# Semantic Analysis

TEACHING ASSISTANT: DAVID TRABISH

# Semantic Analysis

Perform various checks:

- Type checking
  - 1 + “1”
- Scopes
  - Undefined variables
- Other
  - Division by zero
  - Visibility semantics in classes (public, private, …)

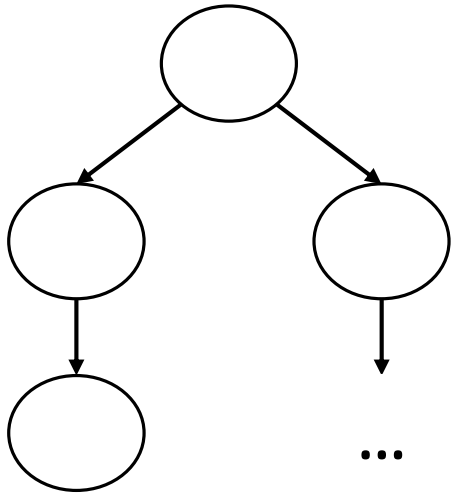
# Visitor Design Pattern

Perform computations over tree-like data structures

$visit(node)$:

// do something with node

$r_1 = visit(node.child_1)$
$r_2 = visit(node.child_2)$
…
// do something with $r_1, r_2, \ldots$



# Visitor Design Pattern: Example

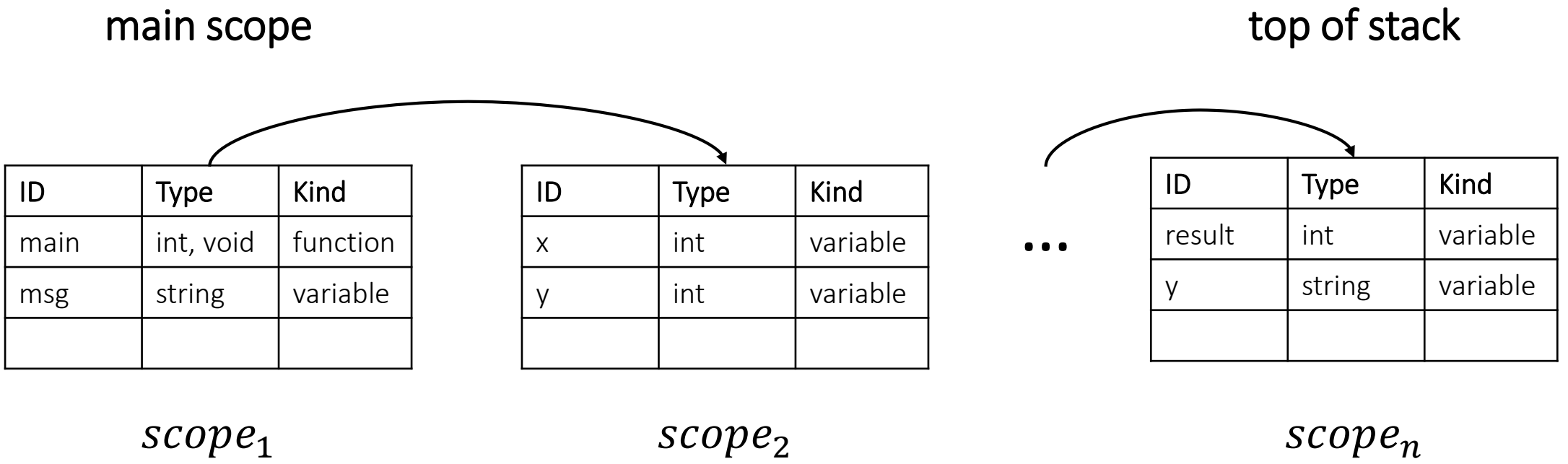
Printing the AST

$visit(node)$:
    $print(node)$
    $for\ child\ in\ node.children$:
        $visit(child)$

# Symbol Table

- Stack of scopes
- Each scope contains information about identifiers
  - Name
  - Type (int, string, …)
  - Kind (variable, function, method, …)

# Symbol Table



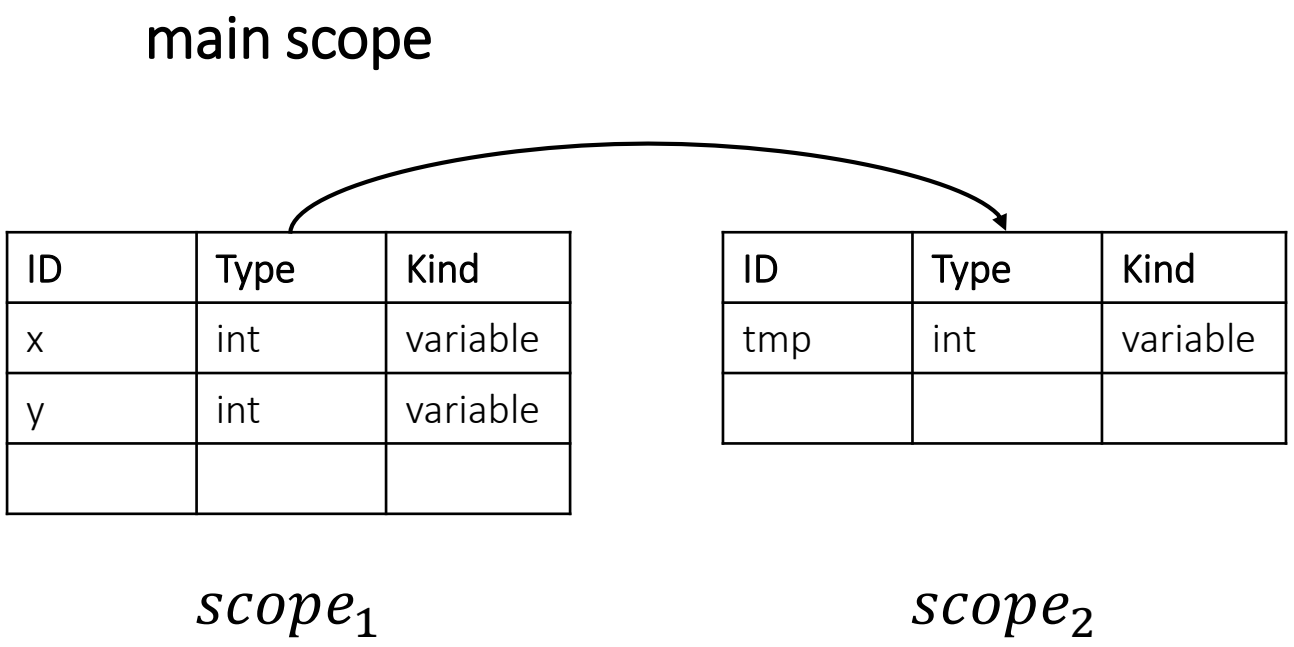
# Symbol Table Operations

- **Insert** symbol
- **Lookup** symbol
- **Enter** scope
- **Exit** scope

# Symbol Table: Insert

Example:

- Insert(z, int, variable)



# Symbol Table: Insert

Example:

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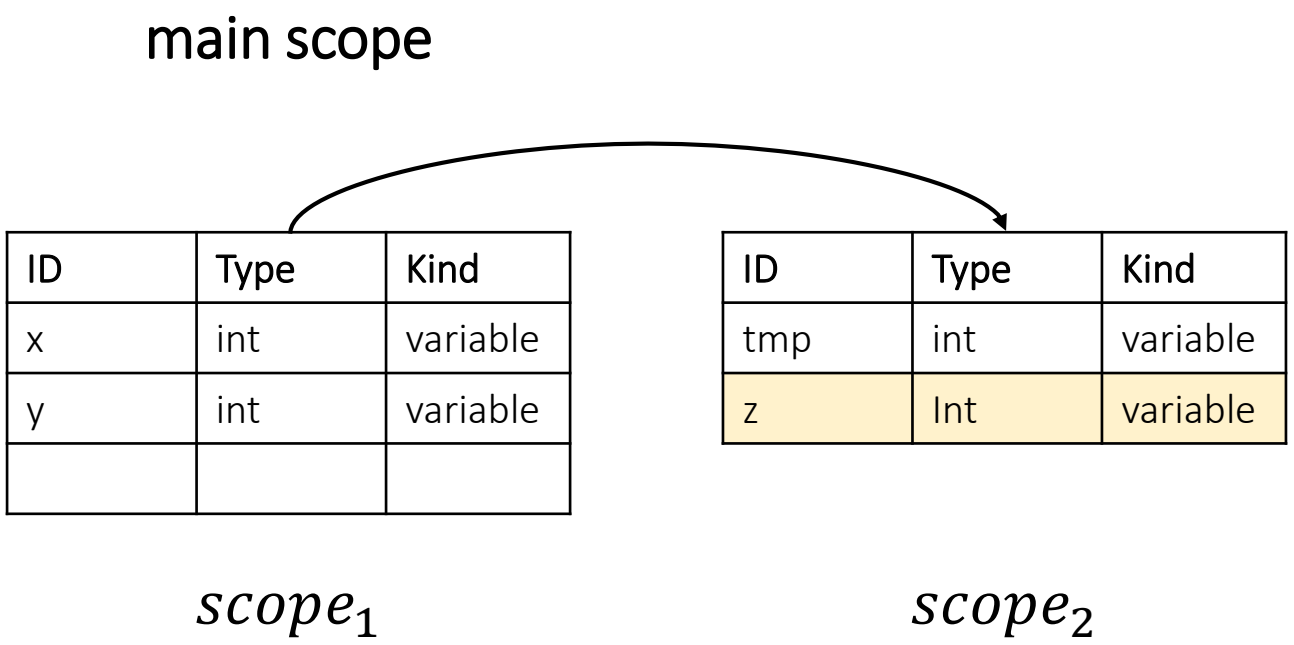
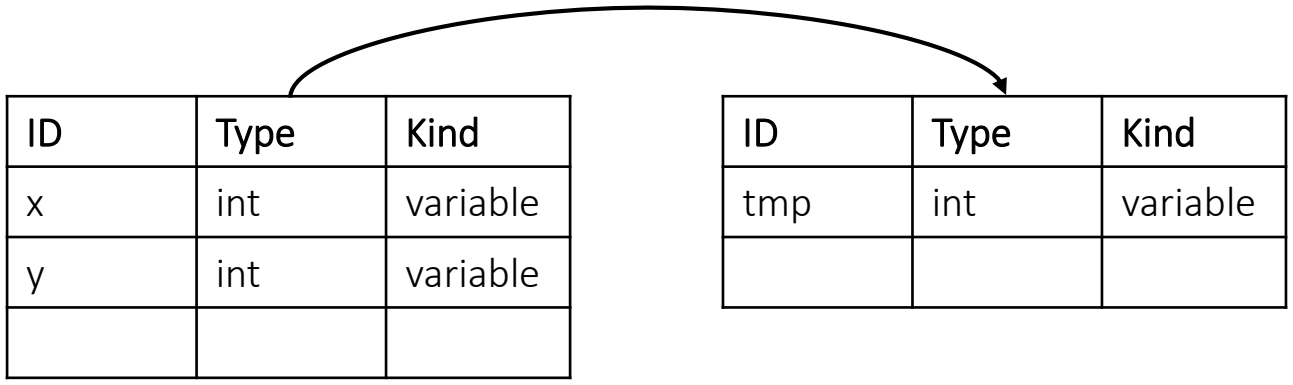


# Symbol Table: Lookup

Example:

- Lookup(y)
  - Start from the top of the stack, return **first** match

**main scope**



| ID | Type | Kind |
|---|---|---|
| x | int | variable |
| y | int | variable |
| | | |

$scope_1$

| ID | Type | Kind |
|---|---|---|
| tmp | int | variable |
| | | |

$scope_2$

# Symbol Table: Lookup

Example:

- Lookup(y)
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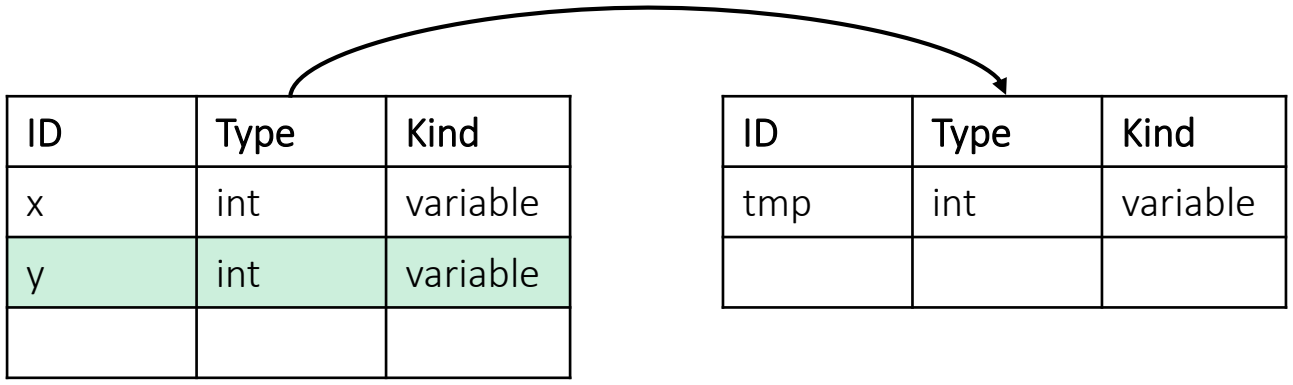

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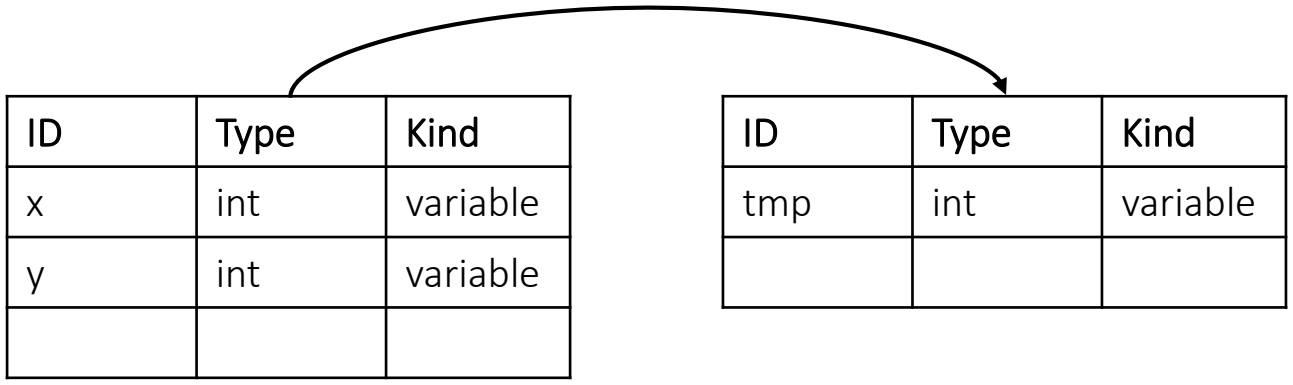
$scope_2$

# Symbol Table: Enter

main scope



| ID | Type | Kind |
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| | | |

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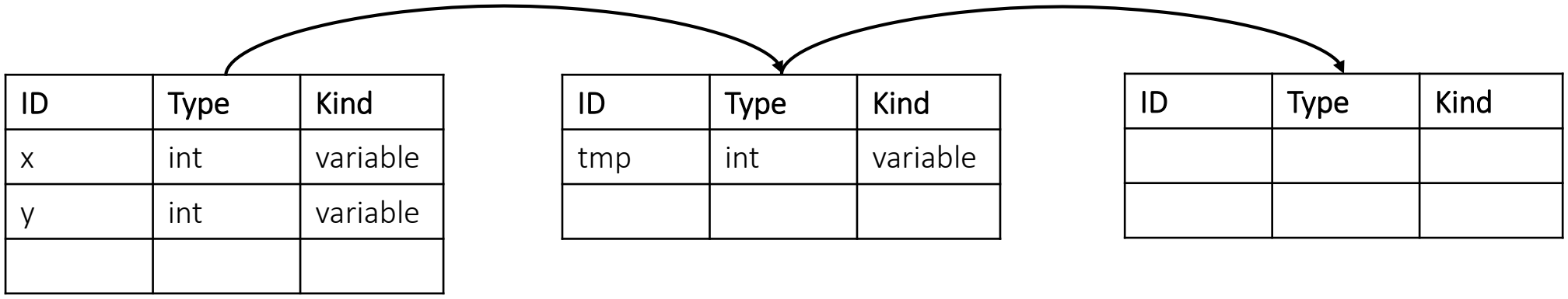
$scope_1$

$scope_2$

# Symbol Table: Enter

main scope



| ID | Type | Kind |
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| x | int | variable |
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| | | |

$scope_1$

| ID | Type | Kind |
|---|---|---|
| tmp | int | variable |
| | | |

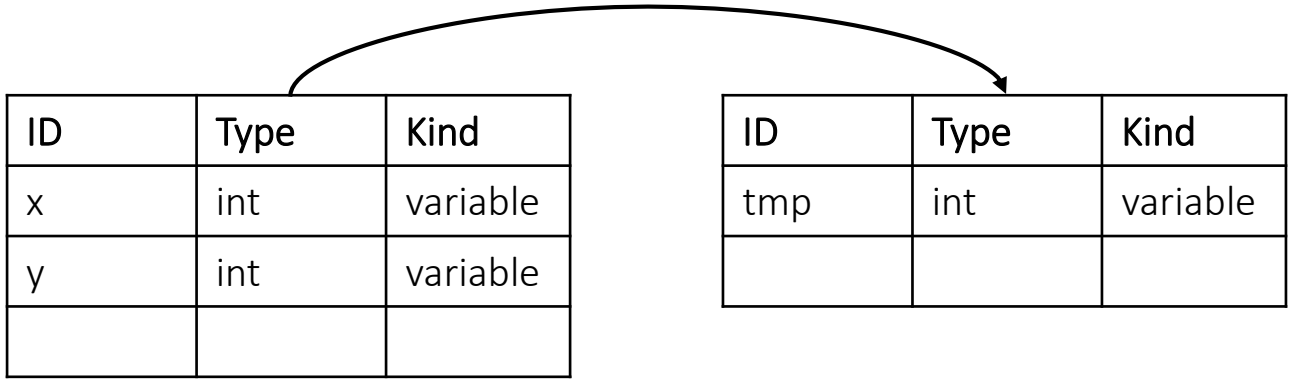
$scope_2$

| ID | Type | Kind |
|---|---|---|
| | | |
| | | |

$scope_3$

# Symbol Table: Exit

main scope



| ID | Type | Kind |
|---|---|---|
| x | int | variable |
| y | int | variable |
| | | |

| ID | Type | Kind |
|---|---|---|
| tmp | int | variable |
| | | |

$scope_1$ $scope_2$

# Symbol Table: Exit

main scope

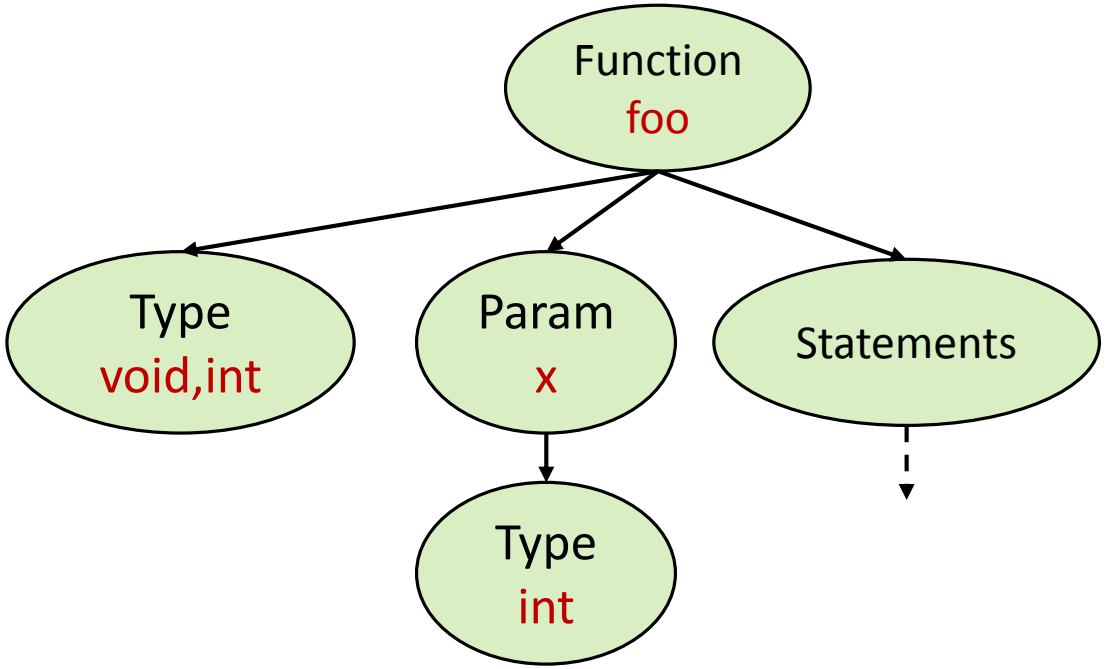
| ID | Type | Kind |
|---|---|---|
| x | int | variable |
| y | int | variable |
| | | |

$scope_1$

# Symbol Table Construction

- Identifier declaration
  - Insert
- Identifier reference
  - Lookup
- When visiting a new block
  - Enter
- When leaving a block
  - Exit

```
void foo(int x) {
  int a = 1;
  int b = 2;
  if (x) {
    string a = "abc";
  }
}
```



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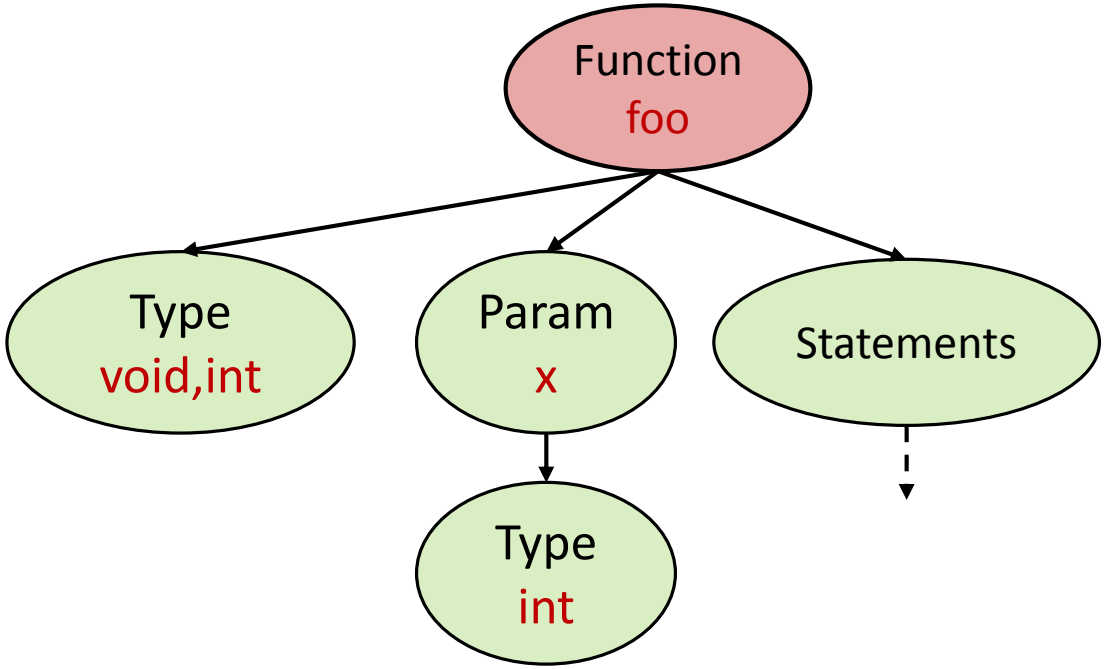


| ID | Type | Kind |
|---|---|---|
| foo | void,int | function |

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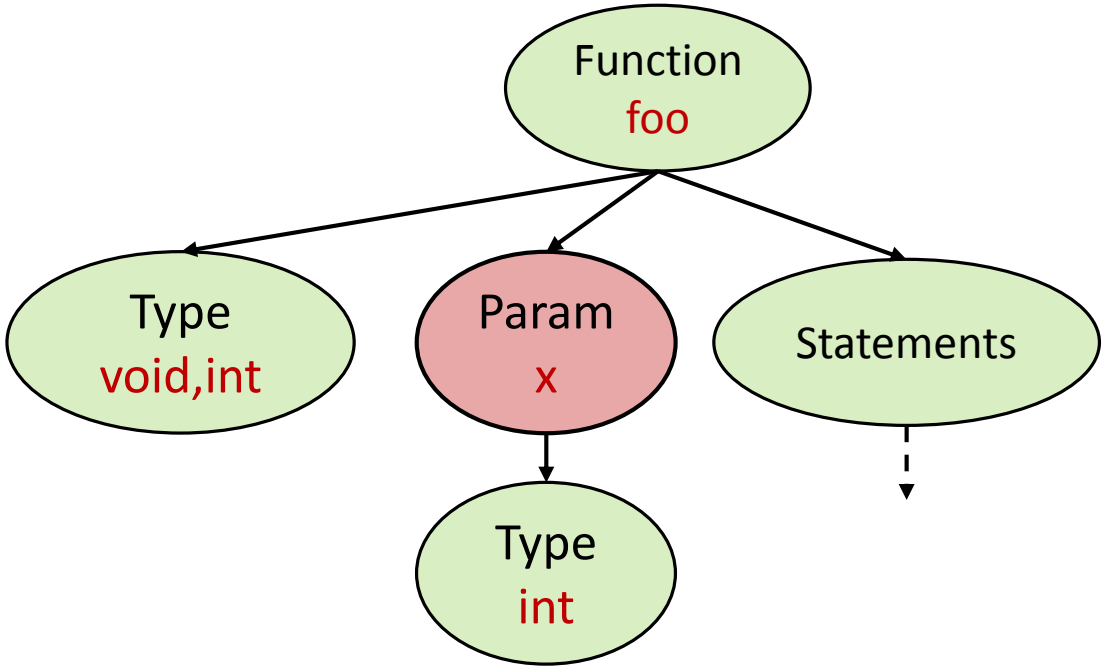


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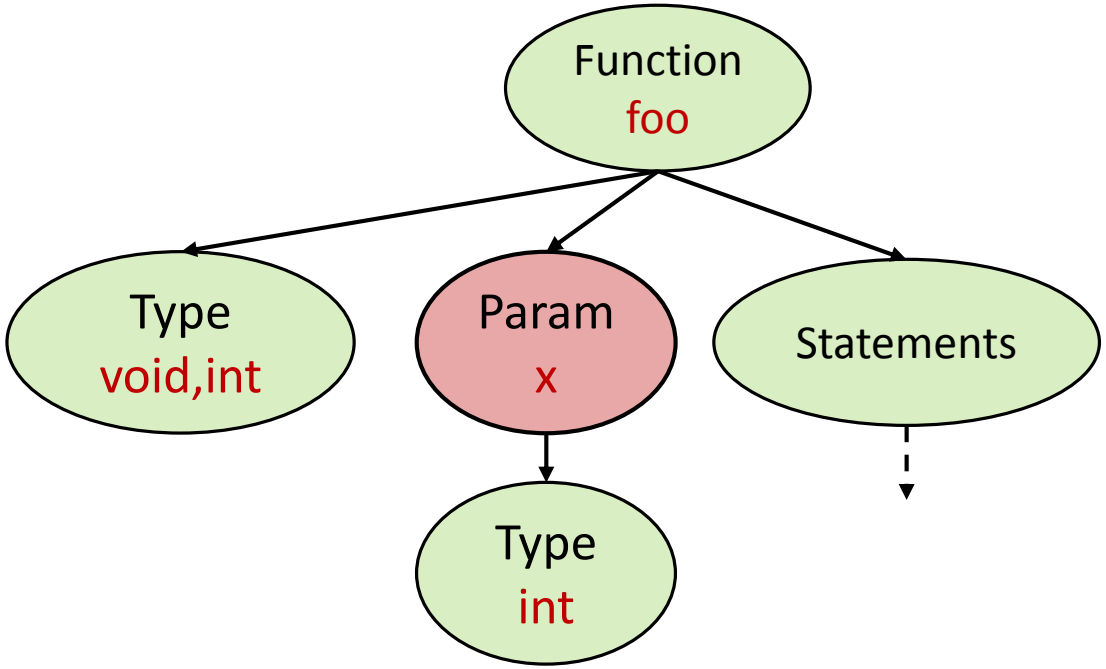


| ID | Type | Kind |
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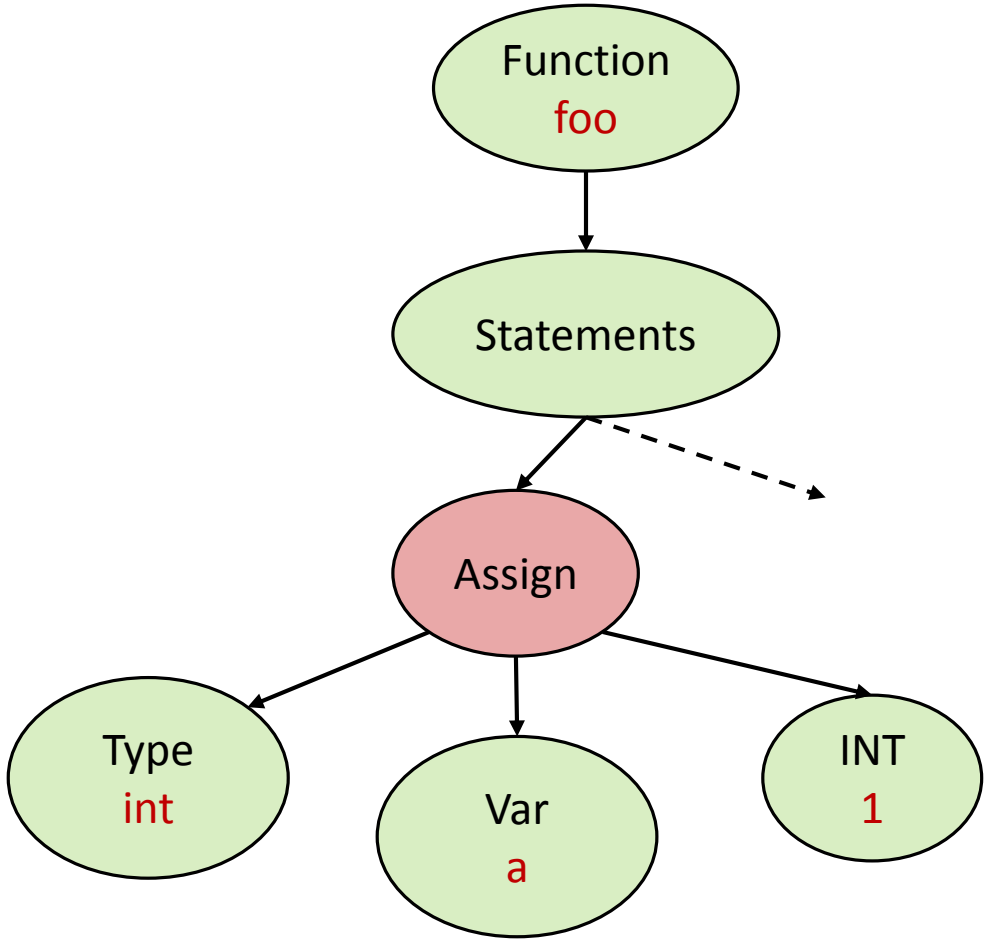

