Name: _____ SOLUTION KEY ________________

CSCI-4430 Programming Languages

Midterm Exam
Part I

1 A Grammar for Simple Arithmetic Expressions

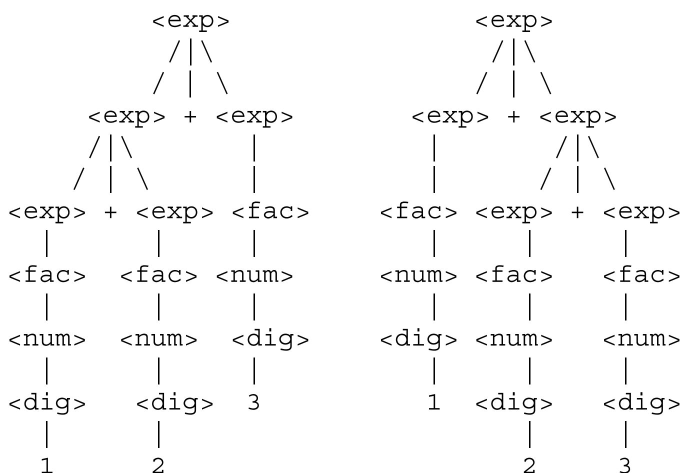
The following is a grammar for simple arithmetic expressions that involve only natural numbers, addition, and multiplication.

$$
\begin{array}{rcl}
\langle\text{digit}\rangle & ::= & 0 \mid 1 \mid 2 \mid 3 \mid 4 \mid 5 \mid 6 \mid 7 \mid 8 \mid 9 \\
\langle\text{number}\rangle & ::= & \{\langle\text{digit}\rangle\}^{+} \\
\langle\text{expression}\rangle & ::= & \langle\text{factor}\rangle \mid \langle\text{expression}\rangle \; \texttt{+} \; \langle\text{expression}\rangle \\
\langle\text{factor}\rangle & ::= & \langle\text{number}\rangle \mid \langle\text{factor}\rangle \; \texttt{*} \; \langle\text{factor}\rangle
\end{array}
$$

1. What are the tokens of this language? **2 pts**

   Solution. The tokens of the language are digits and the symbols `+` and `*`.

2. With this grammar, the expression `1+2+3` has two parse trees:



   The existence of two parse trees for the same string shows that the grammar is (circle one) **2 pts**

   (a) ambiguous
   (b) context-free
   (c) context-sensitive

(d) left-associative

(e) right-associative

Solution. (a)

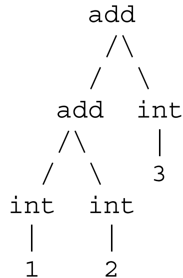
2 Evaluating Simple Arithmetic Expressions

For *evaluation* of expressions by an interpreter (or for code-generation by a compiler), parse trees are not the most convenient representation, because they still contain information about the original string representation that is unnecessary for computation. The following Oz program is a little expression evaluator that assumes its input is in the form of an *abstract syntax tree* constructed from Oz tuples.

```
fun {Eval X}
   case X
   of int(N) then N
   [] add(X Y) then {Eval X}+{Eval Y}
   [] mul(X Y) then {Eval X}*{Eval Y}
   end
end
```

1. For the first parse tree shown in part 2 of the preceding question, draw the corresponding abstract syntax tree. **4 pts**

   Solution.



2. Is the `Eval` function tail-recursive? Explain. **2 pts**

   Solution. No. In fact, none of the recursive calls is a tail-call.

3 Some

Here is a definition of a function that, given a list `Xs` and a function `P`, returns **`true`** if {`P X`} returns **`true`** for some element `X` of `Xs` and otherwise it returns **`false`**.

```
fun {Some Xs P}
   case Xs of
      nil then false
   [] X|Xr then
      if {P X} then true else {Some Xr P} end
      %----------------------------------------
   end
end
```

1. Rewrite the underlined `if` expression using one of Oz's boolean operators instead. **2 pts**

   Solution.

