Lecture 4 – Identifiers (1)

COSE212: Programming Languages

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2024 Fall

Recall

- **ADT** for **Abstract Syntax** of AE

```
enum Expr:
  case Num(number: BigInt)
  case Add(left: Expr, right: Expr)
  case Mul(left: Expr, right: Expr)
```

- **Parser** for **Concrete Syntax** of AE

```
lazy val expr: P[Expr] = ...
```

- **Interpreter** for **Semantics** of AE

```
def interp(expr: Expr): Value = ...
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Recall

- **ADT** for **Abstract Syntax** of AE

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enum Expr:
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- **Parser** for **Concrete Syntax** of AE

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lazy val expr: P[Expr] = ...
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- **Interpreter** for **Semantics** of AE

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def interp(expr: Expr): Value = ...
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- In this lecture, we will learn **identifiers**.

Contents

Contents

Identifiers

PLRG

An **identifier** is a **name** for a certain element in a program.

In Scala, there are diverse kinds of identifiers:

```
/* Scala */

// variable names
val x: Int = 42

// function and parameter names
def f(a: Int, b: Int): Int = a + b

// class and field names
case class Person(name: String, age: Int)

...
```

Bound Identifiers

```scala
/* Scala */
val x: Int = 3

val y: Int = x + z

def add(a: Int, b: Int): Int =
  val x: Int = a + b
  x + add(y, z)

