

A Taste of Dotty

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<https://github.com/hermannhueck/taste-of-dotty>

Abstract

This presentation is an introduction to Dotty / Scala 3 and an overview of many features.

It covers those features which I deem most important for Scala developers.

For detailed information see the [Dotty documentation](#).

The code examples are partly my own. I took many examples (unchanged or modified) from the Dotty Documentation.

The presentation also contains many links to specific chapters in the Dotty docs.

Agenda (1/3)

- >> Design Goals
- >> Project Setup
- >> Using Scala 2 Libraries
- >> Top Level *def*'s and *val*'s
- >> Indentation / Optional Braces
- >> New Control Syntax
- >> Main Methods
- >> Constructor Invocations w/o *new*
- >> Traits with Parameters
- >> Enums and ADTs
- >> Intersection Types

Agenda (2/3)

- >> Union Types
- >> Contextual Abstractions
- >> Implicit Conversions
- >> Extension Methods
- >> Givens
- >> Type Lambdas
- >> Typeclasses
- >> Opaque Type Aliases
- >> Implicit Function Types
- >> Dependent Function Types

Agenda (3/3)

- » Tuples are HLists
- » Match Types
- » Export Clauses
- » Explicit Nulls
- » *inline*
- » Multiversial Equality
- » Typeclass Derivation
- » Given By-Name Parameters
- » Implicit Resolution
- » Overload Resolution
- » Other Features
- » Resources

Design Goals¹

¹ <https://dotty.epfl.ch/docs/index.html>

Design Goals

- >> build on strong foundations (DOT Calculus)
- >> improve language consistency,
- >> eliminate surprising behaviours, puzzlers
- >> better (type) safety and ergonomics, simplify where possible
- >> improve performance

Project Setup²

² <https://dotty.epfl.ch/docs/usage/getting-started.html>

IDE Support³

- >> Dotty comes with a built-in Dotty Language Server.
- >> Should work with any editor that supports LSP.
(Language Server Protocol)
- >> Only Visual Studio Code is officially supported.

³ <https://dotty.epfl.ch/docs/usage/ide-support.html>

Prerequisites

- » *sbt* is installed.
- » VSCode is installed.
- » Make sure you can start VSCode with the CLI command *code*.
This is default on all systems except macOS.
(macOS users should follow the instructions below to install
the *code* command.⁴)

⁴ https://code.visualstudio.com/docs/setup/mac#_command-line

New *sbt* Project

- >> create new project: *sbt new lampepfl/dotty.g8*
- >> (or: *sbt new lampepfl/dotty-cross.g8* for a cross-build project)
- >> *cd* to project directory
- >> in the project directory: *sbt launchIDE*
(starts VSCode with the current folder as workspace,
installs the Dotty Language Server in VSCode)

build.sbt

```
// val dottyVersion = "0.21.0-RC1"
// use latest nightly build of dotty
val dottyVersion = dottyLatestNightlyBuild.get

lazy val root = project
.in(file("."))
.settings(
  name := "dotty-simple",
  version := "0.1.0",
  scalaVersion := dottyVersion,
  libraryDependencies += "com.novocode" % "junit-interface" % "0.11" % "test"
)
```

project/plugin.sbt

```
// sbt-dotty plugin  
addSbtPlugin("ch.epfl.lamp" % "sbt-dotty" % "0.4.0")
```

project/build.properties

```
// change to latest sbt version
```

```
// 1.3.6 in January 2020
```

```
sbt.version=1.2.7
```

Using Scala 2 Libraries^{4a}

^{4a} <https://github.com/lampepfl/dotty-example-project#getting-your-project-to-compile-with-dotty>

Using Scala 2 Libraries

- >> Dotty can already utilize Scala 2 libraries.
- >> This works because Dotty is currently retro-compatible with Scala 2.x.
- >> This allows to migrate to Dotty, even before 3rd party dependencies have been migrated.

```
// build.sbt
```

```
libraryDependencies ++= Seq(  
  "org.typelevel" %% "cats-effect" % catsEffectVersion,  
  "org.scalatest" %% "scalatest" % scalaTestVersion % Test  
)  
.map(module => module.withDottyCompat(scalaVersion.value))
```

Top Level *def*'s and *val*'s⁵

⁵ <https://dotty.epfl.ch/docs/reference/dropped-features/package-objects.html>

Top Level *def*'s and *val*'s

- » Scala 2: *def*'s and *val*'s must be defined in a *trait*, *class* or *object*.
- » Scala 3: *def*'s and *val*'s can be defined at the top level.
- » Scala 2: To provide *def*'s and *val*'s directly in a package, one has to use package objects.
- » Scala 3: Package objects are still available in 3.0, but will be deprecated and removed in 3.1 or 3.2.

```
// whatever.scala
package tasty.dotty

import scala.util.chaining._

val r = scala.util.Random

def randomInt(): Int =
  r.nextInt

def boxed(what: String): String = {
  val line = "\u2500" * 50
  s"$line\n${what.toString}\n$line"
}

def printBoxed(what: String): Unit =
  what pipe boxed pipe println
```

Indentation / Optional Braces⁶

⁶ <https://dotty.epfl.ch/docs/reference/other-new-features/indentation.html>

Indentation / Optional Braces

- » Braces are optional.
- » Without braces indentation becomes significant to delimit a block of code.

with braces:

```
// Scala 2 + 3:  
  
def boxed(what: Any): String = {  
    val line = "\u2500" * 50  
    s"$line\n${what.toString}\n$line"  
}
```

without braces:

```
// Scala 3:  
  
def boxed(what: Any): String =  
    val line = "\u2500" * 50  
    s"$line\n${what.toString}\n$line"
```

New Control Syntax⁷

⁷ <https://dotty.epfl.ch/docs/reference/other-new-features/control-syntax.html>

if ... then ... else

val x = 42

if x < 0 then -x else x

```
if x < 0
  "negative"
else if x == 0
  "zero"
else
  "positive"
```

while ... do (while-loop)

```
var x = 42
```

```
def f(x: Int): Int = x - 10
```

```
while x >= 0 do x = f(x)
```

```
while
```

```
  x >= 0
```

```
do
```

```
  x = f(x)
```

for ... do (for-loop)

```
val xs = List(1, 2, 3)  
val ys = List(10, 20, 30)
```

```
for x <- xs if x > 0  
do println(x * x)
```

```
for  
  x <- xs  
  y <- ys  
do  
  println(x + y)
```

for ... yield (for-comprehension)

```
val xs = List(1, 2, 3)  
val ys = List(10, 20, 30)
```

```
for x <- xs if x > 0  
yield x * x
```

```
for  
  x <- xs  
  y <- ys  
do  
  yield x + y
```

