HONG KONG UNIVERSITY OF SCIENCE & TECHNOLOGY

COMP3031 (Principles of Programming Languages)

Fall 2015

FINAL EXAMINATION

12:30PM - 3:30PM
Dec 10, 2015 Thursday
LG5 Multi-function Room

Name	
Student ID	**ITSC Account**

1. *About the exam:*
    a. *This is a closed-book, closed-note examination.*
    b. *You CANNOT use any electronic devices including calculators during the examination. Please TURN OFF all of your electronic devices (e.g., mobile phone) and put them into your bag.*
    c. *You CANNOT leave during the last 15 minutes of the examination.*
2. *About this paper:*
    a. *This paper contains 14 pages, including this title page.*
    b. *The total number of points is 100, distributed to seven problems.*
3. *About your answers:*
    a. *Write your answers in the designated space following each question.*
    b. *Make sure your final answers are clearly recognizable.*
    c. *Rough work can be done in the provided "additional blank paper for draft work". Do not, however, write answers there as they will NOT be graded.*
    d. *Attempt all questions.*

Problem	1	2	3	4	5	6	7	Total
Marks								

Problem 1. SML Programming (20 points)

Given the following SML datatype:

```
datatype 'a tree = empty_tree |
                   leaf of 'a |
                   node of 'a * 'a tree * 'a tree;
```

a) Write a function `path` to return a list of labels of the tree nodes that form the path from the root to the specified label, if there is such a path in the tree; otherwise, return `nil`. The list is generated through pre-order traversal, and only the first path found is returned.

```
val path = fn : ''a -> ''a tree -> ''a list
```

Examples:

```
-val x = node(0, node(1, leaf(2), leaf(3)),node(2,leaf(3),empty_tree));
val x = node (0,node (1,leaf #,leaf #),node (2,leaf #,empty_tree)) :
int tree
- path 0 x;
val it = [0] : int list
- path 1 x;
val it = [0,1] : int list
- path 2 x;
val it = [0,1,2] : int list
- path 3 x;
val it = [0,1,3] : int list
- path 4 x;
val it = [] : int list
- path true (leaf false);
val it = [] : bool list
```

```
Sol:

fun search x _ empty_tree = []
| search x L (leaf(y)) = if x = y then L@[x] else []
| search x L (node(y, Left, Right)) =
if x = y then L@[x]
else
let
val L1 = L@[y]
val el = search x L1 Left
in
if el = []
then search x L1 Right
else el
end;

fun path x y = search x [] y;
```

```
Sol 2:

fun path x empty_tree = []
| path x (leaf(y)) = if x = y then [x] else []
| path x (node(y, Left, Right)) =
if x = y then [x]
else
let
val el = path x Left
in
if el = []
then
let val er = path x Right
in if er = [] then [] else y::er end
else y::el
end;
```

Grading criteria:
Base case 1: 1 pt
Base case 2: 2 pts
Base case 3: equal case 1 pts; left subtree traversal 2 pts; right subtree traversal 2 pts; “list append” or “list construct” 2 pts.
Syntax error: -1 pt for one category of similar errors

b) Write a function `height` to return the maximum height of a specified label in the tree. If the label is not in the tree, return `~1`.

```
val height = fn : ''a -> ''a tree -> int
```

Examples:

```
- val x = node("a", node("b", leaf("c"), leaf("d")),
node("c",leaf("d"), empty_tree));
val x = node ("a",node ("b",leaf #,leaf #),node ("c",leaf
#,empty_tree))  : string tree
- height "a" x;
val it = 3 : int
- height "b" x;
val it = 2 : int
- height "c" x;
val it = 2 : int
- height "d" x;
val it = 1 : int
- height "e" x;
val it = ~1 : int
- height true empty_tree;
val it = ~1 : int
- height ~1 (leaf ~1);
val it = 1 : int
```

```
Sol:

fun measure empty_tree = 0
| measure (leaf(_)) = 1
| measure (node(_, L, R)) =
let
val l = measure L
val r = measure R
in
if l < r then 1+r else 1+l
end;

fun height x empty_tree = ~1
| height x (leaf(y)) = if x = y then 1 else ~1
| height x (node(y, L, R)) =
if x = y then measure (node(y, L, R))
else let
val l = height x L
val r = height x R
in
if l < r then r else l
end;
```

