Several of the questions in this problem set refer to the following input character strings:
I1 = `((32+100)*(16-4))`, I2 = `((32+(10*10))*(16-4))`, and I3 = `((32+(100*16))-4)`.

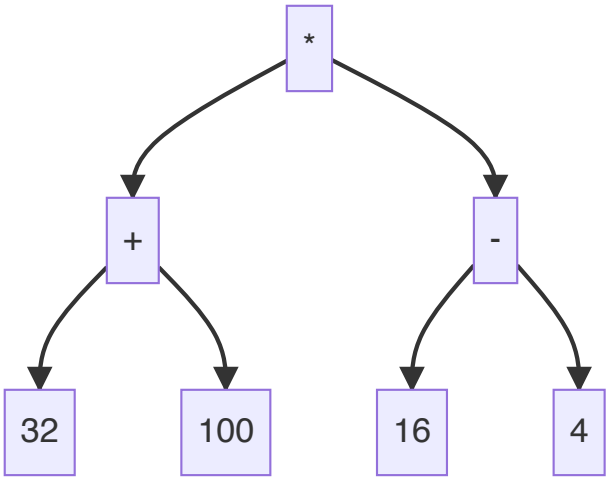
1. *Input character strings and token streams.
   * For each input character string Ik (1 ≤ k ≤ 3), write down the corresponding token stream Sk that SamTokenizer would generate. What are the compression ratios for each input string, where *compression ratio* is defined as the number of characters in the input string divided by the number of resulting tokens?

```
I1:
(
(
32
+
100
)
*
(
16
-
4
)
)
```

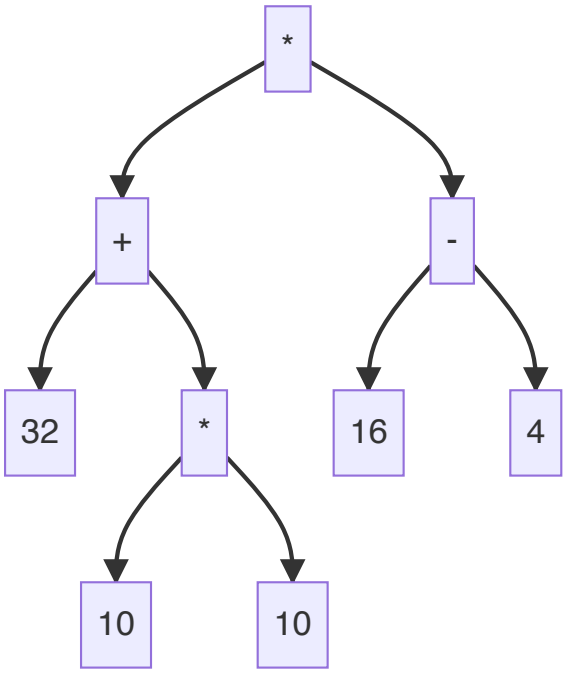
   12 tokens, 13/17

   Same calculation methods for other two

2. *Abstract syntax trees.
   * For each input character string Ik (1 ≤ k ≤ 3), show its corresponding abstract syntax tree Tk when parsed with the expression grammar of LiveOak. In what way are T1 and T2 the same? In what way are they different?
   I1:

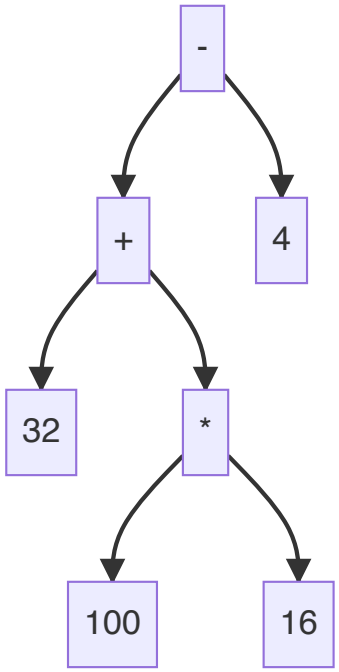


I2:



I1 and I2 are similar in level 0-1, but different at node “*” starting level 2 and down. It is because the expression added a branch in that slot.