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|---|---|---|
| x | int | variable |
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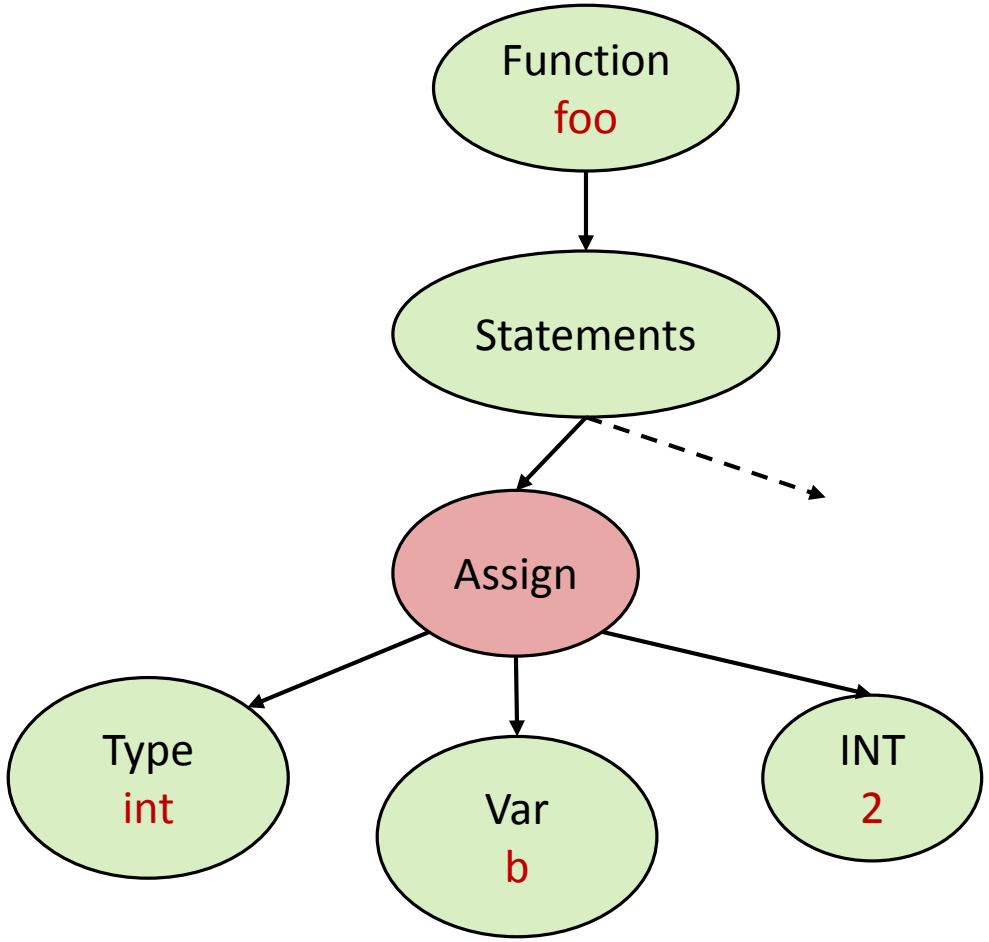

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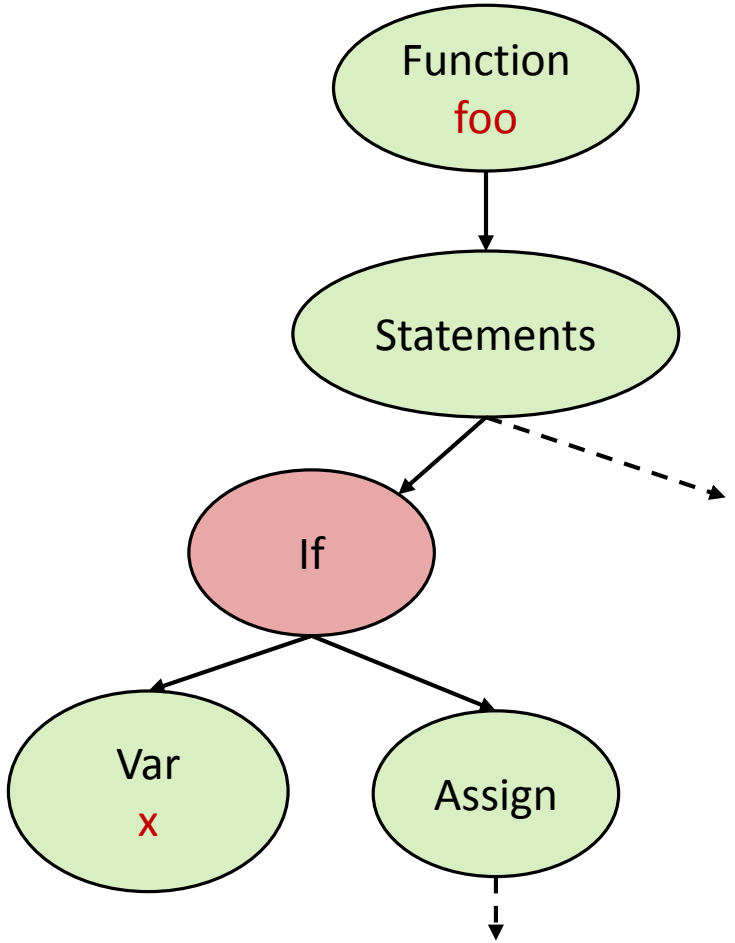

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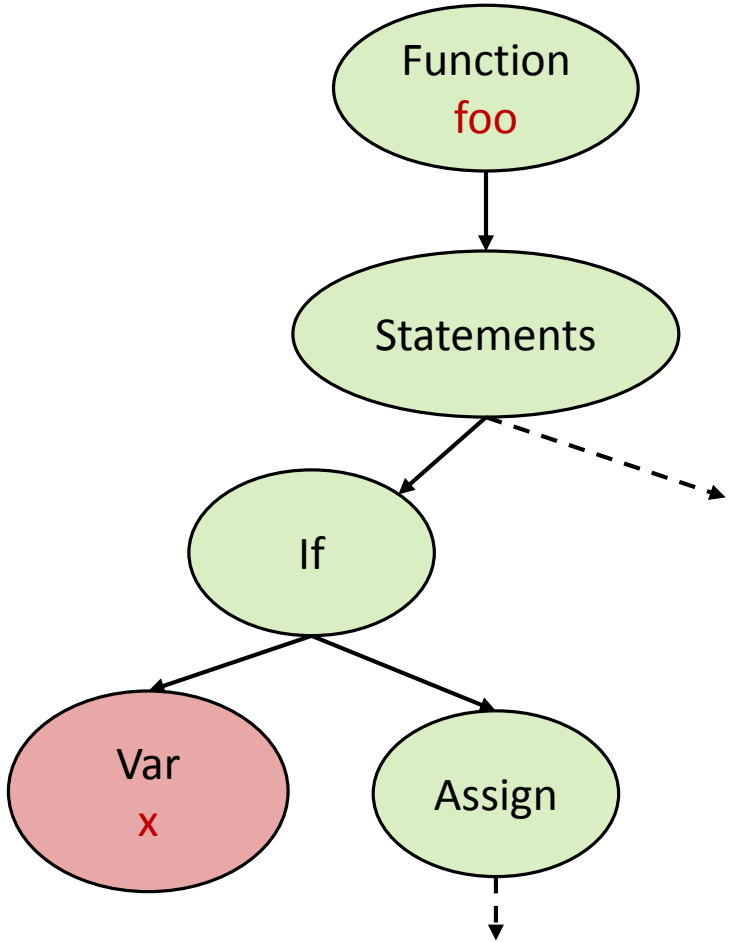

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|---|---|---|
| x | int | variable |
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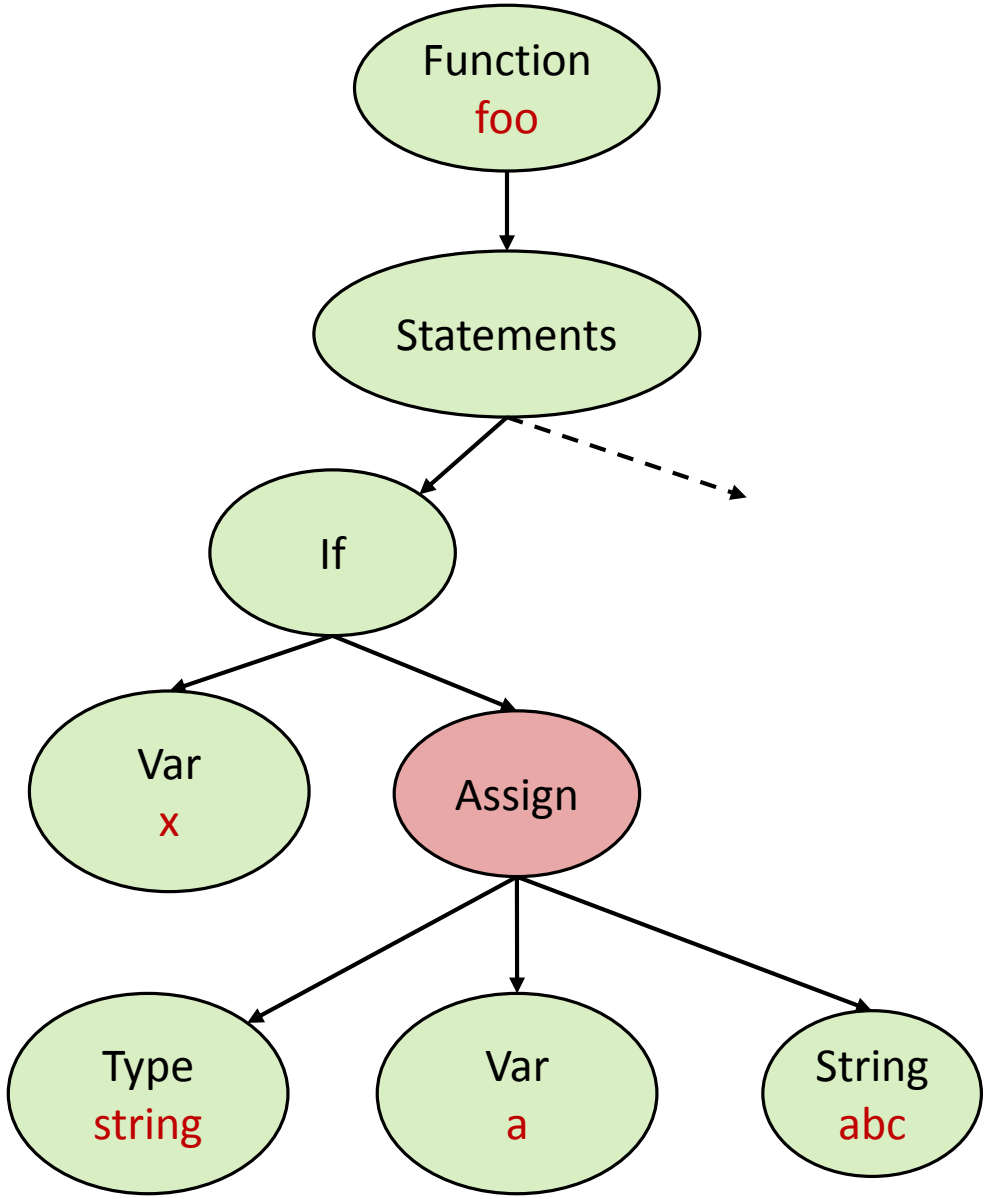
| ID | Type | Kind |
|---|---|---|
| a | string | variable |



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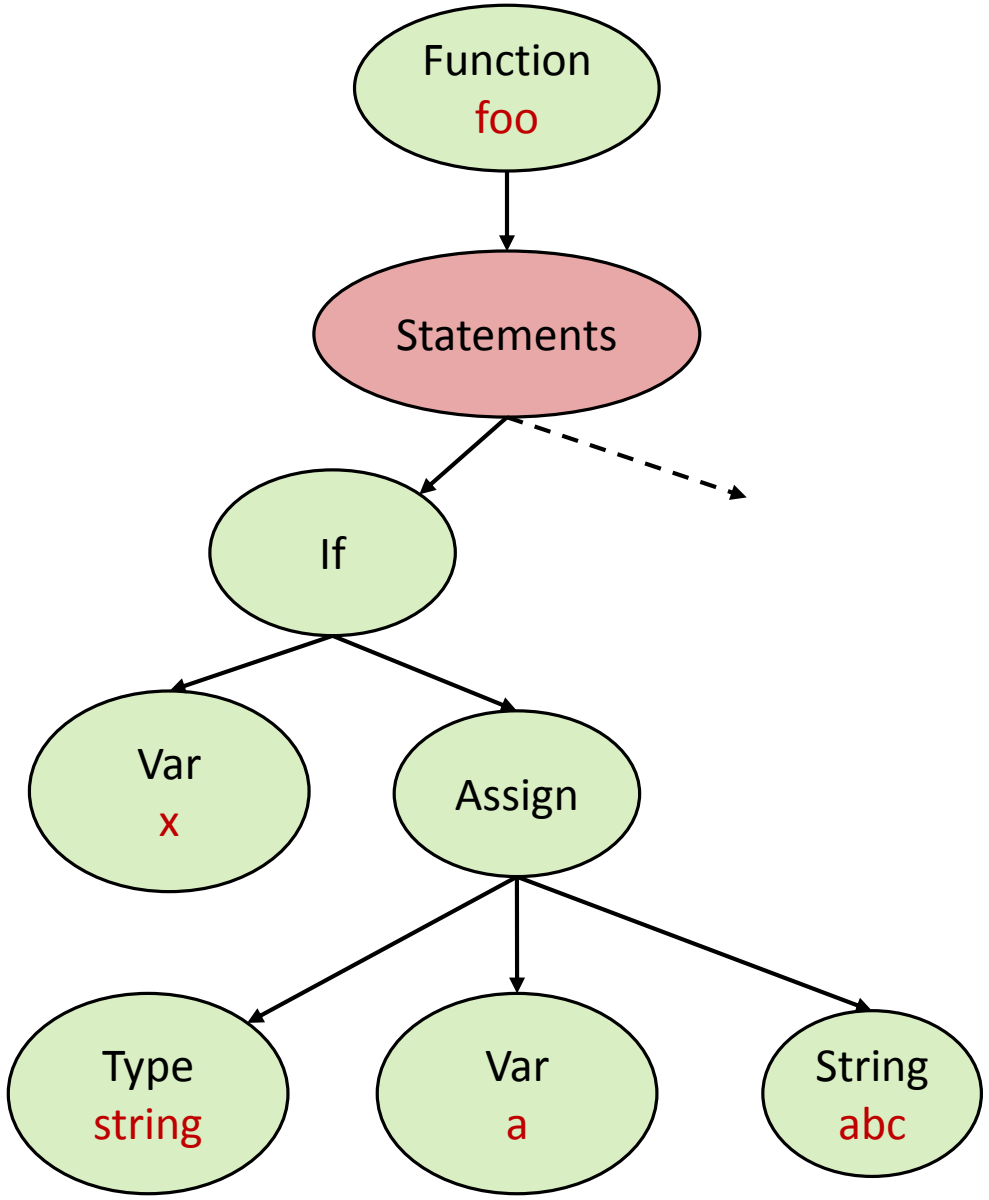

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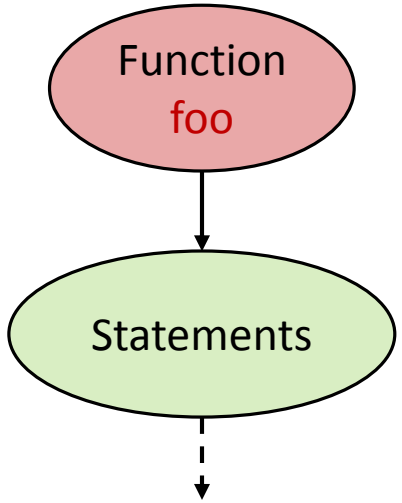


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```

# Type Checking

Goals:

- Type correctness of expressions
- Compute type of expressions

Performed using:

- AST visitor
- Symbol table

# Type Checking

Basic algorithm:

$visit(node)$:

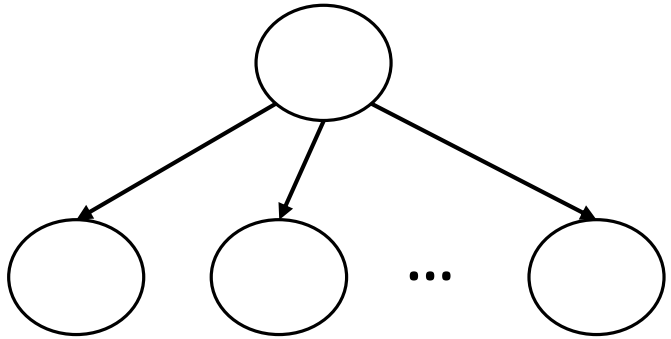
$\mathrm{t}_1 = visit(node.child_1)$

…

$\mathrm{t}_\mathrm{n} = visit(node.child_n)$

$return \underbrace{compute\_type(t_1, \ldots, t_n)}$

node specific



```
int a = foo() + b - 7;
...
```

| ID | Type | Kind |
|---|---|---|
| foo | int,void | function |

| ID | Type | Kind |
|---|---|---|
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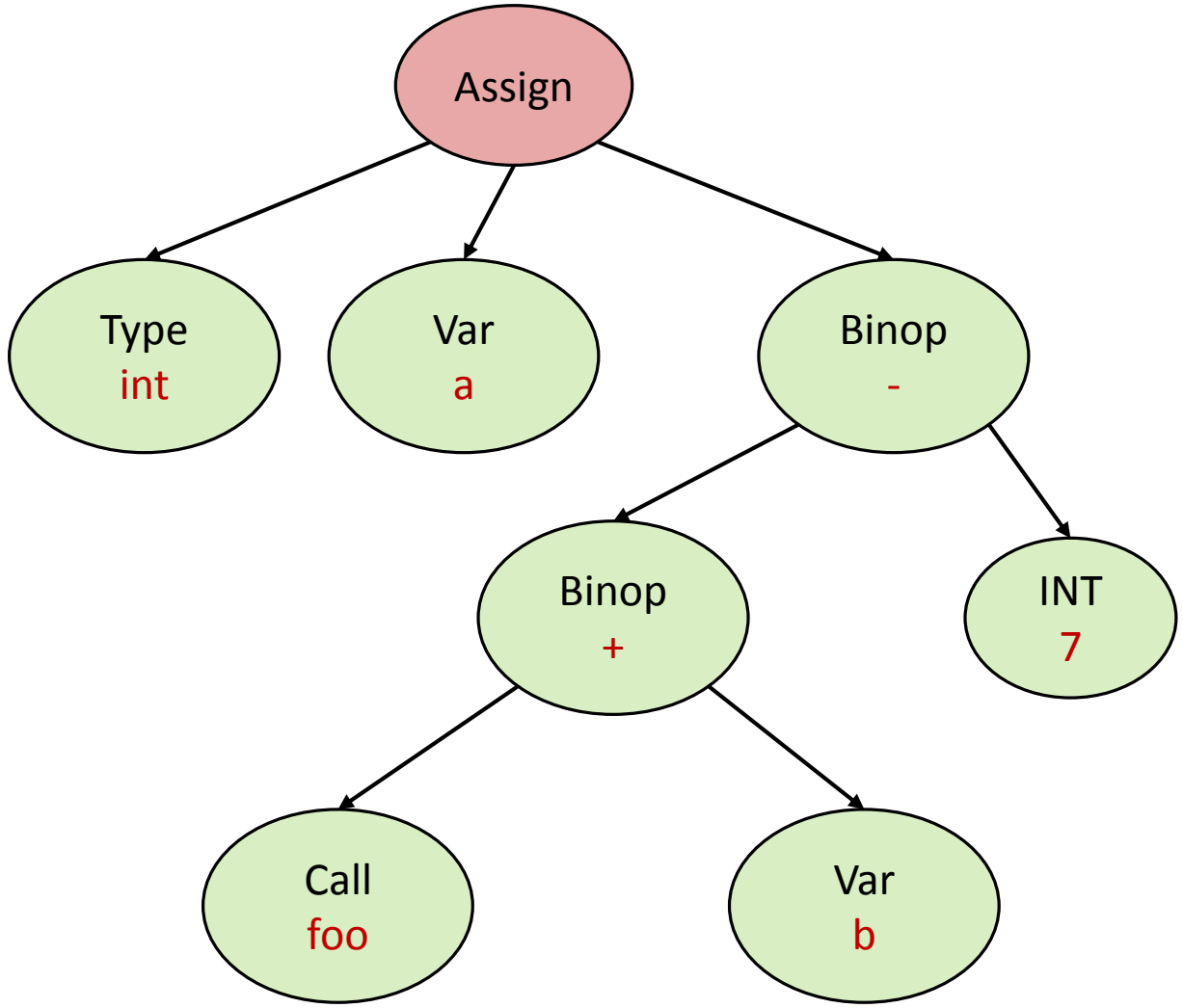

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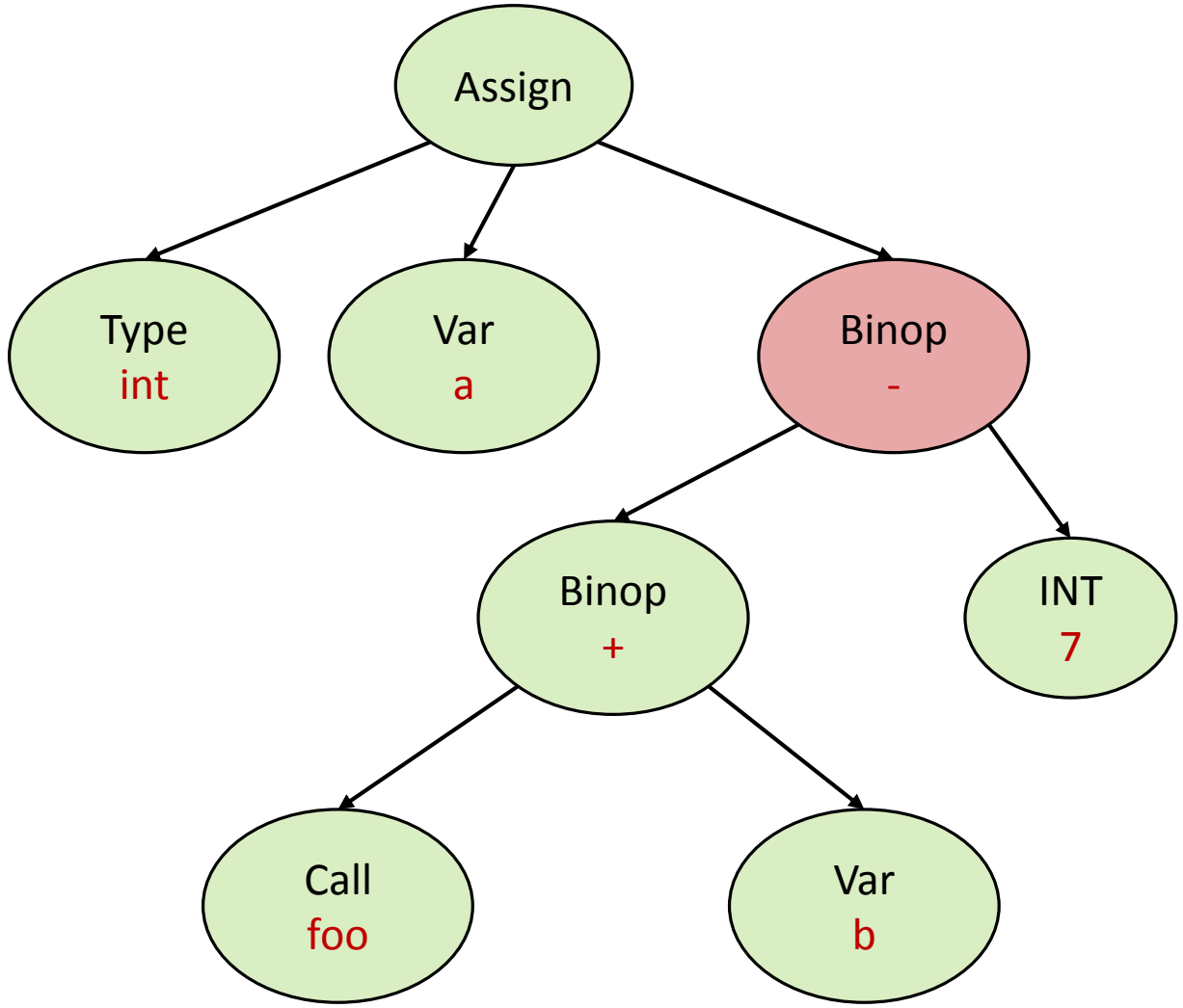

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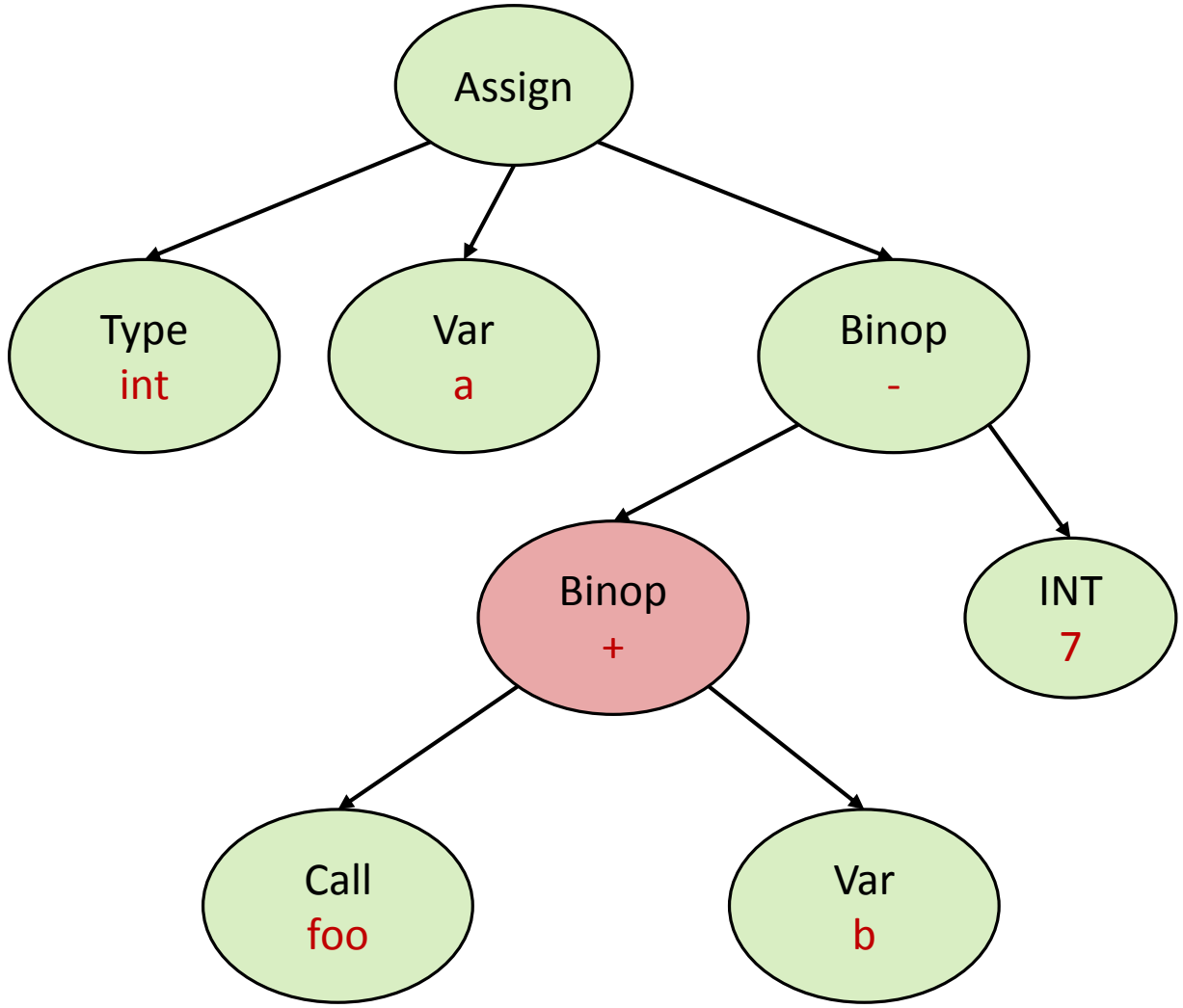

