Programming Language, Assignment 4
Due: June 4, 11:59 pm

For this assignment, edit a copy of the attached hw4.cc. In particular, replace occurrences of “TODO” to complete the problems.

Overview
This homework has to do with MUPL (a Made Up Programming Language). MUPL programs are written directly in C++ by using the constructors defined by the structs defined at the beginning of hw4.cc. This is the definition of MUPL’s syntax:

- If s is a C++ string, then Var(s) is a MUPL expression (a variable use).
- If n is a C++ integer, then Int(n) is a MUPL expression (a constant).
- If e1 and e2 are MUPL expression, then Add(e1, e2) is a MUPL expression (an addition).
- If s1 and s2 are C++ strings and e is a MUPL expression, then Fun(s1, s2, e) is a MUPL expression (a function). In e, s1 is bound to the function itself (for recursion) and s2 is bound to the (one) argument. Also, Fun(“”, s2, e) is allowed for anonymous non-recursive function.
- If e1, e2, e3 and e4 are MUPL expressions, then IfGreater(e1, e2, e3, e4) is a MUPL expression. It is a conditional where the result is e3 if e1 is strictly greater than e2 else the result is e4. The results of the evaluation of e1 and e2 should be Int values. Only one of e3 and e4 is evaluated.
- If e1 and e2 are MUPL expressions, then Call(e1, e2) is a MUPL expression (a function call).
- If s is a C++ string and e1 and e2 are MUPL expressions, then MLet(s, e1, e2) is a MUPL expression (a let expression where the value resulting e1 is bound to s in the evaluation of e2).
- If e1 and e2 are MUPL expressions, then APair(e1, e2) is a MUPL expression (a pair-creator).
- If e1 is a MUPL expression, then Fst(e1) is a MUPL expression (getting the first part of a pair).
- If e1 is a MUPL expression, then Snd(e1) is a MUPL expression (getting the second part of a pair).
- AUnit() is a MUPL expression (holding no data, much like () in ML). Notice AUnit() is a MUPL expression, but AUnit is not.
- If e1 is a MUPL expression, then IsAUnit(e1) is a MUPL expression (testing for AUnit()).
- Closure(env, f) is a MUPL value where f is MUPL function (an expression made from fun) and env is an environment mapping variables to values. Closures do not appear in source programs; they result from evaluating functions.

A MUPL value is a MUPL Int constant, a MUPL Closure, a MUPL AUnit, or a MUPL APair of MUPL values. Similar to ML, we can build list values out of nested pair values that end with a MUPL AUnit. Such a MUPL value is called a MUPL list. You should assume MUPL programs are syntactically correct (e.g., do not worry about wrong things like Int(“hi”) or Int(Int(37)). But do not assume MUPL programs are free of type errors like Add (AUnit(), Int(7)) or Fst(Int(7)).

Submission

Write the functions in problem 1 – 4 in a single file, named *“sol4.cc”.* Then upload the file to the course homepage (under the assignment 4 menu). Make sure that you test your solution code compiles and works correctly.

Problems

1. **Warm-Up**:
   a. Write a C++ function ToMuplList that takes a List<Expr> (presumably of MUPL values but that will not affect your solution) and produces an analogous MUPL list with the same elements in the same order.
   b. Write a C++ function FromMuplList that takes a MUPL list (presumably of MUPL values but that will not affect your solution) and produces an analogous C++ List<Expr> (of MUPL values) with the same elements in the same order.

2. **Implementing the MUPL Language**: Write a MUPL interpreter, i.e., a C++ function eval that takes a MUPL expression e and either returns the MUPL value that e evaluates to under the empty environment or throws std::runtime_error if evaluation encounters a run-time MUPL type error or unbound MUPL variable.
   A MUPL expression is evaluated under an environment (for evaluating variables, as usual). In your interpreter, use a std::map<string, Expr> to represent this environment (which is initially empty) so that you can use without modification the provided envlookup function. Here is a description of the semantics of MUPL expressions:
   - All values (including closures) evaluate to themselves. For example, eval (Int(17)) would return Int(17), not 17.
   - A variable evaluates to the value associated with it in the environment.
   - An addition evaluates its subexpressions and assuming they both produce integers, produces the integer that is their sum. (Note this case is done for you to get you pointed in the right direction.)
   - Functions are lexically scoped: A function evaluates to a closure holding the function and the current environment.
   - An ifgreater evaluates its first two subexpressions to values v1 and v2 respectively. If both values are intergers, it evaluates its third subexpression if v1 is a strictly greater integer than v2 else it evaluates its fourth subexpression.

- An mlet expression evaluates its first expression to a value v. Then it evaluates the second expression to a value, in an environment extended to map the name in the mlet expression to v.
- A call evaluates its first and second subexpressions to values. If the first is not a closure, it is an error. Else, it evaluates the closure's function's body in the closure's environment extended to map the function's name to the closure (unless the name field is #f) and the function's argument to the result of the second subexpression.
- A pair expression evaluates its two subexpressions and produces a (new) pair holding the results.
- A fst expression evaluates its subexpression. If the result for the subexpression is a pair, then the result for the fst expression is the e1 field in the pair.
- A snd expression evaluates its subexpression. If the result for the subexpression is a pair, then the result for the snd expression is the e2 field in the pair.
- An isaunit expression evaluates its subexpression. If the result is an aunit expression, then the result for the isaunit expression is the MUPL integer 1, else the result is the MUPL integer 0.

Hint: The call case is the most complicated. In the sample solution, no case is more than 12 lines and several are 1 line.

3. **Using the Language**: We can write MUPL expressions directly in C++ using the constructors for the structs and also C++ functions that create and return MUPL expressions.
    a. Write the C++ function MuplMap that returns a MUPL function that acts like the map function (as we used extensively in ML). The returned map function should be curried: it should take a MUPL function and return a MUPL function that takes a MUPL list and applies the function to every element of the list returning a new MUPL list. Recall a MUPL list is AUnit or APair where the second component is a MUPL list. The pseudo code (in ML) is shown in the comments of this function in the skeleton file.
    b. Write the C++ function MuplMapAddN that returns a (curried) MUPL function. The returned function takes an MUPL integer I and returns a MUPL function that takes a MUPL list of MUPL integers and returns a new MUPL list of MUPL integers that adds I to every element of the list. Use MuplMap that you implemented above. Also, the pseudo code is shown in the comments of this function in the skeleton file.