Statically-typed Class-based languages – Scala

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Scala

- Statically-typed language
- Compiles to bytecode
- Modern concepts

- Example: E01

Syntax inference

- A line ending is treated as a semicolon unless one of the following conditions is true:
  - The line in question ends in a word that would not be legal as the end of a statement, such as a period or an infix operator.
  - The next line begins with a word that cannot start a statement.
  - The line ends while inside parentheses (...) or brackets [...], because these cannot contain multiple statements anyway.

- Blocks are based on indentation
  - Possible to use curly braces (version 2 syntax)

Comparison: Code Blocks

- 1D syntax
  - Relies on explicitly delineated blocks
    - Curly braces (Java, C, C#, …)
    - Begin/end (Pascal)
- 2D syntax
  - Relies on indentation (Scala 3, Python, YAML)
- Block does not have to corresponding to variable scope
  - Python, “var” in JavaScript – use function scope

Static vs. dynamic typing

- Target function is determined
  - at compile time – static typing
  - at runtime – dynamic typing

- Example: E02

Classes vs. objects

- Scala does not have static method
- Instead it features a singleton object
  - Defines a class and a singleton instance

- Example: E03

- Decompiled – AppLogger, Logger

Comparison: Types of methods

- Instance methods – i.e. qualified by this
  - Virtual vs. non-virtual
  - E.g. instance methods in Java, any method in Scala
  - Python:
    ```
    def foo(self, …)
    ```
- Class methods – i.e. qualified by class
  - Python:
    ```
    @classmethod
    def foo(cls, …)
    ```
- Static methods – i.e. without qualification
  - E.g. static methods Java
  - Python:
    ```
    @staticmethod
    def foo(…)
    ```

Type inference

- Types can be omitted – they are inferred automatically
  - At compile time

- Example: E04

Type Hierarchy

- Everything is an object
  - primitive data types behind the scene (boxing/unboxing)
- Compiler optimizes the use of primitive types
  - a primitive type is used if possible

Companion object

- A class and object may have the same name
  - Must be defined in the same source
- Then the class and object may access each others private fields
- Example: E05

Constructors

- One primary constructor
  - class parameters
  - can invoke superclass constructor

- Auxiliary constructors
  - must invoke the primary constructor (as the first one)
  - must not invoke superclass constructor

Operators

- Scala allows almost arbitrary method names (including operators)
- A method may be called without a dot
- Prefix operators have special names

- Example: E06

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Flexibility in Identifiers and Operators

- Alphanumeric identifier
  - starts with letter or underscore
- Operator identifier
  - an operator character belongs to the Unicode set of mathematical symbols(Sm) or other symbols(So), or to the 7-bit ASCII characters that are not letters, digits
  - any sequence of them
- Mixed identifier
  - e.g. unary_- to denote a prefix operator
- Literal identifier
  - with backticks (e.g. `class`) to avoid clashes with reserved words, etc.

Operator precedences

- Operator precedence determined by the first character
  - Only if the operator ends with “=“, the last character is used

(all other special characters)
* / %
\+ −
:
= !
< >
&
^
|
(all letters)
(all assignment operators)

Comparison: Operator overloading

- Operators typically use syntax different to normal functions, thus they cannot be completely freely defined
- Typically, there is some limited support for their overloading:
  - No overloading – e.g. Java
  - Limited overloading
    - Using a dedicated keyword – e.g. C# or C++
      ```
      public static Complex operator +(Complex c1, Complex c2)          … C#
      Complex operator + (Complex const &obj)                           … C++
      ```
    - Using a dedicated name – e.g. Python
      ```
      def __add__(self, other)
      ```
    - Instance method (C++, Python) vs. static method (C#)
  - Ability to create new operators with some restriction on their names
    - Operators treated almost as regular functions – e.g. Scala, Smalltalk
      - Requires flexible syntax that can infer the “dot” between the receiver and message
        `aSum := aPoint + aSmallInt` … sends message “+” with parameter aSmallInt to object aPoint

Extensions

- Similar to C#, Scala makes it possible to declare an extension of an existing type
- The extensions have to be brought to scope
  - Typically imported

- Example: E07

Context parameters (aka givens)

- Scala allows naming instances (called “givens”) that define canonical values of certain types
  - used to synthetize arguments for context parameters
- Givens have to be brought to scope to be applicable
  - Special import notation
- Example: E08

Implicit conversions

- Scala allows specifying functions that are applied automatically to make the code correct
  - conversion to the type of the argument or to the type of the receiver
  - the conversion is brought in as a “given” – same rules apply for making it visible as for other givens

- This is similar to C# implicit operator
  - `public static implicit operator byte(Digit d) => d.digit;`