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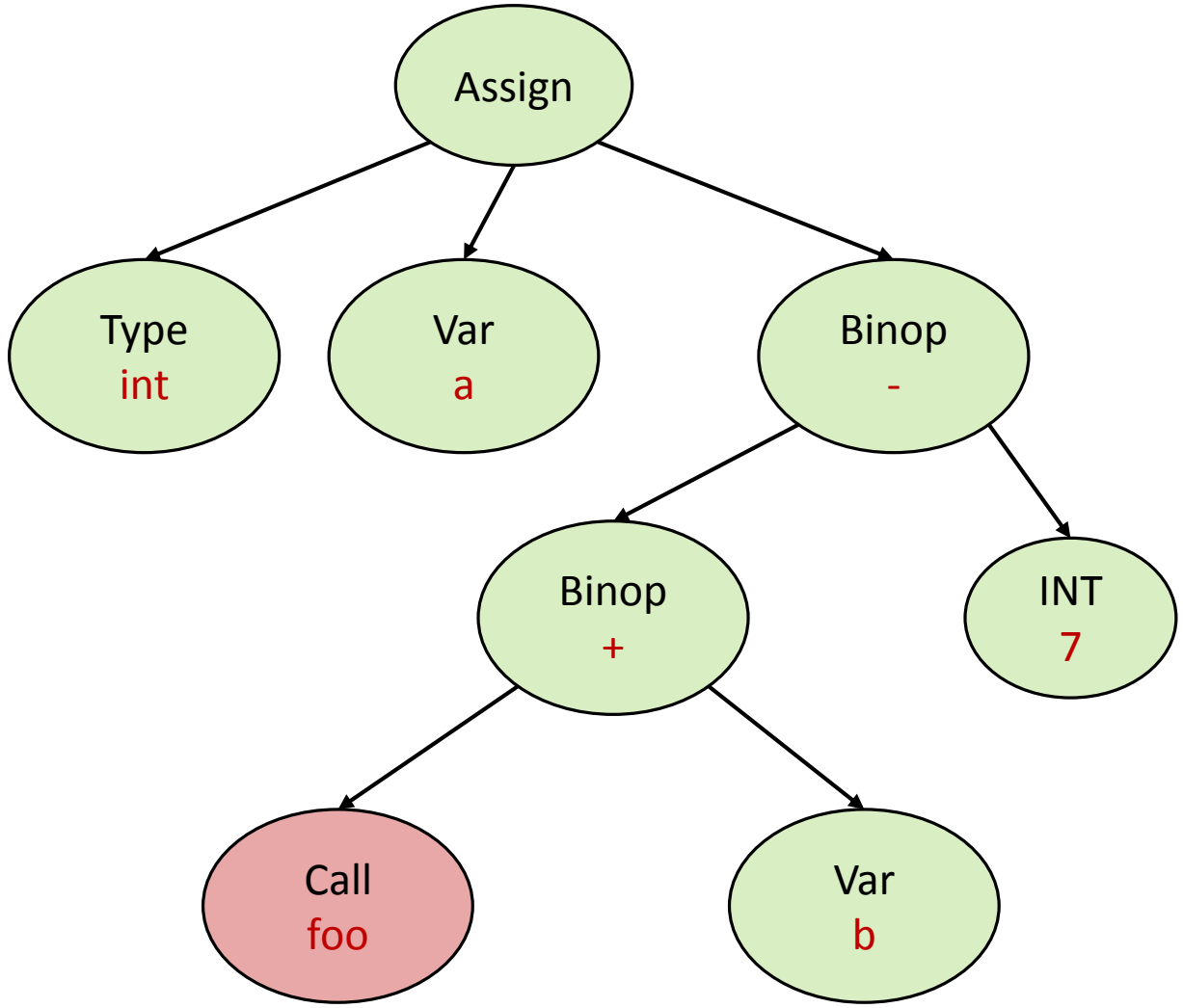

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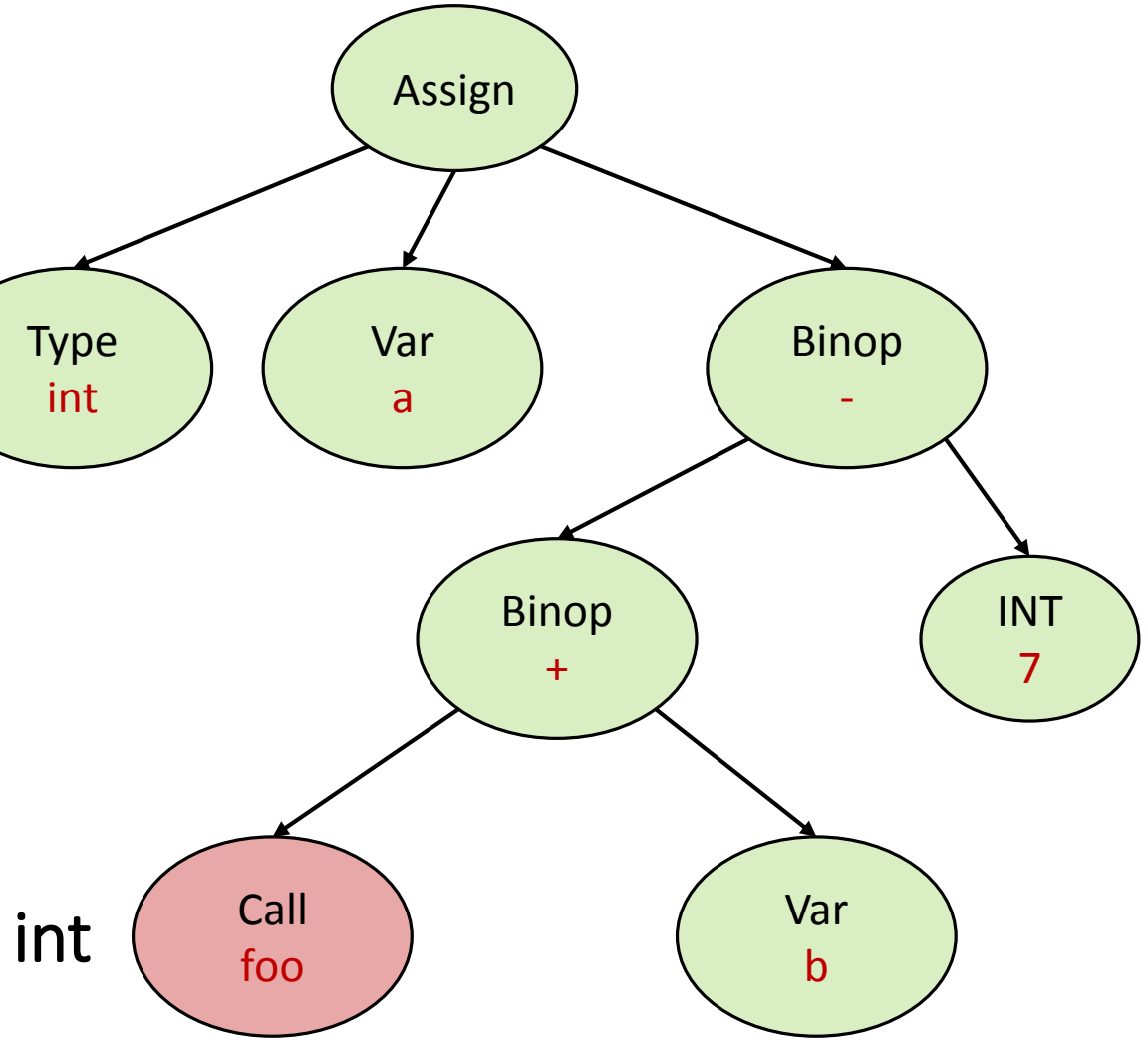

```
int a = foo() + b - 7;
...
```

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|---|---|---|
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| ID | Type | Kind |
|---|---|---|
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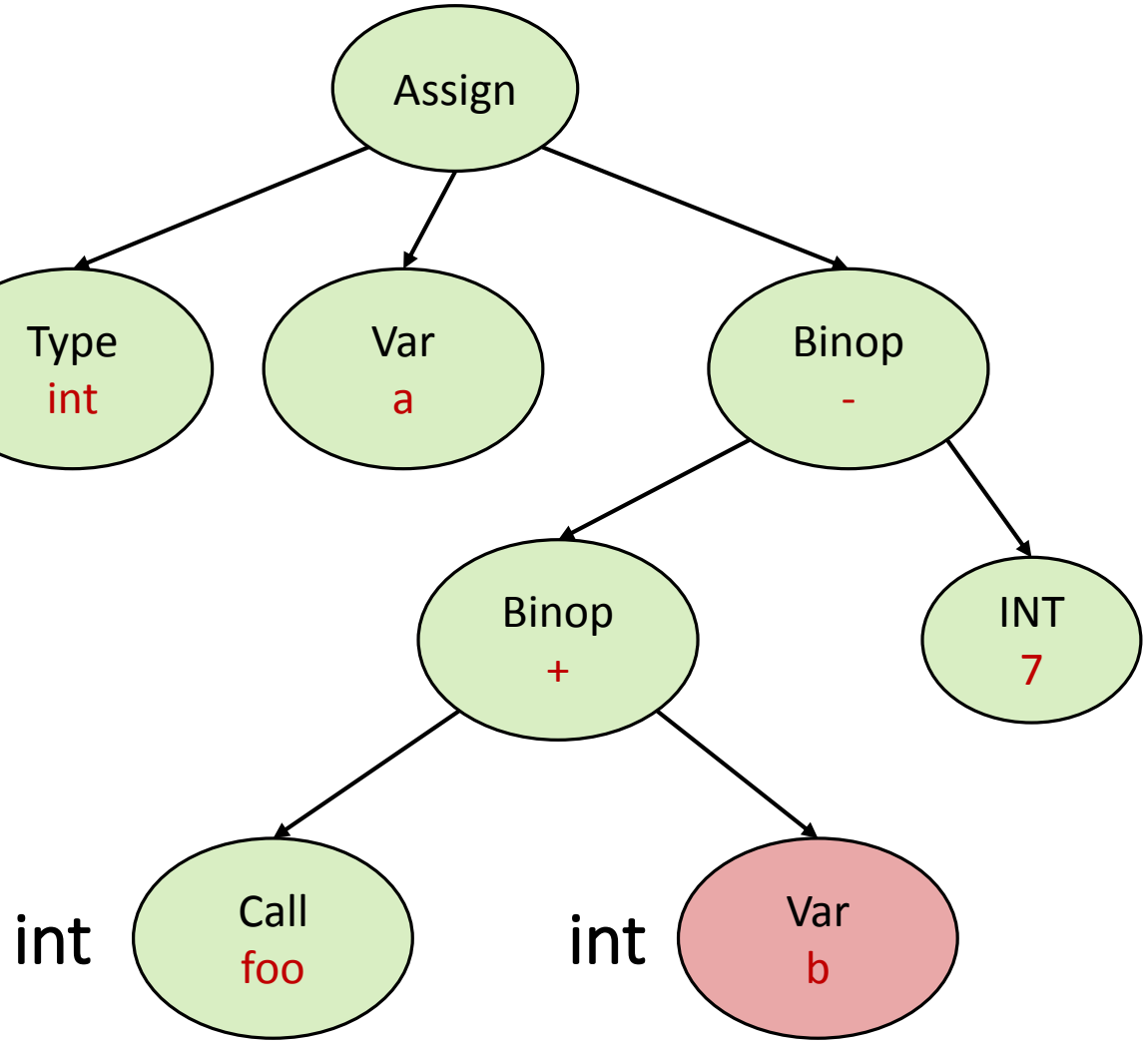

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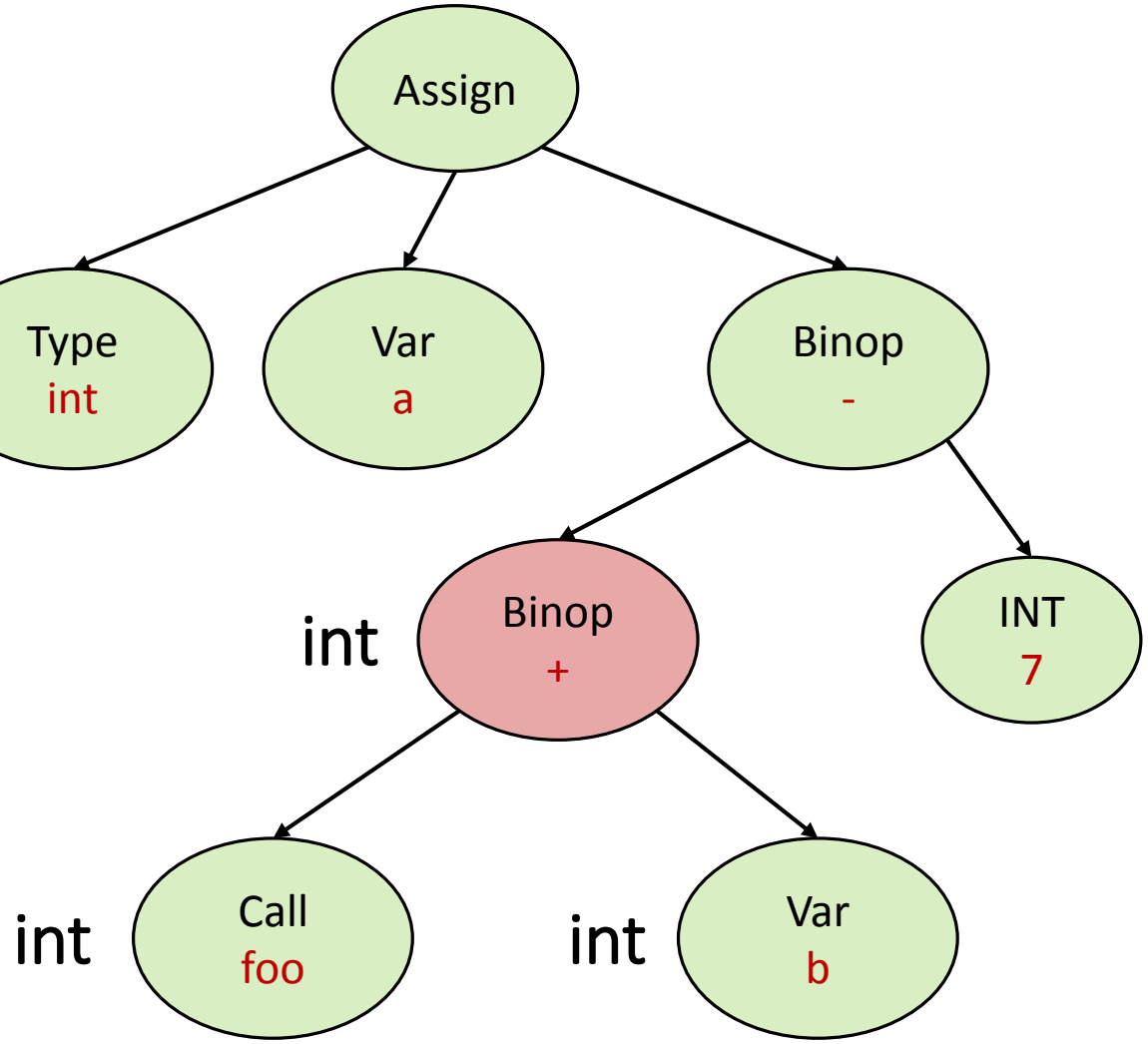

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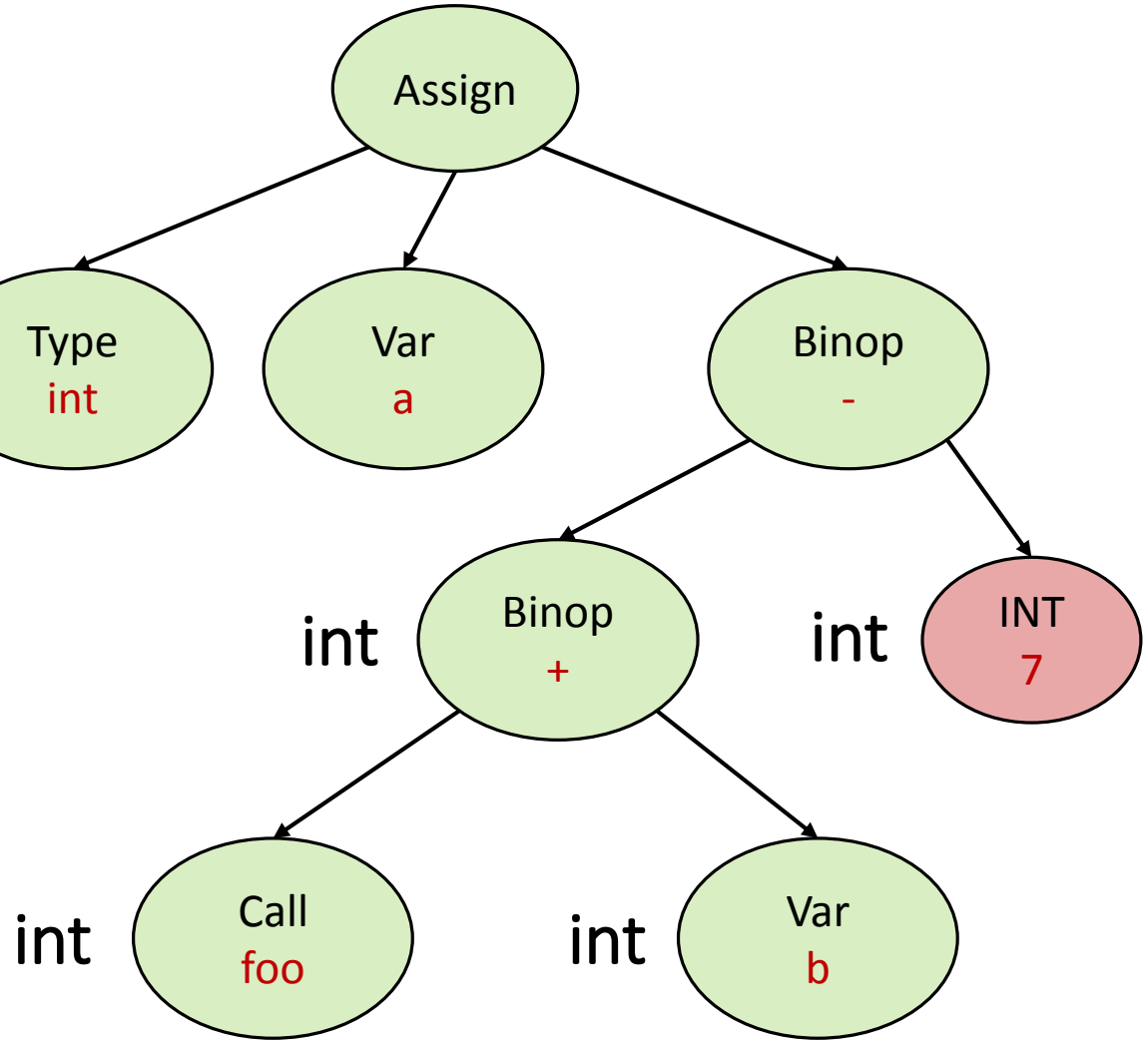

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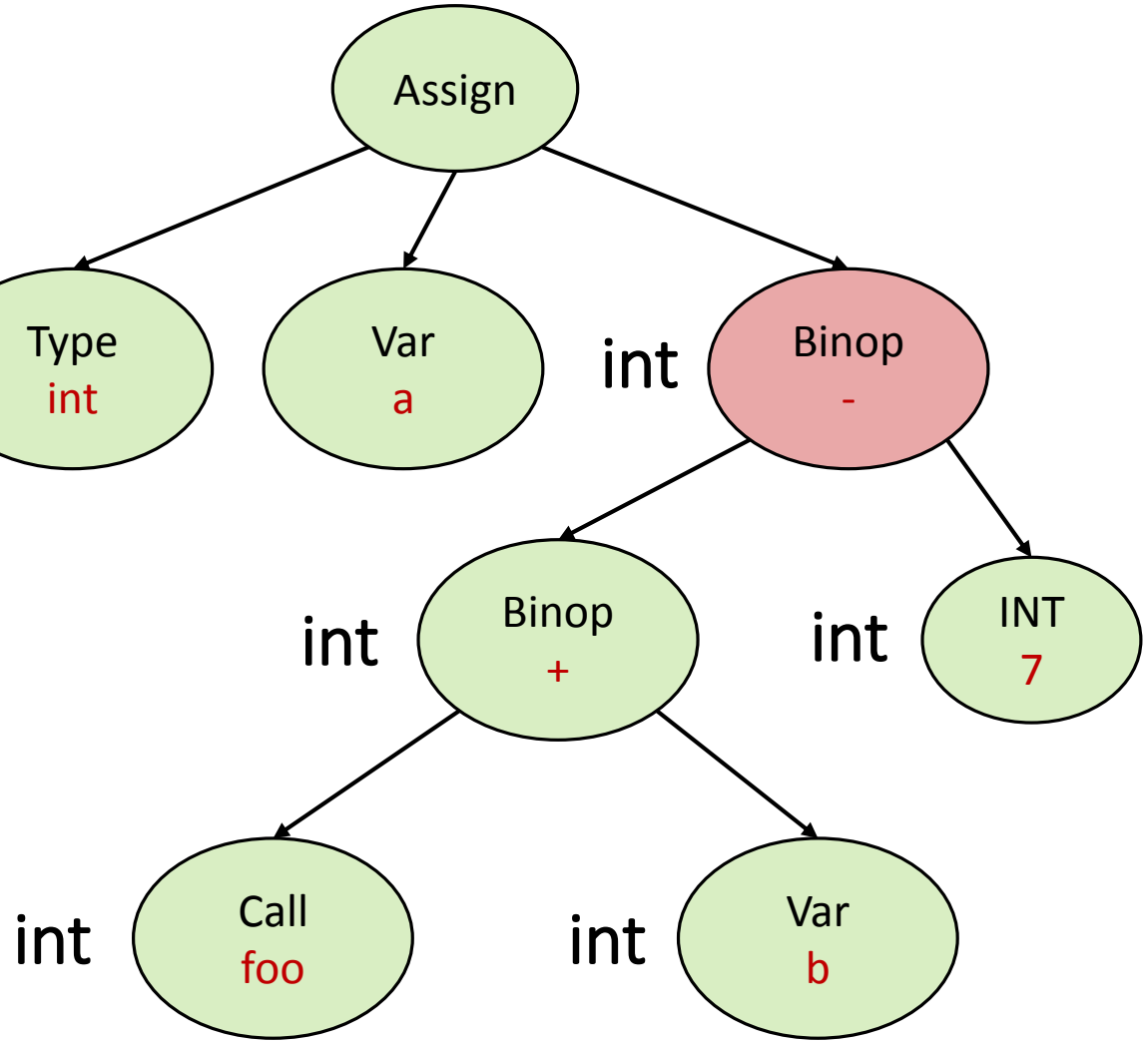
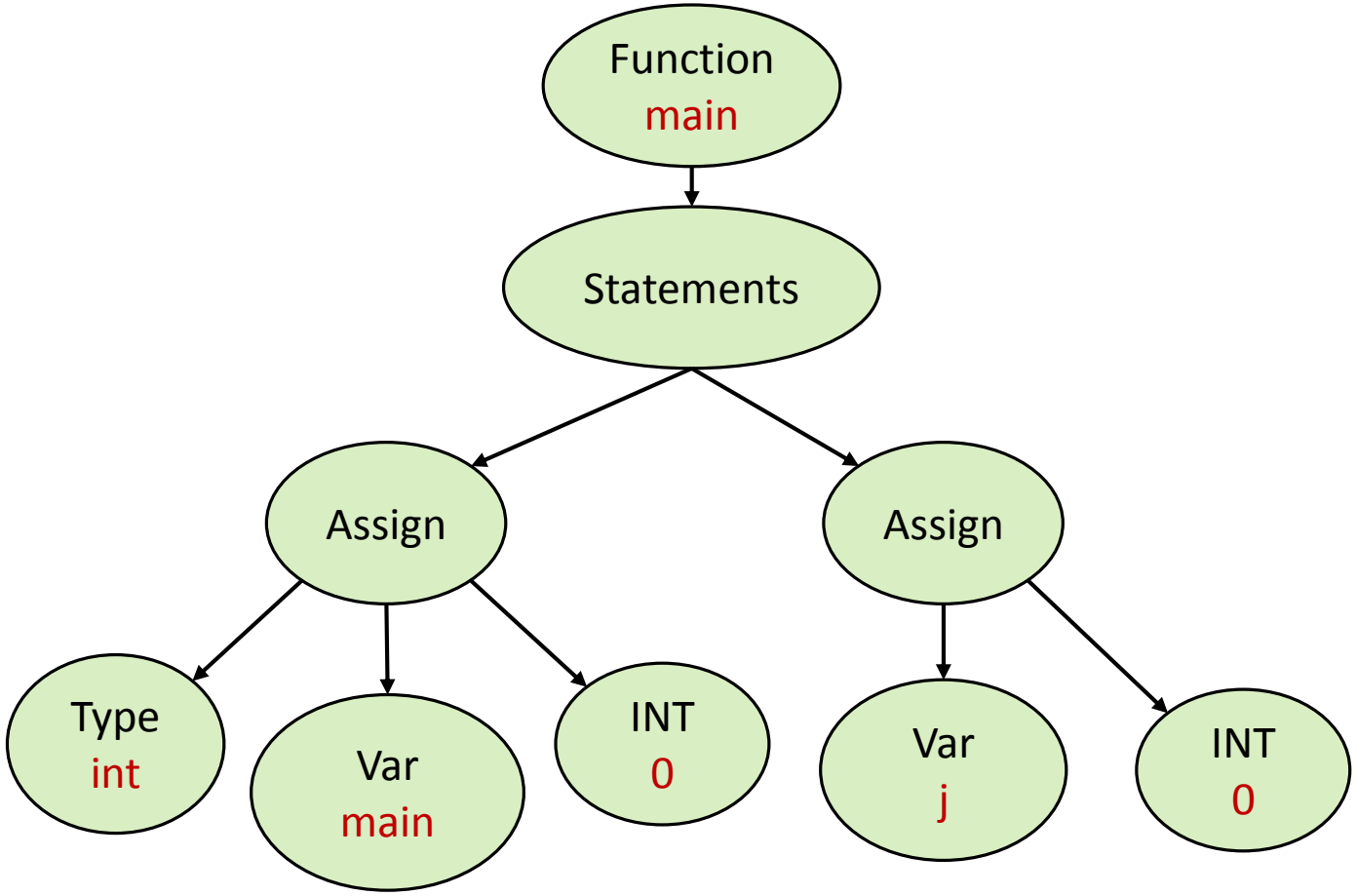


