CMSC330 Spring 2009 Final Exam (Solutions)

	Problem	Score	Max Score
1	Programming languages		14
2	Regular expressions & CFGs		8
3	Finite automata		10
4	Parsing		12
5	OCaml types & type inference		12
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7	Scoping		8
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9	Multithreading		20
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1. (14 pts) Programming languages
    a. (6 pts) List 3 different design choices for *parameter passing* in a programming language. Which choice is seldom used in modern programming languages? Explain why.
        Design choices (need 3) = call-by-value, call-by-reference,
        call-by-name, call-by-result, call-by-value-result, call-by-need
        Seldom used = everything except call-by-value or call-by-reference
        Reason = highly complex, inefficient, can be confusing

    b. List 2 different design choices for *type declarations* in a programming language. Which choice is seldom used in modern programming languages? Explain why.
        Design choices (need 2) = explicit, implicit
        Seldom used = implicit
        Reason = requires static types, requires type inference,
        error messages can be confusing

    c. List 2 different design choices for determining *scoping* in a programming language. Which choice is seldom used in modern programming languages? Explain why.
        Design choices (need 2) = static lexical, dynamic
        Seldom used = dynamic
        Reason = can be confusing

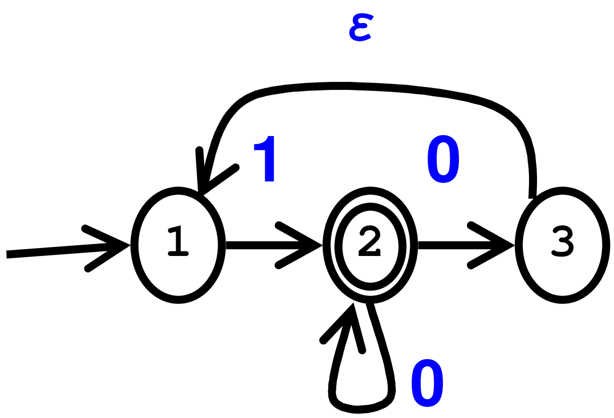
2. (8 pts) Regular expressions and context free grammars
    Give a
    a. Regular expression for binary numbers with an even number of 1s.
        (0*10*10*)*| 0*

    b. Context free grammar for binary numbers with twice as many 1s as 0s
        S → S1S1S0S | S1S0S1S | S0S1S1S | epsilon

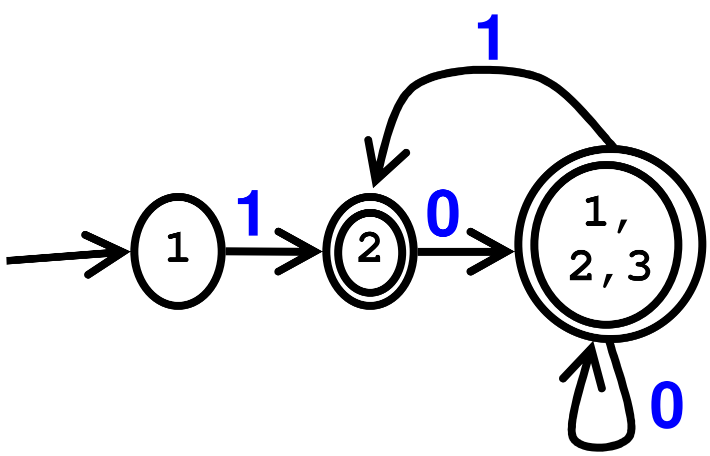
        Many possible answers, one possible solution above.

3. (10 pts) Finite automata

Apply the subset construction algorithm to convert the following NFA to a DFA.
Show the NFA states associated with each state in your DFA.



Answer



4. (12 pts) Parsing

Consider the following grammar:

S → Ac | a
A → bS | epsilon

a. (6 pts) Compute First sets for S and A

First(S) = { a, b, c } //
First(A) = { b, epsilon } //

b. (6 pts) Write the parse_A( ) function for a predictive, recursive descent parser for the grammar (You may assume parse_S( ) has already been written, and match( ) is provided).

```
parse_A( ) {
  if (lookahead == 'b') {       // for correct lookahead
    match('b');                 // for correct body
    parse_S( );
  }
  else   ;          //      just return for other lookaheads
}
```

5. (12 pts) OCaml Types and Type Inference

a. Give the type of the following OCaml expression

let f x y z = y (x z)
Type = ('a -> 'b) -> ('b -> 'c) -> 'a -> 'c //

b. (6 pts) Write an OCaml expression with the following type

int -> (int * int -> 'a) -> 'a
Code = let f x y = y (2, x+1)

c. Give the value of the following OCaml expression. If an error exists, describe the error.

let x y = x in 3
Value = error, unbound symbol x

6. (10 pts) OCaml Programming

Consider the OCaml type *bst* implementing a binary tree:

```
type tree =
   Empty
   | Node of int * tree * tree;;

let rec equal = …                (* type =  (tree * tree) -> bool *)
```