I3:



3. *Parsing and lookahead.
   * Trace the individual steps of parsing and AST generation for input string I1 using a recursive-descent parser driven by the expression grammar of LiveOak. At each step, indicate the current and lookahead tokens, and sketch the shape of the parse tree and AST.

```
getExpr('((32+100)*(16-4))'):
token = '('
lookahead = '('
  getExpr('(32+100)*(16-4))'):
    token = '('
    lookahead = '32'
    token = '32'
    exp1 = `PUSHIMM 32`
    token = '+'
    binop = `ADD`
    token = '100'
    exp2 = `PUSHIMM 100`
    token = ')'
  return expr(exp1+exp2+binop)
exp1 = return1
lookahead = '*'
binop = `TIMES`
token = '('
  getExpr('(16-4))'):
```

```
    token = '('
    lookahead = '16'
    token = '16'
    exp1 = `PUSHIMM 16`
    token = '-'
    binop = `SUB`
    token = '4'
    exp2 = `PUSHIMM 4`
    token = ')'
  return expr(exp1+exp2+binop)
exp2 = return2
token = ')'
return expr(exp1 + exp2 + binop)
```

4. *Code generation.
   * Show the SaM code generated for input string I2. Indicate the correspondence between code fragments and the AST nodes where they are generated and/or assembled.

```
getExpr('((32+(10+10))*(16-4))'):
token = '('
lookahead = '('

  getExpr('(32+(10+10))*(16-4))'):
    token = '('
    lookahead = '32'
    token = '32'
    exp1 = `PUSHIMM 32`
    token = '+'
    binop = `ADD`
    token = '('
    lookahead = '10'

    getExpr('(10+10)*(16-4))'):
      token = '('
      lookahead = '10'
      token = '10'
      exp1 = `PUSHIMM 10`
      token = '+'
      binop = `ADD`
      token = '('
      exp2 = `PUSHIMM 10`
      token = ')'
      return expr(exp1+exp2+binop)

```

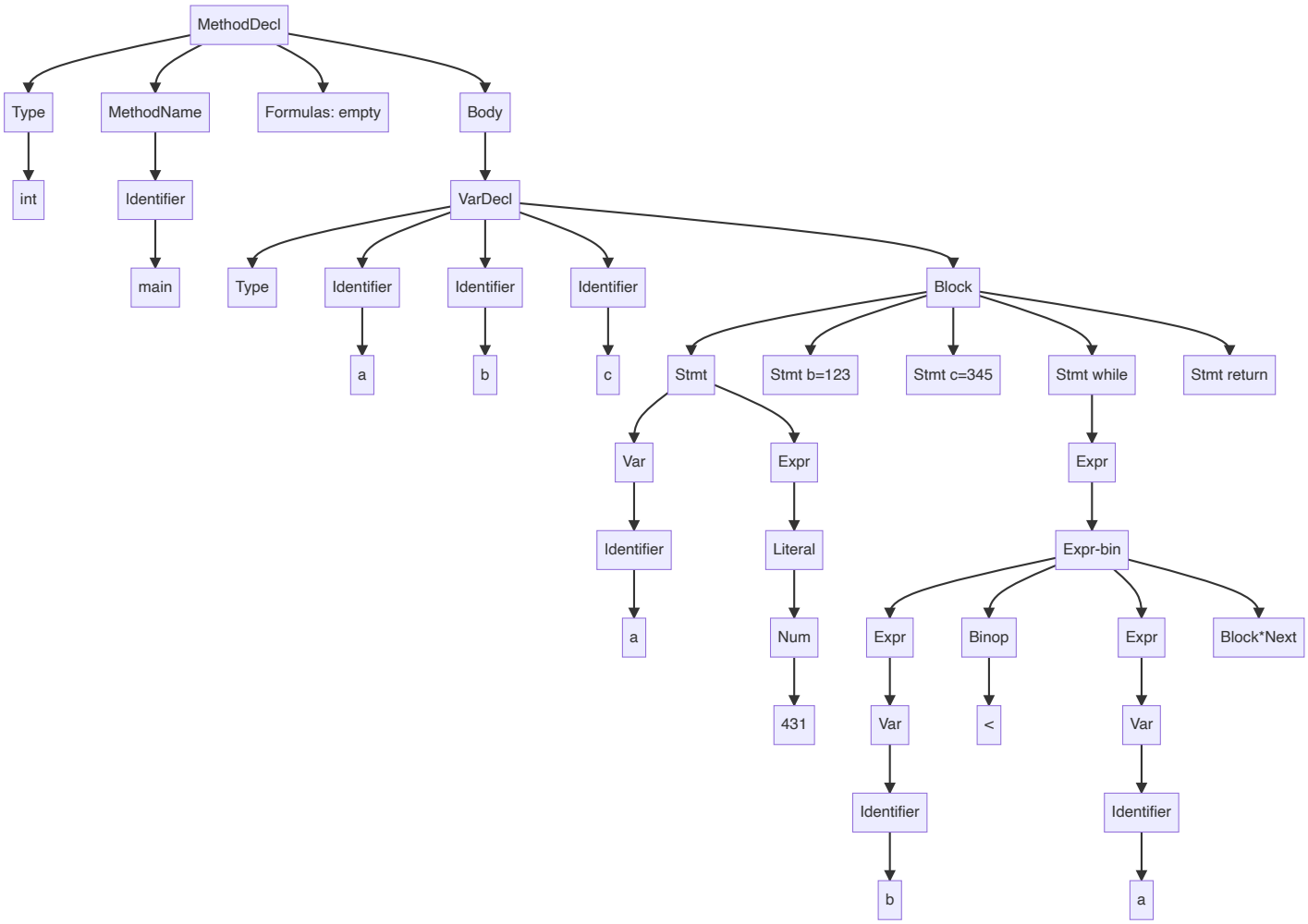
```
    exp2 = return1
    token = ')'
    return expr(exp1+exp2+binop)

exp1 = return1
lookahead = '*'
binop = `TIMES`
token = '('

  getExpr('(16-4))'):
    token = '('
    lookahead = '16'
    token = '16'
    exp1 = `PUSHIMM 16`
    token = '-'
    binop = `SUB`
    token = '4'
    exp2 = `PUSHIMM 4`
    token = ')'
    return expr(exp1+exp2+binop)

exp2 = return2
token = ')'
return expr(exp1 + exp2 + binop)
```