# Examples

# Assignments

```
void main() {
   int main = 0
   j = 0;
}
```



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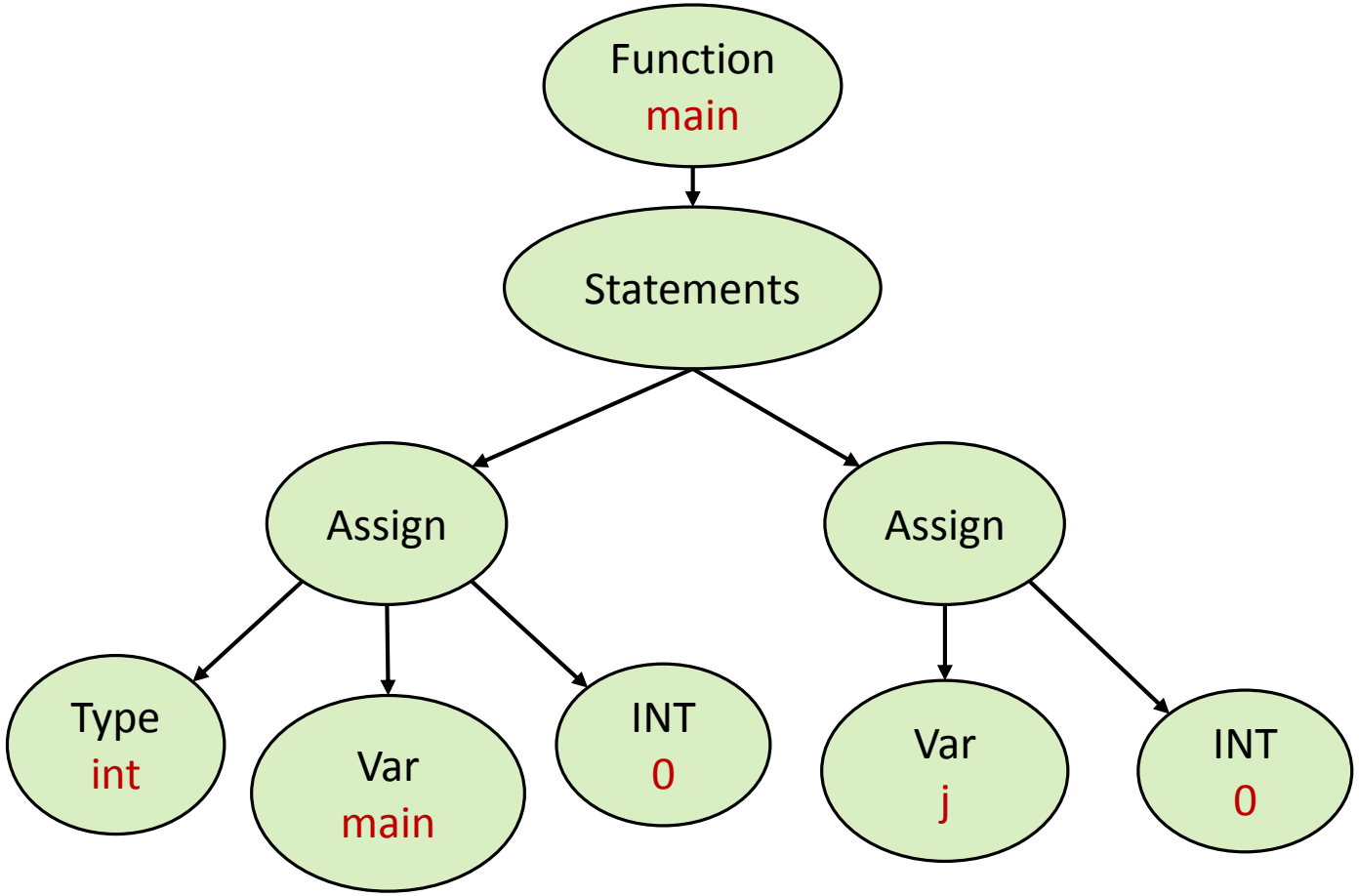
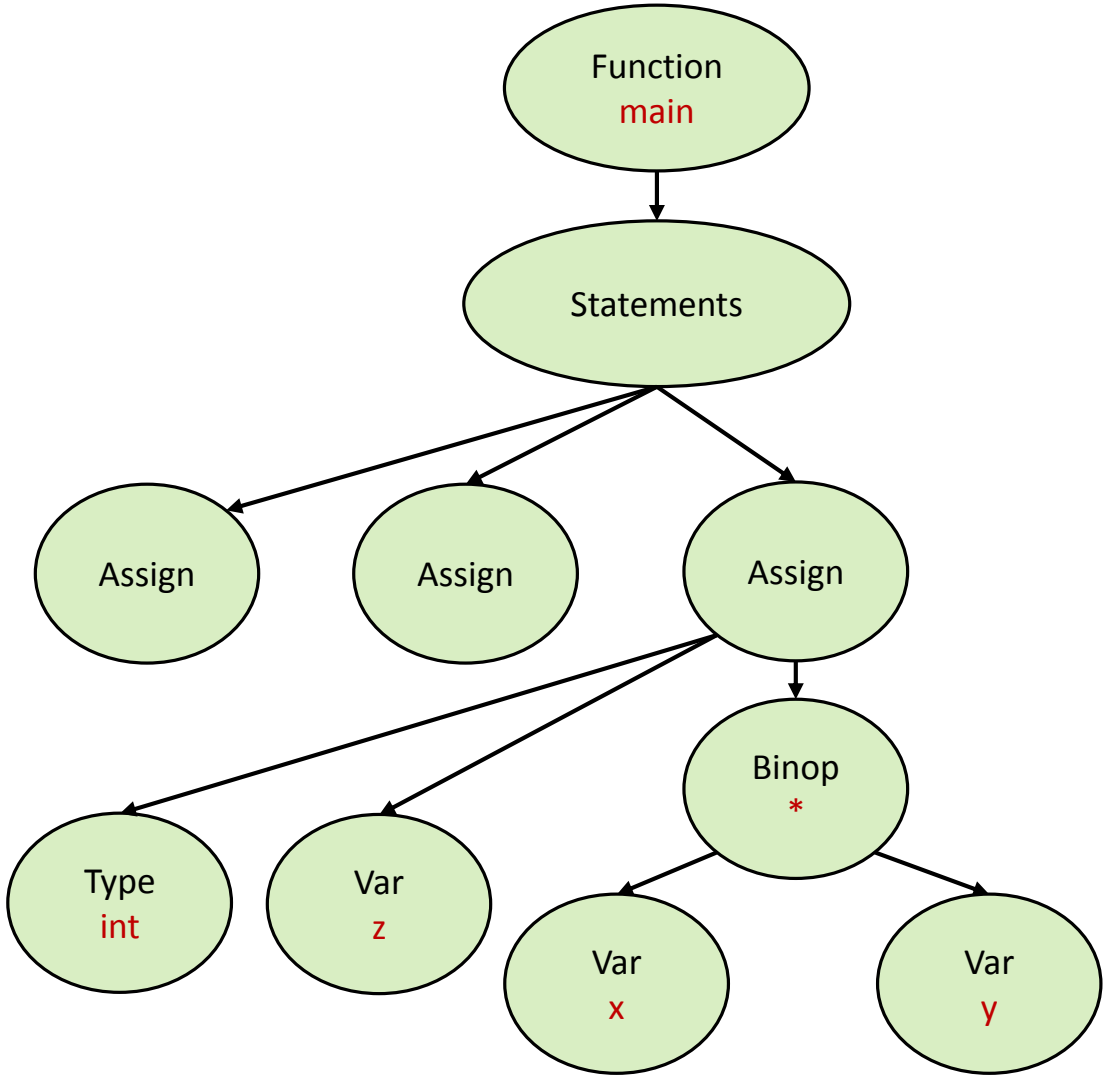



Invalid

# Binary Operations

```
void main() {
   string x = "A";
   string y = "B";
   string z = x * y;
}
```



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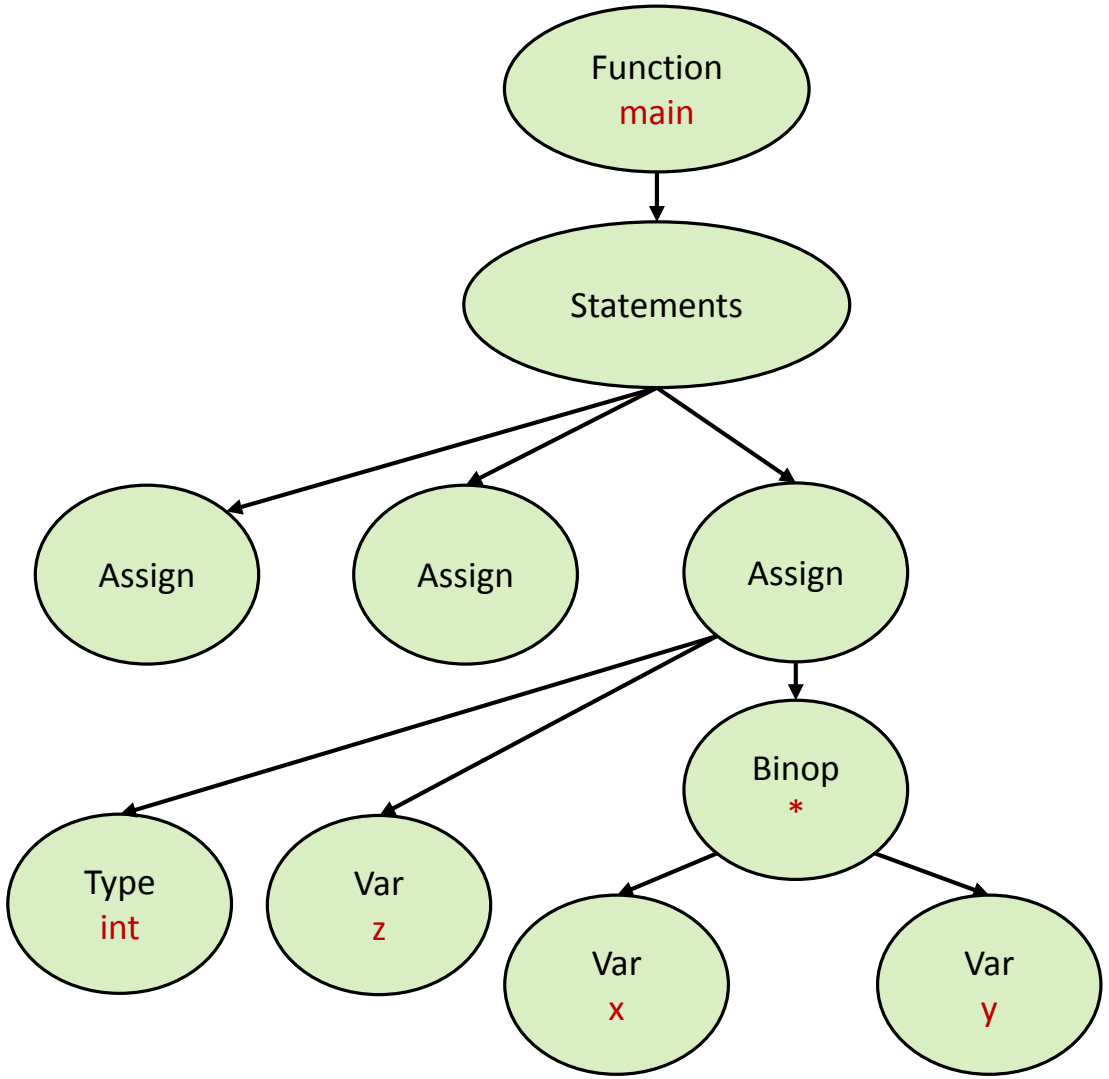
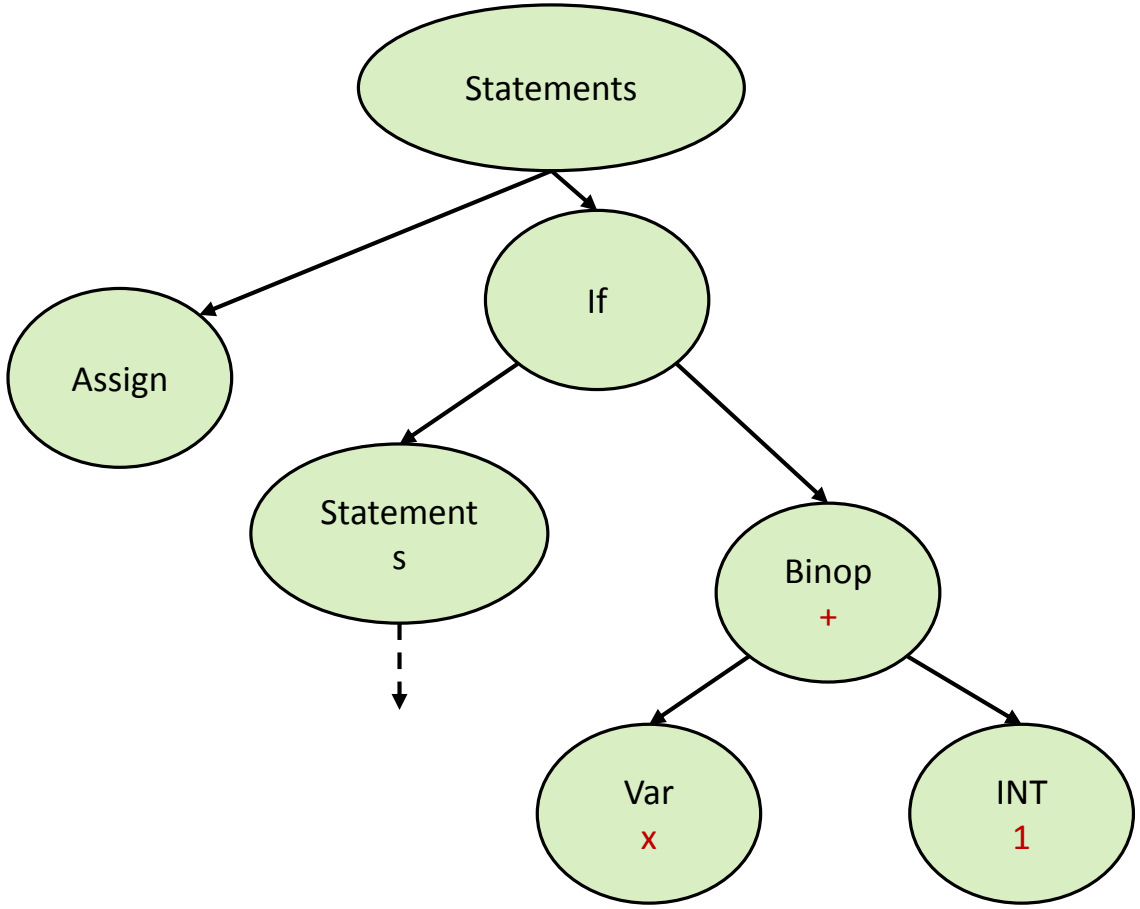



**Invalid**

# If, While, …

```
void main() {
  int x = 1;
  if (x + 1) {
    int z = 2;
  }
}
```



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}
```
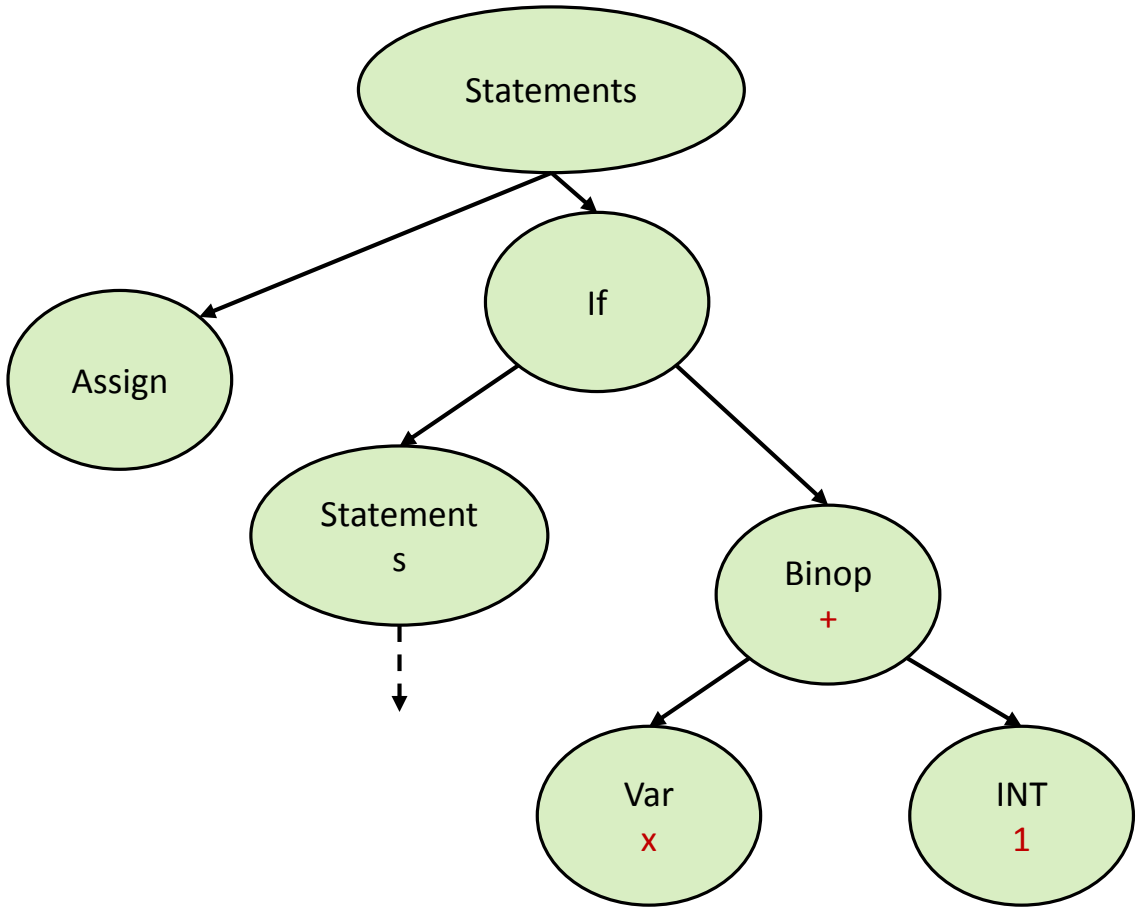
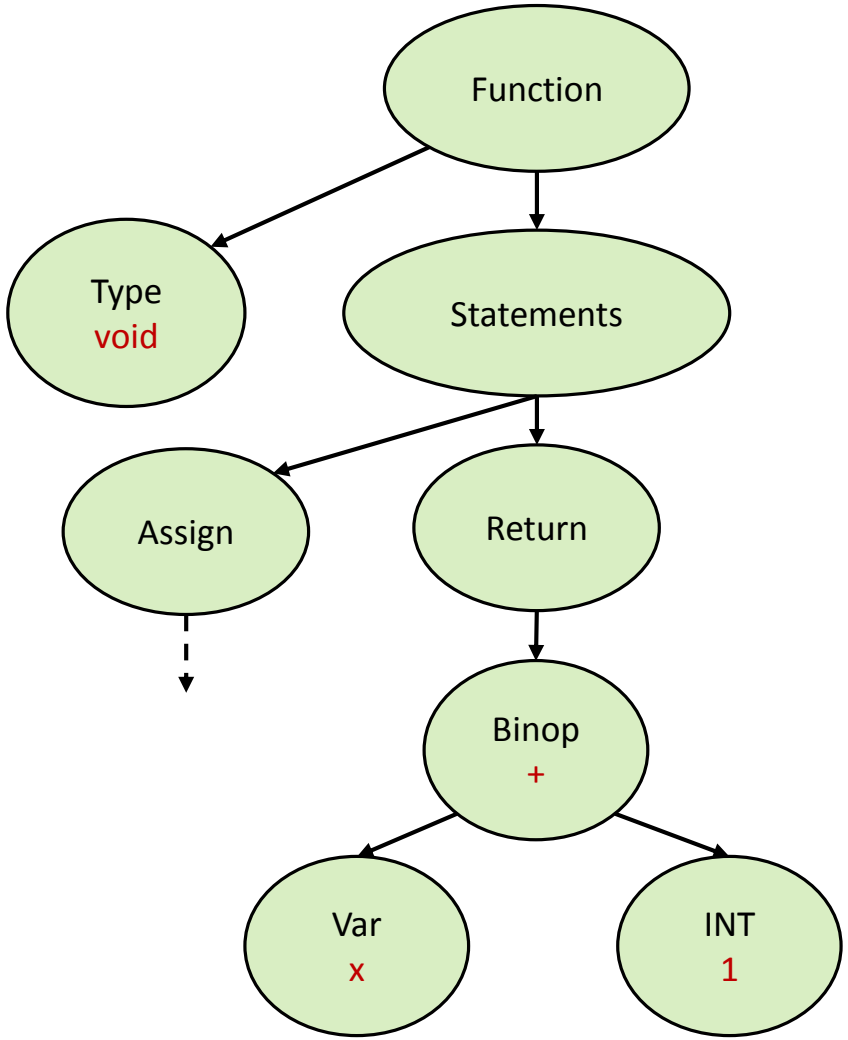




Valid

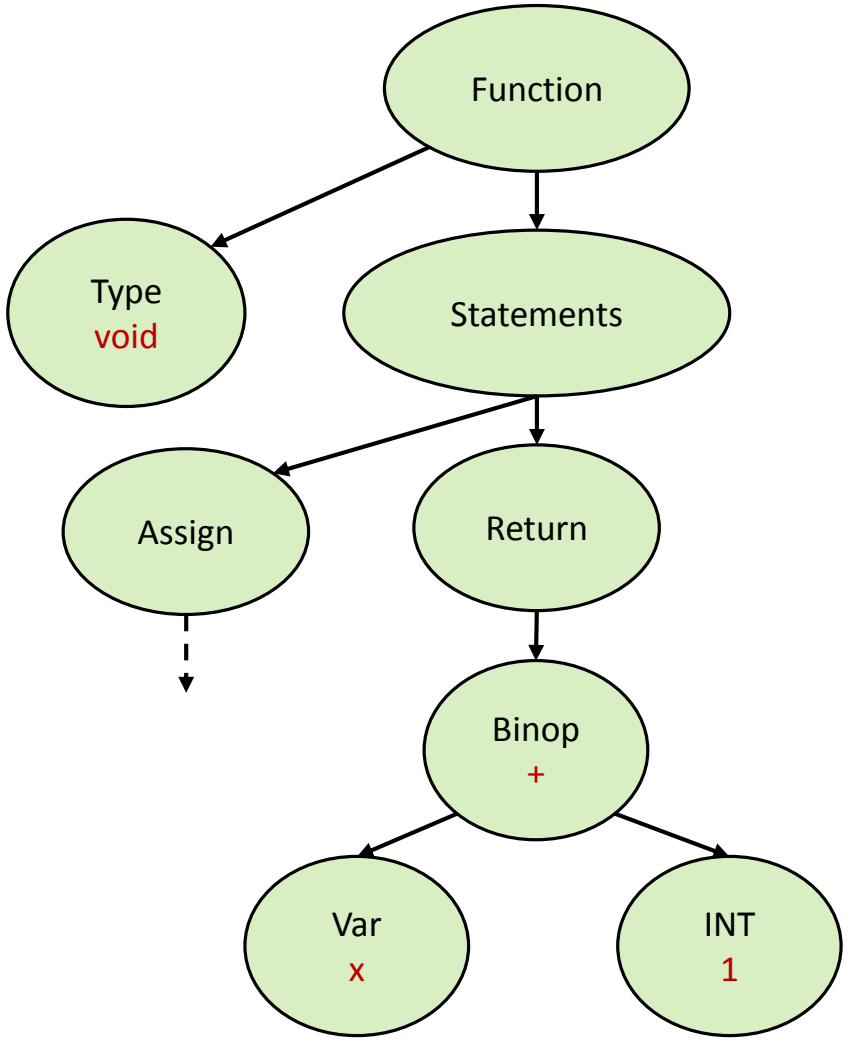
# Return Statement

```
void main() {
  int x = 1;
  return x + 1;
}
```



# Return Statement

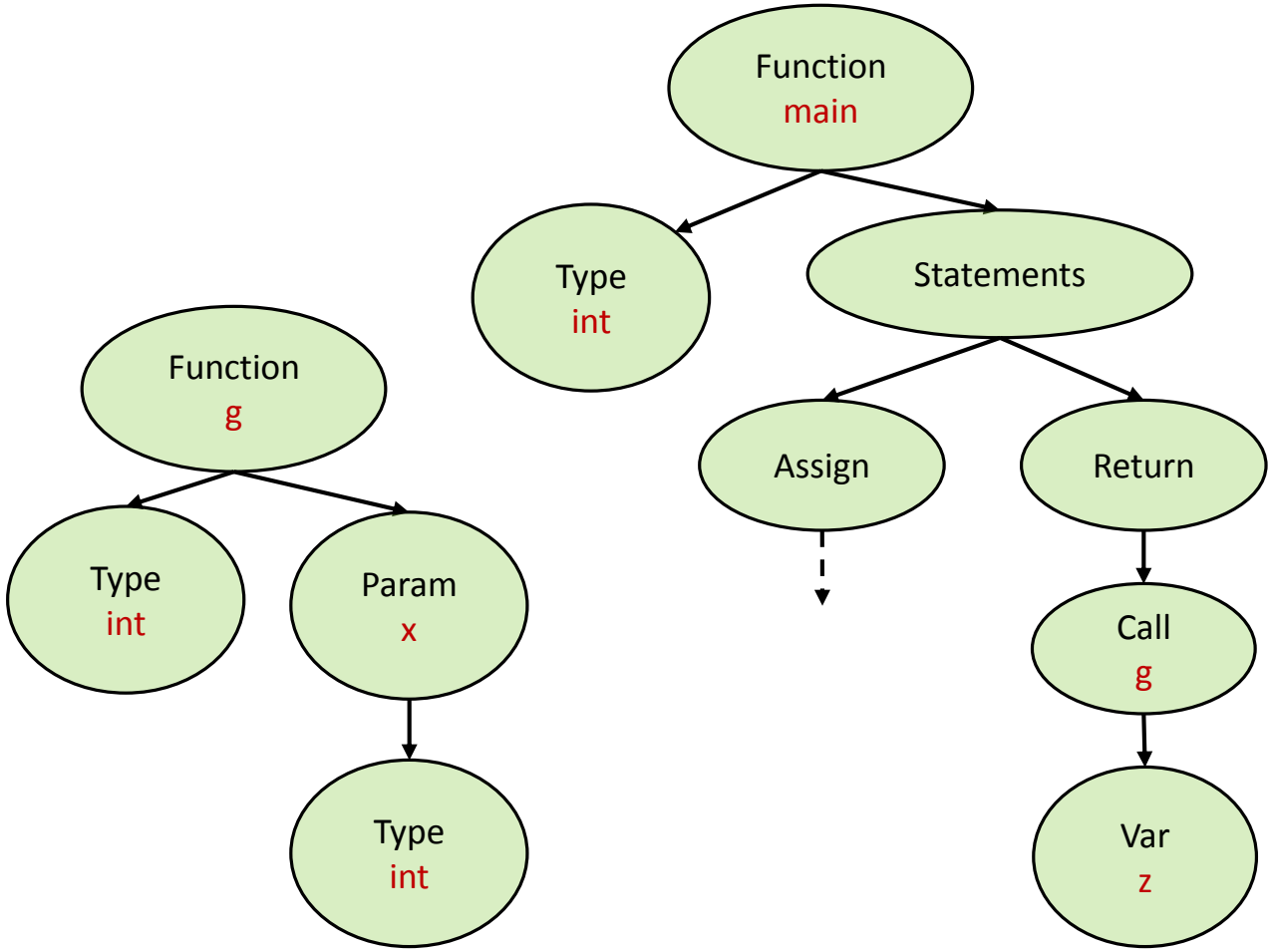
```
void main() {
  int x = 1;
  return x + 1;
}
```




Invalid

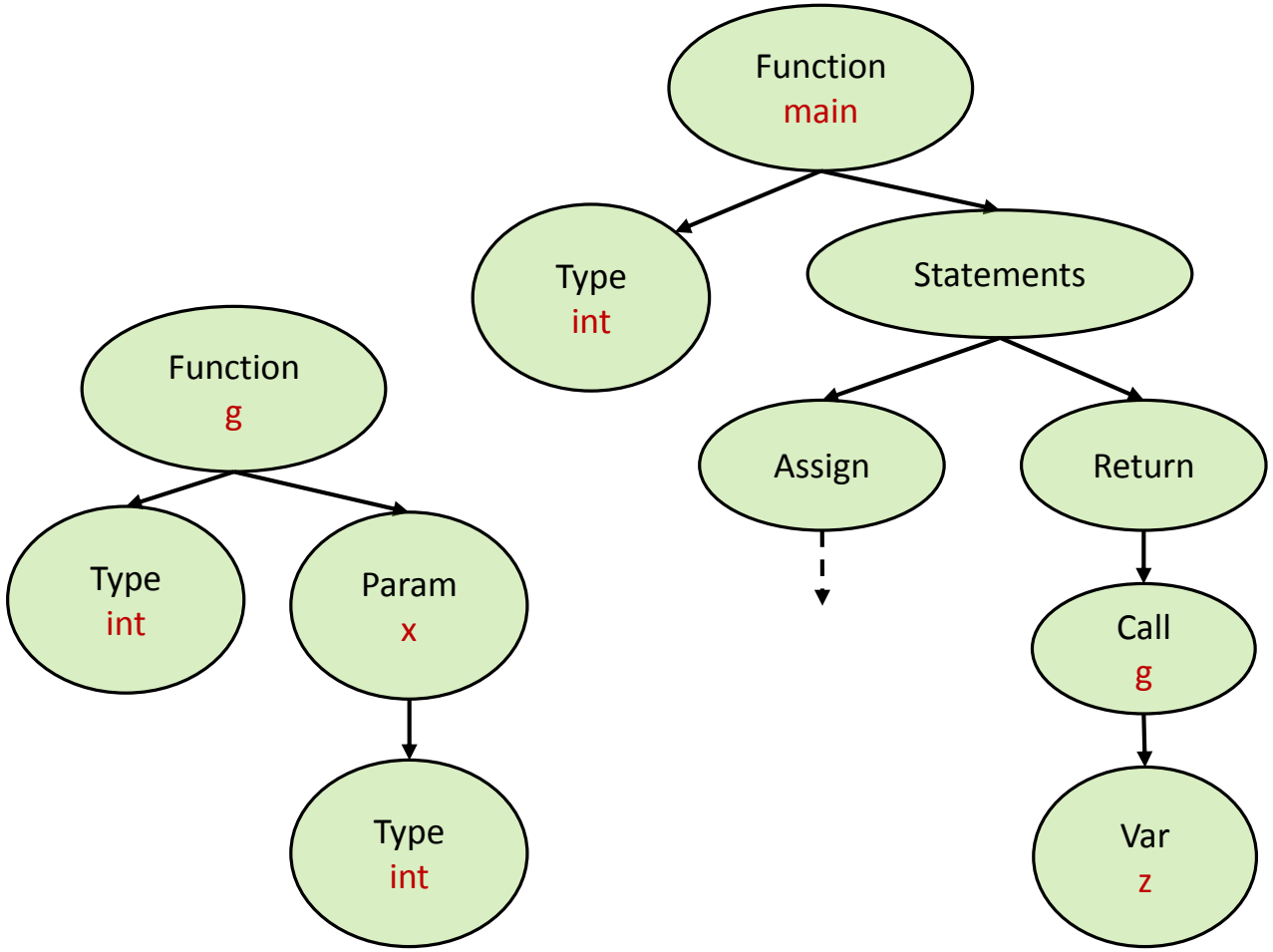
# Function Calls

