Semantic Analysis

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Semantic Analysis

We need to check the following:

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

Symbol Table

- Maintain a stack of scopes
- Each scope maps identifiers to their **type information**
- Identifiers may be:
  - Variable names
  - Function names
  - Method names

Symbol Table

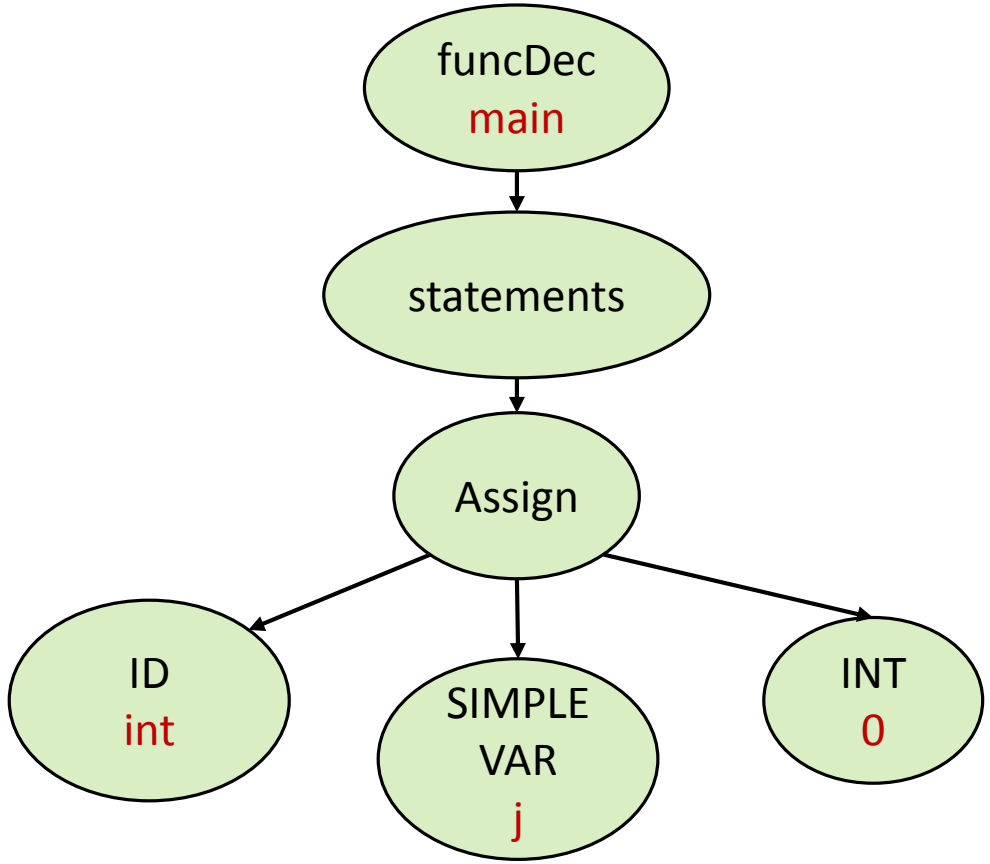
- When we reach a variable/function/… declaration
  - Update the map of the current scope (top of the stack)
- When we reach a new block, **push** a new scope
- When we leave a block, **pop** the top scope
- Begin with the global (initial scope)
  - Functions, global variables, …

Symbol Table

- When we need to resolve an identifier
  - Scan the scopes (starting from the top)
  - Stop at the first matching scope
  - If no scope was found, we have an error…

Assignments

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



Assignments

```
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}
```
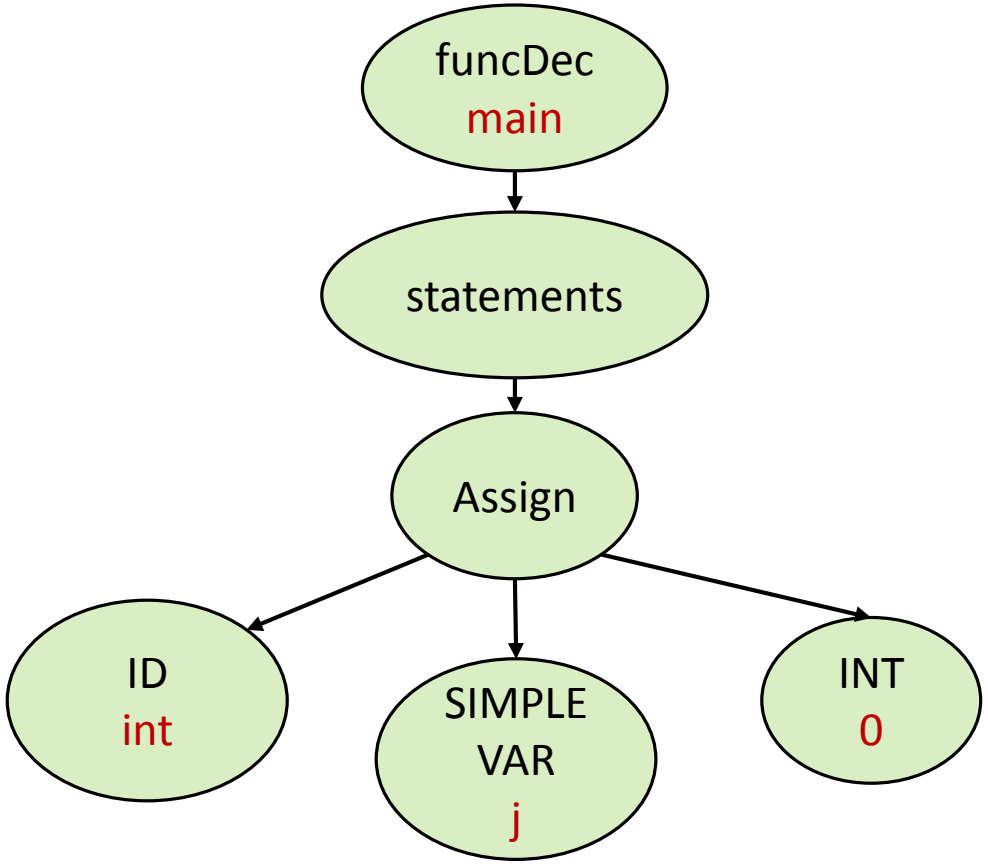

Valid



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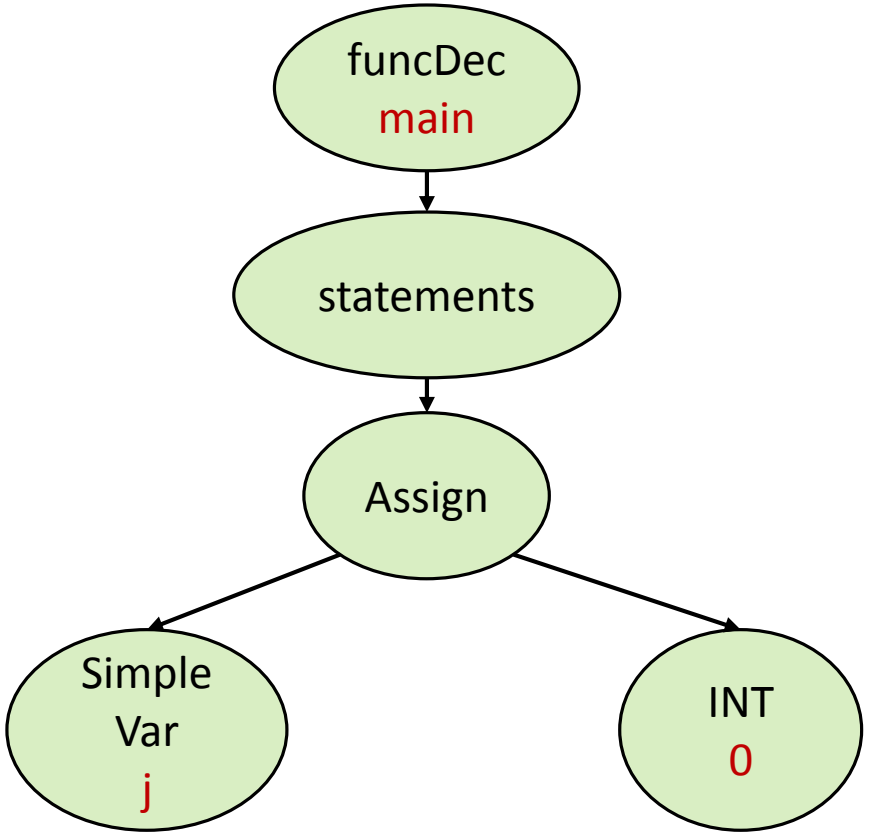

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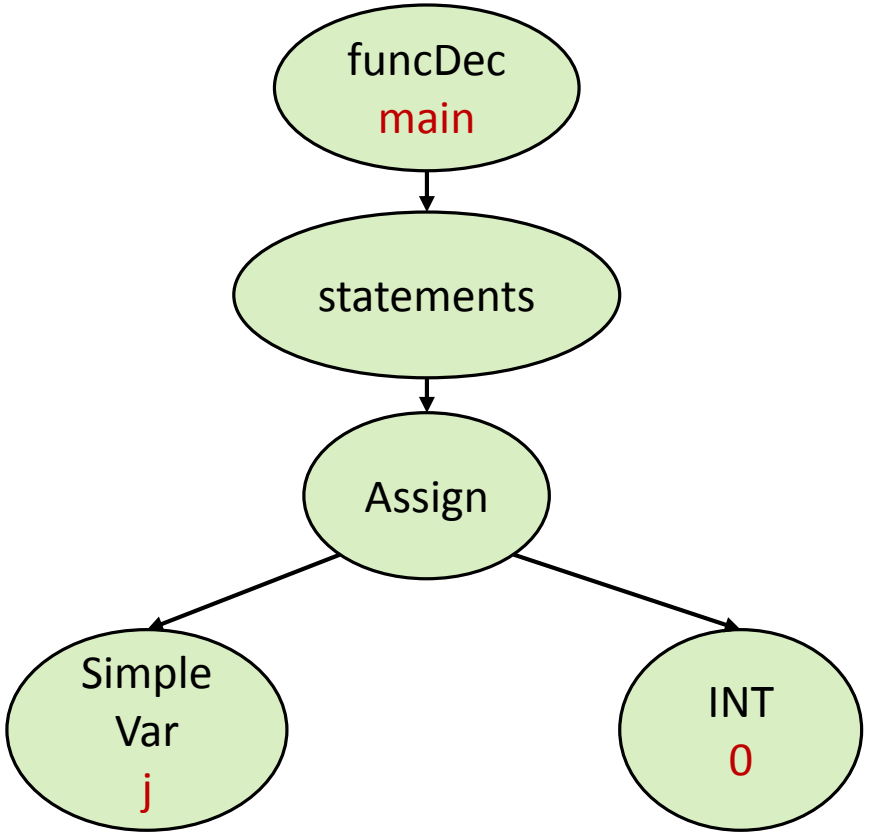
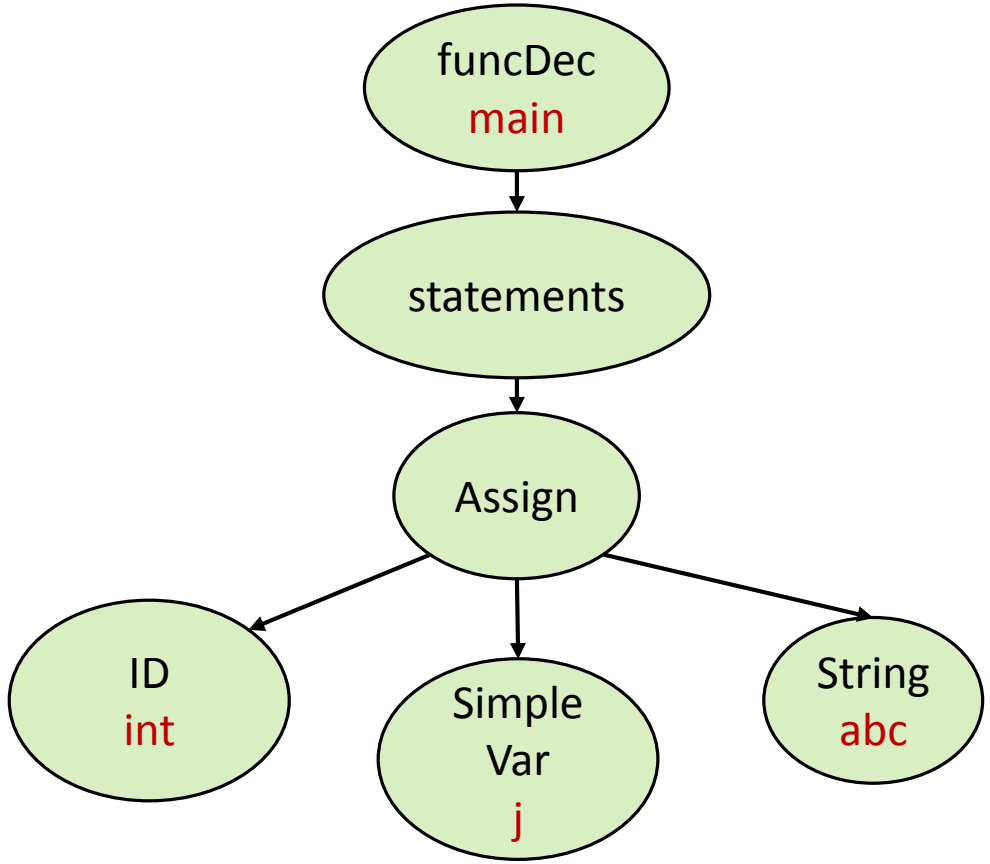


Assignments

```
void main() {
   int j = "abc";
}
```



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   int j = "abc";
}
```

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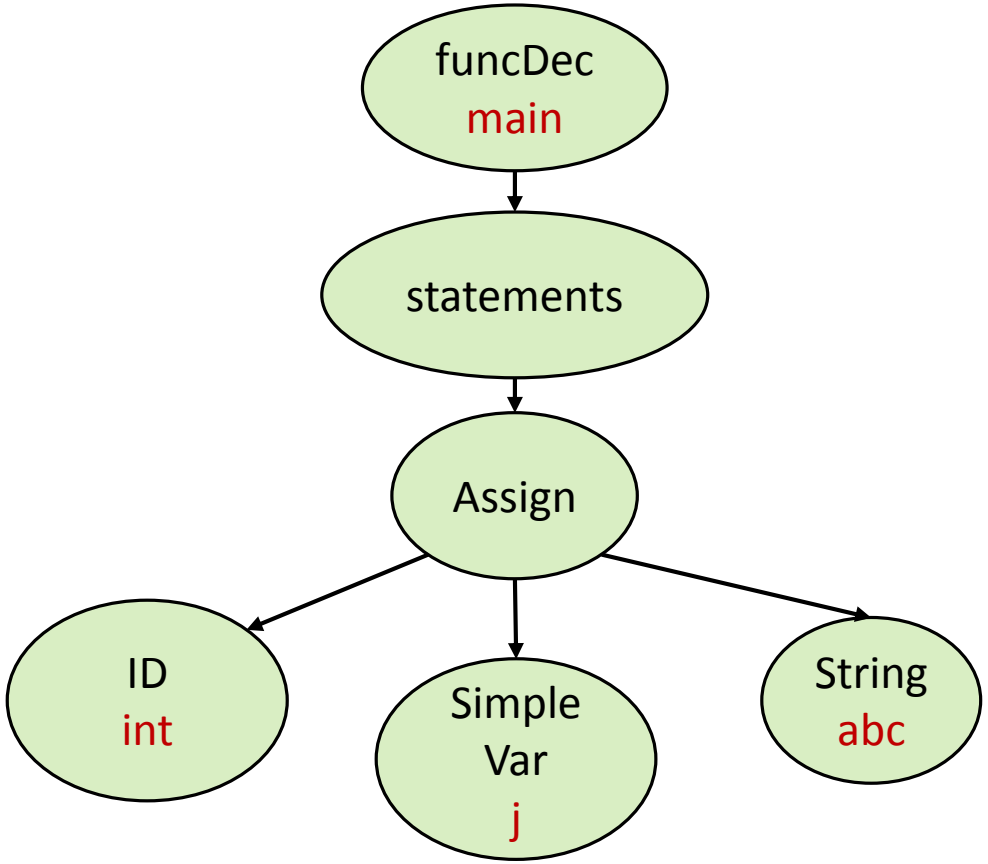
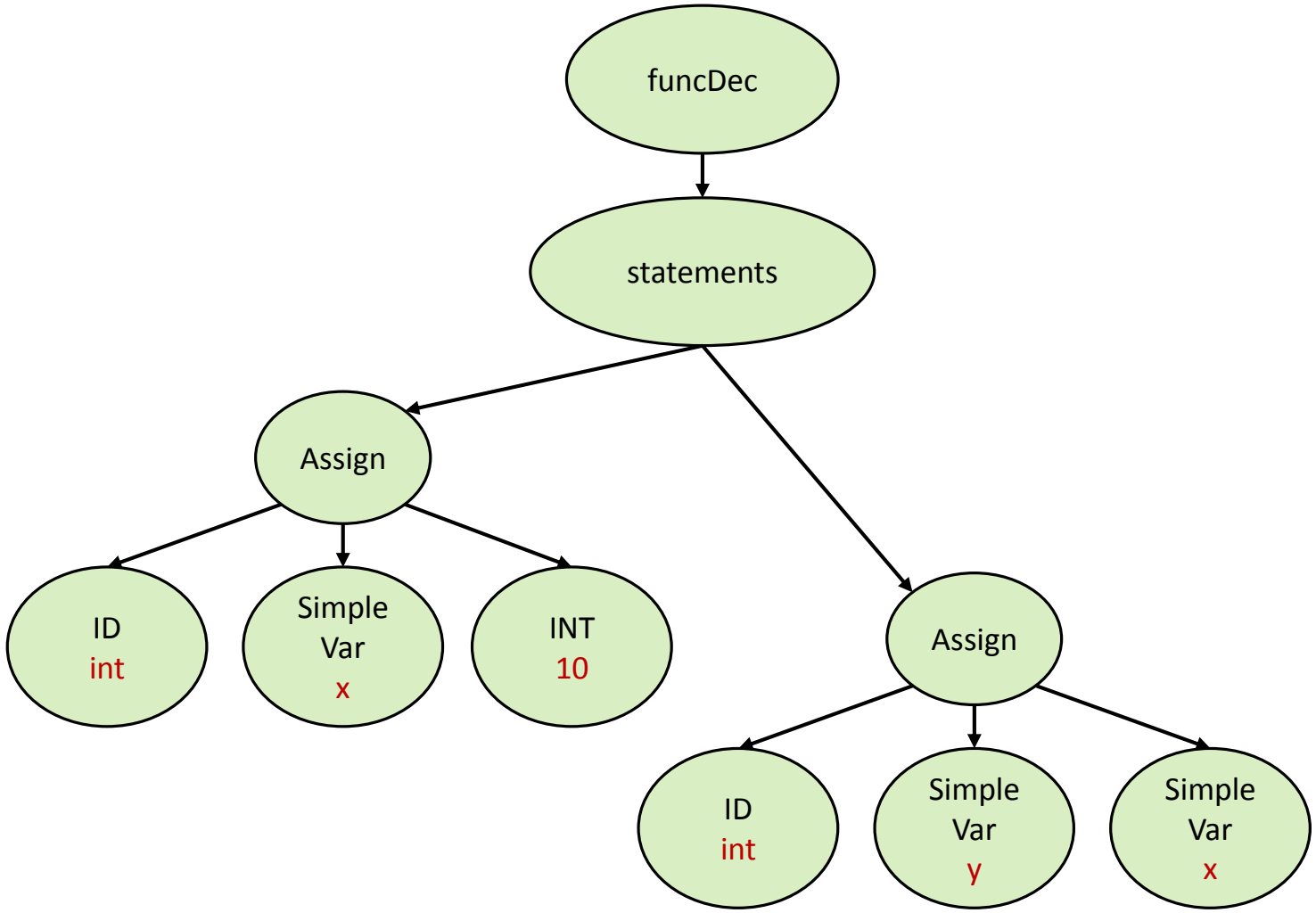


Assignments

```
void main() {
   int x = 10;
   int y = x;
}
```



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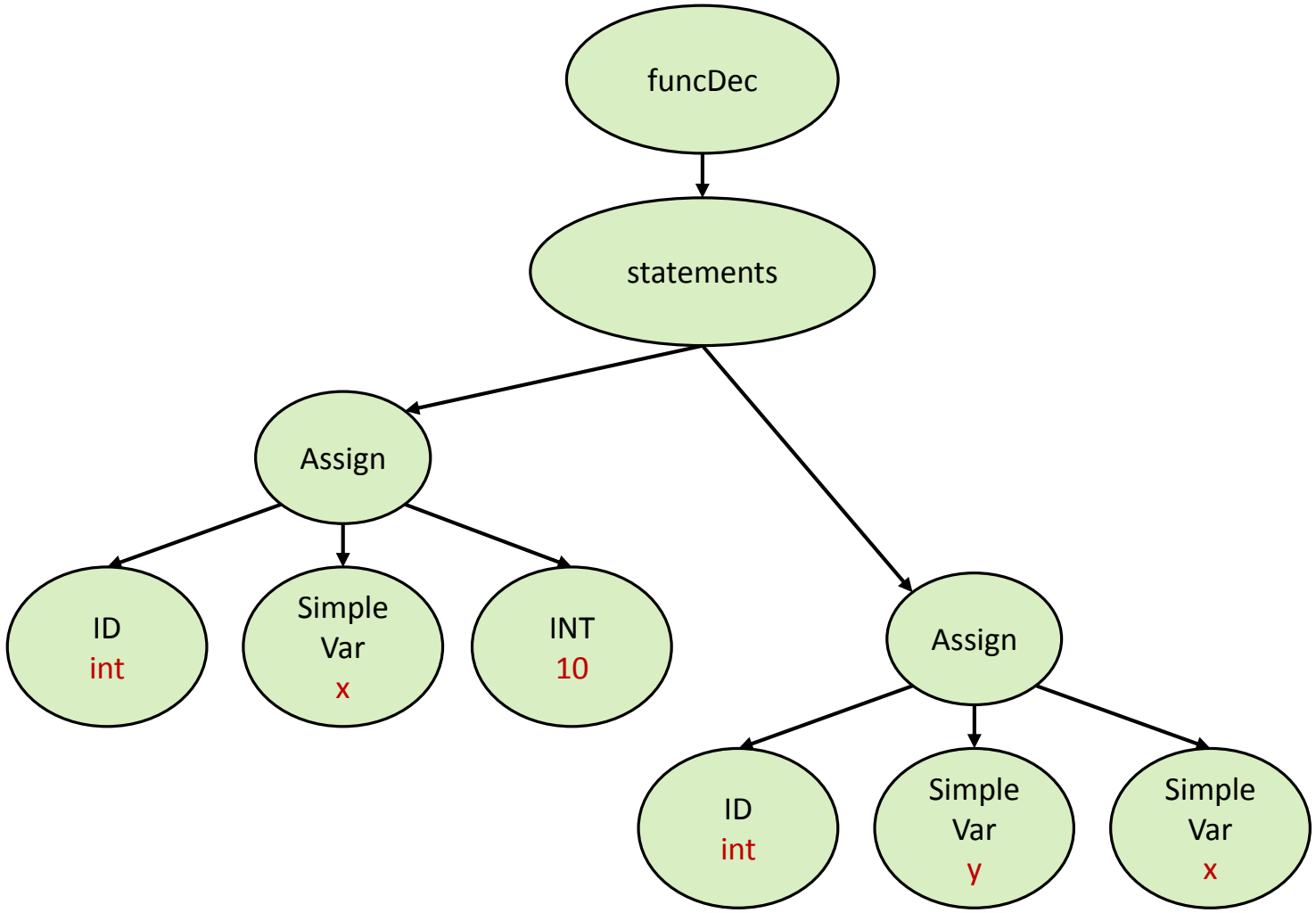

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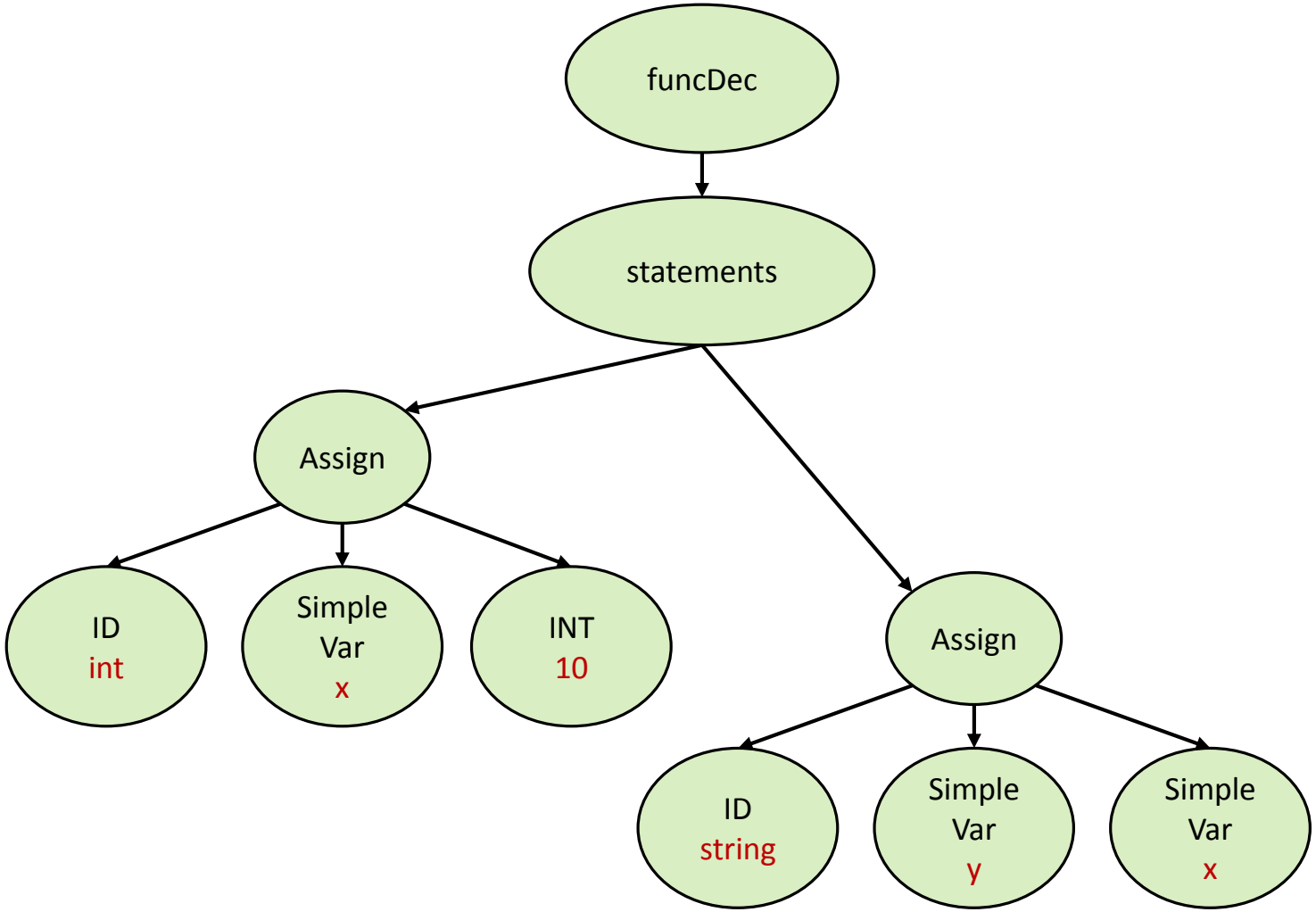

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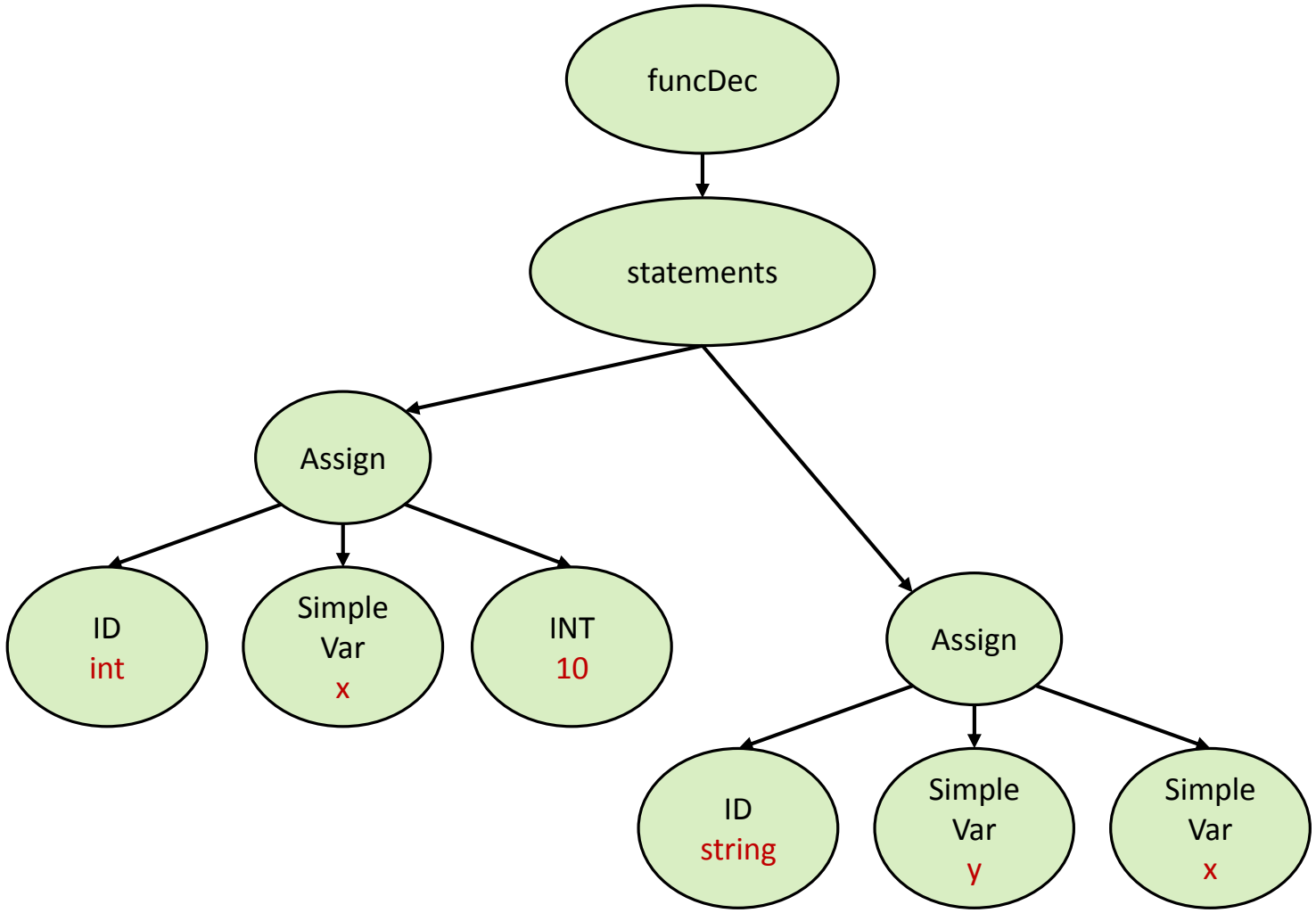
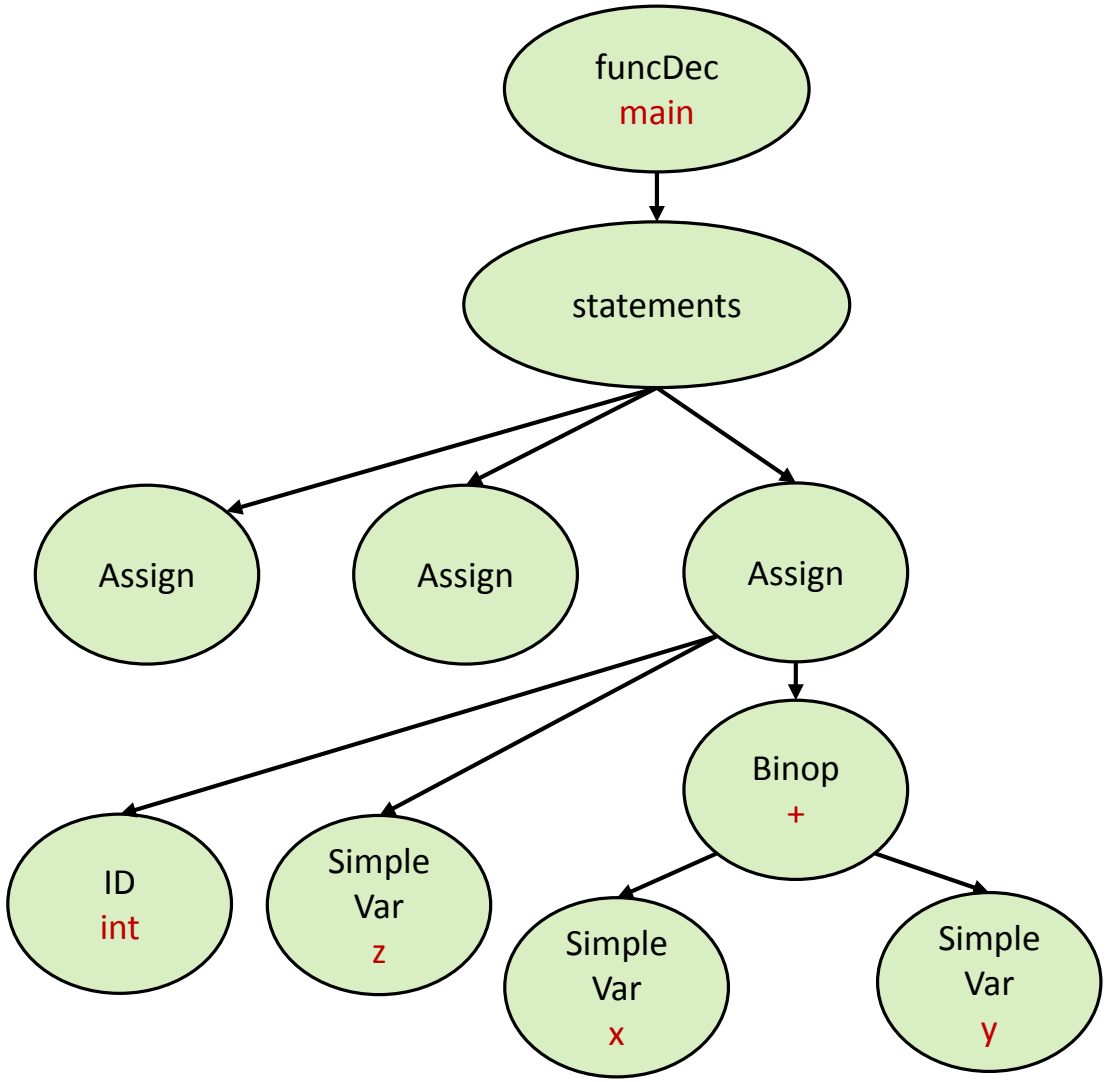


Binary Operations

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



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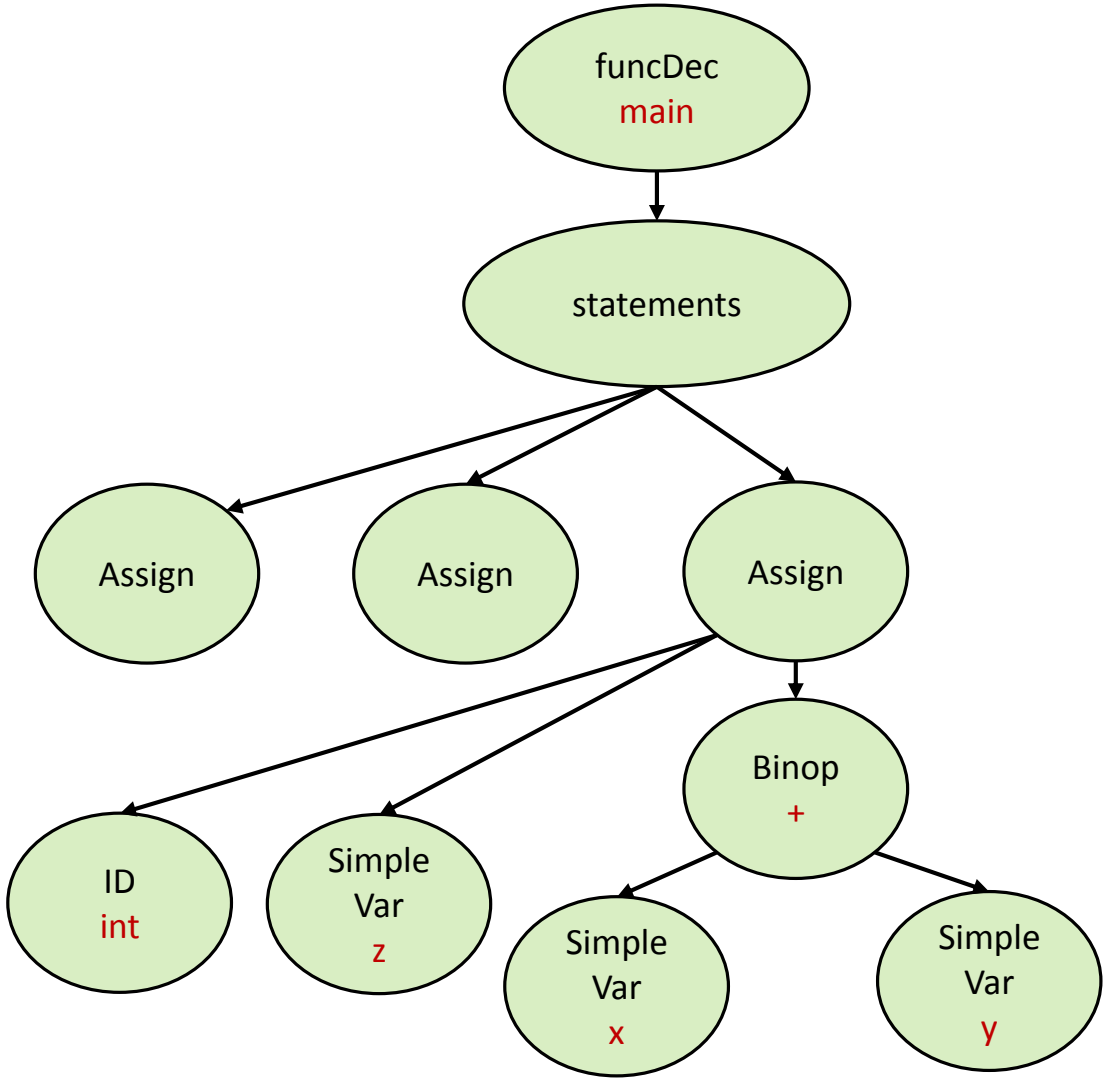

Binary Operations

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void main() {
   int x = 1;
   string y = "A";
   int z = x < y;
}
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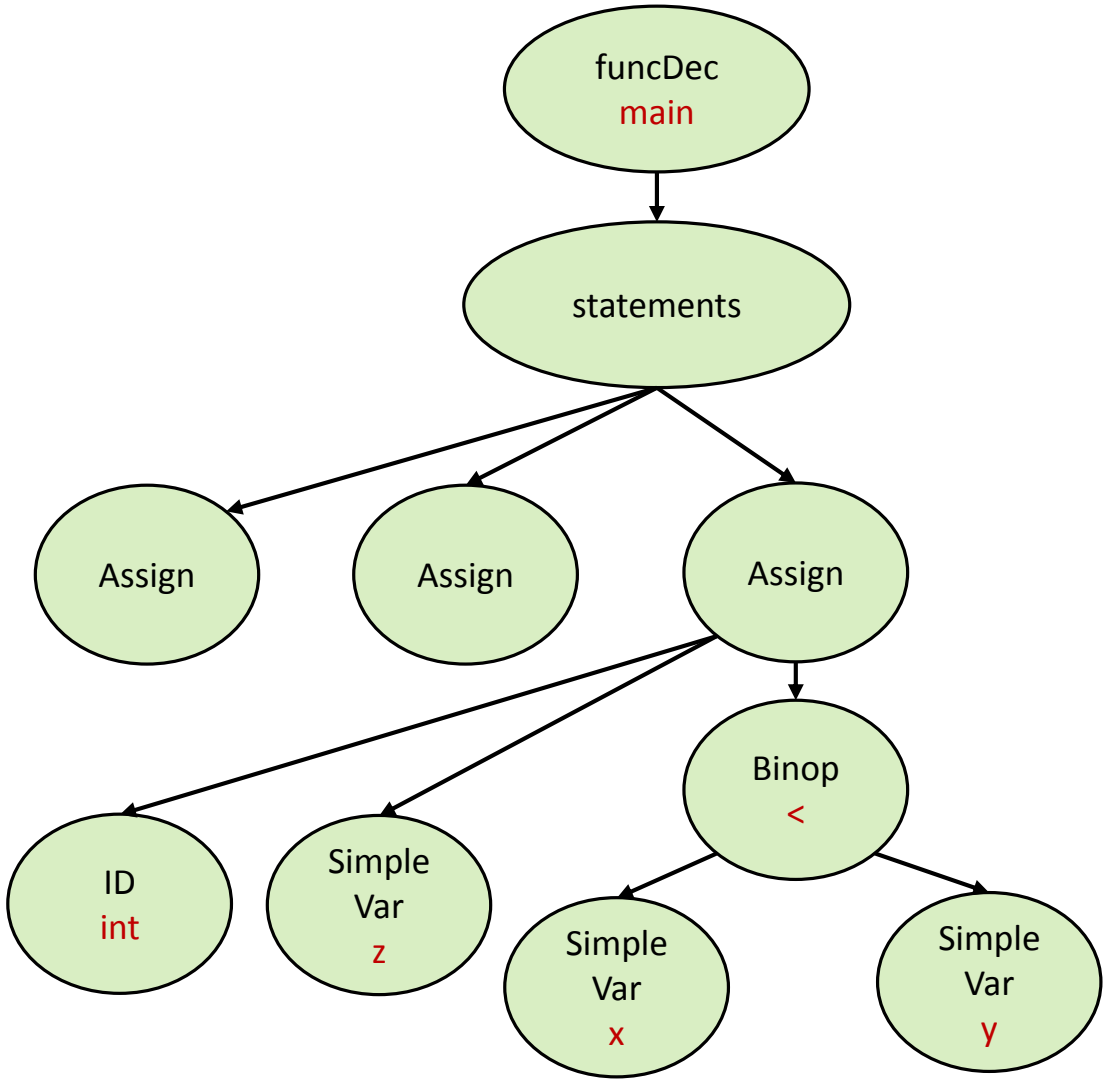

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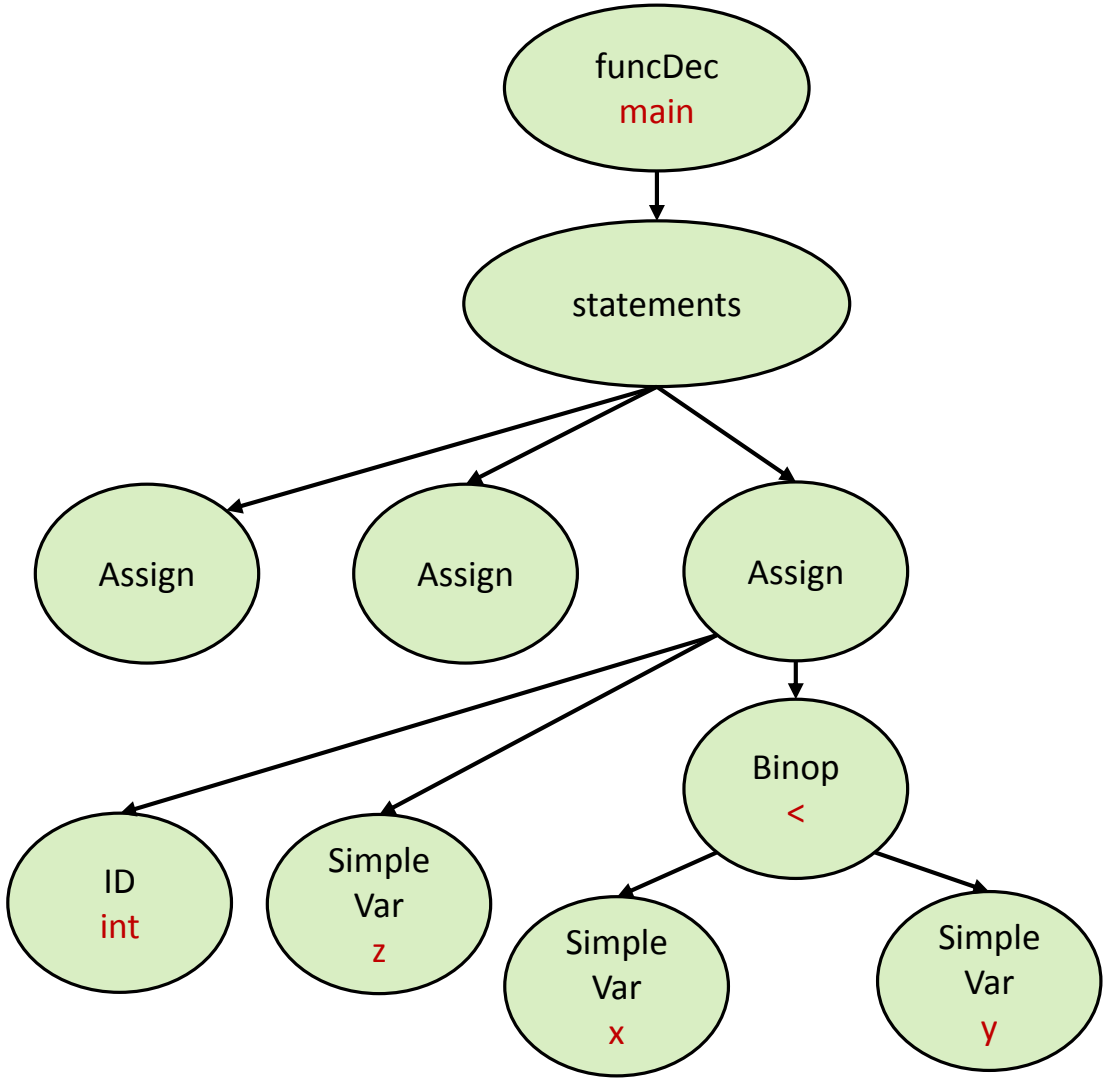

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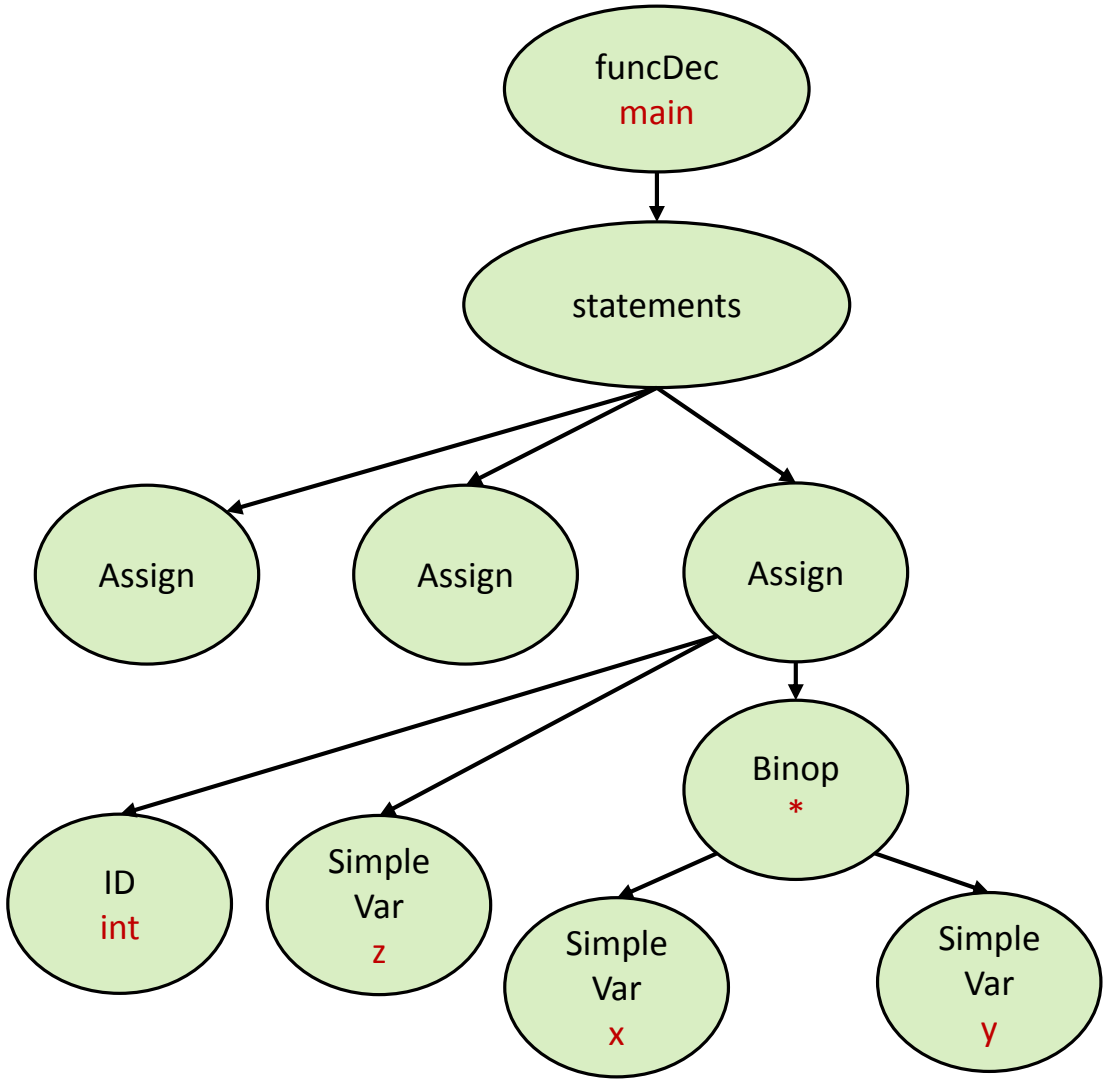

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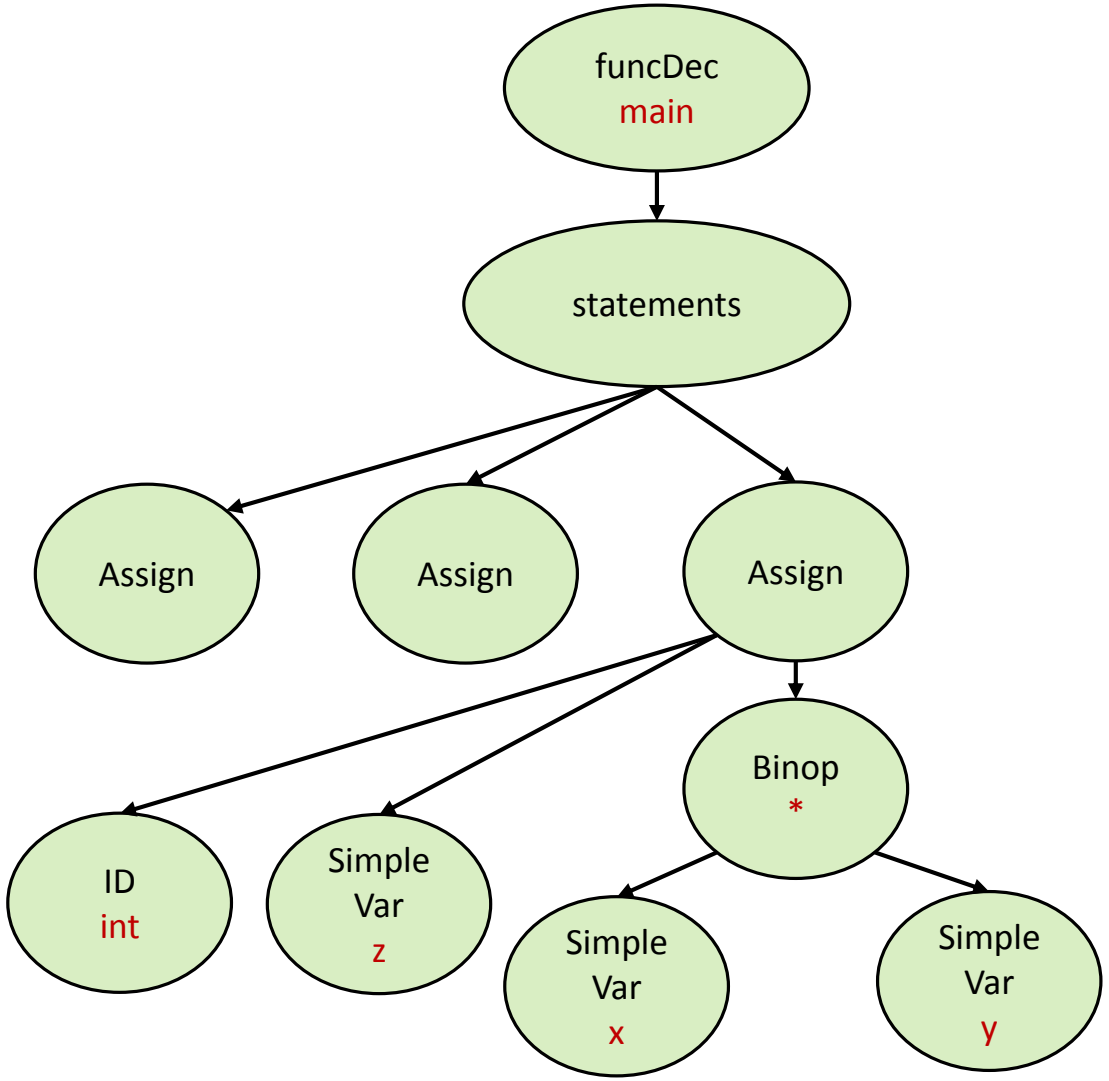

Binary Operations

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void main() {
   int x = 7 / 0;
}
```

