs myfile.js -d out/
```

- Compiled files run normally (as shown below for Node):

```
$ node out/myfile.js
```

Writing a Swap Function in Sweet.js

```
syntax swap = function(ctx){
  let innerCtx = ctx.next().value.inner();
  let first = innerCtx.next().value;
  // Eat the comma
  innerCtx.next(); // No need for "value()"

  // Get the second parameter
  let second = innerCtx.next().value;
  return #`var tmp = ${first};
           ${first} = ${second};
           ${second} = tmp;`;
}
swap(a, b); // Invokes the macro
```

Note #1: The returned string is preceded by a pound (**#**) sign and is enclosed in backticks (`` ` ``).

Note #2: Sweet.js variables are declared with "`let`".

Concatenating Multiple Result Strings

This function squares a set of input variables.

```
syntax square = function(){
  var innerCtx = ctx.next().value.inner();
  // Start with empty results
  result = #``;
  while(let stx of innerCtx){
    result =
      result.concat(#`${stx}=${stx}*${stx};`);
    // Eat comma
    // Ignored if no comma present
    innerCtx.next();
  }
}
square(a, b, c); // Invokes the macro
```

Note #1: Use "`.concat`" to concatenate multiple result strings.

Note #1: If a token is not present, "`.next()`" does not cause an error.

Keywords in Sweet.js

- `let` – Create a Sweet.js variable.
- `ctx.next().value` – Get the next value from the context.
- `` #`...` `` - Used to define a result string.
- `concat` – Used to combine two result strings.
- `let xxx of yyy` – Iterate over a list of tokens.
- `isIndentifier` – Used to check if a Sweet.js variable matches some string.

Input JavaScript `class` Code to be Parsed by Sweet.js

```
class Droid{
  constructor(name, color){
    this.name = name;
    this.color = color;
  }

  rollWithIt(it){
    console.log(this.name + " is rolling "
                + "with " + it);
  }
}
```

A `class` in Sweet.js

```
syntax class = function(ctx){
  let className = ctx.next().value;
  let bodyCtx = ctx.next().value.inner();

  // By default assume empty constructor
  let construct = #`function() { }`;
  let result = #``;

  while( let item of bodyCtx ){

    // Check if constructor
    if(item.isIndenifier('constructor')){
      // Get arguments then function code
      construct = #`function ${className}
                    ${bodyCtx.next().value}
                    ${bodyCtx.next().value}`;
    }
    else {
      // Add the function to the class prototype
      result = result.concat(
          #`${className}.prototype.${item} =
              function ${bodyCtx.next.value}
              ${bodyCtx.next.value}`);
    }
    // Return the constructor and methods
    return construct.concat(result);
```

Lecture #18 – Simply Typed Lambda Calculus

The Typed Arith Language
(with Lamda Functions)

```
e ::= true
    | false
    | 0
    | succ e
    | pred e
    | iszero e
    | if e then e else e
    | λ x.e
    | e e
    | x

v ::= true
    | false
    | i
    | λ x.e

T ::= Bool
    | Int
    | T -> T
```

Options for Determining Function Type

1. **Type Inference**
2. **Require explicit type annotations**

Type Annotation

`λ x:T.e`

Note: `T` is the type of the argument "`x`"

Managing the Type of a Variable

- Use a **typing environment**.
  - **Maps variables to types**
  - Referred to using the Greek letter: Γ (gamma)
- **Typing rules must be defined in terms of the typing environment**.

Turnstile

- $\vdash$ - Used in revised typing relations to indicate that the typing rule is with respect to the specified typing environment (Γ)

Omega Combinator

Definition:

$$\text{Omega} = (\lambda x.\, x\, x)(\lambda x.\, x\, x)$$

Description: Results in an infinite loop since the combinator keeps returning itself. Omega **is a valid a valid program supported by untyped lambda calculus**.

Issue: If this expression is type checked, it enters an infinite type checking loop which causes it to fail

@ Symbol in Haskell

`@` – Allows the programmer to represent an entire expression using a shortened notation.

Example:

