Comp 311
Functional Programming

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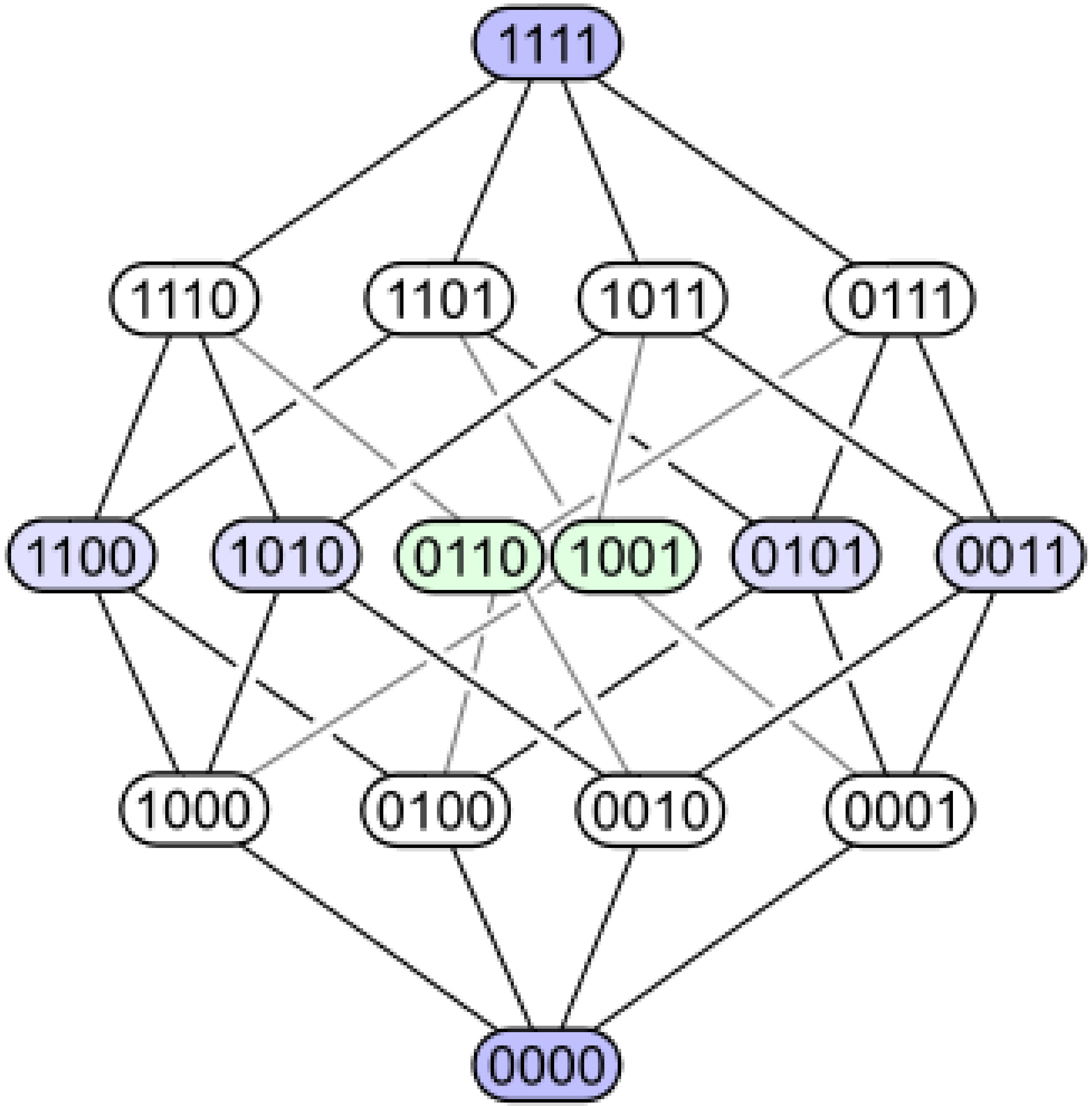
Type Hierarchies

