
A Compiler for the FASTO Language

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1 MULTIPLICATION, DIVISION, BOOLEAN OPERATORS AND LITERALS

Implementing multiplication and division was a simple matter, when having the already implemented code for addition and subtraction to look at. They served as a great way of getting to know the fasto compiler, and how things operate.

Negation is implemented using the Mips.SUB instruction, where we pass the original argument to the operator, and subtracts this from zero.

So the instruction looks like:

```
Mips.SUB(place, "0", t1),
```

where t1 register that holds the argument x for $\sim x$, and place is the register in which we place the result.

Not was more complicated than the previous ones, given that this requires more than one instruction to execute. However, the pattern learned here, proved to be useful for implementing and and or as well.

```
[ Mips.LI (place,"0")  
  , Mips.BNE (b,"0",falseLabel)  
  , Mips.LI (place,"1")  
  , Mips.LABEL falseLabel ]
```

Place is the register in which we want to store our result. We start by putting 0 into place, we then check if our argument b, actually is 0. Since Mips.BNE branches if its arguments are not equal, we will jump to falseLabel if and only if our argument b is 1, thus ending with a 0 in the place register, given we never execute Mips.LI(place, "1").

HAR INGEN IDE OM BOOL LITS

2 FILTER AND SCAN

3 λ -EXPRESSIONS IN SOACS

To implement this we wanted to use as much from regular functions as possible, so we started going through each step, starting from the lexer, discussing how we could use already used code for function, to our advantage.

The lexing and parser part was quite simple, as we know λ -functions always begin with fn and the rest looks like a regular function, so we just pass everything on like a regular function. In the parser we put the whole thing under FunArgs, since λ -functions only are defined as being used in map, filter, scan and reduce.

Below is the FunArg-type shown

<pre>FunArg : ID { FunName (#1 \$1) } FN Type LPAR Params RPAR ARROW Exp</pre>
--

```

    { Lambda ( $2, $4, $7, $1 ) }
  | FN Type LPAR RPAR ARROW Exp
    { Lambda ( $2, [], $6, $1 ) }
;

```

As shown, these arguments are passed on to the Lambda-function in the typeChecker. In the typeChecker, we create a FunDec using a dummy-name, as suggested. This is then passed to checkFunWithVtable where the function is typechecked, then the parameters are typechecked and its passed to the code-generator.

Below is the code for typechecking a Lambda-function shown:

```

| checkFunArg (In.Lambda (ret_type, params, body, funpos)
    , vtab, ftab, pos) =
    let val (Out.FunDec ( name, _, params, body', pos)) = checkFunWithVtable (In.
FunDec ("Lambda", ret_type, params, body, pos), vtab, ftab, funpos)
    val arg_types = map (fn (Param (_, ty)) => ty) params
    in
    (Out.Lambda(ret_type, params, body', funpos), ret_type, arg_types)
    end

```

In the code-generator we need to bind the parameters with the arguments in the SymTab and do so recursively using a local defined function bindVars, that is only available in that scope. The base-cases is checking if one of the two arrays is empty while the other is not and throw and error if that is the case. Otherwise we want to return to updated vtable, once both the array of arguments and the array of parameters both are depleted simultaneously. With the new vtable we then compute the expression for the Lambda-function.

Below is the code-generation for Lambda shown

```

| applyFunArg (Lambda(ret_type, params, body', funpos), args, vtable, place, pos) :
Mips.Prog =
    let
        fun bindVars ([], [], vtable) = vtable
        | bindVars([], args, vtable) = raise Error("stop det pjat", pos)
        | bindVars(params, [], vtable) = raise Error("stop det pjat stadigvæk", pos)
        | bindVars(Param (name, paramtype)::params, arg::args, vtable) = SymTab.bind
name arg (bindVars(params, args, vtable))
        val newVtable = bindVars(params, args, vtable)
        val code1 = compileExp body' newVtable place
    in
        code1
    end

```

To test this, we simply created a test-case for each of the 4 SOACS that can use λ -functions.