```
e @ (ESucc e1)
```

Arith Typing Rules Using a Typing Environment (Γ)

[T–True]

$$\Gamma \vdash \text{true}: \text{Bool}$$

[T–False]

$$\Gamma \vdash \text{false}: \text{Bool}$$

[T–succ]

$$\frac{\Gamma \vdash \text{e}: \text{Int}}{\Gamma \vdash \text{succ e}: \text{Int}}$$

[T–pred]

$$\frac{\Gamma \vdash \text{e}: \text{Int}}{\Gamma \vdash \text{pred e}: \text{Int}}$$

[T–iszero]

$$\frac{\Gamma \vdash \text{e}: \text{Int}}{\Gamma \vdash \text{iszero e}: \text{Bool}}$$

[T-If]

$$\frac{\Gamma \vdash e_1: \text{Bool},\ \Gamma \vdash e_2: T,\ \Gamma \vdash e_3: T}{\Gamma \vdash \text{if } (e_1) \text{ then } (e_2) \text{ else } (e_3) : T}$$

[T-FunctionApplication]

$$\frac{\Gamma \vdash e_1: T_1 \rightarrow T_2,\ \Gamma \vdash e_2: T_1}{\Gamma \vdash e_1\ e_2 : T_2}$$

Note: e_1 is a function while e_2 is a parameter.

[T-LambdaVariable]

$$\frac{x: T \in \Gamma}{\Gamma \vdash x : T}$$

[T-LambdaContext]

$$\frac{\Gamma \vdash x: T_1,\ \Gamma \vdash e: T_2}{\Gamma \vdash \lambda\, x.\ e : T_1 \rightarrow T_2}$$

Lecture #19 – Metaprogramming and JS Proxies

Metaprogramming: Writing programs that manipulate other programs.

- Proposed in ECMAScript 6 for JavaScript.

Terminology in Reflection

- **Introspection:** Ability to examine (but not modify) the structure of a program.
- **Self-modification**: Ability to modify the structure of a program.

Introspection

Ability to **examine** (but not modify) **the structure of a program**.

JavaScript Examples

Property Lookup

```
"x" in o; //o is an object
```

Iterate Over All Properties of an Object

```
for( prop in o ){
  // Do something
  ...
}
```

Self-modification

Ability to **modify the structure of a program**.

JavaScript Examples

```
o["x"]; // Computed property
o.y = 42; // Add new property
delete o.y; // Delete property

// Reflected method call
o["m"].apply(null, [38]);
```

Proxies in JavaScript

- **Metacircular Interpretation** – The language is able to understand its own language.
- Until recently, JavaScript did not support intercession.
  - Javascript proxies are intended to fix that.
- **Node.js' implementation of proxies lags behind the standard**.
- **Proxies only exist for objects and functions**.
  - **Proxies do not exist for primitives**.

Proxies and Common Lisp

- Lisp was developed before object oriented languages were popular.
- Many libraries were created with non-standard OO systems.
- **Common Lisp Object System** (**CLOS**) – Standard object oriented system for Lisp.

Achieving Lisp Object Backwards Compatibility

Option #1: Rewrite all libraries using CLOS.
Disadvantages:

- Huge number of libraries.
- Not feasible to rewrite them all.

Option #2: Make a complex API.
Disadvantages:

- API difficult to understand.
- Systems had conflicting features.

Option #3: Keep API simple and modify object behavior to fit different systems.

- This approach relies on **metaobject protocols**.

Proxies and Handlers

- The behavior of a proxy is determined by **traps** specified in its **handler** (i.e., the **metaobject**).
- **Trap** – **Methods that intercept an operation**.
- **Handler** – The metaobject that **specifies the details of the trap**. The handler itself is **usually a normal object**.
- Using proxies in node requires a special flag: "`--harmony-proxies`". **Example:**

```
$ node --harmony-proxies prog.js
```

Kinds of JavaScript Proxies

- **Object Proxies** – Defined with:

```
Proxy.create(handler, proto)
```

- **Functions** (with extra traps) - Defined with:

```
Proxy.createFunction(handler,
                      callTrap,
                  constructTrap)
```

- **Proxies do not exist for primitives.**

A Simple Proxy

```
var MyHandler = {
  get:function(myProxy, name){
    console.log(name
          + " accessed");
    return 1;
  }
}

var p = Proxy.create(MyHandler);
// Prints "hello accessed.”
var q = p.hello;

// Prints "1"
console.log(q);

// Error since no "set" handler
p.name = "Me";
```

Read Only Handler

- **Information Control** – Share a reference to an object, but do allow it to be modified.
  - **Example**: Reference to the DOM.