Main Methods⁸

⁸ <https://dotty.epfl.ch/docs/reference/changed-features/main-functions.html>

Main Methods

```
@main def happyBirthday(age: Int, name: String, others: String*): Unit =  
  
  val congrats = s"Happy Birthday at age $age to $name" ++ {  
    if others.isEmpty  
      ""  
    else  
      " and " ++ others.mkString(", ")  
  } ++ ". "  
  
  println(congrats)
```

Main Methods

- » A `@main` annotation on a method turns this method into an executable program.
- » The method must be static, i.e. not defined within a class or trait.
- » If annotated the method name is arbitrary.
- » Argument types can not only be `Array[String]`.
- » Any argument type is allowed if an instance of typeclass `scala.util.FromString` is in implicit scope.
- » Dotty checks the arguments passed against the signature of the main function.

Constructor Invocations w/o *new*⁹

⁹ <https://dotty.epfl.ch/docs/reference/other-new-features/creator-applications.html>

Constructors without *new*

- » When constructing instances the *new* keyword is optional.
- » Works not only for case classes but also for regular classes.
- » Works for Java classes too.
- » If no *apply* method is found, the compiler looks for a suitable constructor.

```
val sb =  
  StringBuilder("The keyword 'new'")  
    .append(" is ")  
    .append("optional")  
    .append("!")
```

Traits with Parameters¹⁰

¹⁰ <https://dotty.epfl.ch/docs/reference/other-new-features/trait-parameters.html>

Traits with Parameters

- » Traits can have parameters like classes.
- » Arguments are evaluated before the trait is initialized.
- » They replace early initializers in Scala 2 traits, which have been dropped.

```
trait Greeting(val name: String)
  def msg = s"How are you, $name"

class C extends Greeting("Bob")
  println(msg)

class D extends C with Greeting("Bill") // COMPILE ERROR
// [error] trait Greeting is already implemented by superclass C
// [error] its constructor cannot be called again
```

Enums and ADTs¹¹ ¹²

¹¹ <https://dotty.epfl.ch/docs/reference/enums/enums.html>

¹² <https://dotty.epfl.ch/docs/reference/enums/adts.html>

Simple Enums

- » *enum* is a new keyword.
- » With *enum* one can define a type consisting of a set of named values.

```
enum Color  
case Red, Green, Blue
```

Java compatible Enums

» To make your Scala-defined enums usable as Java enums, you can do so by extending `java.lang.Enum`.

```
enum Color extends java.lang.Enum[Color]
  case Red, Green, Blue
```

Enums with Parameters

» The parameters are defined by using an explicit *extends* clause.

```
enum Color(val escape: String)
  case Red extends Color(Console.RED)
  case Green extends Color(Console.GREEN)
  case Blue extends Color(Console.BLUE)
```

Methods defined for Enums

```
scala> val red = Color.Red  
val red: Color = Red  
scala> red.ordinal  
val res0: Int = 0
```

Methods defined on the companion object

```
scala> Color.valueOf("Blue")  
val res0: Color = Blue  
scala> Color.values  
val res1: Array[Color] = Array(Red, Green, Blue)
```

User-defined members of Enums

- » It is possible to add your own definitions to an enum.
- » You can also define your own methods in the *enum*'s companion object.

```
enum Color(val escape: String)
  case Red extends Color(Console.RED)
  case Green extends Color(Console.GREEN)
  case Blue extends Color(Console.BLUE)
  // user defined method
  def colored(text: String) = s"$escape$text${Console.RESET}"

import Color._

val greenHello = Green.colored("Hello World!")
```

ADTs in Scala 2

- » In Scala 2 ADTS are expressed as sealed traits with a hierarchy of case classes.
- » This syntax is still supported in Scala 3.

```
sealed trait Tree[+T]
object Tree {
  case class Leaf[T](elem: T) extends Tree[T]
  case class Node[T](left: Tree[T], right: Tree[T]) extends Tree[T]
}

import Tree._

val tree: Tree[Int] = Node(Leaf(1), Node(Leaf(2), Leaf(3)))
```

ADTs in Scala 3

» In Scala 3 an ADT can be expressed with *enum* syntax.

```
enum Tree[+T]
  case Leaf(elem: T) extends Tree[T]
  case Node(left: Tree[T], right: Tree[T]) extends Tree[T]

import Tree._

val tree: Tree[Int] = Node(Leaf(1), Node(Leaf(2), Leaf(3)))
```

ADTs with Syntactic Sugar

» The *extends* clause can be omitted in many cases.

```
enum Tree[+T]
  case Leaf(elem: T)
  case Node(left: Tree[T], right: Tree[T])

import Tree._

val tree: Tree[Int] = Node(Leaf(1), Node(Leaf(2), Leaf(3)))
```

ADTs with Methods

» As all other enums, ADTs can define methods.

```
enum Tree[+T]
  case Leaf(elem: T)
  case Node(left: Tree[T], right: Tree[T])
  def count: Int = this match
    case Leaf(_) => 1
    case Node(left, right) => left.count + right.count

import Tree._

val tree: Tree[Int] = Node(Leaf(1), Node(Leaf(2), Leaf(3)))
val count = tree.count // 3
```

Intersection Types¹³

¹³ <https://dotty.epfl.ch/docs/reference/new-types/intersection-types.html>

Intersection Types

- » Used on types, the `&` operator creates an intersection type.
- » The type $A \& B$ represents values that are of the type A and B at the same time.
- » $A \& B$ has all members/properties of A and all members/properties of B .
- » `&` is commutative: $A \& B$ is the same type as $B \& A$.
- » Intersection types will – in the long run – replace compound types: A *with* B
- » *with* is not commutative.

```
trait Resettable
  def reset(): this.type
```

```
trait Growable[T]
  def add(x: T): this.type
```

```
type ResetGrowable[T] =
  Resettable & Growable[T]
```