Below is the test-case for λ -function in map SOAC. The tests for the other SOACs is found in the tests folder for our project.

```

fun int writeInt(int x) = write(x)

fun [int] writeIntArr([int] x) = map(writeInt, x)

fun int main() =
  let N = read(int) in
  let z = iota(N) in
  let w = writeIntArr(map(fn int (int x) => x + 2, z)) in
  let nl = write("\n") in
  writeInt(reduce(op+, 0, w))

```

4 COPY PROPAGATION AND CONSTANT FOLDING

We have implemented *copy propagation and constant folding* in our compiler, though it does not handle shadowing. Furthermore have all the features from **REF TIL TASK 1**.

Below is the test-case for Times explained. This will indicate that both the cases work and it is able to actually optimize by propagating and fold correspondingly.

When we want to fold expressions, we can do so, by predicting what the result is going to be of a given expression and return this instead.

We thought through for each expression, what base-cases there could be and what we then should return.

Below is shown our code for the *Times*-expression.

```

| Times (e1, e2, pos) =>
  let val e1' = copyConstPropFoldExp vtable e1
      val e2' = copyConstPropFoldExp vtable e2
  in case (e1', e2') of
    (Constant (IntVal x, _), Constant (IntVal y, _)) =>
      Constant (IntVal (x*y), pos)
  | (Constant (IntVal 0, _), _) =>
    e1'
  | (_, Constant (IntVal 0, _)) =>
    e2'
  | (Constant (IntVal 1, _), _) =>
    e2'
  | (_, Constant (IntVal 1, _)) =>
    e1'
  | _ =>
    Times (e1', e2', pos)
end

```

We start by optimizing the two subexpressions. Then we check if any of the two expressions evaluates to 0 or 1. If one of them is 0, we return 0. Also, if one of them is 1 then it will be the

other expression that is returned, no matter what it states. If none of the above applies, then we want to compute the expression.

Below is the code for testing *Times*.

```
fun int main() =  
  let a = 5 in  
  let b = a in  
  let c = b in  
    write(b + c * 0)
```

If our propagation is correct, all the variables should evaluate to 5, due to *a* having that constant assigned.

In the *write*-statement we have some expressions which also can be optimized. Since we multiply by 0, that whole expression will evaluate to 0. Then we plus *b* with 0 and end up with *b* as the result, and we end up writing *b*.

In the end, our program will look like this when optimized using copy propagation and constant folding.

```
fun int main() =  
  let a = 5 in  
  let b = 5 in  
  let c = 5 in  
    write(5)
```

APPENDIX

Lexer.lex

```
40 | "fn"          => Parser.FN pos
42 | "not"         => Parser.NOT pos

66 | "true"|"false" { case Bool.fromString (getLexeme lexbuf) of
67 |                 NONE  => lexerError lexbuf "Bad bool"
68 |                 | SOME b => Parser.BOOLEAN (b, getPos lexbuf) }

87 | '*'          { Parser.TIMES (getPos lexbuf) }
88 | '/'          { Parser.DIV (getPos lexbuf) }
89 | '~'          { Parser.NEG (getPos lexbuf) }
91 | ">="          { Parser.ARROW (getPos lexbuf) }
94 | "||"         { Parser.OR (getPos lexbuf) }
95 | "&&"         { Parser.AND (getPos lexbuf) }
```

