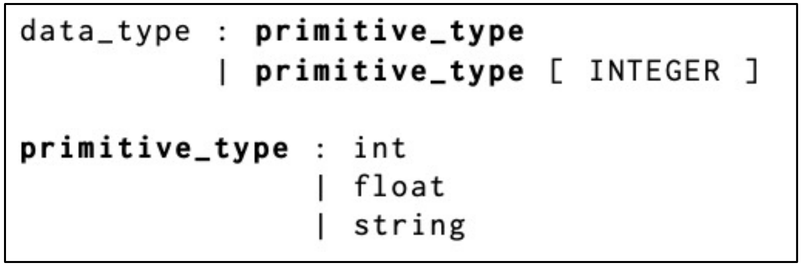
Array Implementation

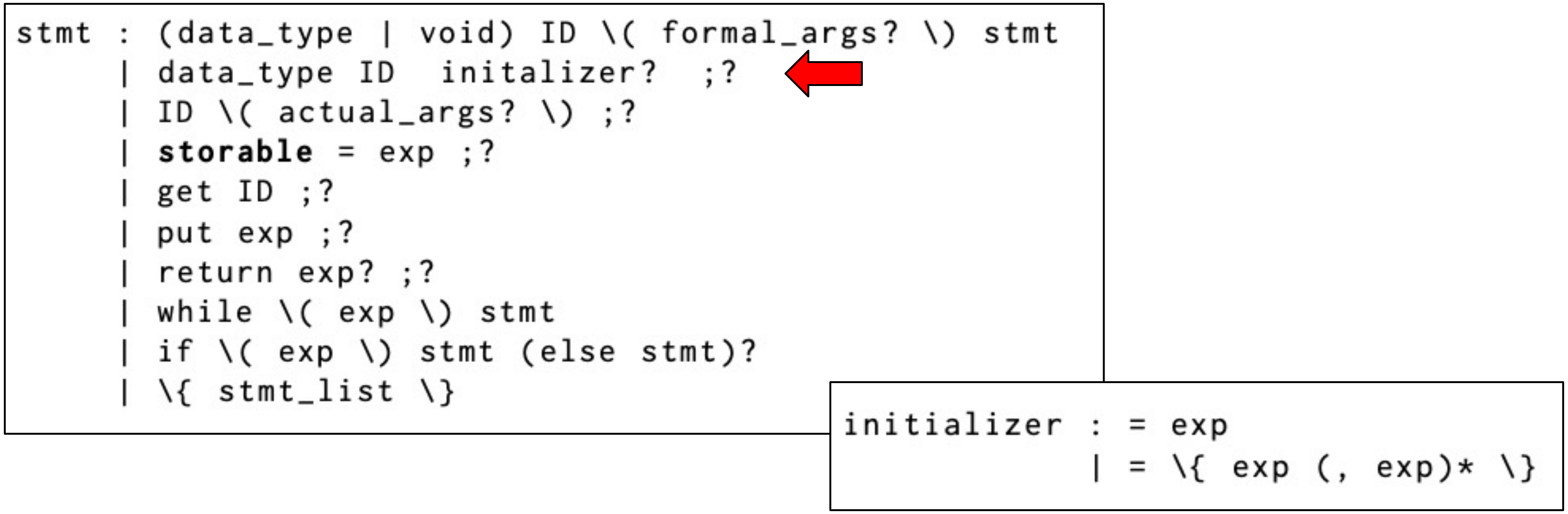
- The key insight here is that arrays can be viewed as *modifiers* to some primitive type such as int or float, e.g. int[10]
- This is expressed with the grammar rules:



```
data_type : primitive_type
          | primitive_type [ INTEGER ]

primitive_type : int
               | float
               | string
```

Array Implementation

- We also need to allow for array initializers of the form int[2] a = {1,2} in addition to the scalar initializers

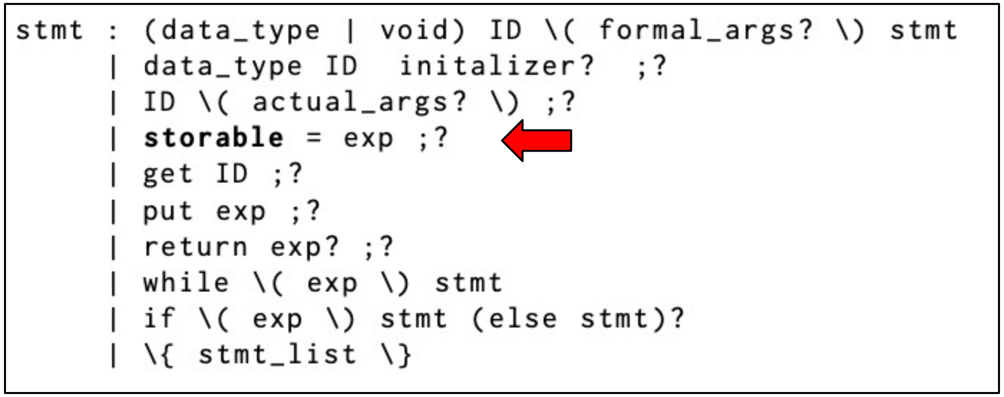


```
stmt : (data_type | void) ID \( formal_args? \) stmt
     | data_type ID  initalizer?  ;?
     | ID \( actual_args? \) ;?
     | storable = exp ;?
     | get ID ;?
     | put exp ;?
     | return exp? ;?
     | while \( exp \) stmt
     | if \( exp \) stmt (else stmt)?
     | \{ stmt_list \}
```