... continued

```
class MyClass(var x : Int = 0) extends Resettable with Growable[Int]
  def reset() =
    x = 0
    this
  def add(x: Int) =
    this.x += x
    this

  def f(x: ResetGrowable[Int]) =
    x.reset()
    x.add(-21)

@main def testIntersect: Unit =
  val obj = new MyClass(42) // 42
  obj.reset() // 0
  obj.add(10) // 10
  f(obj) // 21
```

Union Types¹⁴

¹⁴ <https://dotty.epfl.ch/docs/reference/new-types/union-types.html>

Union Types

- » A union type $A \mid B$ comprises all values of type A and also all values of type B .
- » Union types are duals of intersection types.
- » $A \mid B$ contains all members/properties which A and B have in common.
- » \mid is commutative: $A \mid B$ is the same type as $B \mid A$.
- » Pattern matching is the natural way to decide if an $A \mid B$ is an A or a B .

```
type Hash = Int

case class UserName(name: String)
case class Password(hash: Hash)

def help(id: UserName | Password): String =
  id match
    case UserName(name) => name
    case Password(hash) => hash.toString

val name: UserName = UserName("Eve")

val password: Password = Password(123)

val either: Password | UserName =
  if (true) name else password
```

Contextual Abstractions¹⁵

(Implicits in Scala 2)

¹⁵ <https://dotty.epfl.ch/docs/reference/contextual/motivation.html>

Implicits

- >> Implicits are the fundamental way to abstract over context in Scala 2.
- >> Hard to understand, error-prone, easily mis-used or overused, many rough edges.
- >> Implicits convey mechanism over intent.
- >> One mechanism used for many different purposes:
 - >> implicit conversions
 - >> extension methods
 - >> providing context
 - >> dependency injection
 - >> typeclasses

The new Design in Scala 3 (1/2)

- >> Focus on intent over mechanism
- >> Implicit conversions are hard to mis-use.
- >> Concise syntax for extension methods
- >> New keyword *given*
- >> *given* instances focus on types instead of terms.
- >> *given* clauses replace *implicit* parameters.
- >> *given* imports are distinct from regular imports.

The new Design in Scala 3 (2/2)

- » Typeclasses can be expressed in a more concise way (also due to the new extension methods).
- » Context bounds remain unchanged in syntax and semantics.
- » Typeclass derivation is supported.
- » Implicit Function Types provide a way to abstract over given clauses.
- » Implicit By-Name Parameters are an essential tool to define recursive synthesized values without looping.
- » Multiversal Equality introduces a special typeclass to support type safe equality.
- » Scala 2 implicits remain available in parallel for a long time.

Implicit Conversions¹⁶

¹⁶ <https://dotty.epfl.ch/docs/reference/contextual/conversions.html>

Implicit Conversions

» *scala.Conversion* is a subclass of *Function1*.

```
package scala
abstract class Conversion[-T, +U] extends (T => U)
```

» Implicit Conversions must extend *Conversion*.

```
case class Token(str: String)
given Conversion[String, Token]
  def apply(str: String): Token = Token(str)
```

or even more concise:

```
case class Token(str: String)
given Conversion[String, Token] = Token(_)
```

Implicit Conversion in Scala 2:

```
case class Token(str: String)
```

```
implicit def stringToToken(str: String): Token = Token(str)
```

Syntax can easily be mixed up with other implicit constructs.

Extension Methods¹⁷

¹⁷ <https://dotty.epfl.ch/docs/reference/contextual/extension-methods.html>

Extension Methods

- » Extension methods are methods that have a parameter clause in front of the defined identifier.
- » They translate to methods where the leading parameter section is moved to the front of the method name.
- » Type parameters are moved to the front of the first parameter section.
- » They can be invoked two ways:
method(param) or *param.method*
- » They replace implicit classes of Scala 2.

Extension Methods

```
case class Circle(x: Double, y: Double, radius: Double)

def (c: Circle).circumference: Double = c.radius * math.Pi * 2

val circle = Circle(0, 0, 1)

val cf1 = circle.circumference
val cf2 = circumference(circle)
assert(cf1 == cf2)
```

GivenS¹⁸

¹⁸ <https://dotty.epfl.ch/docs/reference/contextual/motivation.html>

Givens

- >> *given* is a new keyword.
- >> *given*'s in many ways replace implicits.
- >> more concise, less boilerplate
- >> focusses on types instead of terms.

Givens: Future Example 1

>> Future requires a *given ExecutionContext* in nearly every method.

```
import scala.concurrent.{Future, ExecutionContext}

// implicit val ec: ExecutionContext = ExecutionContext.global // Scala 2
given ec: ExecutionContext = ExecutionContext.global // variable ec can be omitted

def someComputation(): Int = ???
val future: Future[Int] = Future { someComputation() }

future onComplete {
  case Success(value) => println(value)
  case Failure(throwable) => println(throwable)
}
```

Givens: Future Example 2

» This example provides the *ExecutionContext* via *import*.

```
import scala.concurrent.{Future, ExecutionContext}

// import ExecutionContext.Implicits.global // Scala 2
import ExecutionContext.Implicits.{given ExecutionContext}

def someComputation(): Int = ???

val future: Future[Int] = Future { someComputation() }

future onComplete {
  case Success(value) => println(value)
  case Failure(throwable) => println(throwable)
}
```

Given Instances: *Ord* Example¹⁹

```
// a type class
trait Ord[T] {
  def compare(x: T, y: T): Int
  def (x: T) < (y: T) = compare(x, y) < 0
  def (x: T) > (y: T) = compare(x, y) > 0
}
```

Typeclass instances to be defined as *given*'s ...

¹⁹ <https://dotty.epfl.ch/docs/reference/contextual/delegates.html>

given Instances

- » They replace *implicit val*'s, *def*'s and *object*'s.
- » They can be defined with only a type omitting a name/symbol.
- » Symbols – if omitted – are synthesized by the compiler.

given Instances for *Ord*

```
// instances with symbols
given intOrd: Ord[Int]
  def compare(x: Int, y: Int) = ???

given listOrd[T](given ord: Ord[T]): Ord[List[T]]
  def compare(xs: List[T], ys: List[T]): Int = ???

// instance without symbols
given Ord[Int]
  def compare(x: Int, y: Int) = ???

given [T](given Ord[T]): Ord[List[T]]
  def compare(xs: List[T], ys: List[T]): Int = ???
```

given Clauses²⁰

- >> They replace the implicit parameter list.
- >> Multiple *given* clauses are allowed.
- >> Anonymous *given*'s: Symbols are optional.
- >> *given* instances can be summoned with the function *summon*.
- >> *summon* replaces Scala 2's *implicitly*.