   ```
   {P X} orelse {Some Xr P}
   ```

2. One of the functions we wrote as a homework exercise was the `Member` function. `{Member Y Xs}` returns `true` if `Y` occurs in list `Xs` and otherwise it returns `false`. Here, instead of writing an independent recursive definition of `Member`, show how to implement it by passing an appropriate function to `Some`. **4 pts**

   Solution.

   ```
   fun {Member Y Xs}
     {Some Xs fun {$ X} Y==X end}
   end
   ```

   or

   ```
   fun {Member Y Xs}
     fun {Check X}
        Y==X
     end
     in {Some Xs Check}
   end
   ```

3. We know that Oz function definitions and function calls are linguistic abstractions; they are defined by translation into kernel language procedure definitions and procedure calls. Translate the definition of `Some` into a procedure definition in kernel language syntax. The first part of the translation is given; fill in the rest. (Hint: Be sure your translation reproduces the semantics of the original when there is an error in calling `Some`, with, say, a number instead of a list.) **6 pts**

   ```
   Some = proc {$ Xs P B}
            case Xs of
              nil then B=false
   ```

```
else case Xs of X|Xr then
```

Solution.

```
Some = proc {$ Xs P B}
         case Xs of
           nil then B=false
         else case Xs of X|Xr then
                local Q in
                   {P X Q}
                   if Q then B=true else {Some Xr P B} end
                end
             else raise error(´missing else clause´) end
         end
       end
```

4 An Abstract Machine Execution

The following sequence of abstract machine states is the beginning of an execution of an Oz (kernel language) statement, expressed in a format similar to one we've used in several lab exercises. Continue the execution to termination. **10 pts**

```
local Y in
   local X in
      X=1
      local X in
         X=2
      end
      Y=X
   end
end
```

Env:{}

Store:{}

⟹

```
local X in
   X=1
   local X in
      X=2
   end
   Y=X
end
```

Env:$\{Y \rightarrow y\}$

Store:$\{y\}$

$\Longrightarrow$

```
X=1
local X in
   X=2
end
Y=X
```

Env:$\{Y \rightarrow y, X \rightarrow x\}$

Store:$\{y, x\}$

$\Longrightarrow$

```
X=1
```

Env:$\{Y \rightarrow y, X \rightarrow x\}$

```
local X in
   X=2
end
Y=X
```

Env:$\{Y \rightarrow y, X \rightarrow x\}$

Store:$\{y, x\}$

$\Longrightarrow$

Solution.

```
local X in
   X=2
end
Y=X
```

Env:$\{Y \rightarrow y, X \rightarrow x\}$

Store:$\{y, x = 1\}$

$\Longrightarrow$

```
local X in
   X=2
end
```

Env:$\{Y \rightarrow y, X \rightarrow x\}$

```
Y=X
```

Env:$\{Y \rightarrow y, X \rightarrow x\}$

Store:$\{y, x = 1\}$

$\Longrightarrow$

```
X=2
```

Env:$\{Y \rightarrow y, X \rightarrow x'\}$

```
Y=X
```

Env:$\{Y \rightarrow y, X \rightarrow x\}$

Store:$\{y, x = 1, x'\}$

$\Longrightarrow$

```
Y=X
```

Env:$\{Y \rightarrow y, X \rightarrow x\}$

Store:$\{y, x = 1, x' = 2\}$

$\Longrightarrow$

Store:$\{y = 1, x = 1, x' = 2\}$

Terminates.

Midterm Exam, Part II

5 Arity

What does `{Arity r(b:1 a:2 3:7)}` return? **2 pts**

Solution. `3 a b`

(2 pts for this exact answer, 1 pt if these features are listed but in a different order)

6 Free and Bound Identifiers

List for each of the following Oz statements the free and bound variable identifiers. (Don't forget: an identifier can be both free and bound in the same statement, because one occurrence of it is free and another occurrence is bound.) **6 pts**

1. `{P X Y}` **`local`** `X` **`in`** `{X P Y}` **`end`**

   Free: ________________ Bound: ________________

2. **`local`** `X` **`in`** **`local`** `Y` **`in`** `{X Y Z}` **`end`** **`end`**

   Free: ________________ Bound: ________________

3. **`case`** `X` **`of`** `f(Y)` **`then`** `{P Y}` **`else`** `{Q Y}` **`end`**

   Free: ________________ Bound: ________________

Solution.