Implement a function *equal* that takes a tuple argument (t1, t2) that returns true if the two trees t1 and t2 are of the same shape *and* equivalent nodes in the trees have the same value, else returns false.

```
let rec equal = function
   (Empty, Empty) -> true                          //   true if both empty
 | (Node(m1, l1, r1), Node(m2, l2, r2)) ->         //   pull apart both trees
     m1 = m2 &&                                    //   check values
     (equal (l1, l2)) &&                           //   check subtrees
     (equal (r1, r2))
 | _ -> false                                      //   false otherwise
```

Other possible answers using "match" to pull apart parts of tree

7. (8 pts) Scoping

Consider the following OCaml code.

```
let app f y = let x = 5 in let y = 7 in let a = 9 in f y ;;
let add x y = let incr a = a+y in app incr x ;;
 (add 1 (add 2 3)) ;;
```

a. What value is returned by (add 1 (add 2 3)) with static scoping? Explain.

17, since the y in incr is bound to the formal parameter y for add

The sequences of calls & resulting values bound to the formal parameters is as follows.

i. **First evaluate (add 2 3) since arguments are evaluated first**
ii. **add (x=2,y=3) calls app (f=incr, y=2) binds (x=5, y=7, a=9) calls incr (a=7, since when incr is called the argument y is bound to 7)**
iii. **In the body of incr y is free and refers to the y in add x y (y=3), leading to a+y=7+3=10**
iv. **(add 1 (add 2 3)) is evaluated next, with the 2nd argument (add 2 3) having value 10**
v. **add (x=1,y=10) calls app (f=incr, y=1) binds (x=5, y=7, a=9) calls incr (a=7, since when incr is called the argument y is bound to 7)**
vi. **In the body of incr y is free and refers to the y in add x y (y=10), leading to a+y=7+10=17**

b. (6 pts) What value is returned by (add 1 (add 2 3)) with dynamic scoping? Explain.

14, since the y in incr is bound to the y=7 in app

The sequences of calls & resulting values bound to the formal parameters is as follows.

Note "let z=5 in …" is really "(fun z-> …) 5" and adds a dynamic scope.

i. **First evaluate (add 2 3) since arguments are evaluated first**
ii. **add (x=2,y=3) calls app (f=incr, y=2) binds (x=5, y=7, a=9) calls incr (a=7, since when incr is called the argument y is bound to 7)**
iii. **In the body of incr y is free and refers to the y in let y = 7 (y=7) in the body of app, leading to a+y=7+7=14**
iv. **(add 1 (add 2 3)) is evaluated next, with the 2nd argument (add 2 3) having value 14**
v. **add (x=1,y=14) calls app (f=incr, y=1) binds (x=5, y=7, a=9) calls incr (a=7, since when incr is called the argument y is bound to 7)**
vi. **In the body of incr y is free and refers to the y in let y = 7 (y=7) in the body of app, leading to a+y=7+7=14**

8. (9 pts) Polymorphism

   Consider the following Java classes:

   class A { public void a( ) { … } }
   class B extends A { public void b( ) { … } }
   class C extends B { public void c( ) { … }}

   (each) Explain why the following code is or is not legal

   a. int count(Set<B> s) { … } … count(new TreeSet<C>( ));

      Illegal

      Actual parameter type (Set<C>) is not a subclass of formal parameter type (Set<B>), even though C is a subclass of B.

   b. int count(Set<? extends B> s) { … } … count(new TreeSet<C>());

      Legal

      Actual parameter type (Set<C>) matches formal parameter type (Set<? extends B>), since "? extends B" can match B and its subclass C

   c. int count(Set<? super C> s) { for (A x : s) x.a( ); … }

      Illegal

      Elements of s may be objects of class Object.

9. (20 pts) Multithreading

   Using Ruby monitors and condition variables, you must implement a multithreaded simulation of factories producing chopsticks for philosophers. Factories continue to *produce* chopsticks one at a time, placing them in a single shared market. The market can only hold 10 chopsticks at a time. Philosophers enter the market to *acquire* 2 chopsticks.

Helpful functions:

m = Monitor.new	// returns monitor
m.synchronize { … }	// only 1 thread can execute code block at a time
c = m.new_cond	// returns conditional variable for monitor
c.wait_while { … }	// sleeps while code in condition block is true
c.broadcast	// wakes up all threads sleeping on condition var
t = Thread.new {… }	// creates thread, executes code block in new thread
t.join	// waits until thread t exits

a. (1) Implement a thread-safe class Market with methods initialize, produce, and acquire that can support multiple multi-threaded factories and philosophers.

```
require "monitor.rb"
class Market
  def initialize
     # initialize synchronization, number of chopsticks
     @current = 0
     @myLock = Monitor.new
     @myCondition = @myLock.new_cond
  end
  def produce
     # produces 1 chopstick if market is not full ( < 10 )
     # increases number of chopsticks in market by 1
     @myLock.synchronize {
          @myCondition.wait_while { @current >= 10 }
          @current = @current + 1
          @myCondition.broadcast
      }

  end
  def acquire
     # acquires 2 chopsticks if market has 2 or more chopsticks
     # decreases number of chopsticks in market by 2
     @myLock.synchronize {
          @myCondition.wait_while { @current < 2 }
          @current = @current - 2
          @myCondition.broadcast
      }
  end
end
```

b. (6 pts) Write a simulation with 2 factories and 2 philosophers using the market. Each factory and philosopher should be in a separate thread. The simulation should exit *after* both philosophers acquire a pair of chopsticks.

```
market = Market.new

factory1 = Thread.new {
        while true
                market.produce
        end
}
factory2 = Thread.new {
        while true
                market.produce
        end
}

philosopher1 = Thread.new { market.acquire }
philosopher2 = Thread.new { market.acquire }

philosopher1.join
philosopher2.join
```