```
function ReadOnlyHandler(obj){
  delete : function(name){
    return obj[name];
  }
  // rcvr can be ignored
  set : function(rcvr, name, val){
    return true;
  }
}
```

A No-op Proxy – All Operations Passed through Unchanged

```
function handlerMaker(obj){
  // Delete a property from an object
  delete : function(name){ return obj[name]; },

  // Check if object has the specified property
  has: function(name){ return name in obj;},

  // Check if object (not prototype chain) has property
  hasOwn : function(name){return Object.property
                                      .hasOwn(obj, name);},

  // Get a property value
  get : function(name){ return obj[name]; },

  // Set a property value
  set : function(rcvr, name, val){ obj[name] = val; },


  // Get all properties of an object
  enumerate : function(){
    var props = [];
    var prop;
    for(prop in obj){ props.push(prop); }
    return props;
  },

  // Get all of the keys of an object
  keys: function(){ return Object.keys(obj); }
}
```

Aspect Oriented Programming

- **Some code not well organized into objects**. Example:
  - **Cross-cutting concern** where code is spread throughout a program.
- **Canonical Example:** Logging Statements
  - **Littered throughout the code**
  - **Swapping out a logger requires massive code changes**.
- **Solution:** Use a proxy

Lecture #20 – Introduction to Ruby

Influences of Ruby

- **SmallTalk**
  - Everything is an object
  - Blocks
  - Metaprogramming
- **Perl**
  - Regular Expressions
  - Function names

Ruby on Rails

- "Killer" app for Ruby
  - **Lightweight web framework**
  - "**Convention over configuration**" – If use standard configuration, very little configuration required.
- Initial framework was PHP, but that was abandoned.

Basic Ruby Syntax

```
puts "Hello World"

a = [1, 2, 3]
m = { 'a' => "Apple",
      'b' => "Bear",
      'c' => "Cat" }

# Prints "1"
puts a[0]

# Prints "Apple"
puts m['a']
```

Keywords

`@` - Represents an object property

Returning From a Function

- **Every function in Ruby returns a value**, even if return is not used.
- If no return is specified, a function returns the last used value.

Basic Ruby Class

```
class Person
  # Constructor
  def initialize name # Parameter
    # Attribute
    @name = name
  end
  # Getter
  def name
    return @name
  end
  # Setter
  def name = newName
    @name = name
  end
  # Method
  def say_hi
    puts "Hi my name is #{@name}"
  end
end
```

Using Metaprogramming for Getters and Setters

```
class Person
  # Replaces getters and setters
  # Uses metaprogramming
  attr_accessor :name
  # Constructor
  def initialize name
    # Attribute
    @name = name
  End

  # Method
  def say_hi
    puts "Hi my name is #{@name}"
  end
end
```

Using a Class in Ruby

```
p = Person.new "Joe"

puts "Name is #{p.name}"

p.say_hi
```

`#{...}` – Embeds a variable in a Ruby String

Getters and Setters the Ruby Way

Relies on metaprogramming

- `attr_reader` – Getter only
- `attr_writer`- Setter only
- `attr_accessor` – Getter and setter

Reopening a Class in Ruby

- **Class definitions can be changed during runtime** in Ruby.
- This is known as "reopening the class"

Inheritance in Ruby

Parent Class

```
class Dog
  # Parentheses optional
  def initialize(name)
    @name = name
  end
  def speak
    puts "#{@name} says bark"
  end
end
```

Child Class

```
class GuardDog < Dog
  attr_accessor :breed
  def initialize(name, breed)
    # Use parent constructor
    super(name)
    @breed = breed
  end
  def attack
    puts "Grrr"
  end
end
```

`Note:` Inheritance is doing **using the less than** (**<**) operator.

Mixin

- Add features to a class
- **Similar to interfaces in Java** with the exception that they **can include functionality**.
- `module` – Keyword to define a Mixin.
- `include` – Keyword to include a Mixin into a class.

Blocks in Ruby

- **Superficially similar to blocks in other languages**.
- Create custom control structures.
- **Can be represented with curly brackets** (`{…}`) or `do`/`end`.

File IO without Blocks