Parser.grm

```

10 %token <(int*int)> IF THEN ELSE LET IN INT BOOL CHAR EOF
11 %token <string*(int*int)> ID STRINGLIT
12 %token <int*(int*int)> NUM
13 %token <char*(int*int)> CHARLIT
14 %token <bool*(int*int)> BOOLEAN
15 %token <(int*int)> PLUS MINUS DEQ EQ LTH NEG NOT ARROW
16 %token <(int*int)> TIMES DIV AND NOT OR LPAR RPAR LBRACKET RBRACKET LCURLY RCURLY
17 %token <(int*int)> COMMA
18 %token <(int*int)> FUN FN IOTA REPLICATE MAP REDUCE FILTER SCAN READ WRITE
19 %token <(int*int)> OP

21 %nonassoc ifprec letprec
22 %left DEQ LTH
23 %left OR
24 %left AND
25 %nonassoc NOT
26 %left PLUS MINUS
27 %left TIMES DIV
28 %nonassoc NEG

84         | Exp TIMES Exp
85             { Times($1, $3, $2) }
86         | Exp DIV Exp
87             { Divide($1, $3, $2) }
88         | NEG Exp
89             { Negate($2, $1) }
90         | Exp AND Exp { And($1, $3, $2) }
91         | Exp OR Exp
92             { Or($1, $3, $2) }

117        | SCAN LPAR FunArg COMMA Exp COMMA Exp RPAR
118            { Scan ($3, $5, $7, (), $1) }
119        | FILTER LPAR FunArg COMMA Exp RPAR
120            { Filter ($3, $5, (), $1) }

126        | NOT Exp %prec ifprec { Not ( $2, $1 ) }

133 FunArg : ID { FunName (#1 $1) }
134         | FN Type LPAR Params RPAR ARROW Exp
135           { Lambda ( $2, $4, $7, $1 ) }
136         | FN Type LPAR RPAR ARROW Exp
137           { Lambda ( $2, [], $6, $1 ) }
138 ;

```

TypeChecker.sml

```

255 | In.Times (e1, e2, pos)
256   => let val (_, e1_dec, e2_dec) = checkBinOp ftab vtab (pos, Int, e1, e2)
257       in (Int,
258           Out.Times(e1_dec, e2_dec, pos))
259       end
260
261 | In.Divide (e1, e2, pos)
262   => let val (_, e1_dec, e2_dec) = checkBinOp ftab vtab (pos, Int, e1, e2)
263       in (Int,
264           Out.Divide(e1_dec, e2_dec, pos))
265       end
266
267 | In.Negate (e1, pos)
268   => let val (t1, e1') = checkExp ftab vtab e1
269       in (Int, Out.Negate(e1', pos))
270       end
271
272 | In.Not (e1, pos)
273   => let val (t1, e1') = checkExp ftab vtab e1
274       in (Bool, Out.Not(e1', pos))
275       end
276
277 | In.Or (e1, e2, pos)
278   => let val (t1, e1') = checkExp ftab vtab e1
279       val (t2, e2') = checkExp ftab vtab e2
280       in
281         if (t1 = Bool andalso t2 = Bool) then
282           (Bool, Out.Or(e1', e2', pos))
283         else
284           raise Error("Type Error: Non-boolean arguments given to ||", pos)
285       end
286
287 | In.And (e1, e2, pos)
288   => let val (t1, e1') = checkExp ftab vtab e1
289       val (t2, e2') = checkExp ftab vtab e2
290       in
291         if (t1 = Bool andalso t2 = Bool) then
292           (Bool, Out.And(e1', e2', pos))
293         else
294           raise Error("Type Error: Non-boolean arguments given to &&", pos)
295       end
296
297 | In.Scan (f, n_exp, arr_exp, _, pos) 256
298   => let val (n_type, n_dec) = checkExp ftab vtab n_exp
299       val (arr_type, arr_dec) = checkExp ftab vtab arr_exp
300       val elem_type =
301         case arr_type of
302           Array t => t
303         | other => raise Error ("Scan: argument is not an array", pos)
304       val (f', f_arg_type) =
305         case checkFunArg (f, vtab, ftab, pos) of
306           (f', res, [a1, a2]) =>