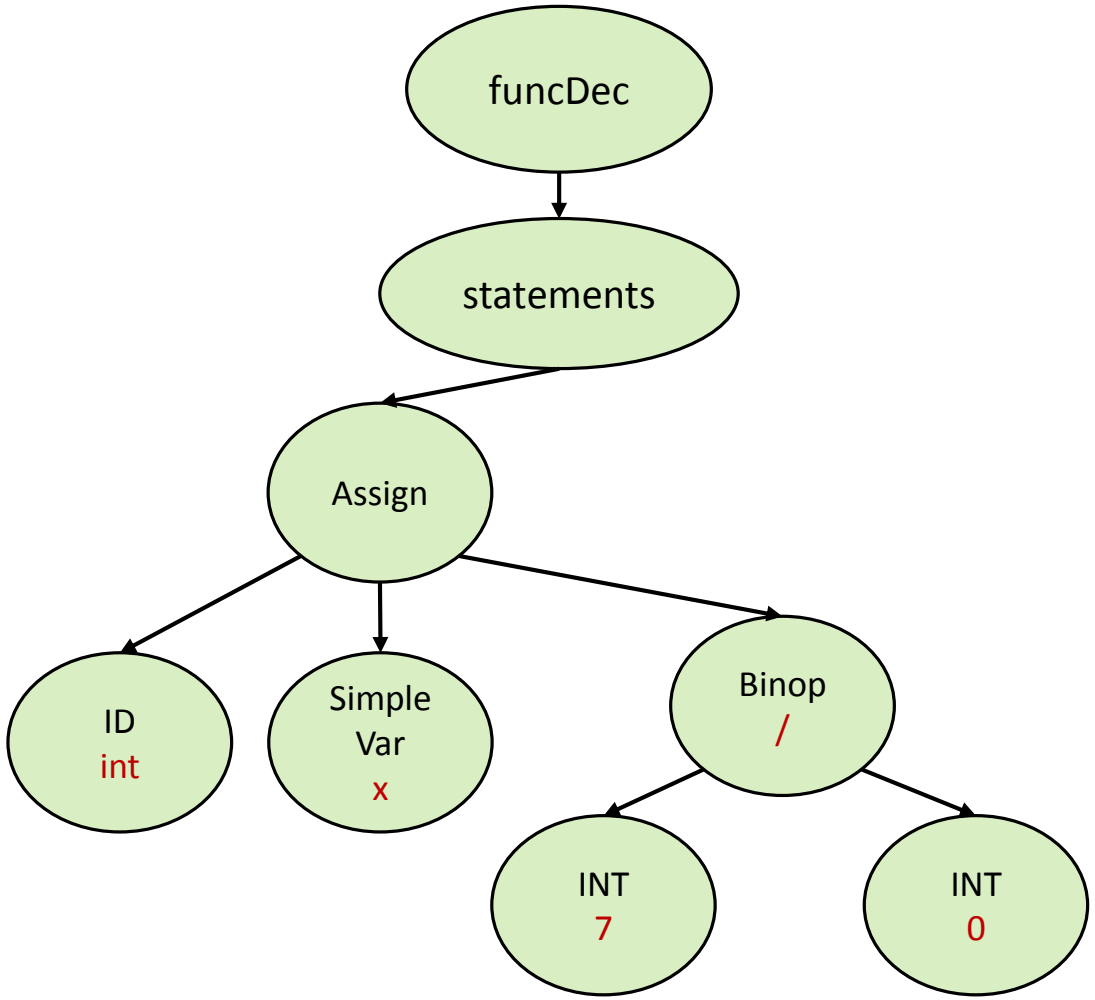

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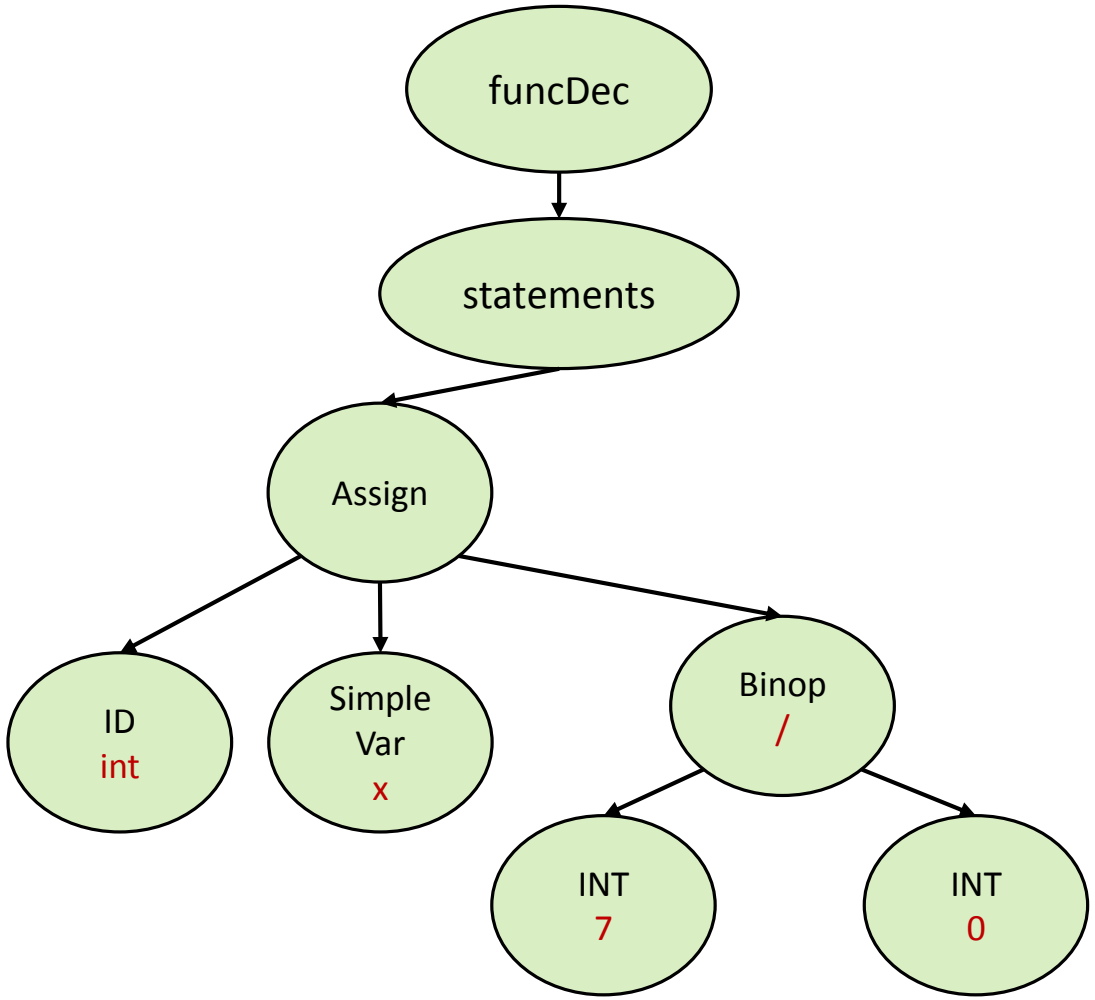

Binary Operations

```
void main() {
   int k = 0;
   int x = 7 / k;
}
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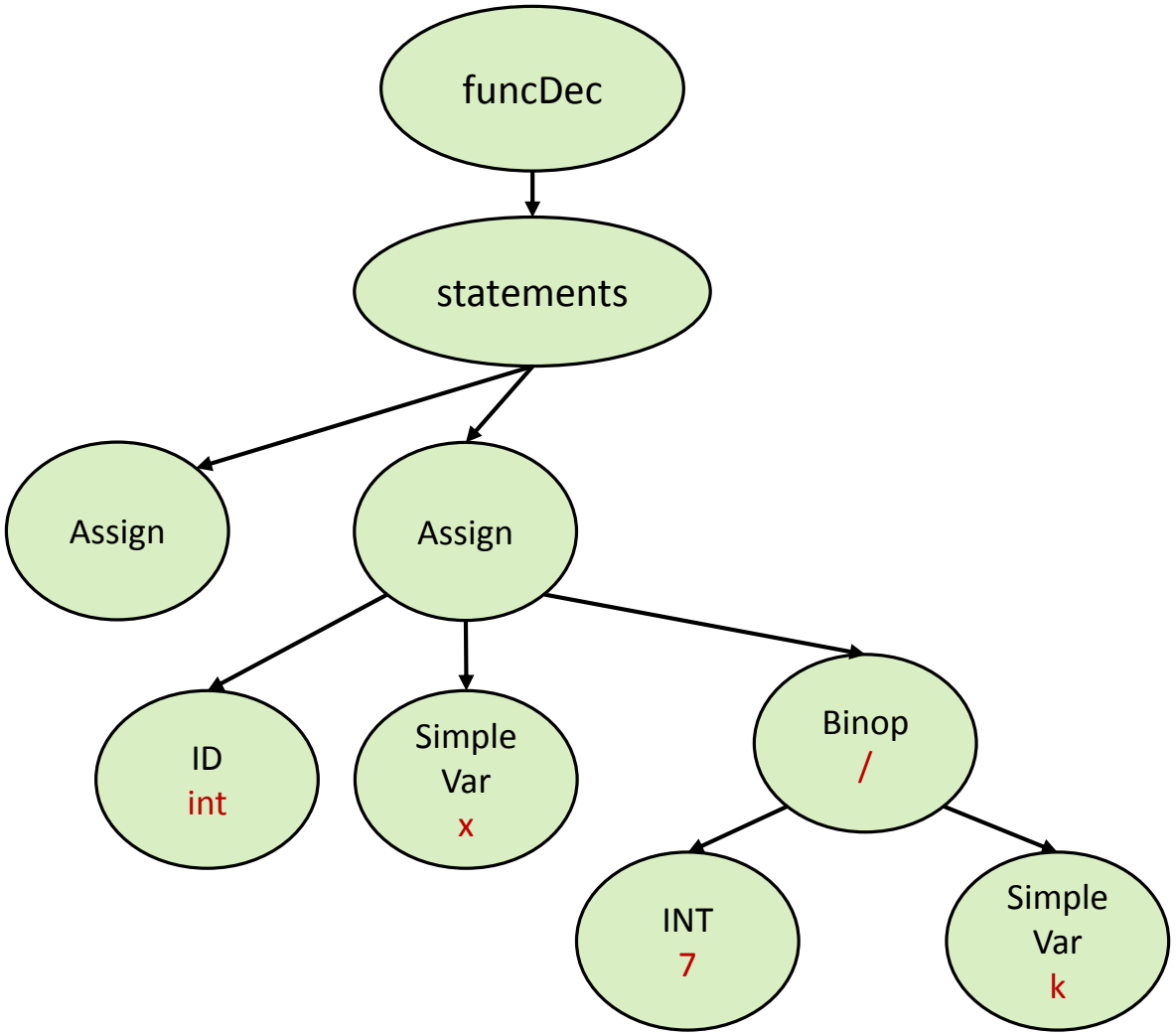

Binary Operations

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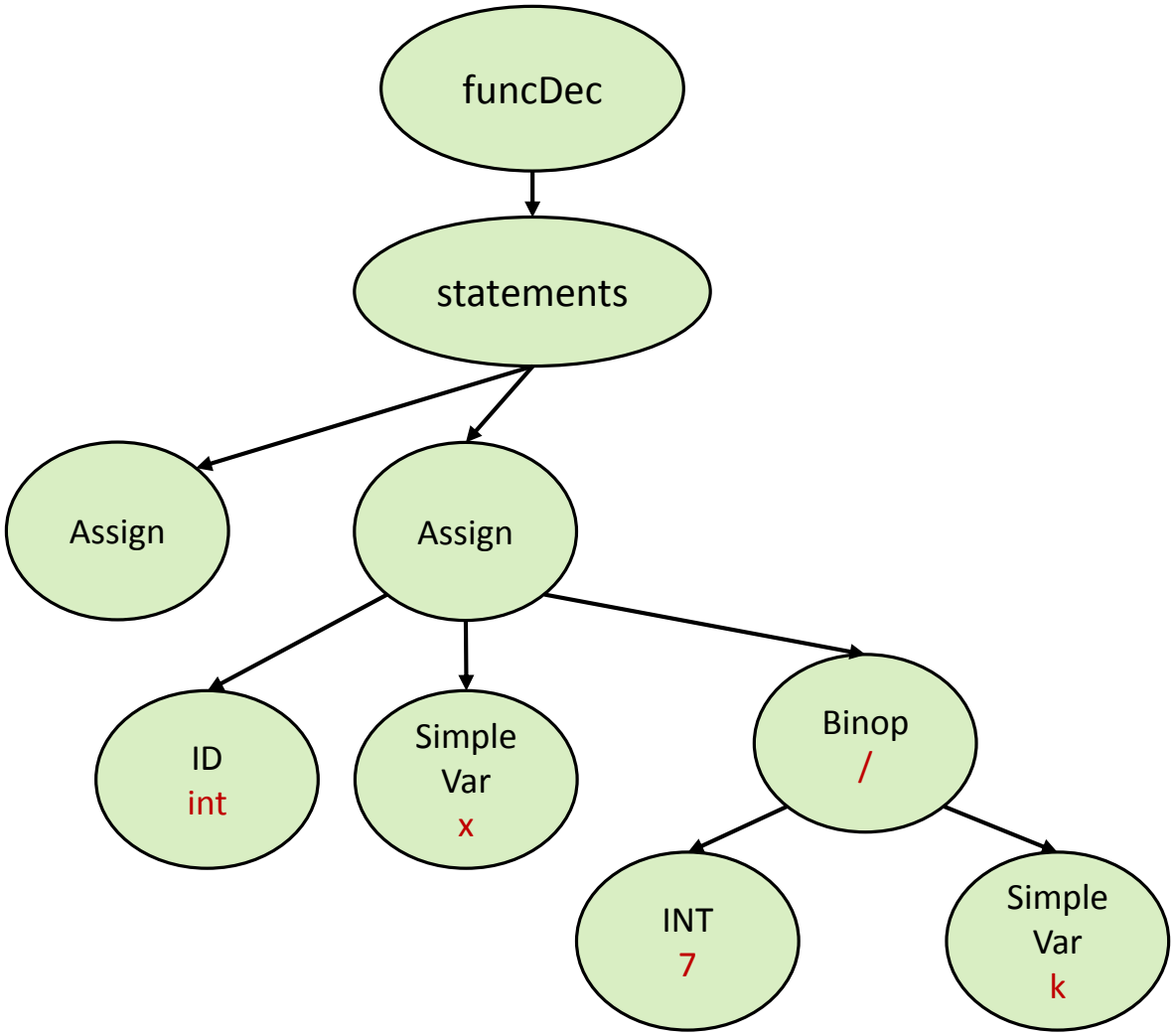
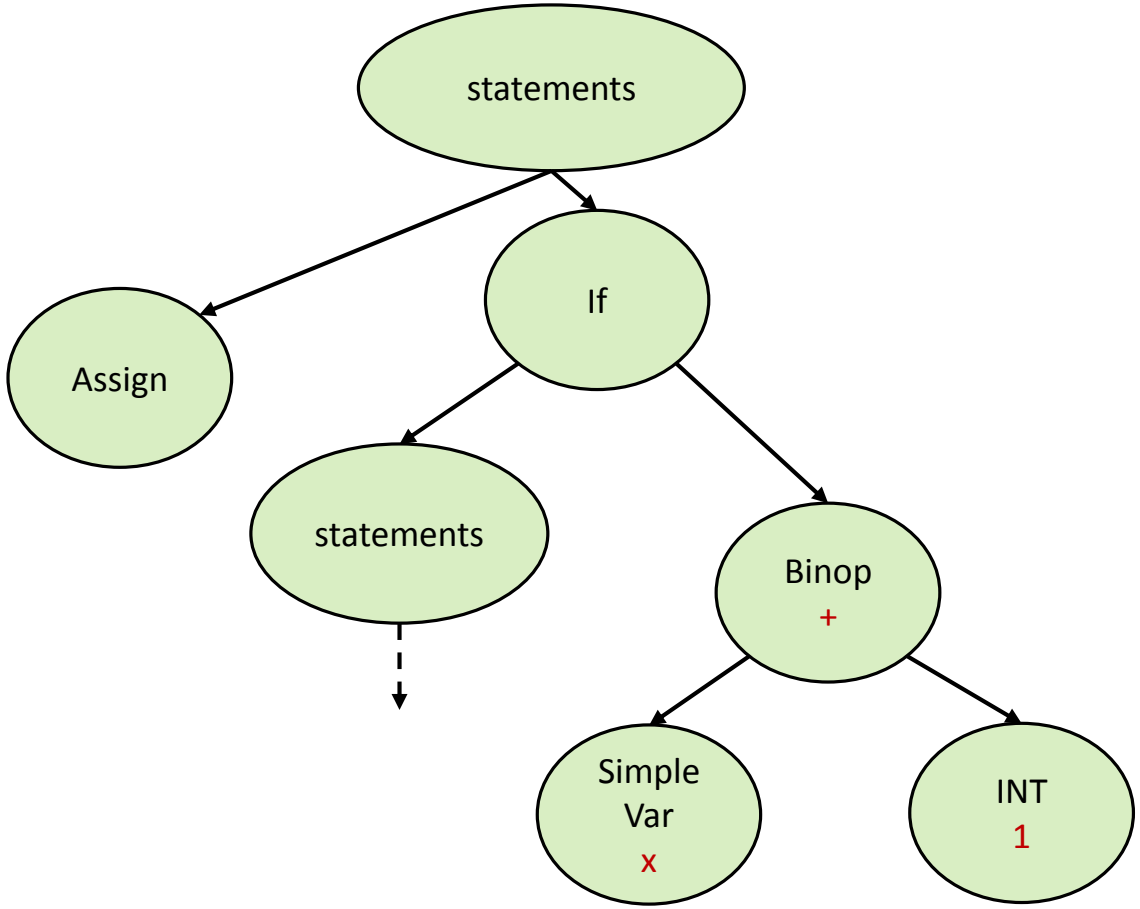


If, While, …

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



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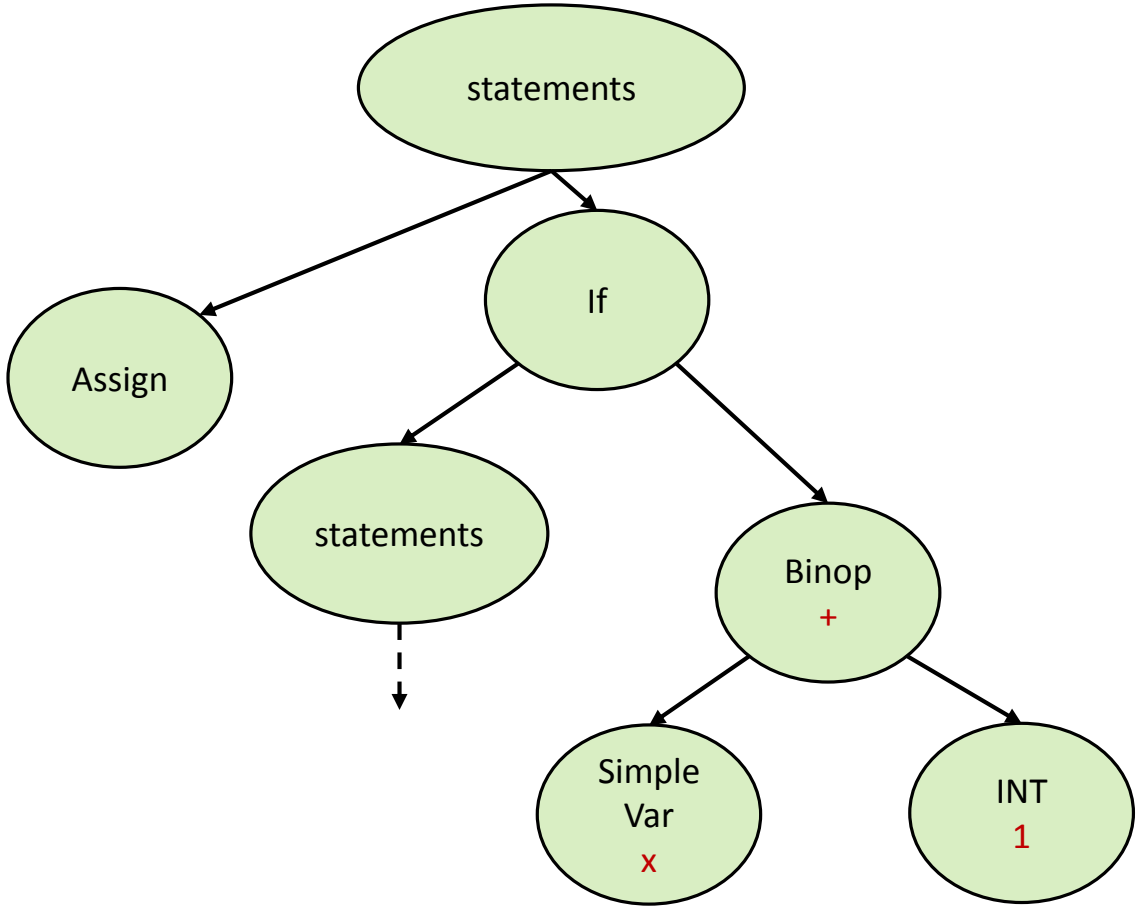
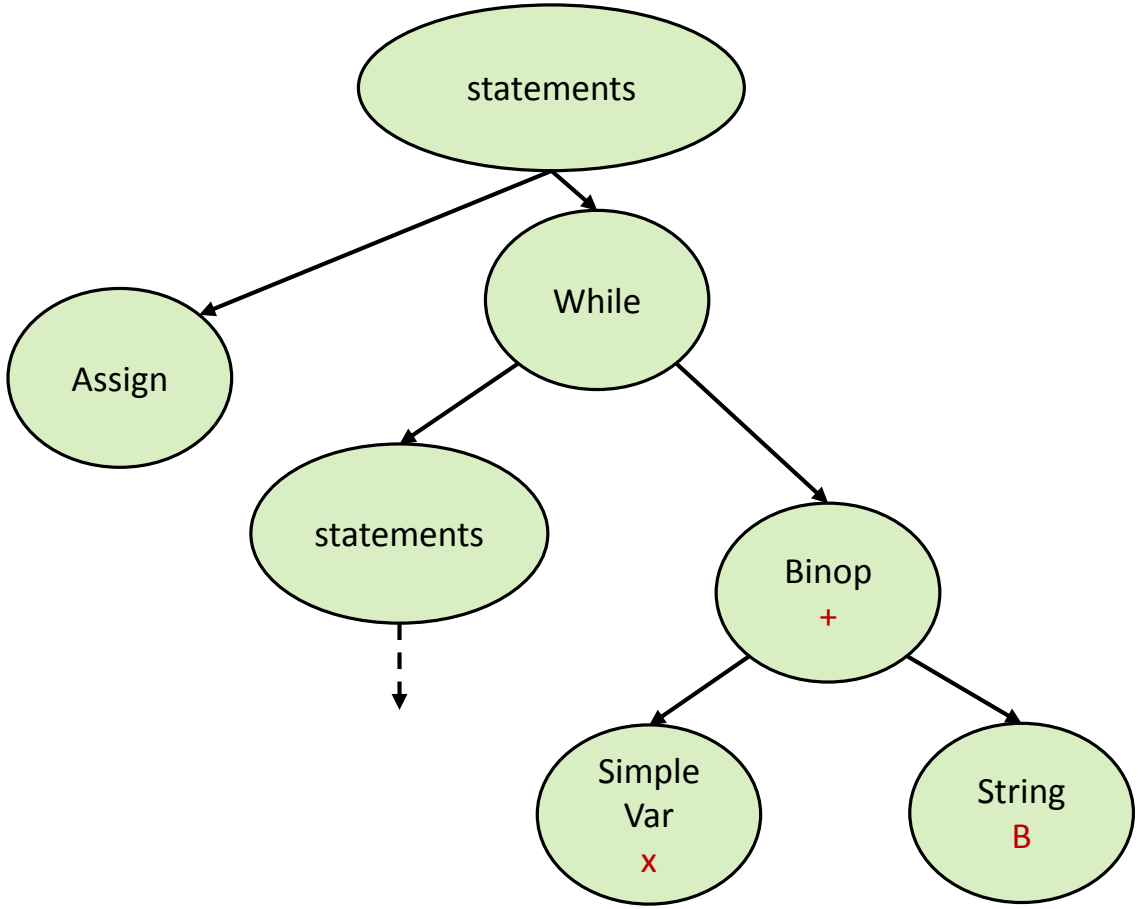


If, While, …

```
void main() {
   string x = "A";
   while (x + "B") {
      int z = 2;
   }
}
```



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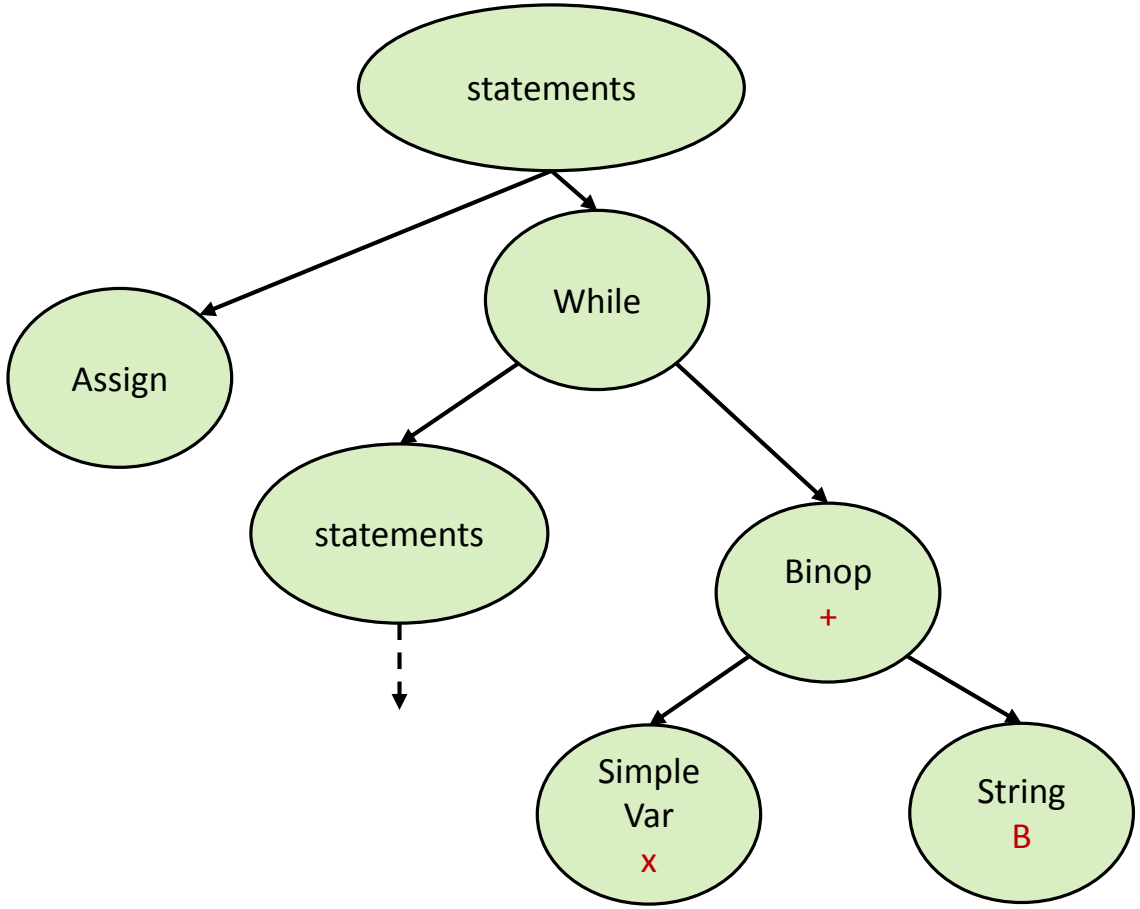
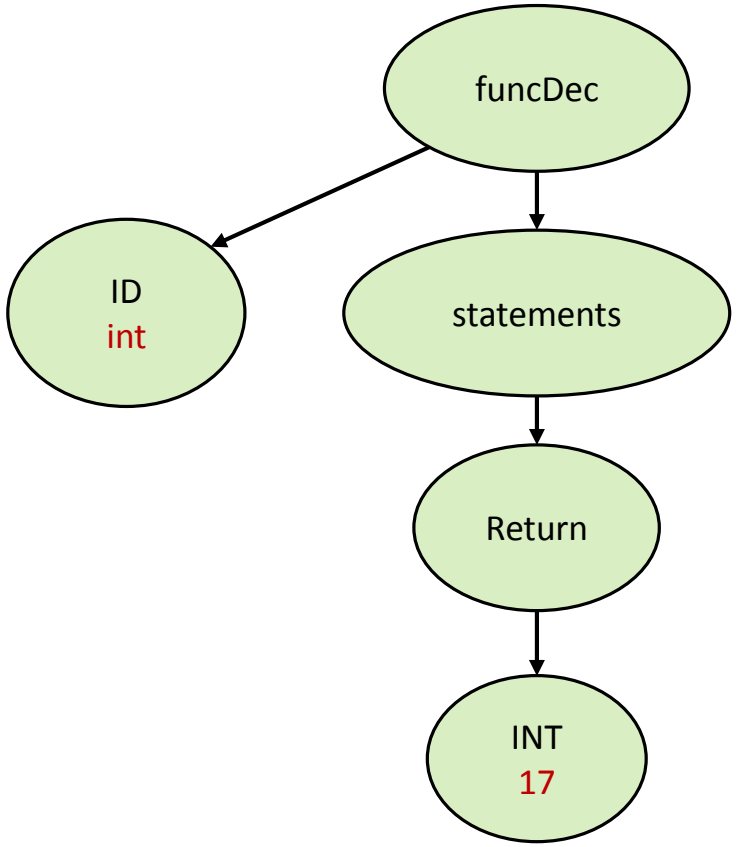


Return Statement

```
int main() {
   return 17;
}
```



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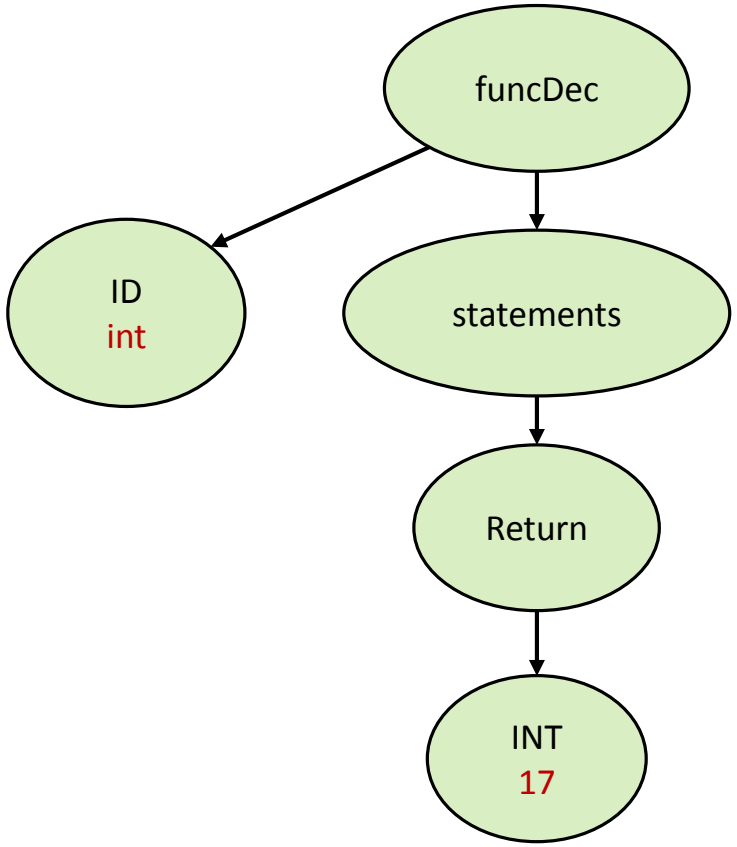
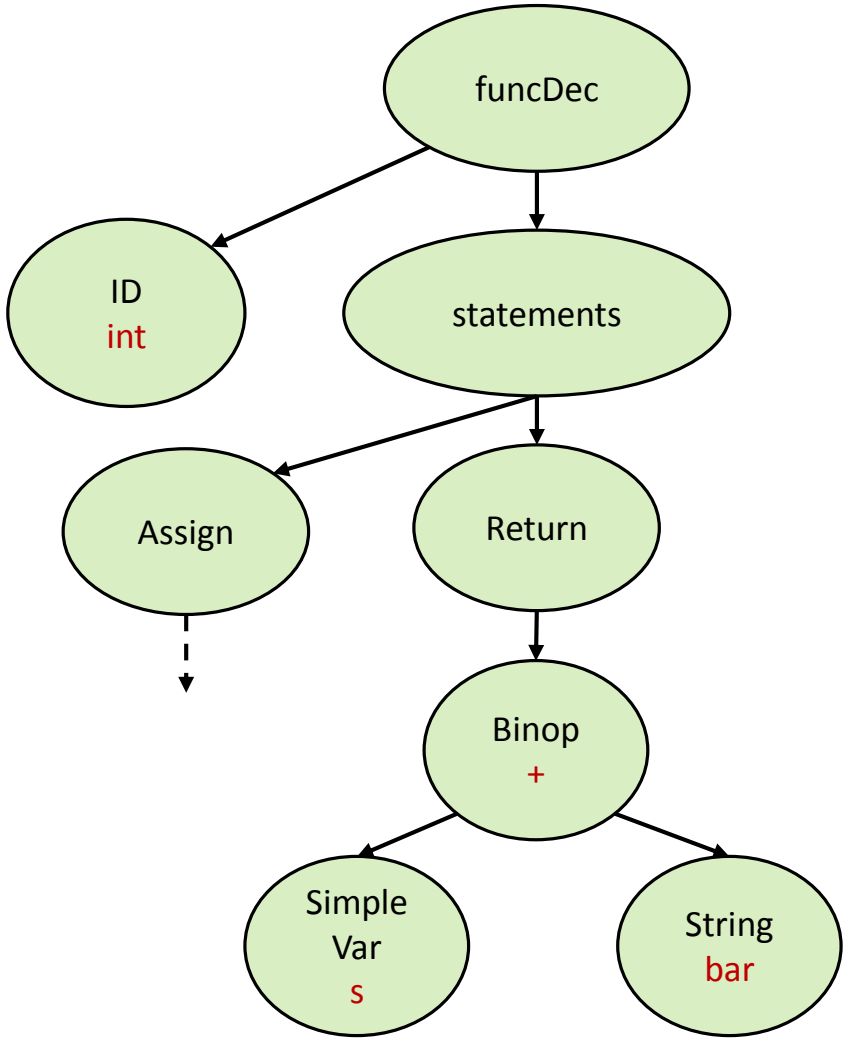


Return Statement