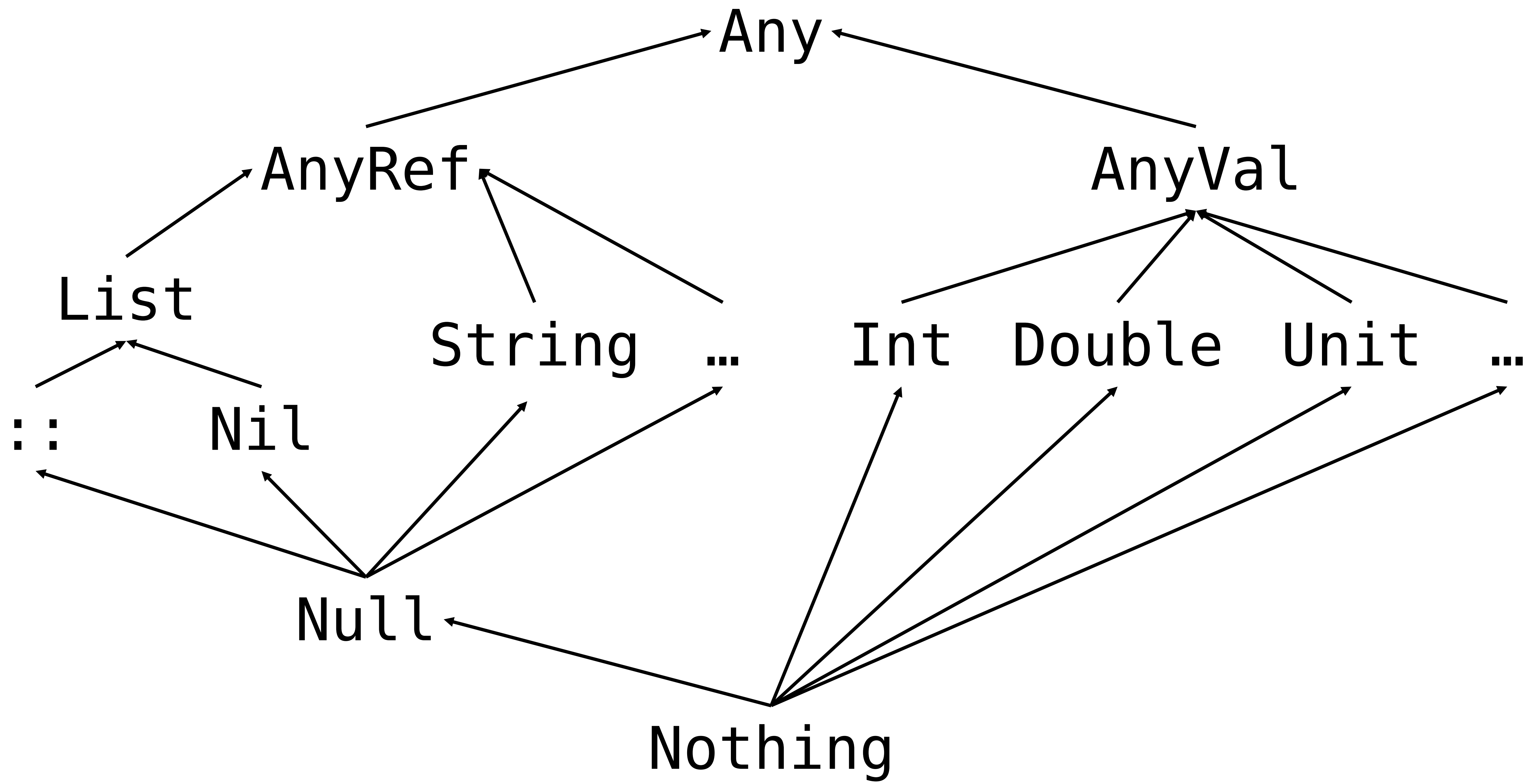
Inheritance (subclass / superclass relationships) form a *complete lattice* in the Scala type system:

- Each pair of classes has exactly one:
  - *Least upper-bound*
  - *Greatest lower-bound*
- The same applies to all value types

Hasse Diagrams



Scala Type Lattice



Multiple Inheritance

- Multiple inheritance is achieved in Scala using *traits* (we'll discuss the details of traits in a later lecture)

- Types using multiple inheritance don't form a lattice:

    - No unique *least-upper-bound*

    - No unique *greatest-lower-bound*

Overrides

Overriding Methods

- Use the *override* keyword
- Not strictly necessary if the superclass's method is abstract (unimplemented), but it helps you catch errors

Overriding toString

```
case class Sum(x: Expr, y: Expr) extends Expr {
  override def toString: String = {
    s"${x} + ${y}"
  }
}
```

Semantics of Exceptions

Continuations

- Reification of *what happens next*
- Captures the remainder of the computation at a given point in a computation
- Example:

$$\underbrace{\texttt{f(x, y)}}_{\text{Currently evaluating}}\ \underbrace{\texttt{+ z}}_{\text{Continuation}}$$

More Continuation Examples

- **Tail calls**
  A function call is a tail call iff the continuation of the call in the current method is empty; i.e., the continuation is returning to the parent caller.