```



```

308         if a1 = a2 andalso a2 = res
309         then (f', res)
310         else raise Error
311             ("Scan: incompatible function type of "
312              ^ In.ppFunArg 0 f ^ ": " ^ showFunType ([a1, a2], res),
pos)
313     | (_, res, args) =>
314         raise Error ("Scan: incompatible function type of "
315                      ^ In.ppFunArg 0 f ^ ": " ^ showFunType (args, res),
pos)
316     fun err (s, t) =
317         Error ("Scan: unexpected " ^ s ^ " type " ^ ppType t ^
318              ", expected " ^ ppType f_arg_type, pos)
319     in if elem_type = f_arg_type
320        then if elem_type = n_type
321            then (Array elem_type,
322                  Out.Scan (f', n_dec, arr_dec, elem_type, pos))
323            else raise (err ("neutral element", n_type))
324        else raise err ("array element", elem_type)
325    end

329 | In.Filter (f, arr_exp, _, pos) 260
330   => let val (arr_type, arr_exp_dec) = checkExp ftab vtab arr_exp
331
332       val elem_type =
333         case arr_type of
334           Array t => t
335         | other => raise Error ("Filter: argument is not an array", pos)
336
337       val (f', f_res_type, f_arg_type) =
338         case checkFunArg (f, vtab, ftab, pos) of
339           (f', Bool, [a1]) => (f', Bool, a1)
340         | (_, res, args) =>
341           raise Error ("Filter: incompatible function type of "
342                        ^ In.ppFunArg 0 f ^ ": " ^ showFunType (args, res),
pos)
343
344       in (arr_type,
345          Out.Filter (f', arr_exp_dec, elem_type, pos))
346     end

362 | checkFunArg (In.Lambda (ret_type, params, body, funpos) 276
363                  , vtab, ftab, pos) =
364     let val (Out.FunDec (name, _, params, body', pos)) = checkFunWithVtable (In.
365 FunDec ("Lambda", ret_type, params, body, pos), vtab, ftab, funpos)
366     in
367       val arg_types = map (fn (Param (_, ty)) => ty) params
368     in
369       (Out.Lambda(ret_type, params, body', funpos), ret_type, arg_types)
370     end

```

CodeGen.sml

```

614 | Constant (BoolVal b, pos) =>
615     if(b) then
616         [Mips.LI(place, "1")]
617     else
618         [Mips.LI(place, "0")]

624 | Times (e1, e2, pos) =>
625     let val t1 = newName "times_L"
626         val t2 = newName "times_R"
627         val code1 = compileExp e1 vtable t1
628         val code2 = compileExp e2 vtable t2
629     in code1 @ code2 @ [Mips.MUL (place, t1, t2)]
630     end

631 | Divide (e1, e2, pos) =>
632     let val t1 = newName "div_L"
633         val t2 = newName "div_R"
634         val code1 = compileExp e1 vtable t1
635         val code2 = compileExp e2 vtable t2
636     in code1 @ code2 @ [Mips.DIV (place, t1, t2)]
637     end

638
639 | Negate (e1, pos) =>
640     let val t1 = newName "negateVal"
641         val code1 = compileExp e1 vtable t1
642     in code1 @ [ Mips.SUB(place, "0", t1) ]
643     end

645 | Not (b_exp, pos) =>
646     let val b = "boolean"
647         val code1 = compileExp b_exp vtable b
648         val falseLabel = newName "false"
649     in code1 @
650         [ Mips.LI (place, "0")
651         , Mips.BNE (b, "0", falseLabel)
652         , Mips.LI (place, "1")
653         , Mips.LABEL falseLabel ]
654     end

655
656 | Or (e1, e2, pos) =>
657     let val trueLabel = newName "trueLabel"
658         val falseLabel = newName "falseLabel"
659         val endLabel = newName "endLabel"
660         val code1 = compileCond e1 vtable trueLabel falseLabel
661         val code2 = compileCond e2 vtable trueLabel endLabel
662     in [Mips.LI(place, "0")] @
663         code1 @
664         [Mips.LABEL falseLabel] @
665         code2 @
666         [Mips.LABEL trueLabel, Mips.LI(place, "1"), Mips.LABEL endLabel]
667     end

668
669 | And (e1, e2, pos) =>