add(x, b)
```

A **bound identifier** is an identifier that is **defined** in a program.

- A **binding occurrence** of an identifier denotes its **definition** site.
- A **scope** of an identifier denotes where the identifier is **usable**.
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Binding Occurrences

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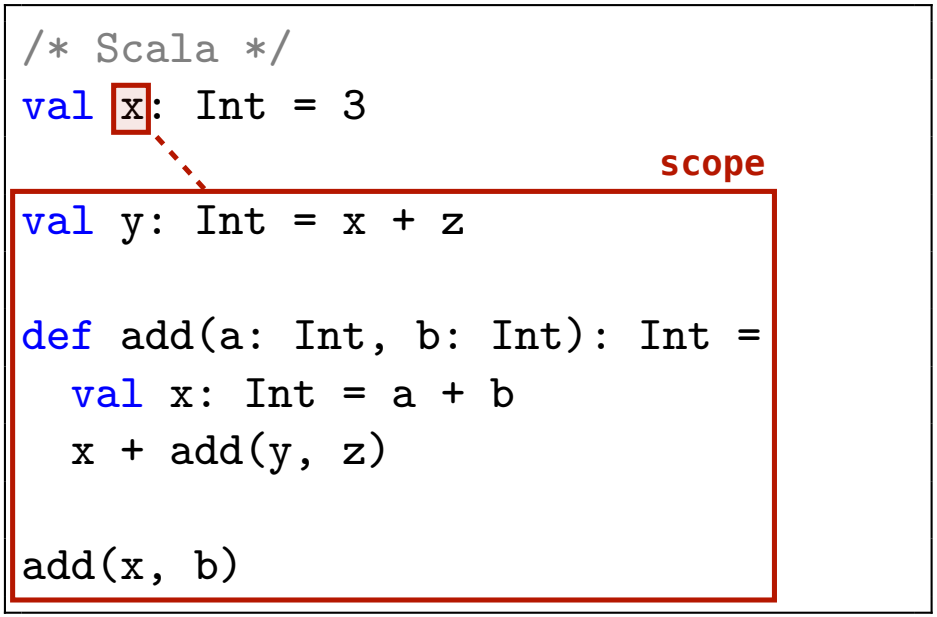

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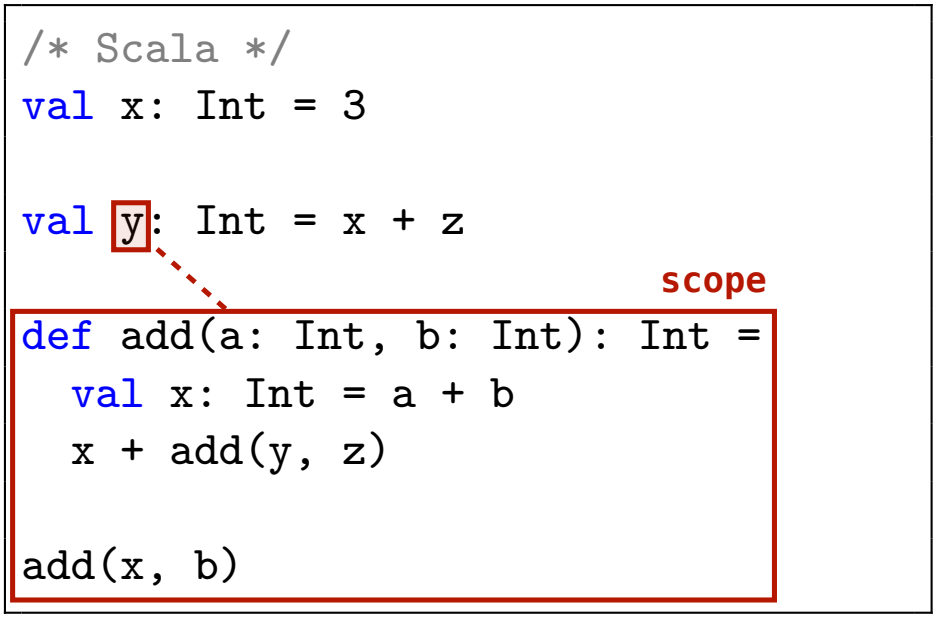

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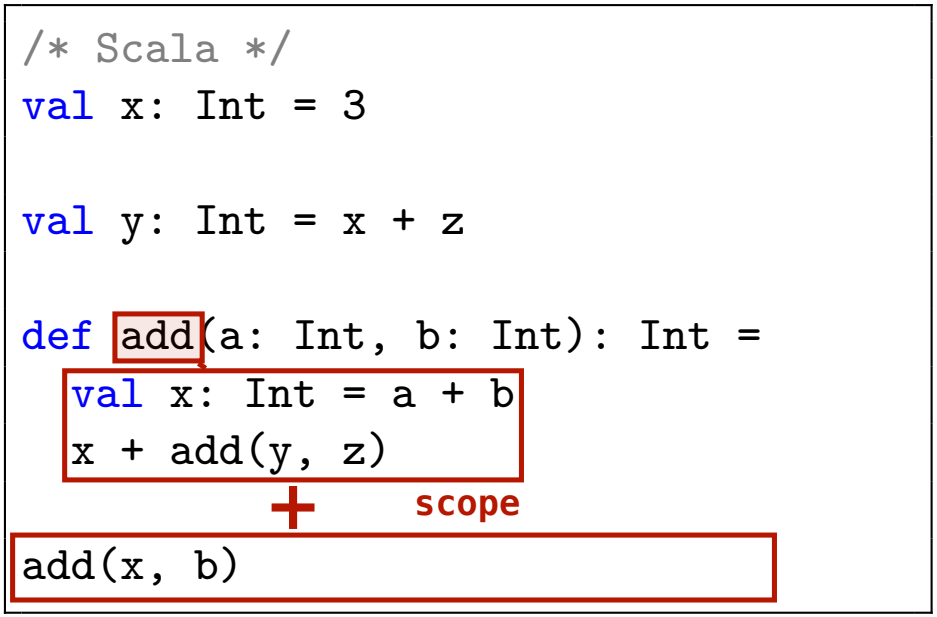