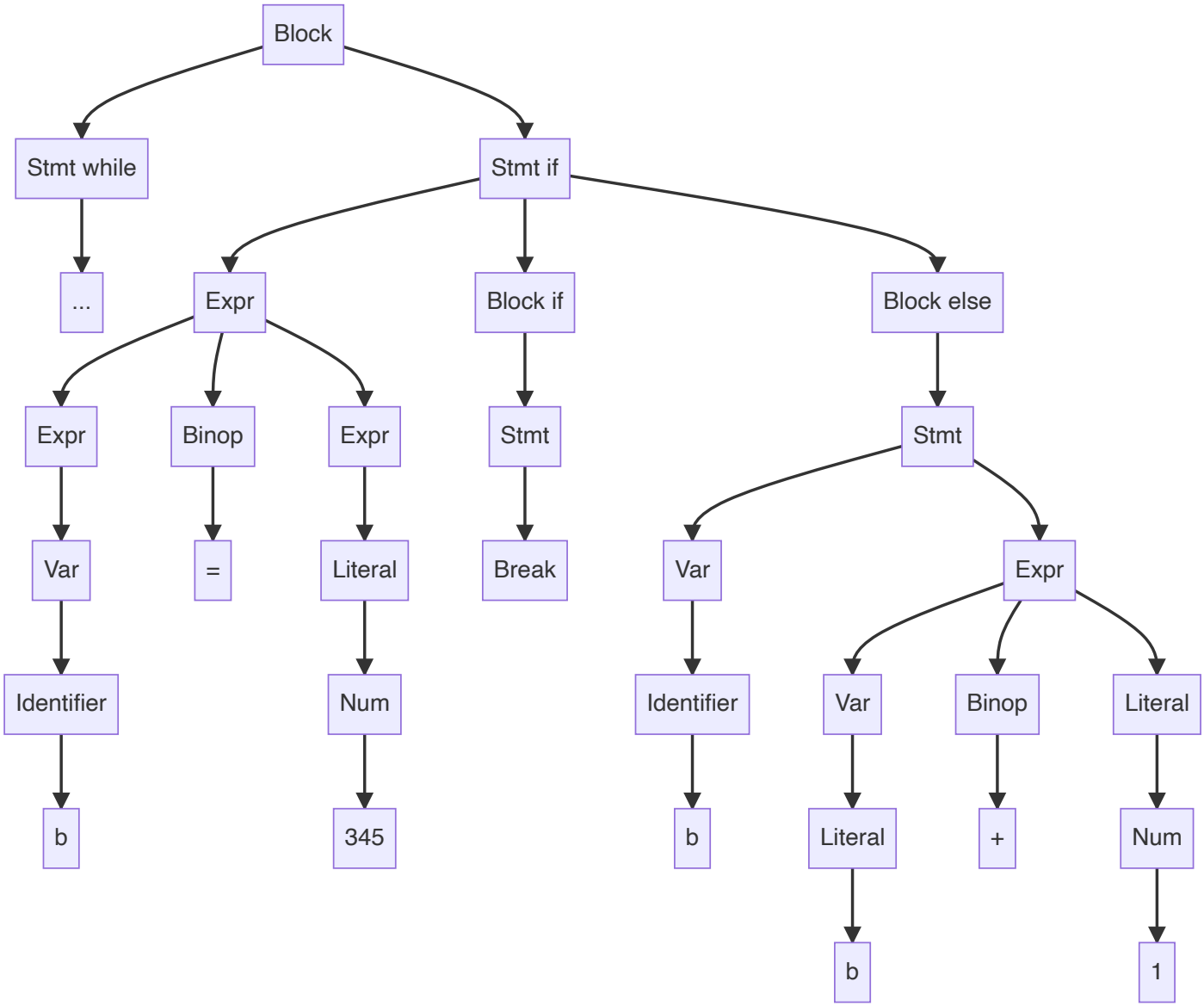
```
// (...) * (...)
  // (32 + (...))
  PUSHIMM 32
    // (10+10)
    PUSHIMM 10
    PUSHIMM 10
    ADD
  ADD

  // (16 - 4)
  PUSHIMM 16
  PUSHIMM 4
  SUB

TIMES
```