```

```

670     let val trueLabel = newName "trueLabel"
671         val falseLabel = newName "falseLabel"
672         val endLabel = newName "endLabel"
673         val code1 = compileCond e1 vtable trueLabel falseLabel
674         val code2 = compileCond e2 vtable endLabel falseLabel
675     in [Mips.ADD(place, "0", "1")] @
676        code1 @
677        [Mips.LABEL trueLabel] @
678        code2 @
679        [Mips.LABEL falseLabel, Mips.ADD(place, "0", "0"), Mips.LABEL endLabel]
680    end

688    (* Scan(f, e, [a1, a2, ..., an]) = [e, f(e, a1), f(f(e, a1), a2), ...] *)
689    | Scan (farg, acc_exp, arr_exp, elem_type, pos) =>
690        let val in_size_reg = newName "in_size_reg" (* size of input array *)
691            val out_size_reg = newName "out_size_reg" (* size of output array *)
692            val acc_reg = newName "acc_reg" (* last computed value for output *)
693            val i_reg = newName "i_reg" (* Iterator register *)
694            val addr_reg = newName "addr_reg" (* address of element in output array
*)
695            val arr_reg = newName "arr_reg"
696            val elem_reg = newName "elem_reg"
697
698            val arr_code = compileExp arr_exp vtable arr_reg
699            val acc_code = compileExp acc_exp vtable acc_reg
700
701            val get_size = [ Mips.LW (in_size_reg, arr_reg, "0") (* Loads array-size
into in_size_reg *)
702                           , Mips.ADDI(out_size_reg, in_size_reg, "1") (* Puts size
into out_size_reg *)
703                           ]
704
705            (* Initiate registers.
706               Put address of place into addr_reg, so we return proper addresses.
707               Increment in_size_reg by 1 to determine out_size_reg, since output
array is
708               1 element longer. *)
709            val init_regs = [ Mips.ADDI (addr_reg, place, "4") (* point to the next
word *)
710                           , Mips.SW (acc_reg, addr_reg, "0")
711                           , Mips.ADDI (addr_reg, addr_reg, "4") (* point to next
word*)
712                           , Mips.MOVE(i_reg, "0") (* initialize iterator*)
713                           , Mips.ADDI (arr_reg, arr_reg, "4") (* Look at first
element in input array*)
714                           ]
715
716
717            val loop_beg = newName "loop_beg"
718            val loop_end = newName "loop_end"
719            val tmp_reg = newName "tmp_reg"
720
721            (* while i_reg < in_size_reg*)
722            val loop_head =

```

```

723         [ Mips.LABEL(loop_beg)
724         , Mips.SUB(tmp_reg, i_reg, out_size_reg) (* make statement*)
725         , Mips.BGEZ(tmp_reg, loop_end) ] (* if statement is equal to zero,
jump to end *)
726     (* loads next value in input array into tmp_reg *)
727     val load_value =
728         case getElemSize elem_type of
729             One => [ Mips.LB (elem_reg, arr_reg, "0")
730                     , Mips.ADDI (arr_reg, arr_reg, "1") ]
731             | Four => [ Mips.LW (elem_reg, arr_reg, "0")
732                       , Mips.ADDI (arr_reg, arr_reg, "4") ]
733
734     val apply_code =
735         applyFunArg(farg, [acc_reg, elem_reg], vtable, acc_reg, pos)
736
737     (* save the current accumulated value to a register for later
computations,
and to memory for later output *)
738     val save_value =
739         case getElemSize elem_type of
740             One => [ Mips.SB (acc_reg, addr_reg, "0")
741                     , Mips.ADDI (addr_reg, addr_reg, "1")]
742             | Four => [ Mips.SW (acc_reg, addr_reg, "0")
743                       , Mips.ADDI (addr_reg, addr_reg, "4")]
744
745
746
747     (* increments i_reg *)
748     val loop_foot =
749         [ Mips.ADDI(i_reg, i_reg, "1")
750         , Mips.J loop_beg
751         , Mips.LABEL loop_end ]
752
753
754 in [Mips.LABEL "Det_her_er_starten"]
755 @ arr_code
756 @[Mips.LABEL "array_kode"]
757 @ acc_code
758 @[Mips.LABEL "akku_kode"]
759 @ get_size
760 @[Mips.LABEL "Stoerrelsen_på_dyret"]
761 @ dynalloc (out_size_reg, place, elem_type)
762 @[Mips.LABEL "init_regz"]
763 @ init_regs
764 @[Mips.LABEL "starten_af_loopet"]
765 @ loop_head
766 @[Mips.LABEL "midten_af_loopet"]
767 @ load_value
768 @[Mips.LABEL "mere_midte"]
769 @ apply_code
770 @[Mips.LABEL "gem_den_akku"]
771 @ save_value
772 @[Mips.LABEL "foden_af_loopet"]
773 @ loop_foot
774 @ [Mips.LABEL "Det_her_er_slutningen_SCAN"]