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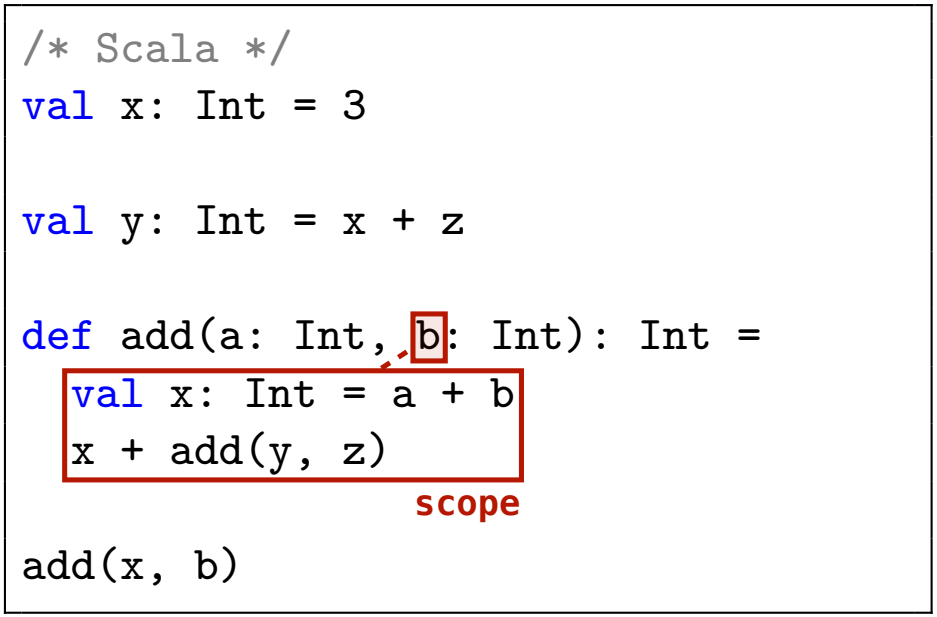

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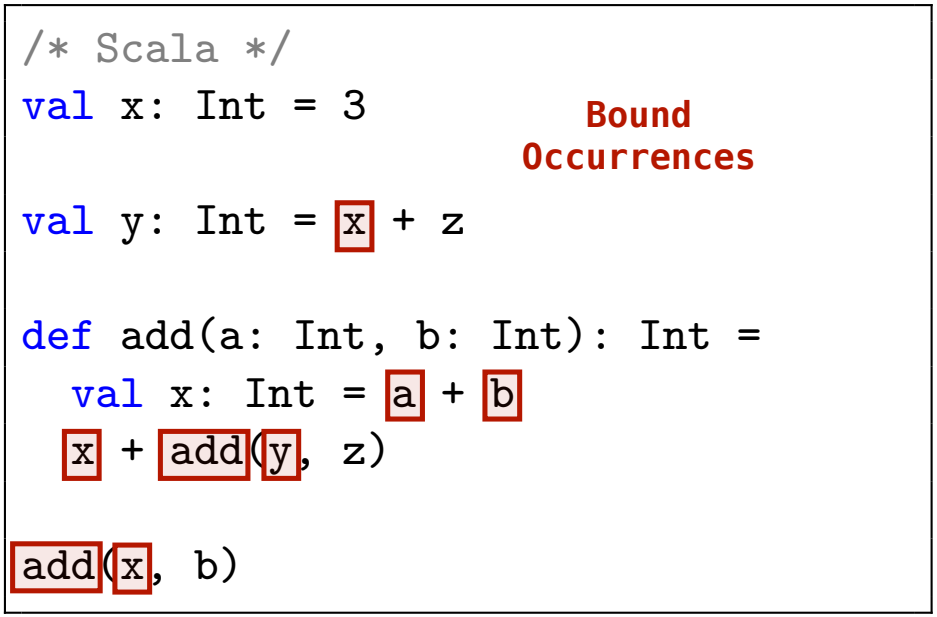

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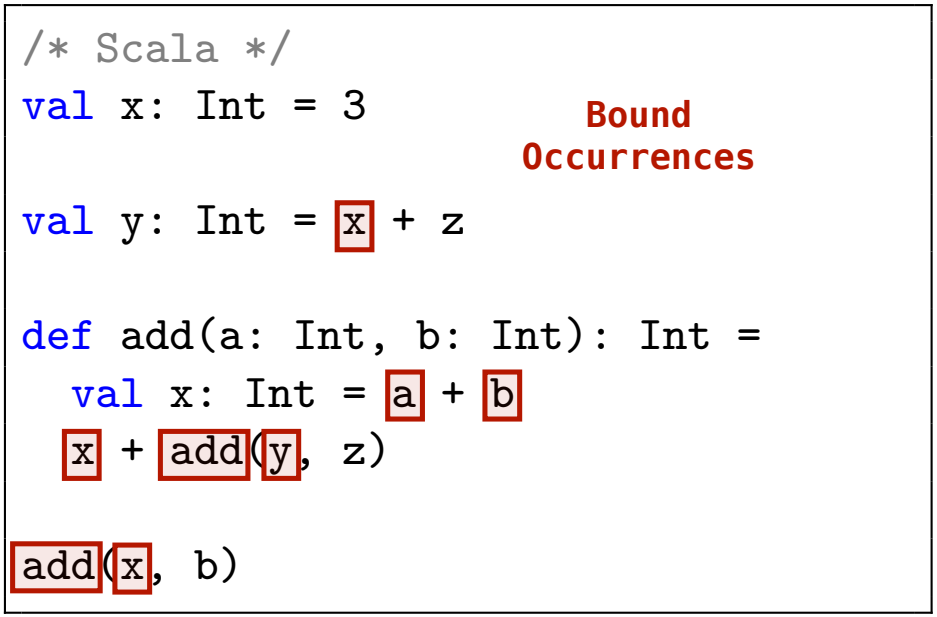