```
file = File.open('test.txt','r')
file.each_line do |line|
  puts line
end
file.close
```

Note #1: Contains "boilerplate" code of open and closing the file.

Note #2: It is possible one **may forget to the close the file**.

File IO with Blocks

```
File.open('test.txt','r') do |file|
  file.each_line { |line|
    puts line
  }
end
```

Note #1: Eliminates the "boilerplate" code.

Note #2: When using a block (both `do`/`end`, and **curly brackets**), **surround the variable names in pipes** (`|`).

Example: Mixin

```
# Define the mixin
module RevString
  def to_rev_s
    # Object is implicit
    to_s.reverse
  end
end

# Reopen the Person Class
class Person include RevSting
  def to_s
    # Returns the value
    @name
  end
end
```

Dynamic Code Evaluation (`eval`)

- **Executes source code dynamically**
    - Code passed as either a string (or a block of code)
- **Popular feature in JavaScript**
    - Early usage was to convert JSON strings to variables since not supported by JavaScript.
- **Source of security concerns**.

Additional Ruby `eval` Methods

- `instance_eval` – Evaluates code within an object's body.
    - **Access the internals of an object**.
- `class_eval` – Evaluates code within a class' body.
    - **Modifies the class' definition**.
- Takes either a string or block of code. Block of code is more secure.

Example: Use `instance_eval` to Change an Object's Value

```
# Create with the name Bob
bob = Person.new “Bob”

# Change his name
bob.instance_eval do
  @name = "Steve"
end

# Prints "Steve"
puts bob.name
```

Regular Expressions in Ruby

- `sub` – Replaces the first instance of a string match.
    - **To perform the modification in place, must include** an **exclamation point** (**!**) after sub.
- `gsub` – Replaces all instance of a string match.
    - **To perform the modification in place, must include** an **exclamation point** (**!**) after sub.

Example: `class_eval` in Ruby

```
# Applies to all classes
class Class
  # Simulate the "attr_accessor" function
  def my_attr_accessor(args)
    args.each do |prop|
      # Create getter
      self.class_eval("def #{prop};
                          return @#{prop};
                        end”)
      # Create setter
      self.class_eval("def #{prop} = v;
                          @#{prop} = v;
                        end”)

    end
  end
end
# Use the new attribute
class Musician
  my_attr_accessor :name, :genre
end

m = Musician.new
m.name = "Bob Marley"
puts m.name # Prints "Bob Marley"
```

Example: Using Regular Expressions in Ruby

```
s = "Hi, I'm Larry; this is my" +
    " brother Darryl, and this" +
    " is my other brother Darryl."
s.sub(/Larry/,'Laurent')

# Prints s unchanged
puts s

# Changes first "Larry" to "Laurent"
s.sub!(/Larry/,'Laurent')
puts s

# Prints first "brother" replaced with
# "frere". s is unchanged, bt it did
# return the modified string.
puts s.sub(/brother/, 'frère')

# Same as previous except all where
# changed when printing.
puts s.gsub(/brother/, 'frère')
```

Regular Expression Symbols in Ruby

`/./` - Any character except a newline	`/\w/` – Any word character: `[a-zA-Z0-9_]`	`/\d/` – Any digit character: `[0-9]`	`/\s/` – Any whitespace character: `[ \t\r\n\f]`
	`/\W/` – Any **non**-word character: `[^a-zA-Z0-9_]`	`/\D/` – Any **non**-digit character: `[^0-9]`	`/\S/`– Any **non**-whitespace character: `[^ \t\r\n\f]`
`*` – Zero or more times	`+` – One or more times	`?` – Zero or one time (optional)	

Important Syntax in Ruby

For Each Loop

```
object.each do |val|
  ...
end
```

Create a Mixin

```
module Name
  ...
end
```

Return from a Block

```
def block_name
   ...
   yield x
   ...
end
```

Single Line If Statement

```
x = 5
# Does nothing
x = 3 if (x > 10)
puts x # Prints "5"
```

Ranges

```
# Create list from 1 to 5
x = (1..5)
```

Note: Uses parentheses.

Run Ruby on Command Line

`irb` – Command line for Ruby similar to GHCi.

Use a Mixin in a Class