```
int main() {
   string s = "foo"
   return s + "bar";
}
```



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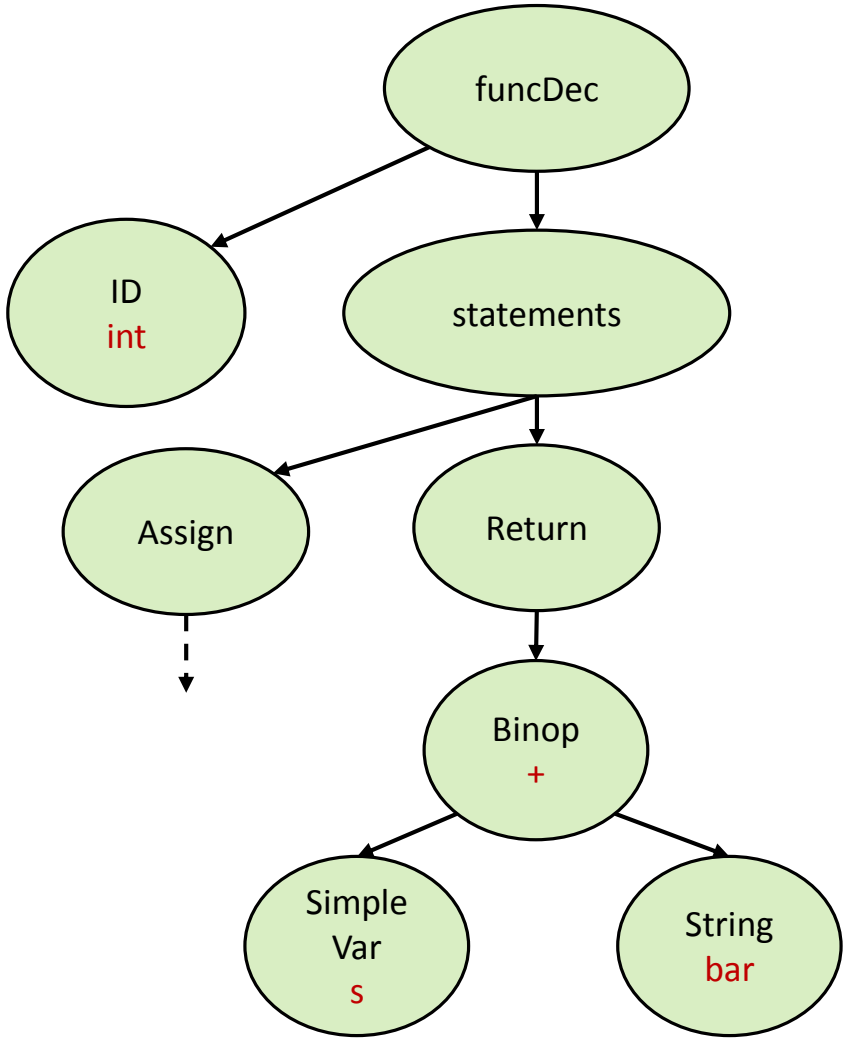
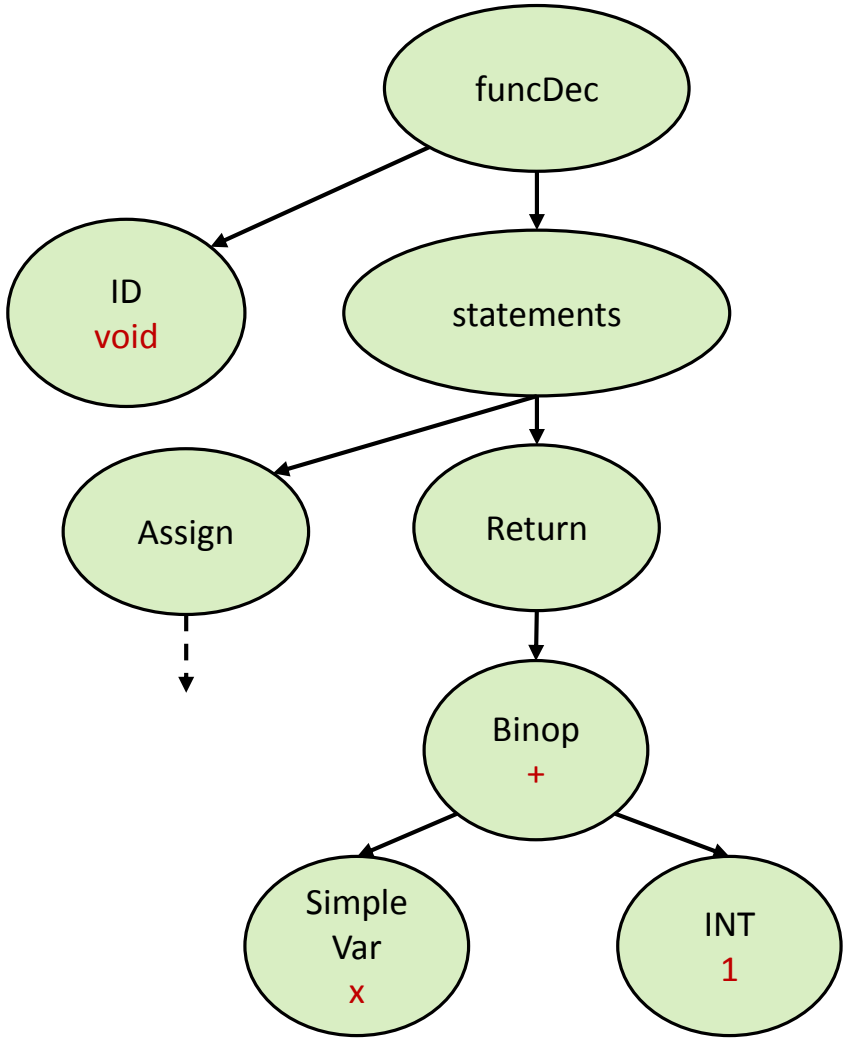


Return Statement

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



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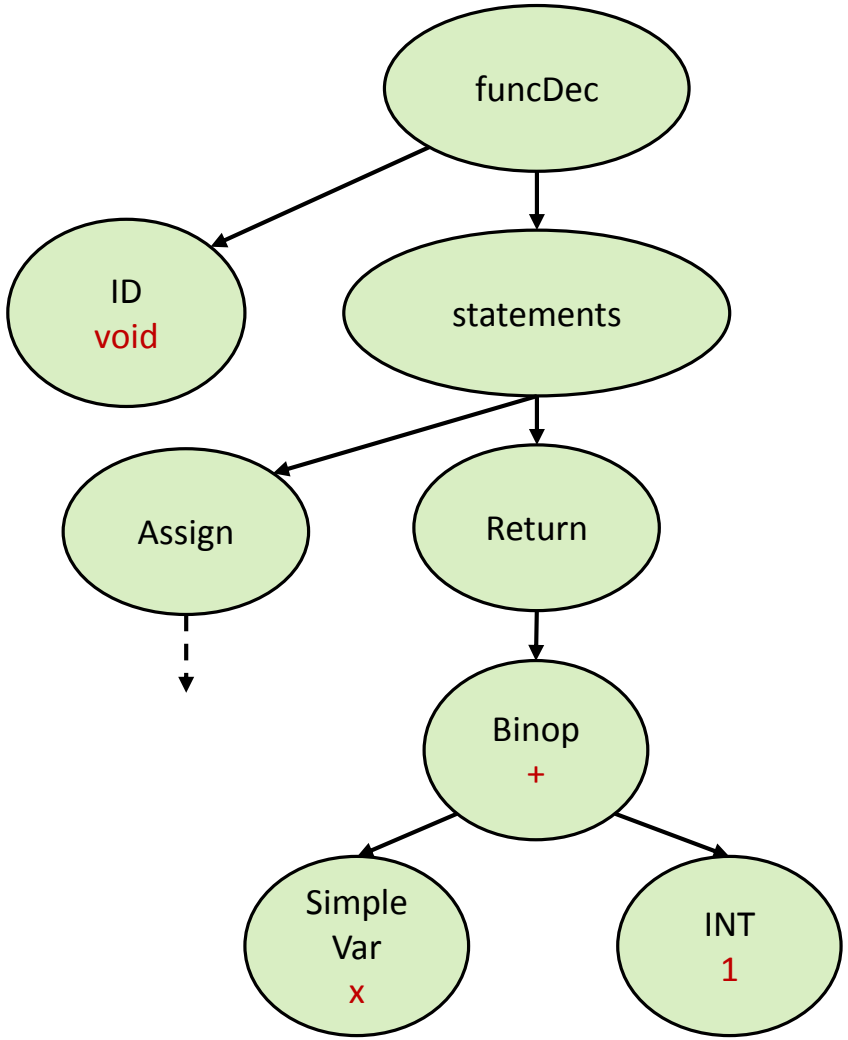
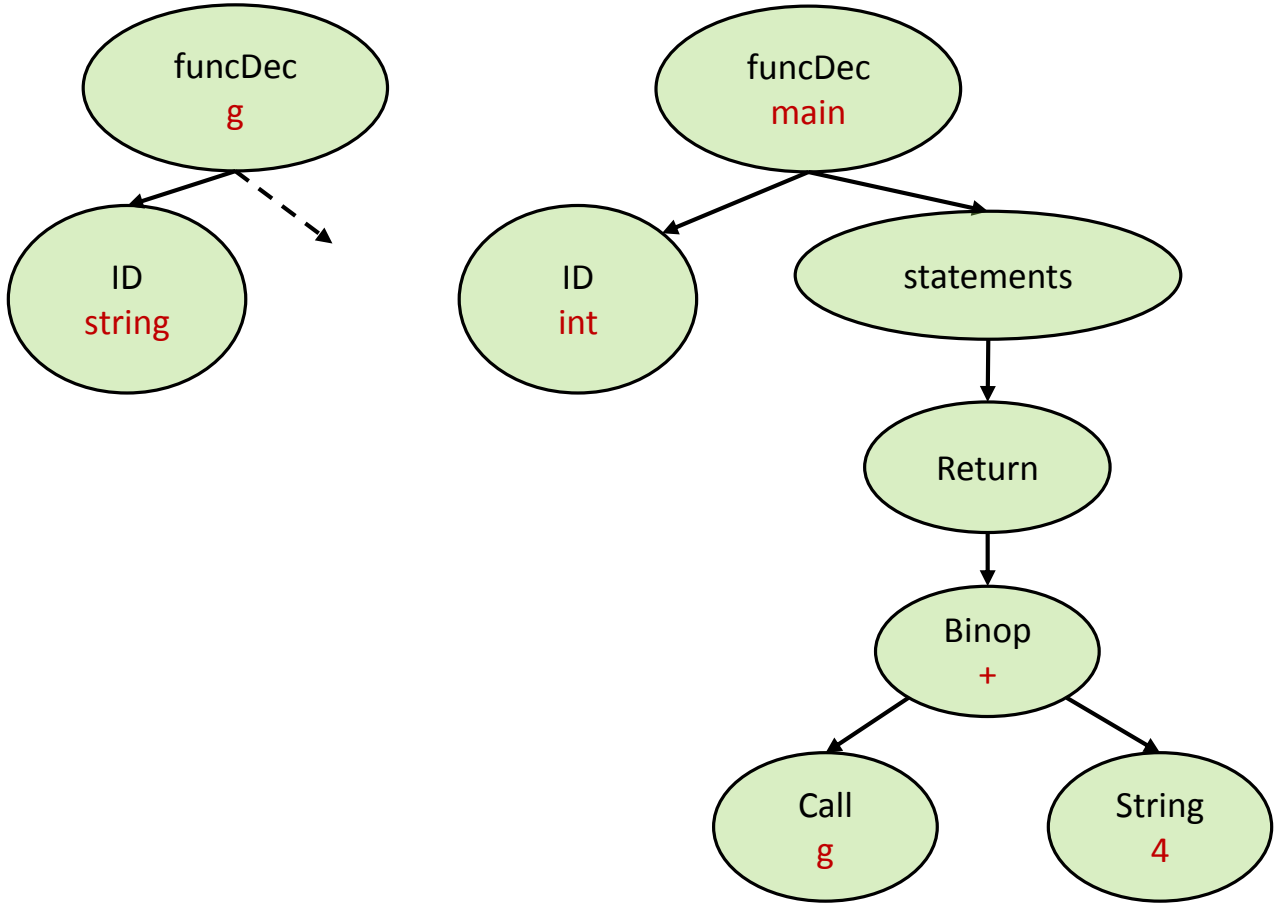


Return Statement

```
string g() {
  return "123";
}
int main() {
  return g() + "4";
}
```



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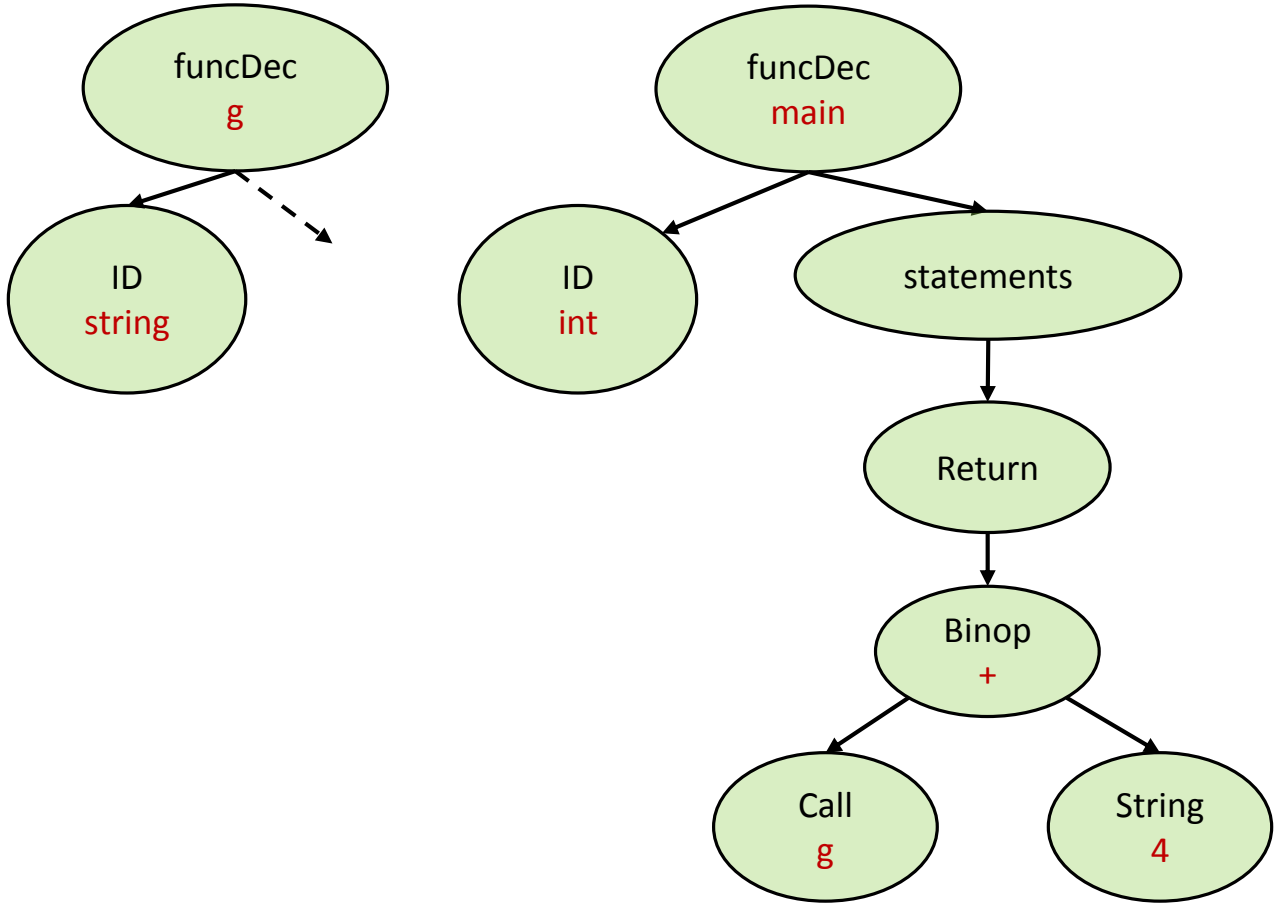
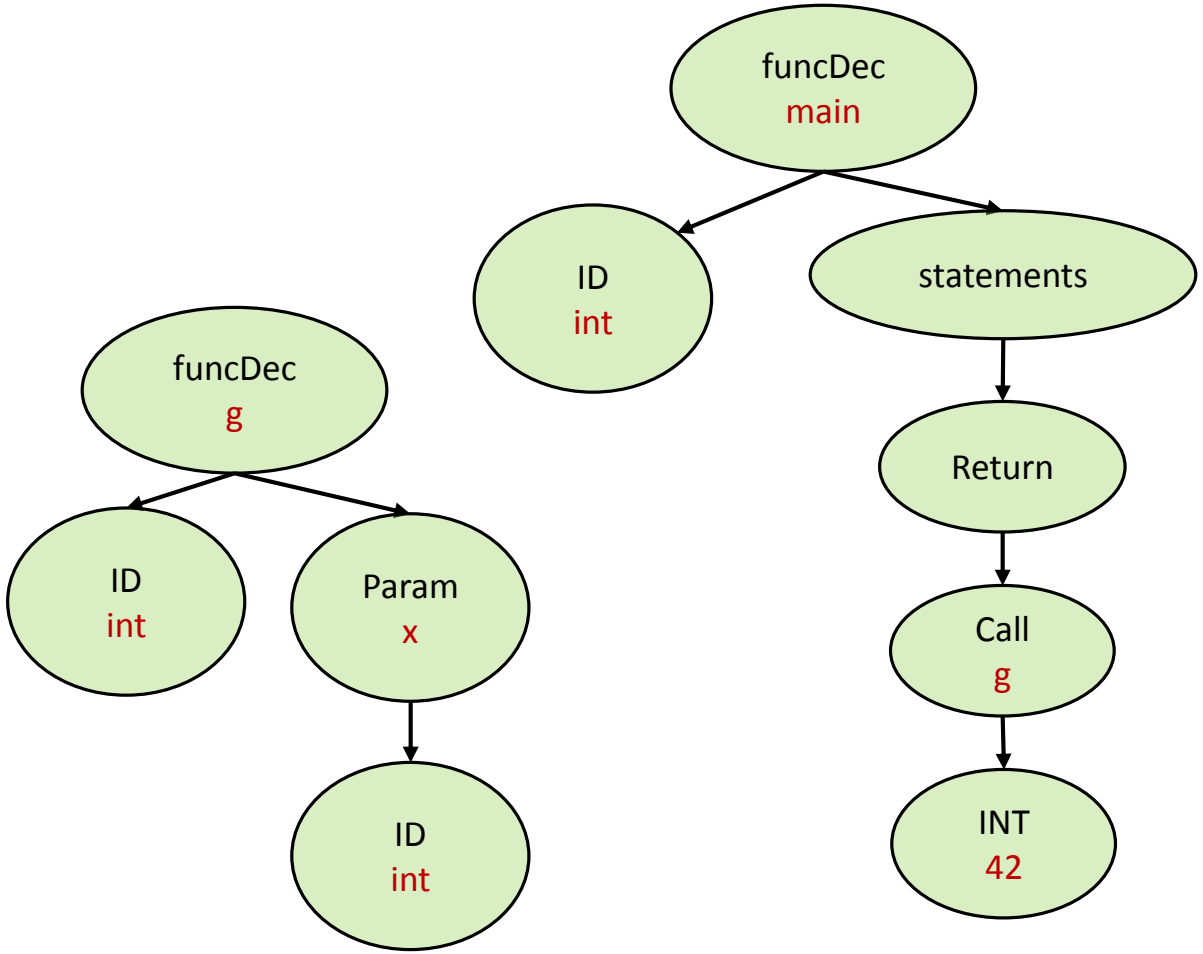


Function Calls