Grading criteria:
Measure the height of a subtree: 4 pts (1, 1, 2 for each base case)
Function height: 6 pts (1, 2, 3 for each base case)
Syntax error: -1 pt for one category of similar errors

Problem 2. Prolog Programming (20 points)

Given a knowledge base of facts in the form of `node(X, L, R),` where X is the label of a tree node, and L and R labels of the left and right children of the node. The set of facts represents a binary tree where all labels of the tree nodes are unique:

```
node(a,b,c).
node(b,d,e).
node(e,f,g).
```

a) Define a predicate `path(X, L)` in which X is the label of a tree node, and L is a list of labels that form the path from the root node of the tree to X, if X is in the tree; otherwise, L is an empty list. The code skeleton is given. You only need to fill in the missing predicates, one predicate per blank.

Examples:

```
?- path(c,X).
X = [a, c].
?- path(X,[a,c]).
X = c.
?- path(g,X).
X = [a, b, e, g].
?- path(h,X).
X = [].
```

```
path(X, []) :- ___\+ node(X, _, _)_________,
               ___\+ node(_, X, _)_________,
               ___\+ node(_, _, X)_________, !.

path(X, [X]) :- __node(X, _, _)____________,
               ___\+ node(_, X, _)_________,
               ___\+ node(_, _, X)_________, !.
path(X, L) :- node(P, X, _),
               ___path(P, L1)______________,
               ___append(L1, [X], L)_______, !.

path(X, L) :- node(P, _, X),
               ___path(P, L1)_____________,
               ___append(L1, [X], L)______, !.
```

Grading criteria: 1 pt for each blank Order error of predicates in path(X, L): -1 pt in total

b) Define a predicate `height(X,H)` such that for a given node X, H is the maximum height of the node in the tree, if the node is in the tree; otherwise, the predicate returns false. The code skeleton is given. You only need to fill in the missing predicates, one predicate per blank.

Examples:

```
?- height(a,X).
X = 4.
?- height(b,X).
X = 3.
?- height(c,X).
X = 1.
?- height(d,X).
X = 1.
?- height(e,X).
X = 2.
?- height(f,X).
X = 1.
?- height(h,X).
false.
```

```
max(A,B,A) :- A>B, !.

max(A,B,B).

height(A,1) :- node(_,A,_), \+ node(A,_,_), !.

height(A,1) :- node(_,_,A), \+ node(A,_,_), !.

height(X, H) :- ____node(X, L, R)__________,

                ____height(L, H1)__________,

                ____height(R, H2)__________,

                ____max(H1, H2, M)_________,

                ____H is M + 1_____________, !.
```

Grading criteria:
2 pts for each blank Order error of predicates: -1 pt in total

Problem 3. Cuts and Negation in Prolog (10 points)

Given each of the Prolog programs a) – e), write the *first* answer to the query:

```
?- likes(X,a).
```

a)

```
bear(a).
animal(a).
likes(X, Y) :- Y=b, !, X=d.
likes(c, Y) :- animal(Y).
```

X=c. (2pts)

b)

```
bear(a).
animal(a).
likes(X, Y) :- Y=a, !, X=d.
likes(X,Y)  :- animal(Y).
```

X=d. (2pts)

c)

```
bear(a).
animal(a).
likes(c, X) :- \+ X=a.
likes(c, X) :- \+ animal(X).
```

false. (2pts)

d)

```
bear(a).
animal(a).
likes(c, X) :- bear(X), !, fail.
likes(c, X) :- animal(X).
```

false. (2pts)

e)

```
bear(a).
animal(a).
likes(c, X) :- \+ bear(X).
likes(c, X) :- animal(X).
```

X=c. (2pts)

Problem 4. Prolog Search Tree (10 points)