```
class MyClass
  include MixinName
  ...
end
```

Reference a Variable in a String

```
age = 30
x = “My age is #{age}”
```

Note: Surround variable name is `#{…}`

Access Command Line Arguments

```
ARGV[0]  #First argument
ARGV[1]  #Second argument
```

For Loop

```
for i in (0..5)
  puts i
end
```

Note: This loop runs 6 times since the range is inclusive.

Select Case

```
case x
  when y
    ...
  when z
    ...
  else
    ...
end
```

Lecture #21 – Blocks and Messages

Influence of Smalltalk on Ruby

- Everything is an object
- Blocks
- Message passing

Benefits of Blocks in Ruby

- Create custom control structures
- Eliminate boilerplate code.
- Ruby blocks are closures, but they are different than JavaScript blocks.

Example: `do_noisy` Block

```
def do_noisy
  puts "About to call block"
  yield # Calls block code
  puts “Just called block
end
```

Note: Called with a `do`/`end` or with curly brackets.

Example: Extend Array Class to Return Lowercase Version of Every Element

```
# Reopen the Array class
class Array
  def each_downcase
    self.each do |val|
      yield val.downcase
    end
  end
end
```

Example: Using the `each_downcase` Block

```
arr = ["Alpha","Beta",
       "So On"]
arr.each_downcase do |val|
  puts val
end
```

Example: Probabilistic Run Block

```
# Probabilistic Run Block
def with_prob(prob)
  yield if (Random.rand < prob)
end

with_prob 0.42 do
  puts "Prints 42% of time."
end
```

Example: Passing Code to a Block

```
def with_prob2(prob, &blk)
  blk.call if (Random.rand < prob)
end
```

`blk` – Block of code passed to the function.

Note #1: Argument name has an ampersand (&) before it.

Note #2: No ampersand is used when calling the block.

Example: Sharing Code Between Blocks

```
def half_the_time(prob, &blk)
  with_prob2(0.5, &blk)
end
```

Note: Need to pass argument to the function with the ampersand (&).

Example: `with_prob` in JavaScript

```
function with_prob(prob, f){
  if(Math.random() < prob){
    return f();
  }
}
```

Note: The JavaScript implementation relies on callbacks.

Example: Difference Between Ruby and JavaScript Blocks

Ruby

```
def coin_flip
  with_prob 0.5 do
    return "Heads”
  end
  return "Tails"
end
```

Note: This returns “Heads” half the time and “Tails” half the time.

- This is because a return in a Ruby block returns for the entire function.

JavaScript

```
function coin_flip(){
  with_prob(0.5, function(){
                 return "Heads";}
  return "Tails";
}
```

Note: This always returns “Tails”

- This is because even if “with_prob” runs, the return only occurs within the anonymous function.

Singleton Classes

- In Ruby, every object has its own singleton class.
- This class holds methods and fields unique to that object.
- This is different from Singleton Objects in design patterns.

Example: Adding a Property to a *Variable* in *JavaScript*

```
function Employee(name, salary){
  this.name = name;
  this.salary = salary;
}
var a = new Employee("Alice", 500);
var b = new Employee("Bob", 1000);

// Add a signing bonus to "Alice"
a.signingBonus = 2000;
```

Accessing Singleton Classes in Ruby

- To open an object's singleton class, use double less than symbols (“<<”).
- Code only added to the specific object being reference.

Example: Adding a Property to an *Object* in *Ruby*

```
class Employee
  attr_accessor :name,:salary
  def initialize(name, salary)
    @name = name
    @salary = salary
  end
  def to_s
    @name # No return required
  end
end

# Create the Objects
a = Employee.new("Alice", 500)
b = Employee.new("Bob", 1000)

# Access the singleton class of "a"
class << a
  def signing_bonus
    2000
  end
end
```

Example: **Using a Singleton Class to Create Static Methods**