```
int g(int x) {
  return x + 1;
}
int main() {
  return g(42);
}
```



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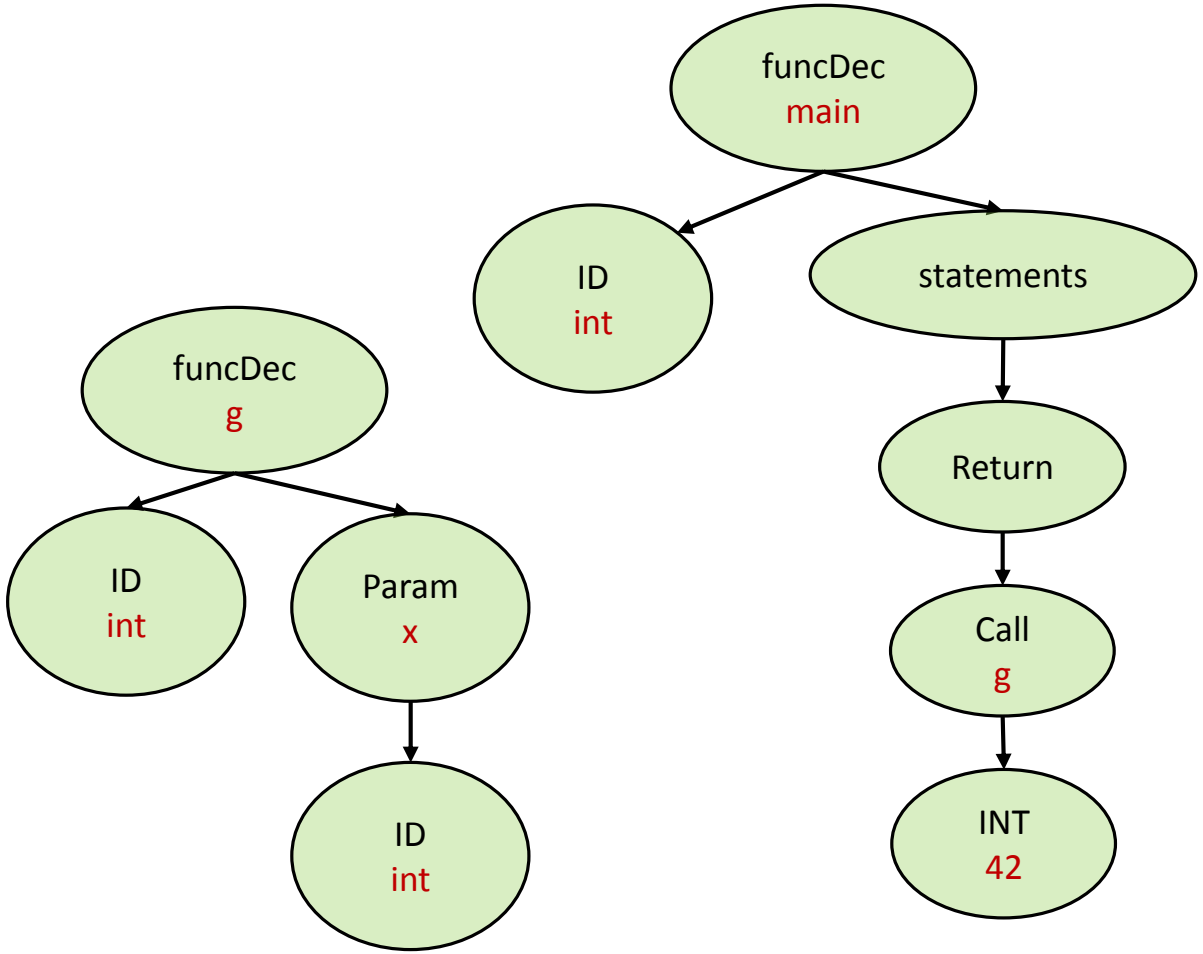
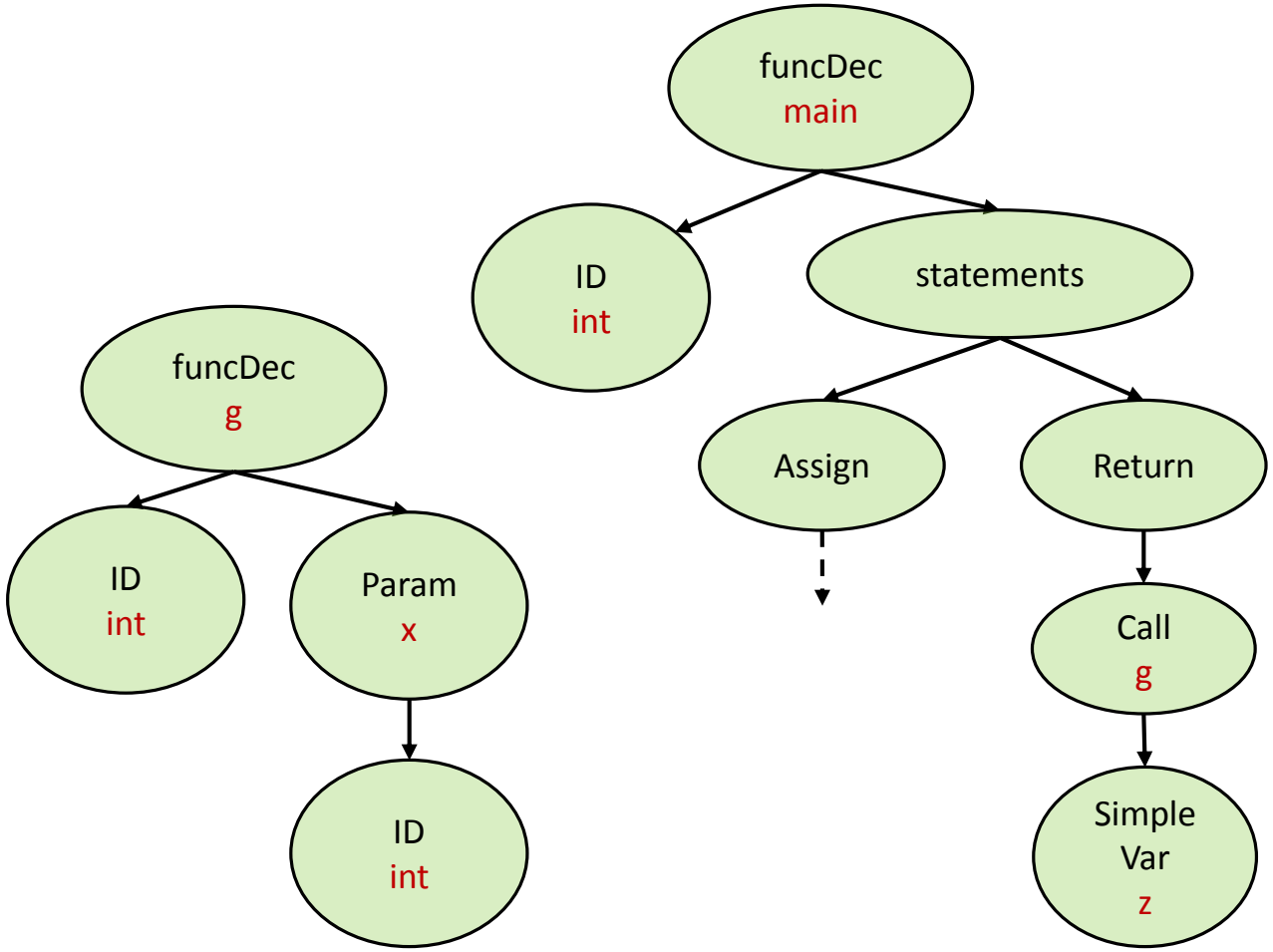


Function Calls

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



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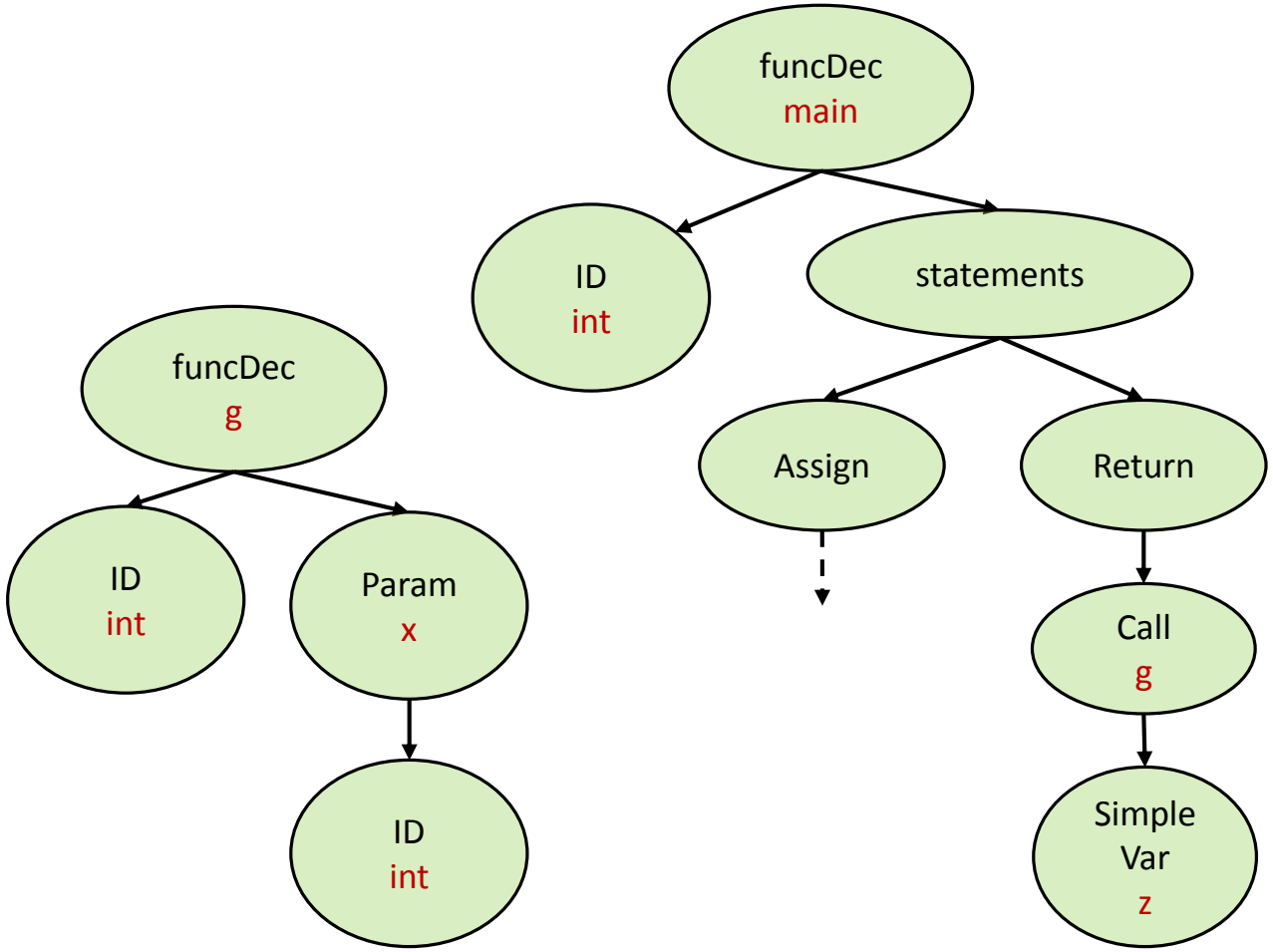
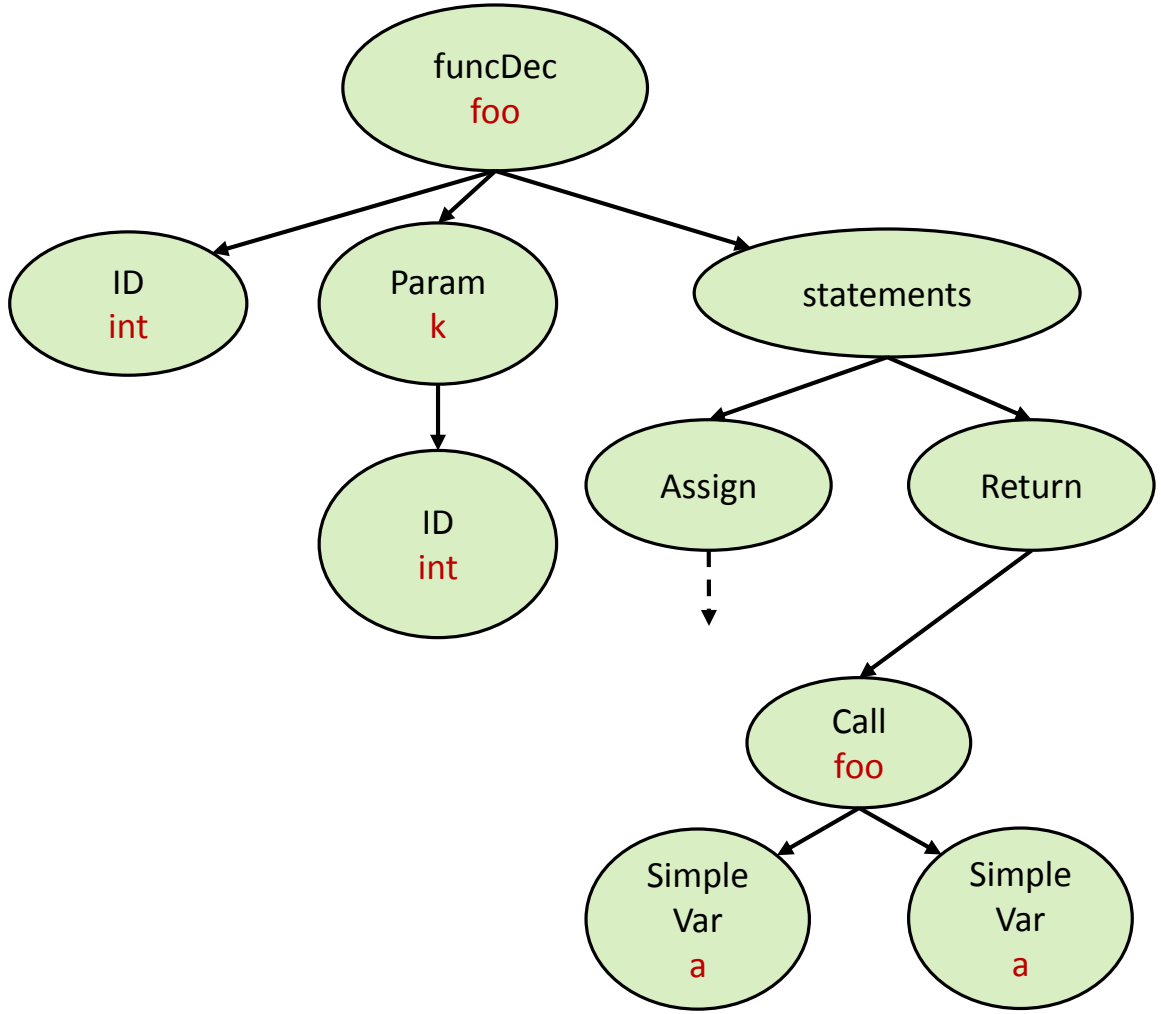


Function Calls

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



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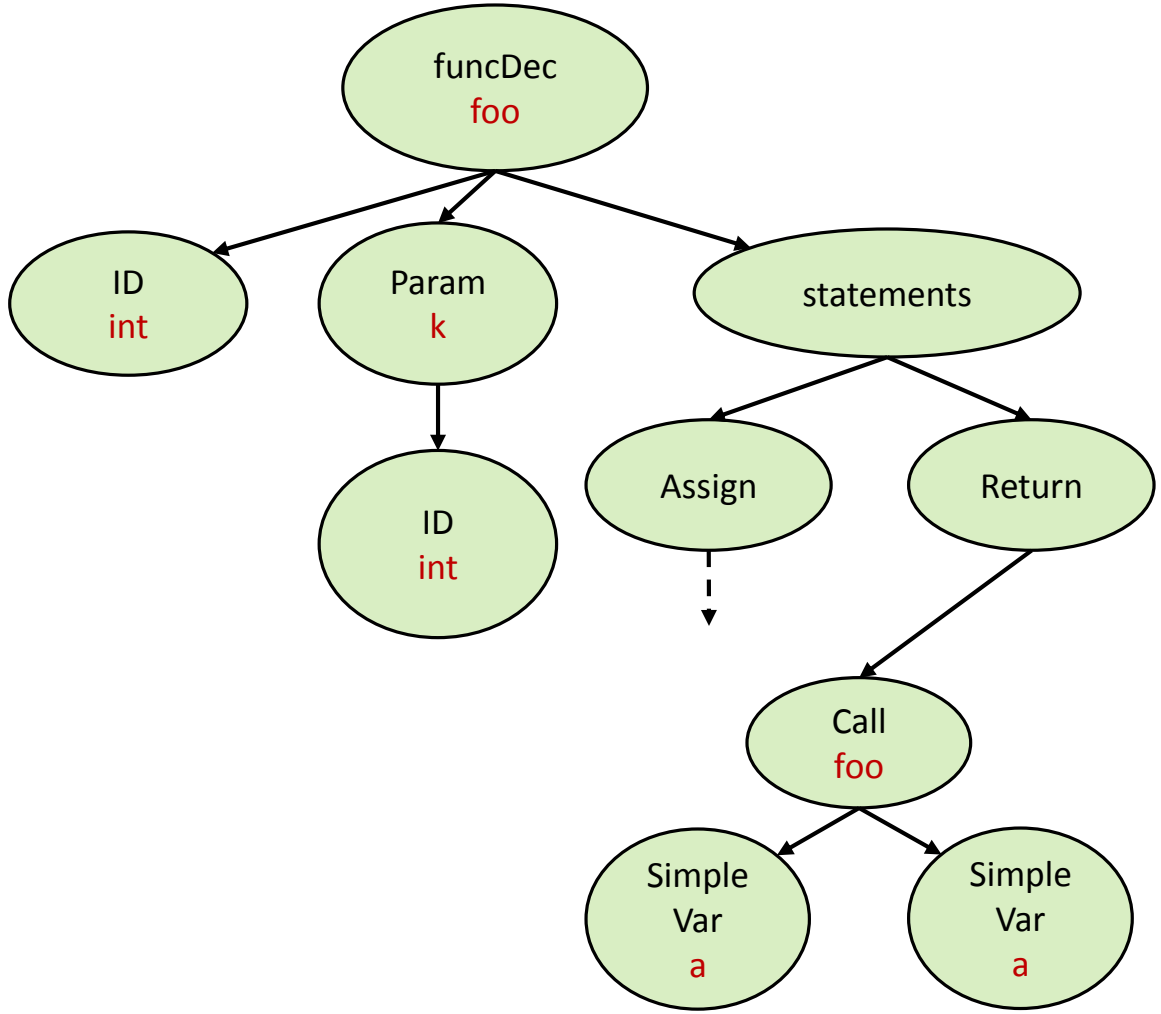
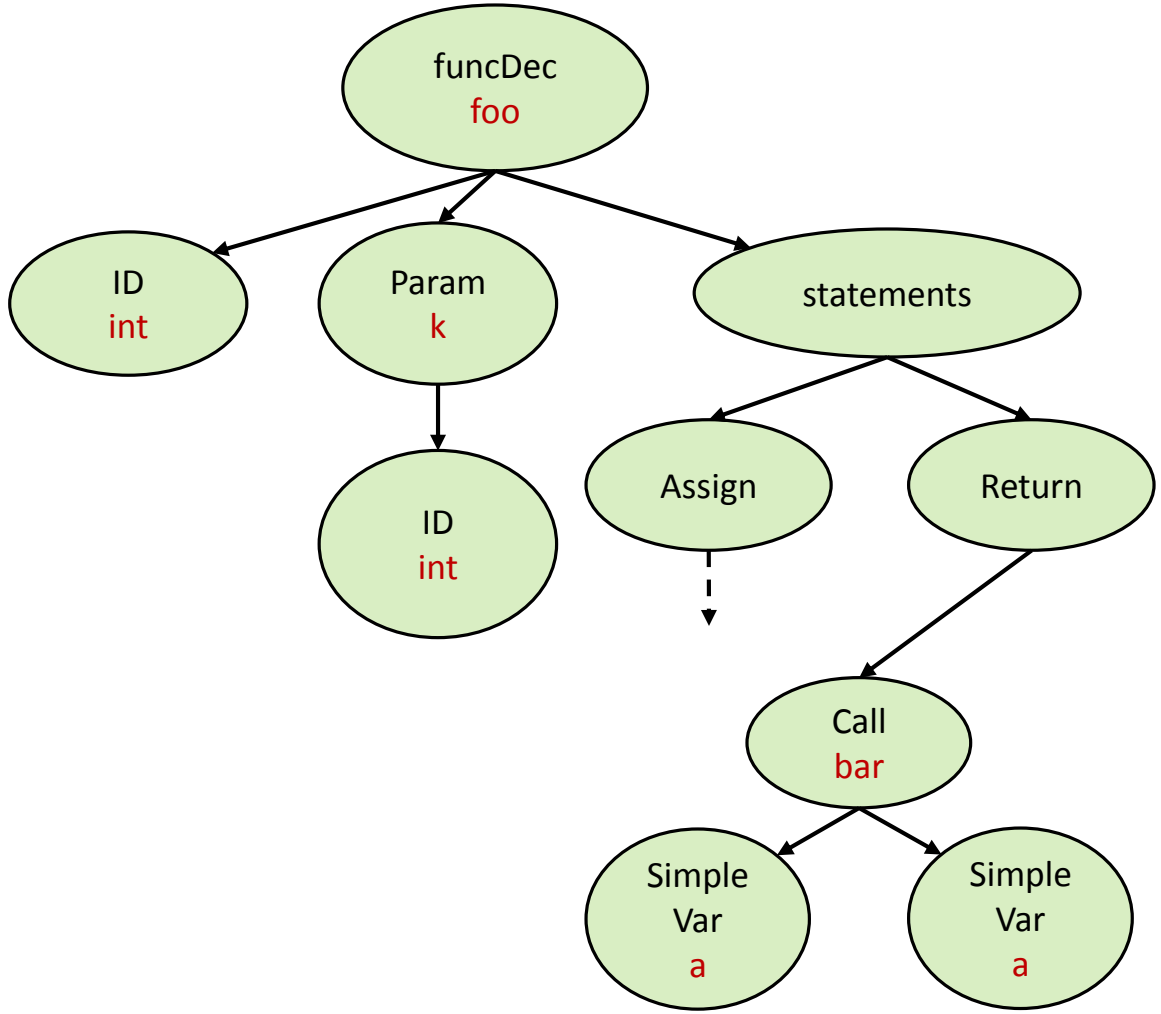


Function Calls

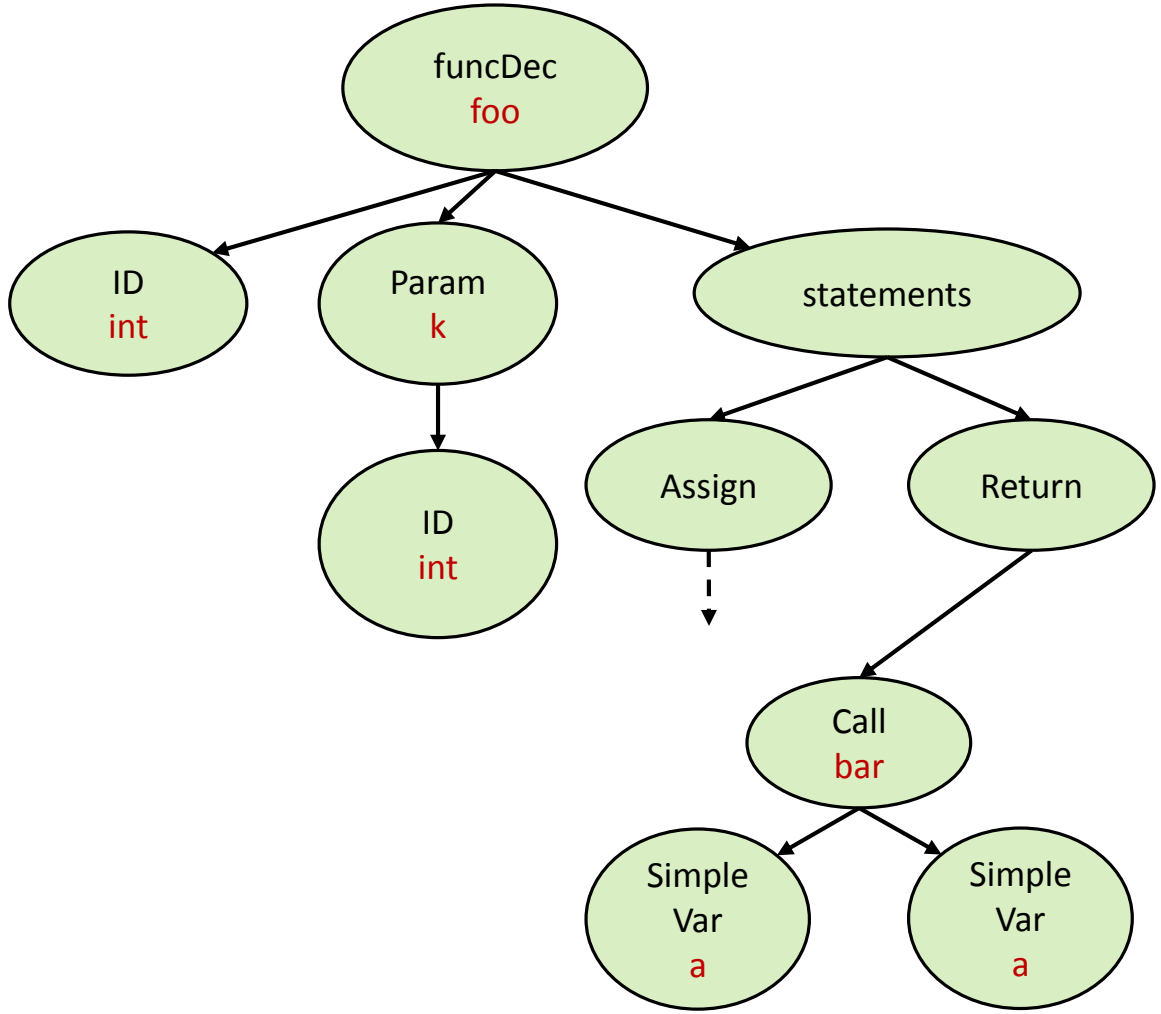
```
int foo(int k) {
  int a = k * 10;
  return bar(a, a);
}
```



Function Calls

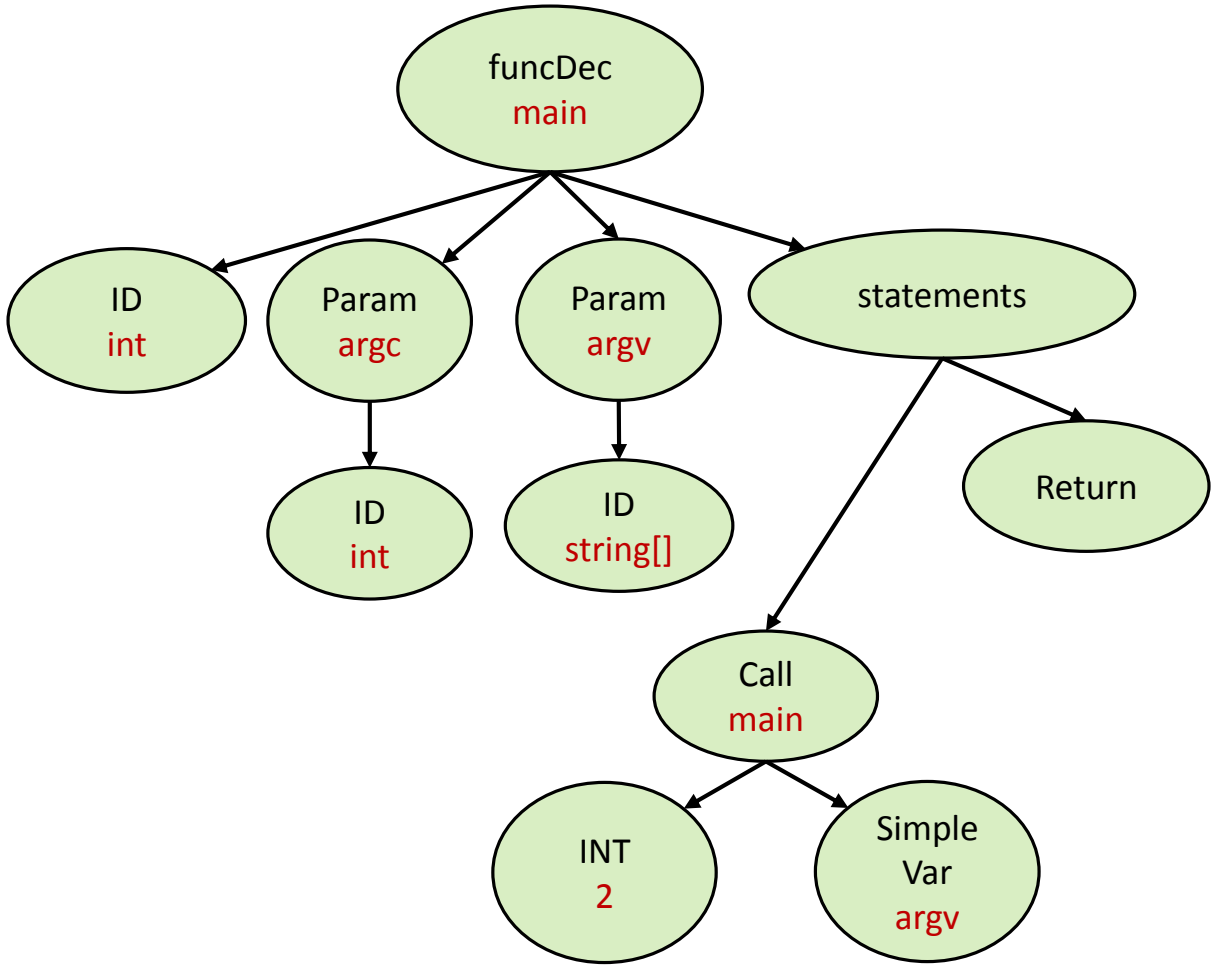
```
int foo(int k) {
  int a = k * 10;
  return bar(a, a);
}
```

Invalid



Function Calls

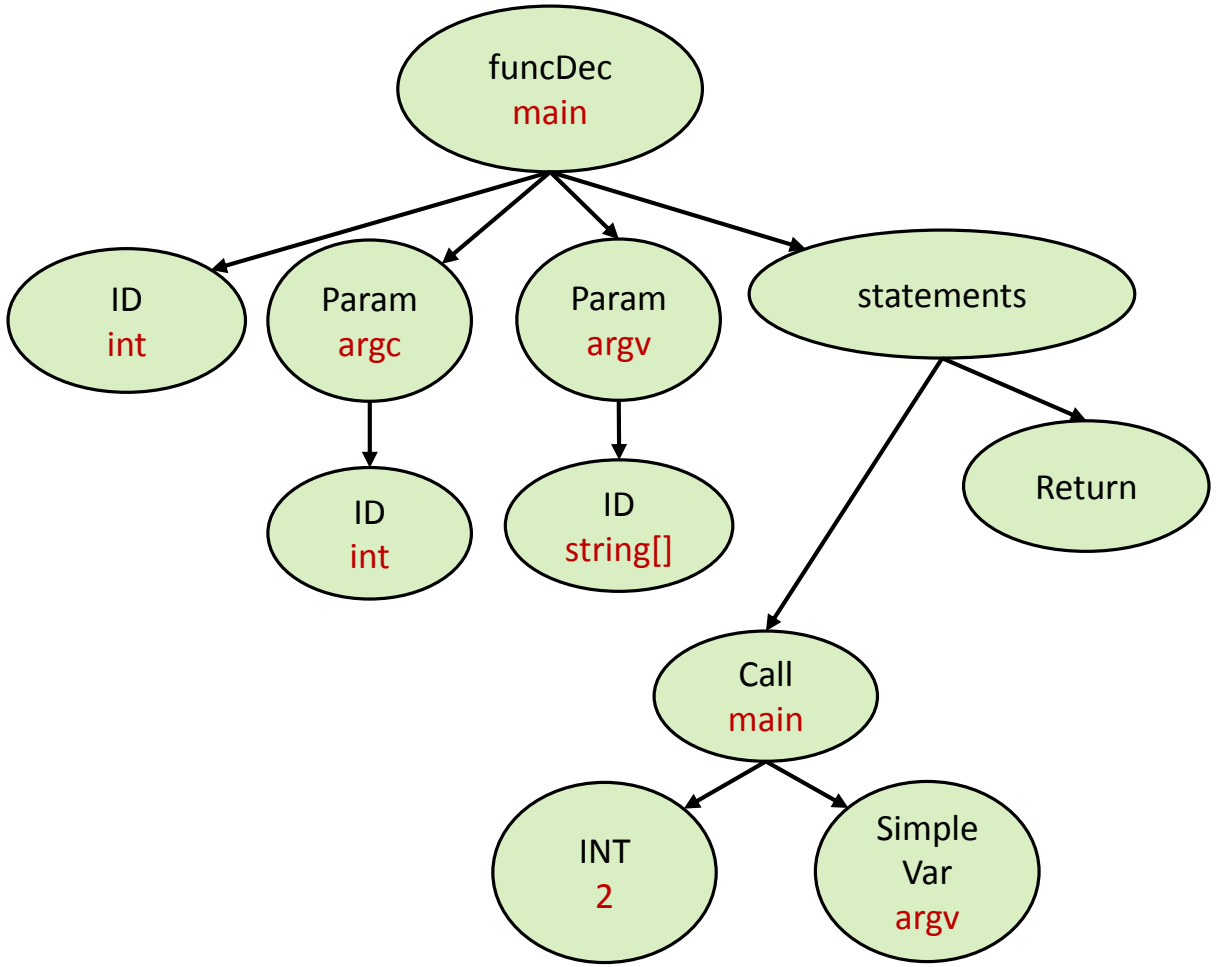
```
int main(int argc,
         string argv[]){
  main(2, argv);
  return 0;
}
```



Function Calls

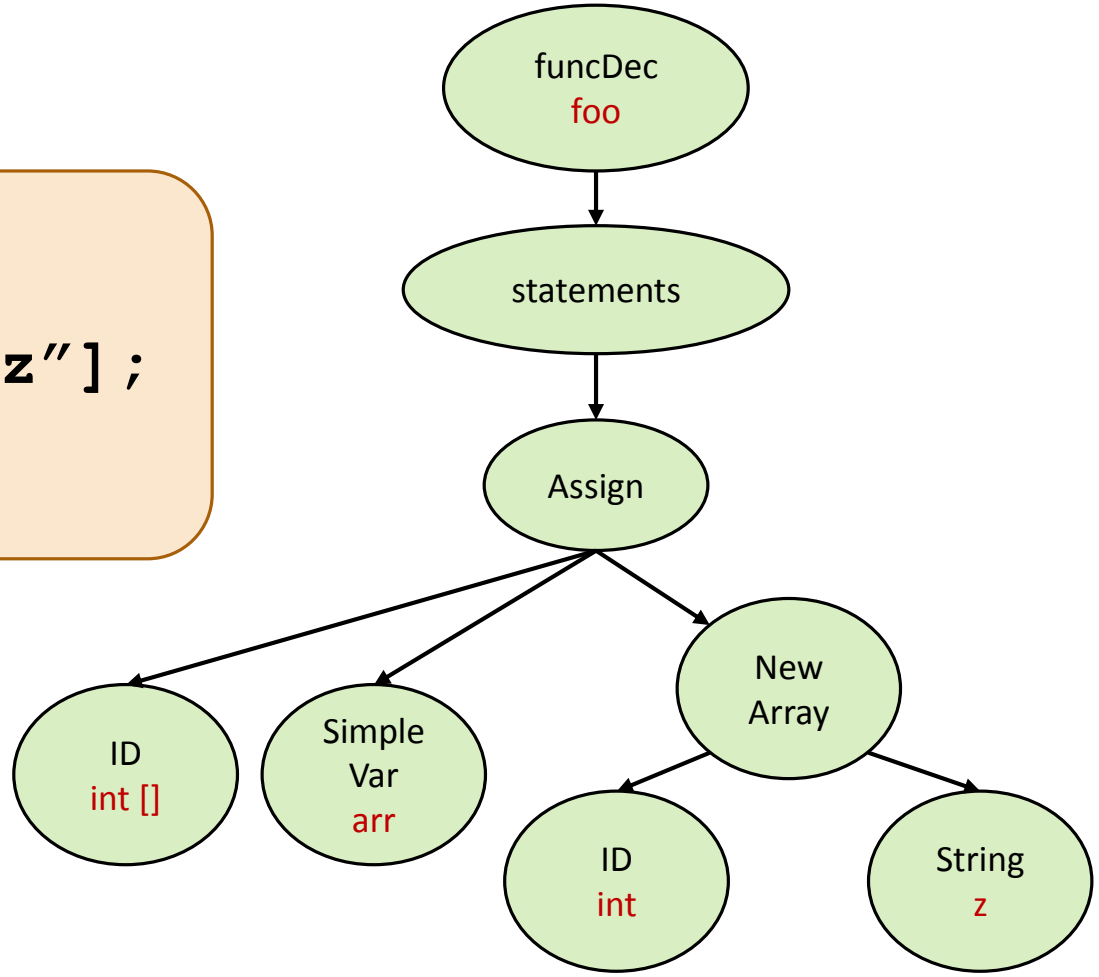
```
int main(int argc,
         string argv[]){
  main(2, argv);
  return 0;
}
```

Valid



Arrays

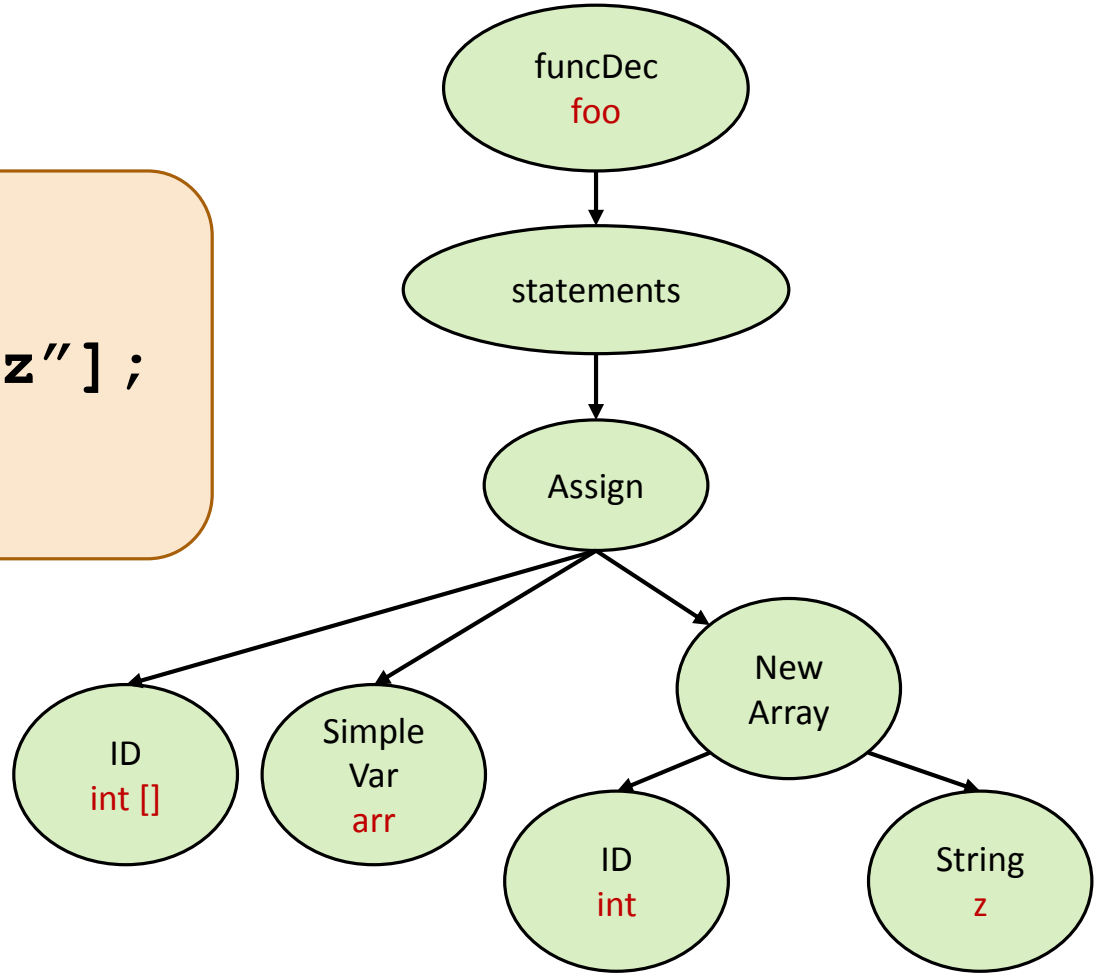
```
void foo(void) {
  int[] arr = new int[“z”];
}
```



Arrays

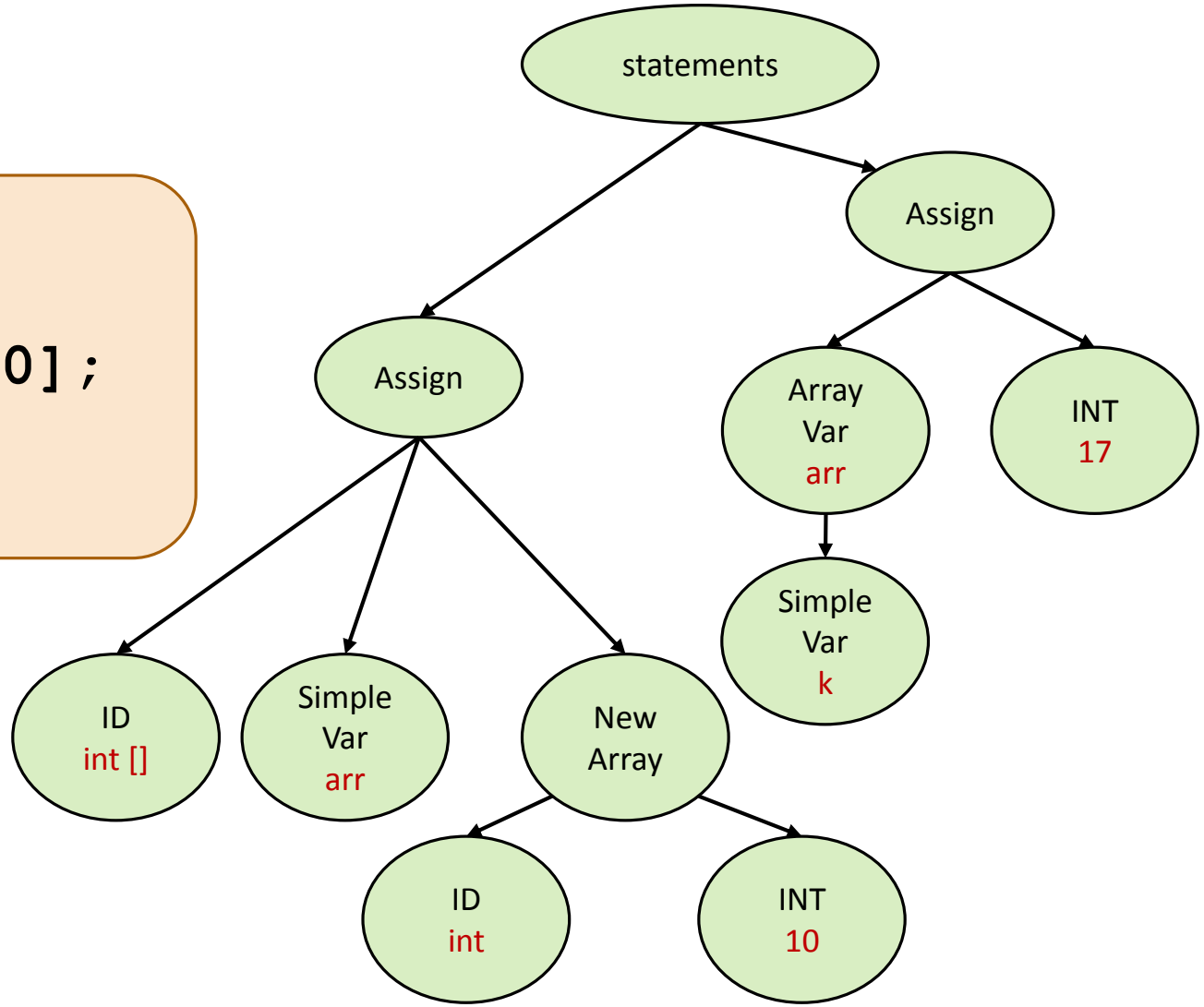
```
void foo(void) {
  int[] arr = new int[“z”];
}
```

Invalid



Arrays

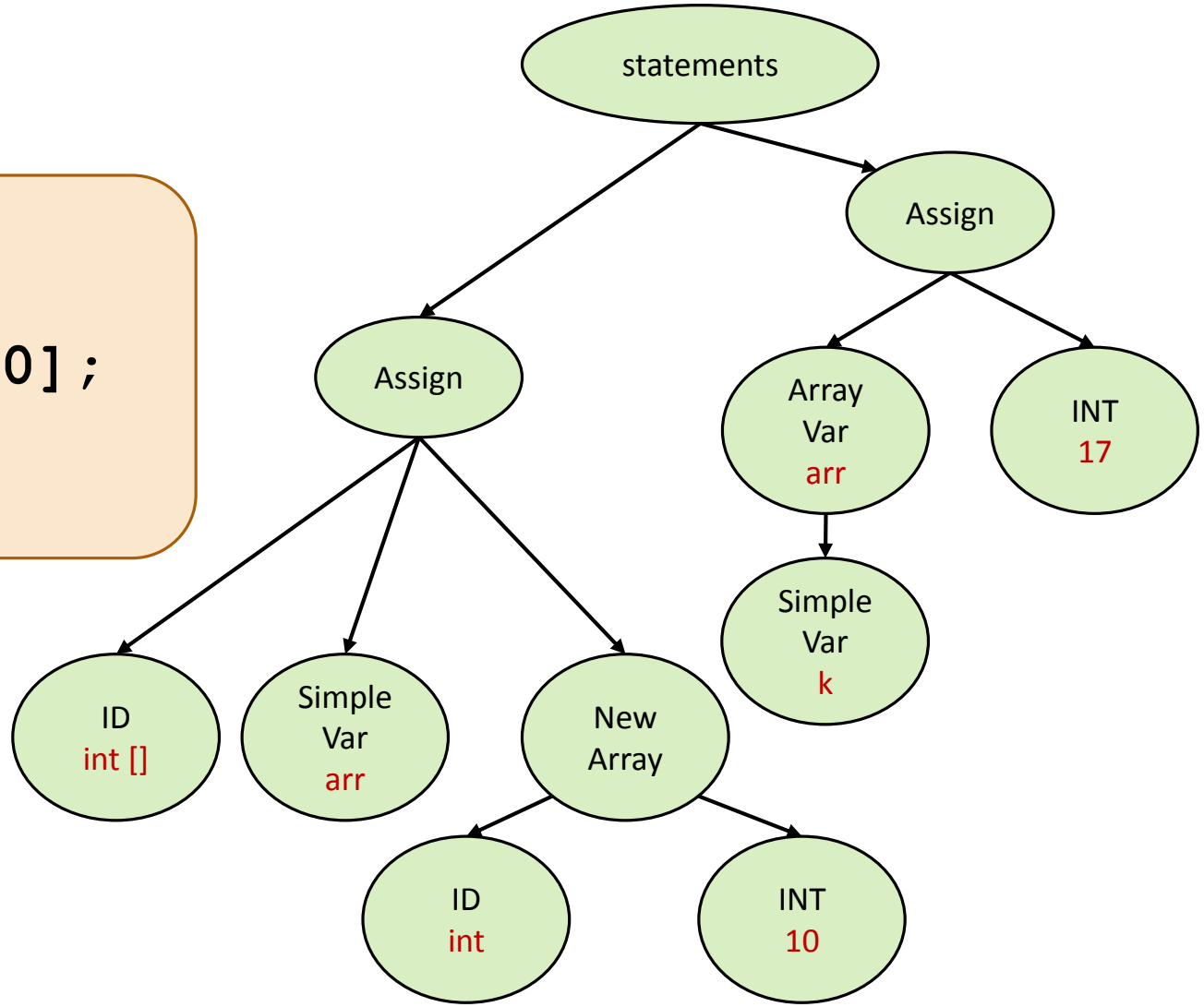
```
void foo(int d) {
   int k = 3;
   int[] arr = new int[10];
   arr[k] = 17;
}
```



Arrays

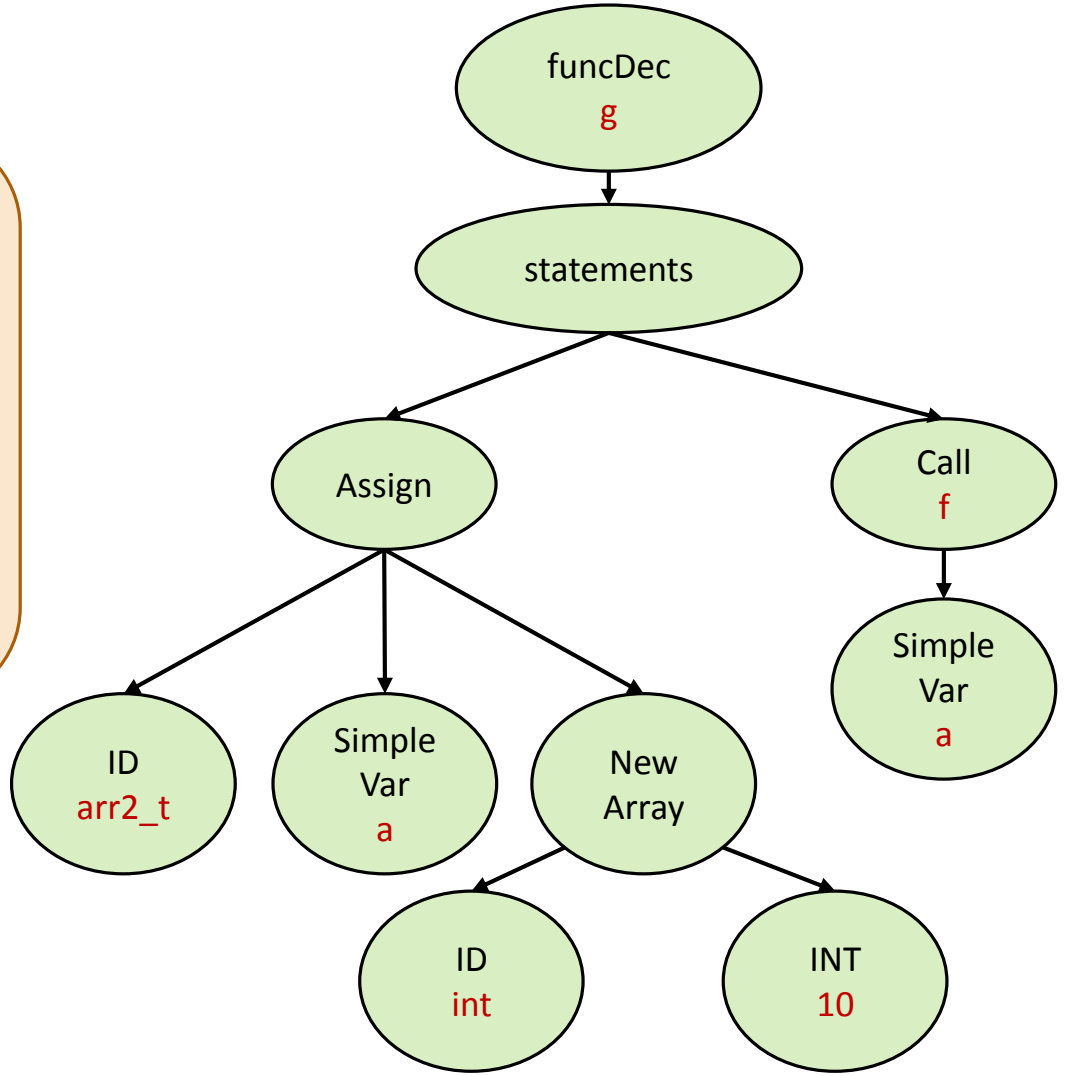
```
void foo(int d) {
   int k = 3;
   int[] arr = new int[10];
   arr[k] = 17;
}
```

Valid



Arrays

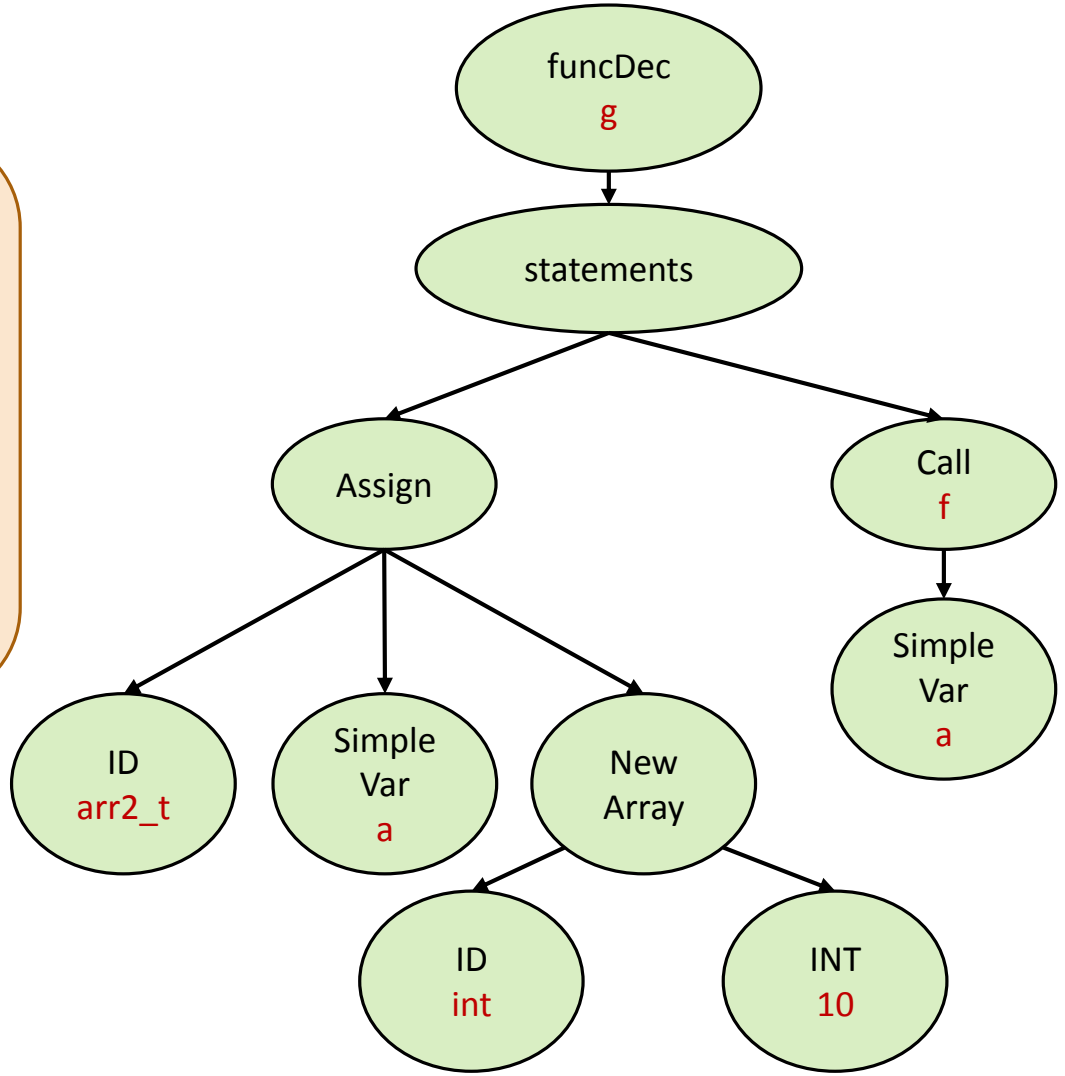
```
typedef int arr1_t[];
typedef int arr2_t[];
void f(arr1_t a) { }
void g() {
  arr2_t a = new int[10];
  f(a);
}
```



Arrays

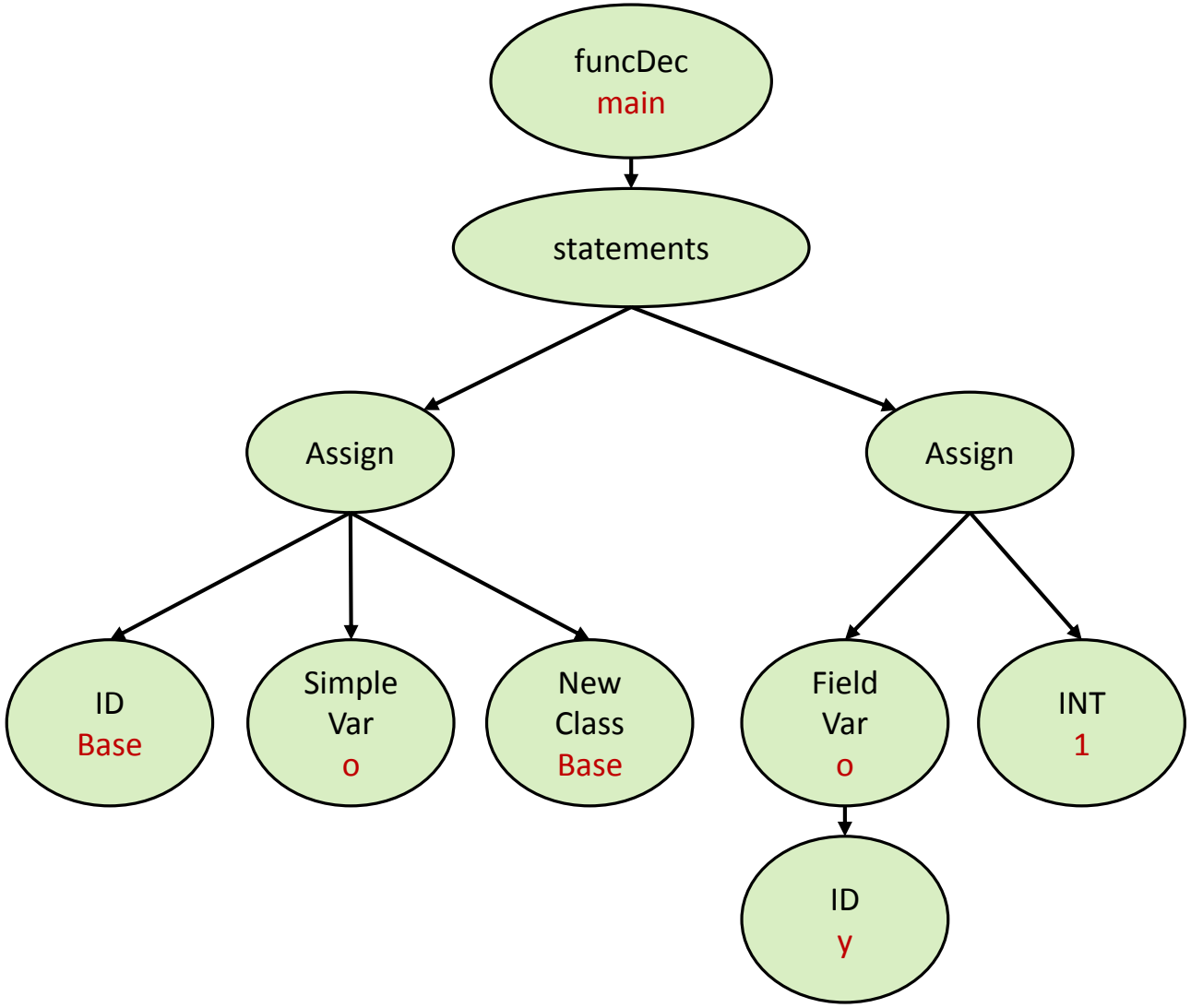
```
typedef int arr1_t[];
typedef int arr2_t[];
void f(arr1_t a) { }
void g() {
  arr2_t a = new int[10];
  f(a);
}
```

Invalid



Classes

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



Classes

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}
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   o.y = 1;
}
```
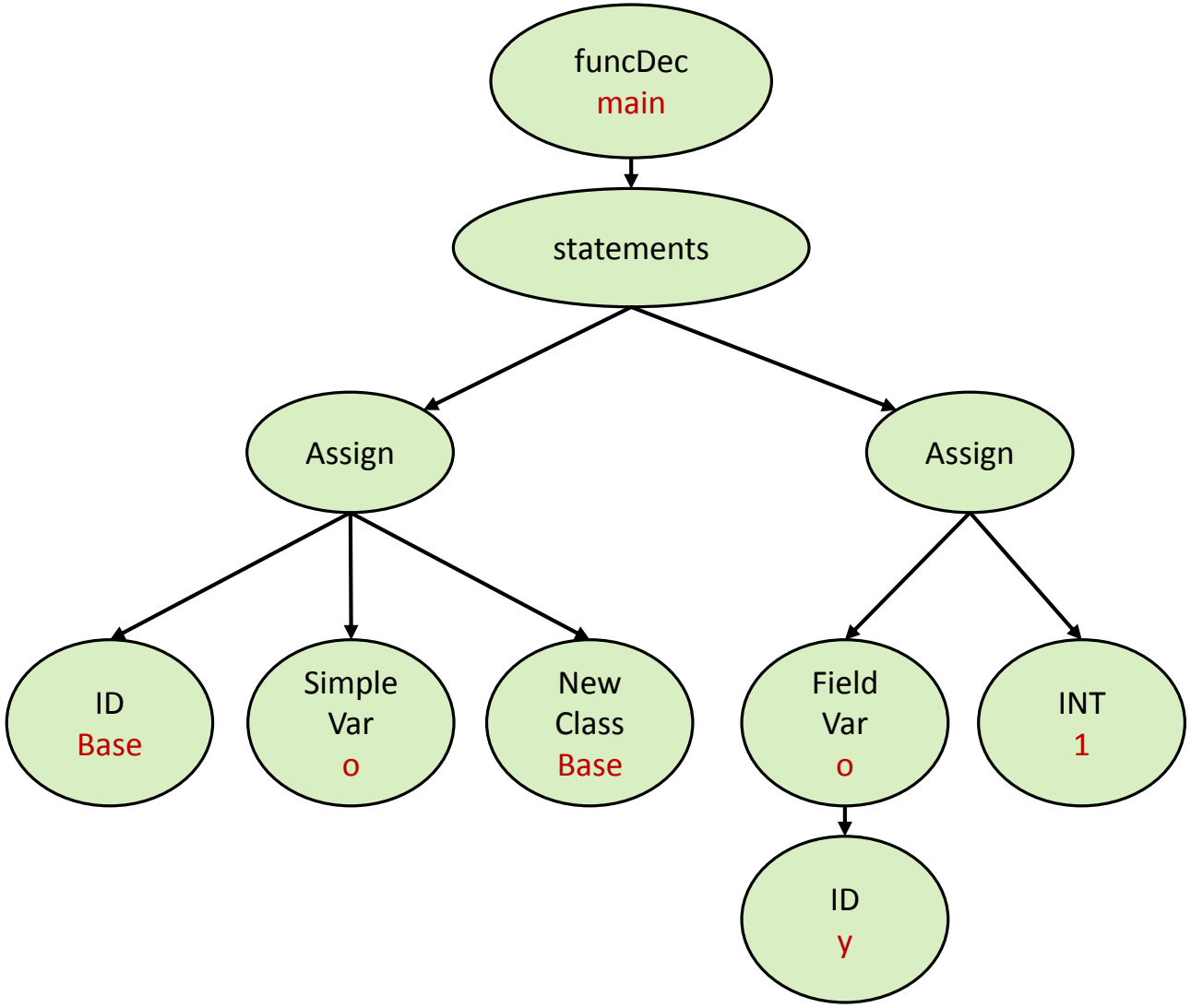

Invalid



Classes

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}
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  o.x = 1;
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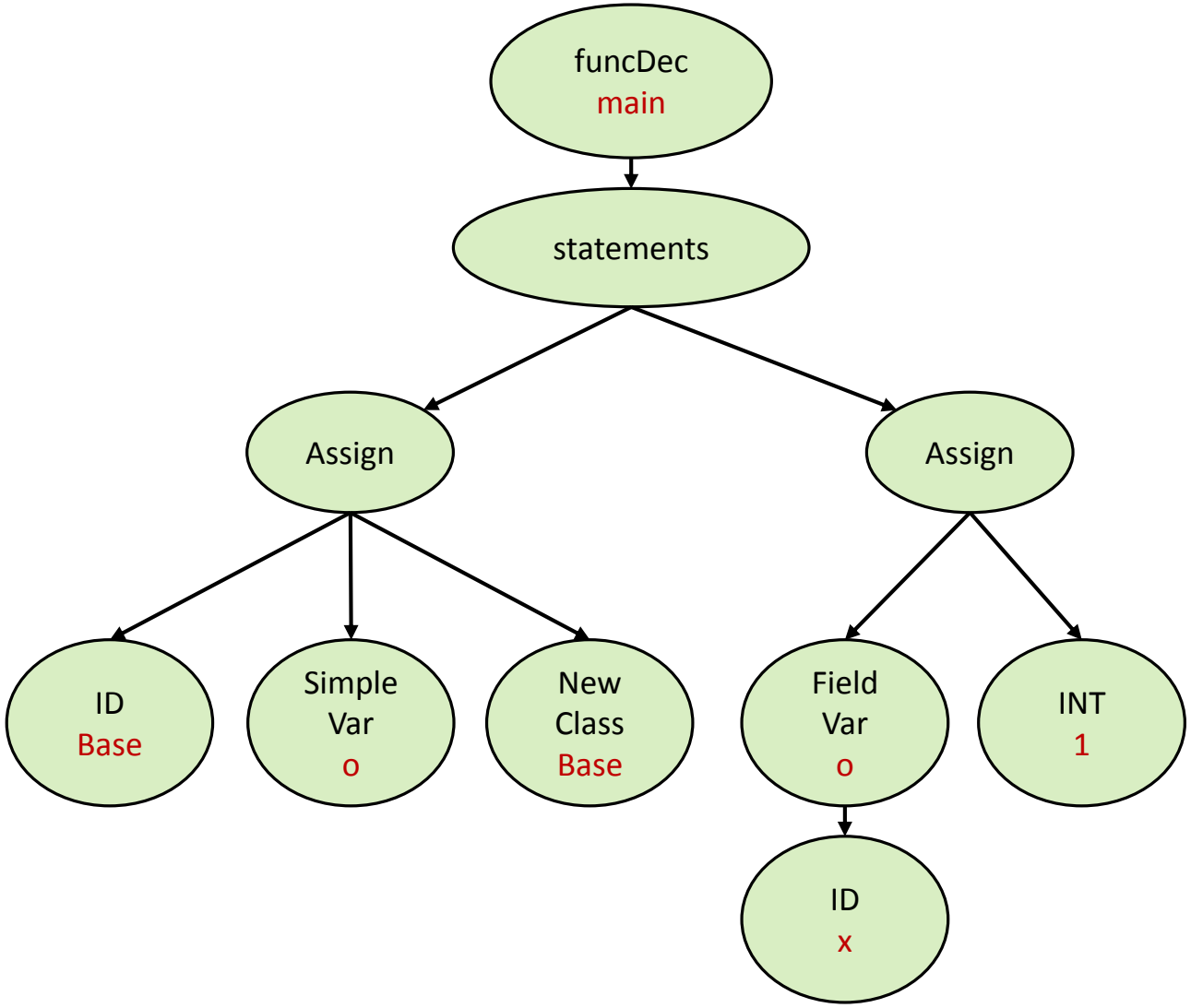
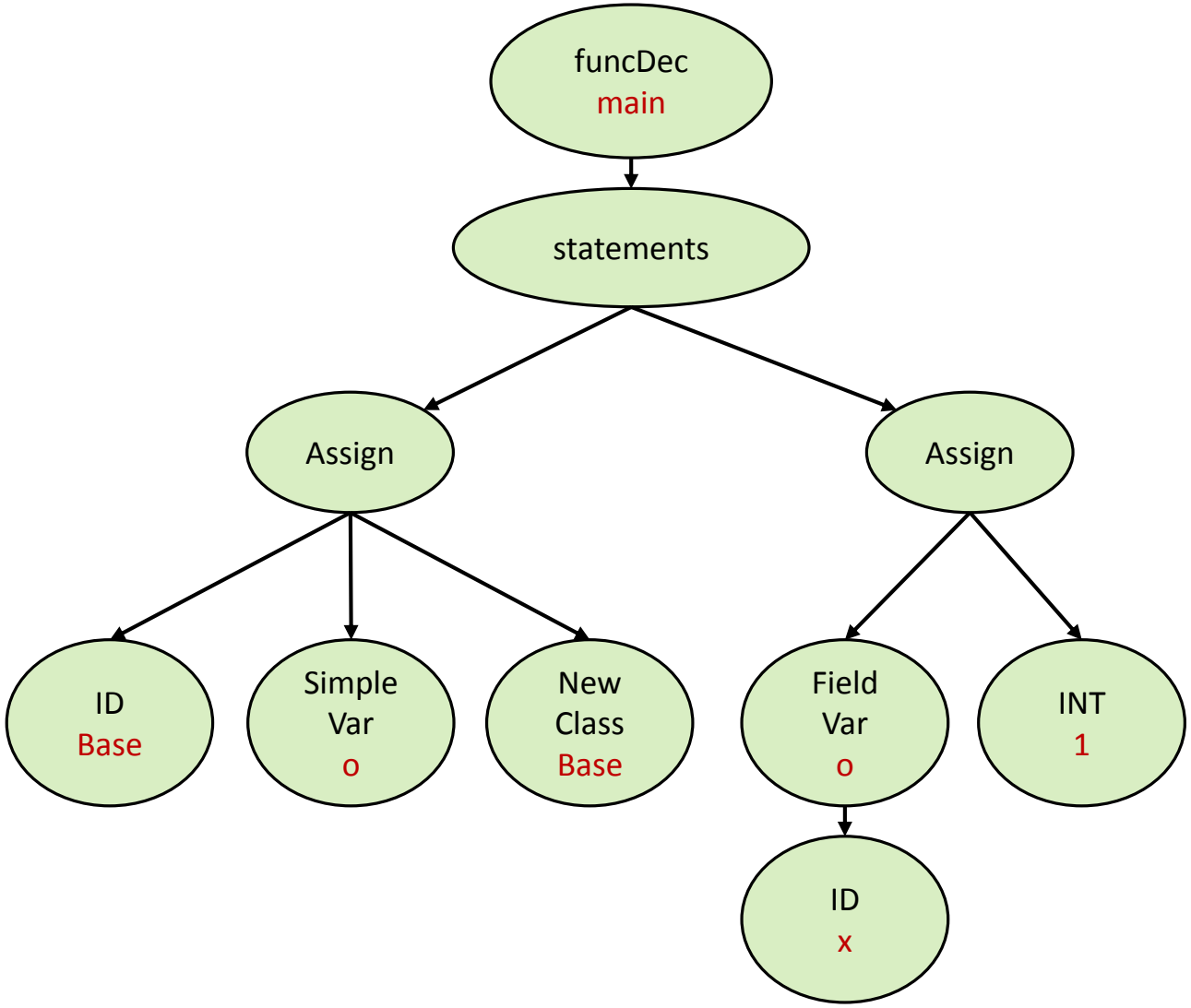