```
int g(int x) {
  return x + 1;
}
int main() {
  string z = "..."
  return g(z);
}
```



# Function Calls

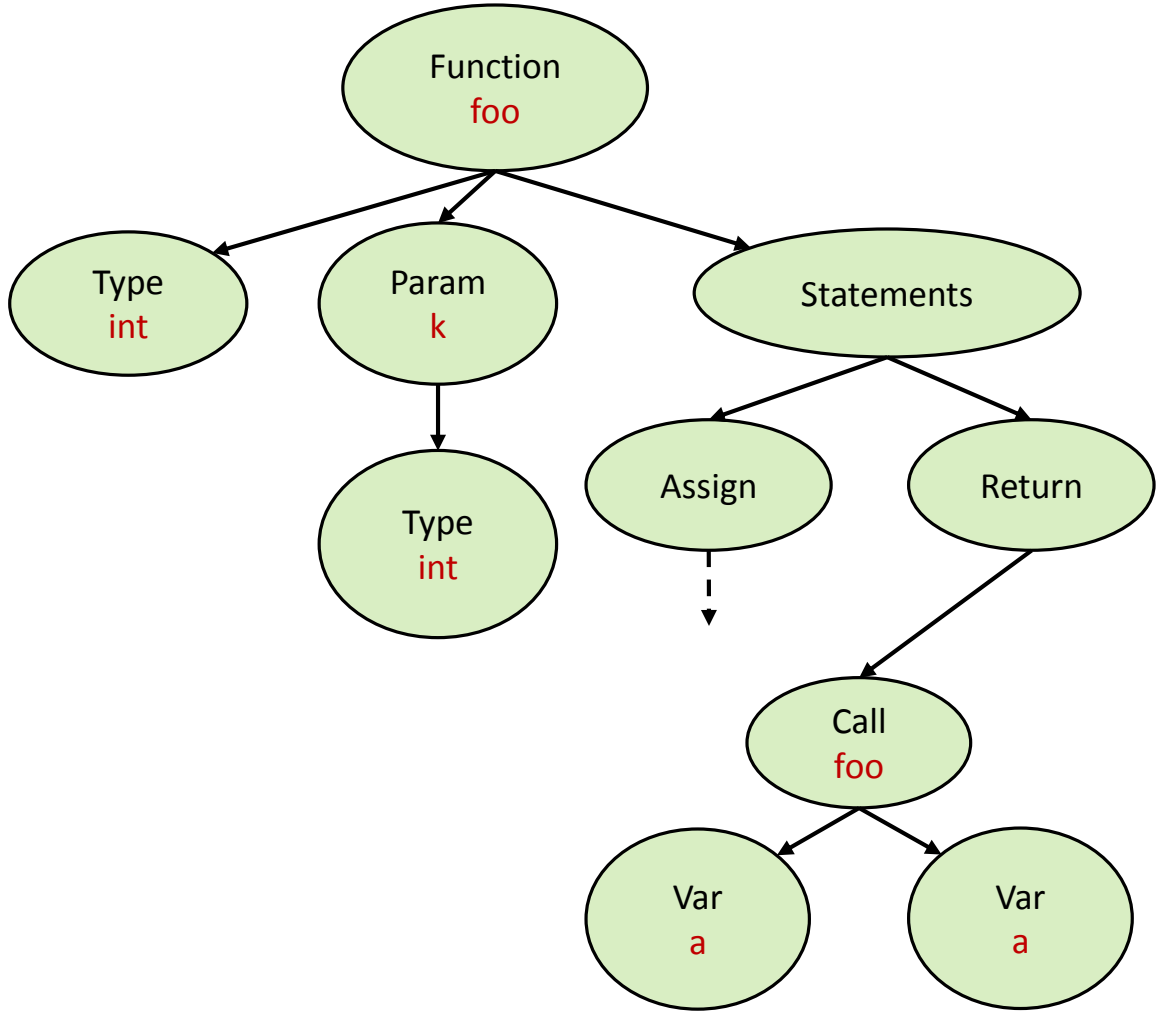
```
int g(int x) {
  return x + 1;
}
int main() {
  string z = "..."
  return g(z);
}
```




Invalid

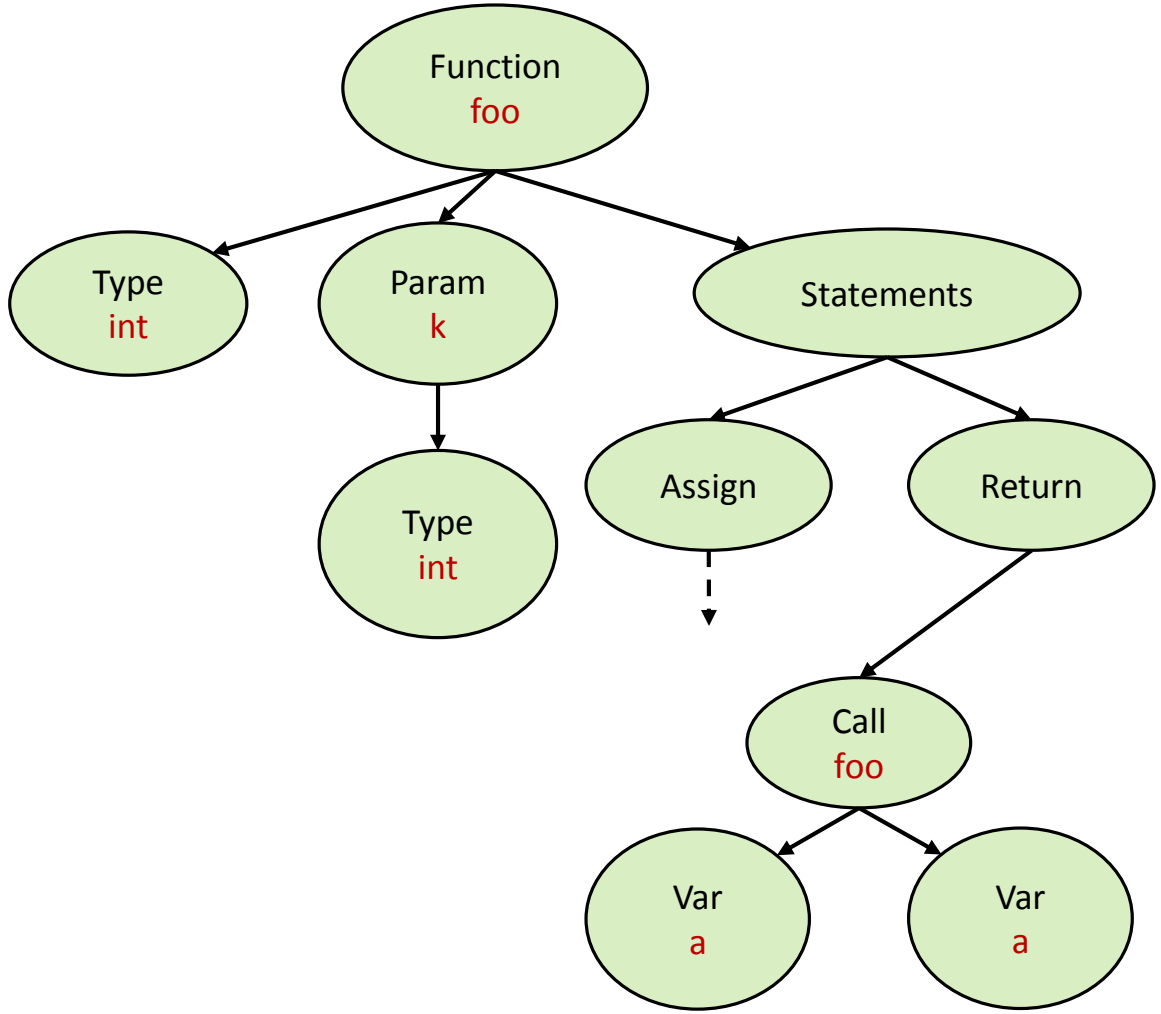
# Function Calls

```
int foo(int k) {
  int a = k * 10;
  return foo(a, a);
}
```



# Function Calls

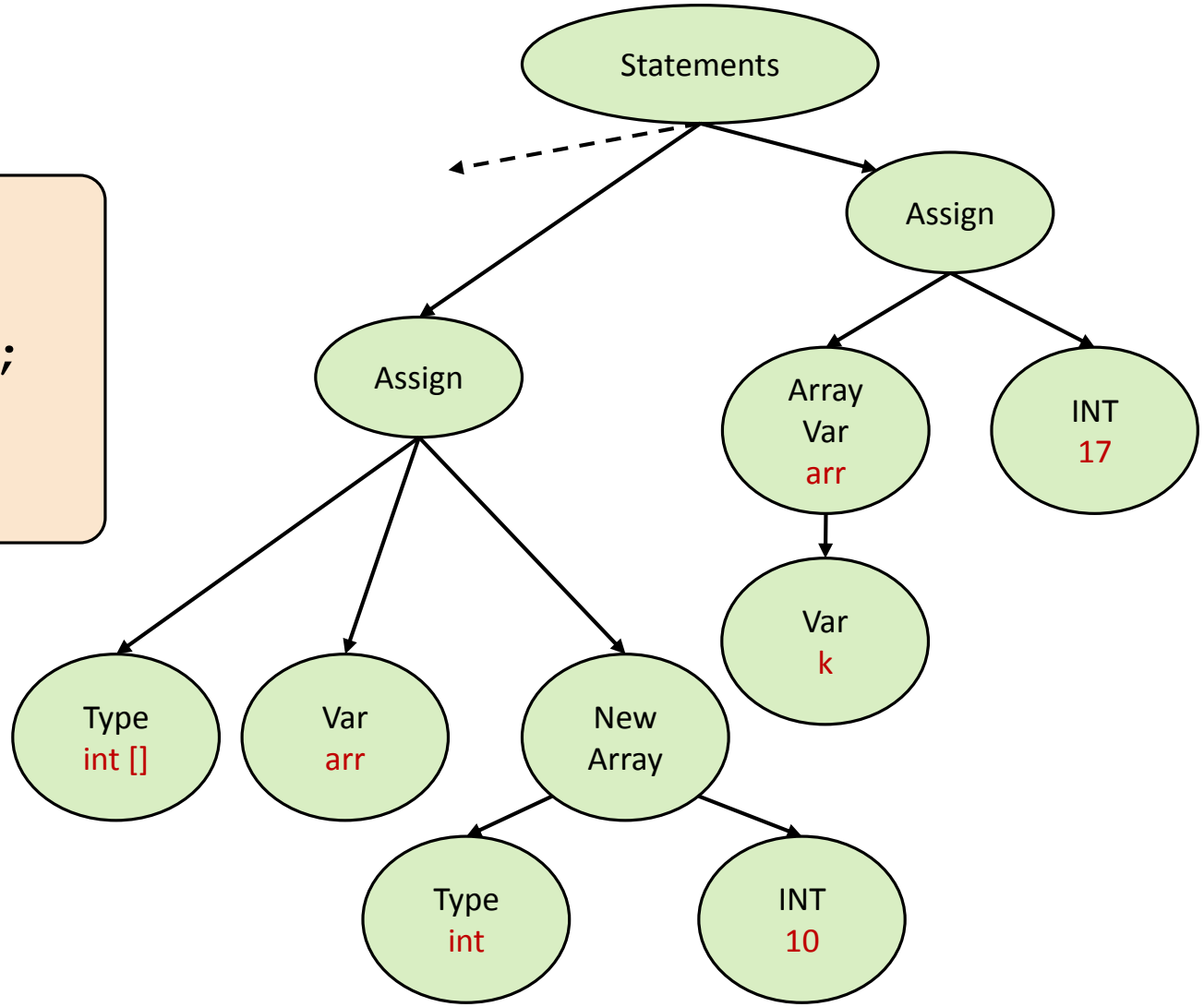
```
int foo(int k) {
  int a = k * 10;
  return foo(a, a);
}
```




Invalid

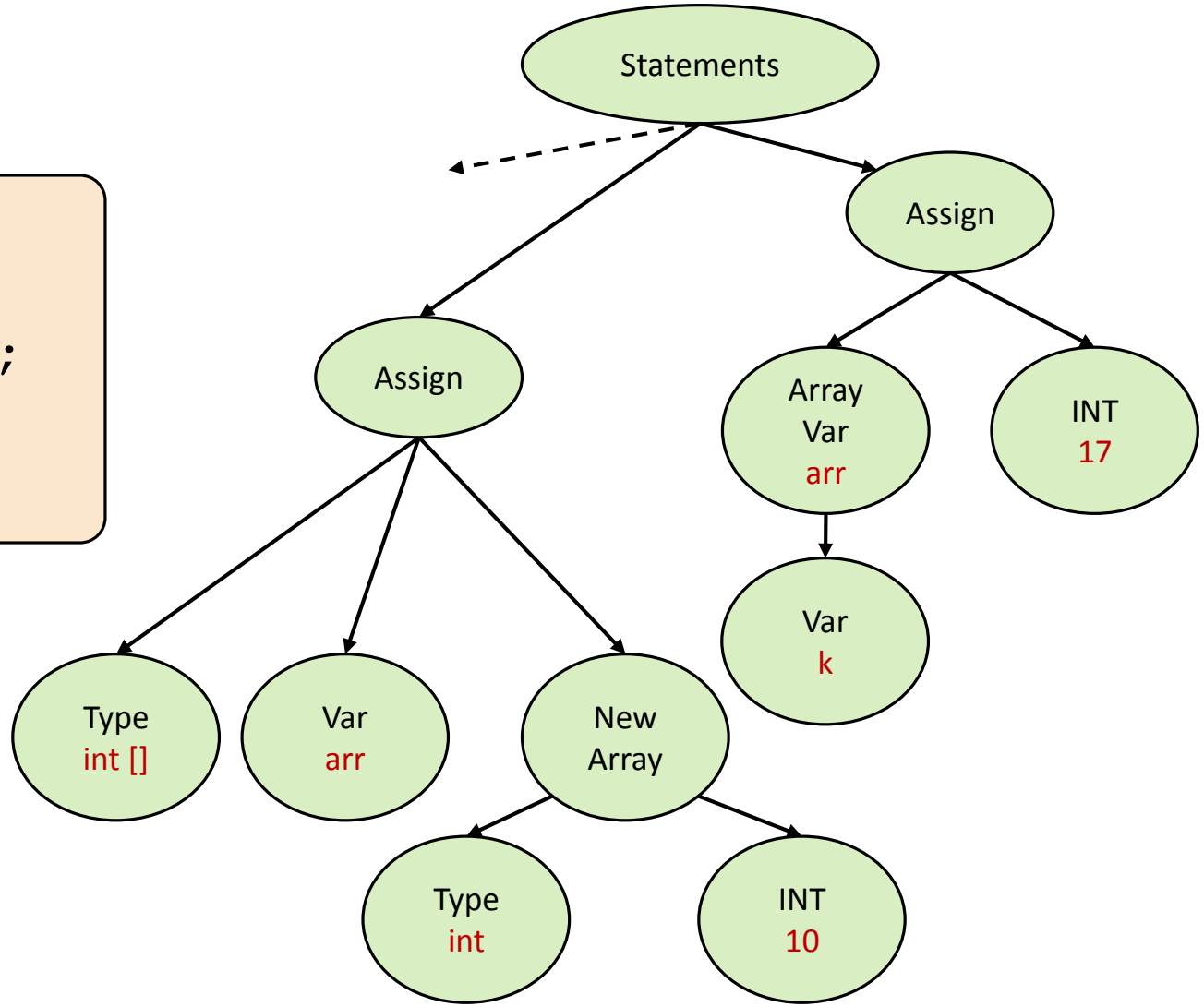
# Arrays

```
void foo(int d) {
  int k = 3;
  int[] arr = new int[10];
  arr[k] = 17;
}
```



# Arrays

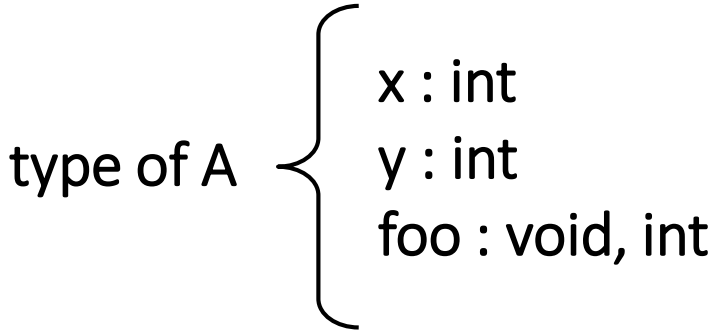
```
void foo(int d) {
  int k = 3;
  int[] arr = new int[10];
  arr[k] = 17;
}
```




Valid

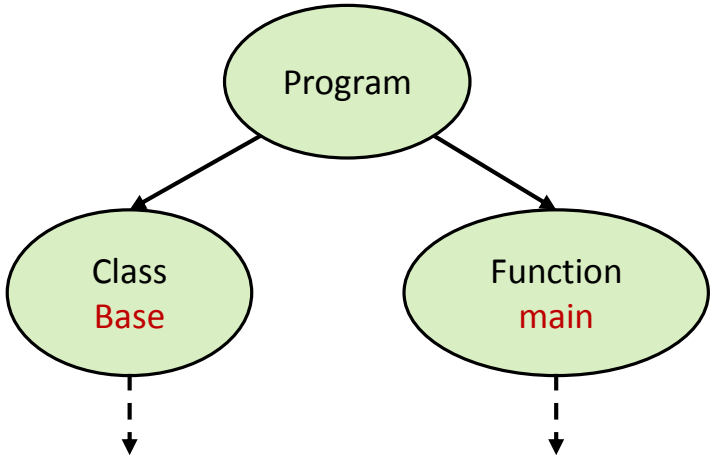
# Classes

```
class A {
  int x;
  int y;
  void foo(int) { }
}
```



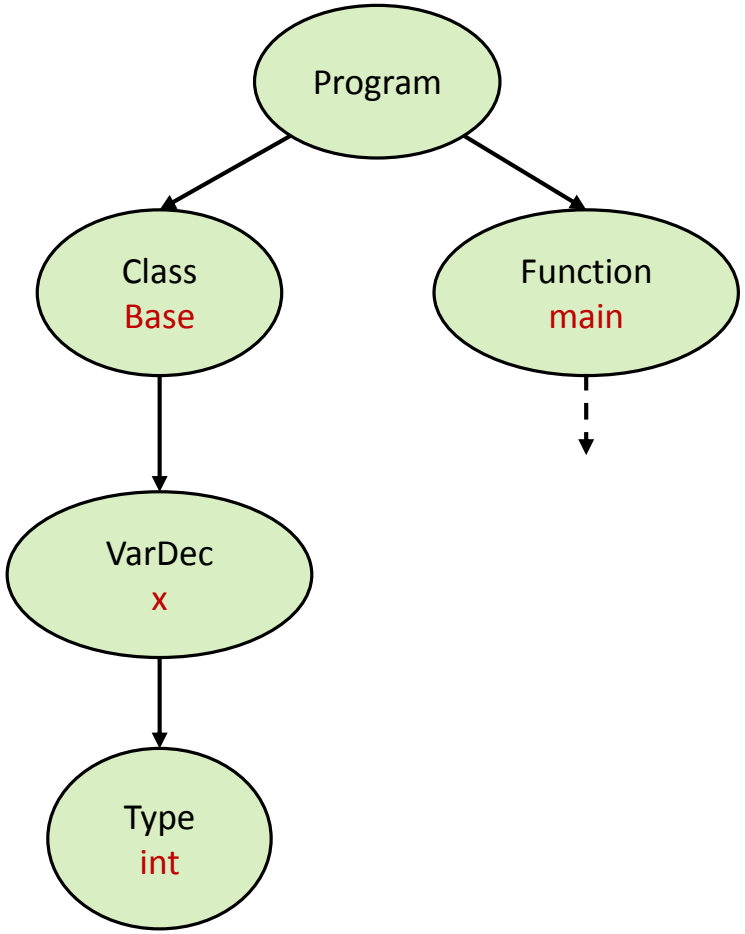
# Classes

```
class Base {
  int x;
}
void main() {
  Base o = new Base;
  o.y = 1;
}
```



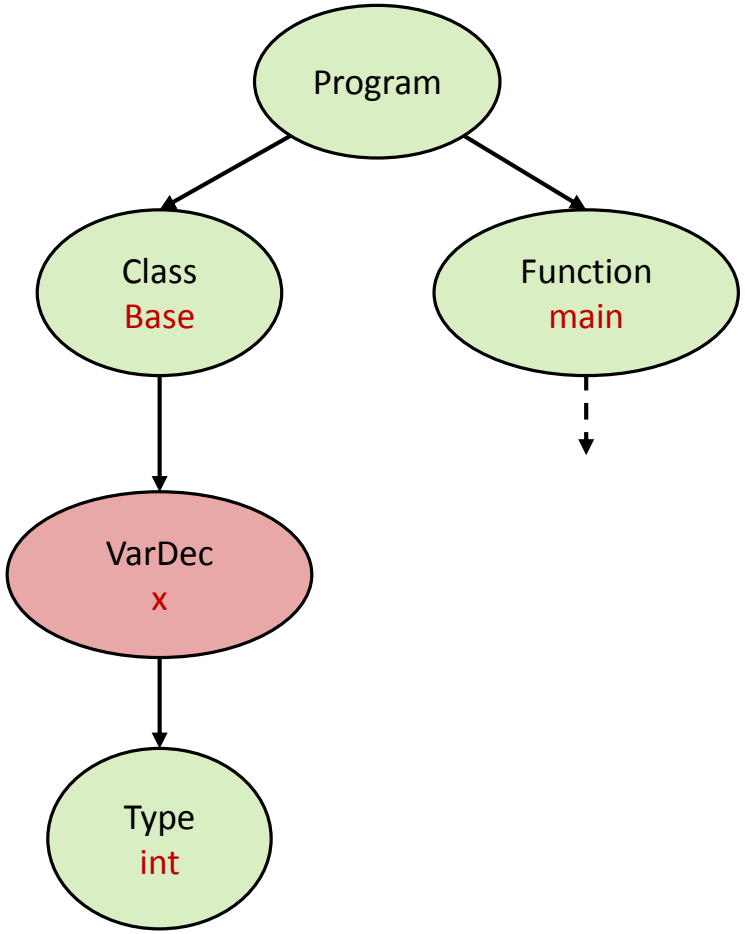
# Classes

```
class Base {
  int x;
}
void main() {
  Base o = new Base;
  o.y = 1;
}
```



# Classes

```
class Base {
  int x;
}
void main() {
  Base o = new Base;
  o.y = 1;
}
```




| ID | Type | Kind |
|---|---|---|
| Base | … | class |
| | | |

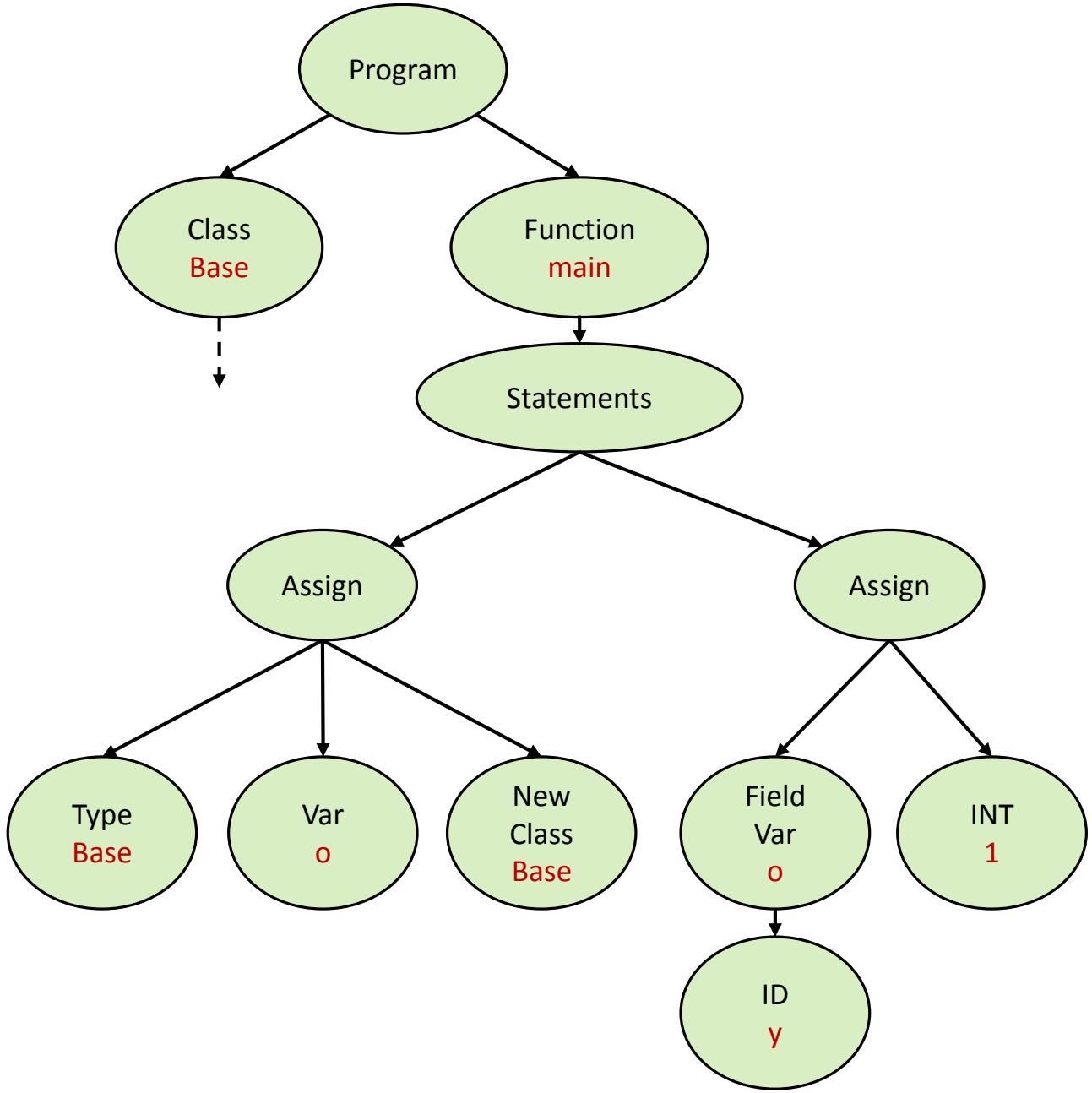
$scope_1$

| ID | Type | Kind |
|---|---|---|
| x | int | variable |
| | | |

$scope_2$

# Classes