```
# Add Static Methods to Employee Class
class Employee
  class << self
    def get_employee_by_name(name)
      @employee[name] # No return needed
    end
    # Called in constructor
    def add(emp)
      puts "Adding #{emp}"
      # Create map if not exist
      @employee = Hash.new unless @employee
      @employee[emp.name] = emp
    end
  end
end
```

Message Passing

- Represents **inter-object interaction**.

- **Sender Sends**:
  - **Method name**
  - Data: **Method parameters** (if any)

- **Receiver**:
  - **Processes the message**
  - (***Optionally***) **returns data**

- **Receiver may not understand the message**.

`method_missing`

- Method that is part of every class. Can by overridden.
  - **Smalltalk Name:** `doesNotUnderstand`
  - **Ruby Name:** `method_missing`

- Invoked whenever an unknown method is called.

Example: `missing_method` **in Ruby**

```
class Person
  attr_accessor :name
  def initialize(name)
    @name = name
  End
  # Called when method unknown
  def method_missing(m)
    puts "Didn't understand #{m}"
  end
end
```

Active Record and Message Passing

- Relational database tool in Ruby.

- Specify fields in the database to be extracted based off method names. **Example:**

```
Person.find_by_first_name "John"
```

Lecture #22 – Virtual Machines and Just-In Time Compilation

Virtual Machine Overview

- Code is compiled to bytecode
  - **Byte code is low level**
  - **Platform independent**
- The VM interprets the bytecode

Scheme

- Similar to an AST. Uses parentheses.
- Relies on a stack.

Supported VM Operations

- **PUSH** – Adds an argument to the stack
- **PRINT** – Pops an argument off the stack and prints it.
- **ADD** – Pops two elements off the stack, adds them, and places result on the stack.
- **SUB** – Similar to add but for subtraction. If "A" is on the top of the stack and "B" is below it, the result is B – A
- **MUL** – Similar to add but with multiplication.

Compilers vs. Interpreters vs. JIT

- **Compiler**
  - **Efficient execution**
- **Interpreter**
  - **Runtime flexibility**
- **JIT**
  - **Efficient execution with runtime flexibility.**

Just-In-Time Compliers

- Interpret code
- "**Hot**" (i.e., heavily-used) **sections** are **compiled at runtime**.
- **Advantages**
  - **Speed of compiled code**
  - **Flexibility of interpreter**
- **Disadvantages**
  - **Overhead of compiler and interpreter**
  - **Complex implementation**

Dynamic Recompilation

- JIT pursues aggressive optimizations
  - **Makes assumptions about the code**
  - **Guard conditions verify assumptions**
- **Unexpected cases are interpreted** (i.e., not compiled)
- **Can in some corner cases outperform static compilation**.

Types of JITs

- **Method Based** – Compile Methods
- **Trace Based** – Compile loops

How to Support JITs for a Language

- **Option #1:** Build your own JIT.
  - Study the latest techniques
  - Build large code bases to test.
  - Profile the code execution
- **Option #2:** Use someone else's Just-In-Time VM.

Final Exam Review Notes

Parsec

- Parser combinator in Haskell.

- **Example Question:** Write a grammar at the same level of complexity as the CSV parser.

JavaScript

- Prototype based language.
  - **Inherit from an object not from a class.**
  - Add properties and methods on the fly.

- **Closure** – By wrapping an inner function with an outer function, the inner function can encapsulate variables.
  - **Have a scope chain.**

Example: Write a Function that Toggles a Variable Each Time the Function is Called

Example #1: Use a Global

```
var b = true;
function flip(){
  if(b) b = false;
  else  b = true;
  return b;
}
```

Example #2: Use a Closure

```
var flip = function(){
  var b = true;
  return function(){
    if(b)  b = false;
    else   b = true;
    return b;
  };
}(); // Needed to call out function
```

JavaScript – Multiparadigm Language

- **Imperative**
- **Object Oriented**
- **Functional**
  - **Supports higher order functions** but **not purely functional** since not immutable.

JavaScript Scoping

- **No block scope**

- **Variable declaration hoisting to the top of the function.**

`this` in JavaScript

- In a **method**, this refers to the associated object.
- In a **non-method**, this refers to the global scope.
- **Constructor** (**with new**) – Refers to the object being created.
- **DOM for Event Listeners** – Refers to the DOM element.
- `apply`, `call`, `bind` – User can define what "`this`" refers to.

Scope Precedence in JavaScript

From highest to lowest precedence

1. **Variable object**
   a. **Arguments pass to the function**
   b. **Special `arguments` object**
   c. **Local variables**
2. **Scope Chain**
3. **Global object** (i.e., `this`)

Example: Scope Chain