Classes

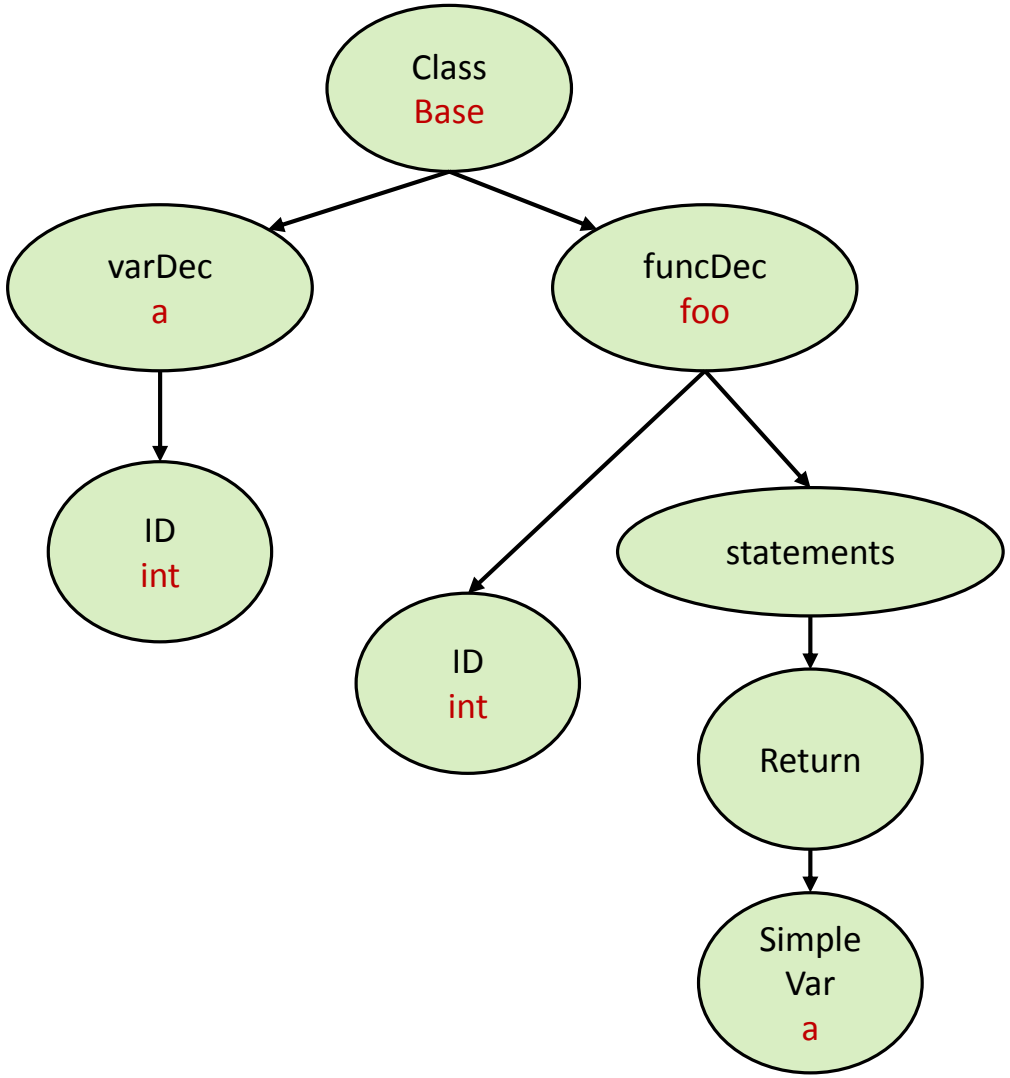
```
class Base {
  int x;
}
void main() {
  Base o = new Base;
  o.x = 1;
}
```

Valid



Classes

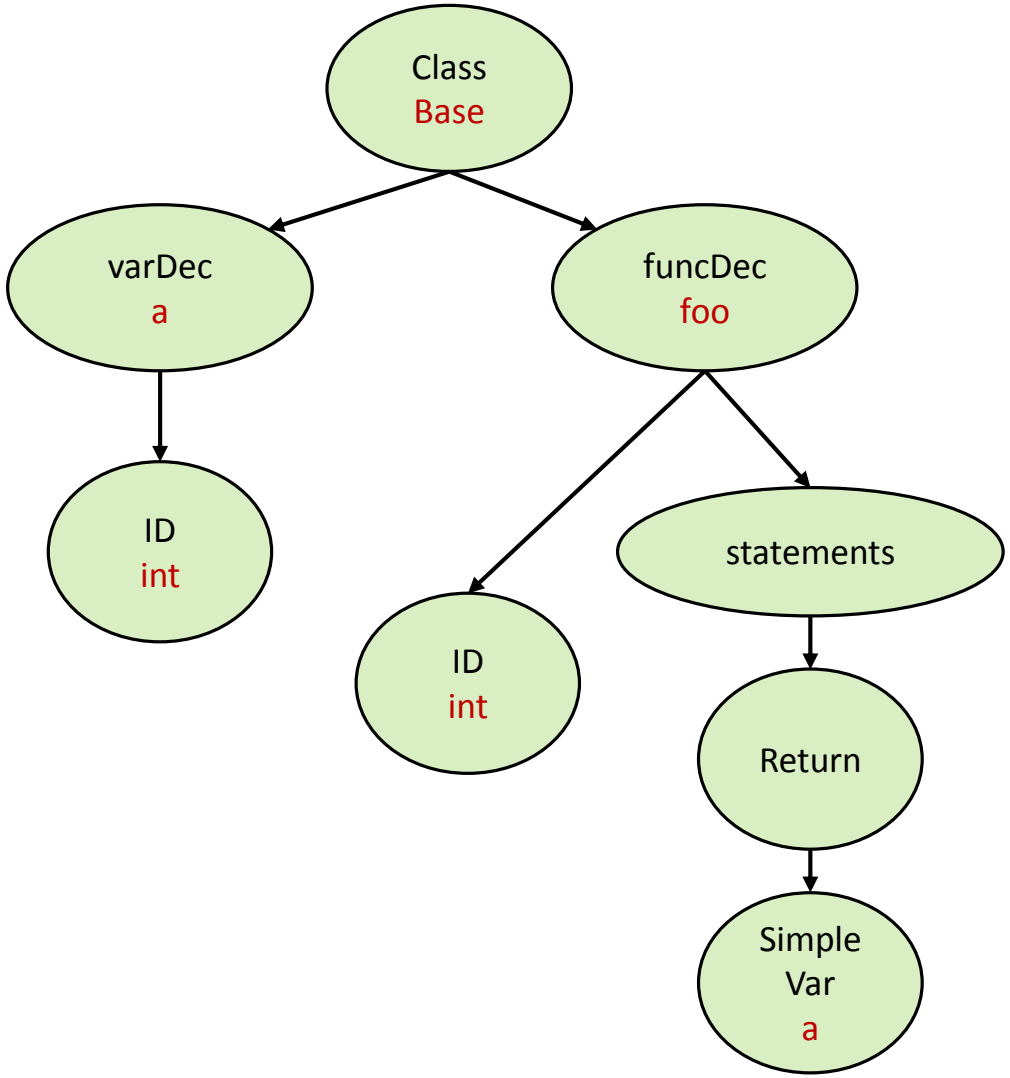
```
class Base {
   int a;
   int foo() {
      return a;
   }
}
```



Classes

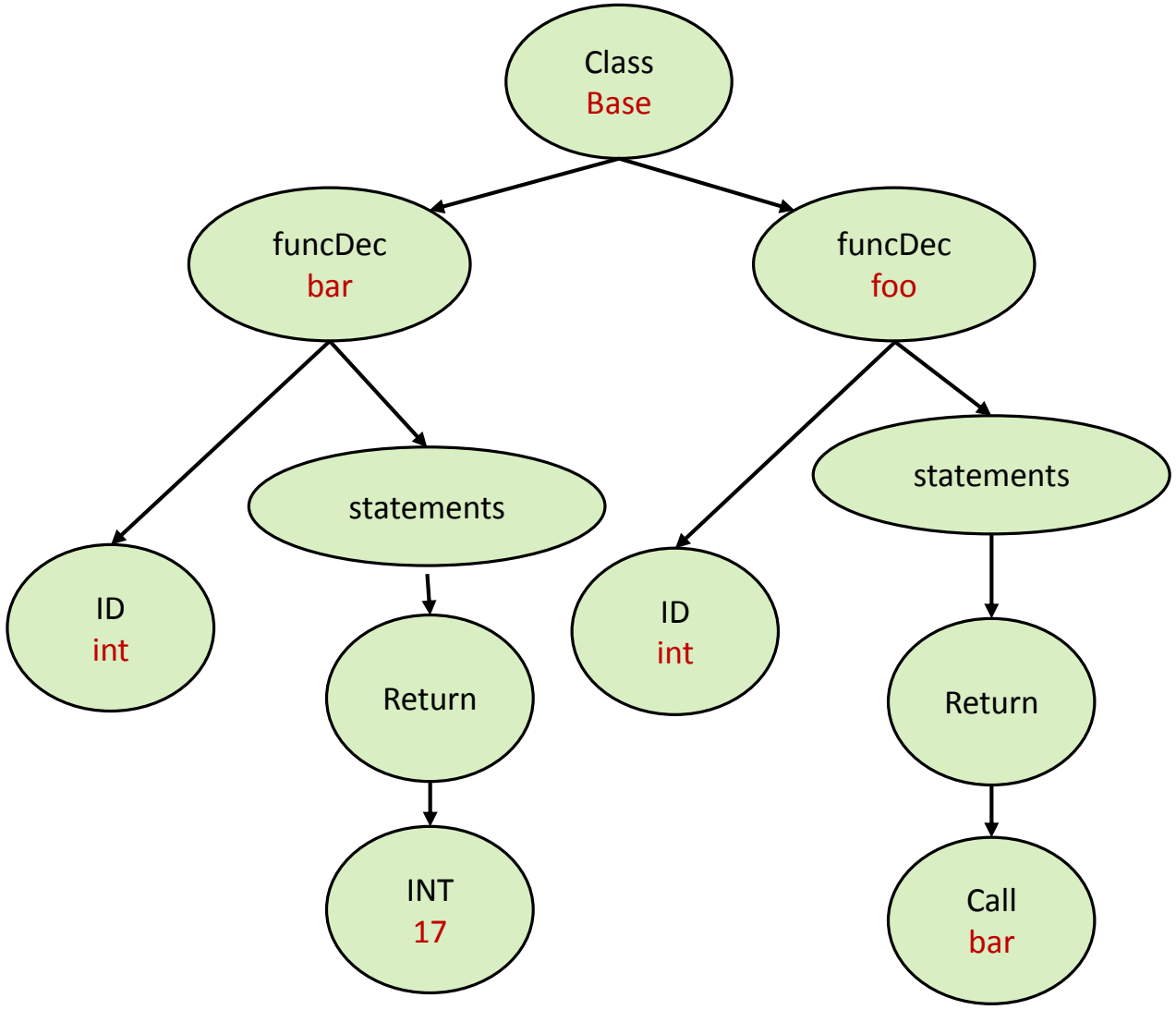
```
class Base {
   int a;
   int foo() {
      return a;
   }
}
```

Valid



Classes

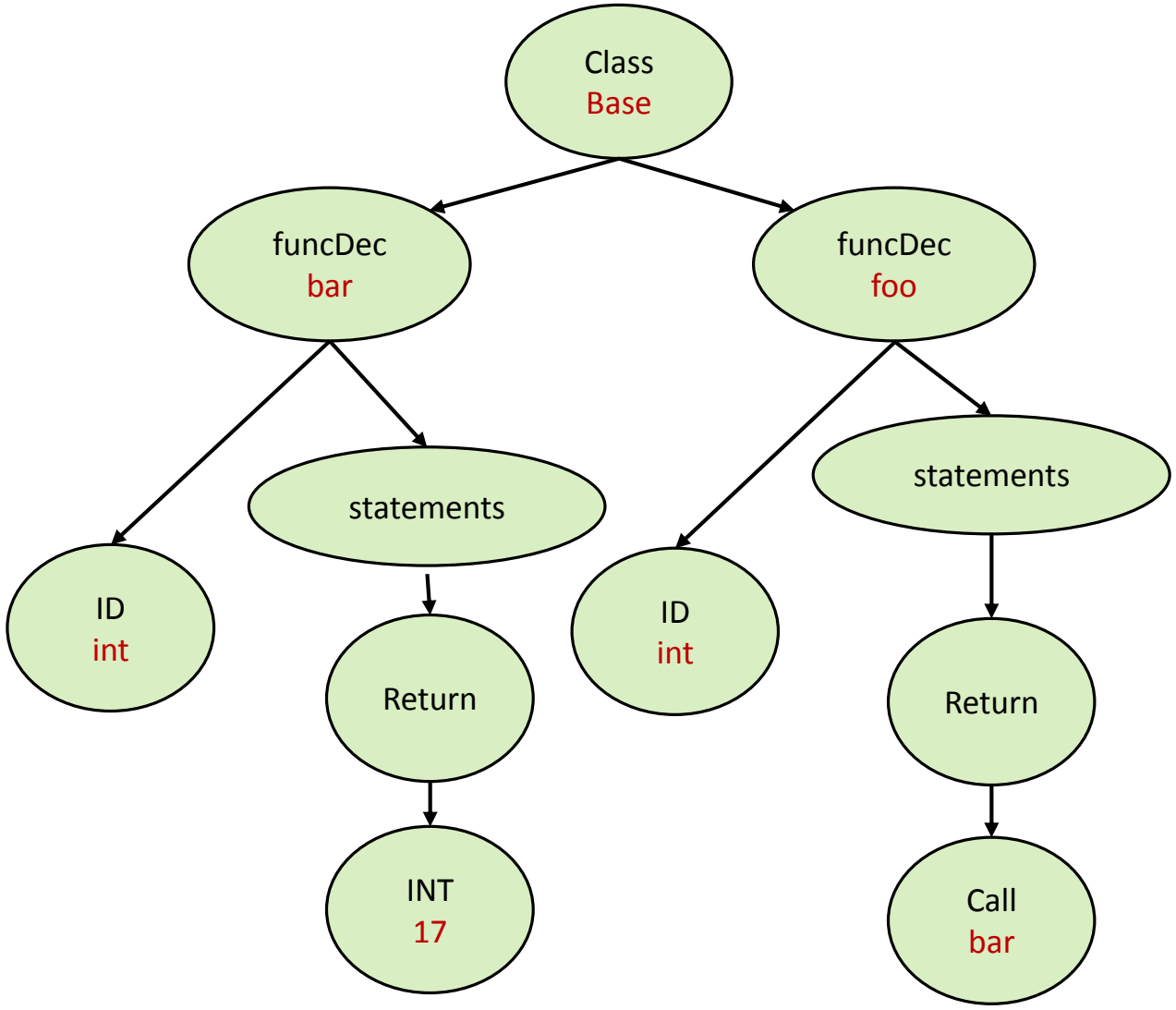
```
class Base {
  int bar() {
    return 17;
  }
  int foo() {
    return bar();
  }
}
```



Classes

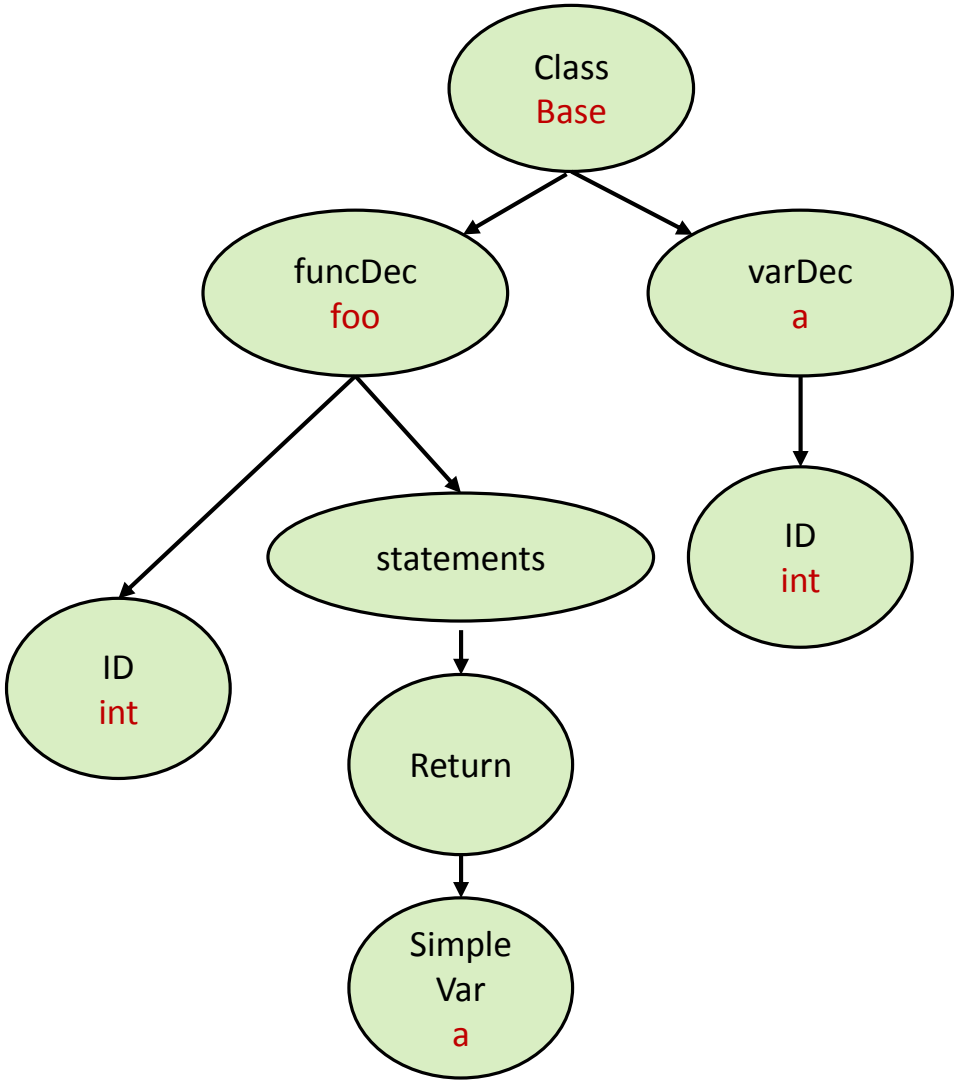
```
class Base {
   int bar() {
      return 17;
   }
   int foo() {
      return bar();
   }
}
```

Valid



Classes

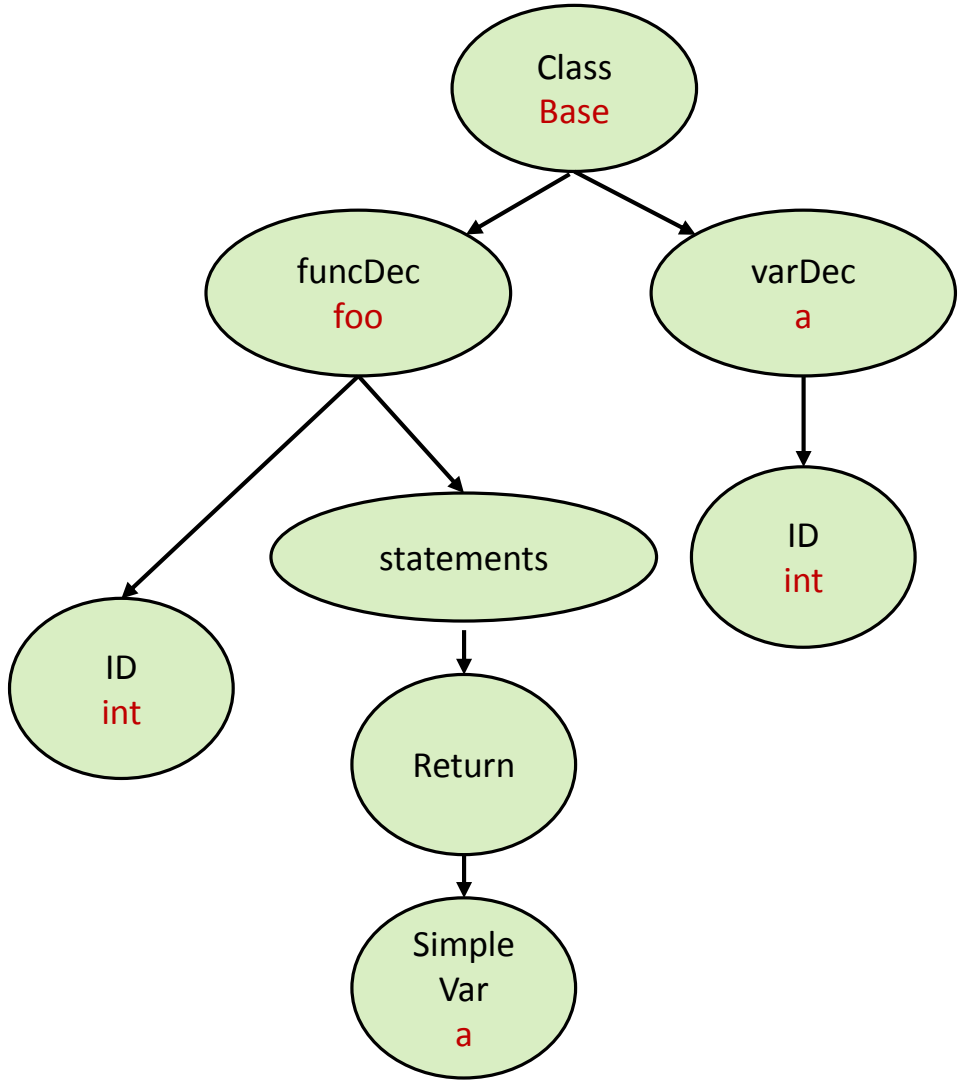
```
class Base {
  int foo() {
    return a;
  }
  int a;
}
```



Classes

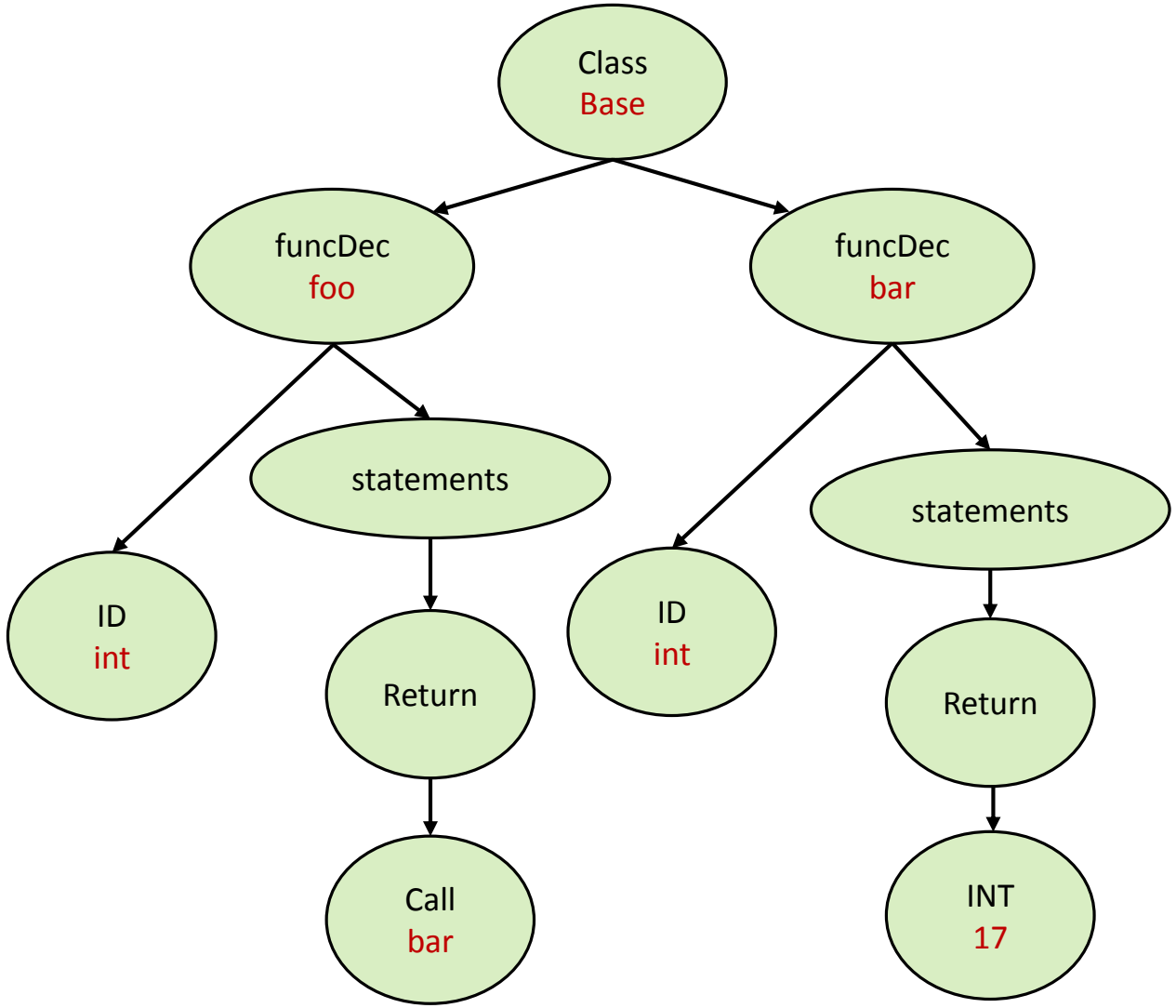
```
class Base {
   int foo() {
      return a;
   }
   int a;
}
```

Invalid



Classes

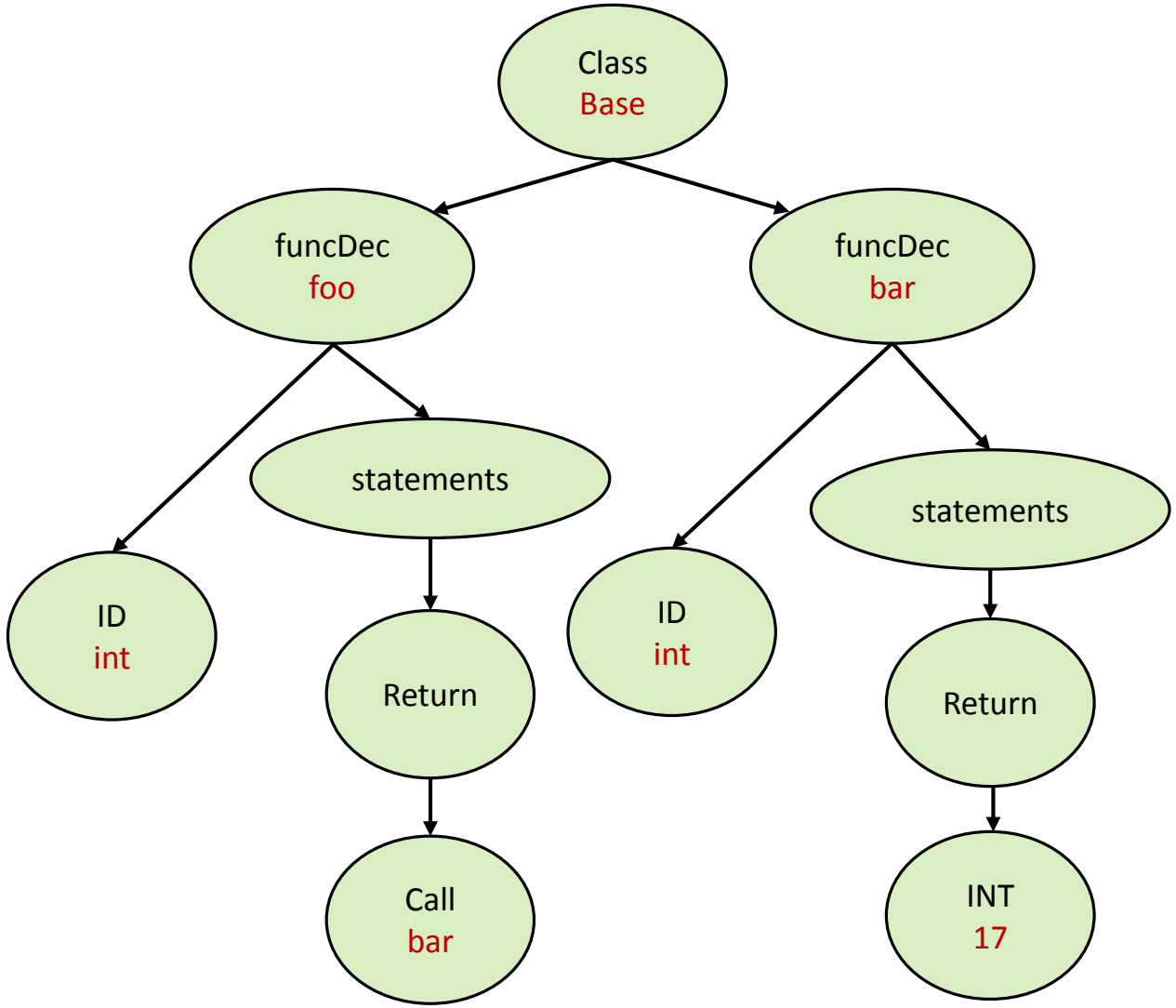
```
class Base {
  int foo() {
    return bar();
  }
  int bar() {
    return 17;
  }
}
```



Classes

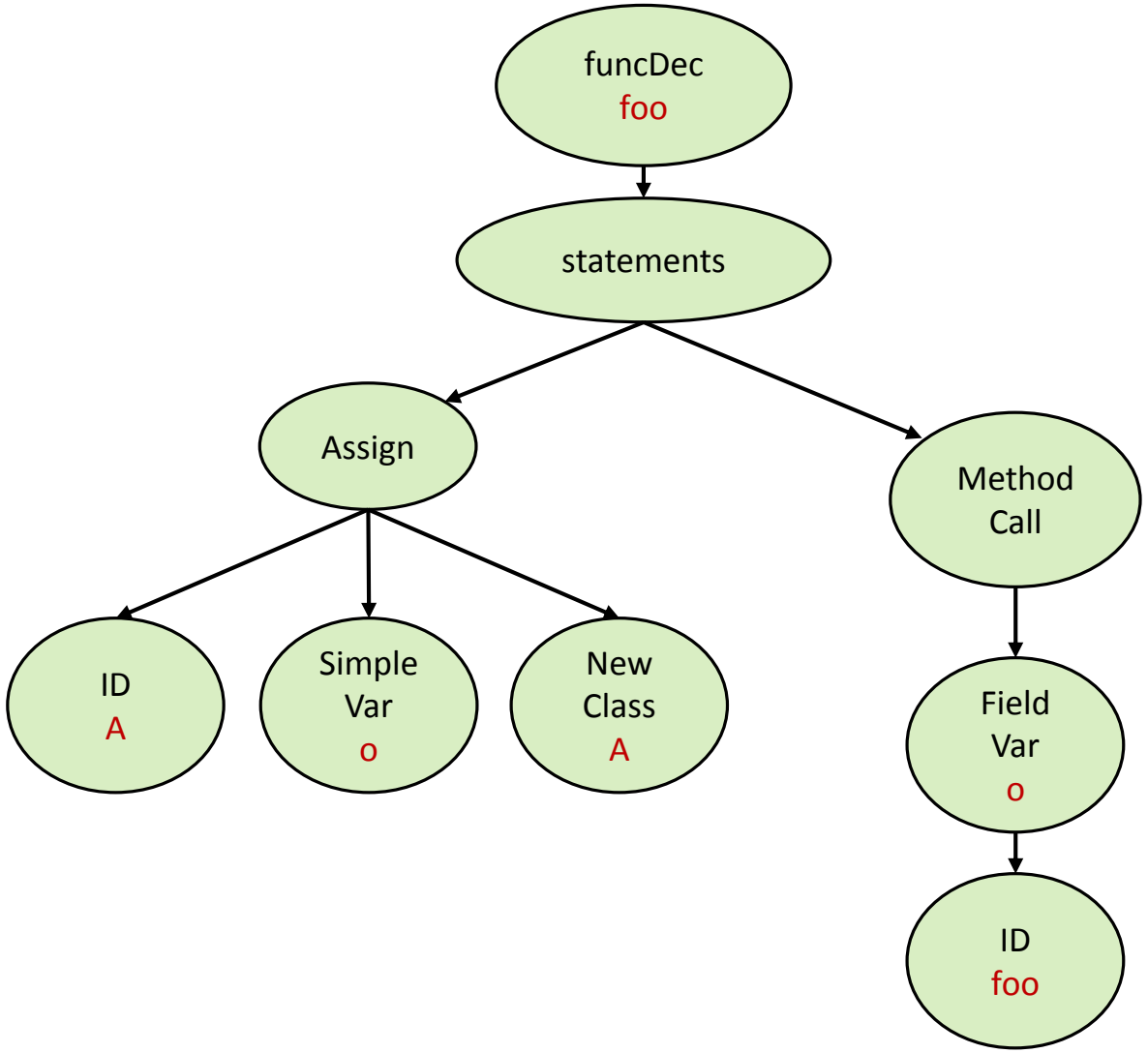
```
class Base {
   int foo() {
      return bar();
   }
   int bar() {
      return 17;
   }
}
```

Invalid



Classes

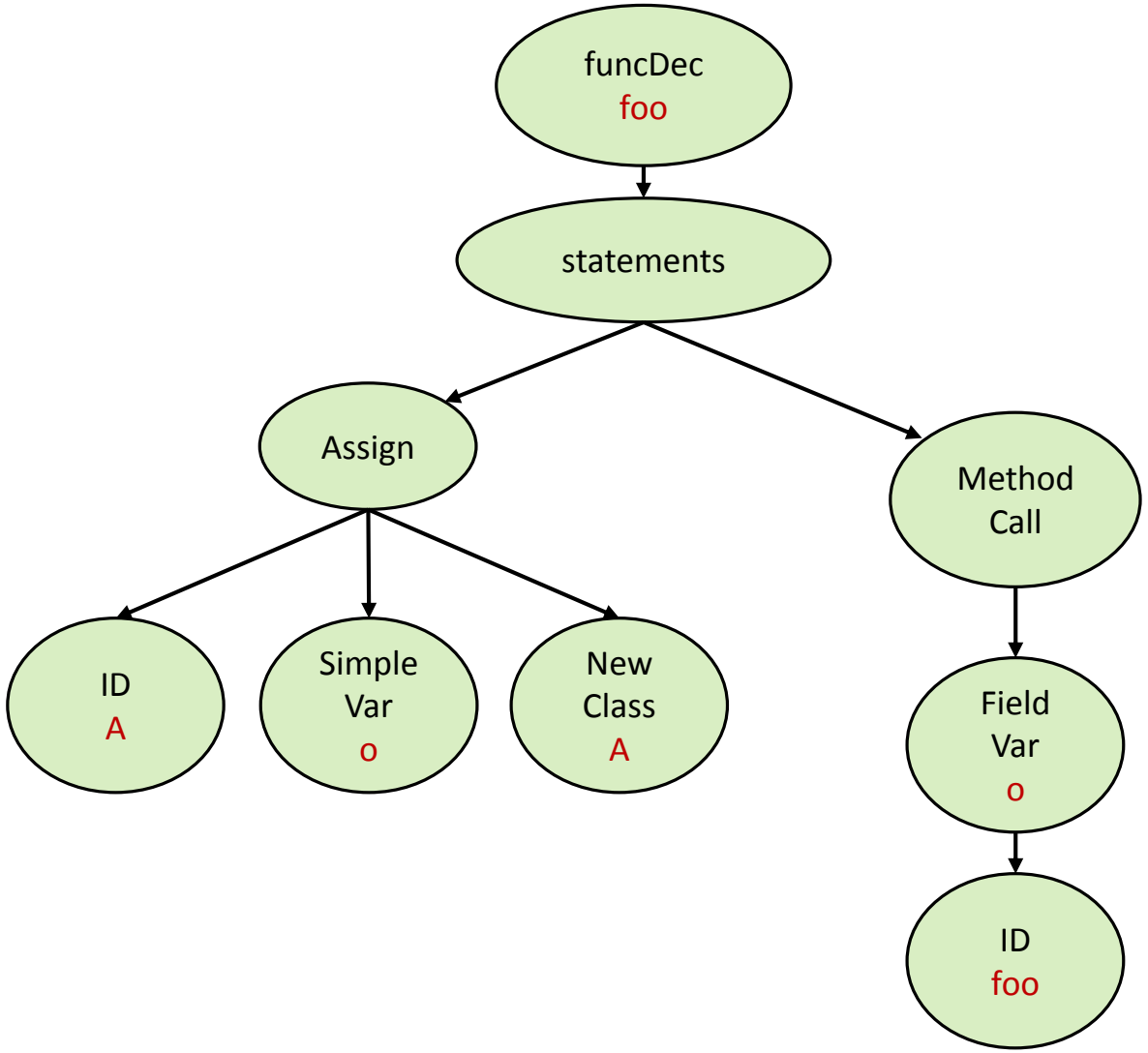
```
class A {
  void foo() {
    A o = new A;
    o.foo();
  }
}
```



Classes

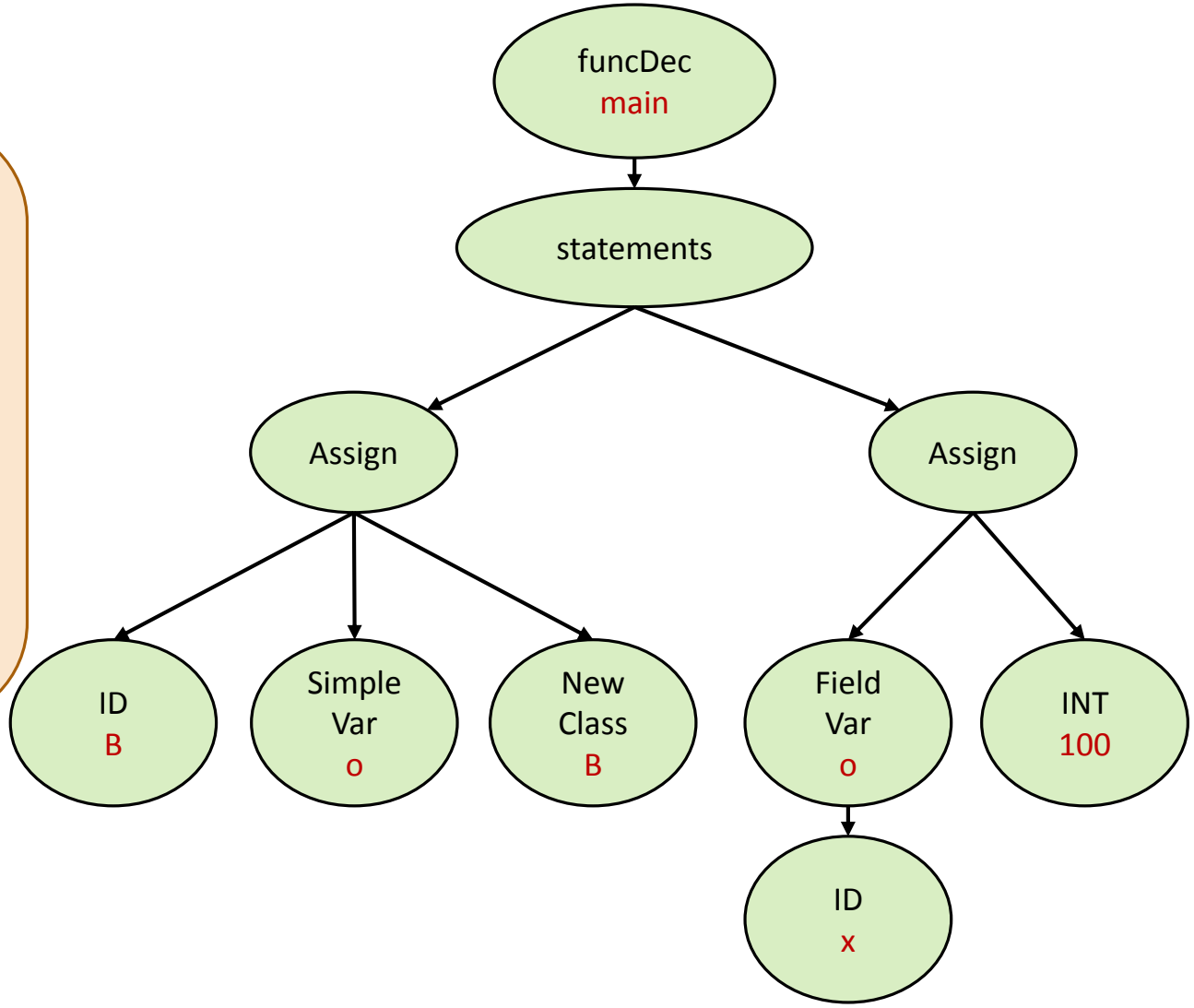
```
class A {
  void foo() {
    A o = new A;
    o.foo();
  }
}
```