10. (16 pts) Lambda calculus

Find all free (unbound) variables in the following λ-expressions

a. (λa. c b) λb. a

(λa. c b) λb. a **// rightmost a**
// b in body of 1^{st} λ
// c

(each) Evaluate the following λ-expressions as much as possible

b. (λx.λy.y x) a b

(λx.λy.y x) a b → (λy.y a) b → b a

c. (λz.z x) (λy.y x)

(λz.z x) (λy.y x) → (λy.y x) x → x x

d. Write a small λ-expression which requires alpha-conversion to evaluate properly.

(λx.λy.x) y // argument of 1^{st} λ matches formal parameter of 2^{nd} λ in body

11. (16 pts) Lambda calculus encodings

Prove the following using the appropriate λ-calculus encodings, given**:**

1 = λf.λy.f y
2 = λf.λy.f (f y)
3 = λf.λy.f (f (f y))
4 = λf.λy.f (f (f (f y)))
M * N = λx.(M (N x))
Y = λf.(λx.f (x x)) (λx.f (x x))
succ = λz.λf.λy.f (z f y)

a. (10 pts) 2 * 2 = 4

(2 * 2)	**// replacing * w/ encoding**
= λx.(2 (2 x))	**// replacing 2 w/ encoding**
= λx.(2 ((λf.λy.f (f y)) x))	**// β-reduction: f → x**
= λx.(2 (λy.x (x y)))	**// replacing 2 w/ encoding**
= λx.((λf.λy.f (f y)) (λy.x (x y)))	**// a-conversion: y → a**
= λx.((λf.λa.f (f a)) (λy.x (x y)))	**// β-reduction: f → λy.x (x y)**
= λx.(λa. (λy.x (x y)) ((λy.x (x y))a))	**// β-reduction: 2^{nd} y → a**
= λx.(λa. (λy.x (x y)) (x (x a)))	**// β-reduction: y → x (x a)**
= λx.(λa. x (x (x (x a))))	**// apply encoding for 4**
= 4	**// result**

b. (6 pts) (Y succ) x = succ (Y succ) x // you do not need to expand succ

(Y succ) x	**// replace Y w/ encoding**
= (λf.(λx.f (x x)) (λx.f (x x)) succ) x	**// 1^{st} f → succ**
= (λx.succ (x x)) (λx.succ (x x)) x	**// 1^{st} x → λx.succ (x x)**
= (succ ((λx.succ (x x)) (λx.succ (x x)))) x	**// encoding for (Y succ)**
= (succ (Y succ)) x	**// result**

12. (8 pts) Operational semantics

Use operational semantics to determine the values of the following OCaml codes:

(fun x = + 4 x) 2

• ; (fun x = + 4 x) → (• , λx.+ 4 x)	**// evaluate function to closure**
• ; 2 → 2	**// evaluate argument**
(x:2, + 4 x) → 6	**// evaluate body in extended env**
• ; (fun x = + 4 x) 2 → 6	**// result of proof**

13. (8 pts) Markup languages

Creating your own XML tags, write an XML document that organizes the following information: Yoda is a 900 year old Jedi with rank Grandmaster, Obi-Wan is a 36 year old Jedi with rank Master, Anakin is an 9 year old Jedi with rank Padawan.

```
<JediList>
    <Jedi>
        <name>Yoda</name>
        <age>900</age>
        <rank>Grandmaster</rank>
    </Jedi>
    <Jedi>
        <name>Obi-Wan</name>
        <age>36</age>
        <rank>Master</rank>
    </Jedi>
    <Jedi>
        <name>Anakin</name>
        <age>9</age>
        <rank>Padawan</rank>
    </Jedi>
</JediList >
```

14. (9 pts) Garbage collection

Consider the following Java code.

```
Jedi Darth, Anakin;
private void plotTwist( ) {
        Anakin = new Jedi( );  // object 1
        Darth = new Jedi( );     // object 2
        Darth = Anakin;
        Anakin = Darth;
}
```

a. What object(s) are garbage when plotTwist ( ) returns? Explain why.

Object 2 is garbage because it is no longer reachable (once the reference to it is overwritten by "Darth = Anakin;")

b. (3pts) Explain why stop-and-copy has to copy live objects.

Live objects must be moved to a new semi-space since all objects in the current semi-space will be freed.

c. How can garbage collection take advantage of the fact an object is from an older generation?

Objects from older generations are presumed longer-lasting and do not need to be processed as frequently (i.e., can be moved to a separate semi-space that is not checked as frequently by garbage collection)