```
class Base {
  int x;
}
void main() {
  Base o = new Base;
  o.y = 1;
}
```



# Classes

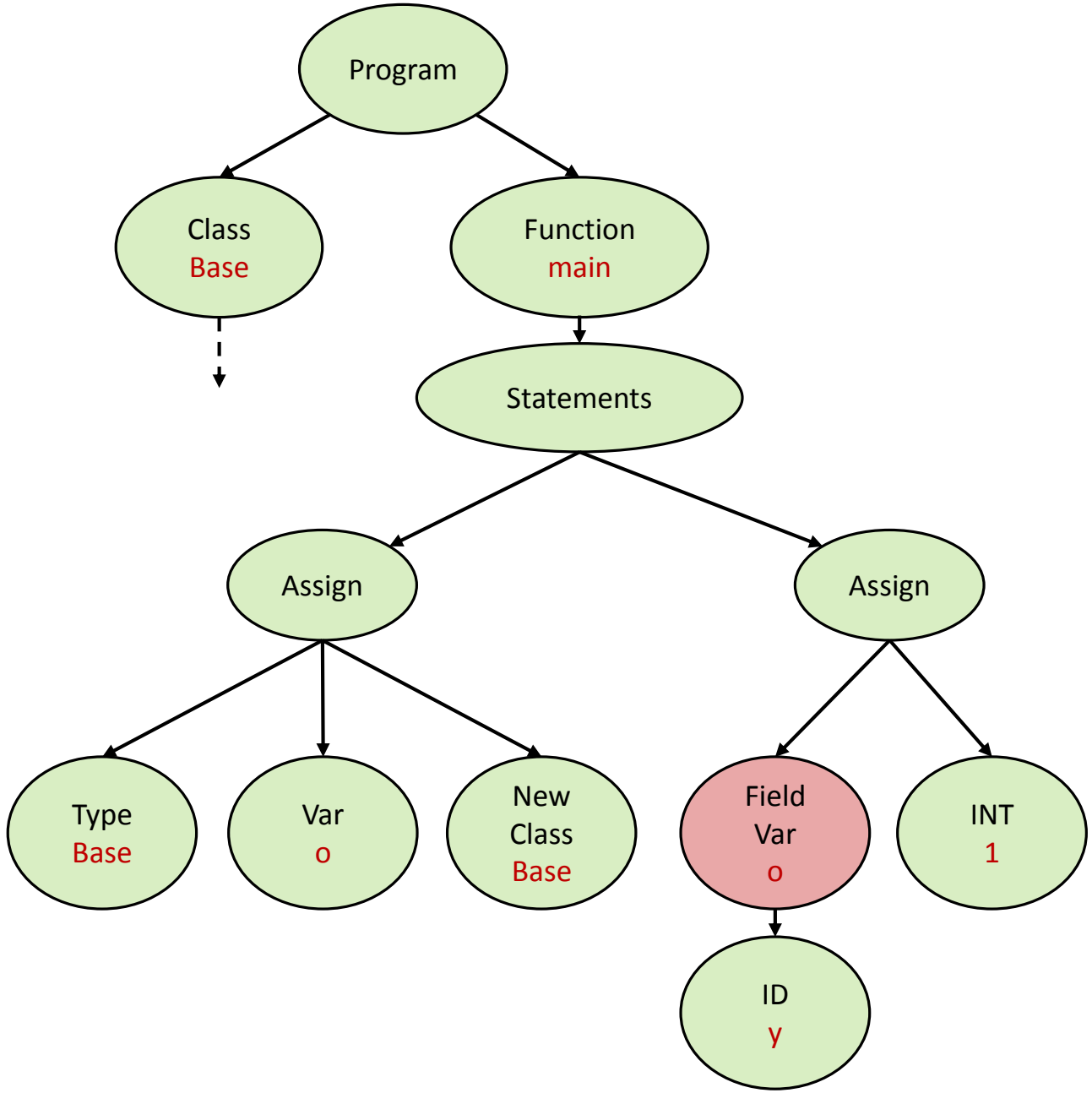
```
class Base {
  int x;
}
void main() {
  Base o = new Base;
  o.y = 1;
}
```

| ID | Type | Kind |
|---|---|---|
| Base | … | class |
| main | … | function |

$scope_1$

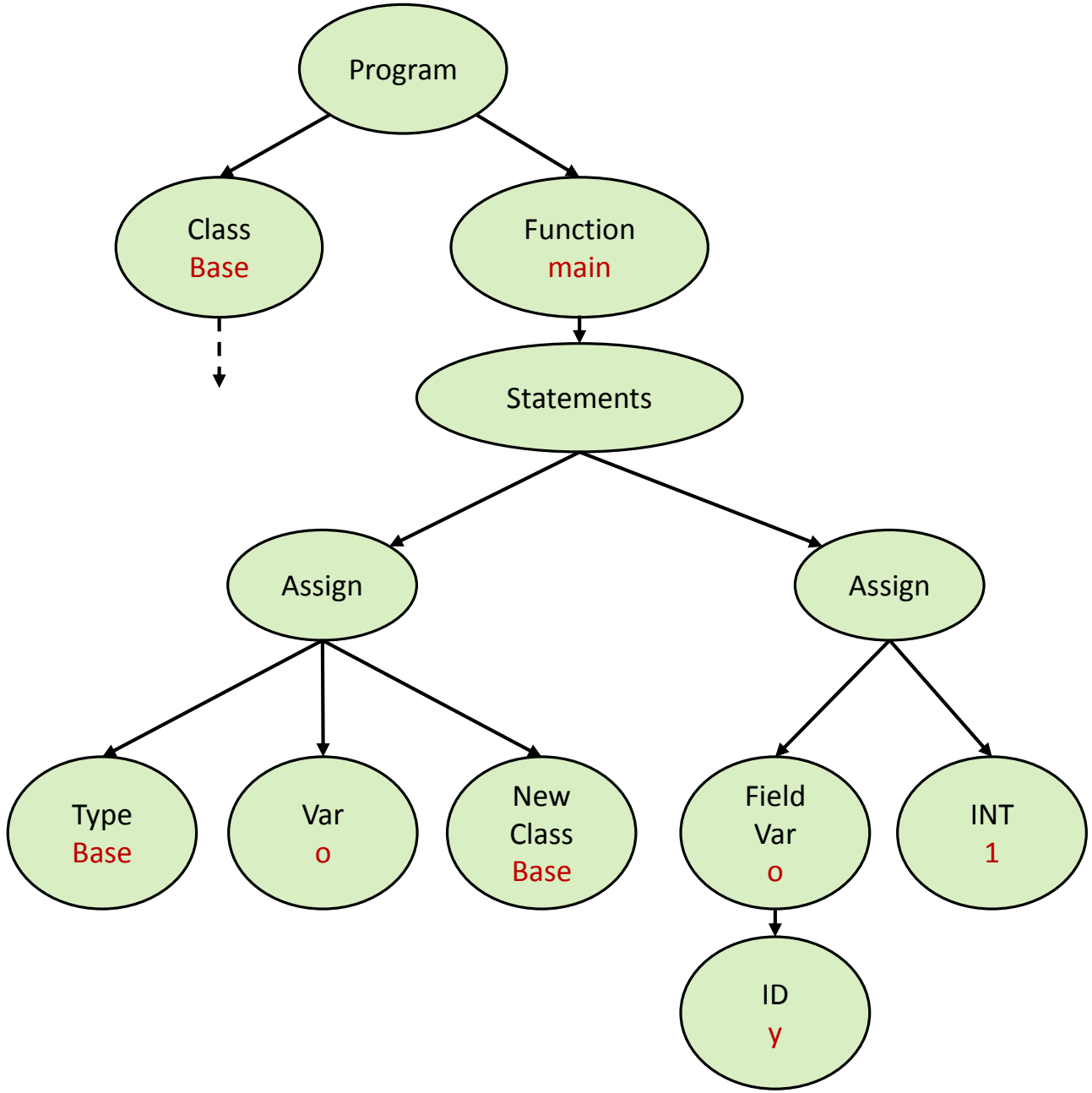
| ID | Type | Kind |
|---|---|---|
| o | Base | variable |
| | | |

$scope_2$



# Classes

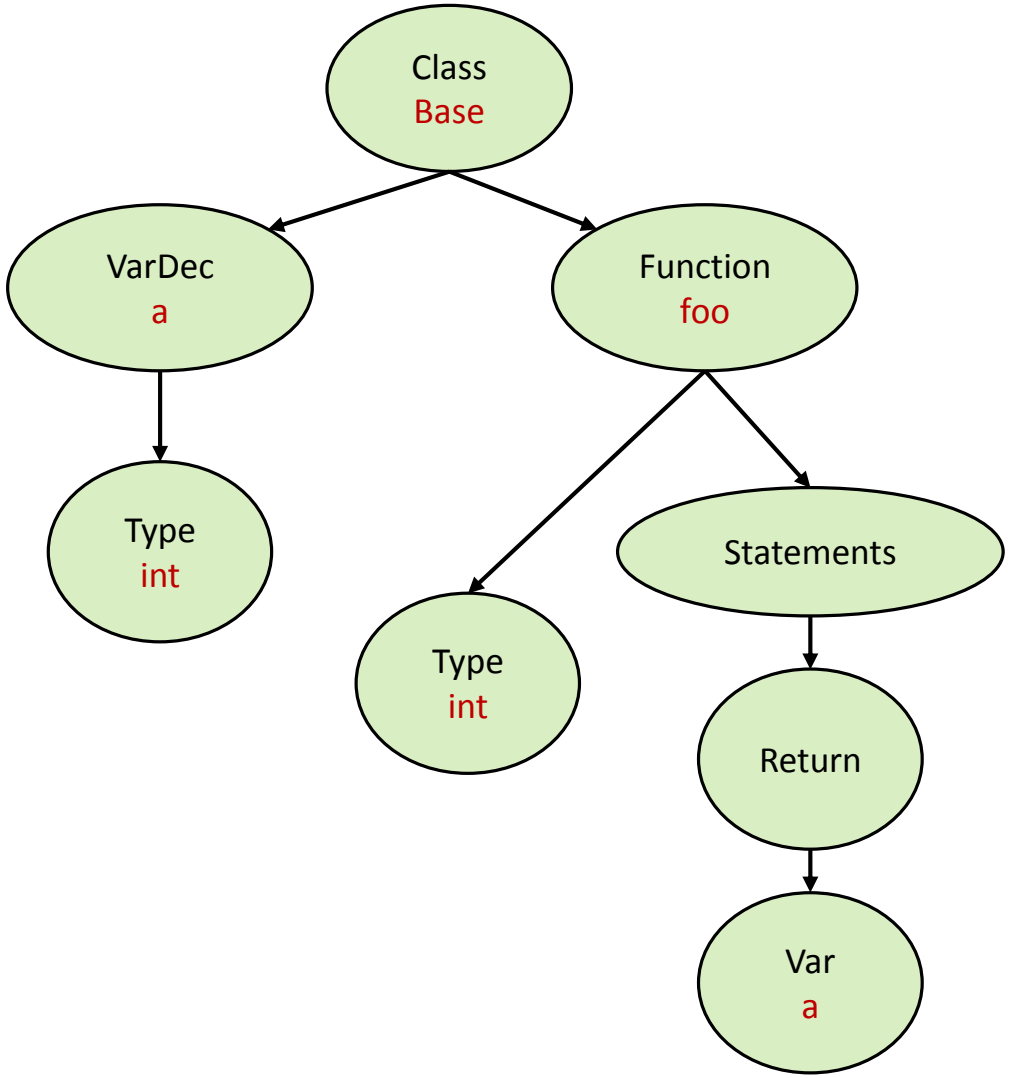
```
class Base {
  int x;
}
void main() {
  Base o = new Base;
  o.y = 1;
}
```




Invalid

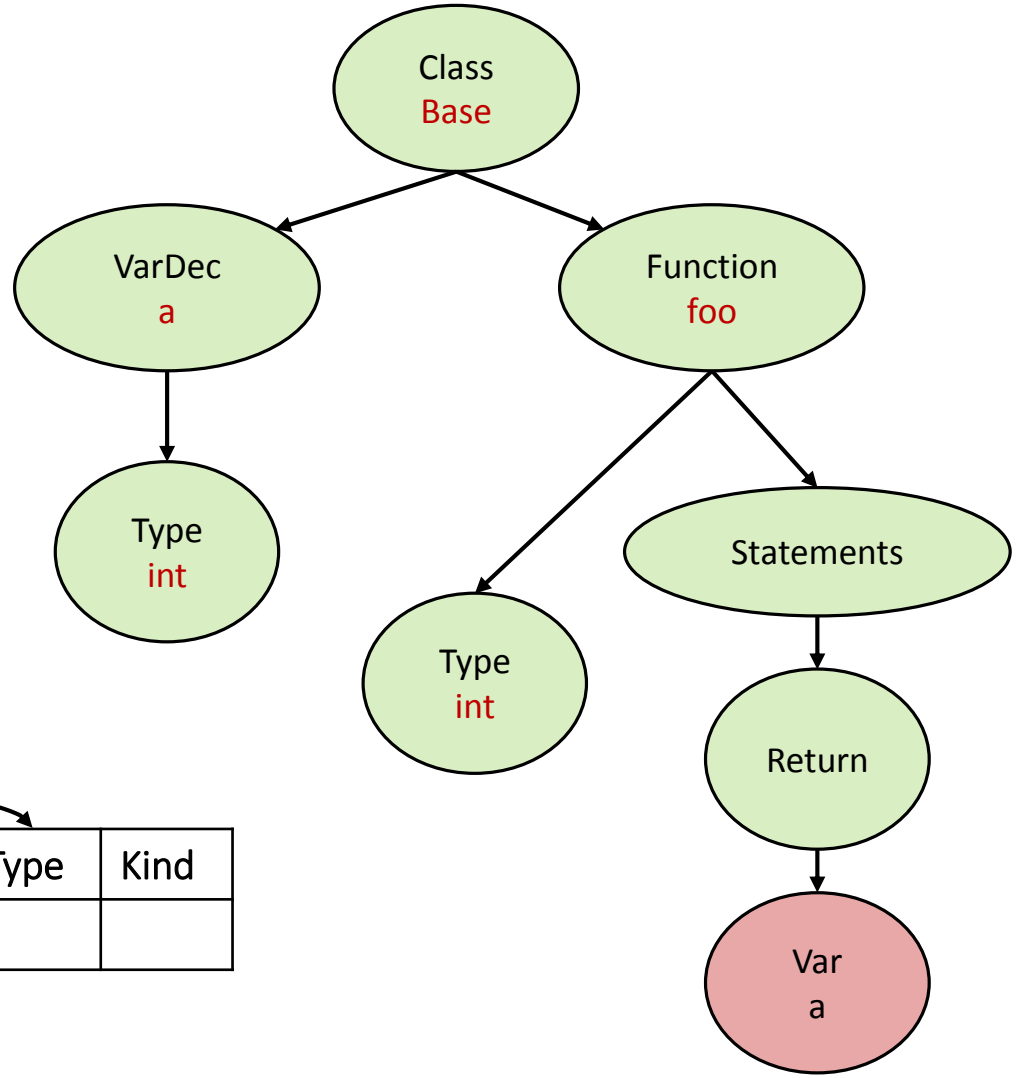
# Classes

```
class Base {
  int a;
  int foo() {
    return a;
  }
}
```



# Classes

```
class Base {
  int a;
  int foo() {
    return a;
  }
}
```




| ID | Type | Kind |
|---|---|---|
| Base | … | class |
| | | |

$scope_1$

| ID | Type | Kind |
|---|---|---|
| a | int | variable |
| foo | … | function |

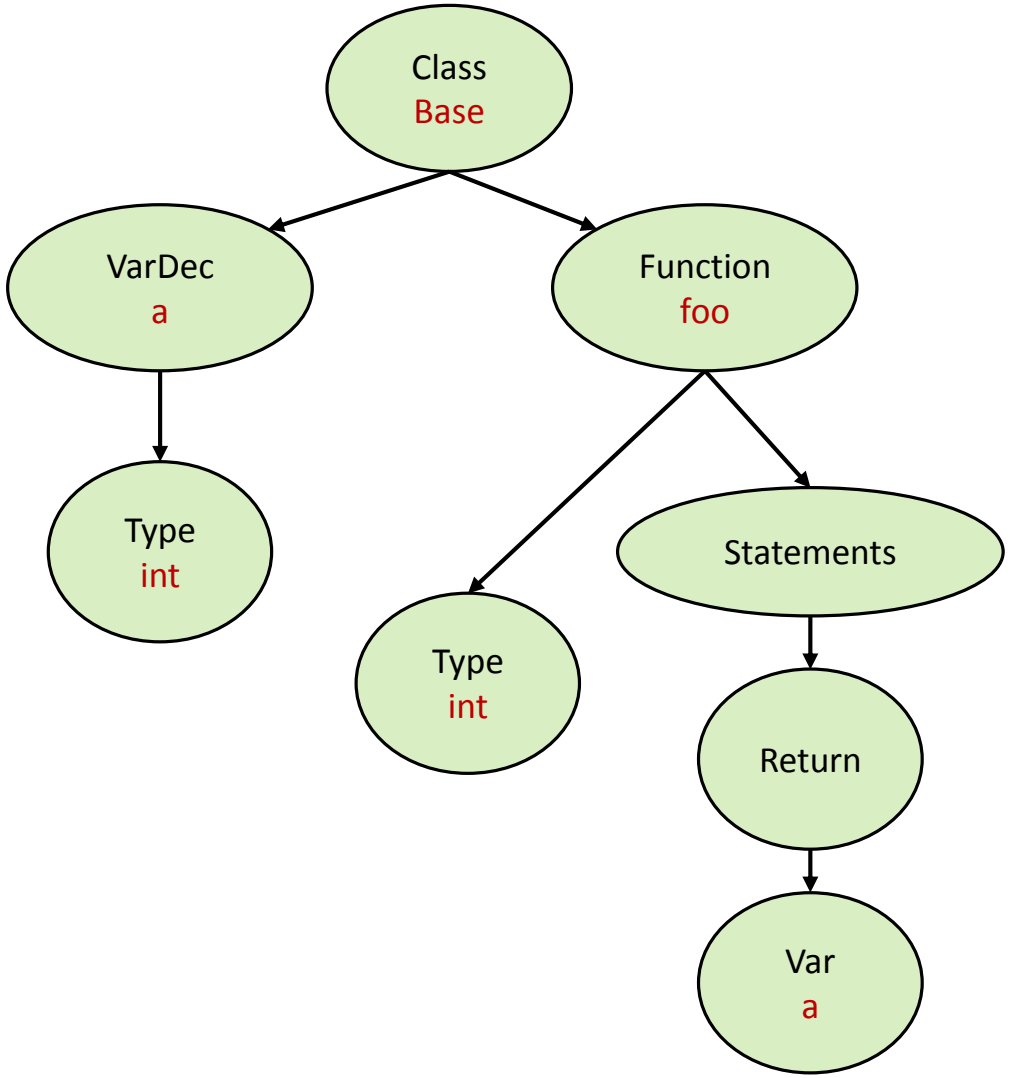
$scope_2$

| ID | Type | Kind |
|---|---|---|
| | | |

$scope_3$

# Classes

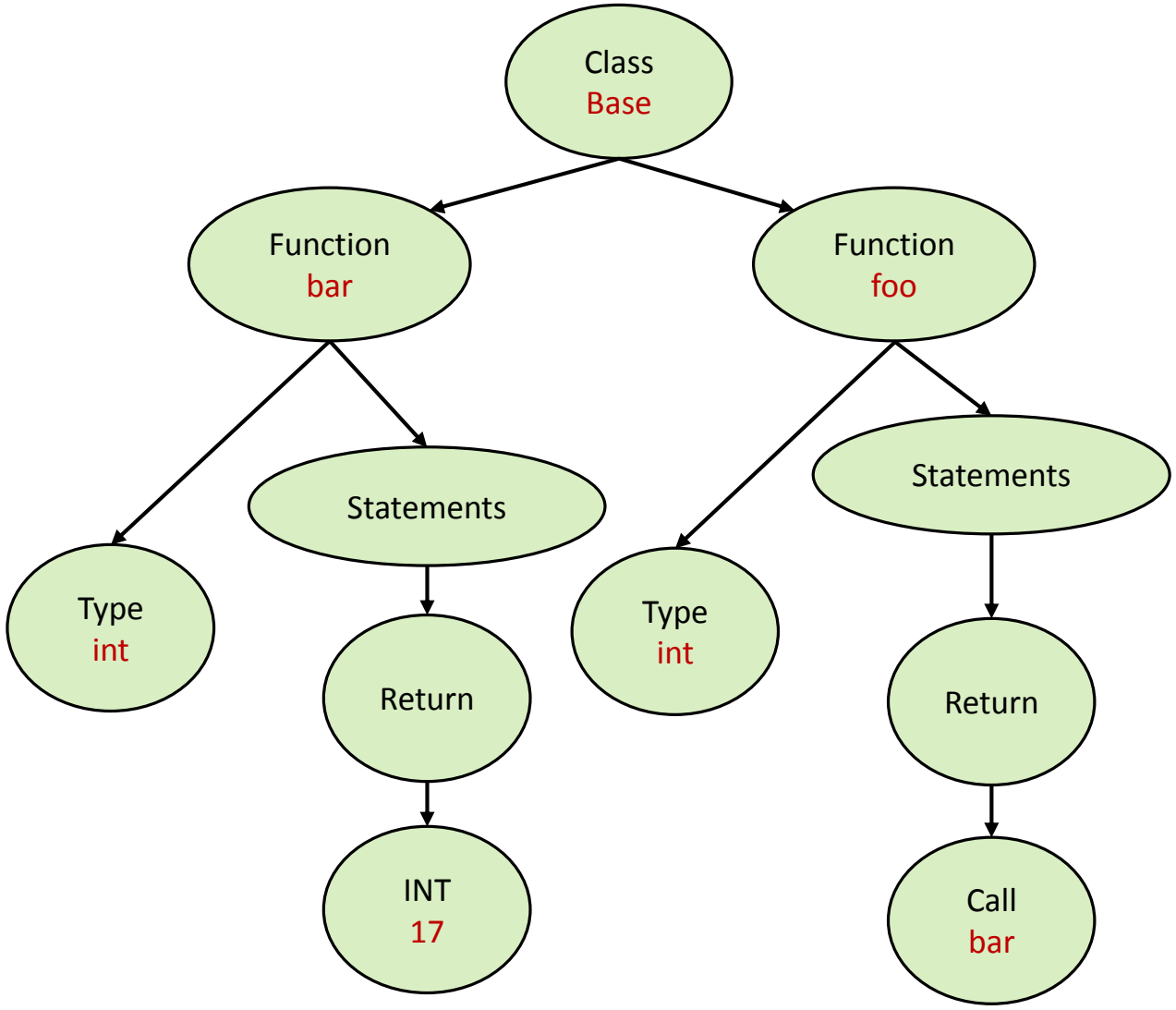
```
class Base {
  int a;
  int foo() {
    return a;
  }
}
```




Valid

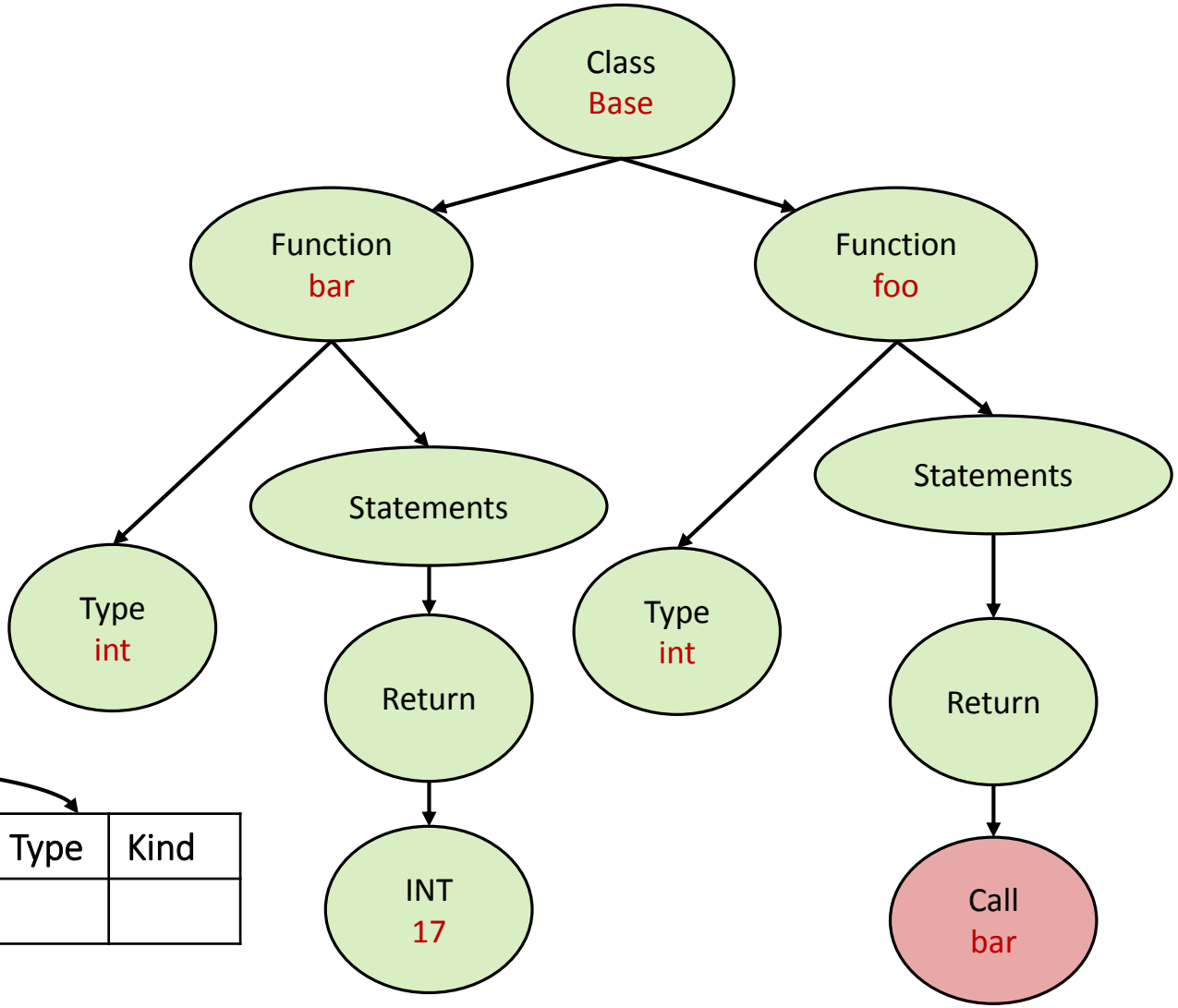
# Classes

```
class Base {
  int bar() {
    return 17;
  }
  int foo() {
    return bar();
  }
}
```



# Classes