Valid



Inheritance

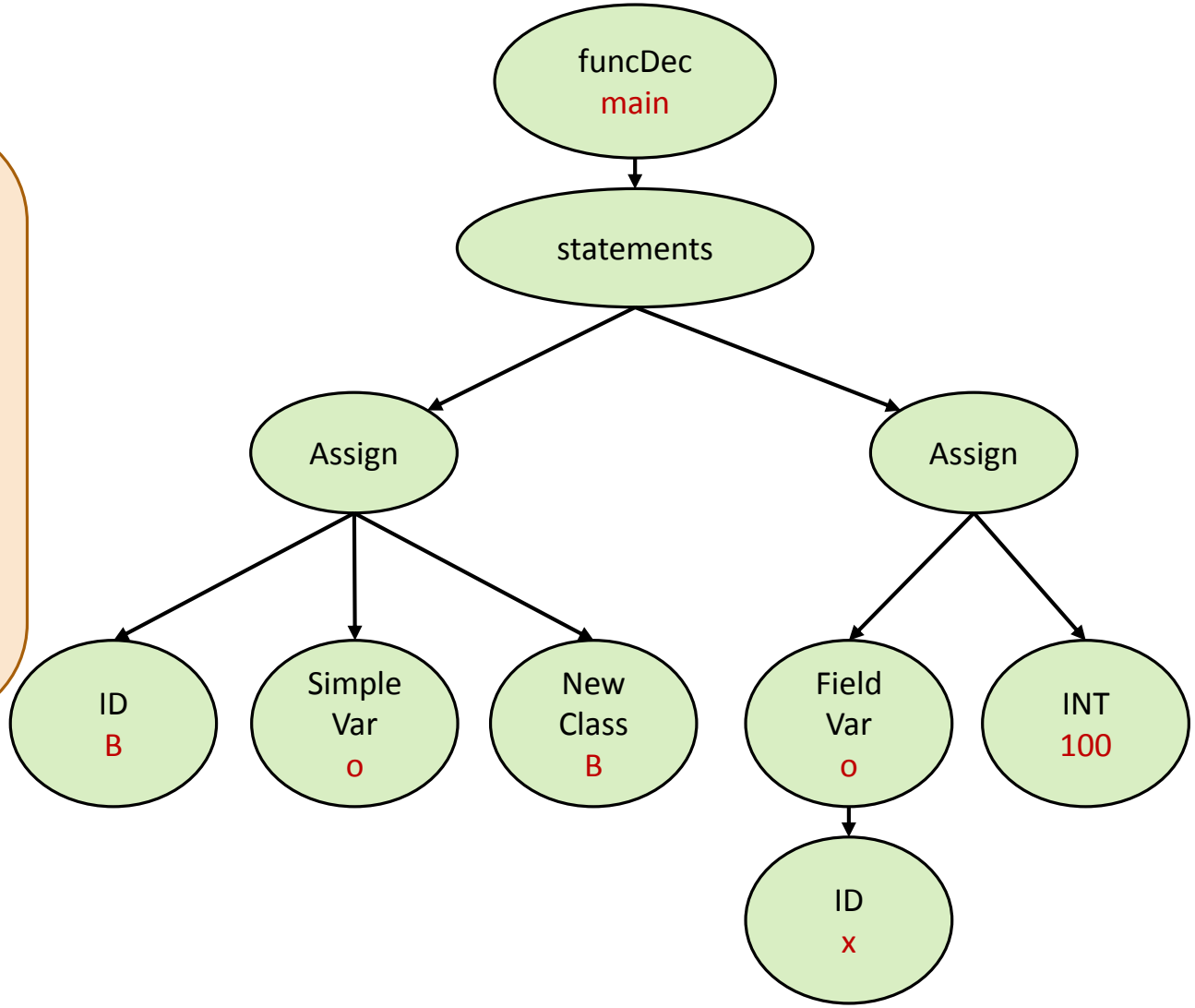
```
class A {
   int x;
}
class B extends A { }
void main() {
   B o = new B;
   o.x = 100;
}
```



Inheritance

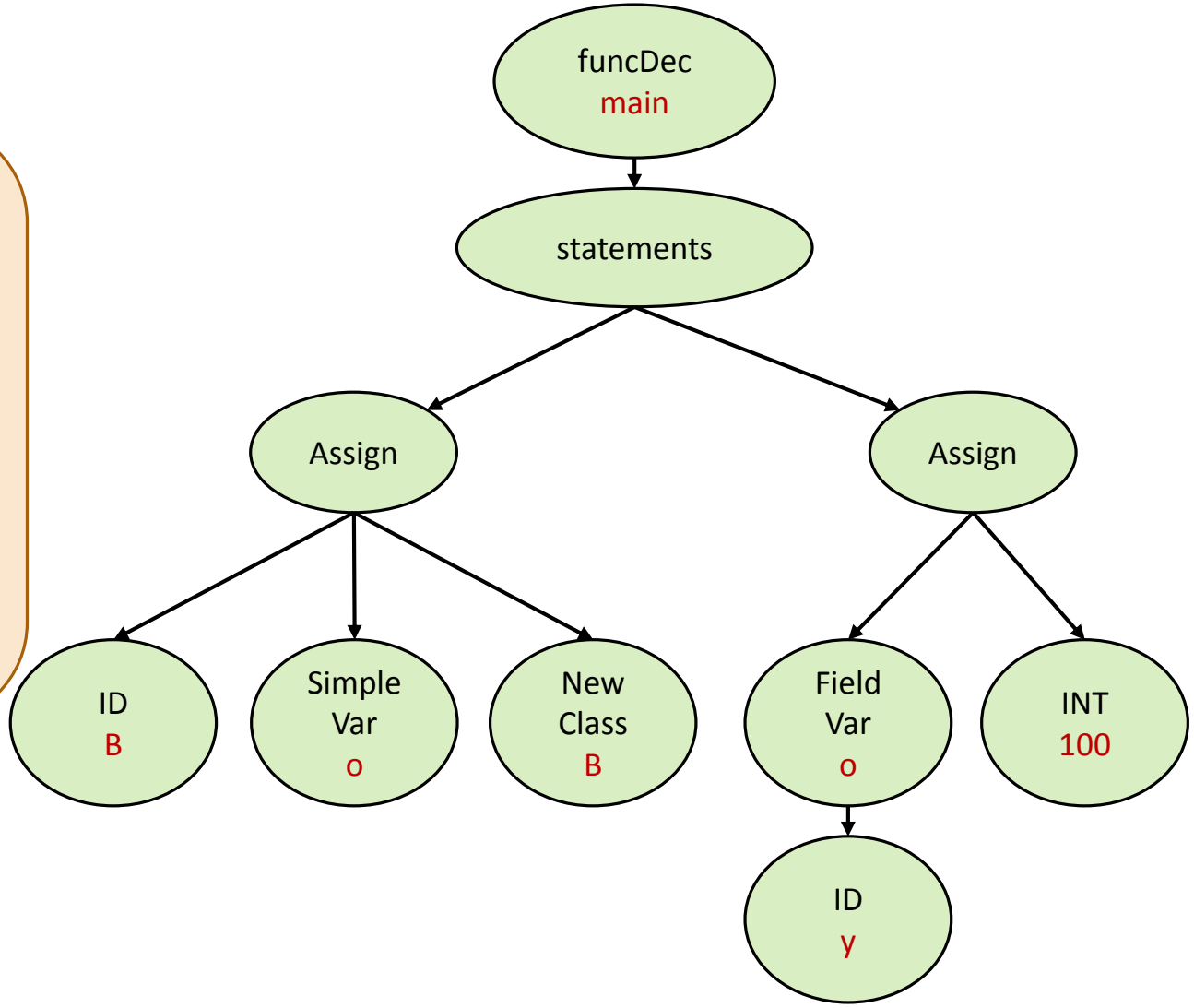
```
class A {
   int x;
}
class B extends A { }
void main() {
   B o = new B;
   o.x = 100;
}
```

Valid



Inheritance

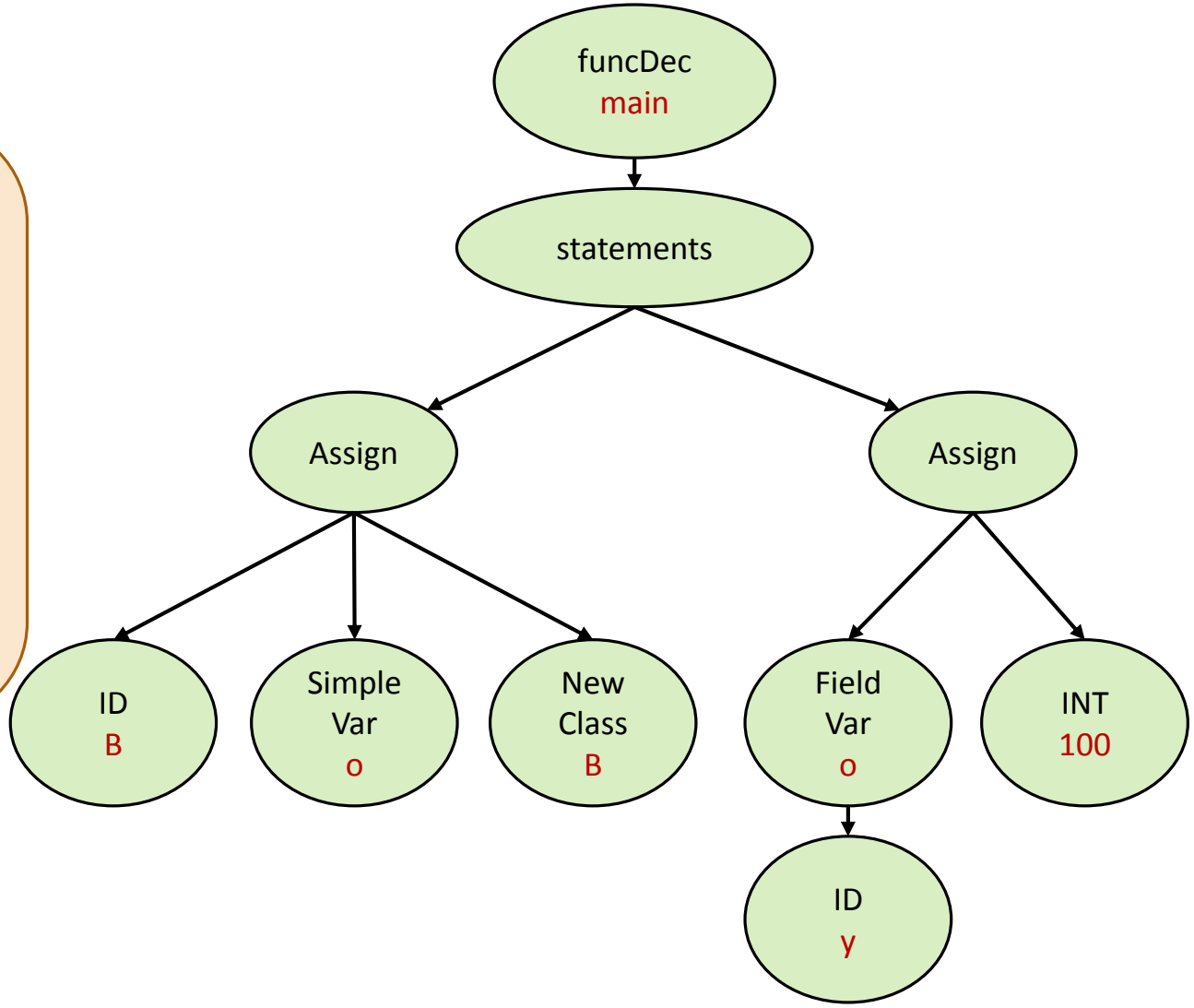
```
class A {
   int x;
}
class B extends A { }
void main() {
   B o = new B;
   o.y = 100;
}
```



Inheritance

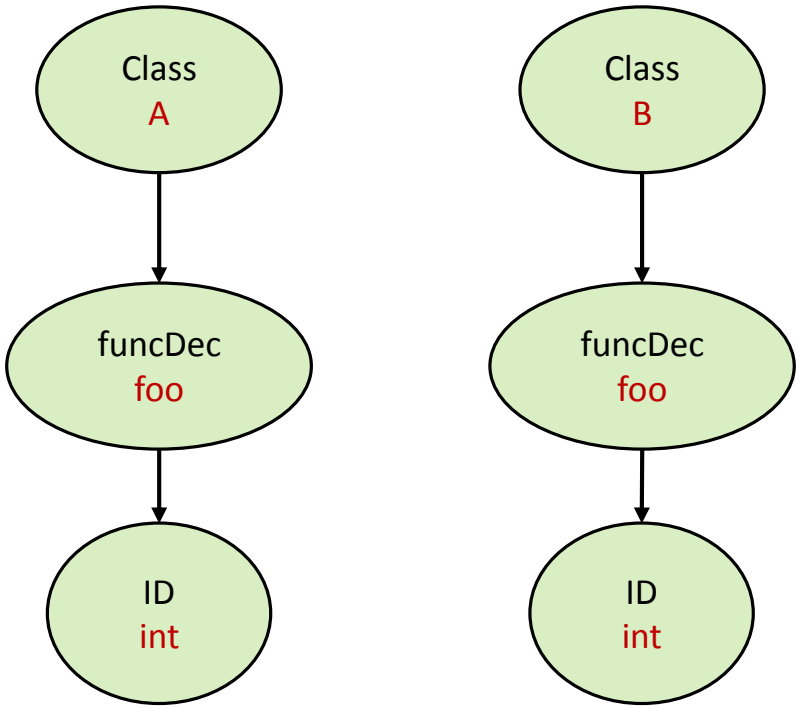
```
class A {
   int x;
}
class B extends A { }
void main() {
   B o = new B;
   o.y = 100;
}
```

Invalid



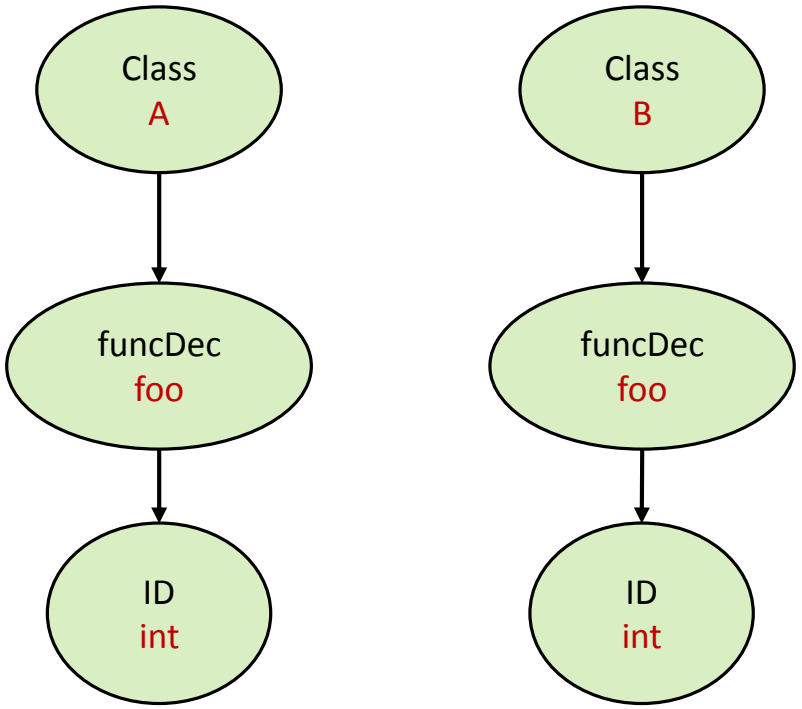
Inheritance

```
class A {
   int foo() {
      return 17;
   }
}
class B extends A {
   int foo() {
      return 18;
   }
}
```



Inheritance

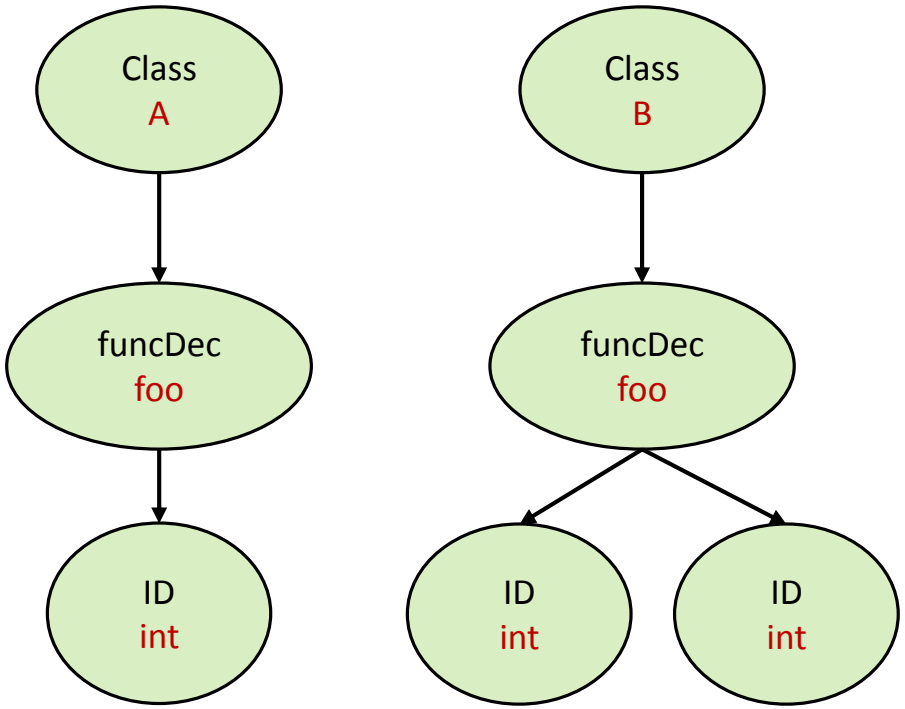
```
class A {
   int foo() {
      return 17;
   }
}
class B extends A {
   int foo() {
      return 18;
   }
}
```



Valid

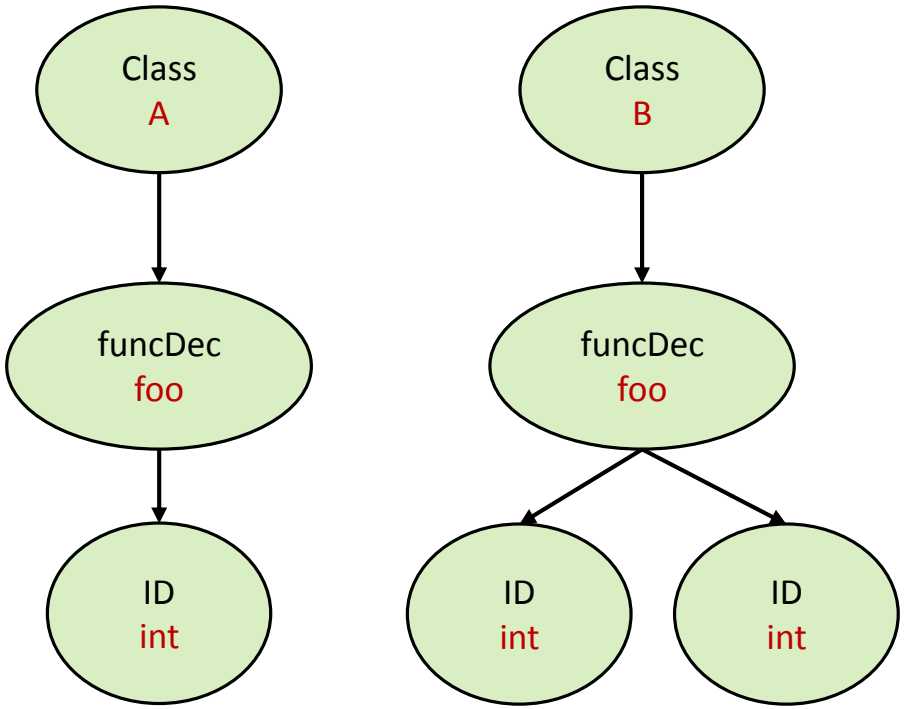
Inheritance

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



Inheritance

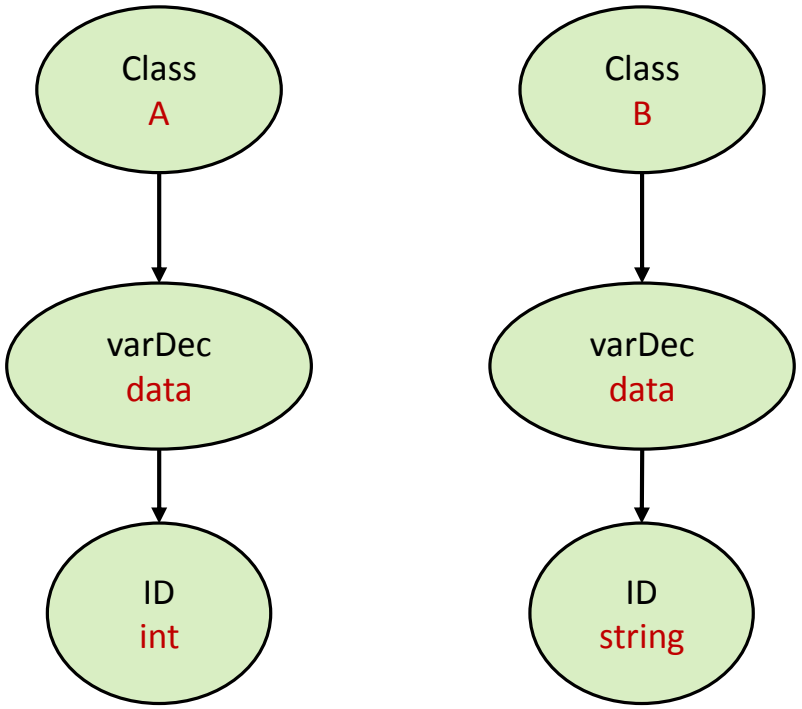
```
class A {
   int foo() {
      return 17;
   }
}
class B extends A {
   int foo(int x) {
      return x + 1;
   }
}
```



Invalid

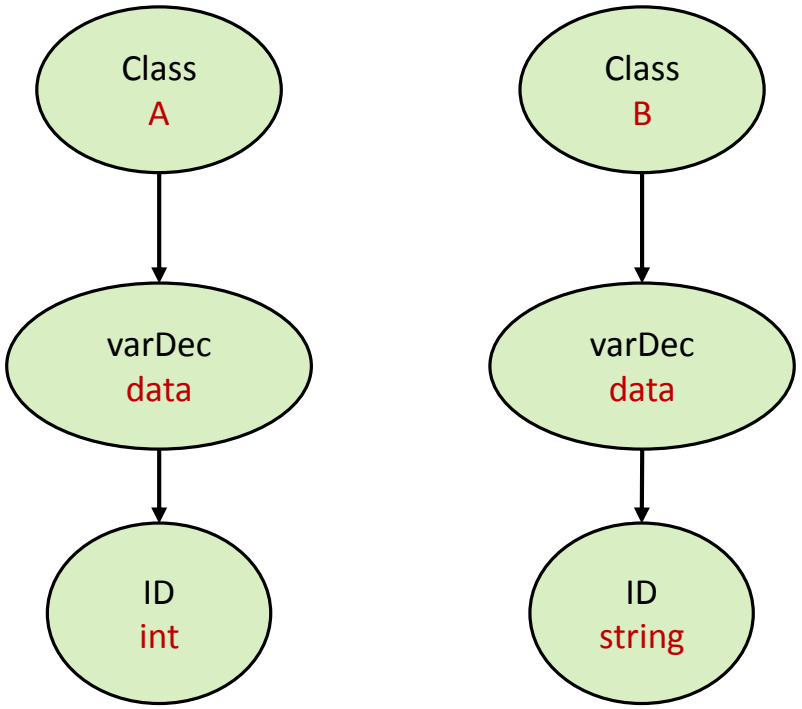
Inheritance

```
class A {
   int data;
}
class B extends A {
   string data;
}
```



Inheritance

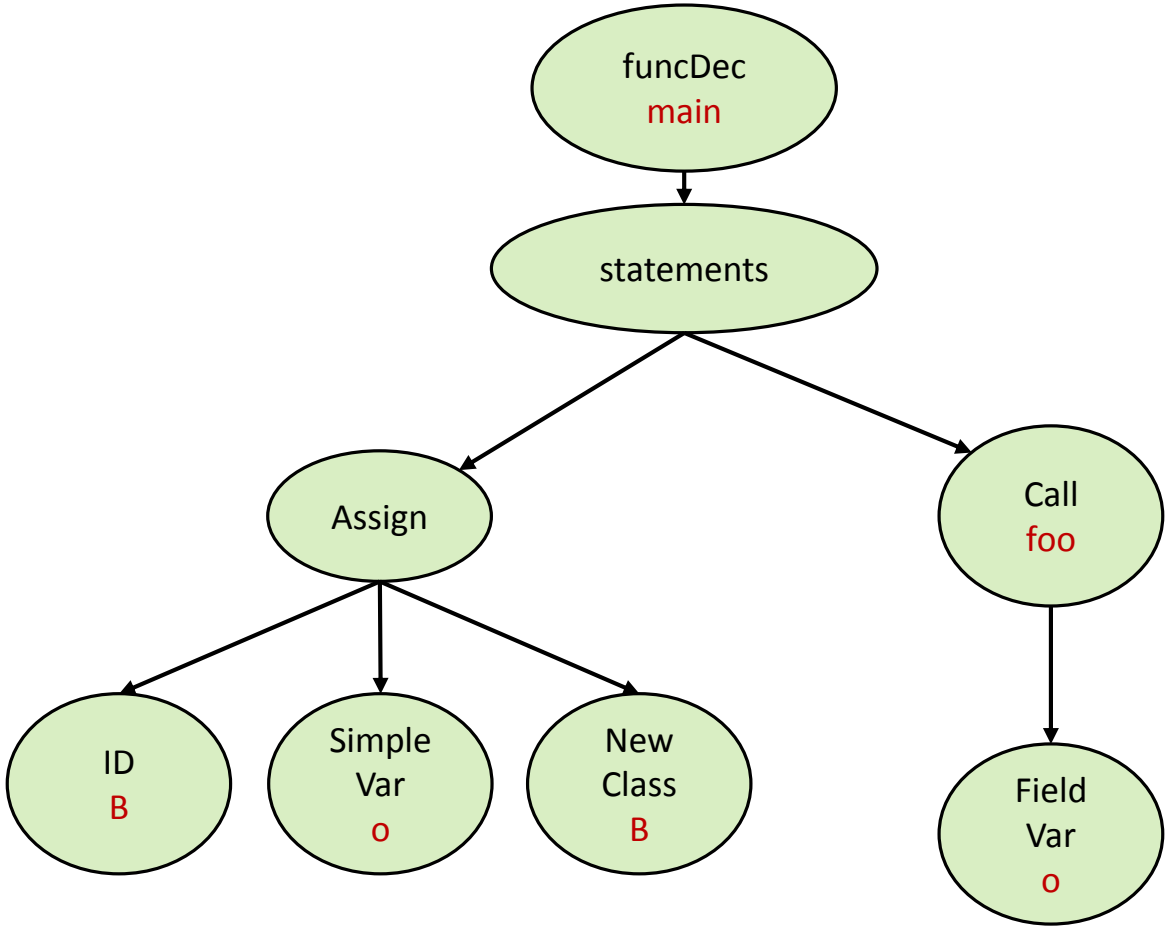
```
class A {
   int data;
}
class B extends A {
   string data;
}
```



Invalid

Inheritance

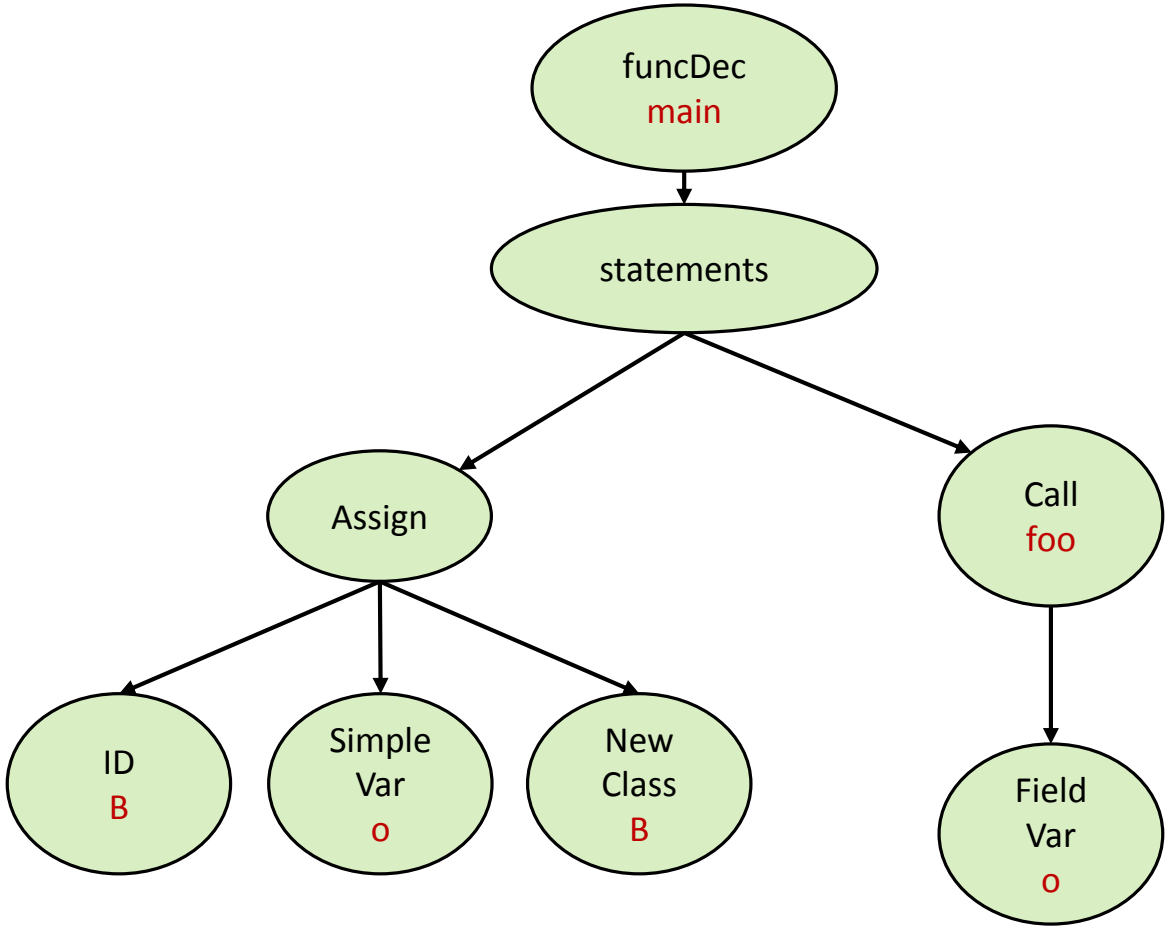
```
class A { }
class B extends A { }
void foo(A a) { }
void main() {
  B o = new B;
  foo(o);
}
```



Inheritance

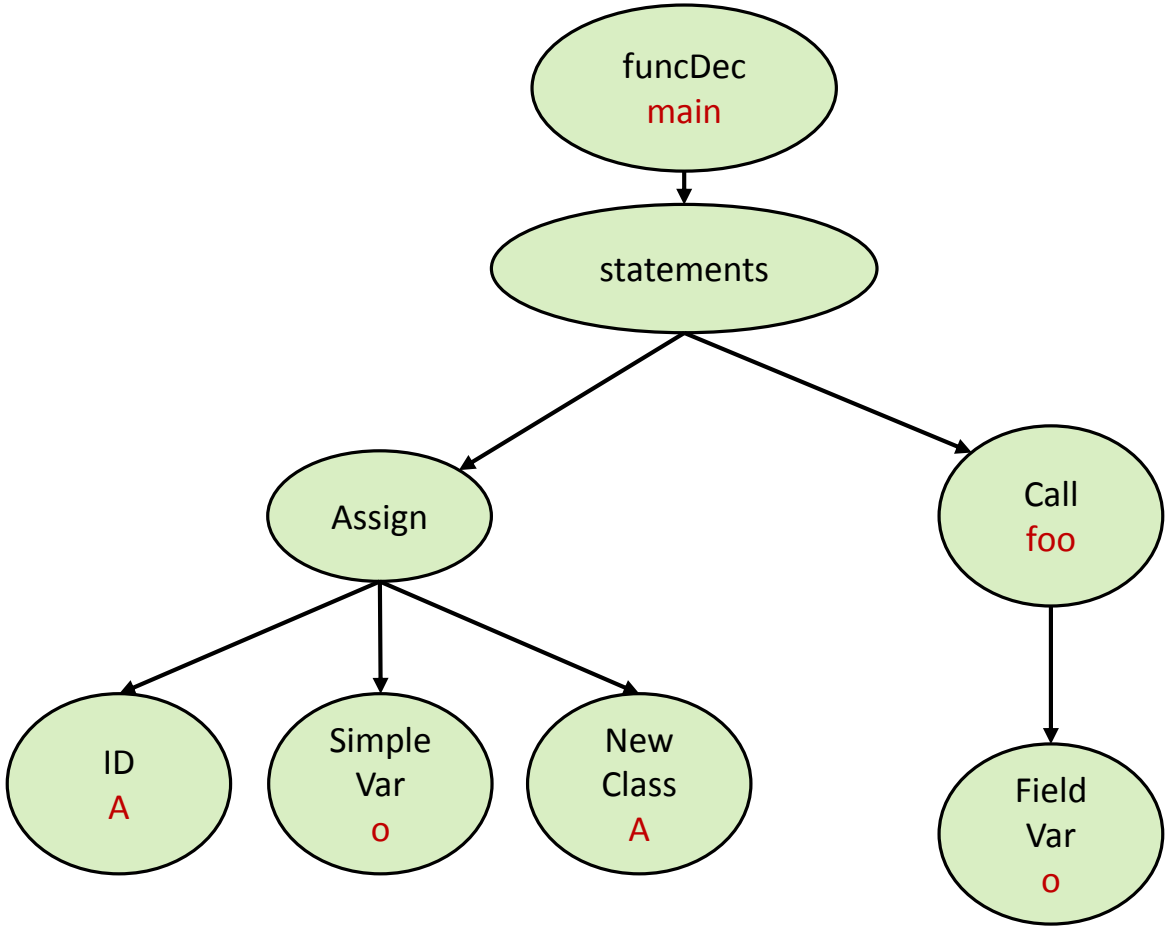
```
class A { }
class B extends A { }
void foo(A a) { }
void main() {
  B o = new B;
  foo(o);
}
```

Valid



Inheritance

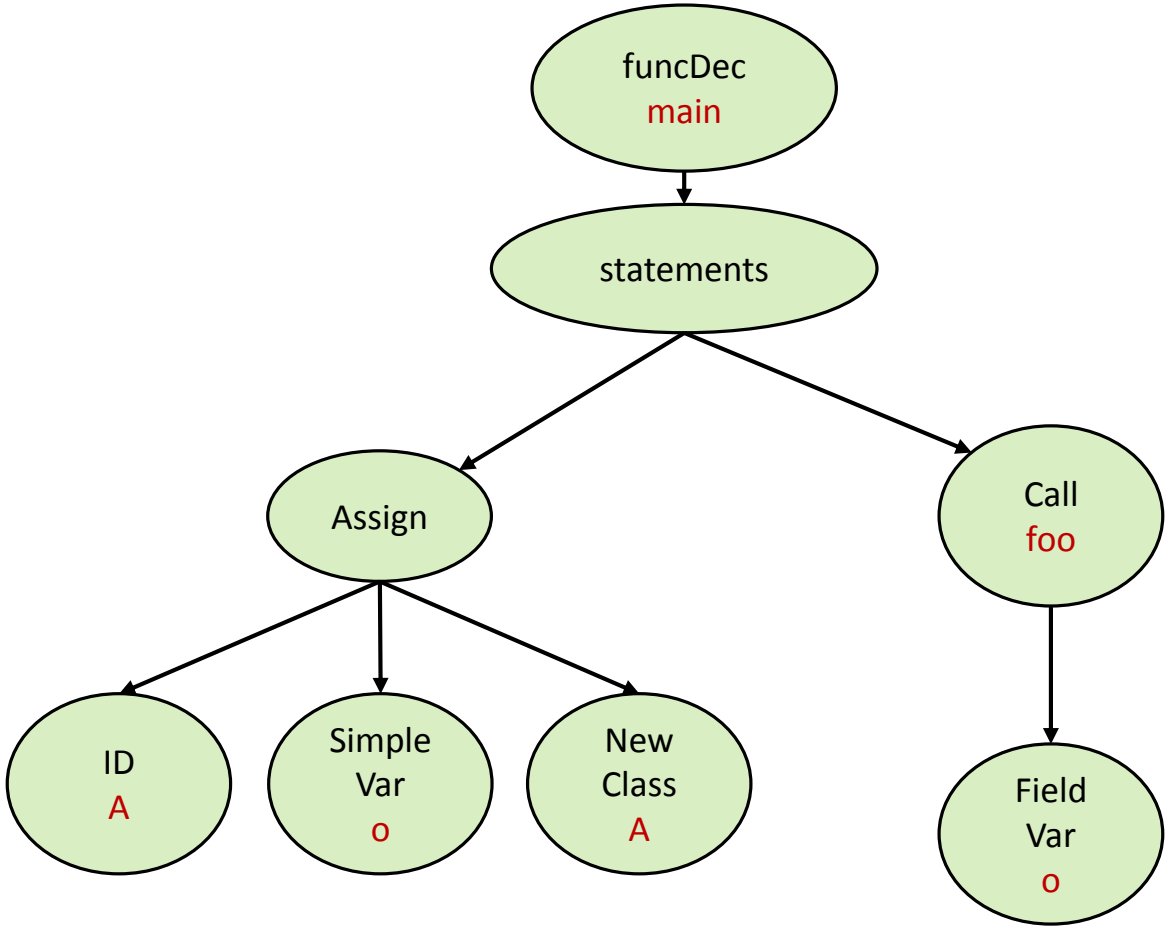
```
class A { }
class B extends A { }
void foo(B b) { }
void main() {
  A o = new A;
  foo(o);
}
```



Inheritance

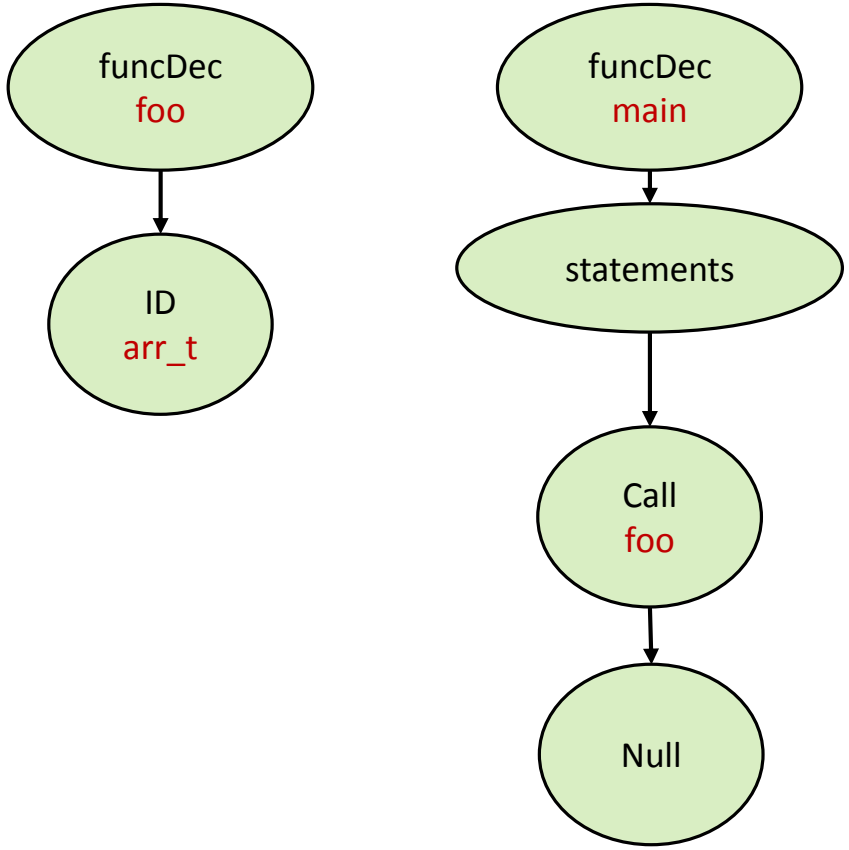
```
class A { }
class B extends A { }
void foo(B b) { }
void main() {
  A o = new A;
  foo(o);
}
```

Invalid



Null

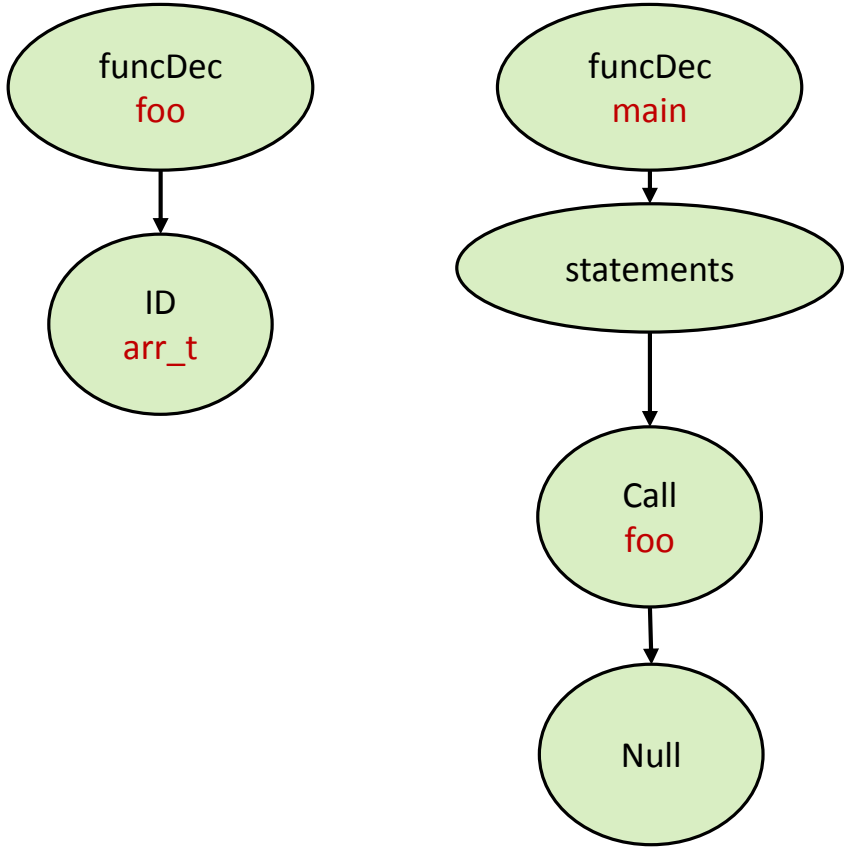
```
typedef int arr_t[];
void foo(arr_t a) { }
void main() {
  foo(null);
}
```



Null

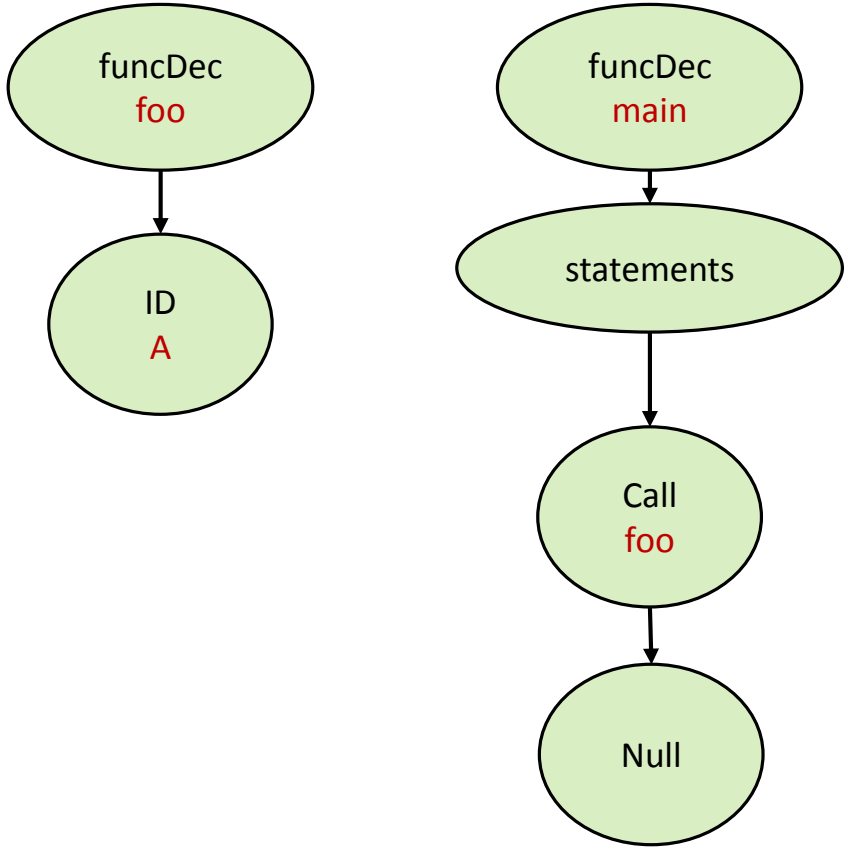
```
typedef int arr_t[];
void foo(arr_t a) { }
void main() {
  foo(null);
}
```