1. Free: `P`, `X`, `Y`; bound: `X`.
2. Free: `Z`; bound: `X`, `Y`.
3. Free: `P`, `X`, `Y`, `Q`; bound: `Y`.

7 Producing Power Functions

Consider the following variant of the `Pow`-function we've seen in lectures and labs.

```
fun {PowFactory X}
   fun {PowAcc N A}
      if N==0 then A
      else {PowAcc N-1 X*A}
      end
   end
   fun {Pow N}
      {PowAcc N 1}
   end
in
   Pow
end
```

1. Write an expression using `PowFactory` to compute 3 to the 5-th power. **4 pts**

   Solution.

   ```
   local P3 = {PowFactory 3} in {P3 5} end
   ```

   or simply

   ```
   {{PowFactory 3} 5}
   ```

2. Give the external references for `PowAcc` **2 pts**

   Solution. `PowAcc` itself and `X`.

3. Give the external references for `Pow`. **2 pts**

   Solution. `PowAcc`.

8 Semantics of exceptions

When an exception is raised in an Oz program by the (kernel language) semantic statement

$$(\texttt{raise}\ \langle x \rangle\ \texttt{end}, E)$$

semantic statements are popped off the semantic stack looking for a catch statement.

1. No computation is involved in processing each semantic statement that is popped off, other than checking whether or not it is a catch. In C++, on the other hand, the corresponding way of raising an exception (with a `throw` statement) must process each popped stack frame to call the destructors of all objects referenced in the stack frame. Explain why this is necessary in a C++ program but not in an Oz program. **4 pts**

   Solution. The main point to note in the answer is that C++ doesn't have automatic garbage collection, while Oz does. As discussed in class, since C++ doesn't have it, the referenced object destructors have to be called since otherwise there could be a memory leak. In Oz, on the other hand, when a store variable is no longer accessible (no environment on the semantic stack has a binding that maps to it or to a record containing it), the garbage collector will reclaim it.

2. Assuming

   $$(\texttt{catch}\ \langle y\rangle\ \texttt{then}\ \langle s\rangle\ \texttt{end}, E_c)$$

   is the `catch` statement found, which of the following is the semantic statement pushed on the semantic stack as the last step of processing the `raise` statement? (Hint: Only one of these really makes any sense, if you remember how environments are used in the abstract machine.) **4 pts**

   (a) $(\langle s\rangle, E + \{\langle y\rangle \to E_c(\langle x\rangle)\})$
   (b) $(\langle s\rangle, E + \{\langle y\rangle \to E(\langle x\rangle)\})$
   (c) $(\langle s\rangle, E_c + \{\langle y\rangle \to E(\langle x\rangle)\})$
   (d) $(\langle s\rangle, E_c + \{\langle y\rangle \to E_c(\langle x\rangle)\})$

   Solution. (c)

9 A Translation Attempt

The semantics of the try-finally statement in Oz

```
try <s>1 finally <s>2 end
```

is defined by translating it into a kernel language try-catch:

```
try
  <s>1
catch X then
  <s>2
  raise X end
end
<s>2
```

If <s>2 is a large statement (perhaps composed of dozens of smaller statements), it's a problem that this translation duplicates it. Consider the following alternative translation that uses a boolean variable to keep track of whether an exception has occurred in order to avoid duplicating <s>2:

```
local ExceptionOccurred SavedException in
  ExceptionOccurred=true
  try
    <s>1
    ExceptionOccurred = false
  catch X then
    SavedException=X
  end
  <s>2
  if ExceptionOccurred then
    raise SavedException end
  end
end
```

However, this statement does **not** have the same semantics as the first translation. Why not? Make your answer precise by describing a case where the two statements would execute differently. **6 pts**

Solution. Assume that neither <s>1 nor <s>2 raises an exception. With the first translation, both are executed and no exception is raised. But with the second translation, there are two assignments, with different values, to `ExceptionOccurred`. Since it's a single assignment variable, the second assignment itself raises an exception, which will be caught by the catch statement and re-raised at the end.