```
class Base {
  int bar() {
    return 17;
  }
  int foo() {
    return bar();
  }
}
```




| ID | Type | Kind |
|---|---|---|
| Base | … | class |
| | | |

$scope_1$

| ID | Type | Kind |
|---|---|---|
| bar | … | function |
| foo | … | Function |

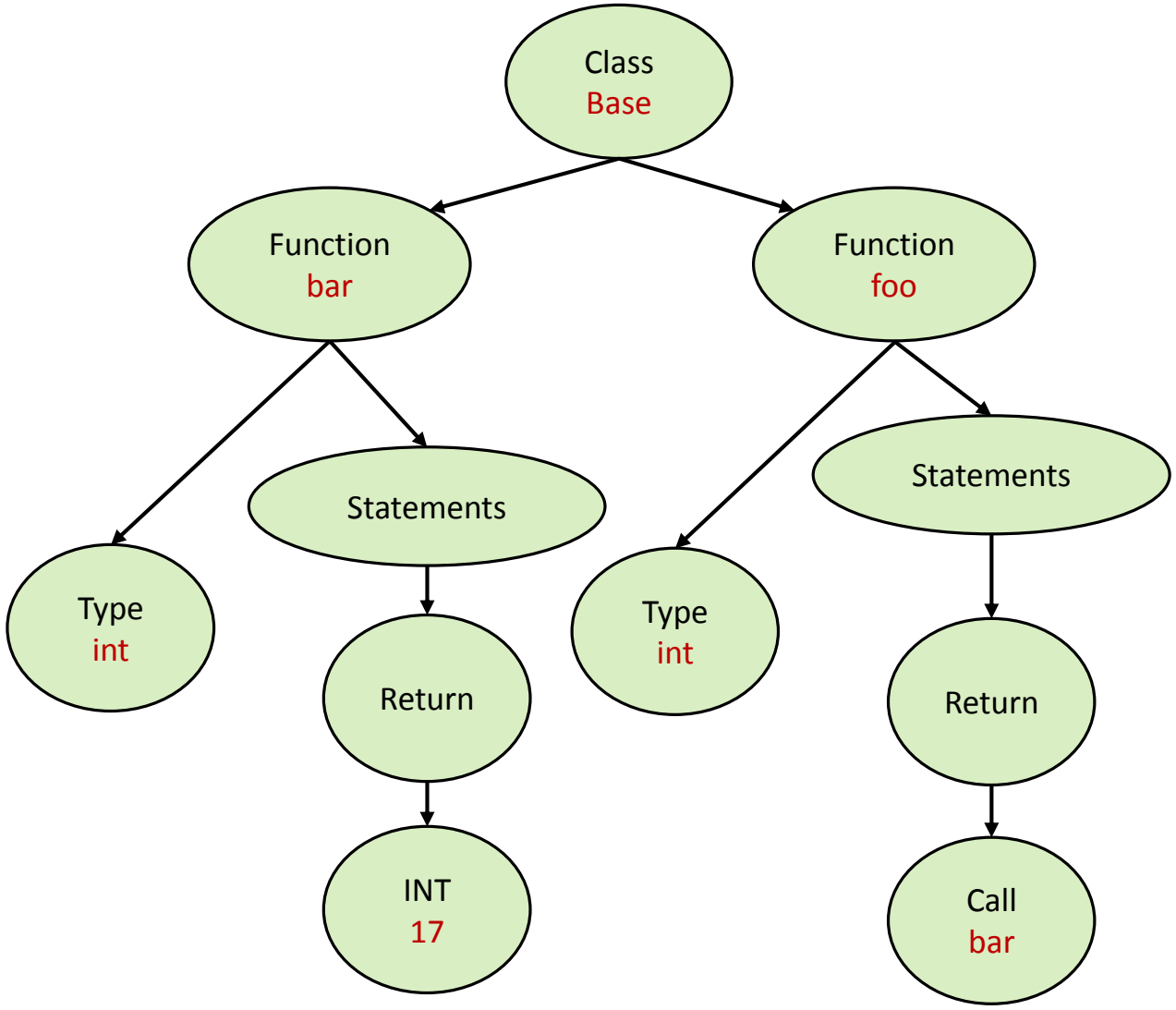
$scope_2$

| ID | Type | Kind |
|---|---|---|
| | | |

$scope_3$

# Classes

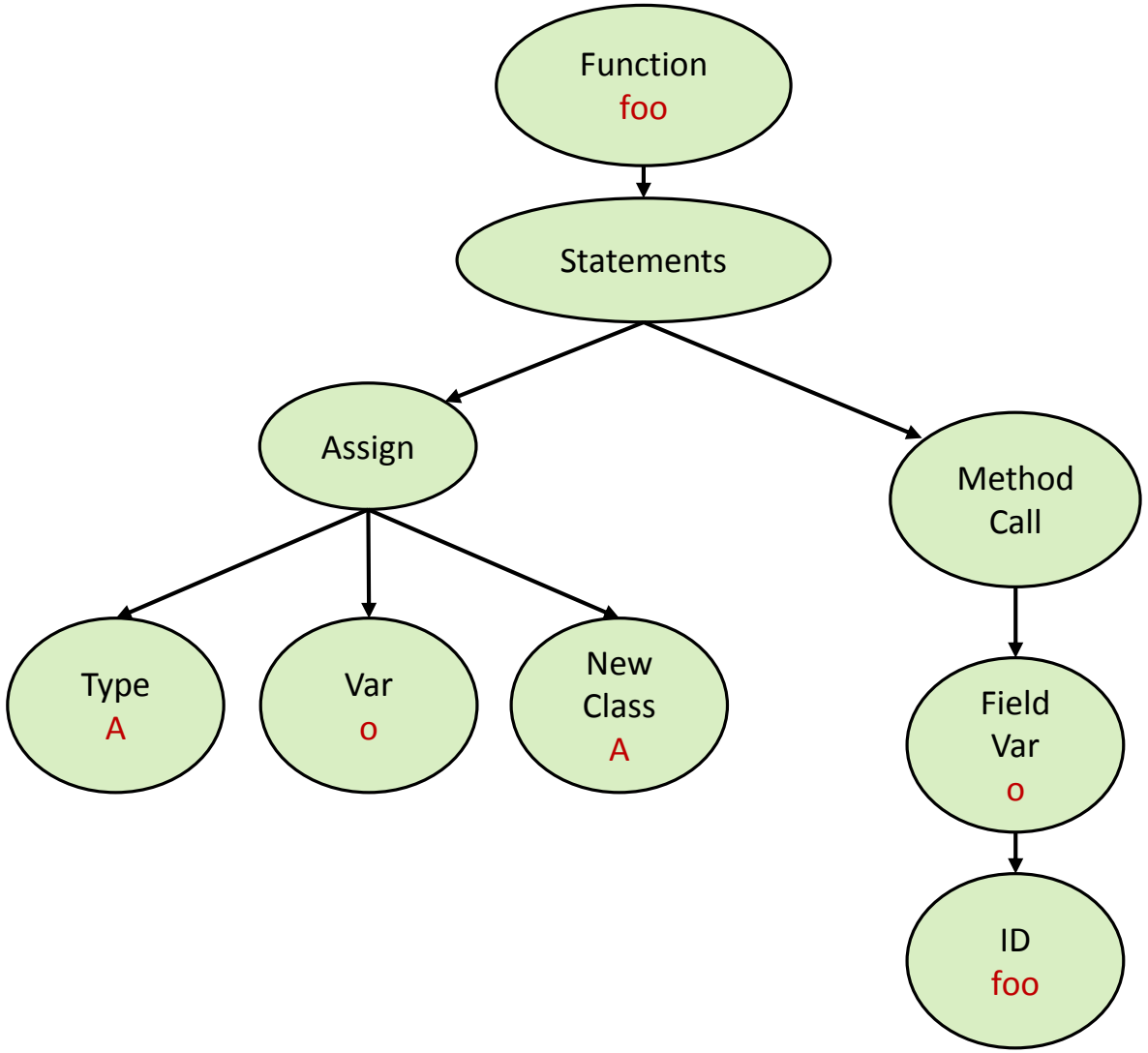
```
class Base {
  int bar() {
    return 17;
  }
  int foo() {
    return bar();
  }
}
```




Valid

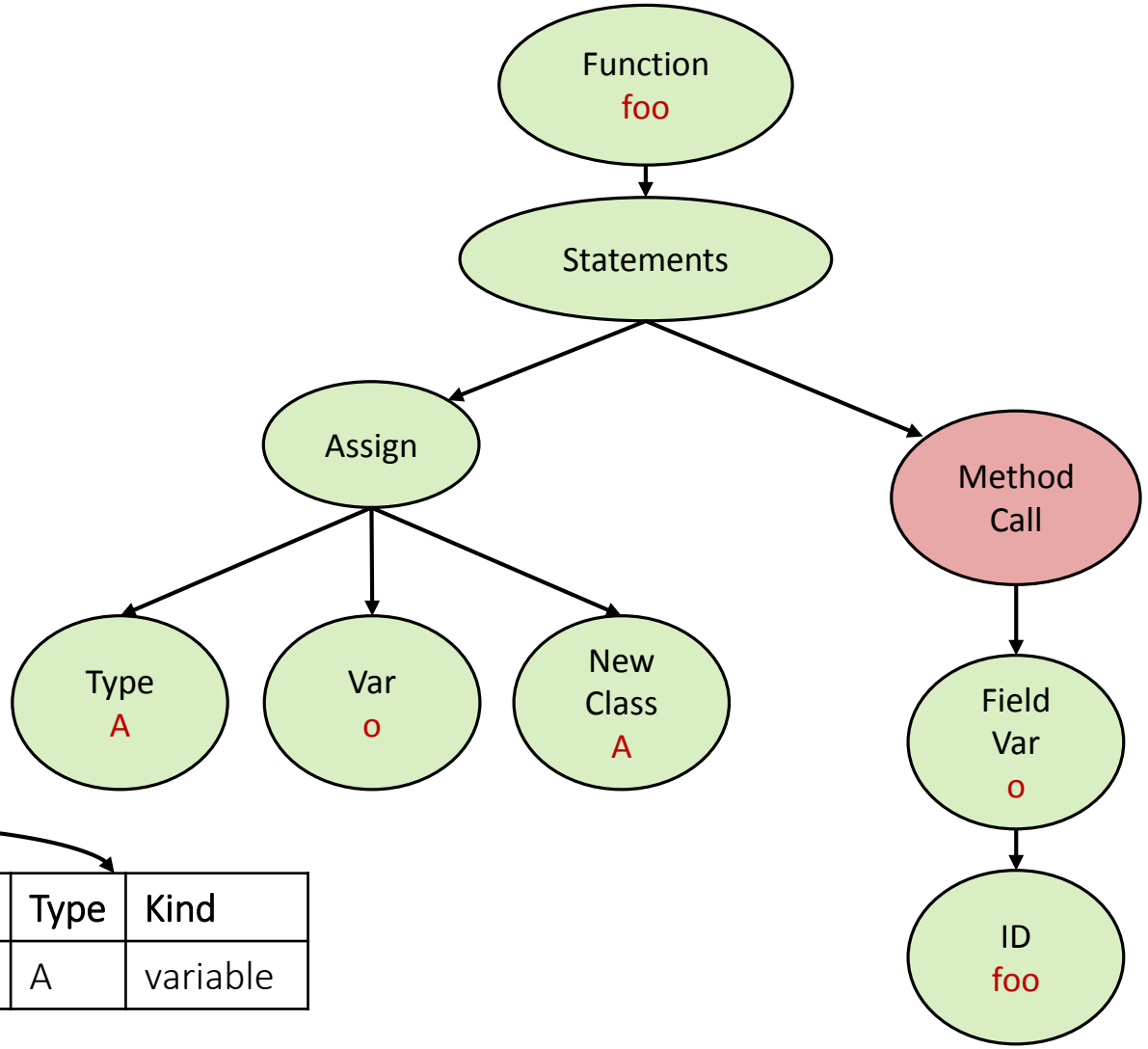
# Classes

```
class A {
  void foo() {
    A o = new A;
    o.foo();
  }
}
```



# Classes

```
class A {
  void foo() {
    A o = new A;
    o.foo();
  }
}
```




| ID | Type | Kind |
|---|---|---|
| A | … | class |
| | | |

$scope_1$

| ID | Type | Kind |
|---|---|---|
| foo | … | function |

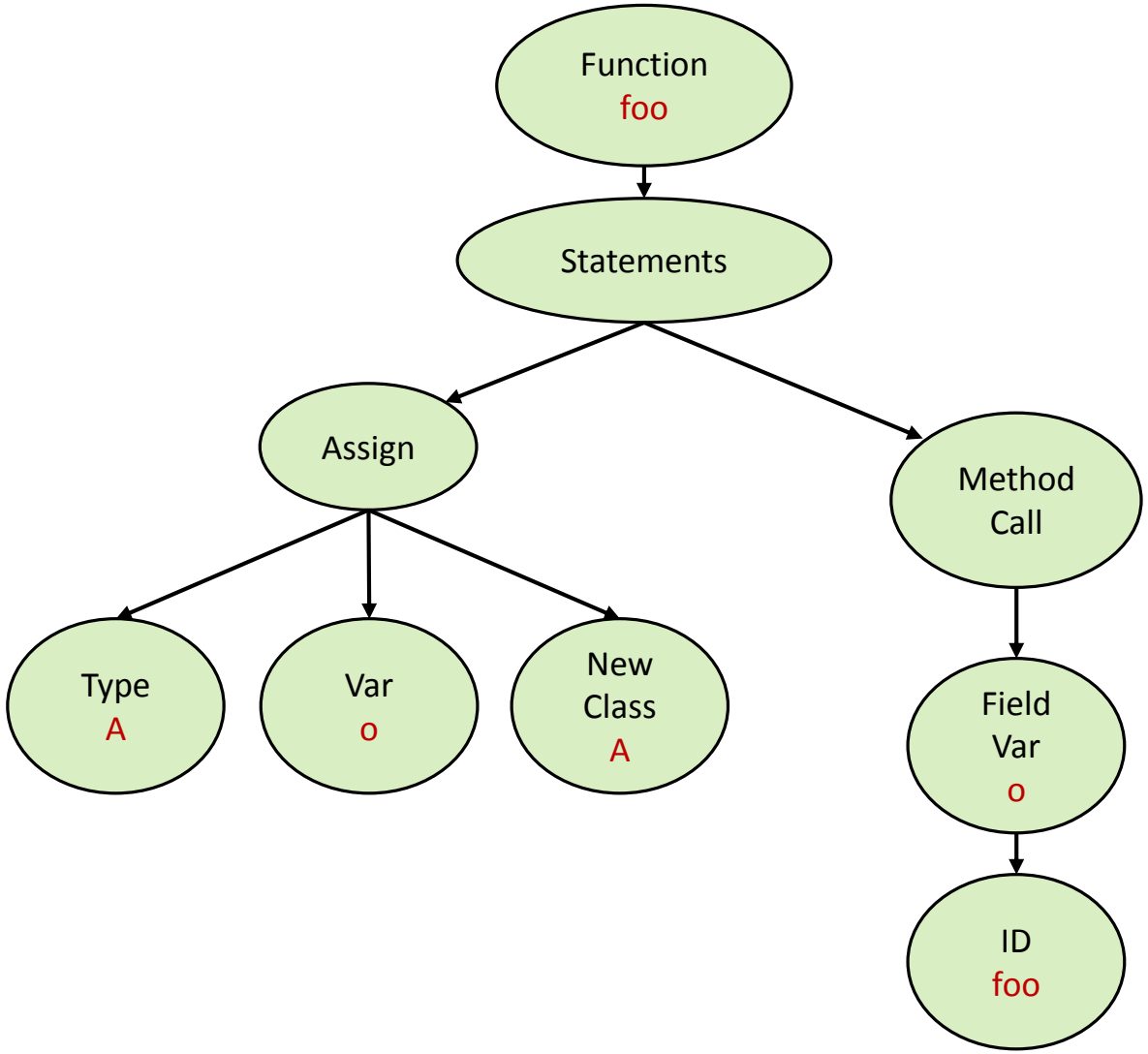
$scope_2$

| ID | Type | Kind |
|---|---|---|
| o | A | variable |

$scope_3$

# Classes

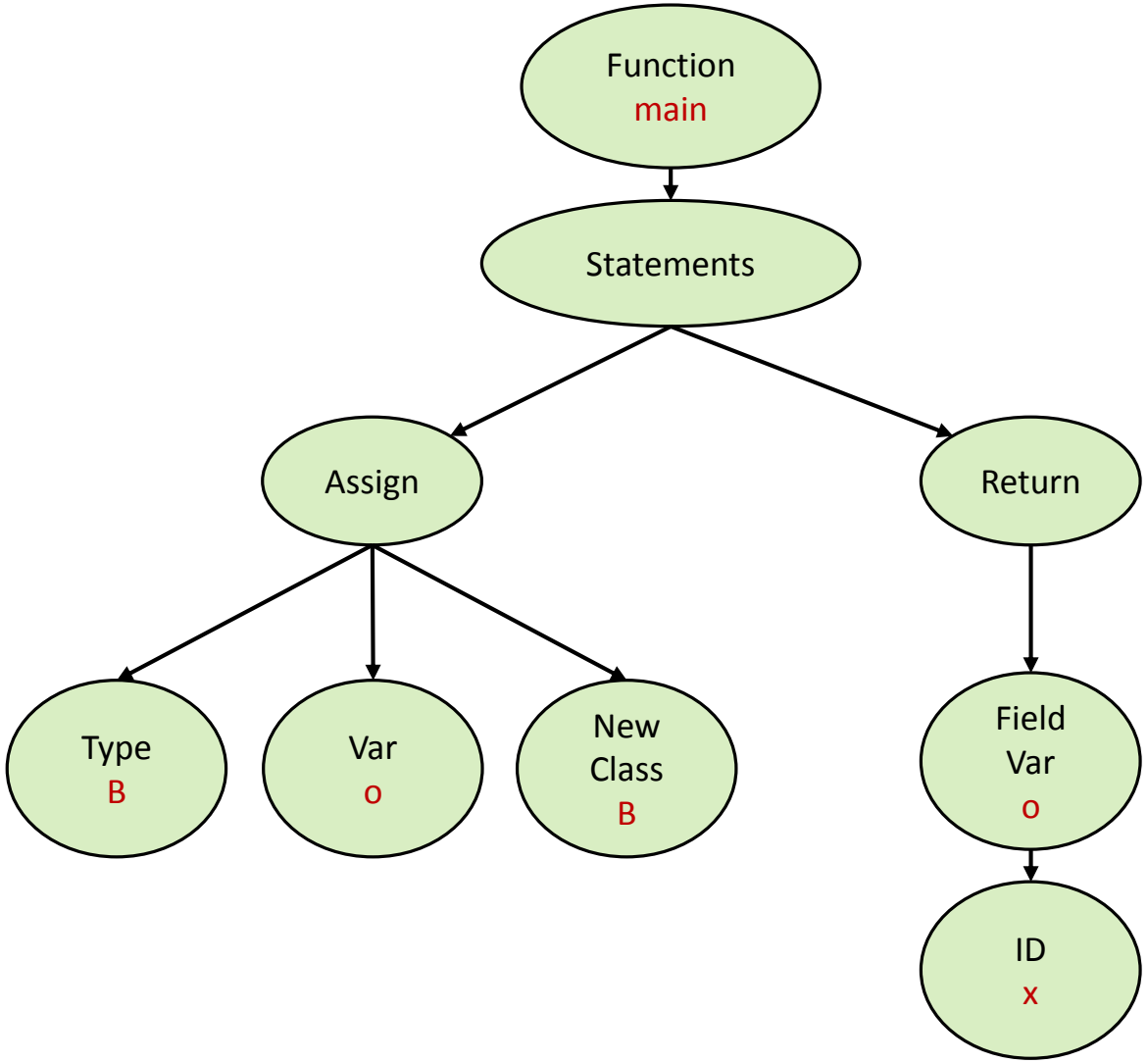
```
class A {
  void foo() {
    A o = new A;
    o.foo();
  }
}
```




Valid

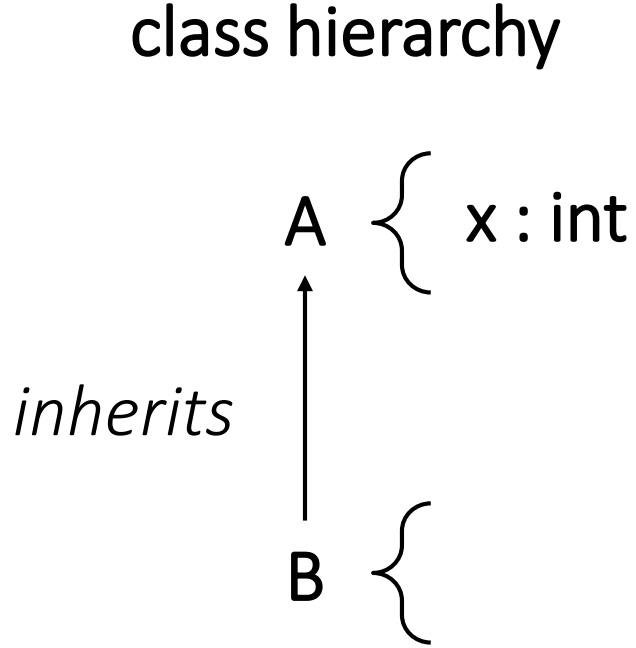
# Inheritance

```
class A {
  int x;
}
class B extends A {
  int foo() {
    B o = new B;
    return o.x;
  }
}
```



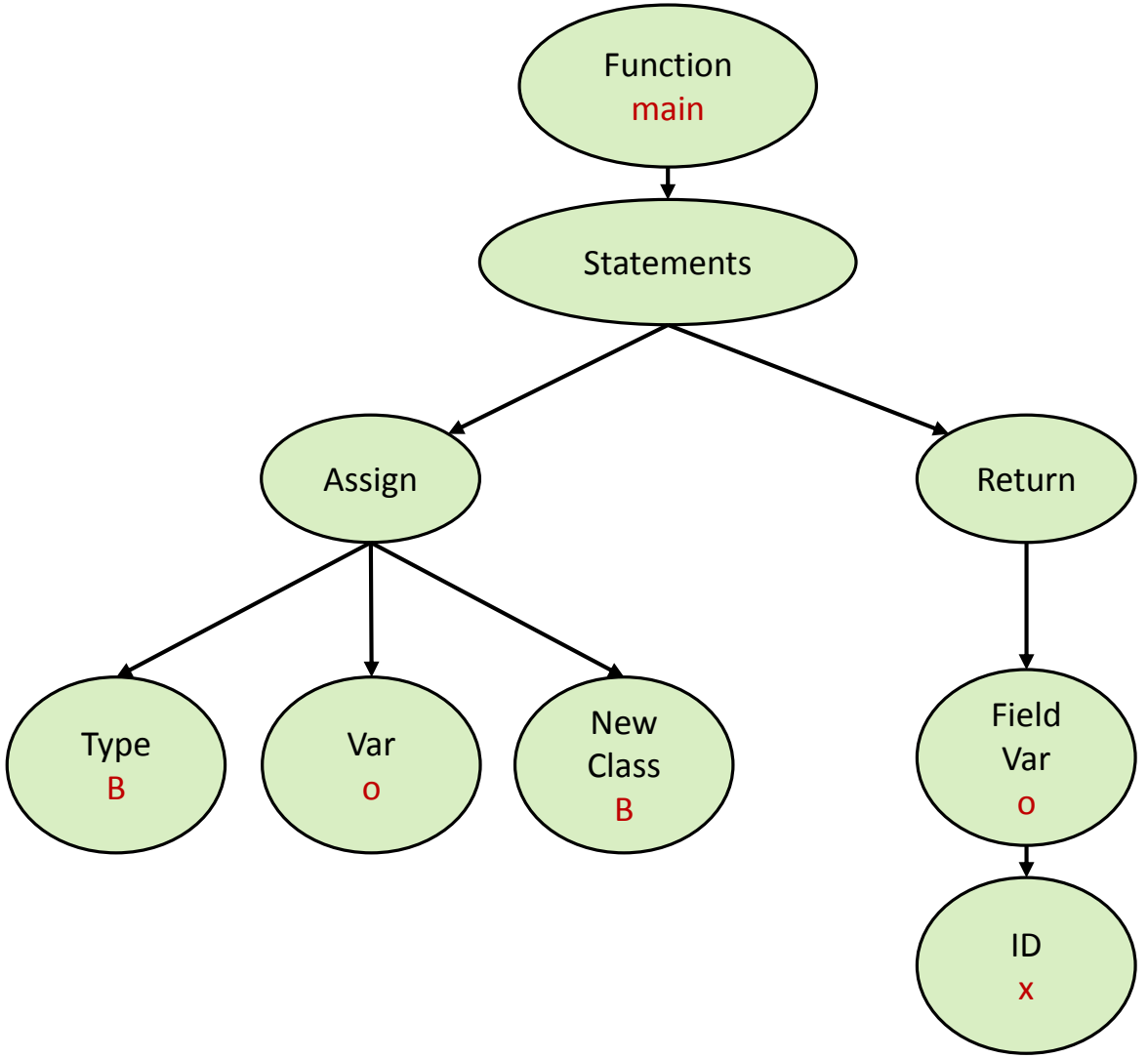
# Inheritance

```
class A {
  int x;
}
class B extends A {
  int foo() {
    B o = new B;
    return o.x;
  }
}
```



# Inheritance

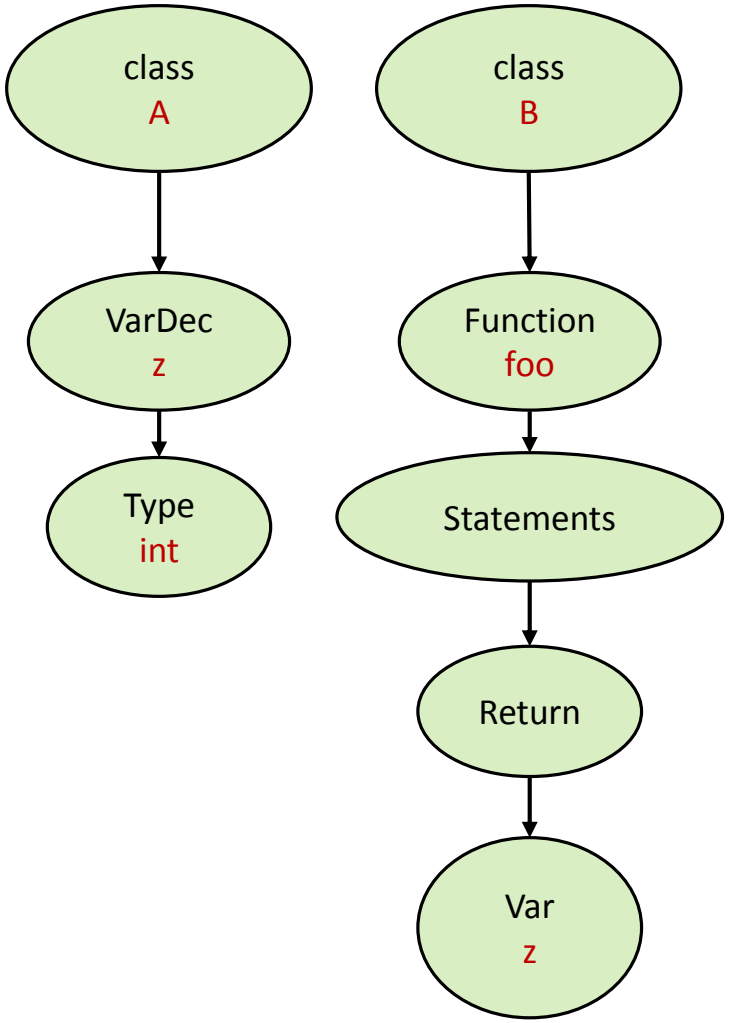
```
class A {
  int x;
}
class B extends A {
  int foo() {
    B o = new B;
    return o.x;
  }
}
```




Valid

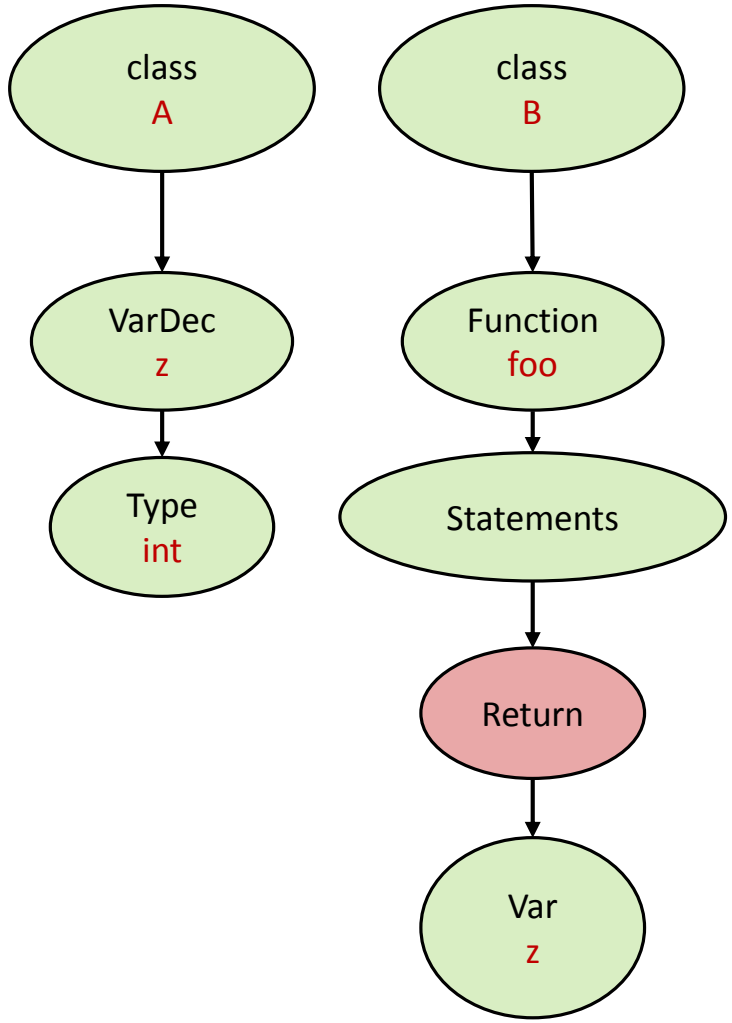
# Inheritance

```
class A {
  int z;
}
class B extends A {
  int foo() {
    return z;
  }
}
```



# Inheritance