²⁰<https://dotty.epfl.ch/docs/reference/contextual/given-clauses.html>

given Clauses using Symbols

```
def max[T](x: T, y: T)(given ord: Ord[T]): T =  
  if (ord.compare(x, y) < 0) y else x
```

```
def maximum[T](xs: List[T])(given Ord[T]): T =  
  xs.reduceLeft(max)
```

```
def descending[T](given asc: Ord[T]): Ord[T] = new Ord[T] {  
  def compare(x: T, y: T) = asc.compare(y, x)  
}
```

```
def minimum[T](xs: List[T])(given ord: Ord[T]) =  
  maximum(xs)(given descending)
```

Anonymous *given* Clauses (without Symbols)

```
def max[T](x: T, y: T)(given Ord[T]): T =  
  if (summon[Ord[T]].compare(x, y) < 0) y else x
```

```
def maximum[T](xs: List[T])(given Ord[T]): T =  
  xs.reduceLeft(max)
```

```
def descending[T](given Ord[T]): Ord[T] = new Ord[T] {  
  def compare(x: T, y: T) = summon[Ord[T]].compare(y, x)  
}
```

```
def minimum[T](xs: List[T])(given Ord[T]) =  
  maximum(xs)(given descending)
```

Usages

» When passing a *given* explicitly, the keyword *given* is required in front of the symbol.

```
val xs = List(1, 2, 3)
```

```
max(2, 3) // max of two Ints
```

```
max(2, 3)(given int0rd) // max of two Ints - passing the given explicitly
```

```
max(xs, Nil) // max of two Lists
```

```
minimum(xs) // minimum element of a List
```

```
maximum(xs)(given descending) // maximum element of a List (in desc order)
```

Context Bounds²¹

- » These remain nearly unchanged.
- » A context bound is syntactic sugar for the last given clause of a method.

```
// using an anonymous given
def maximum[T](xs: List[T])(given Ord[T]): T =
  xs.reduceLeft(max)
```

```
// using context bound
def maximum[T: Ord](xs: List[T]): T =
  xs.reduceLeft(max)
```

²¹ <https://dotty.epfl.ch/docs/reference/contextual/context-bounds.html>

Given Imports²²

```
object A
  class TC
  given tc: TC
  def f(given TC) = ???

object B
  import A._ // imports all members of A except the given instances
  import A.given // imports only the given instances of A

object C
  import A.{given, _} // import givens and non-givens with a single import

object D
  import A.{given A.TC} // importing by type
```

²² <https://dotty.epfl.ch/docs/reference/contextual/import-delegate.html>

Type Lambdas²³

²³ <https://dotty.epfl.ch/docs/reference/new-types/type-lambdas.html>

Type Lambdas

- » Type Lambdas are new feature in Scala 3.
- » Type Lambdas can be expressed in Scala 2 using a weird syntax with existential types and type projections.
- » The *kind-projector* compiler plugin brought a more convenient type lambda syntax to Scala 2.
- » Existential types and type projections are dropped from Scala 3.²⁴ ²⁵
- » Type lambdas remove the need for *kind-projector*.

²⁴ <https://dotty.epfl.ch/docs/reference/dropped-features/existential-types.html>

²⁵ <https://dotty.epfl.ch/docs/reference/dropped-features/type-projection.html>

Type Lambdas

- >> A type lambda lets one express a higher-kinded type directly, without a type definition.
- >> Type parameters of type lambdas can have variances and bounds.

A parameterized type definition or declaration such as

```
type T[X] = (X, X)
```

is a shorthand for a plain type definition with a type-lambda as its right-hand side:

```
type T = [X] =>> (X, X)
```

Type Lambda Example: Either Monad Instance

```
// Scala 2 without kind-projector
implicit def eitherMonad[L]: Monad[({type lambda[x] = Either[L, x]})#lambda] = ...
```

```
// Scala 2 using kind-projector
implicit def eitherMonad[L]: Monad[lambda[x => Either[L, x]]] = ...
```

```
// Scala 2 using kind-projector with ? syntax (use * in newer versions of kind-projector)
implicit def eitherMonad[L]: Monad[Either[L, ?]] = ...
```

```
// Scala 3 using a type lambda
given eitherMonad[L]: Monad[[R] ->> Either[L, R]] { ... }
```

```
// Scala 3 using compiler option -Ykind-projector
given eitherMonad[L]: Monad[Either[L, *]] { ... }
```

Typeclasses²⁶

(Monad Example)

²⁶<https://dotty.epfl.ch/docs/reference/contextual/typeclasses.html>

Typeclasses: Monad Trait

- » The previous type class *Ord* defined an *Ordering* for some type *A*.
- » *Ord* was polymorphic and parameterized with type *A*.
- » *Functor* and *Monad* are parameterized with the higher-kinded type *F[?]*. (Higher-kinded polymorphism)

```
trait Functor[F[_]] // use _ or ? for wildcard type
  def [A, B](x: F[A]) map (f: A => B): F[B]
```

```
trait Monad[F[_]] extends Functor[F] // use _ or ? for wildcard type
  def pure[A](a: A): F[A]
  def [A, B](fa: F[A]) flatMap (f: A => F[B]): F[B]
  override def [A, B] (fa: F[A]) map (f: A => B): F[B] =
    flatMap(fa)(f andThen pure)
  def [A](fa: F[F[A]]) flatten: F[A] =
    flatMap(fa)(identity)
```