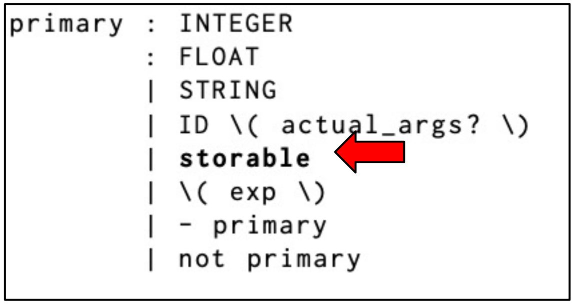
```
initializer : = exp
            | = \{ exp (, exp)* \}
```

Array Implementation

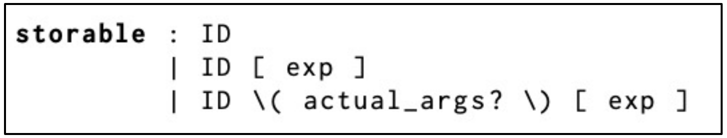
- The last thing we need to address are the contexts array expression can appear in:
  - Left hand side of an assignment statement
  - Within an expression
- We do this with the idea of a <u>storable</u>:



```
stmt : (data_type | void) ID \( formal_args? \) stmt
     | data_type ID  initalizer?  ;?
     | ID \( actual_args? \) ;?
     | storable = exp ;?
     | get ID ;?
     | put exp ;?
     | return exp? ;?
     | while \( exp \) stmt
     | if \( exp \) stmt (else stmt)?
     | \{ stmt_list \}
```



```
primary : INTEGER
        : FLOAT
        | STRING
        | ID \( actual_args? \)
        | storable
        | \( exp \)
        | - primary
        | not primary
```

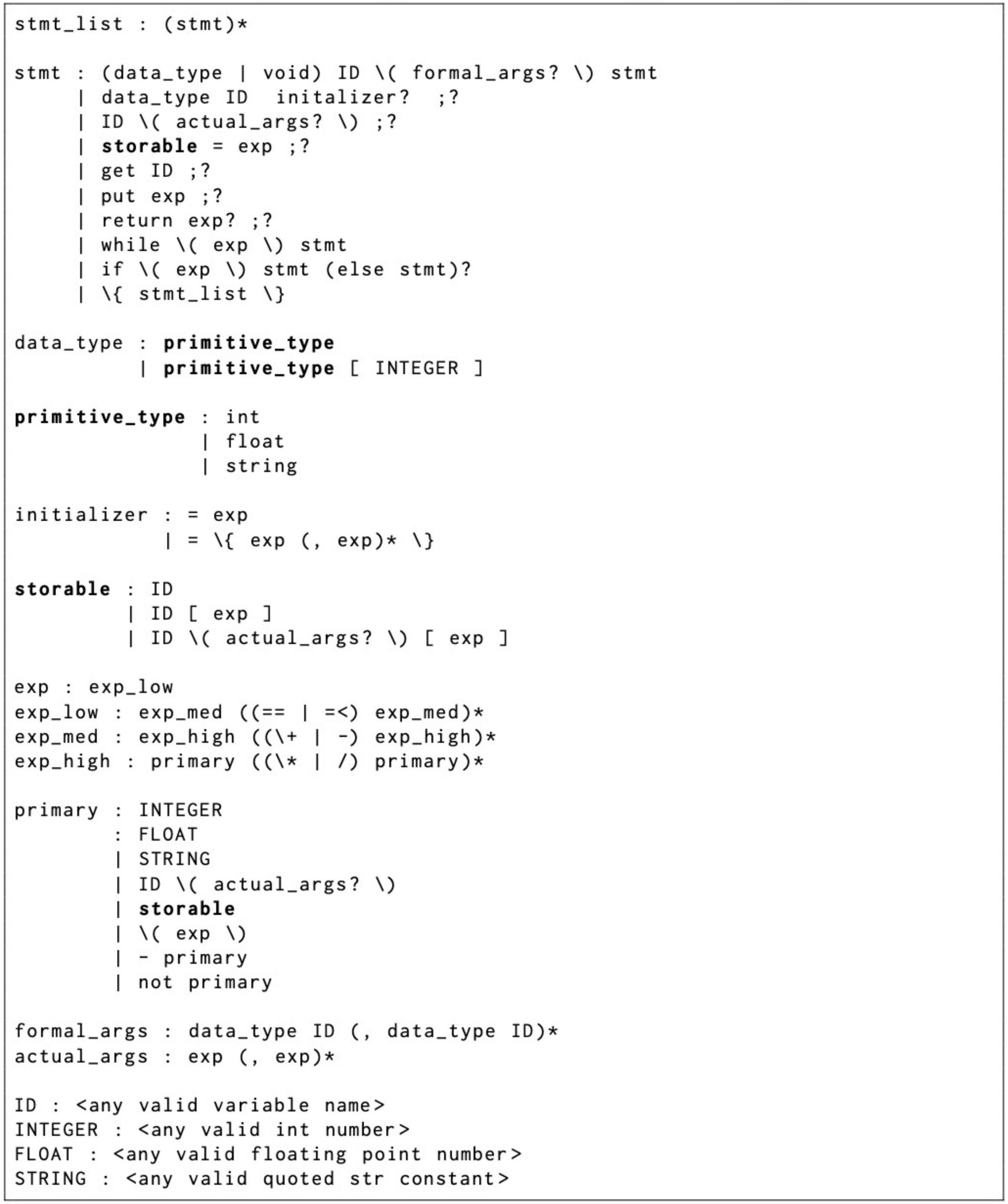


```
storable : ID
         | ID [ exp ]
         | ID \( actual_args? \) [ exp ]
```

The Frontend

This grammar can easily be transformed into an LL(1) by factoring common prefixes.