- Example: E09 + H1

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Rich wrappers

- Implicit conversions used to implement so called Rich wrappers
- Standard library contains rich types for the basic ones
  - E.g. RichInt – defines methods to, until, …

Comparison: Extending functionality of existing classes

- A typical problem: `3 + aRational`
- Possible solutions:
  - Extension methods – e.g. C#, Scala
    - `public static int add(this int lhs, Rational rhs)` … C# (but as of 2022 no “extension operators”)
    - `extension (lhs: Int)`
      `def + (rhs: Rational) = Rational(lhs) + rhs` … Scala
  - Implicit conversion – e.g. Scala
    - `given Conversion[Int, Rational] = new Rational(_)`
  - Right-hand side operators – e.g. Python
    - `def __radd__(self, other)`
    - Note tha Python has similar functions also for in-place updates (x += y) – e.g. `__iadd__`

Namespaces

- Scala allows groups classes to packages (similar to Java and C#)
- Similar to C#, it allows defining multiple classes and even packages in the same file

- Example: E10

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First-class functions

- Functions are first-class citizens
- May be passed as parameters
- Anonymous functions, …
- Anonymous functions are instances of classes
  - Function1, Function2, …

- Example: E11

Tail recursion

- The compiler can do simple tail recursion
  - If the return value of a function is a recursive call to the function itself
- Example: E12

For-comprehension

- Generalized for-loops
  - generators, definitions, filters
- Translated to operations over collections
  - map, flatMap, withFilter, foreach
- Example: E13

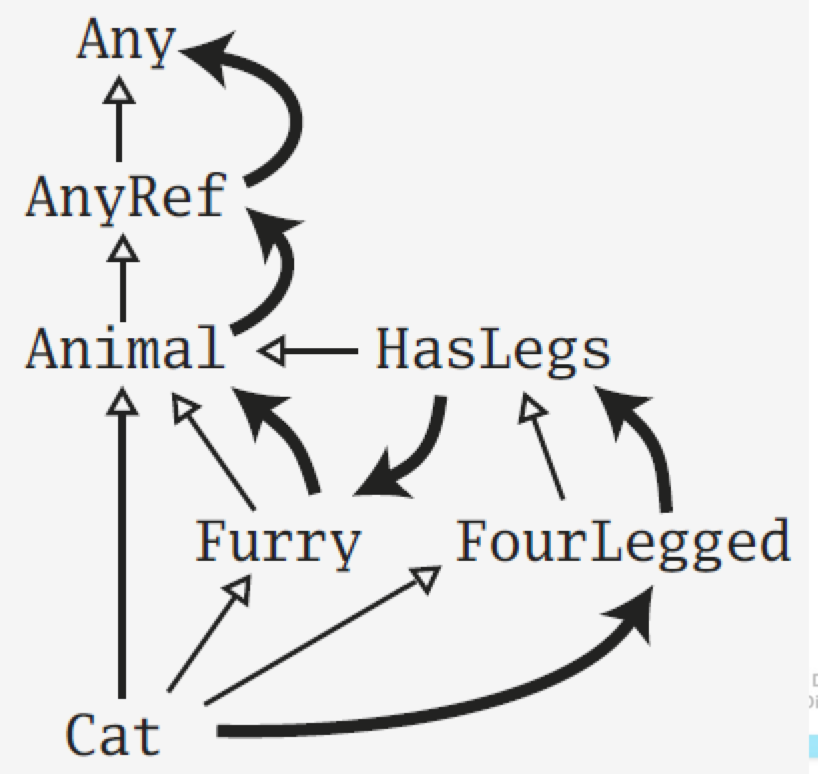
Traits

- Scala does not have interfaces
  - It has something stronger – mixins (called traits)
- A trait is like an interface, but allows for defining methods and variables

- Example: E14

Linearization

- As opposed to multiple inheritance, traits do not suffer from the diamond problem
- This is because the semantics of super is determined only when the final type is defined
- Example: E15



Comparison: Composing behavior

- Multiple inheritance
  - Without linearization – e.g. C++
    - Difficulties connected with diamond inheritance problem
  - With linearization – e.g. Python
    - Similar possibilities as with Scala, but certain problems are not there because Python is a dynamically typed language with limited abstractions for declaring classes
- Default methods in interfaces
  - Java, C#
  - No support for constructors, linearization (i.e., stackable behavior), no possibility of adding fields (i.e. state)
- Traits – e.g. Scala, Groovy
  - Support for constructors, fields, and stackable behavior

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Note on Terminology: C++ “Traits”

- The term “trait” in C++ has a different meaning
- Connected with templates, it means common characteristics of types
- E.g. std::numeric_limits

```
template<class T>
T findMax(const T const * data, const size_t const numItems) {
  T largest = std::numeric_limits<T>::min();
  for(unsigned int i=0; i<numItems; ++i)
    if (data[i] > largest) largest = data[i];
  return largest;
}
```

C++ Custom Trait Definition

```
template< typename T >
struct is_void{
  static const bool value = false;
};

template<>
struct is_void< void >{
  static const bool value = true;
};
```

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Composing Traits

- Composition of traits can be used to address the same problem as Dependency injection addresses
  - “Cake pattern”

- Example: E16

Abstract types

- What about if we want methods in a subclass to specialize method parameters?