Typeclasses: Monad Instances

```
object Monad {  
  
  given Monad[List]  
    override def pure[A](a: A): List[A] = List(a)  
    override def [A, B](list: List[A]) flatMap (f: A => List[B]): List[B] =  
      list flatMap f  
  
  given Monad[Option]  
    override def pure[A](a: A): Option[A] = Some(a)  
    override def [A, B](option: Option[A]) flatMap (f: A => Option[B]): Option[B] =  
      option flatMap f  
  
  given [L]: Monad[[R] =>> Either[L, R]]  
    def pure[A](a: A): Either[L, A] = Right(a)  
    def [A, B](fa: Either[L, A]) flatMap (f: A => Either[L, B]): Either[L, B] =  
      fa flatMap f  
}
```

Typeclasses: Using the Monad Instances

```
def compute[F[?]: Monad, A, B](fa: F[A], fb: F[B]): F[(A, B)] =  
  for  
    a <- fa  
    b <- fb  
  yield (a, b)  
  
val l1 = List(1, 2, 3)  
val l2 = List(10, 20, 30)  
val lResult = compute(l1, l2) // List((1,10), (1,20), (1,30), (2,10), (2,20), (2,30), (3,10), (3,20), (3,30))  
  
val o1 = Option(1)  
val o2 = Option(10)  
val oResult = compute(o1, o2) // Some((1,10))  
  
val e1 = Right(1).withLeft[String]  
val e2 = Right(10).withLeft[String]  
val eResult = compute(e1, e2) // Right((1,10))
```

Opaque Type Aliases²⁷

²⁷ <https://dotty.epfl.ch/docs/reference/other-new-features/opaques.html>

Opaque Type Aliases

- » Opaque types aliases provide type abstraction without any overhead.
- » No Boxing !!!
- » They are defined like normal type aliases, but prefixed with the new keyword *opaque*.
- » They must be defined within the scope of an object, trait or class.
- » The alias definition is visible only within that scope.
- » Outside the scope only the defined alias is visible.
- » Opaque type aliases are compiled away and have no runtime overhead.
- » In Scala 2 one could use Value Classes to avoid boxing. (Many limitations!)

```
object Geometry {  
    opaque type Length = Double  
    opaque type Area = Double  
  
    object Length { def apply(d: Double): Length = d }  
    object Area { def apply(d: Double): Area = d }  
  
    extension on (length: Length)  
        def double: Double = length  
    extension on (area: Area)  
        def double: Double = area  
  
    enum Shape {  
        case Circle(radius: Length)  
        case Rectangle(width: Length, height: Length)  
  
        def area: Area = this match  
            case Circle(r) => math.Pi * r * r  
            case Rectangle(w, h) => w * h  
        def circumference: Length = this match  
            case Circle(r) => 2 * math.Pi * r  
            case Rectangle(w, h) => 2 * w + 2 * h  
    }  
}
```

- >> Outside the *object Geometry* only the types *Length* and *Area* are known.
- >> These types are not compatible with *Double*.
- >> A *Double* value cannot be assigned to a variable of type *Area*.
- >> An *Area* value cannot be assigned to a variable of type *Double*.

```
import Geometry._  
import Geometry.Shape._  
  
val circle = Circle(Length(1.0))  
  
// val cArea: Double = circle.area // error: found: Area, required: Double  
val cArea: Area = circle.area  
val cAreaDouble: Double = cArea.double  
  
// val cCircumference: Double = circle.circumference // error: found: Length, required: Double  
val cCircumference: Length = circle.circumference  
val cCircumferenceDouble: Double = cCircumference.double
```

Implicit Function Types²⁸

²⁸<https://dotty.epfl.ch/docs/reference/contextual/implicit-function-types.html>

Implicit Function Types

- » Implicit functions are functions with (only) implicit parameters.
- » Their types are implicit function types with their parameters preceded with the keyword *given*.

Implicit Function Literals

- » Like their types, implicit function literals are also prefixed with *given*.
- » They differ from normal function literals in two ways:
 - » Their parameters are defined with a given clause.
 - » Their types are implicit function types.

Example with *ExecutionContext*

```
type Executable[T] = (given ExecutionContext) => T

given ec: ExecutionContext = ExecutionContext.global

def f(x: Int): Executable[Int] = {
    val result: AtomicInteger = AtomicInteger(0)
    def runOnEC(given ec: ExecutionContext) =
        ec.execute(() => result.set(x * x)) // execute a Runnable
        Thread.sleep(100L) // wait for the Runnable to be executed
        result.get
    runOnEC
}

val res1 = f(2)(given ec)    //=> 4 // ExecutionContext passed explicitly
val res2 = f(2)              //=> 4 // ExecutionContext resolved implicitly
```

Example: *PostConditions*

```
object PostConditions {  
  
    opaque type WrappedResult[T] = T  
  
    def result[T](given r: WrappedResult[T]): T = r  
  
    def [T](x: T) ensuring(condition: (given WrappedResult[T]) => Boolean): T =  
        assert(condition(given x))  
        x  
  
    }  
  
    import PostConditions.{ensuring, result}  
  
    val sum = List(1, 2, 3).sum.ensuring(result == 6)
```

Dependent Function Types²⁹

²⁹ <https://dotty.epfl.ch/docs/reference/new-types/dependent-function-types.html>

Dependent Function Types

- » In a dependent method the result type refers to a parameter of the method.
- » Scala 2 already provides dependent methods (but not dependent functions).
- » Dependent methods could not be turned into functions (there was no type that could describe them).

```
trait Entry { type Key; val key: Key }

def extractKey(e: Entry): e.Key = e.key           // a dependent method
val extractor: (e: Entry) => e.Key = extractKey // a dependent function value
//          ||  ↓  ↓  ↓  ↓  ↓  ↓  ↓  ||
//          ||  Dependent    ||
//          ||  Function Type ||
//          ||  _____||

val intEntry = new Entry { type Key = Int; val key = 42 }
val stringEntry = new Entry { type Key = String; val key = "foo" }

val intKey1 = extractKey(intEntry) // 42
val intKey2 = extractor(intEntry) // 42
val stringKey1 = extractKey(stringEntry) // "foo"
val stringKey2 = extractor(stringEntry) // "foo"

assert(intKey1 == intKey2)
assert(stringKey1 == stringKey2)
```