```
function my_hello(){
  var x = 5;
  // Scope Chain
  function print_hello(){
    console.log("Hello " + x);
  }
  print_hello();
}

my_hello();
```

Quirks of JavaScript

- Semicolon insertion

- `typeOf`
  - `typeOf NaN` – Number
  - `typeOf null` – Object

- `==` Not Transitive
  - If `a == b` and `b == c`, it is not guaranteed that `a == c`

JSLint

- Designed to catch common JavaScript errors.

- Based off lint for the C language.

- Performs **static code analysis**

TypeScript

- Developed by Microsoft

- **Source-to-source compiler** (i.e., transpiler)

- **Compiles to JavaScript**

- **Provides type annotation and classes.**

Event Based Programming

- Relies on **listeners**
- **Events are placed into an event queue.**
- **No concurrency.**
- `emit` – Invokes an event
- `on` – Registers a listener
- **Client-Based Programming** – Often used in GUIs.

Metaprogramming

- **Reflection** – Two primary categories. **Both occur at runtime.**
  - **Introspection** – Examine program's execution at runtime.
  - **Self-modification** – Modify a program execution at runtime.

- **Intercession** – Trigger or control interaction at runtime.

- Reflection is more common, but intercession is more powerful.

Aspect-Oriented Programming

Designed to address cross-cutting code (i.e., code that is interspersed everywhere in a program.

Metaobject Protocols

- **Metaobject** – Any object that can reason about the behavior of other objects.
  - **Example:** Proxies

- **Handler**
  - Type of Meta Object.
  - **Defines traps.**

- **Trap** – Methods that intercept an operation.

Macros Sweet.js

- Source-to-source compiler (**transpiler**)

- **Hygiene** – **No inadvertent variable capture.**

- **Text Substitution Macro** – Works at the lexeme or text level.

- **Syntactic Macro** – Works at the Abstract Syntax Tree (AST) level.

Lambda Calculus

- **Simple, Touring complete language.**
- Based off anonymous functions (lambda)
- **Expressions:**

  $x \mid \lambda x\,.\,e \mid e\ e$

- **Values:**

  $\lambda x\,.\,e$

Evaluation Strategies

- **Strict Evaluation Strategies**
  - **Call by Value** – Pass a **copy** of the parameter.
  - **Call by Reference** – **Implicit reference** (e.g., a pointer to the parameter is passed.

- **Lazy Evaluation Strategies**
  - **Call by Name** – Re-evaluate the expression each time it is needed.
  - **Call by Need** – Evaluate when needed and memo-ize the result.

Advantages and Disadvantages of Type Systems

Benefits:

- Enforced documentation
- Tips for IDEs and Developers
- Prevent code with errors from running.

Disadvantage:

- May prevent valid code from running.

Simply-Type Lambda Calculus

- Relies on a **typing environment** (**Γ**)
- **Not Turing complete.**

Type Safety – Two Components

- **Progress** – Valid input continues to evaluation or reaches a value.

- **Preservation** – Evaluation does not change the type of an object.

Influences of Ruby

- **SmallTalk**
  - Everything is an object
  - Blocks
  - **Metaprogramming** – `method_missing` and message passing.

- **Perl**
  - Regular expressions
  - Names of functions.

Goals of Ruby

- Object oriented scripting language.

- Dynamically typed

- Interpreted.

Ruby Features

- `eval` – Execute a string as code.

- **Singleton Classes**
  - No relation to singleton objects
  - **Class for a single object.**
  - Can be used to create static methods in a class.

Virtual Machine	**Interpreters vs. Compilers**	**Just-In-Time Compiler**
• Source compiled to **byte code**. • **Byte code executed by an interpreter**.	• **Interpreter** – Runtime flexibility • **Compiler** – Efficient code • **JIT** – **Benefits *and* overhead** of both an interpreter and compiler.	• Identify "**hot**" (i.e. frequently run) code. • **Optimize for most common cases and skip corner cases**. ○ Guards protect for corner cases which are interpreted. • **May outperform statically compiled code**.

```
var b = true;
function flip(){
  if(b) b = false;
  else  b= true;
  return b;
}

var flip = function(){
  var b = true;
  return function(){
    if(b)  b = false;
    else   b = true;
    return b;
  };
};
```