Listing 12.1: A grammar for the Cuppa5 language.



```
stmt_list : (stmt)*

stmt : (data_type | void) ID \( formal_args? \) stmt
     | data_type ID  initializer?  ;?
     | ID \( actual_args? \) ;?
     | storable = exp ;?
     | get ID ;?
     | put exp ;?
     | return exp? ;?
     | while \( exp \) stmt
     | if \( exp \) stmt (else stmt)?
     | \{ stmt_list \}

data_type : primitive_type
          | primitive_type [ INTEGER ]

primitive_type : int
               | float
               | string

initializer : = exp
            | = \{ exp (, exp)* \}

storable : ID
         | ID [ exp ]
         | ID \( actual_args? \) [ exp ]

exp : exp_low
exp_low : exp_med ((== | =<) exp_med)*
exp_med : exp_high ((\+ | -) exp_high)*
exp_high : primary ((\* | /) primary)*

primary : INTEGER
        : FLOAT
        | STRING
        | ID \( actual_args? \)
        | storable
        | \( exp \)
        | - primary
        | not primary

formal_args : data_type ID (, data_type ID)*
actual_args : exp (, exp)*

ID : <any valid variable name>
INTEGER : <any valid int number>
FLOAT : <any valid floating point number>
STRING : <any valid quoted str constant>
```

Array Types

- We expand our notion of type tuples with the introduction of array types.
- We have to capture the nuances of array types, the type

  `int[10]`

  is different from the type

  `int[20]`

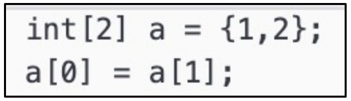
  and is certainly different from the type

  `int`

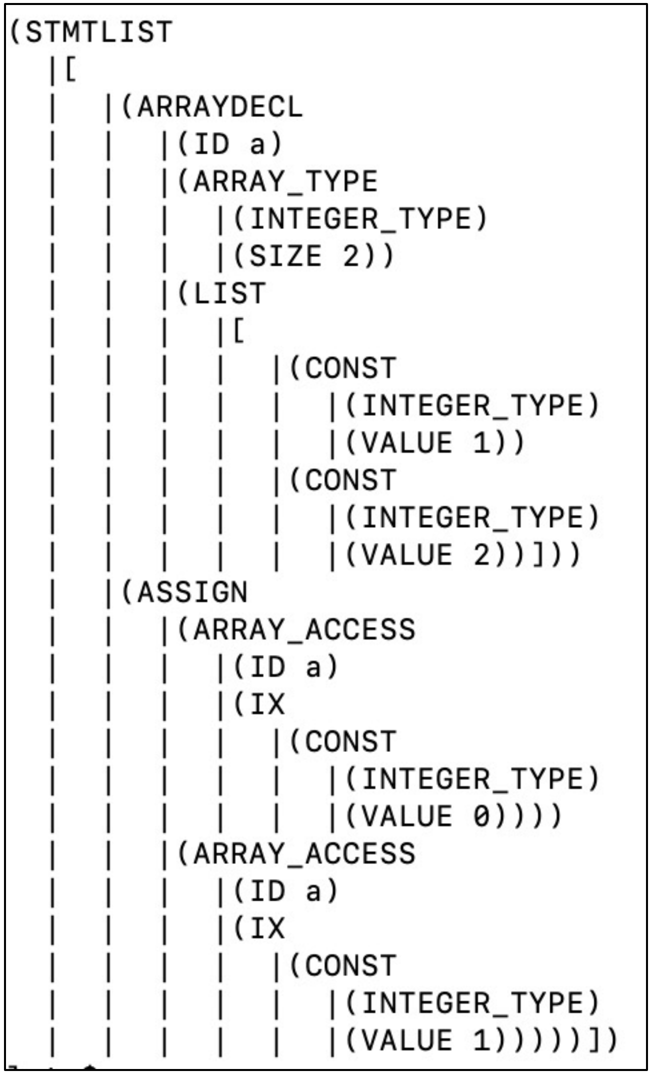
Array Types

- Adding array types to our type system gives us
  - (‘INTEGER_TYPE’,)
  - (‘FLOAT_TYPE’,)
  - (‘STRING_TYPE’,)
  - (‘VOID_TYPE’,)
  - (‘FUNCTION_TYPE, <return-type>, <list-of-formal-arg-types>)
  - (‘ARRAY_TYPE’, <elem-type>, <size>)