Tuples are HLists

Tuples are HLists

- » Tuples and HList express the same semantic concept.
- » Scala 3 provides Tuple syntax (like Scala 2) and HList syntax to express this concept.
- » Both are completely equivalent.
- » In Scala 2 the number of Tuple members is limited to 22, in Scala 3 it is unlimited.
- » This is beneficial for *shapeless3* (must no longer convert between tuples and HLists).

```
// Scala 2 + 3: Tuple syntax
val isb1: (Int, String, Boolean) = (42, "foo", true)

// Scala 3: HList syntax
val isb2: Int *: String *: Boolean *: Unit = 42 *: "foo" *: true *: ()

// HList in Scala 2 with 'shapeless'
// val isb3: Int :: String :: Boolean :: HNil = 42 :: "foo" :: true :: HNil

summon[Int, String, Boolean] ==: Int *: String *: Boolean *: Unit] // identical types

assert(isb1 == isb2) // identical values
```

Match Types³⁰

³⁰ <https://dotty.epfl.ch/docs/reference/new-types/match-types.html>

Match Types

- » Match types are *match* expressions on the type level.
- » The syntax is analogous to *match* expressions on the value level.
- » A match type reduces to one of a number of right hand sides, depending on the scrutinee type.

```
type Elem[X] = X match
  case String => Char
  case Array[t] => t
  case Iterable[t] => t

// proofs
summon[Elem[String]]      ==:= Char
summon[Elem[Array[Int]]]   ==:= Int
summon[Elem[List[Float]]]  ==:= Float
summon[Elem[Nil.type]]     ==:= Nothing
```

Recursive Match Types

» Match types can be recursive.

```
type LeafElem[X] = X match
  case String => Char
  case Array[t] => LeafElem[t]
  case Iterable[t] => LeafElem[t]
  case AnyVal => X
```

» Recursive match types may have an upper bound.

```
type Concat[Xs <: Tuple, +Ys <: Tuple] <: Tuple = Xs match
  case Unit => Ys
  case x *: xs => x *: Concat[xs, Ys]
```

Export Clauses³¹

³¹ <https://dotty.epfl.ch/docs/reference/other-new-features/export.html>

Export Clauses aka Export Aliases

- >> An export clause syntactically has the same format as an import clause.
- >> An export clause defines aliases for selected members of an object.
- >> Exported members are accessible from inside the object as well as from outside ...
 - >> ... even when the aliased object is private.
- >> Export aliases encourage a best practice: Prefer composition over inheritance.
- >> They also fill the gap left by deprecated/removed package objects which inherited from some class or trait.
- >> A *given* instance can also be exported, if the exported member is also tagged with *given*.

Export Clauses

```
class A
  def a1 = 42
  def a2 = a1.toString

class B
  private val a = new A
  export a.{a2 => aString} // exports a.a2 aliased to aString

  val b = new B

// a.a1 and a.a2 are not directly accessible as a is private in B.
// The export clause makes a.a2 (aliased to aString) accessible as a member of b.
  val bString = b.aString ensuring (_ == 42.toString)
```

Explicit Nulls³²

³² <https://dotty.epfl.ch/docs/reference/other-new-features/explicit-nulls.html>

Explicit Nulls

- » Explicit nulls are an opt-in feature, enabled via the `-Yexplicit-nulls` compiler flag.
- » This modifies the Scala type system, making reference types (anything that extends `AnyRef`) non-nullable.
- » Explicit nulls change the type hierarchy, so that `Null` is only a subtype of `Any`, as opposed to every reference type.
- » After erasure, `Null` remains a subtype of all reference types (as forced by the JVM).
- » $T \mid Null$ expresses nullability. It is the type of a nullable value.

```
// error: found `Null`, but required `String`  
val s1: String = null
```

```
// Ok  
val s2: String | Null = null
```

Explicit Nulls: Unsoundness

- » There are still instances where an expression has a non-nullable type like String, but its value is null.
- » The unsoundness happens because uninitialized fields in a class start out as null.

```
class C {  
    val f: String = foo(f)  
    def foo(f2: String|Null): String = if (f2 == null) "field is null" else f2  
}  
  
val c = new C()  
// c.f == "field is null"
```

Explicit Nulls: Equality Checks

- >> Comparison between AnyRef and Null (using `==`, `!=`, `eq` or `ne`) is no longer allowed.
- >> `null` can only be compared with `Null`, nullable union ($T \mid Null$), or `Any` type.

```
val x: String = "foo"
val y: String | Null = "foo"

x == null      // error: Values of types String and Null cannot be compared with == or !=
x eq null     // error
"hello" == null // error

y == null      // ok
y == x         // ok

(x: String | Null) == null // ok
(x: Any) == null          // ok
```

Working with Nulls

- >> An extension method `.nn` is provided to "cast away" nullability.

```
val strOrNull: String|Null = "foo"  
val str: String = strOrNull.nn
```

Java Interop

- >> Java reference types (loaded from source or from byte code) are always nullable.
- >> E.g. a Java value or method returning *String* is patched to return *String|JavaNull*.
- >> *JavaNull* is an alias for *Null* with 'magic properties' (see [documentation](#)).

*inline*³³

³³ <https://dotty.epfl.ch/docs/reference/metaprogramming/inline.html>

inline

- » Scala 3 introduces a new modifier *inline*.
- » ... to be used with methods, *val*'s, parameters, conditionals and match expressions.
- » *val*'s and parameters, expressions must be fixed at compile time to be inlinable.
- » The compiler guarantees inlining or fails to compile.
- » In Scala 2 the `@inline` annotation was a hint to the compiler to inline if possible.
- » Use annotation `@forceInline` when cross-compiling for Scala 2 and Scala 3.
- » `@forceInline` is equivalent to the modifier *inline* in Scala 3 and ignored in Scala 2.
- » For cross-compilation use both annotations: `@forceInline` as well as `@inline`.

inline Example

```
object Config {  
    inline val logging = false // RHS must be a constant expression (i.e. known at compile time)  
}  
  
object Logger {  
    inline def log[T](msg: String)(op: => T) =  
        if Config.logging // Config.logging is a constant condition known at compile time.  
            println(s"START: $msg")  
            val result = op  
            println(s"END: $msg; result = $result")  
            result  
        else  
            op  
}
```

- » The Logger object contains a definition of the *inline* method *log*, which will always be inlined at the point of call.
- » In the inlined code, an if-then-else with a constant condition will be rewritten to its then- or else-part.