1. *Code shape.
   * Consider the following piece of LiveOak-2 code.

```
int main() {
        int a, b, c;

        a = 431; b = 123; c = 345;
        while((b<a)) {
            while((b<c))
                    b = (b+1);
            if((b = 345))
                    break;
            else
                    b = (b + 1);
        }
        return b;
}
```

Work through the actions of the recursive-descent parser and the SaM code generator on this input. Show the structure of the AST and the contents of the symbol table. Indicate how the various code fragments are generated, stitched together, and passed around in the tree representation of the pro- gram.


MethodDecl
Type
MethodName
Formulas: empty
Body
int
Identifier
main
VarDecl
Type
Identifier
Identifier
Identifier
a
b
c
Block
Stmt
Stmt b=123
Stmt c=345
Stmt while
Stmt return
Var
Expr
Expr
Identifier
Literal
Expr-bin
a
Num
Expr
Binop
Expr
Block*Next
431
Var
<
Var
Identifier
Identifier
b
a




```
// MethodDecl
  // VarDecl int a, b, c
    ADDSP 3
    (addToSymbolTable(a,b,c))
    (numVars = 3)

  // Stmt a = 431
    // Var a
      (symbol = symbolTable[a])
      PUSHOFF symbol.offset // redundent PUSH
     PUSHIMM 431
```

```
    STOREOFF symbol.offset
    ADDSP -1 // remove redundant PUSH

// Stmt b = 123
  // Var b
    (symbol = symbolTable[b])
    PUSHOFF symbol.offset // redundent PUSH
    PUSHIMM 123
    STOREOFF symbol.offset
    ADDSP -1 // remove redundant PUSH

// Stmt c = 345
  // Var c
    (symbol = symbolTable[c])
    PUSHOFF symbol.offset // redundent PUSH
    PUSHIMM 345
    STOREOFF symbol.offset
    ADDSP -1 // remove redundant PUSH

// Stmt While
    // Expr (b<a)
        // Var b
          (symbol = symbolTable[b])
          PUSHOFF symbol.offset
        // Var a
          (symbol = symbolTable[a])
          PUSHOFF symbol.offset
        LESS

    // Block
        // Stmt While
            (Ltop, Lmid = newlabel(), newlabel())

            JUMP Lmid

            Ltop:
            // Block-Stmt b = (b+1)
              // Var b
                (symbol = symbolTable[b])
                PUSHOFF symbol.offset // redundent PUSH
              // Expr (b+1)
                // Var b
                  (symbol = symbolTable[b])
                  PUSHOFF symbol.offset
                PUSHOFF 1
                ADD
```

```
                STOREOFF symbol.offset
                ADDSP -1 // remove redundant PUSH

            Lmid:
            // Expr (b<c)
              // Var b
                (symbol = symbolTable[b])
                PUSHOFF symbol.offset
              // Var c
                (symbol = symbolTable[c])
                PUSHOFF symbol.offset
              LESS

        // Stmt if
            (Lif, Lbreak = newlabel(), newlabel())
            // Expr (b = 345)
                // Var b
                  (symbol = symbolTable[b])
                  PUSHOFF symbol.offset
                PUSHOFF 1
                EQUAL

            JUMPC Lif

            // Block else b = (b + 1)
              // Var b
                (symbol = symbolTable[b])
                PUSHOFF symbol.offset // redundent PUSH
              // Expr (b+1)
                // Var b
                  (symbol = symbolTable[b])
                  PUSHOFF symbol.offset
                PUSHOFF 1
                ADD
              STOREOFF symbol.offset
              ADDSP -1 // remove redundant PUSH

           Lif:
           // Block if
                // break
                    JUMPC Lbreak

           Lbreak:

// Stmt return b
  // Var b
```

```
      (symbol = symbolTable[b])
      PUSHOFF symbol.offset
    JUMP fEnd

fEnd:
  STOREOFF -1 // [Q: should return slot always at -1?]
  ADDSP -numVars
  JUMPIND

```