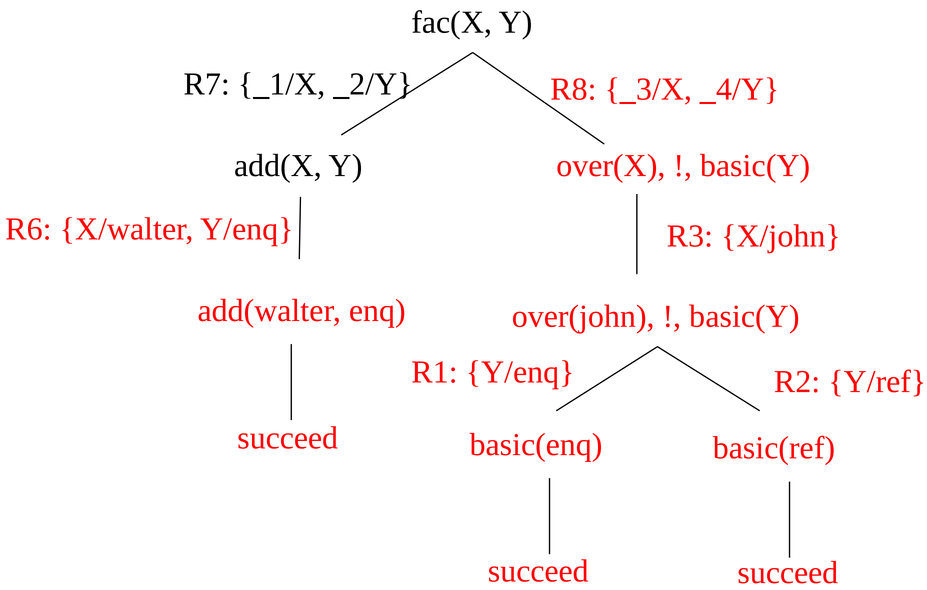
Consider the following program:

```
/*R1*/ basic(enq).
/*R2*/ basic(ref).
/*R3*/ over(john).
/*R4*/ over(walter).
/*R5*/ gen(book).
/*R6*/ add(walter, enq).
/*R7*/ fac(P, F) :- add(P, F).
/*R8*/ fac(P, F) :- over(P), !, basic(F).
/*R9*/ fac(P, F) :- gen(F).
```

Draw the complete Prolog search tree for the query `fac(X,Y)`, giving **all** answers. At each **tree edge**, whenever applicable, **i)** indicate the rule number Ri, i=1,..,9, of the rule being applied, and **ii)** the unification(s) being made. At each **tree node** indicate the goal to be satisfied. At each leaf node indicate "succeed" or "fail". The initial step has been done for you.

fac(X,Y)
R7: {_1/X, _2/Y}/
add(X,Y)

Sol:



Grading criteria:
2 pts for each rule (R6, R8, R3, R1, R2)
-2 pts for every extra answer

Problem 5. Flex and Bison (20 points)

Given the following grammar for expressions on a binary tree where every non-empty tree node has a numeric label:

<expression> ::= sum(<tree>) | product(<tree>)
<tree> ::= empty | node(<num>,<tree>,<tree>)
<num> ::= <D1><N> | <N>
<D1> ::= <D1><N> | <D2>
<D2> ::= [1-9]
<N> ::= [0-9]

An expression is either a *sum* or a *product*. A *sum* operation adds up the numeric label values of all nodes in the tree. A *product* operation, multiplies the numeric label values of all nodes in the tree. An empty node has a numeric value of 1 in a *product* and 0 in a *sum*. Some examples:

sum(node(4,empty,empty)) = 4+0+0 = 4

sum(node(9,node(5,empty,node(2,empty,empty)),node(1,empty,empty)))
= 9+(5+0+(2+0+0))+(1+0+0) = 17

product(node(12,empty,empty)) = 12*1*1 = 12

product(node(20,node(6,empty,node(4,empty,empty)),node(7,empty,empty)))
= 20*(6*1*(4*1*1))*(7*1*1) = 3360

Complete the Flex and Bison files so that when they are compiled and run, it will give the following output on the **input**:

sum(node(4,empty,empty))
4
sum(node(9,node(5,empty,node(2,empty,empty)),node(1,empty,empty)))
17
product(node(12,empty,empty))
12
product(node(20,node(6,empty,node(4,empty,empty)),node(7,empty,empty)))
3360