Valid



Null

```
class A { };
void foo(A a) { }
void main() {
  foo(null);
}
```



Null

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  foo(null);
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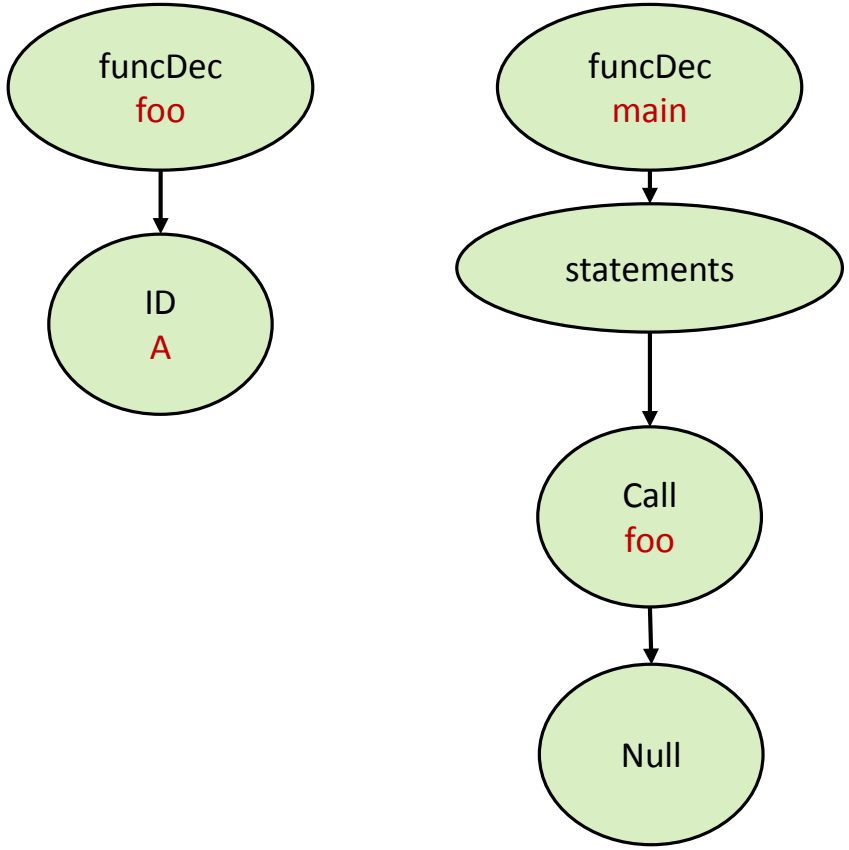
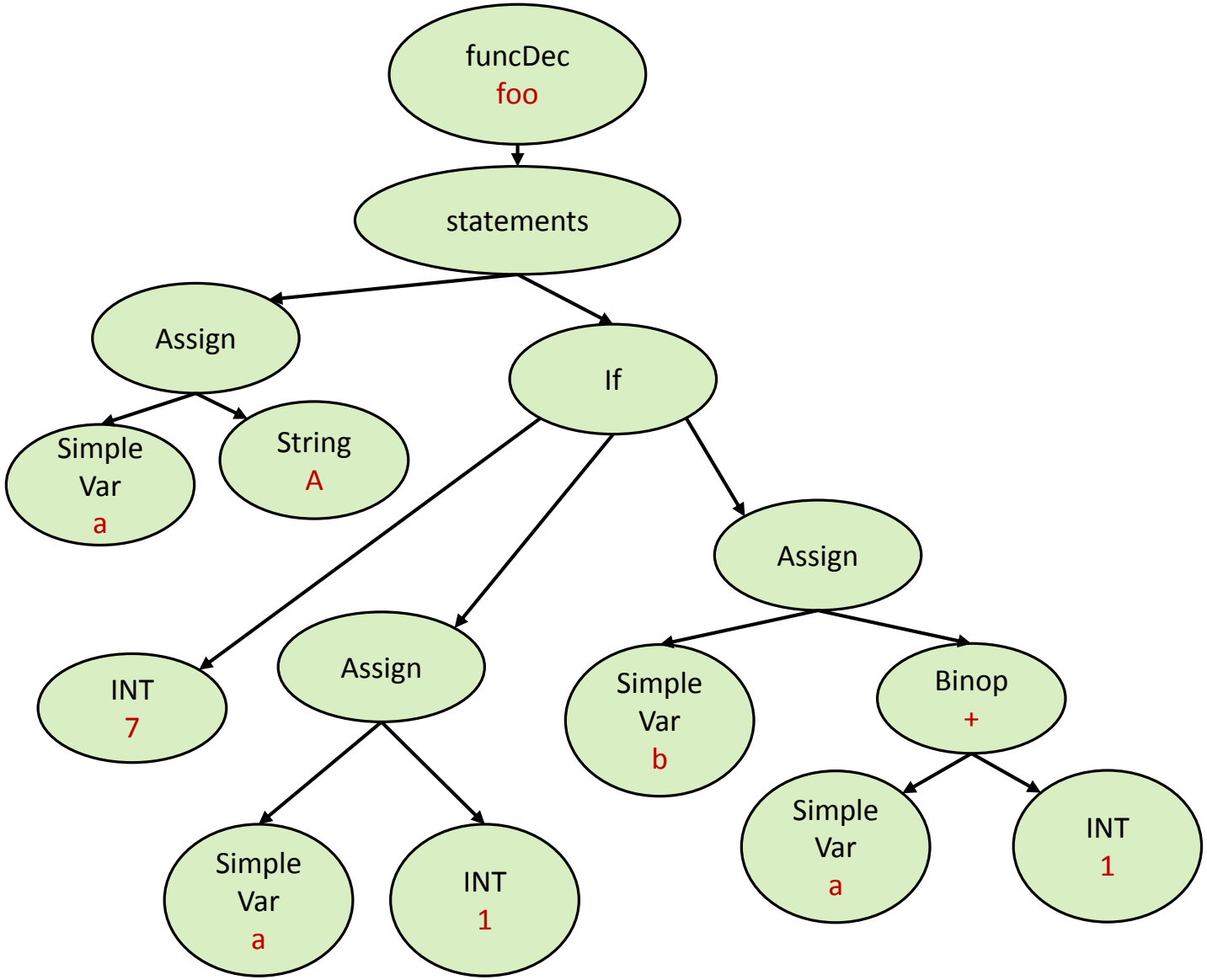
```



Valid

Scopes

```
void foo(void) {
  string a = "A";
  if (7) {
    int a = 1;
    int b = a + 1;
  }
}
```



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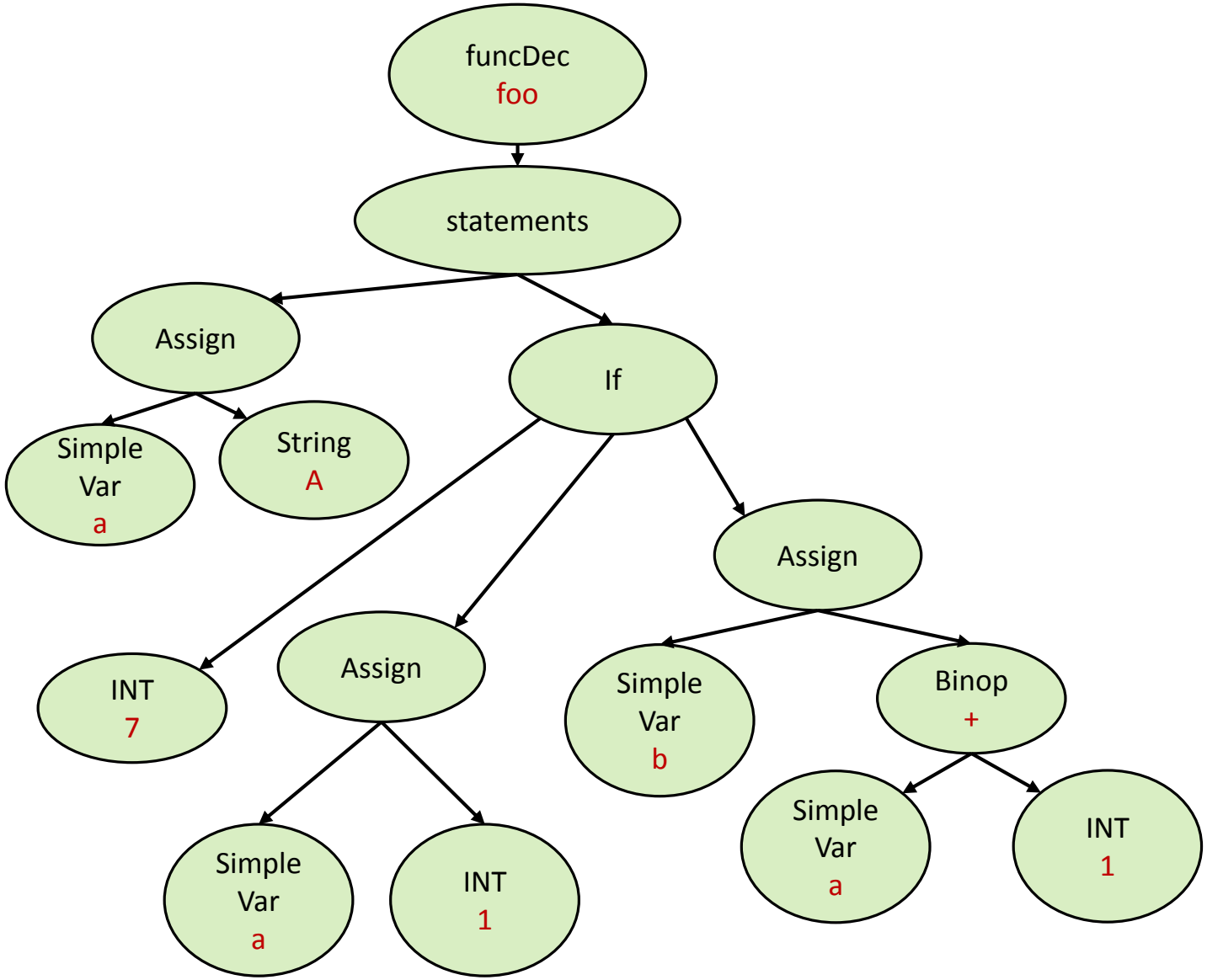
Valid



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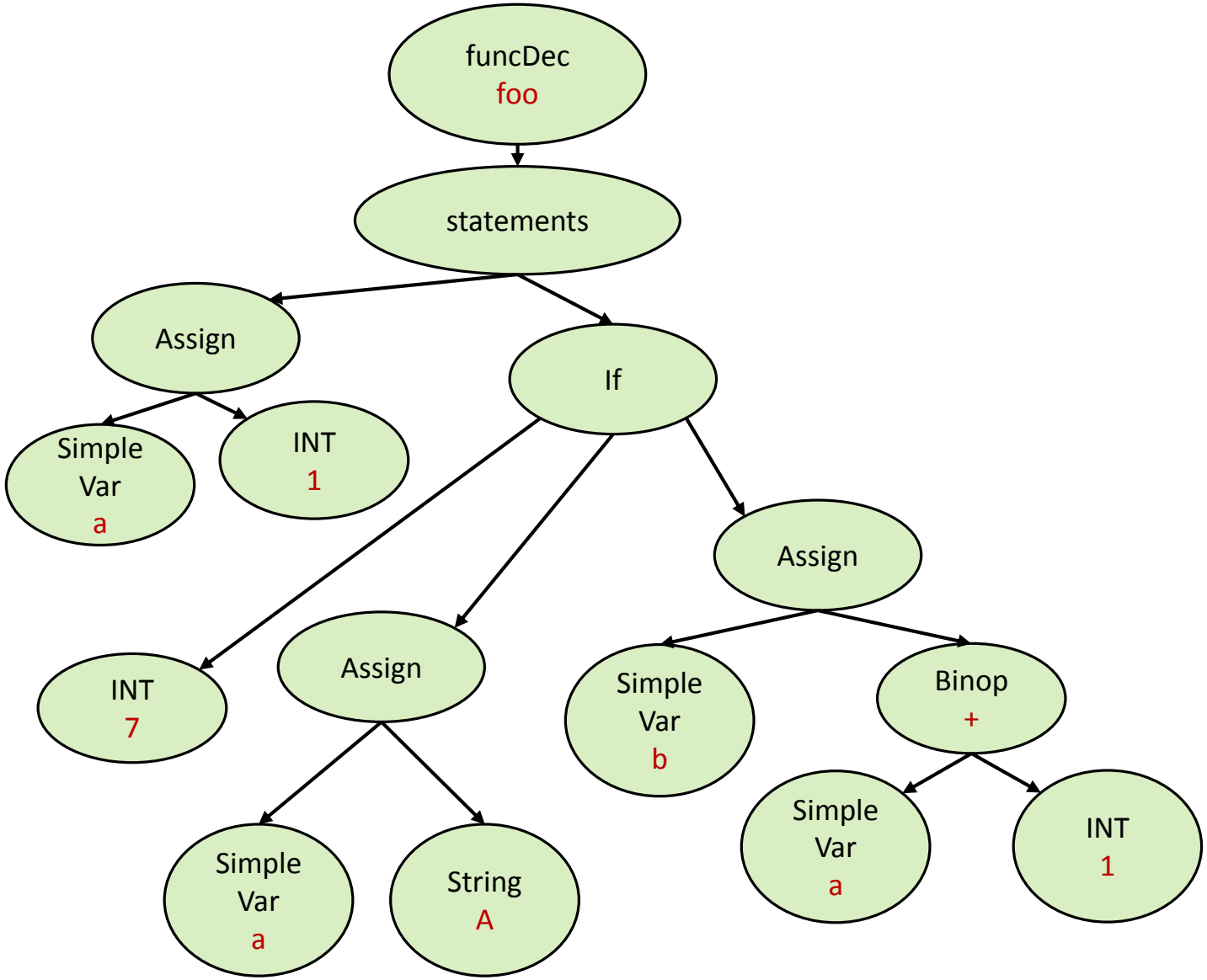

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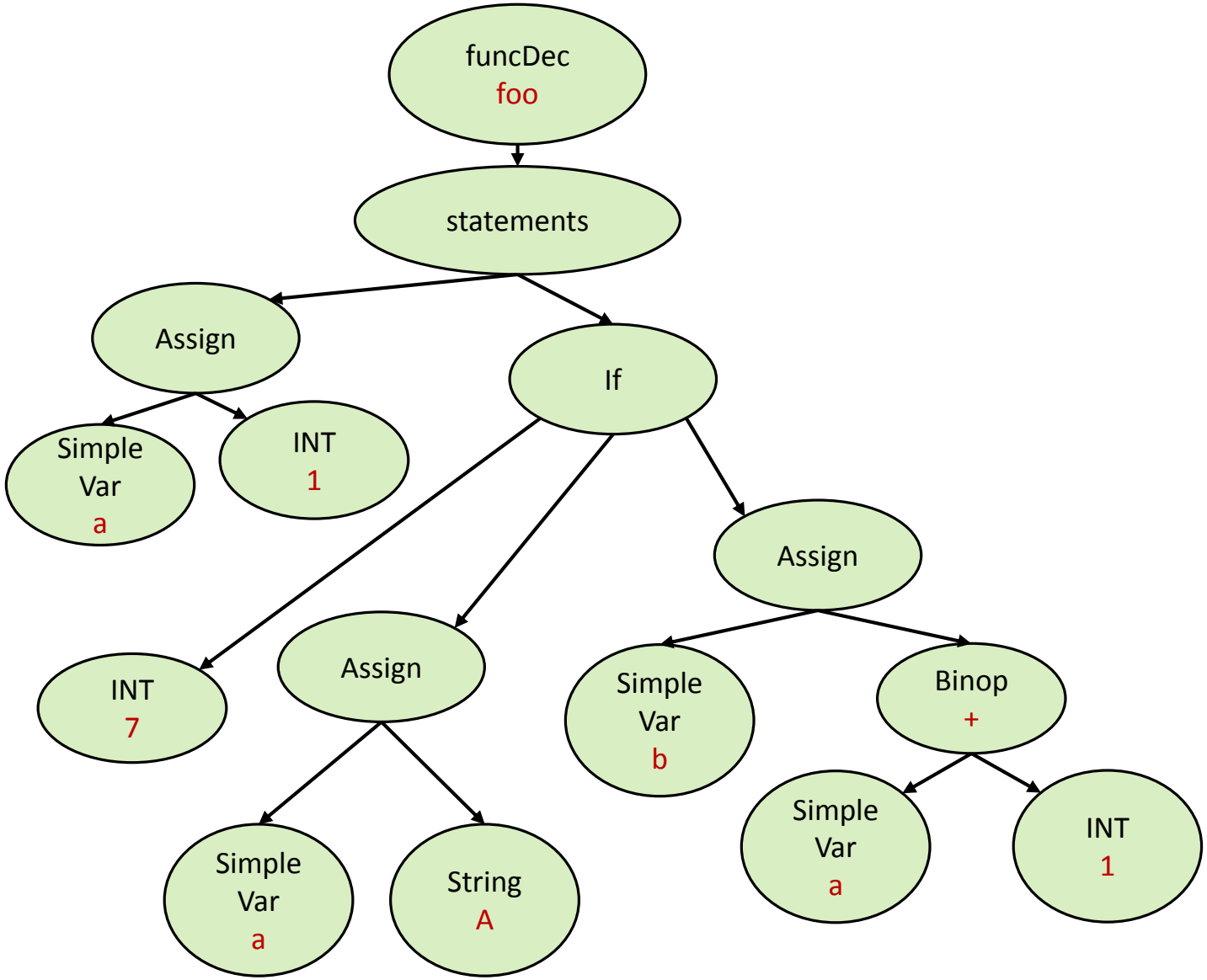
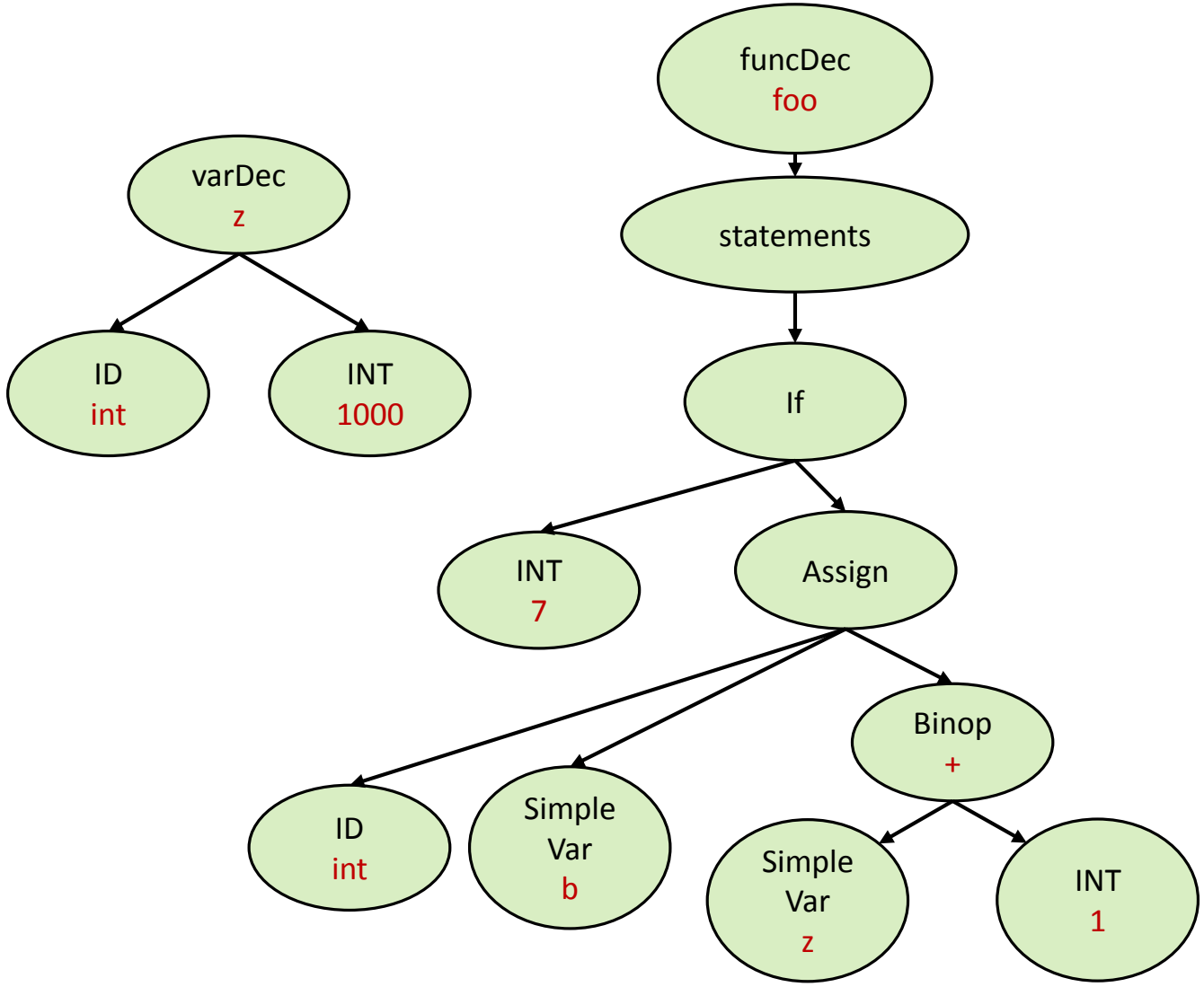
Invalid



Scopes

```
int z = 1000;
void foo(int z) {
  if (7) {
    int b = z + 1;
  }
}
```



Scopes

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int z = 1000;
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   if (7) {
      int b = z + 1;
   }
}
```
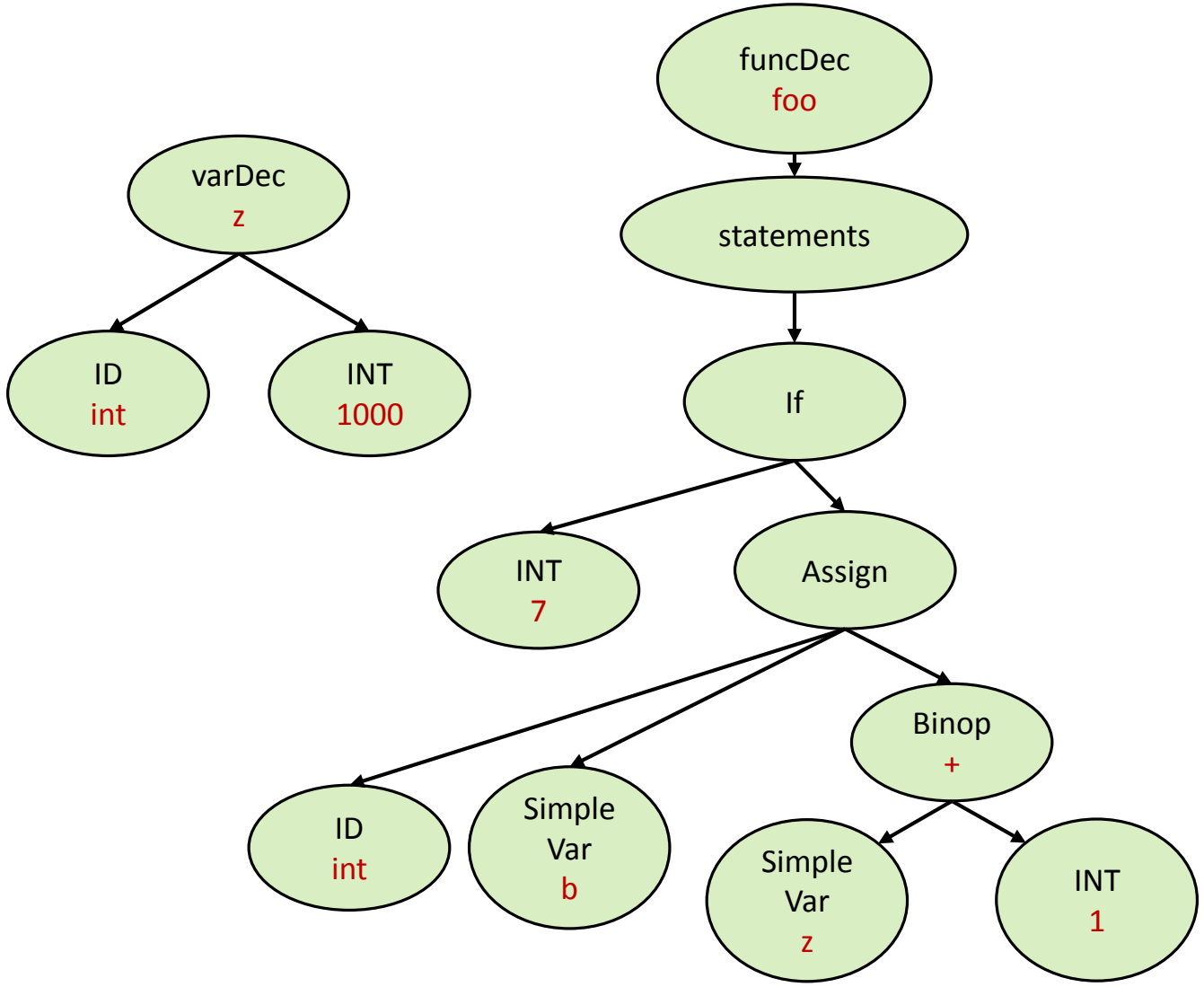
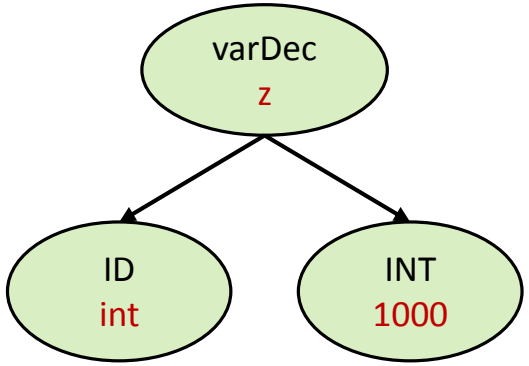
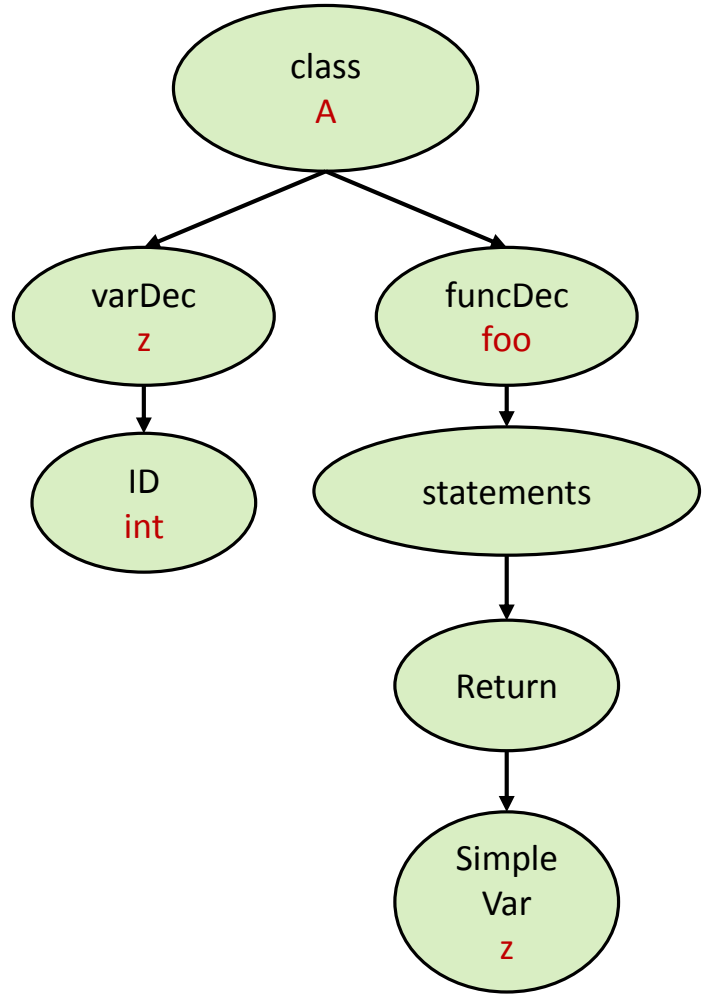

Valid



Scopes

```
int z = 1000;
class A {
   int z;
   int foo() {
      return z;
   }
}
```





Scopes

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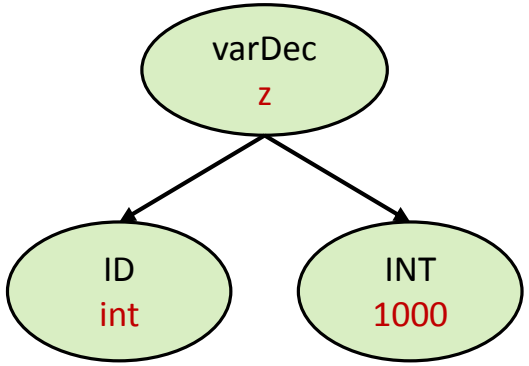
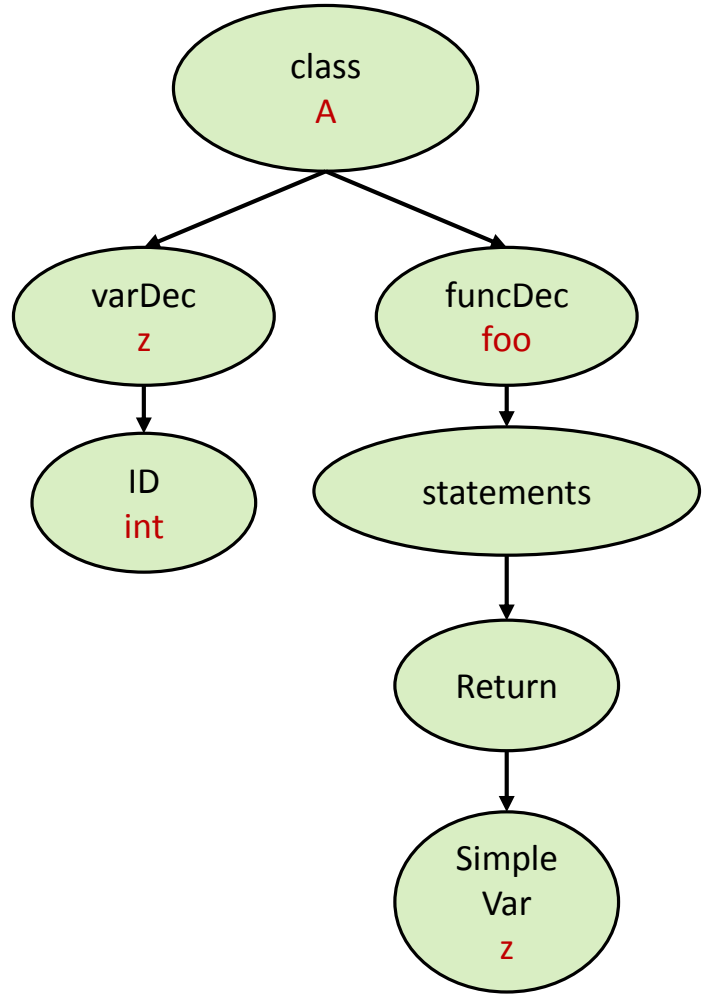
int z = 1000;
class A {
   int z;
   int foo() {
      return z;
   }
}
```

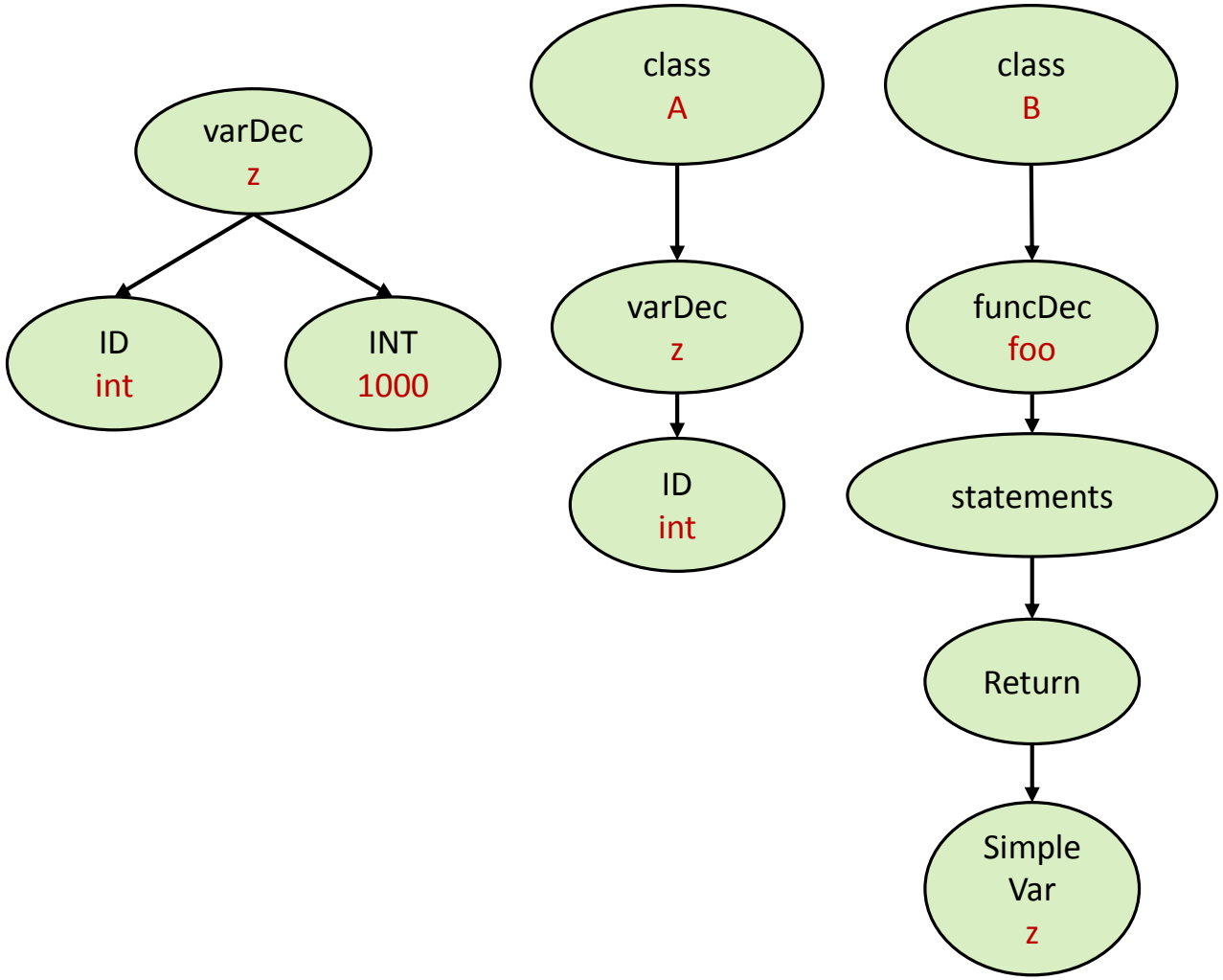
Valid





Scopes

```
int z = 1000;
class A {
  int z;
}
class B extends A {
  int foo() {
    return z;
  }
}
```



Scopes

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class A {
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class B extends A {
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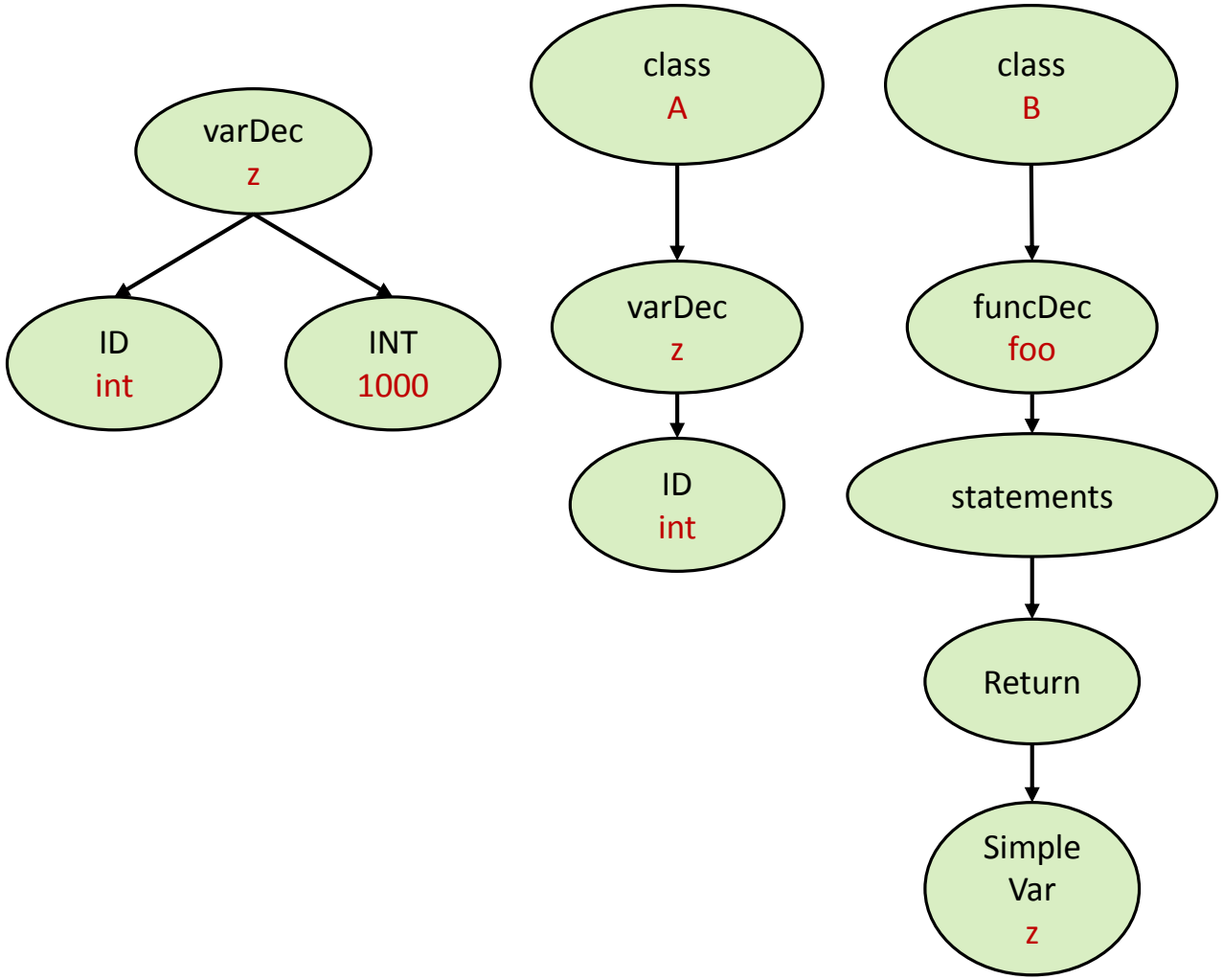
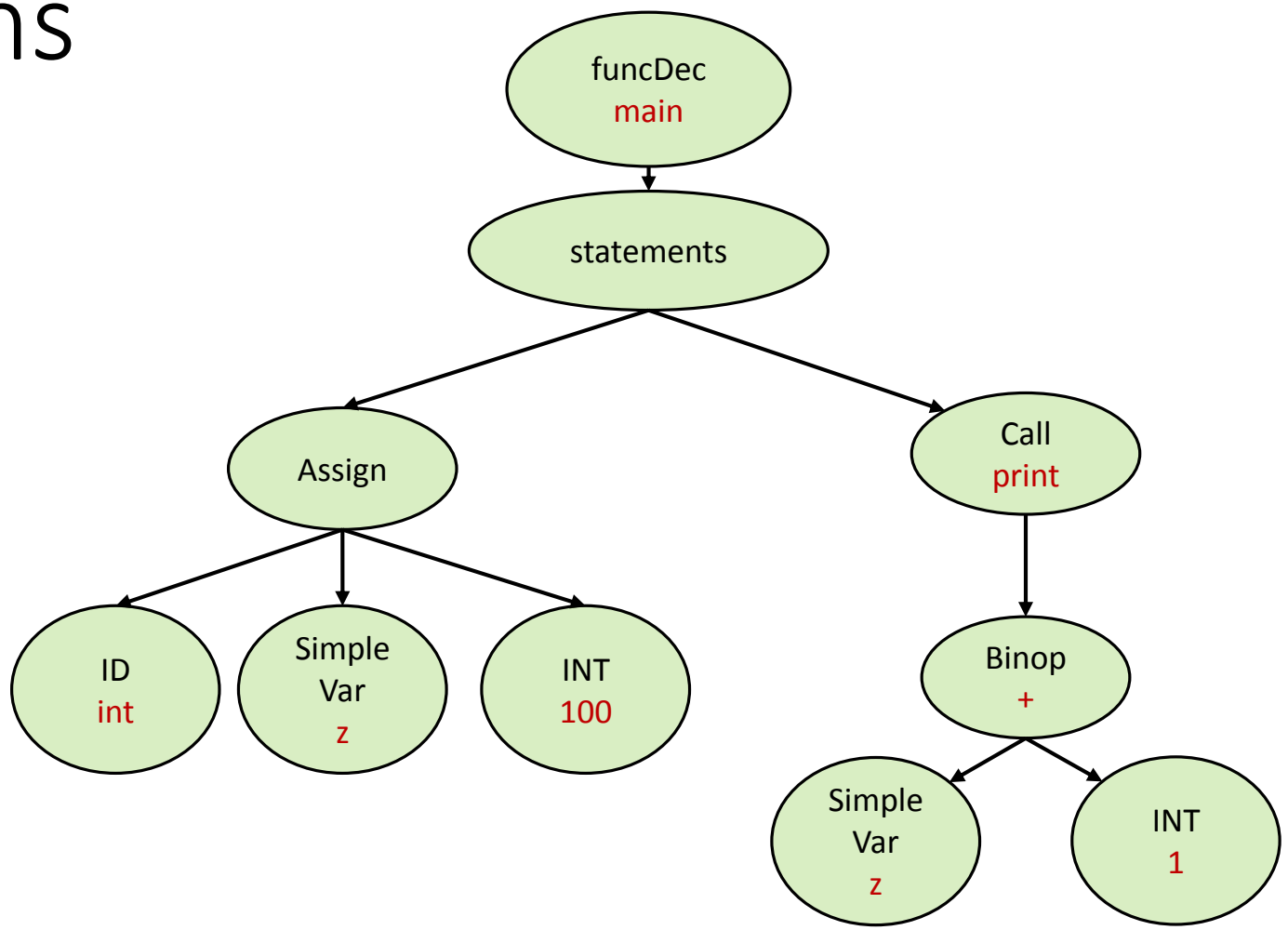
Valid



Library Functions

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



Library Functions

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void main() {
  int z = 100;
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```
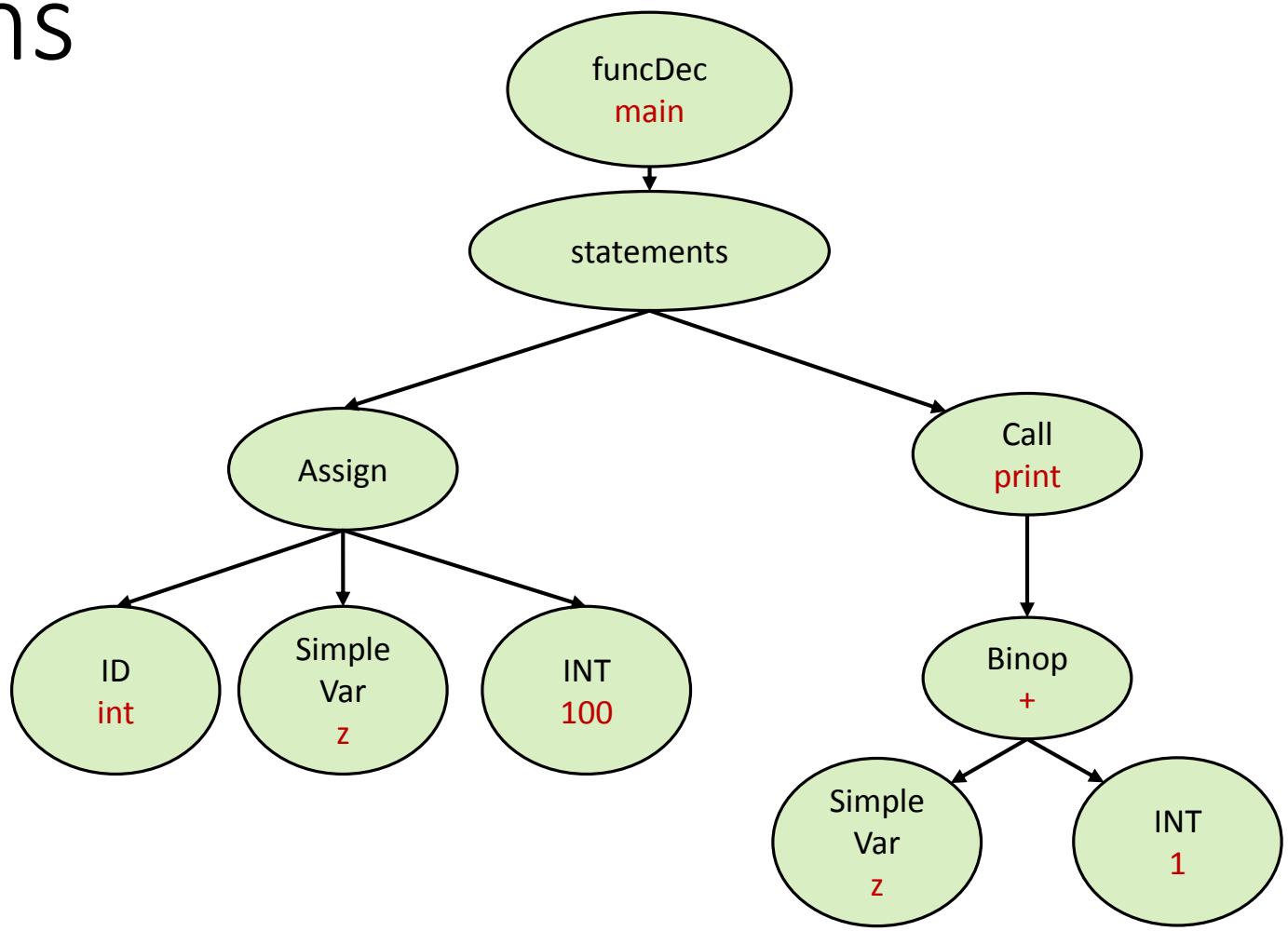

Valid



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
  - In the skeleton it's called *semantMe*
- 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
    }
    …
  }
}
```