```

```

775         end

783         (* filter(f(), acc, [a1,a2]) = [f(acc, a1), f(acc, a2)] *)
784         | Filter (farg, arr_exp, elem_type, pos) =>
785             let val size_reg = newName "size_reg" (* size of input/output array *)
786                 val arr_reg = newName "arr_reg" (* address of input array *)
787                 val elem_reg = newName "elem_reg" (* address of single element *)
788                 val res_reg = newName "res_reg"
789                 val val_reg = newName "val_reg"
790                 val arr_code = compileExp arr_exp vtable arr_reg
791
792                 val get_size = [ Mips.LW (size_reg, arr_reg, "0") ] (* *)
793
794                 val addr_reg = newName "addr_reg" (* address of element in new array *)
795                 val i_reg = newName "i_reg"
796                 val j_reg = newName "j_reg"
797                 val init_regs = [ Mips.ADDI (addr_reg, place, "4") (*point to the next
word, so we don't overwrite the size*)
798                                     , Mips.MOVE (i_reg, "0")
799                                     , Mips.LI (j_reg, "0")
800                                     , Mips.ADDI (elem_reg, arr_reg, "4") ]
801
802                 val loop_beg = newName "loop_beg"
803                 val loop_end = newName "loop_end"
804                 val tmp_reg = newName "tmp_reg"
805                 val loop_header = [ Mips.LABEL (loop_beg)
806                                     , Mips.SUB (tmp_reg, i_reg, size_reg)
807                                     , Mips.BGEZ (tmp_reg, loop_end)
808                                     , Mips.ADDI (i_reg, i_reg, "1") ]
809
810                 (* map is 'arr[i] = f(old_arr[i])'. *)
811                 val loop_load =
812                     case getElemSize elem_type of
813                         One => Mips.LB(val_reg, elem_reg, "0")
814                             :: applyFunArg(farg, [val_reg], vtable, res_reg, pos)
815                             @ [ Mips.ADDI(elem_reg, elem_reg, "1") ]
816                     | Four => Mips.LW(val_reg, elem_reg, "0")
817                             :: applyFunArg(farg, [val_reg], vtable, res_reg, pos)
818                             @ [ Mips.ADDI(elem_reg, elem_reg, "4") ]
819
820                 val check_fun = [ Mips.BEQ (res_reg, "0", loop_beg)
821                                     , Mips.ADDI (j_reg, j_reg, "1") ]
822
823                 val loop_save =
824                     case getElemSize elem_type of
825                         One => [ Mips.SB (val_reg, addr_reg, "0") ]
826                     | Four => [ Mips.SW (val_reg, addr_reg, "0") ]
827
828                 val loop_footer =
829                     [ Mips.ADDI (addr_reg, addr_reg,
830                                 makeConst (elemSizeToInt (getElemSize elem_type)))
831                     , Mips.J loop_beg
832                     , Mips.LABEL loop_end
833                     , Mips.SW (j_reg, place, "0")

```

```

834         ]
835     in [Mips.LABEL "array_kode"]
836         @ arr_code (* make arr_reg point to input array*)
837         @[Mips.LABEL "measuring"]
838         @ get_size (* gets the size of the input array *)
839         @[Mips.LABEL "allocating_da_mem"]
840         @ dyncall (size_reg, place, elem_type) (* return place, which is an
address where the output array is going to be *)
841         @[Mips.LABEL "initializing"]
842         @ init_regs
843         @[Mips.LABEL "loopin"]
844         @ loop_header
845         @ loop_load
846         @ check_fun
847         @ [Mips.LABEL "saving"]
848         @ loop_save
849         @ loop_footer
850     end

868 | applyFunArg (Lambda(ret_type, params, body', funpos), args, vtable, place,
pos) : Mips.Prog =
868     let
869         fun bindVars ([], [], vtable) = vtable
870         | bindVars([], args, vtable) = raise Error("stop det pjat", pos)
871         | bindVars(params, [], vtable) = raise Error("stop det pjat stadigvæk",
pos)
872         | bindVars(Param (name, paramtype)::params, arg::args, vtable) = SymTab.
bind name arg (bindVars(params, args, vtable))
873     val newVtable = bindVars(params, args, vtable)
874     val code1 = compileExp body' newVtable place
875     in
876         code1
877     end