Array Types & the Frontend



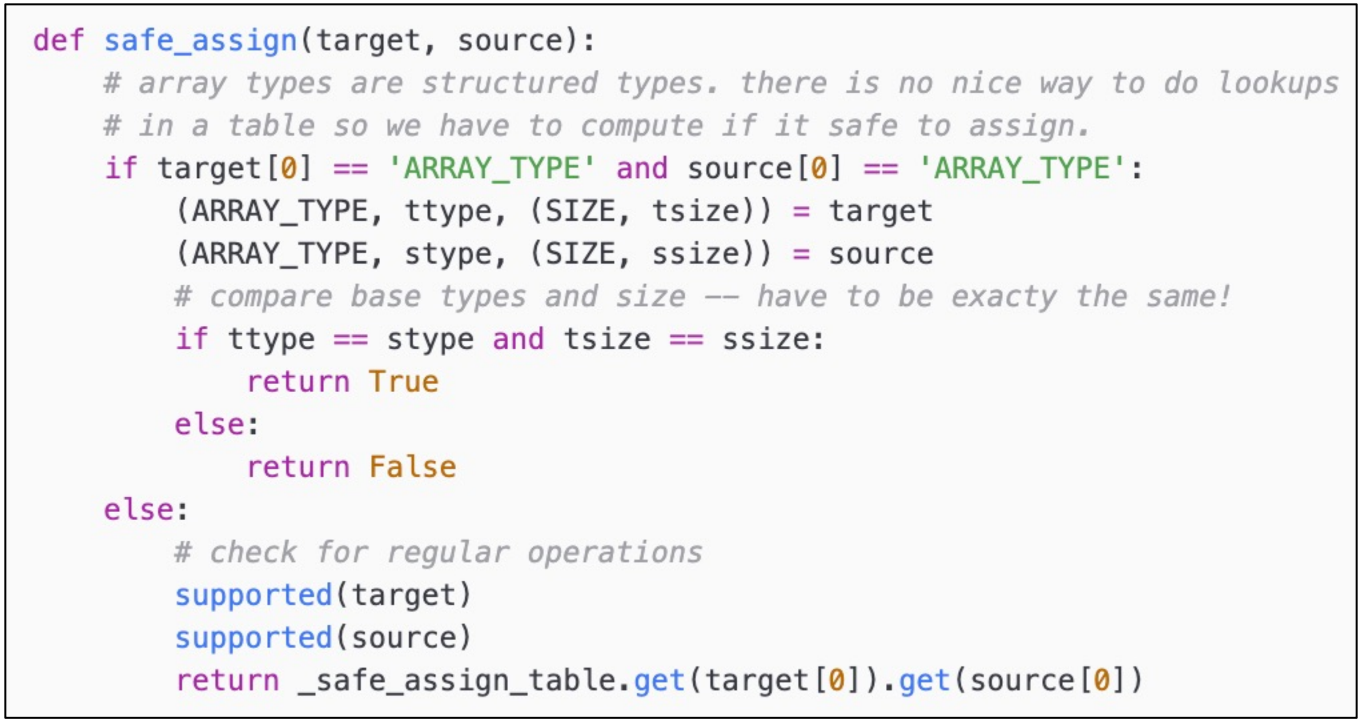
```
int[2] a = {1,2};
a[0] = a[1];
```



```
(STMTLIST
  |[
  |   |(ARRAYDECL
  |   |   |(ID a)
  |   |   |(ARRAY_TYPE
  |   |   |   |(INTEGER_TYPE)
  |   |   |   |(SIZE 2))
  |   |   |(LIST
  |   |   |   |[
  |   |   |   |   |(CONST
  |   |   |   |   |   |(INTEGER_TYPE)
  |   |   |   |   |   |(VALUE 1))
  |   |   |   |   |(CONST
  |   |   |   |   |   |(INTEGER_TYPE)
  |   |   |   |   |   |(VALUE 2))]))
  |   |(ASSIGN
  |   |   |(ARRAY_ACCESS
  |   |   |   |(ID a)
  |   |   |   |(IX
  |   |   |   |   |(CONST
  |   |   |   |   |   |(INTEGER_TYPE)
  |   |   |   |   |   |(VALUE 0))))
  |   |   |(ARRAY_ACCESS
  |   |   |   |(ID a)
  |   |   |   |(IX
  |   |   |   |   |(CONST
  |   |   |   |   |   |(INTEGER_TYPE)
  |   |   |   |   |   |(VALUE 1))))))])
```

Type Checking

- We have to extend our Cuppa4 type checker in order to include arrays.

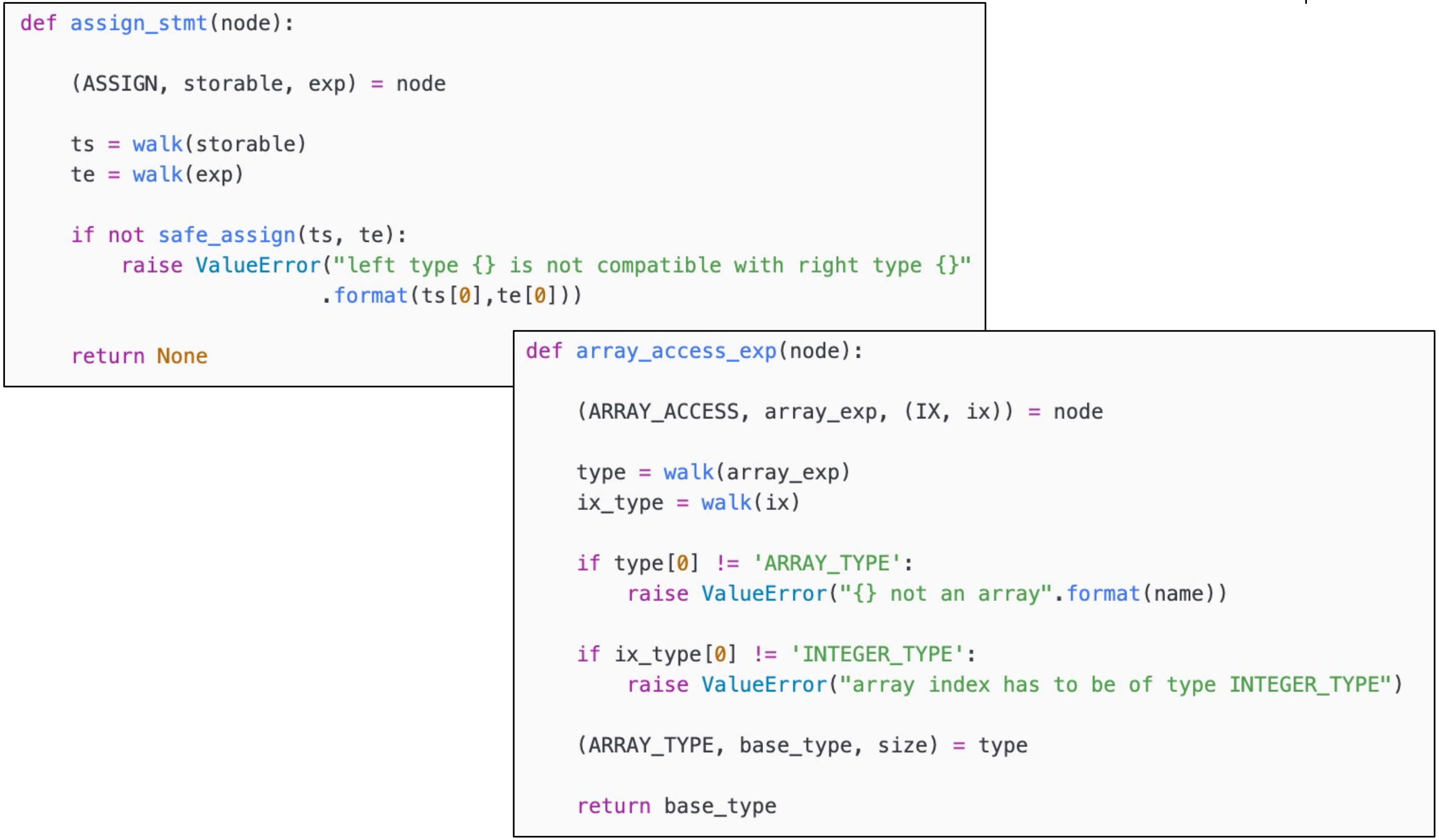


```
def safe_assign(target, source):
    # array types are structured types. there is no nice way to do lookups
    # in a table so we have to compute if it safe to assign.
    if target[0] == 'ARRAY_TYPE' and source[0] == 'ARRAY_TYPE':
        (ARRAY_TYPE, ttype, (SIZE, tsize)) = target
        (ARRAY_TYPE, stype, (SIZE, ssize)) = source
        # compare base types and size -- have to be exacty the same!
        if ttype == stype and tsize == ssize:
            return True
        else:
            return False
    else:
        # check for regular operations
        supported(target)
        supported(source)
        return _safe_assign_table.get(target[0]).get(source[0])
```