- `if (x) y else z`
  Continuation of *x* is *y* when *x* is true, and *z* otherwise

- `f(x match {case A => {…} case B => {…}})`
  Continuation of *case A => {…}* is to call the function *f* with the resulting value

Semantics of Exceptions

- Thrown exceptions cause a sudden change in a program's flow of control
- Exceptions cause the current *continuation* to be replaced with an error handler
- The `catch` block of the closest enclosing `try` block is the current error handler (if it has a matching `case`)
- If there is no error handler, then evaluation ends in an error state with the thrown exception value

Try/Catch Blocks

```
try {
  expression$_0$
}
catch {
  case ExceptionPattern$_1$ => expression$_1$
  case ExceptionPattern$_2$ => expression$_2$
  …
}
```

Exception Reduction Rules

To reduce an expression `throw x`, where *x* has already been reduced to some exception value:

- Replace the entire body of the closest-enclosing `try` block with `throw x`
- If one of the `case` clauses in the corresponding `catch` block matches the exception *x*, then reduce the try/catch block to the case's expression (just like you would do for a `match` block)
- If none of the cases match, then propagate `throw x` to the next-closest enclosing `try` block
- If there are no more enclosing `try` blocks, then replace the entire remainder of the program with `throw x` as the final result

Reducing to an Error

```
require(false) ↦
throw new IllegalArgumentException()
```

```
1 / 0 ↦
throw new ArithemeticException()
```

```
{
  val x: List[Int] = Nil
  val List(y, z) = x
  …
} ↦
throw new MatchError()
```

Try/Catch Example

```
100 +
try {
  try {
    5 + 1 / 0
  }
  catch {
    case _: AssertionError => -1
    case _: MatchError => -2
  }
}
catch {
  case _: Exception => -3
}
```

Try/Catch Example

```
100 +
try {
  try {
    5 + throw new ArithmeticException()
  }
  catch {
    case _: AssertionError => -1
    case _: MatchError => -2
  }
}
catch {
  case _: Exception => -3
}
```

Try/Catch Example

```
100 +
try {
  try {
    throw new ArithmeticException()
  }
  catch {
    case _: AssertionError => -1
    case _: MatchError => -2
  }
}
catch {
  case _: Exception => -3
}
```

No matching case clause

Try/Catch Example

```
100 +
try {
  throw new ArithmeticException()
}
catch {
  case _: Exception => -3
}
```

Matching case clause

Try/Catch Example

`100 + { -3 }` ↦ **97**

Expressions that *Throw*

- ArithmeticException: divide by zero
- NoSuchElementException:
  `Nil.head, Map(1→2).get(3), …`
- ArrayIndexOutOfBoundsException
- MatchError
- AssertionError: `assert`, `ensuring` clause failures
- IllegalArgumentException: `require` clause failure

More on Operators

Operator Precedence

Based on starting character, lowest to highest:

1. Assignment operators[†]
2. Any letter
3. |
4. ^
5. &
6. = !
7. < >
8. :
9. + -
10. * / %
11. All other symbols

[†] *The = operator, plus any other operator that ends with =, but doesn't start with =, and is not <=, >=, or !=*

Precedence Example

```
         1 % 2 → 4 ** 2 == 5 EQ true ^ false
       1 % (2 → 4) ** 2 == 5 EQ true ^ false
     (1 % (2 → 4)) ** 2 == 5 EQ true ^ false
   ((1 % (2 → 4)) ** 2) == 5 EQ true ^ false
   ((1 % (2 → 4)) ** 2) == 5 EQ (true ^ false)
(((1 % (2 → 4)) ** 2) == 5) EQ (true ^ false)
```

Colon Operators

- Binary operators ending with : are applied in reverse
    - The receiver is the *second* argument
    - The parameter is the *first* argument
- X :: Y ⇒ Y.`::`(X)
- X +: Y ⇒ Y.`+:`(X)
- X :+ Y ⇒ X.`:+`(Y)

Destructuring with Binary Constructor Patterns

Binary case class factory methods can be used in patterns as binary operators for destructuring:

- The “cons” operator for matching head and tail of list:
  ```
  val x :: xs = List(1, 2, 3, 4)
  ```
- Any arity-2 case class constructor works:
  ```
  val a Tuple2 b = 5 → "five"
  ```
- Used a lot in Scala’s parser combinators:
  ```
  A ~ B // match A followed by B
  ```