```

Interpreter.sml

```

412 | evalExp ( Times(e1, e2, pos), vtab, ftab ) =
413     let val res1 = evalExp(e1, vtab, ftab)
414         val res2 = evalExp(e2, vtab, ftab)
415     in evalBinopNum(op *, res1, res2, pos)
416     end
417
418 | evalExp ( Divide(e1, e2, pos), vtab, ftab ) =
419     let val res1 = evalExp(e1, vtab, ftab)
420         val res2 = evalExp(e2, vtab, ftab)
421     in evalBinopNum(op div, res1, res2, pos)
422     end
423
424 | evalExp ( Negate(e1, pos), vtab, ftab ) =
425     let val res1 = evalExp(e1, vtab, ftab)
426         val res2 = evalExp(Constant(IntVal 0, pos), vtab, ftab)
427     in evalBinopNum(op +, res1, res2, pos)
428     end
429
430 | evalExp ( Not(e1, pos), vtab, ftab ) =
431     let val res1 = evalExp(e1, vtab, ftab)
432     in case res1 of
433         BoolVal true => BoolVal false
434       | BoolVal false => BoolVal true
435       | _ => raise Error("Input is not of type bool", pos)
436     end
437
438 | evalExp ( And(e1, e2, pos), vtab, ftab ) =
439     let val res1 = evalExp(e1, vtab, ftab)
440         val res2 = evalExp(e2, vtab, ftab)
441     in case res1 of
442         BoolVal false => res1
443       | BoolVal true => (case res2 of
444           BoolVal _ => res2
445         | _ => raise Error("Second argument is not of type
446 bool", pos))
447     | _ => raise Error("First argument is not of type bool", pos)
448     end
449
450 | evalExp ( Or(e1, e2, pos), vtab, ftab ) =
451     let val res1 = evalExp(e1, vtab, ftab)
452         val res2 = evalExp(e2, vtab, ftab)
453     in case res1 of
454         BoolVal true => res1
455       | BoolVal false => (case res2 of
456           BoolVal _ => res2
457         | _ => raise Error("Second argument is not of type
458 bool", pos))
459     | _ => raise Error("First argument is not of type bool", pos)
460     end

```

```
517 | evalFunArg (Lambda(ret_type, params, exp, pos), vtab, ftab, callpos) =  
518 |   let  
519 |     val fundec = FunDec ("Lambda", ret_type, params, exp, pos)  
520 |   in  
521 |     (fn aargs => callFunWithVtable(fundec, aargs, vtab, ftab, callpos), ret_type)  
522 |   end
```


CopyConstPropFold.sml

```
16 fun copyConstPropFoldExp vtable e =
17   case e of
18     Constant x => Constant x
19   | StringLit x => StringLit x
20   | ArrayLit (es, t, pos) =>
21     ArrayLit (map (copyConstPropFoldExp vtable) es, t, pos)
22   | Var (name, pos) =>
23     (* TODO TASK 4: This case currently does nothing.
24
25     You must perform a lookup in the symbol table and if you find
26     a Propagatee, return either a new Var or Constant node. *)
27     let
28       val value = SymTab.lookup name vtable
29     in
30       case value of
31         SOME (VarProp v) => copyConstPropFoldExp vtable (Var(v, pos))
32       | SOME (ConstProp v) => copyConstPropFoldExp vtable (Constant(v, pos))
33       | NONE => Var(name, pos)
34     end
102 let val e' = copyConstPropFoldExp vtable e
103 in
104   let
105     val vtable' =
106       case e' of
107         (Var (vname, p)) => (SymTab.bind name (VarProp(vname)) vtable)
108       | (Constant (vval, p)) => (SymTab.bind name (ConstProp(vval)) vtable)
109       | _ => vtable
110   in
111     Let (Dec (name, e', decpos), copyConstPropFoldExp vtable' body, pos)
112   end
113 end
```