Type Checking

```
def arraydecl_stmt(node):

    (ARRAYDECL, (ID, name), type, (LIST, init_val_list)) = node
    (ARRAY_TYPE, base_type, (SIZE, size)) = type

    if not size > 0:
        raise ValueError("illegal array size")

    if len(init_val_list) != size:
        raise ValueError("array size {} and length of initializer {} don't agree"
                    .format(size, len(init_val_list)))

    # walk through initializers and make sure they are type safe
    for ix in range(size):
        ti = walk(init_val_list[ix])
        if not safe_assign(base_type, ti):
            raise ValueError(
                "type {} of initializer is not compatible with declaration type {}"
                .format(ti[0],base_type[0]))

    symtab.declare(name, type)

    return None
```

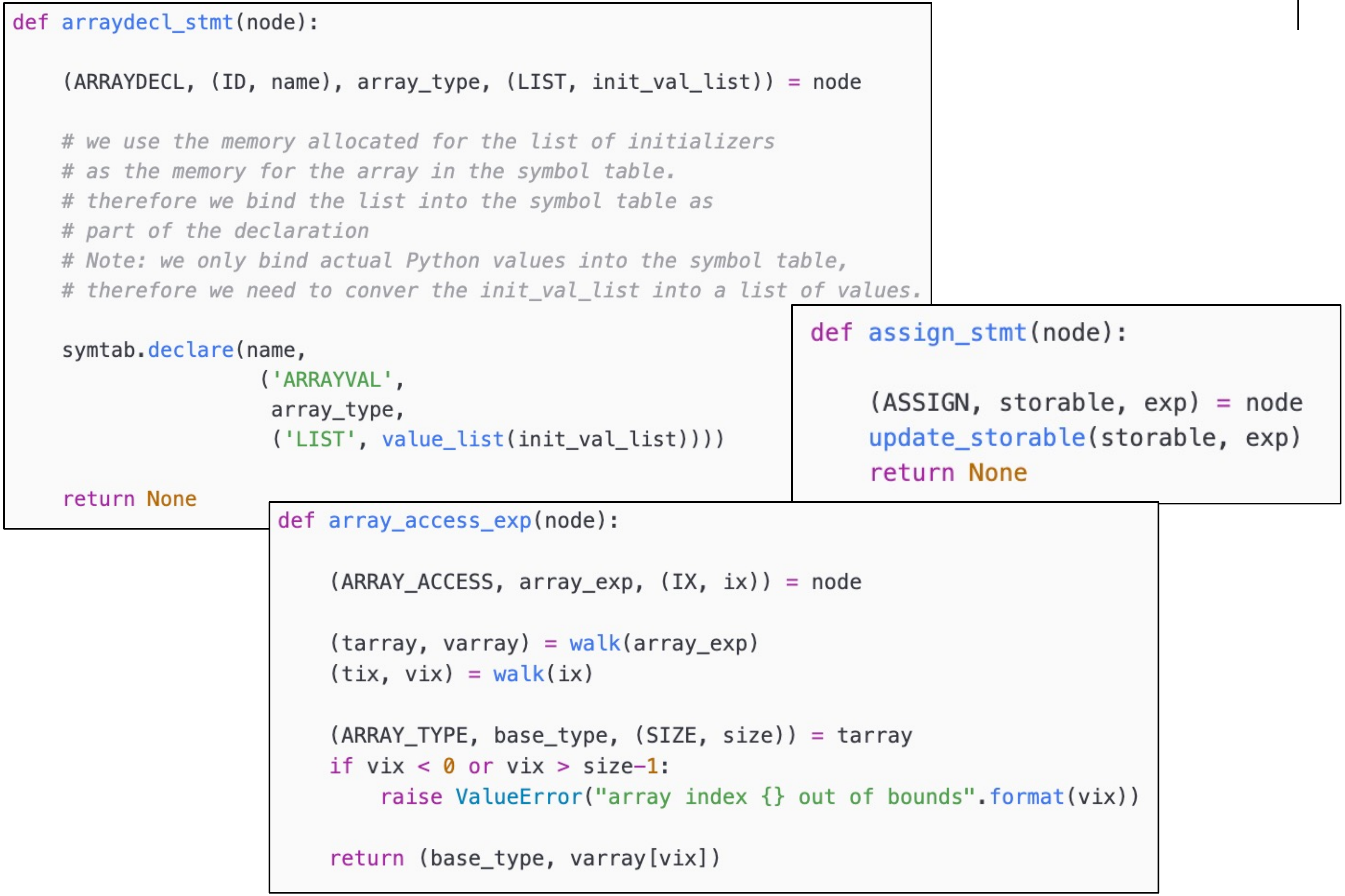
Type Checking



```
def assign_stmt(node):

    (ASSIGN, storable, exp) = node

    ts = walk(storable)
    te = walk(exp)

    if not safe_assign(ts, te):
        raise ValueError("left type {} is not compatible with right type {}"
                        .format(ts[0],te[0]))

    return None
```

```
def array_access_exp(node):

    (ARRAY_ACCESS, array_exp, (IX, ix)) = node

    type = walk(array_exp)
    ix_type = walk(ix)

    if type[0] != 'ARRAY_TYPE':
        raise ValueError("{} not an array".format(name))

    if ix_type[0] != 'INTEGER_TYPE':
        raise ValueError("array index has to be of type INTEGER_TYPE")

    (ARRAY_TYPE, base_type, size) = type

    return base_type
```