- Example: E17

Comparison: Type Parameters vs. Type Variables

- Type can be "passed" to a class
  - via a type parameter connected with a constructor
  - via a type assignment from a descendant

```
abstract class Animal:
 type SuitableFood <: Food

class Cow extends Animal:
 override type SuitableFood = Grass

…

val c: Animal = new Cow()
```

```
abstract class Animal[SuitableFood]

class Cow extends Animal[Grass]

…

val c: Animal[_] = new Cow()
```

This Type

- Represent the type of the descendant in the parent class
- Can be regarded as an implicit abstract type
- Useful for defining chainable methods

- Example: E18

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Embedding and exporting

- Alternative to composing functionalities by traits
- Instead of extending a class, an object is embedded and its methods are exported on the interface
  - Invocation of those methods act on the embedded object
  - Also known as “Composition over inheritance”
- This is similar to type embedding in Go
  - But since Go lacks inheritance or mixins, the embedding (with all its limits) is the only way of composing functionality

- Example E19

Example: Embedding in Go

```go
// Types

type Base struct {
  b int
}

type Container struct {
  Base c string
}

func (base Base) Describe() string {
  return fmt.Sprintf("base %d", base.b)
}
```

```go
// Usage

co := Container{Base: Base{b: 10}, c: "foo"}

// OR

co := Container{}
co.b = 1
co.c = "string“

// Calling a method declared on the Base
fmt.Println(cc.Describe())
```

New control structures

- Currying – function that returns function
- By-name parameters
  - omitting empty parameter list in an anonymous function

- Example: E20

String interpolation

- String interpolation implemented by rewriting code at compile time
- Standard interpolators
  - s – interpolator

    ```
    val name = "reader"
    println(s"Hello, $name!")
    ```
  - raw – interpolator

    ```
    println(raw"No\\\\escape!") // prints: No\\\\escape!
    ```
  - f – interpolator (printf-like formatter)

    ```
    f"${math.Pi}%.5f"
    ```

- Custom interpolators can be defined
- Example: E21

Case-classes, pattern matching

- Scala allows for simple pattern matching (similar to Prolog terms)
- Case-classes
  - factory method (no new necessary)
  - all parameters are vals

- Example: E22

Case sequences & Partial functions

- Functions may be defined as case sequences
  - It’s like a function with more entry points

- Since the case sequence does not have to cover all cases, it yields a partial function
  - Partial function may be queried if a given value is in its domain
  - or it throws a runtime exception if called with an unsupported input argument

- Example: E23 + H3

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Extractors

- Pattern matching relies on method unapply
  - apply – takes arguments, returns an object
  - unapply – takes an object, returns a tuple or sequence of arguments
- Allows creating custom matchers
- Example: E24, E25