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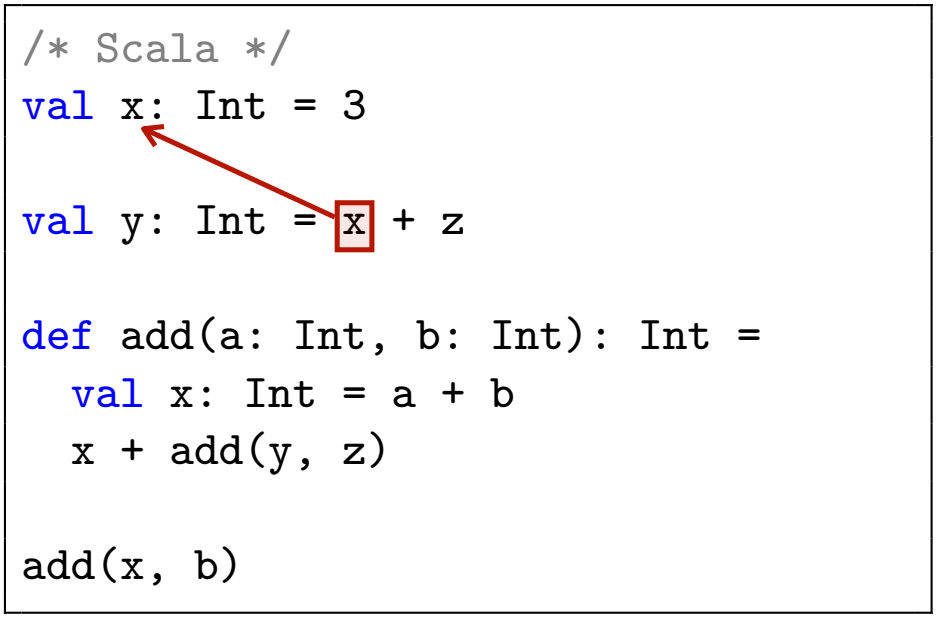

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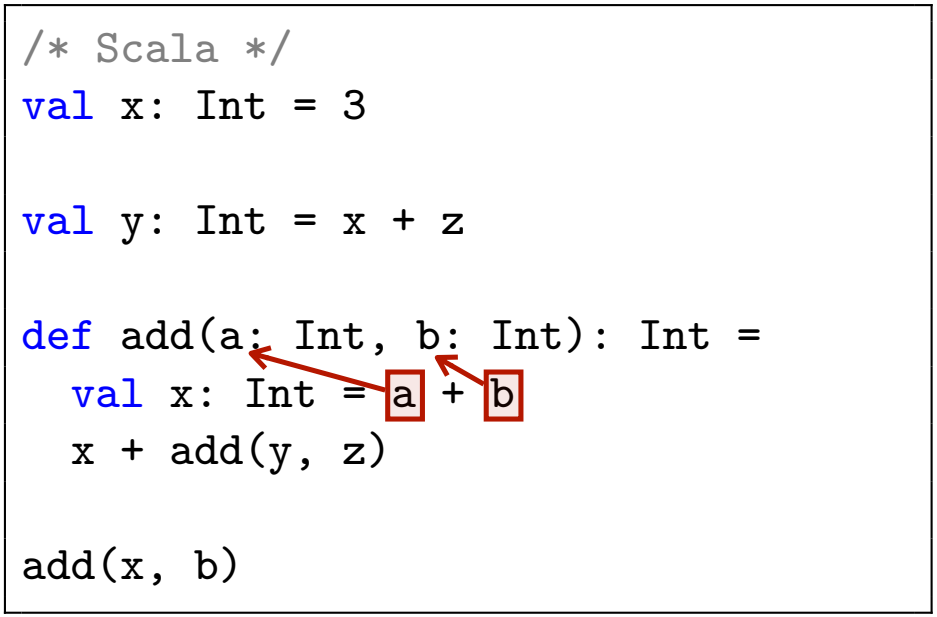

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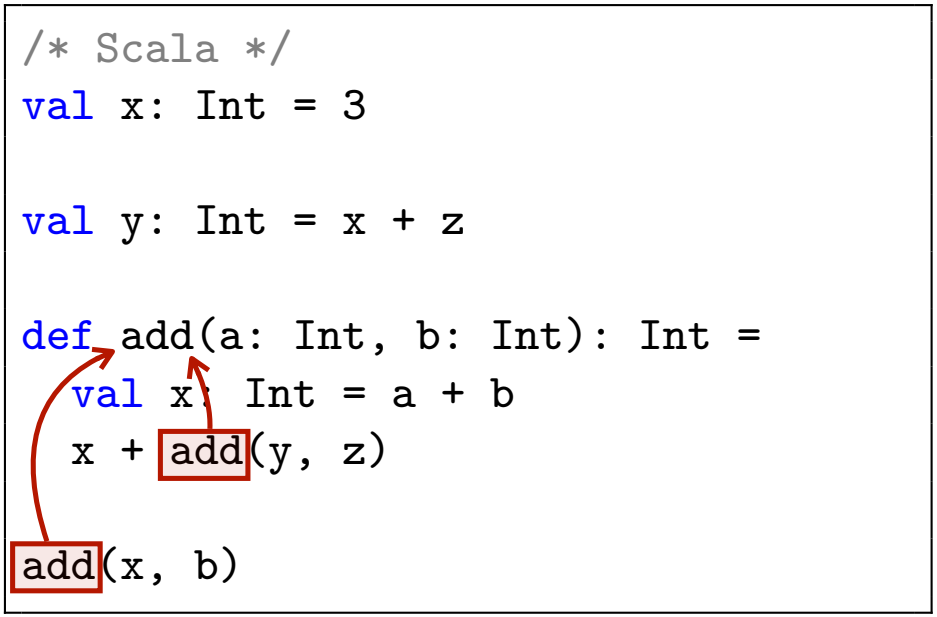

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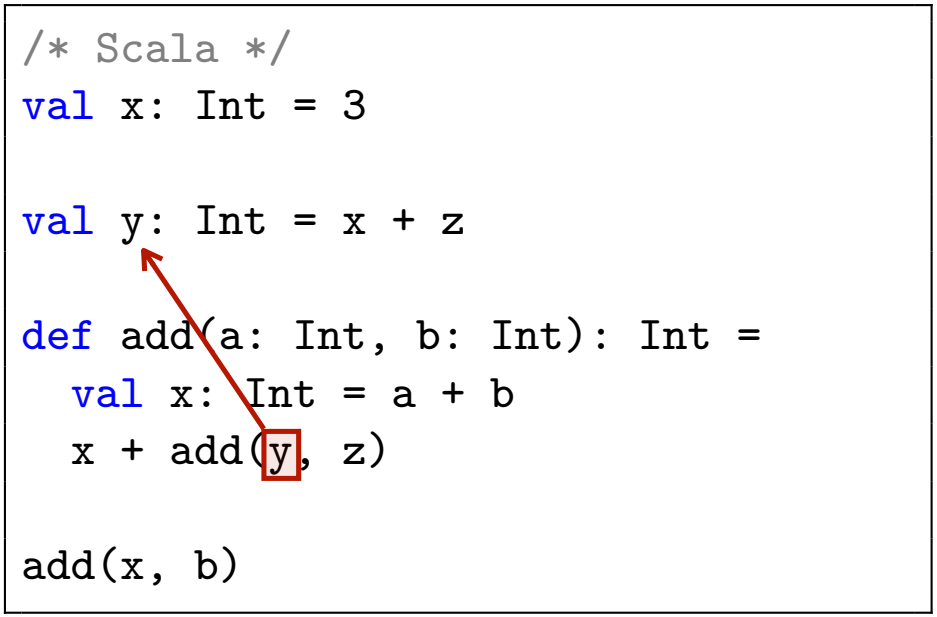