Interpretation

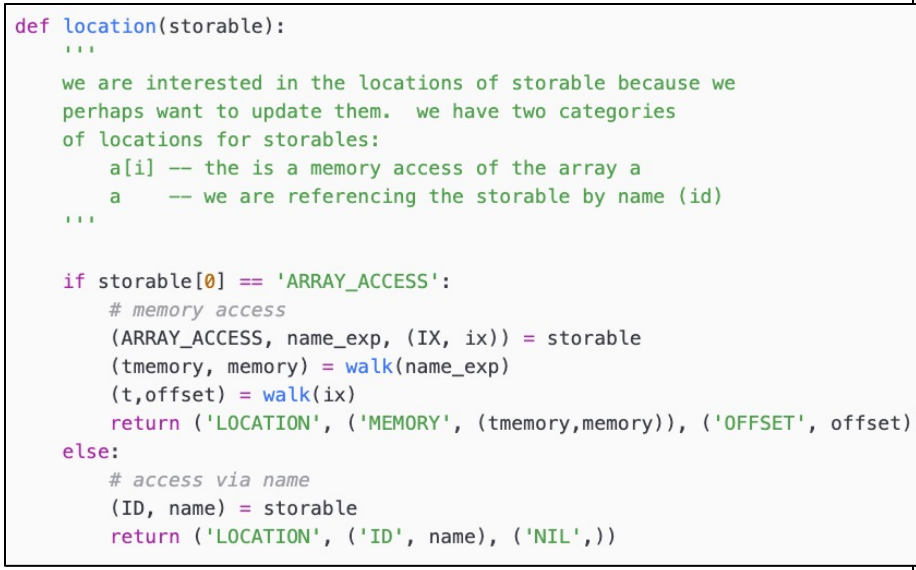


```
def arraydecl_stmt(node):

    (ARRAYDECL, (ID, name), array_type, (LIST, init_val_list)) = node

    # we use the memory allocated for the list of initializers
    # as the memory for the array in the symbol table.
    # therefore we bind the list into the symbol table as
    # part of the declaration
    # Note: we only bind actual Python values into the symbol table,
    # therefore we need to conver the init_val_list into a list of values.

    symtab.declare(name,
                   ('ARRAYVAL',
                    array_type,
                    ('LIST', value_list(init_val_list))))

    return None
```

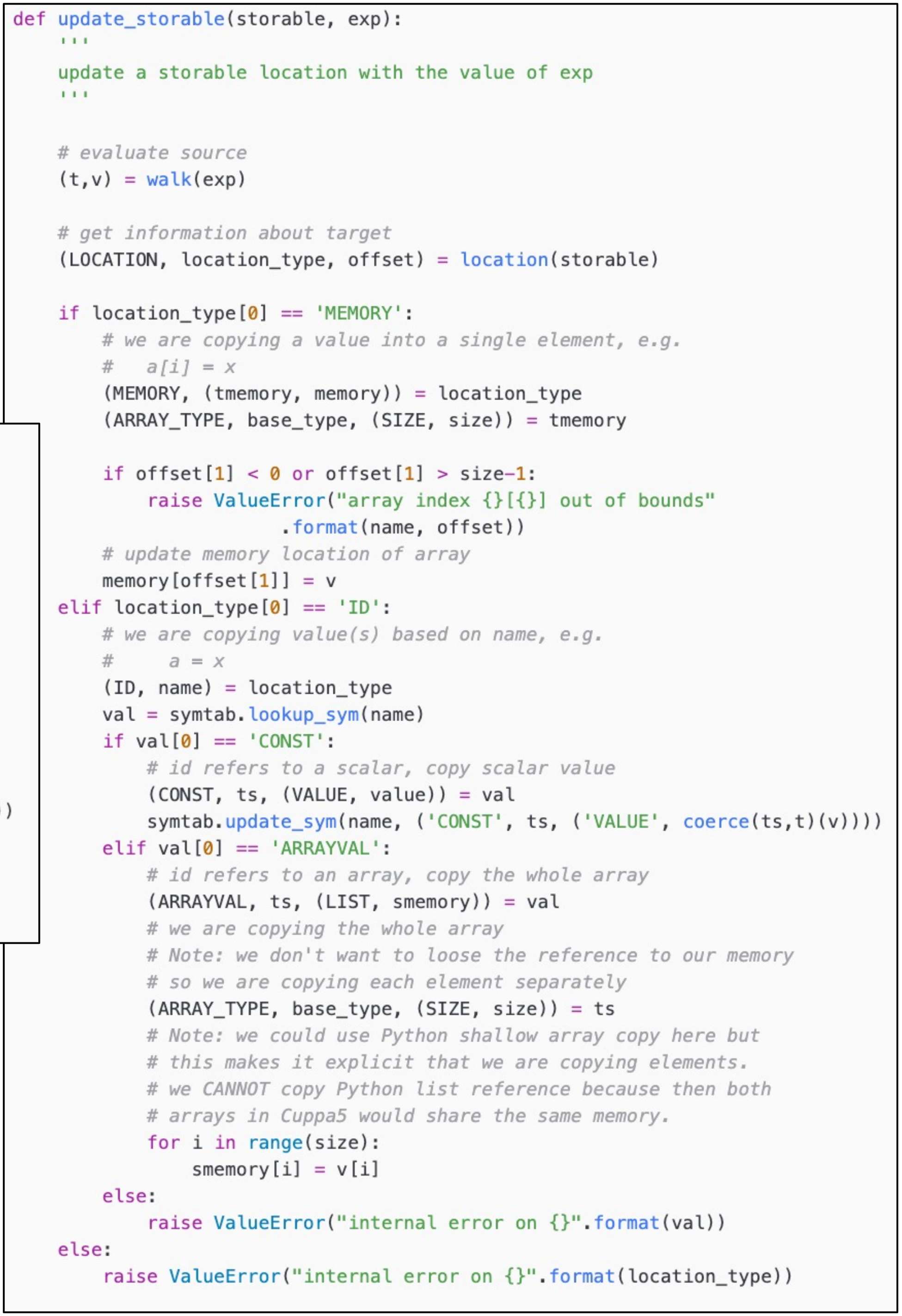
```
def assign_stmt(node):

    (ASSIGN, storable, exp) = node
    update_storable(storable, exp)
    return None
```

```
def array_access_exp(node):

    (ARRAY_ACCESS, array_exp, (IX, ix)) = node

    (tarray, varray) = walk(array_exp)
    (tix, vix) = walk(ix)

    (ARRAY_TYPE, base_type, (SIZE, size)) = tarray
    if vix < 0 or vix > size-1:
        raise ValueError("array index {} out of bounds".format(vix))

    return (base_type, varray[vix])
```