Flex file “tree.lex”:

```
%option noyywrap

%{
struct treenode
{
 int sum;
 int product;
};

#define YYSTYPE treenode
#include "tree.tab.h"

%}

num [0-9]|[1-9][0-9]+   (4pts)
op [(),\n]
ws [ \t]+

%%
{num}      { yylval.sum = atoi(yytext); yylval.product = atoi(yytext);  (4pts)
             return NUM;}
{op}         return *yytext;
{ws}
empty        return EMPTY;
sum          return SUM;
product      return PRODUCT;
node
%%
```

Bison file "tree.y":

```
%{
#include <iostream>
using namespace std;

struct treenode
{
 int sum;
 int product;
};

#define YYSTYPE treenode
int yylex(void);
int yyerror(const char*);

%}

%token NUM
%token EMPTY
%token SUM
%token PRODUCT

%%

/* Fill in the blanks in the grammar rules and actions*/

input: /* empty */ | input line ;

line: '\n'

|SUM '(' tree ')' '\n' { cout << $3.sum << endl;} (1pt)

| PRODUCT '(' tree ')' '\n' { cout << $3.product << endl;}; (1pt)


tree:
EMPTY { $$.SUM = 0; $$.PRODUCT = 1;} (4pts, 1pt for grammar, 3pts for
action)
| '(' NUM ',' tree ',' tree ')' { $$.sum = $2.sum + $4.sum + $6.sum; $$.product =
$2.product * $4.product * $6.product;}; （6pts, 3pts for grammar, 3pts for action)

%%
int main() { return yyparse();}

int yyerror(const char* s) {
      cout << "error" << endl;
      return 0;
}
```

Problem 6. Parameter Passing Methods (10 Points)

The following program is in an imaginary D language, which has a syntax similar to the C language, but can apply static or dynamic scoping as well as various parameter passing methods as we specify. Determine the output of the following D program with each specified scoping and parameter passing method:

```
int x = 3;
int y = 2;
void final(int a, int b)
{
      a++;
      b = x - 2;
      printf("(%d,%d)",x,y);
      x--;
      y = b + 1;
      printf("(%d,%d)",x,y);
}
int main(int argc, char **argv)
{
      int x = 4;
      final(y, x);
      printf("(%d,%d)",x,y);
}
```

Static scoping, call by value:

(3,2)(2,2)(4,2)   (2.5pts)

Static scoping, call by reference:

(3,3)(2,2)(1,2)   (2.5pts)

Static scoping, call by value-result:

(3,2)(2,2)(1,3)   (2.5pts)

Dynamic scoping, call by name:

(2,3)(1,2)(1,2)   (2.5pts)

(* 0.5 pts are deducted for each incorrect value, at most 2.5 pts are deducted for each blank. *)
(* 0.5 pts in total are deducted for missing parentheses and comma. *)

Problem 7. Activation Records (10 points)

Recall that the C language by default uses static scoping on variable names and passing-by-value for parameter passing in procedure calls. Complete the activation records, including the variables and their values if known, the parameters and their values if known, and the control links for the following C program at specified point in time:

(i) right before calling main;
(ii) right before calling mul;
(iii) right before exiting the call of mul;
(iv) right before exiting main;
(v) right after exiting main and before the program terminates.

```
#include <stdio.h>

int x = 3;
int y = 4;
int a[2] = {5, 6};

void mul(int x, int b, int z[ ])
{
      int i=0, size=2;
      for (i=0; i < size; i++) {
            a[i] *= x++;
            z[i] *= b++;
      }
      y=x*b;
}

int main()
{
      int y = 5;
      int b[2] = {2, 3};
      mul(y, x, b);
}
```

i) (1pt)

x:3
y:4
a[0]:5
a[1]:6

ii) (2pts, 1pt for each blank)

x:3
y:4
a[0]:5
a[1]:6

main:
y:5
b[0]:2
b[1]:3

iii) (4pts, 1pt for each blank, 1pt for the control link)

x:3
y:35
a[0]:25
a[1]:36

main:
y:5
b[0]:6
b[1]:12

mul:
x:7
b:5
z:
i:2
size:2

iv) (2pts, 1pt for each blank)

x:3
y:35
a[0]:25
a[1]:36

main:
y:5
b[0]:6
b[1]:12

v) (1pt)

x:3
y:35
a[0]:25
a[1]:36