Recursive Inline Methods

```
inline def power(x: Double, inline n: Int): Double = { // for inlining n must be a constant.  
  if n == 0 then 1.0  
  else if n == 1 then x  
  else  
    val y = power(x, n / 2)  
    if n % 2 == 0 then y * y else y * y * x  
}  
  
power(expr, 10)  
// translates to:  
//   val x = expr  
//   val y1 = x * x    // ^2  
//   val y2 = y1 * y1 // ^4  
//   val y3 = y2 * x  // ^5  
//   y3 * y3          // ^10
```

inline Conditionals

- >> If the condition of an if-then-else expressions is a constant expression then it simplifies to the selected branch.
- >> When prefixing an if-then-else expression with inline the condition has to be a constant expression.
- >> This guarantees that the conditional will always simplify.

```
inline def update(delta: Int) =  
  inline if delta >= 0 then increaseBy(delta)  
  else decreaseBy(-delta)
```

A call *update(22)* would rewrite to *increaseBy(22)* as 22 is a compile-time constant. If *update* was not called with a constant, this code snippet doesn't compile.

Inline Matches

- » A match expression in the body of an inline method definition may also be prefixed by the inline modifier.
- » If there is enough static information to unambiguously take a branch, the expression is reduced to that branch.
- » Otherwise a compile-time error is raised that reports that the match cannot be reduced.

```
inline def g(x: Any) <: Any = inline x match {  
  case x: String => (x, x) // return type: Tuple2[String, String](x, x)  
  case x: Double => x      // return type: Double  
}
```

```
val res1: Double = g(1.0d) // Has type 1.0d which is a subtype of Double  
val res2: (String, String) = g("test") // Has type (String, String)
```

Multiversial Equality³⁴ ³⁵

³⁴ <https://dotty.epfl.ch/docs/reference/contextual/multiversal-equality.html>

³⁵ <https://heikoseeberger.rocks/2020/01/07/2020-01-07-dotty-4/>

Universial Equality

- » In Scala 2 and Scala 3 you can compare values of any two different types with == and !=.
- » These comparisons are not type safe.
- » The operators internally use *Any#equals*.
- » This is the heritage of *java.lang.Object#equals*

```
final case class Foo()
```

```
Foo() == Foo()           // true
```

```
Foo() == Option(Foo()) // false - but should not compile
```

Multiversal or Strict Equality (1/5)

- >> Scala 3 gives you strict equality as an opt-in feature.
- >> Import `scala.language.strictEquality` or add `-language:strictEquality` to scalacOptions.
- >> Enabling this feature prevents successful compilation for all comparisons ...
- >> ... with some exceptions. You can still compare numbers.

`scala.language.strictEquality`

```
Foo() == Foo()          // does not compile
Foo() == Option(Foo()) // does not compile
```

Multiversal or Strict Equality (2/5)

- » For the types you want to compare you have to provide an *Eql* instance.

```
given Eql[Foo, Foo] = Eql.derived
```

```
Foo() == Foo() // compiles; result: true
```

```
Foo() == Option(Foo()) // does not compile, as we want
```

Multiversal or Strict Equality (3/5)

» You can also use the *derives* clause when defining your class.

```
final case class Bar() derives Eql
// this is equivalent to
// given Eql[Bar, Bar] = Eql.derived

Bar() == Bar()          // true
Bar() == Option(Bar())  // does not compile

// you can still not compare _Foo_’s with _Bar_’s.
Foo() == Bar()          // does not compile
Bar() == Foo()          // does not compile
```

Multiversal or Strict Equality (4/5)

- >> If you want to compare *Foo*'s with *Bar*'s ...
- >> provide two *Eql* instances which allow the comparison.

```
given Eql[Foo, Bar] = Eql.derived
given Eql[Bar, Foo] = Eql.derived

Foo() == Bar()           // compiles; result is false
Bar() == Foo()           // compiles; result is false
```

Multiversal or Strict Equality (5/5)

- » The Scala standard library provides bidirectional `Eql` instances for several types:
- » Numeric types can be compared with each other and with `java.lang.Number`.
- » `Boolean` can be compared to `Boolean` and to `java.lang.Boolean`.
- » `Char` can be compared to `Char` and to `java.lang.Character`.
- » `Seq[T]` can be compared to `Seq[T]` (or any sub type) if their element types can be compared.
- » `Set[T]` can be compared to `Set[T]` (or any sub type) if their element types can be compared.
- » Any subtype of `AnyRef` can be compared with `Null`.

```
42 == 42L          // true
42 == 42.0         // true
List(1, 2, 3) == Vector(1, 2, 3) // true
Foo() == null      // false
```

Typeclass Derivation³⁶

³⁶ <https://dotty.epfl.ch/docs/reference/contextual/derivation.html>

Typeclass Derivation

- » In Scala 2 type class derivation wasn't baked into the language.
- » Type class derivation was provided by 3rd party libraries:
shapeless, Magnolia, scalaz-derived.
- » These libraries were based on Scala 2 macros.
- » Scala 3 comes with low level mechanics for typeclass derivation,
- » which are provided primarily for library authors (not for users).

Typeclass Derivation (how it works)

- » Type class derivation supports product types (case classes) and sum types (enums, ADTs).
- » The typeclass author provides the typeclass trait and a method *derived* in the typeclass companion object.
- » *derived* – not necessarily but typically – has a parameter of type *Mirror*.
- » *Mirror* provides the meta information of the typeclass, useful to implement *derived*.
- » The typeclass user can easily create an instance of the type class by adding a *derives* clause to a type.
- » Code structure in the subsequent slides
- » For details see the [Dotty documentation](#)

Typeclass Derivation (code structure 1/2)

```
import scala.deriving._

trait Eq[T]    // type class 'Eq'
  def eqv(x: T, y: T): Boolean
  def (x: T) === (y: T): Boolean = eqv(x, y)
  def (x: T) !== (y: T): Boolean = !eqv(x, y)

object Eq     // type class 'Eq' companion
  inline given derived[T](given m: Mirror.Of[T]): Eq[T] =
    // use Mirror for the implementation
    ???

enum Tree[+T] derives Eq    // type Tree with derived instance of Eq
  case Leaf(elem: T)
  case Node(left: Tree[T], right: Tree[T])
```