Storables



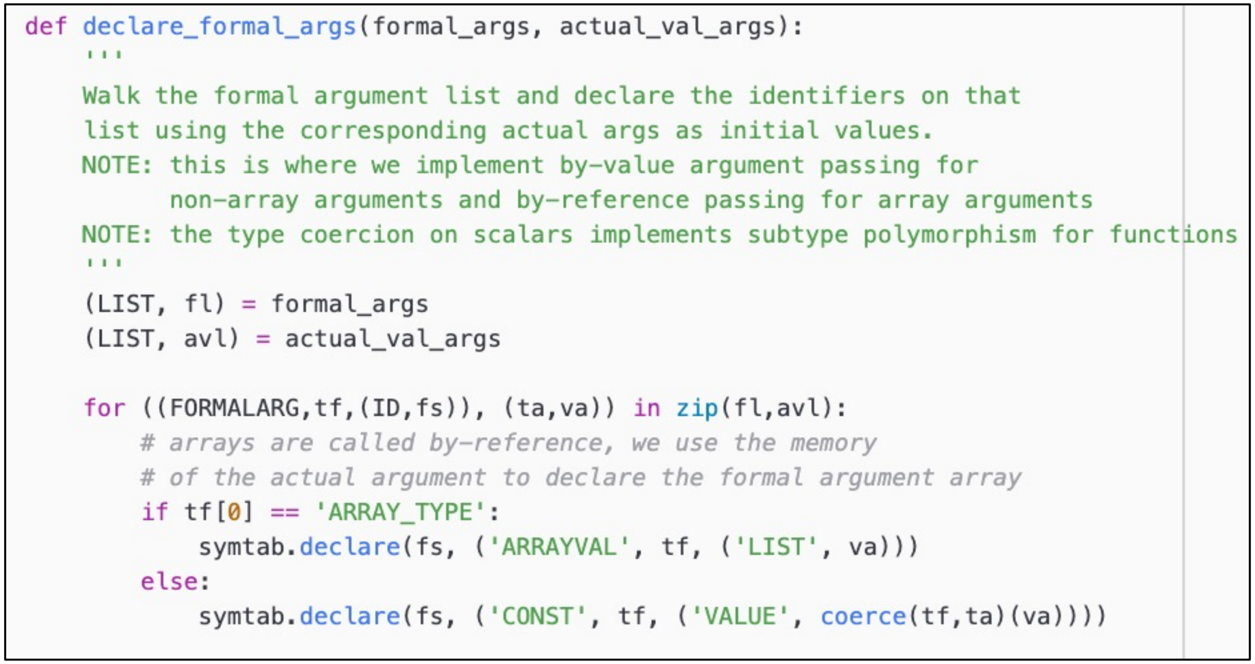
```
def location(storable):
    '''
    we are interested in the locations of storable because we
    perhaps want to update them.  we have two categories
    of locations for storables:
        a[i] -- the is a memory access of the array a
        a    -- we are referencing the storable by name (id)
    '''

    if storable[0] == 'ARRAY_ACCESS':
        # memory access
        (ARRAY_ACCESS, name_exp, (IX, ix)) = storable
        (tmemory, memory) = walk(name_exp)
        (t,offset) = walk(ix)
        return ('LOCATION', ('MEMORY', (tmemory,memory)), ('OFFSET', offset))
    else:
        # access via name
        (ID, name) = storable
        return ('LOCATION', ('ID', name), ('NIL',))
```



```
def update_storable(storable, exp):
    '''
    update a storable location with the value of exp
    '''

    # evaluate source
    (t,v) = walk(exp)

    # get information about target
    (LOCATION, location_type, offset) = location(storable)

    if location_type[0] == 'MEMORY':
        # we are copying a value into a single element, e.g.
        #   a[i] = x
        (MEMORY, (tmemory, memory)) = location_type
        (ARRAY_TYPE, base_type, (SIZE, size)) = tmemory

        if offset[1] < 0 or offset[1] > size-1:
            raise ValueError("array index {}[{}] out of bounds"
                        .format(name, offset))
        # update memory location of array
        memory[offset[1]] = v
    elif location_type[0] == 'ID':
        # we are copying value(s) based on name, e.g.
        #     a = x
        (ID, name) = location_type
        val = symtab.lookup_sym(name)
        if val[0] == 'CONST':
            # id refers to a scalar, copy scalar value
            (CONST, ts, (VALUE, value)) = val
            symtab.update_sym(name, ('CONST', ts, ('VALUE', coerce(ts,t)(v))))
        elif val[0] == 'ARRAYVAL':
            # id refers to an array, copy the whole array
            (ARRAYVAL, ts, (LIST, smemory)) = val
            # we are copying the whole array
            # Note: we don't want to loose the reference to our memory
            # so we are copying each element separately
            (ARRAY_TYPE, base_type, (SIZE, size)) = ts
            # Note: we could use Python shallow array copy here but
            # this makes it explicit that we are copying elements.
            # we CANNOT copy Python list reference because then both
            # arrays in Cuppa5 would share the same memory.
            for i in range(size):
                smemory[i] = v[i]
        else:
            raise ValueError("internal error on {}".format(val))
    else:
        raise ValueError("internal error on {}".format(location_type))
```