```
class A {
  int z;
}
class B extends A {
  int foo() {
    return z;
  }
}
```




| ID | Type | Kind |
|---|---|---|
| A | … | class |
| B | … | class |

$scope_1$

| ID | Type | Kind |
|---|---|---|
| foo | … | function |

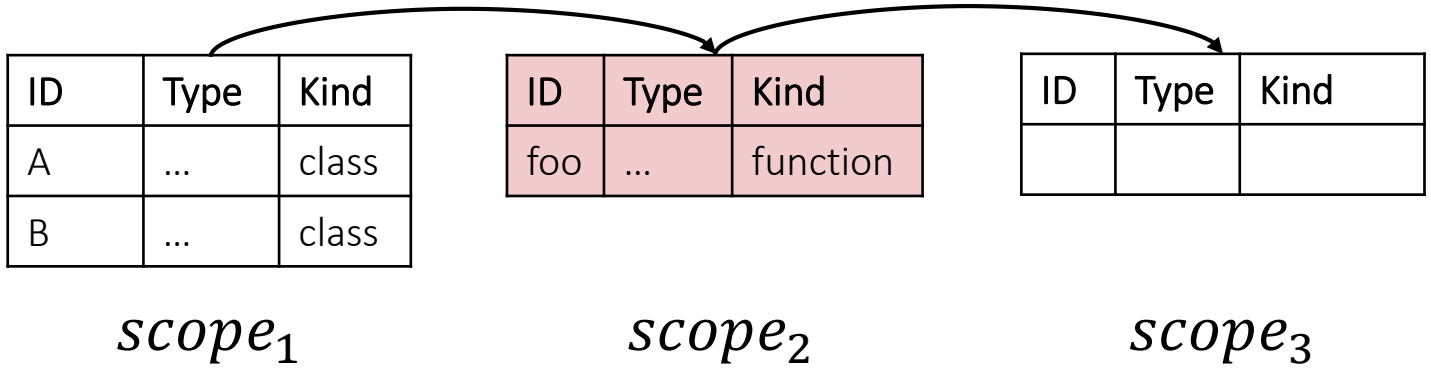
$scope_2$

| ID | Type | Kind |
|---|---|---|
| | | |

$scope_3$

# Inheritance

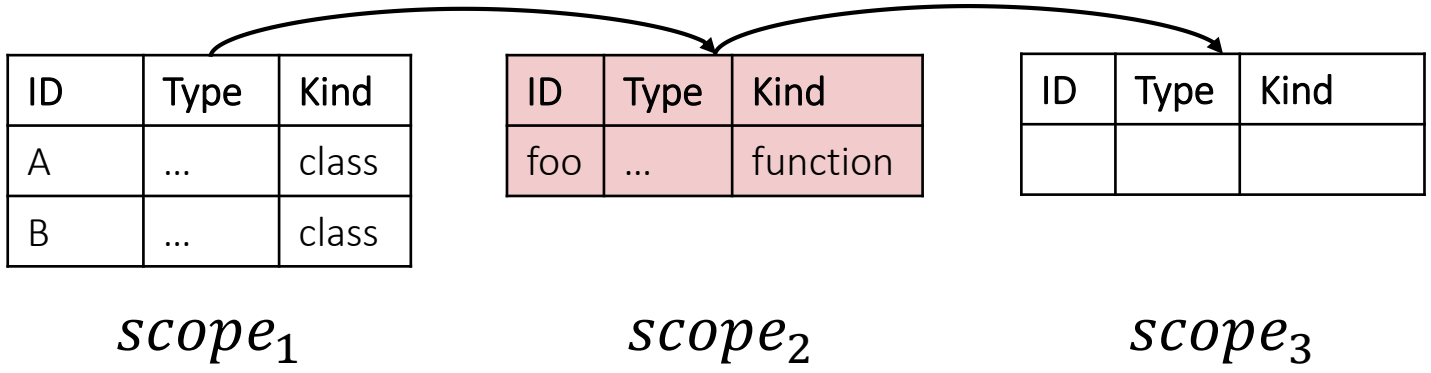
```
class A {
  int z;
}
class B extends A {
  int foo() {
    return z;
  }
}
```



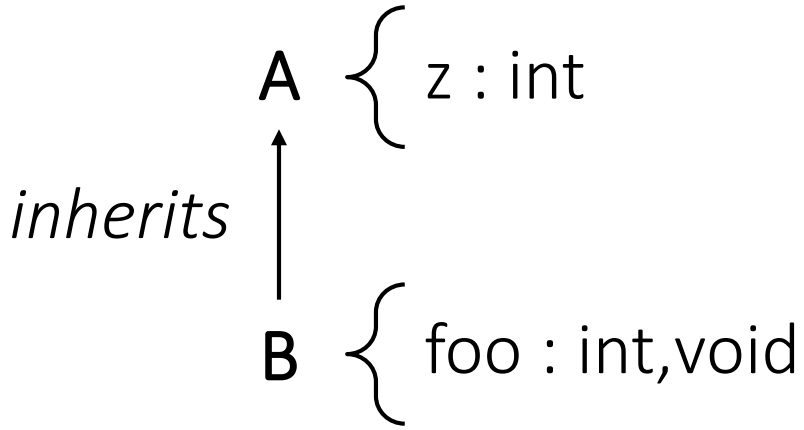

(scope of class B)

# Inheritance

```
class A {
  int z;
}
class B extends A {
  int foo() {
    return z;
  }
}
```

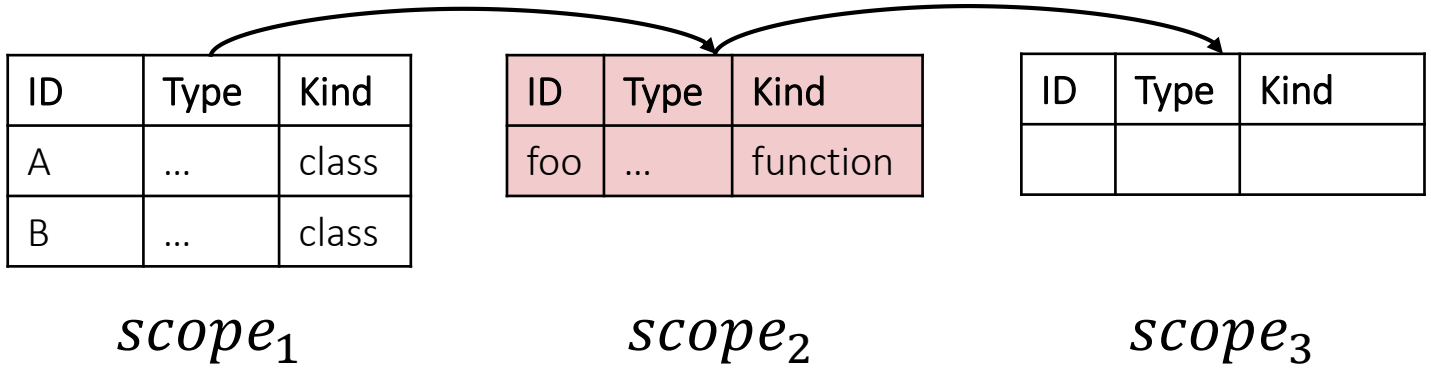



(scope of class B)

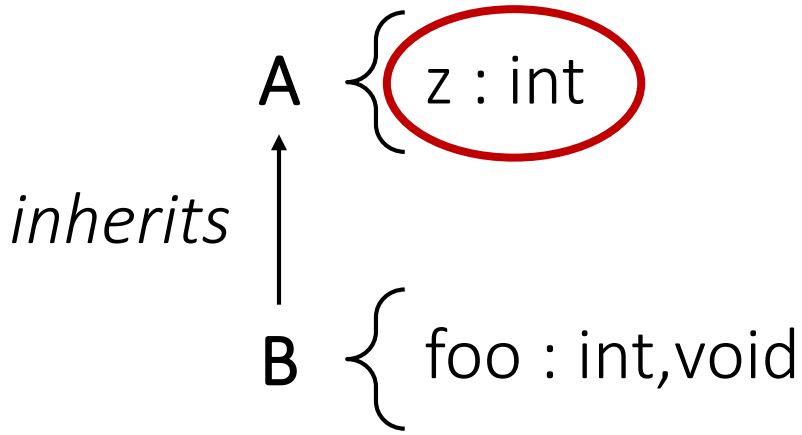


# Inheritance

```
class A {
  int z;
}
class B extends A {
  int foo() {
    return z;
  }
}
```

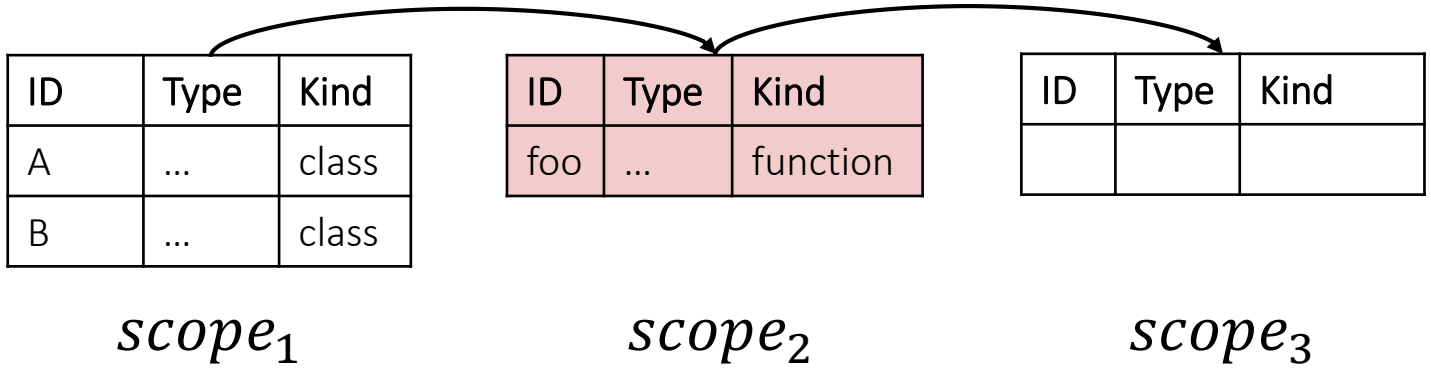


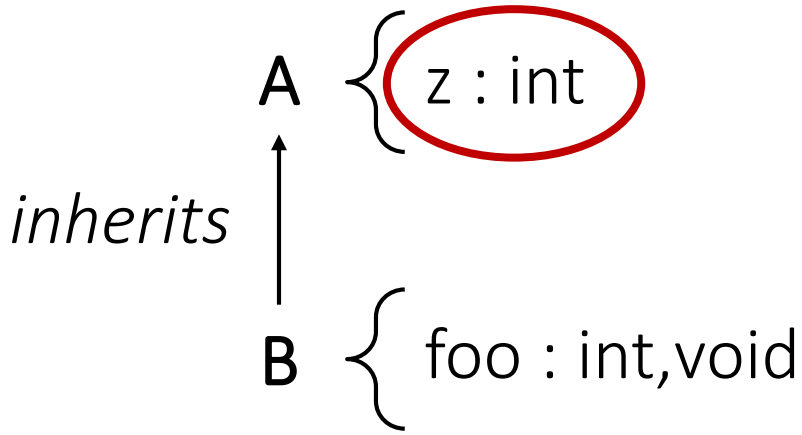

(scope of class B)



# Inheritance

```
class A {
  int z;
}
class B extends A {
  int foo() {
    return z;
  }
}
```

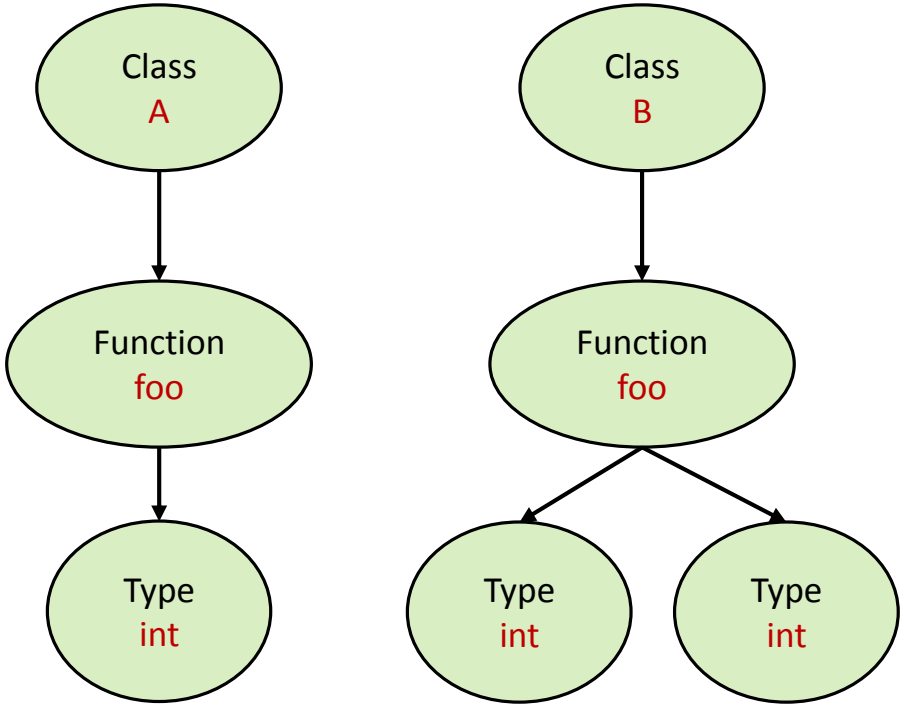



Valid

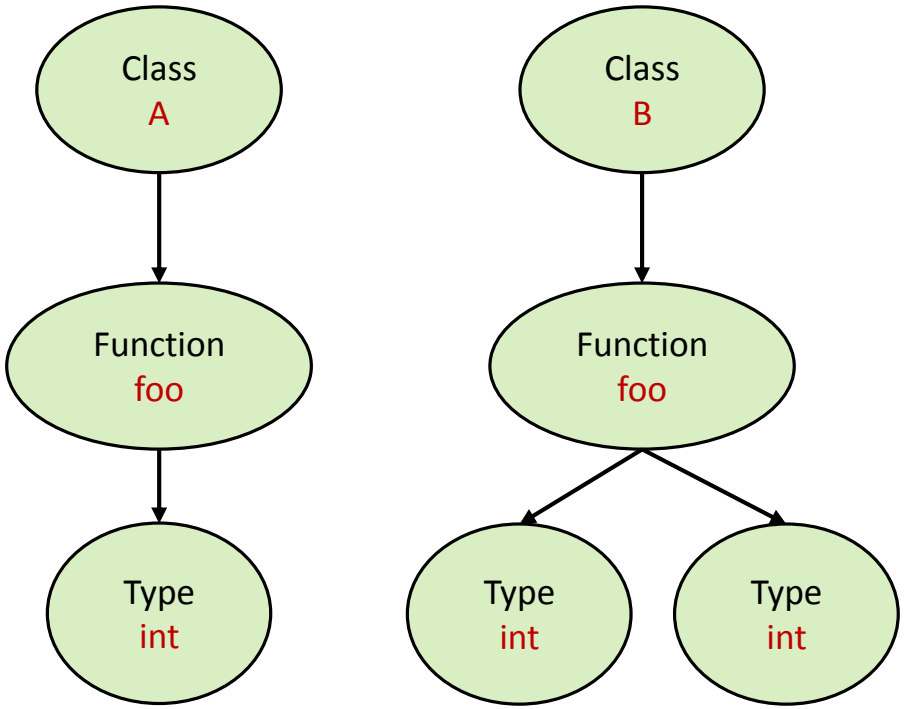
# Inheritance

```
class A {
  int foo() {
    return 17;
  }
}
class B extends A {
  int foo(int x) {
    return x + 1;
  }
}
```



# Inheritance

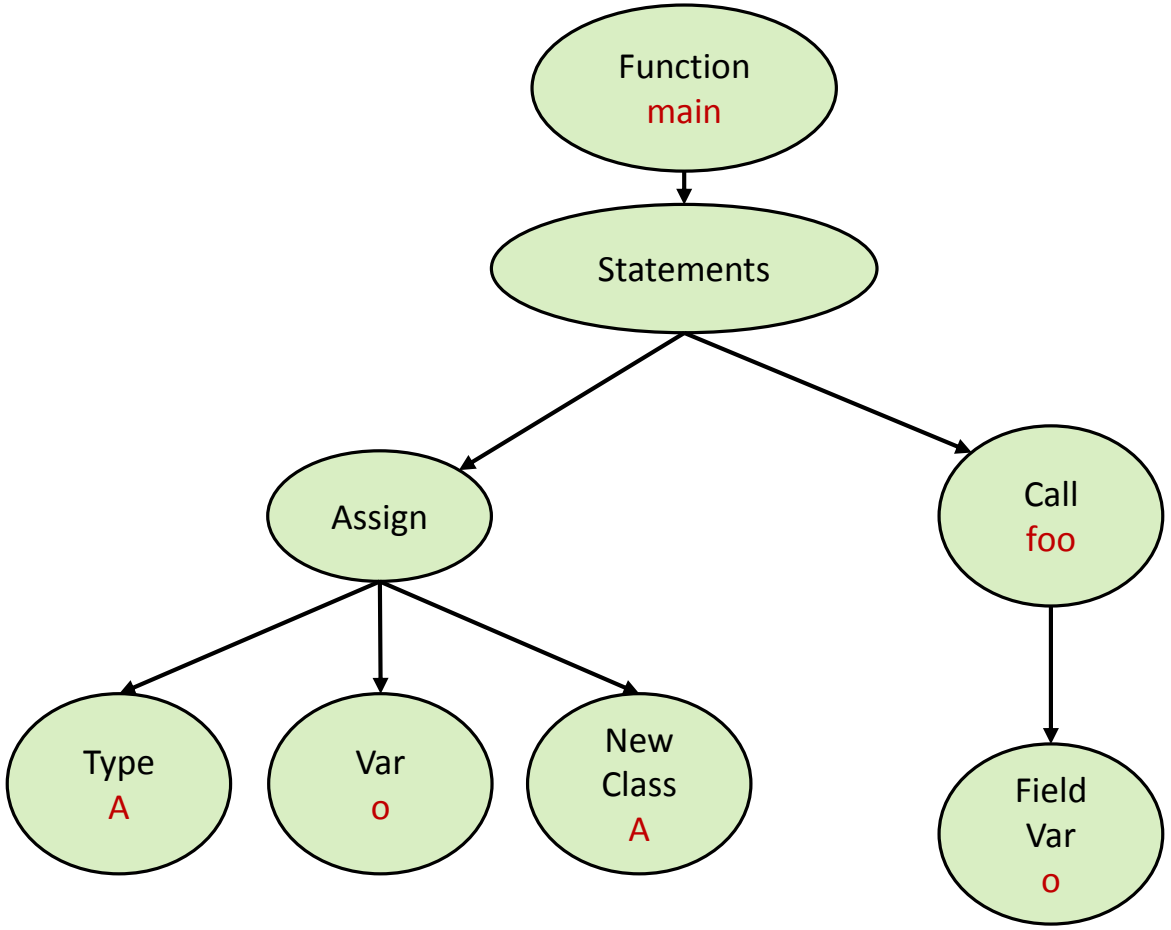
```
class A {
  int foo() {
    return 17;
  }
}
class B extends A {
  int foo(int x) {
    return x + 1;
  }
}
```




Invalid

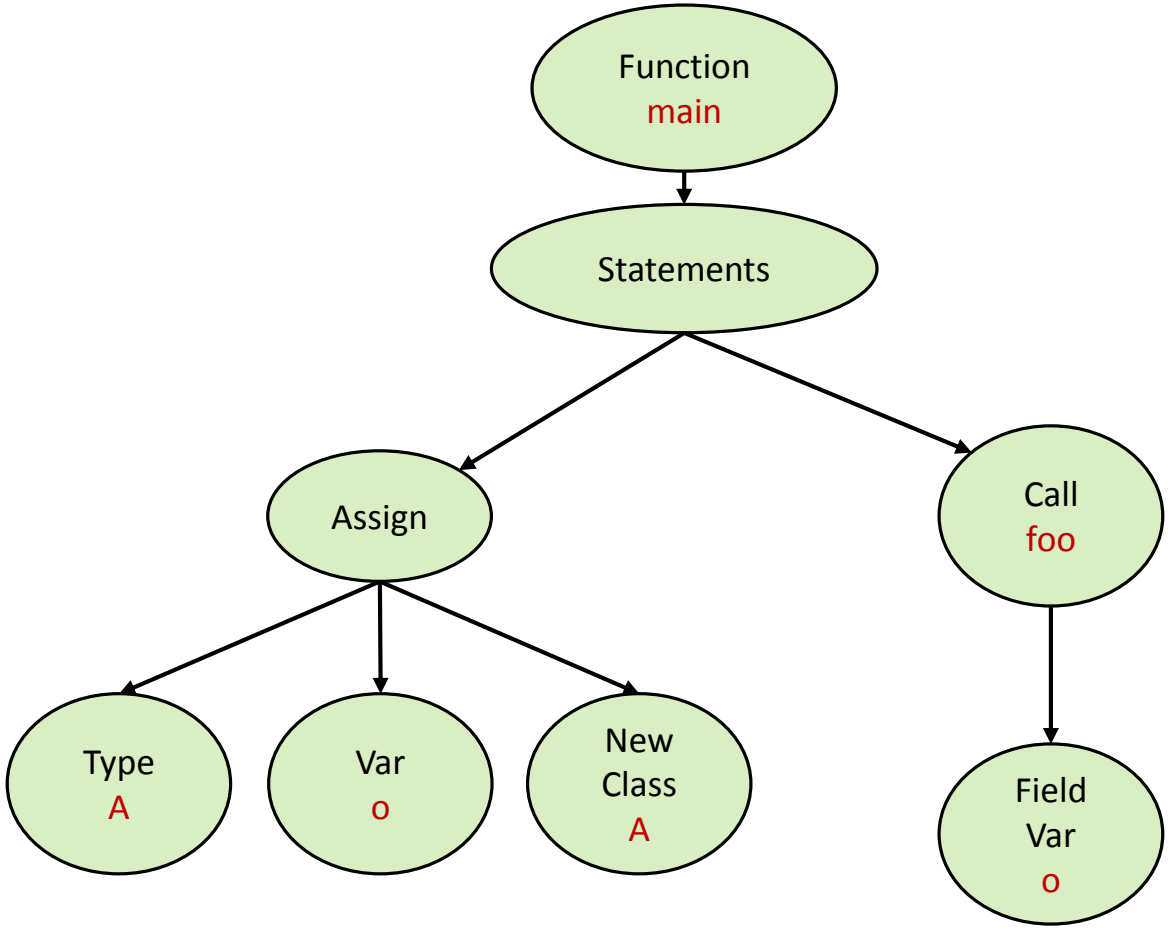
# Inheritance

```
class A { }
class B extends A { }
void foo(B b) { }
void main() {
  A o = new A;
  foo(o);
}
```



# Inheritance

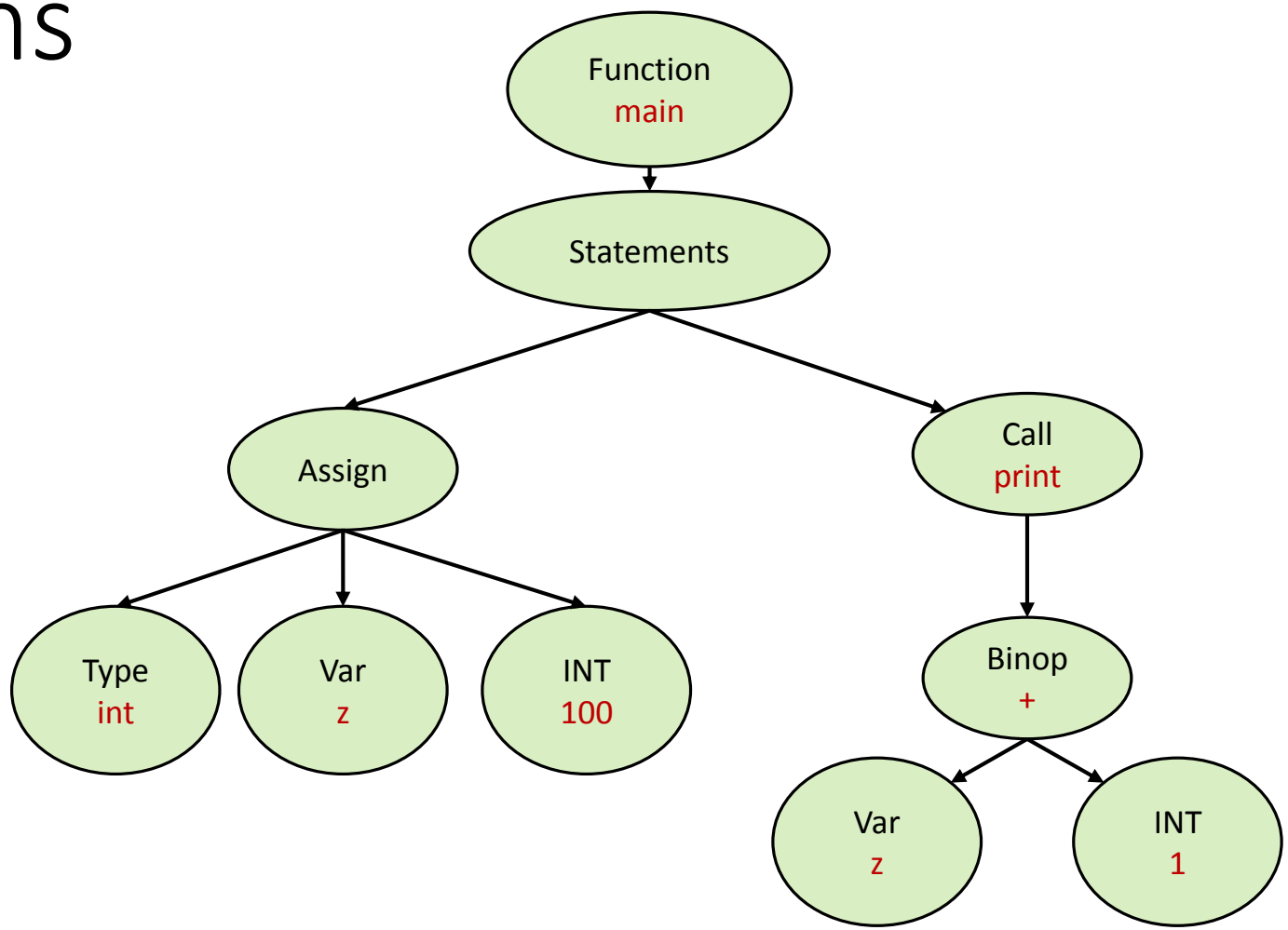
```
class A { }
class B extends A { }
void foo(B b) { }
void main() {
  A o = new A;
  foo(o);
}
```




Invalid

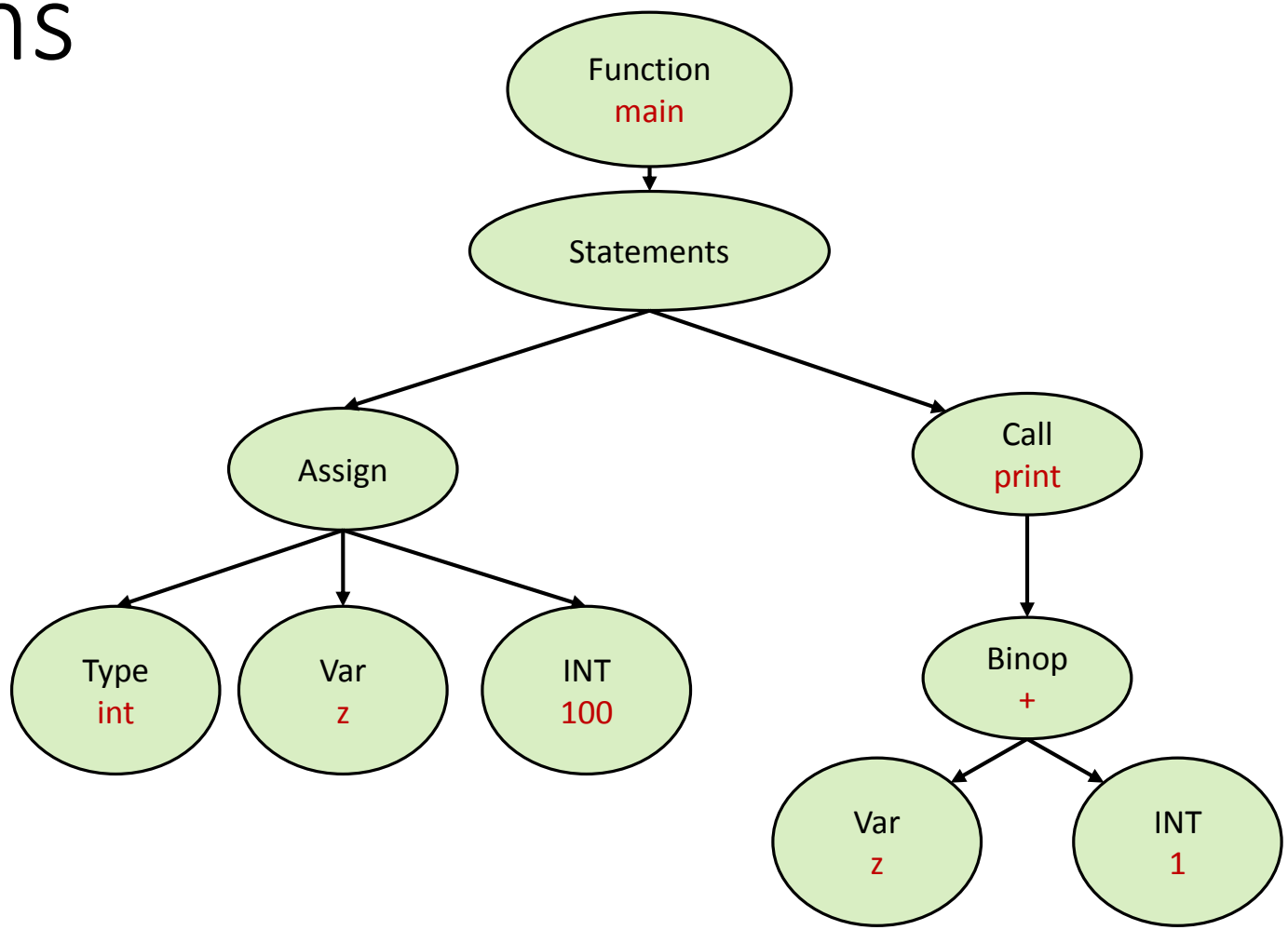
# Library Functions

```
void main() {
  int z = 100;
  print(z + 1);
}
```



# Library Functions

```
void main() {
  int z = 100;
  print(z + 1);
}
```




Valid

# Implementation

The AST is traversed in a top-down manner:

- Each AST node class, has a **visit** API
  - Performs the relevant semantic checks
  - May call the visitors of the node's children
- The traversal starts from the root node

# Implementation

```
class ASTExpBinOp {
  public ASTExp left;
  public ASTExp right;
  …
  public Type visit() {
    Type t1 = left.visit();
    Type t2 = right.visit();
    if (t1 != t2) { // error }
    // check if op is supported w.r.t. t1/t2
    return t1;
  }
}
```

# Implementation

```
class ASTStatmentList {
  public ASTStatement head;
  public ASTStatmentList tail;
  …
  public Type visit() {
    if (head)
      head.visit();
    if (tail)
      tail.visit();
    return null;
  }
}
```