Typeclass Derivation (code structure 2/2)

```
import Tree._

// summon Eq for Tree[Int] instance into local scope
given Eq[Tree[Int]] = summon[Eq[Tree[Int]]]

// check equality of two trees using the given instance of Eq[Tree[Int]]
val tree1 = Node(Leaf(1), Node(Leaf(2), Leaf(3)))
val tree2 = Node(Leaf(1), Node(Leaf(2), Leaf(3)))
val tree3 = Node(Leaf(2), Leaf(3))

assert(tree1 === tree2)
assert(tree1 !== tree3)
```

Given By-Name Parameters³⁷

³⁷ <https://dotty.epfl.ch/docs/reference/contextual/implicit-by-name-parameters.html>

Given By-Name Parameters

- » Implicit parameters can be declared by-name to avoid a divergent inferred expansion.
- » Like a normal by-name parameter the argument for a *given* parameter is evaluated lazily on demand.
- » This feature is available since Scala 2.13 (but with *implicit* by-name parameters).

```
trait Codec[T]
def write(x: T): Unit

given intCodec: Codec[Int] = ???

given optionCodec[T](given ev: => Codec[T]): Codec[Option[T]] // given param ev is evaluated lazily
  def write(xo: Option[T]) = xo match
    case Some(x) => ev.write(x)
    case None =>

val s = summon[Codec[Option[Int]]]
s.write(Some(33))
s.write(None)
```

Implicit Resolution³⁸

³⁸ <https://dotty.epfl.ch/docs/reference/changed-features/implicit-resolution.html>

Implicit Resolution

- » New algorithm which caches implicit results more aggressively for performance.
- » Types of implicit values and result types of implicit methods must be explicitly declared.
- » Nesting is now taken into account when selecting an implicit.
- » Package prefixes no longer contribute to the implicit scope of a type (which was the case in Scala 2).
- » More details and rules in the [Dotty documentation](#)

Overload Resolution³⁹

³⁹ <https://dotty.epfl.ch/docs/reference/changed-features/overload-resolution.html>

Looking Beyond the First Argument List

» Overloading resolution now do not only take the first argument list into account when choosing among a set of overloaded alternatives.

```
def f(x: Int)(y: String): Int = 0
def f(x: Int)(y: Int): Int = 0

f(3)("")      // ok, but ambiguous overload error in Scala 2

def g(x: Int)(y: Int)(z: Int): Int = 0
def g(x: Int)(y: Int)(z: String): Int = 0

g(2)(3)(4)    // ok // but ambiguous overload error in Scala 2
g(2)(3)("")   // ok // but ambiguous overload error in Scala 2
```

Parameter Types of Function Values

» Improved handling of function values with missing parameter types

```
def h(x: Int, h: Int => Int) = h(x)
def h(x: String, h: String => String) = h(x)
h(40, _ + 2)           // ok // but missing parameter type error in Scala 2
h("a", _.toUpperCase) // ok // but missing parameter type error in Scala 2
```

Parameter Untupling⁴⁰

⁴⁰ <https://dotty.epfl.ch/docs/reference/other-new-features/parameter-untupling.html>

Parameter Untupling

- » In a mapping (or other) function you pattern match the tuples to dissect them into their parts.
- » Scala 3 can untuple the tuples into a parameter list of elements.
- » So you can omit the keyword *case*.

```
val l1 = List(1, 2, 3)
val l2 = List(10, 20, 30)
val tuples: List[(Int, Int)] = l1 zip l2
```

```
// Scala 2 style mapping function with pattern matching
val sums1 = tuples map { case (x, y) => x + y }
```

```
// Scala 3 style mapping function with untupled parameters
val sums2 = tuples map { (x, y) => x + y }
val sums3 = tuples map { _ + _ }
```

Other Features

Dropped Scala 2 Features

- >> Dropped Limit 22 for Tuples and Functions
- >> Dropped Procedure Syntax
- >> Dropped Symbol Literals
- >> Dropped DelayedInit
- >> Dropped Auto-Application
- >> Dropped Early Initializers
- >> Dropped Existential Types
- >> Dropped Type Projection
- >> Dropped Scala 2 Macros
- >> and more ...

New or Changed Features

- >> Open Classes
- >> Improved Lazy Vals Initialization
- >> Kind Polymorphism
- >> Tupled Function
- >> Option-less pattern matching
- >> Macros: Quotes and Splices
- >> and more ...

Resources

Links

>> This presentation: code and slides

<https://github.com/hermannhueck/taste-of-dotty>

>> Dotty Documentation

<https://dotty.epfl.ch/docs/>

>> Scala 2 Roadmap Update: the Road to Scala 3

<https://www.scala-lang.org/2019/12/18/road-to-scala-3.html>

Talks

- » Martin Odersky (Lightbend Webinar): Scala 3 is Coming (published July 2019)
https://www.youtube.com/watch?v=U2tjcwSag_0
- » Martin Odersky at ScalaSphere Krakow: Revisiting Implicits (published October 2019)
<https://www.youtube.com/watch?v=h4dS5WRGJtE>
- » Nicolas Stucki at ScalaDays Lausanne: Metaprogramming in Dotty (published July 2019)
https://www.youtube.com/watch?v=ZfDS_gJyPTc
- » Guillaume Martres at ScalaDays Lausanne: Future proofing Scala through TASTY (published July 2019)
<https://www.youtube.com/watch?v=zQFjC3zLYwo>
- » Guillaume Martres at ScalaWorld GB: Scala 3, Type Inference and You! (published September 2019)
<https://www.youtube.com/watch?v=lMvOykNQ4zs>
- » Lukas Rytz at ScalaDays Lausanne: How are we going to migrate to Scala 3.0, aka Dotty? (published July 2019)
<https://www.youtube.com/watch?v=KUl1Ilcfob8>
- » Sébastien Doeraene at ScalaSphere Krakov: How will TASTY affect the Scala ecosystem, exactly? (published January 2020)
https://www.youtube.com/watch?v=_N7zNhLdB1Y
- » Josh Suereth & James Ward at Devoxx Belgium: What's coming in Scala 3 (published November 2019)
<https://www.youtube.com/watch?v=Nv-BzYOMiWY>

Thank You !

Questions ?

<https://github.com/hermannhueck/taste-of-dotty>