Implementation

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

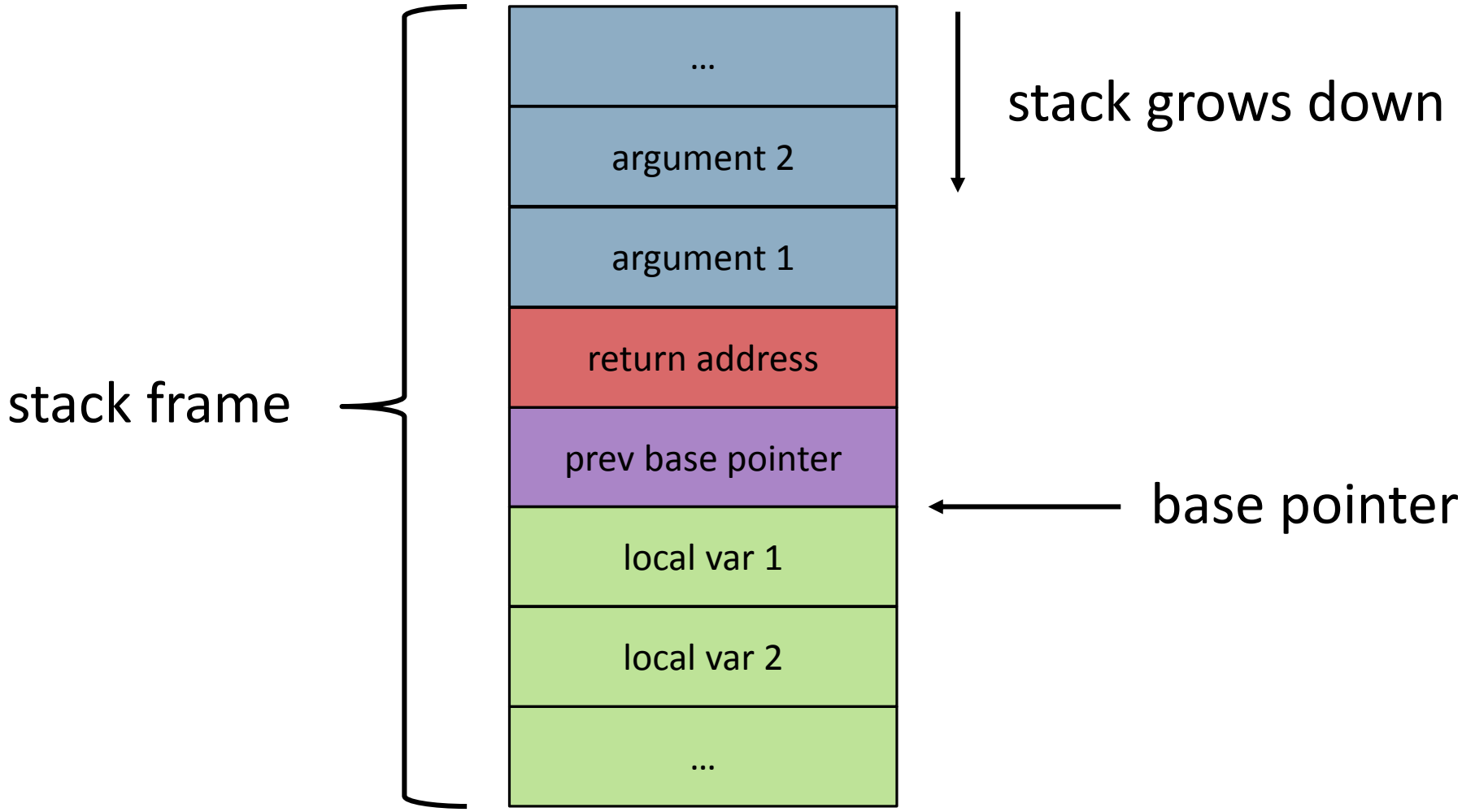
AST Annotations

AST Annotations

While analyzing the AST, we can extend it with useful information:

- Variable offsets
- Parameter offsets
- Class layout
- Type size

Stack

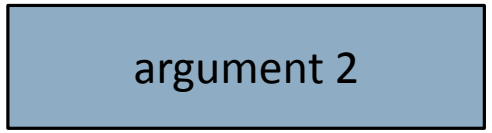

...
argument 2
argument 1
return address
prev base pointer
local var 1
local var 2
...
stack grows down
stack frame
base pointer

Stack

```
int f(int x, int y){
  int z = x + y;
  return z;
}
int g() {
  int x = f(10, 20)
}
```

```
f:
push   %ebp
mov    %esp,%ebp
sub    $0x10,%esp
mov    0x8(%ebp),%edx
mov    0xc(%ebp),%eax
add    %edx,%eax
mov    %eax,-0x4(%ebp)
mov    -0x4(%ebp),%eax
leave
ret

g:
…
push   $0x14
push   $0x0a
call   24 <g+0xe>
…
```

Stack

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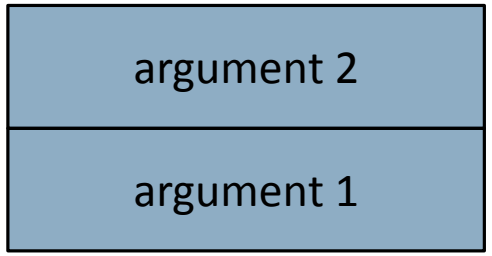


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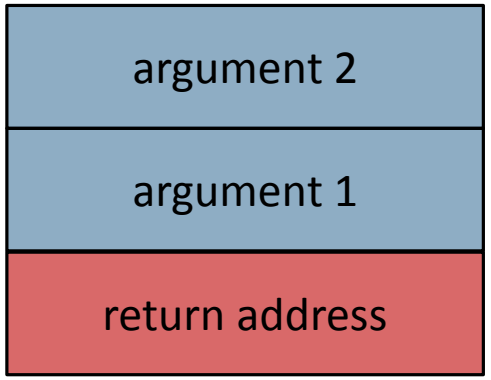


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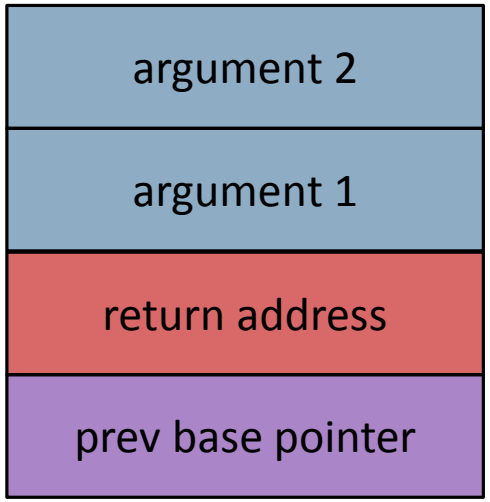


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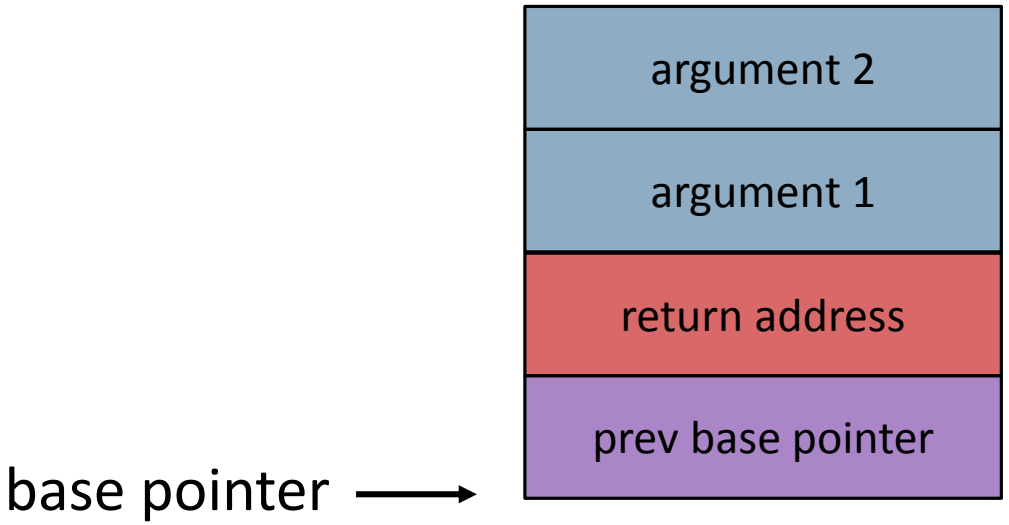


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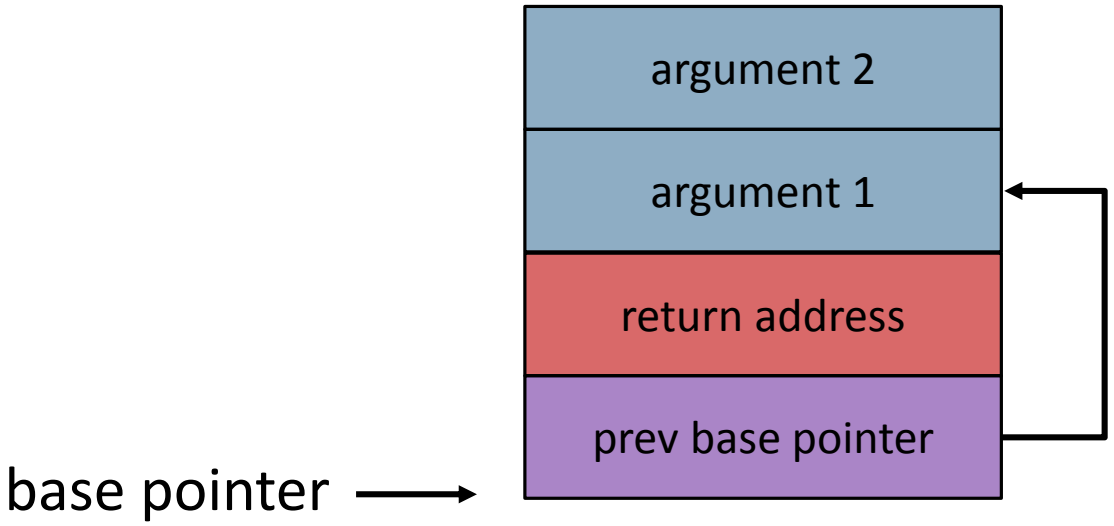


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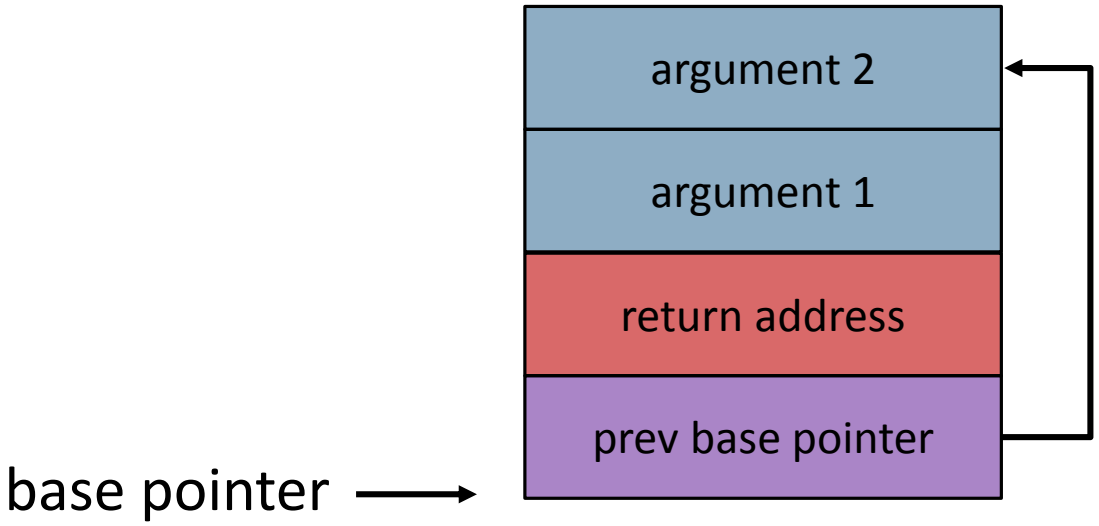


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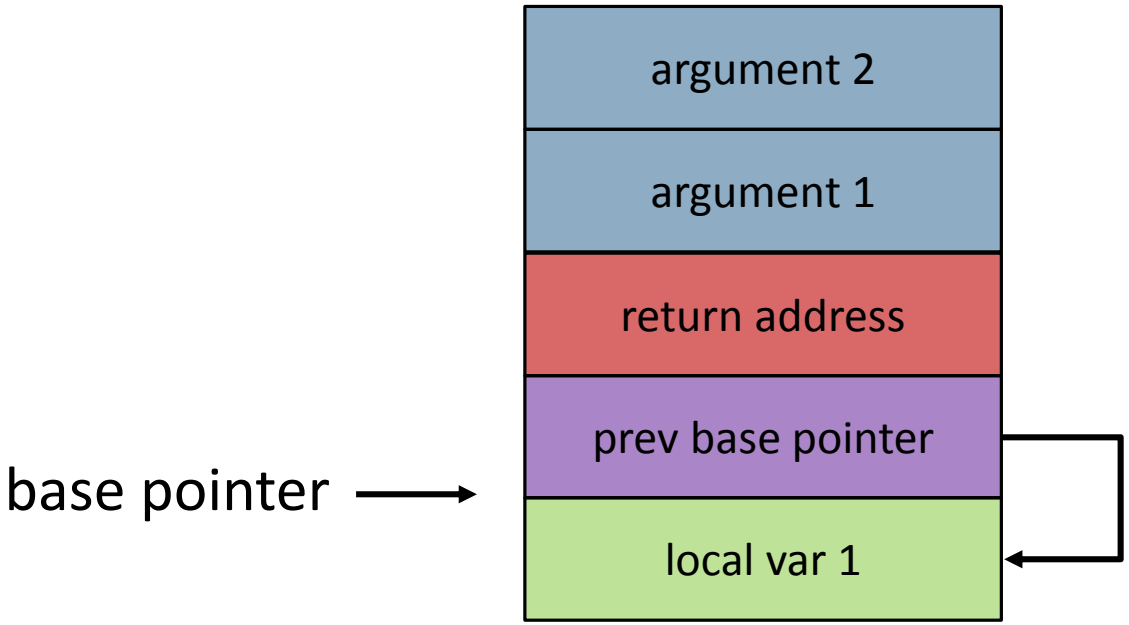


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leave
ret

g:
…
push   $0x14
push   $0x0a
call   24 <g+0xe>
…
```

Variable Offsets

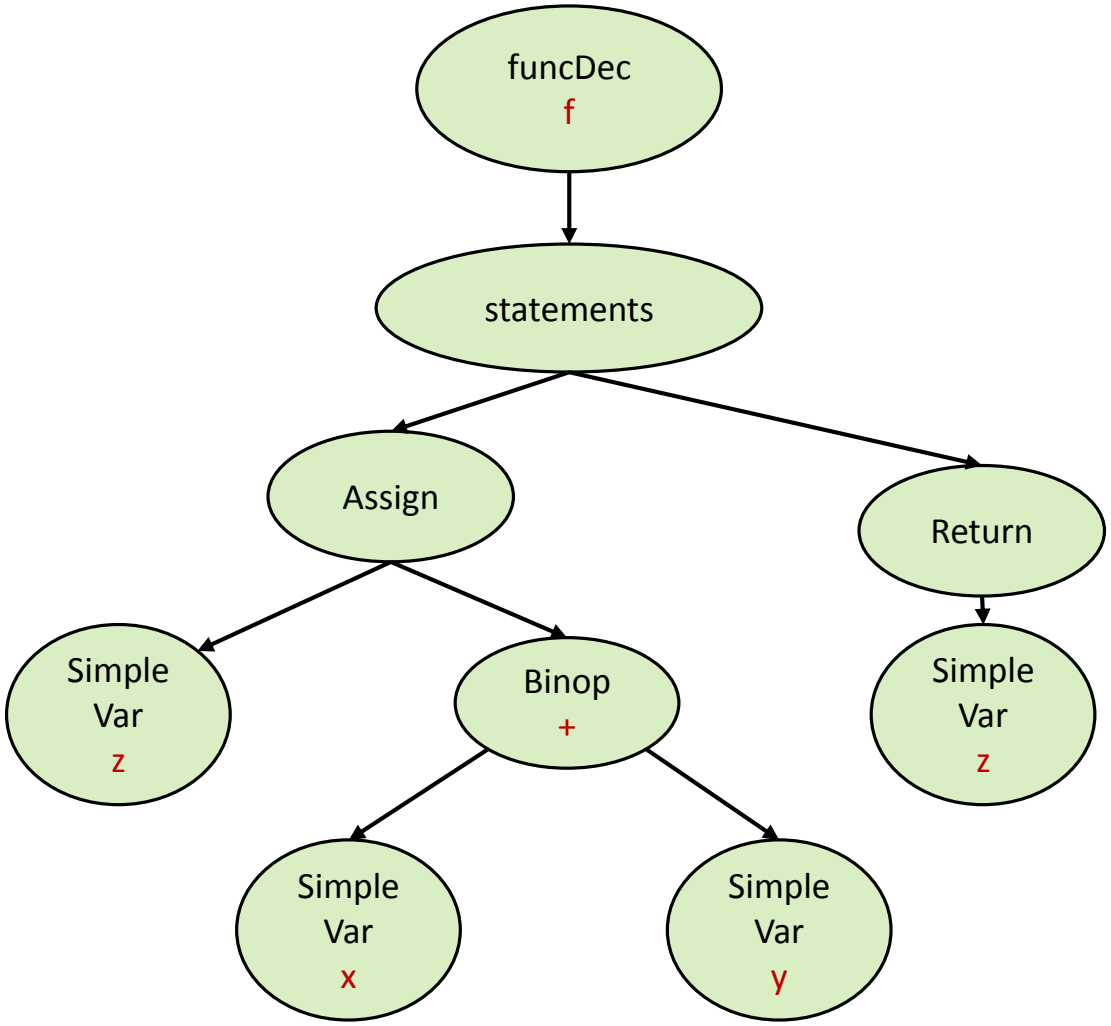
Machine code **does not** contain names of:

- Local variables
- Parameters

Instead, we use offsets **relatively** from the **stack base pointer**

Variable Offsets

```
int f(int x, int y){
  int z = x + y;
  return z;
}
```



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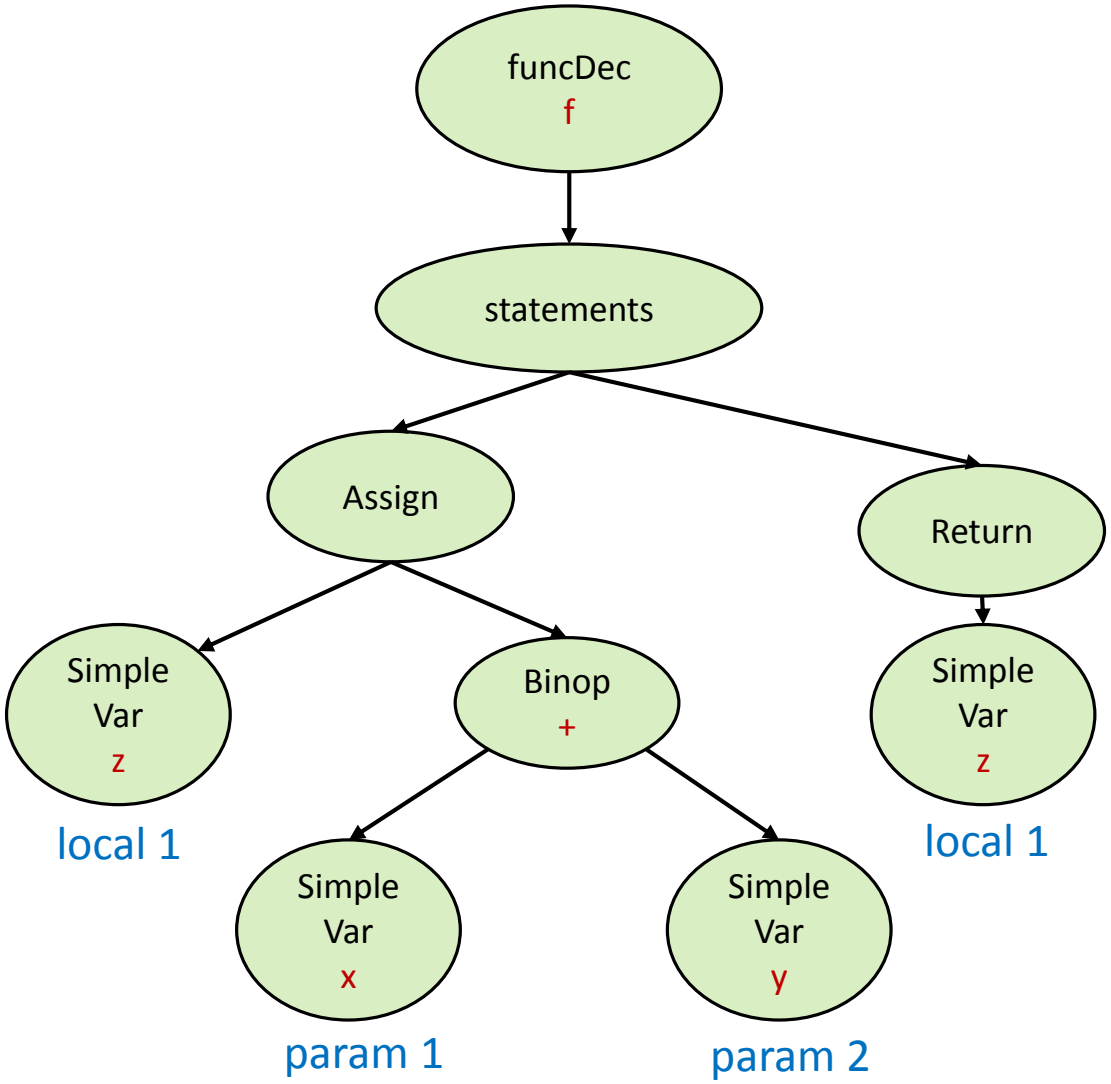
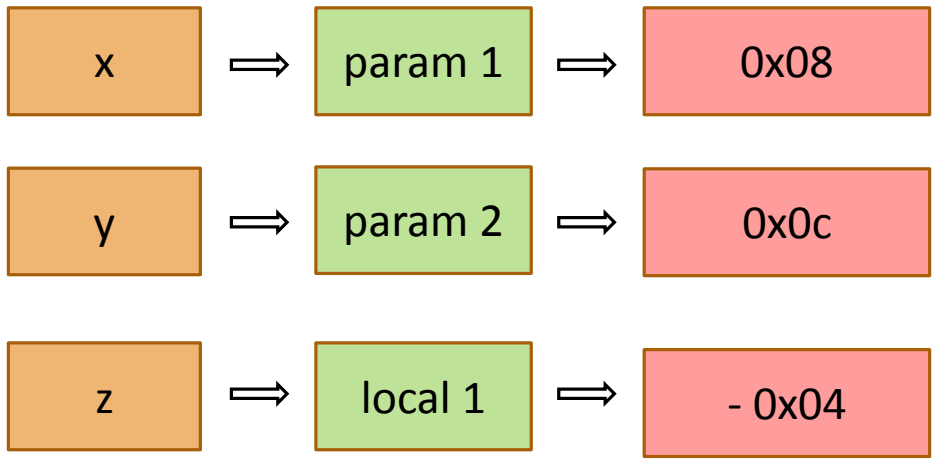


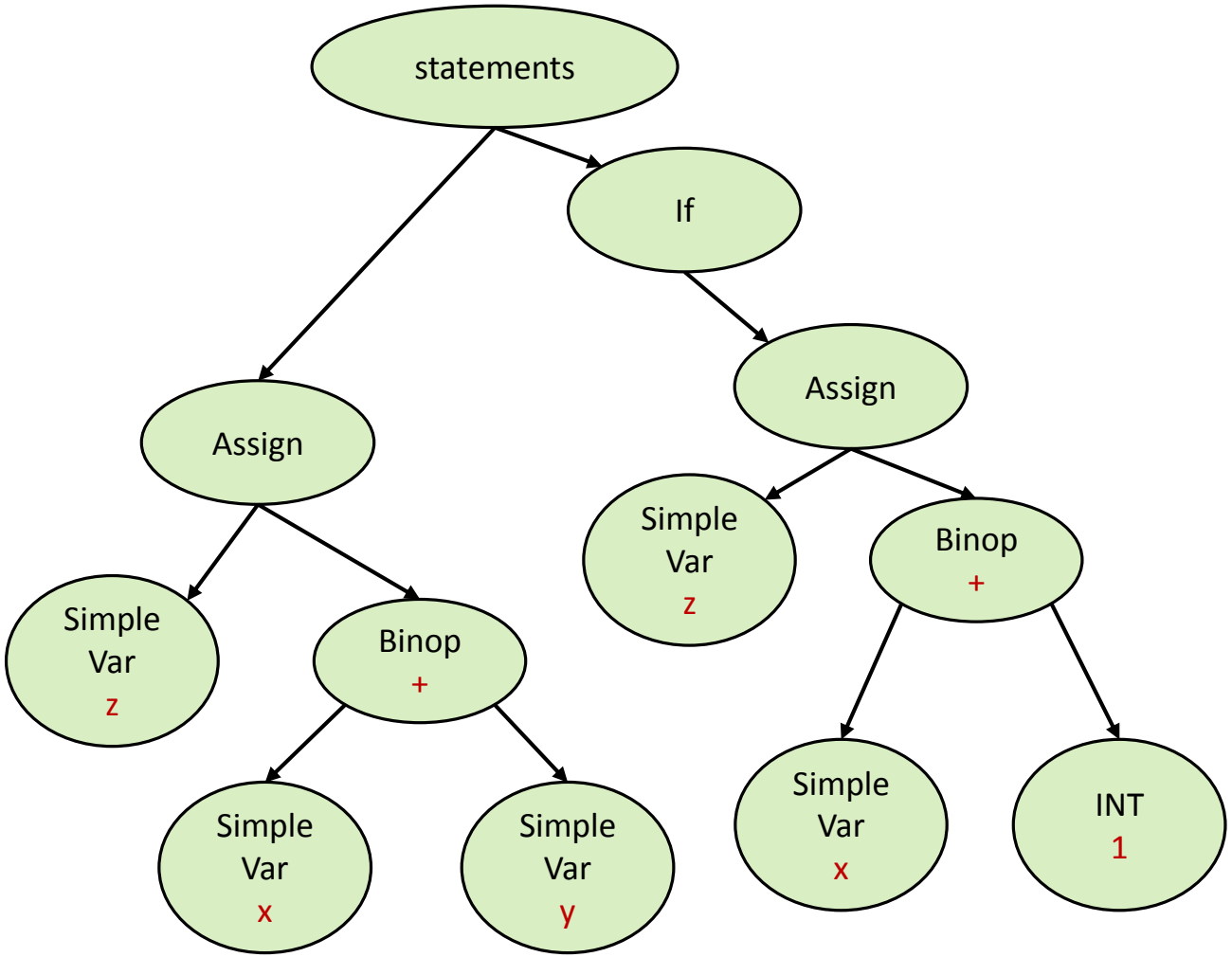
Variable Offsets

```
int f(int x, int y){
   int z = x + y;
   return z;
}
```



Variable Offsets

```
void f(int x, int y){
   int z = x + y;
   if (z > 1) {
      int z = x + 1;
   }
}
```



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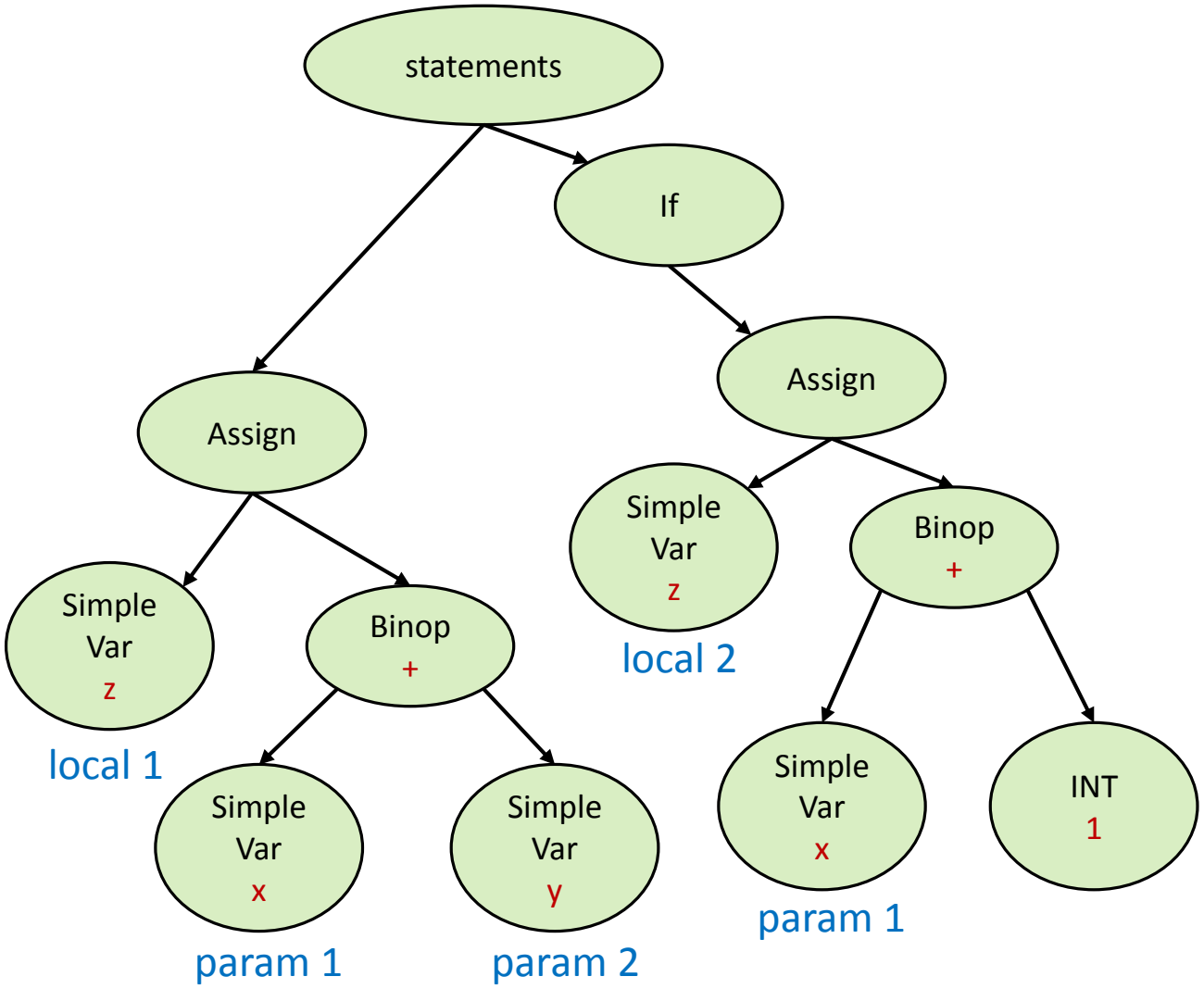

Field Offsets

How does an object of this class look in memory?

```
class Point {
  int x;
  int y;
}
void f(Point p) {
  p.x = 0xaa;
  p.y = 0xbb;
}
```

Field Offsets

How does an object of this class look in memory?

```
class Point {
  int x;
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}
void f(Point p) {
  p.x = 0xaa;
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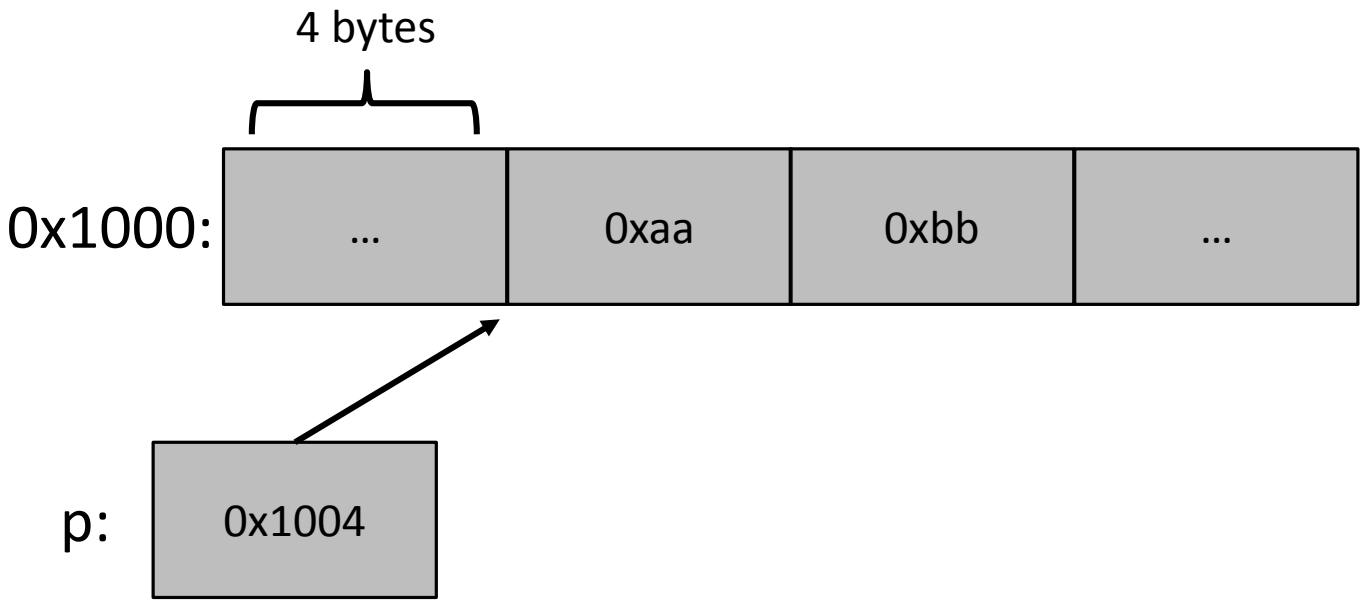
}
```



Field Offsets

How does an object of this class look in memory?

```
class Point {
  int x;
  int y;
}
void f(Point p) {
  p.x = 0xaa;
  p.y = 0xbb;
}
```

```
f:
push    %ebp
mov     %esp,%ebp
mov     0x8(%ebp),%eax
movl    $0xaa,(%eax)
mov     0x8(%ebp),%eax
movl    $0xbb,0x4(%eax)
pop     %ebp
ret
```

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ret
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Field Offsets

Each class field should have an index

```
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  int y;
}
void f(Point p) {
  p.x = 0xaa;
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}
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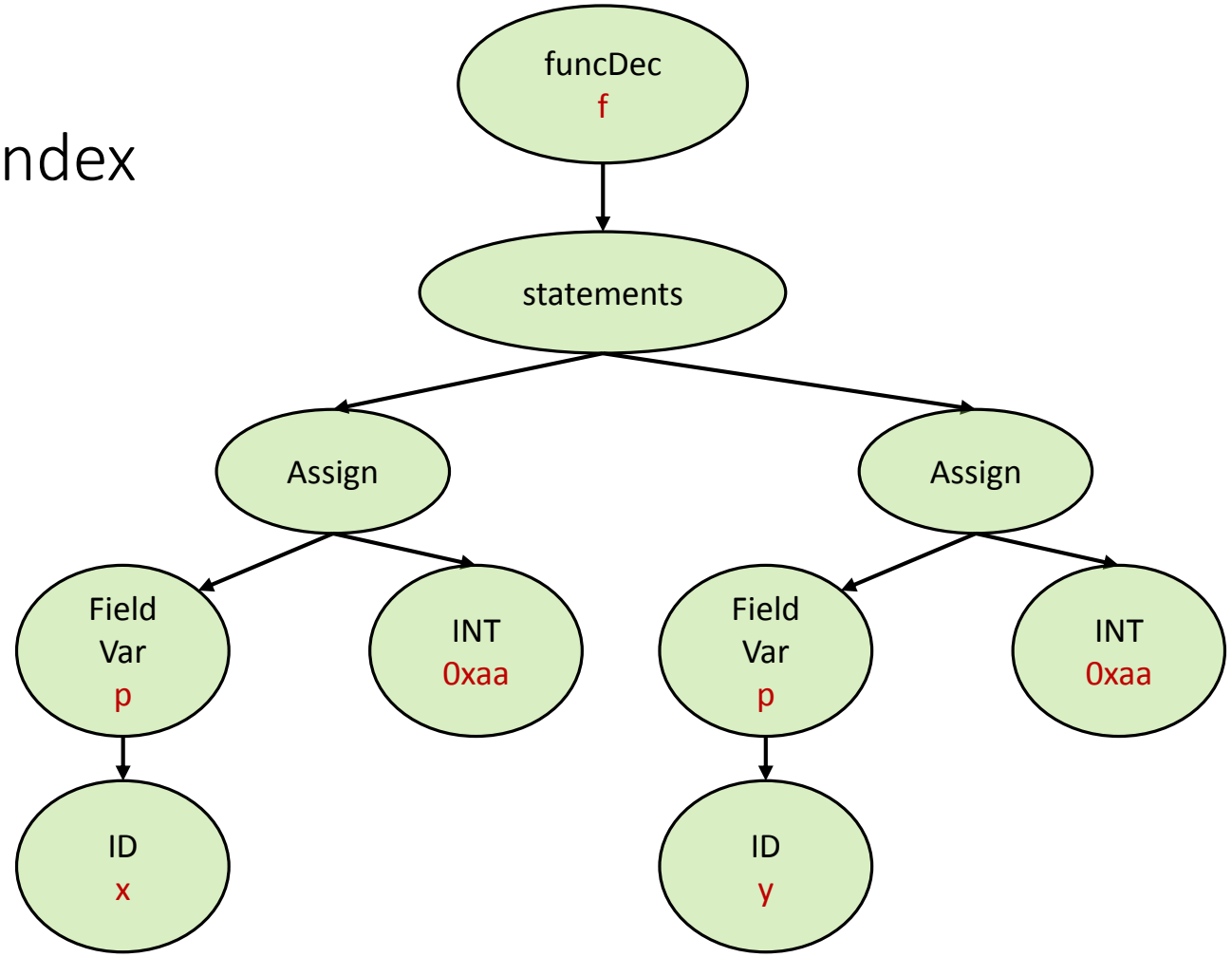

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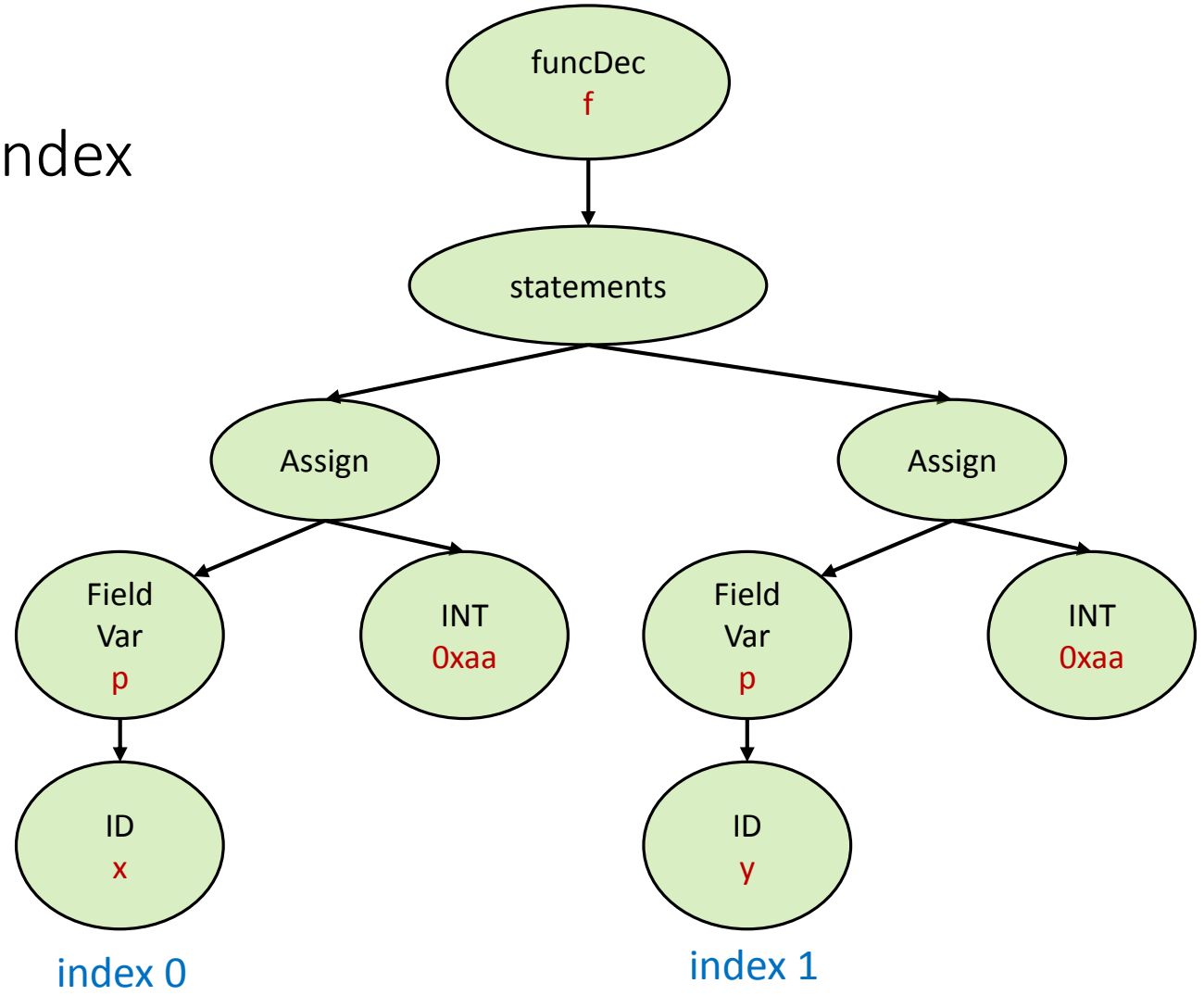

Type Sizes

```
class Point {
  int x;
  int y;
}
void f(Point p) {
  Point p = new Point;
}
```

```
f:
push   %ebp
mov    %esp,%ebp
sub    $0x18,%esp
sub    $0xc,%esp
push   $0x8
call   56 <foo+0xc>
add    $0x10,%esp
mov    %eax,-0xc(%ebp)
leave
ret
```

Type Sizes

```
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  int x;
  int y;
}
void f(Point p) {
  Point p = new Point;
}
```

```
f:
push   %ebp
mov    %esp,%ebp
sub    $0x18,%esp
sub    $0xc,%esp
push   $0x8
call   56 <foo+0xc>
add    $0x10,%esp
mov    %eax,-0xc(%ebp)
leave
ret
```

Type Sizes

```
class Point {
  int x;
  int y;
  string name;
}
void f(Point p) {
  Point p = new Point;
}
```

```
f:
push   %ebp
mov    %esp,%ebp
sub    $0x18,%esp
sub    $0xc,%esp
push   ?
call   56 <foo+0xc>
add    $0x10,%esp
mov    %eax,-0xc(%ebp)
leave
ret
```

Type Sizes

```
class Point {
  int x;
  int y;
  string name;
}
void f(Point p) {
  Point p = new Point;
}
```

```
f:
push   %ebp
mov    %esp,%ebp
sub    $0x18,%esp
sub    $0xc,%esp
push   $0xc
call   56 <foo+0xc>
add    $0x10,%esp
mov    %eax,-0xc(%ebp)
leave
ret
```