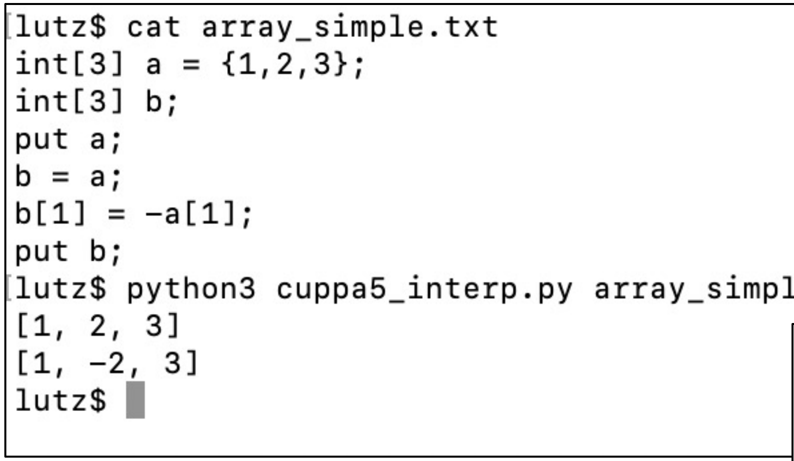
Call-by-Reference

- The call-by-reference for arrays is implemented in the declare_formal_args function

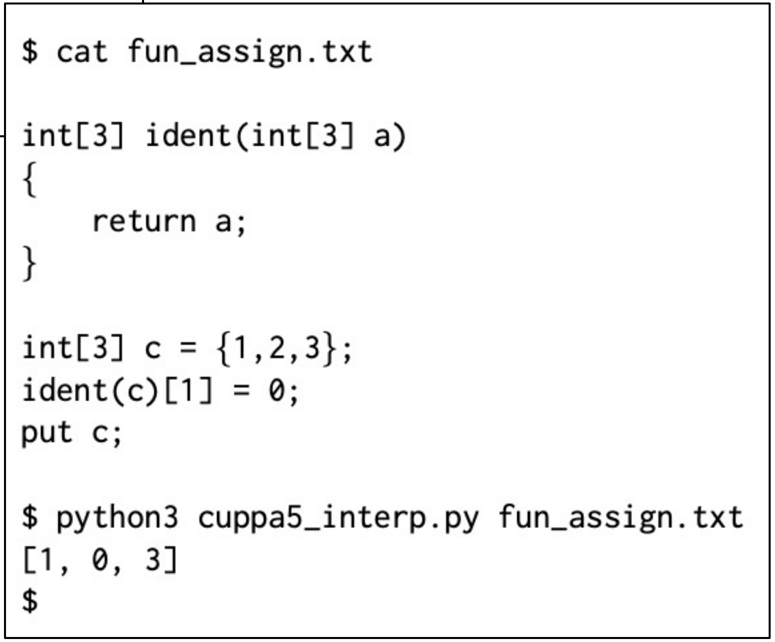


```
def declare_formal_args(formal_args, actual_val_args):
    '''
    Walk the formal argument list and declare the identifiers on that
    list using the corresponding actual args as initial values.
    NOTE: this is where we implement by-value argument passing for
          non-array arguments and by-reference passing for array arguments
    NOTE: the type coercion on scalars implements subtype polymorphism for functions
    '''
    (LIST, fl) = formal_args
    (LIST, avl) = actual_val_args

    for ((FORMALARG,tf,(ID,fs)), (ta,va)) in zip(fl,avl):
        # arrays are called by-reference, we use the memory
        # of the actual argument to declare the formal argument array
        if tf[0] == 'ARRAY_TYPE':
            symtab.declare(fs, ('ARRAYVAL', tf, ('LIST', va)))
        else:
            symtab.declare(fs, ('CONST', tf, ('VALUE', coerce(tf,ta)(va))))
```

Test Driving the Interpreter



```
lutz$ cat array_simple.txt
int[3] a = {1,2,3};
int[3] b;
put a;
b = a;
b[1] = -a[1];
put b;
lutz$ python3 cuppa5_interp.py array_simple.txt
[1, 2, 3]
[1, -2, 3]
lutz$ 
```



```
$ cat fun_assign.txt

int[3] ident(int[3] a)
{
    return a;
}

int[3] c = {1,2,3};
ident(c)[1] = 0;
put c;

$ python3 cuppa5_interp.py fun_assign.txt
[1, 0, 3]
$
```