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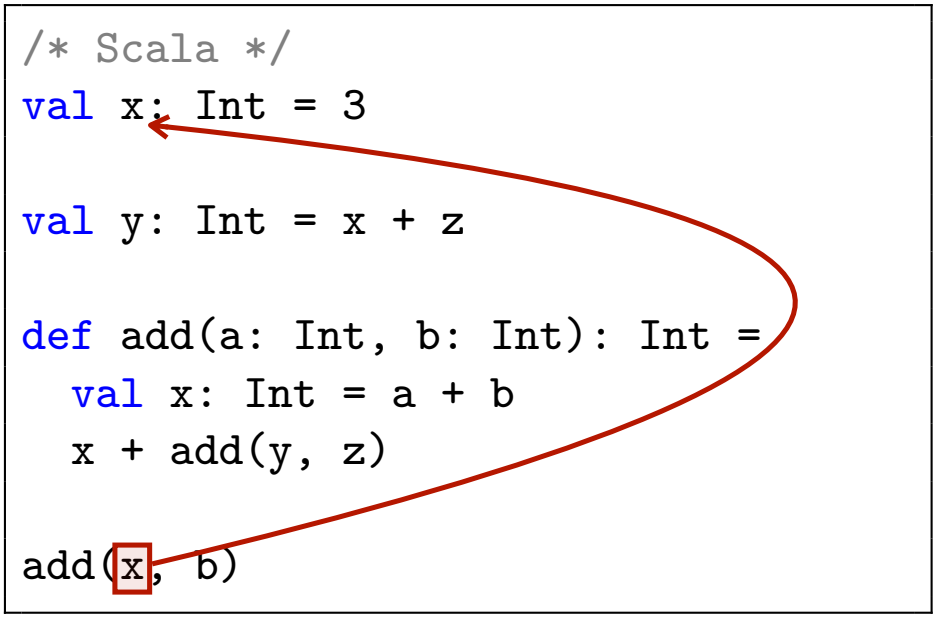

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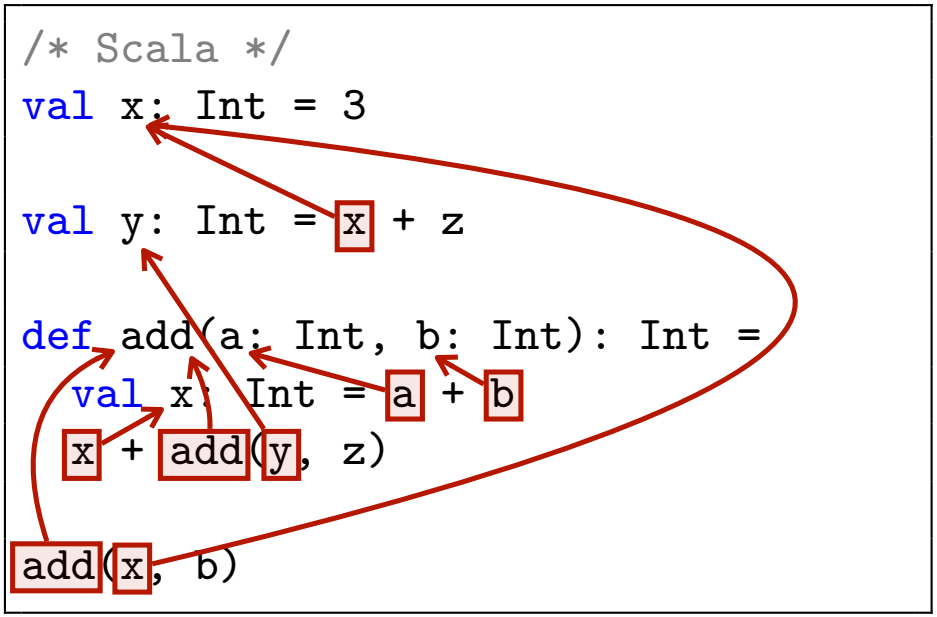

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Free Identifiers