Regular Expressions

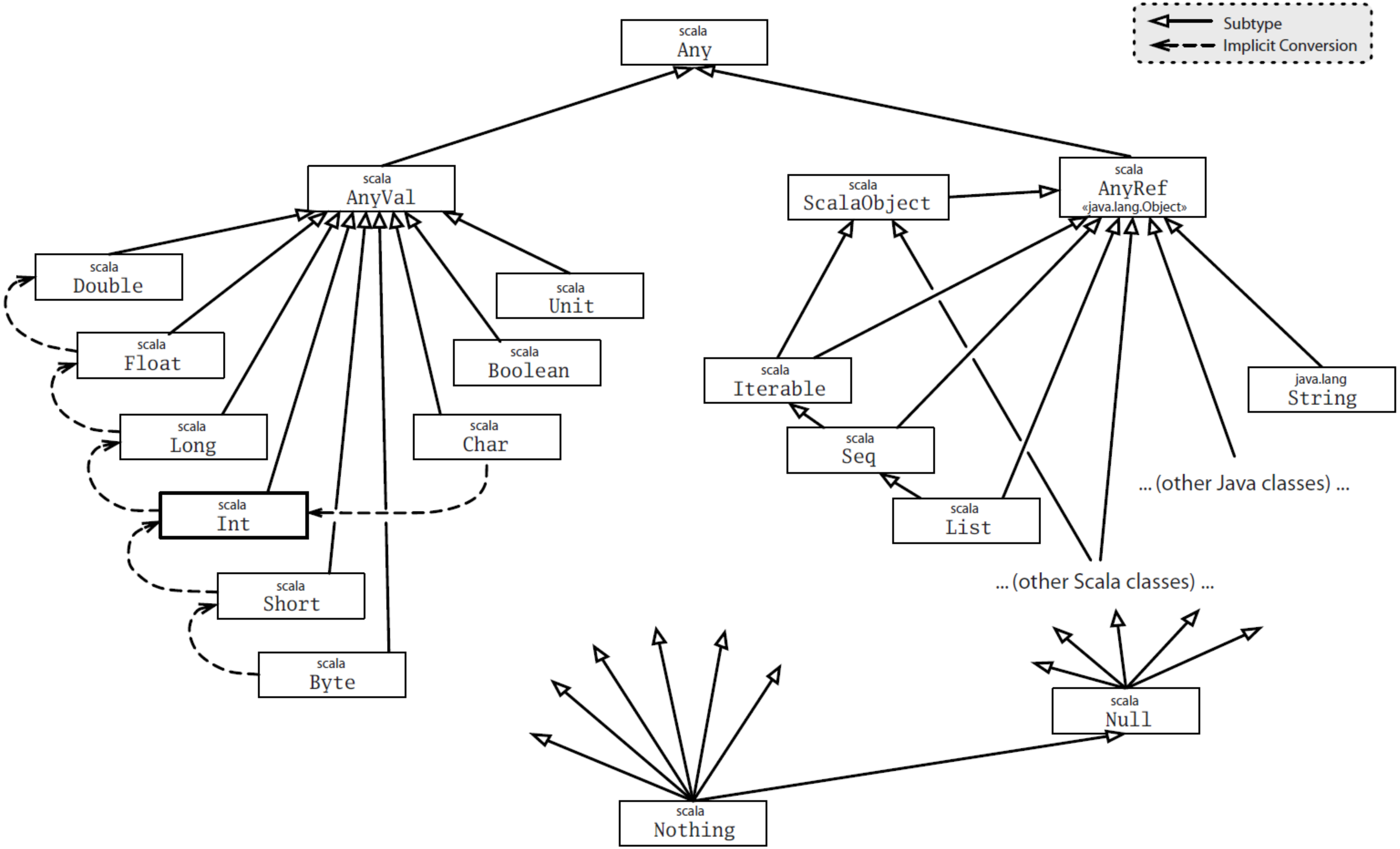
- Regular expressions are normal library class
- They can be used as extractors
  - Even more interesting when combined with string interpolation

- Example: E26

Type parameterization

- Each class and method may be parameterized by a type
- Lower and upper bounds
- Example: E27

Type Hierarchy



Null and Nothing types

- **null** is singleton instance of Null
  - can be assigned to any AnyRef

- Nothing is a subtype of everything
  - Can be assigned to anything, but does not have any instance

```
def doesNotReturn(): Nothing =
  throw new Exception
```

Nothing in Use I

```
def fail(msg: String): Nothing =
     println(msg)
     sys.exit(1)



val y = if x != null then x else fail("$&#@!")
```

Nothing in Use II

```
abstract class Option[+A]:
  def isEmpty
  def get: A


case class Some[+A](x: A) extends Option[A]:
  def isEmpty = false
  def get = x


case object None extends Option[Nothing]:
  def isEmpty = true
  def get = throw NoSuchElementException()
```

Type variance

- Assuming: A <: B (A subtype of B) and X[T]
- What is the relation of **X[A]** and **X[B]** ?
  - X[A] **<:** X[B] … X is covariant in its type parameter T
  - X[A] **>:** X[B] … X is contravariant in its type parameter T
  - No relation … X is invariant w.r.t. to the type parameter T

- Example: E28

Instance private data

- The mutable state in a class typically prevents the covariance/contravariance
- Why?
- Example: E29

Collections

- Scala offers immutable and mutable variants of collections (immutable ones preferred)
  - List vs. ListBuffer
  - HashSet vs. mutable.HashSet
  - HashMap vs. mutable.HashMap

- To achieve performance, immutable types are internally often backed by mutable structures

Path dependent types

- Nested traits/classes are specific to the instance of the outer class
- This makes types different based on the instance they are tied with
  - Though this is a runtime property, it can be with some effort checked statically
- Example: E29

Structural subtyping

- It is possible to specify only properties of a type
- Example: E30

Ways to achieve polymorphism

- Overloaded methods
  - Target types represented as variants of the same method
- Interfaces/traits/inheritance
  - Target types are individual sub-classes or they need to be wrapped by and adaptor
- Typeclasses – ad-hoc polymorphism

Typeclasses

- I.e. grouping/set of types
- Used for ad-hoc polymorphism

- Example: E31, E32