```scala
/* Scala */
val x: Int = 3

val y: Int = x + z

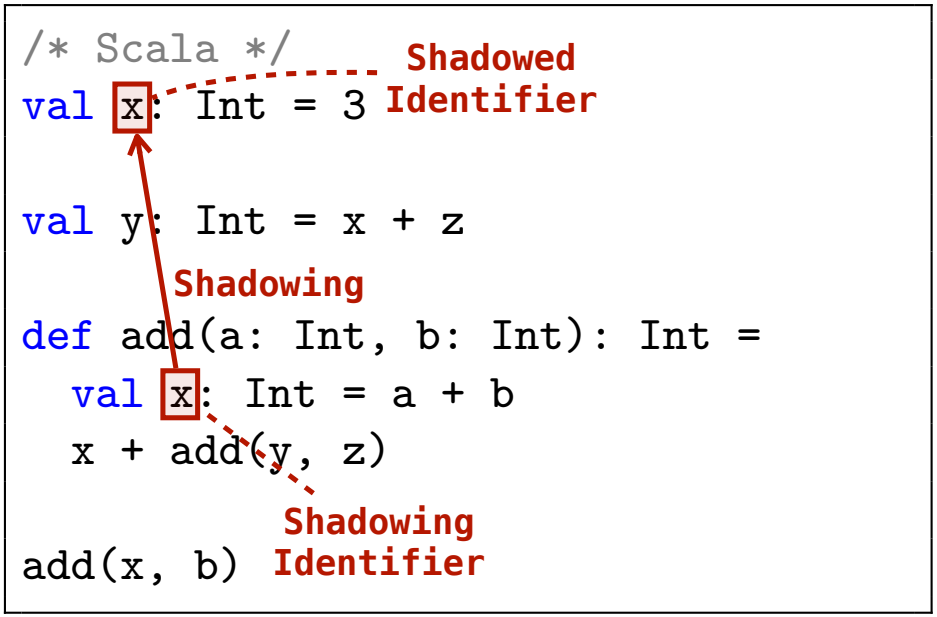
def add(a: Int, b: Int): Int =
  val x: Int = a + b
  x + add(y, z)

add(x, b)
```

Free Identifiers

A **free identifier** is an identifier that is **not defined** in the current scope of the program.

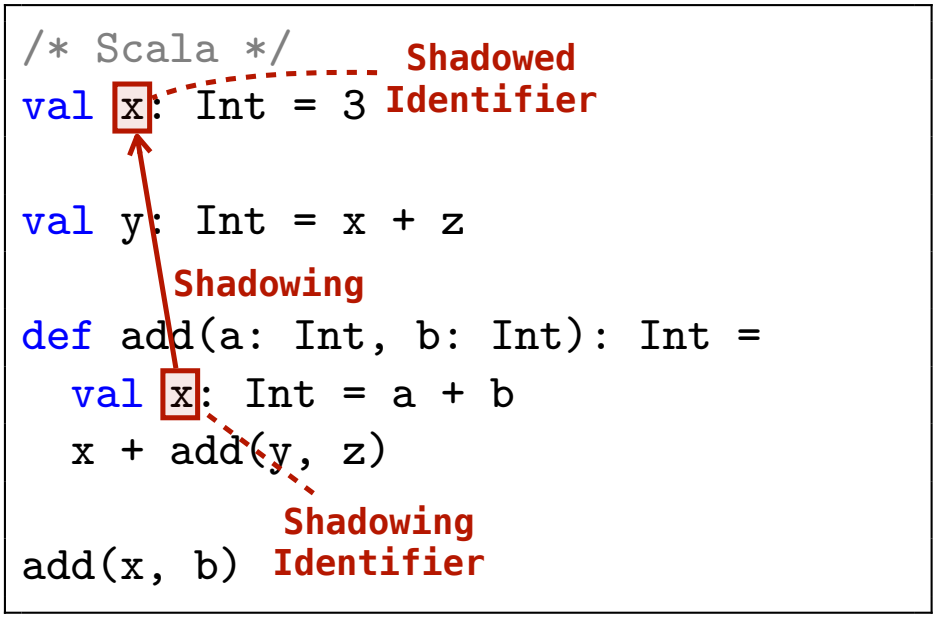
Shadowing



Shadowing means that the innermost binding occurrence shadows the outer binding occurrences of the same name.

- A **shadowing identifier** is an identifier that shadows another
- A **shadowed identifier** is an identifier that is shadowed by another.

Shadowing



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- A **shadowed identifier** is an identifier that is shadowed by another.

Note that shadowing is **NOT** a mutation.

Contents

VAE – AE with Variables

Now, we want to extend AE into VAE with **variables**:

```
/* VAE */
val x = 1 + 2;  // x = 1 + 2 = 3
val y = x + 3;  // y = x + 3 = 3 + 3 = 6
y + 4           // 6 + 4 = 10
```

VAE – AE with Variables

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val x = 1 + 2;  // x = 1 + 2 = 3
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```

First, we define the **concrete syntax** of **identifiers** used in VAE:

```
<digit>    ::= "0" | "1" | "2" | "3" | "4" | "5" | "6" | "7" | "8" | "9"
<number>   ::= "-"? <digit>+
<alphabet> ::= "A" | "B" | "C" | ... | "Z" | "a" | "b" | "c" | ... | "z"
<idstart>  ::= <alphabet> | "_"
<idcont>   ::= <alphabet> | "_" | <digit>
<keyword>  ::= "val"
<id>       ::= <idstart> <idcont>* butnot <keyword>
```

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<idcont>    ::= <alphabet> | "_" | <digit>
<keyword>   ::= "val"
<id>        ::= <idstart> <idcont>* butnot <keyword>
```

For example, the following are valid identifiers:

```
x    y    get_name    getName    add42
```

Concrete Syntax

Then, let's define the **concrete syntax** of VAE in BNF:

```
<expr> ::= <number>
         | <expr> "+" <expr>
         | <expr> "*" <expr>
         | "(" <expr> ")"
         | "{" <expr> "}"
         | "val" <id> "=" <expr> ";" <expr>
         | <id>
```

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Note that each variable definition creates a **new scope**.

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Note that each variable definition creates a **new scope**. For example:

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/* VAE */
val x = 1 + 2;
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y + 4
```

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Note that each variable definition creates a **new scope**. For example:

```
/* VAE */
val x = 1 + 2;
val y = x + 3;
y + 4
```

means

```
/* VAE */
val x = 1 + 2;
{ // scope of x
  val y = x + 3;
  { // scope of y
    y + 4
  }
}
```

Abstract Syntax

Let's define the **abstract syntax** of VAE in BNF:

Numbers	$n \in \mathbb{Z}$	(`BigInt`)
Identifiers	$x \in \mathbb{X}$	(`String`)

Expressions	e	$::=$ n	(`Num`)
		$\mid$ e `+` e	(`Add`)
		$\mid$ e `*` e	(`Mul`)
		$\mid$ `val` x `=` e`;` e	(`Val`)
		$\mid$ x	(`Id`)

Abstract Syntax

PLRG

Let's define the **abstract syntax** of VAE in BNF:

Numbers $n \in \mathbb{Z}$ (`BigInt`)

Identifiers $x \in \mathbb{X}$ (`String`)

Expressions

$$
\begin{array}{lll}
e ::= & n & \texttt{(Num)} \\
\mid & e \texttt{ + } e & \texttt{(Add)} \\
\mid & e \texttt{ * } e & \texttt{(Mul)} \\
\mid & \texttt{val } x \texttt{ = } e\texttt{; } e & \texttt{(Val)} \\
\mid & x & \texttt{(Id)}
\end{array}
$$

We can define an **ADT** for the abstract syntax of VAE in Scala:

```
enum Expr:
  case Num(number: BigInt)
  case Add(left: Expr, right: Expr)
  case Mul(left: Expr, right: Expr)
  // variable definition
  case Val(name: String, init: Expr, body: Expr)
  // variable lookup
  case Id(name: String)
```

Abstract Syntax

PLRG

```
enum Expr:
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  case Val(name: String, init: Expr, body: Expr)
  case Id(name: String)
```

Parser implementation is given and you don't need to implement it.

You can freely use `Expr` to parse VAE programs as follows:

```
Expr("val x = 1; x + 2")
// Val("x", Num(1), Add(Id("x"), Num(2)))

Expr("val a = 1; val b = 2; a + b")
// Val("a", Num(1), Val("b", Num(2), Add(Id("a"), Id("b"))))
```

Examples

PLRG

For each VAE program, please draw:

- an **arrow** from each **bound occurrence** to its **binding occurrence**.
- a **dotted arrow** from each **shadowing variable** to its **shadowed one**.
- an **X mark** on each **free variable**.

```
/* VAE */
val x = 1; x
```

```
/* VAE */
val x = x + 1;
val y = x * 2;
val x = y + x;
x * z
```

```
/* VAE */
val x = 1;
val y = {
  val x = 2 * x;
  { val y = x; y } + { val y = 3; y }
};
x + y
```

Summary

PLRG

1. Identifiers
    - Bound Identifiers
    - Free Identifiers
    - Shadowing

2. VAE – AE with Variables
    - Concrete Syntax
    - Abstract Syntax
    - Examples

Next Lecture

- Identifiers (2)

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