
Datatype Generic Programming with Scala 3

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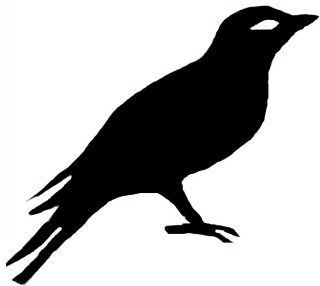
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<https://github.com/y-yu/scalamatsuri2023> (bb5b286)

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Who am I ?



- Recruit Co., Ltd.
 - StudySapuri ENGLISH server side
- Quantum Information & Algorithms
- Cryptography & Security
- Programming & \LaTeX typesetting
 - Scala, Rust, Go, Swift

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TestObject: generating fixtures for unit tests

- We use `TestObject` on our product, which is a utility for generating dummy objects(also known as *fixtures*) for unit tests.

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case class StudySapuriSession(  
  /* very complicated! */  
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- Type class `TestObject[A]` provides us with a way to generate some value of `A`.

```
trait TestObject[A] {  
  def generate: State[Int, A]  
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```
implicit val strInstance: TestObject[String] = new TestObject {  
  def generate: State[Int, A] = State(s => (s + 1, s.toString))  
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- In a naive way, we would have to define too many `TestObject` implicit instances for every type used in our product, but it's not possible or reasonable.

TestObject and datatype generic programming

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- The many `TestObject` instances can be provided by *datatype generic programming*, rather than manually.
 - We can easily obtain `dummyData: StudySapuriSession` once we define `TestObject` instances for primitive or Java types,
 - And then datatype generic programming generates the other instances for our defined data structures(= case objects).

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- Datatype generic programming is one of the ways of meta-programming.
- In this talk I'll explain datatype generic programming with Scala 3.

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- Almost every data structure can be classified as either “tuple”-like or “enum”-like:

```
case class TupleLike(  
  field1: Int, field2: String  
)
```

```
sealed trait EnumLike  
case class Pattern1(v: Int) extends EnumLike  
case class Pattern2(v: String) extends EnumLike
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- `TupleLike` requires both two values of `Int` and `String`, whereas `EnumLike` requires either an `Int` value or a `String` value.

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- `TupleLike` requires both two values of `Int` and `String`, whereas `EnumLike` requires either an `Int` value or a `String` value.
- Datatype generic programming provides us with the following two functions: ① converting a value to the analogy tuple or enum ② and reverting it to the original type.

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 - ① First, convert user-defined data structures(= case objects) to tuple or enum like using datatype generic programming.
 - ② Then, find some implicit instances based on the types included in the tuple or enum.
 - ③ Finally, revert the derived instance for tuple or enum like to one for the original data type.

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 - ① First, convert user-defined data structures(= case objects) to tuple or enum like using datatype generic programming.
 - ② Then, find some implicit instances based on the types included in the tuple or enum.
 - ③ Finally, revert the derived instance for tuple or enum like to one for the original data type.
- `case class TupleLike(field1: Int, field2: String)` example:

$$\frac{\text{TupleLike} \Leftrightarrow (\text{Int}, \text{String}) \quad \frac{\text{TestObject}[\text{Int}] \quad \text{TestObject}[\text{String}]}{\text{TestObject}[(\text{Int}, \text{String})]} \textcircled{2}}{\text{TestObject}[\text{TupleLike}] \textcircled{1}}$$

where `TupleLike` \Leftrightarrow `(Int, String)` is powered by datatype generic programming.

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- In our product, we compile & test both of Scala 2 and 3 for almost all of our code.
- There is no compatibility of macros between Scala 2 and 3 😊
- It follows that `TestObject` implemented on Scala 2 won't work well in Scala 3.
 - *shapeless* 3[2] for Scala 3 is being developed but unfortunately it doesn't have compatibility of *shapeless* for Scala 2 😊

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- There is no compatibility of macros between Scala 2 and 3 🙄
- It follows that `TestObject` implemented on Scala 2 won't work well in Scala 3.
 - *shapeless* 3[2] for Scala 3 is being developed but unfortunately it doesn't have compatibility of *shapeless* for Scala 2 🙄
- Eventually we (mainly *ScalaNinja*) began to develop another `TestObject` implementation for Scala 3



Fig 1: ScalaNinja

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- Some functions can be used to convert case objects from/to tuple like without any libraries like follows:

```
import scala.compiletime.*
import scala.deriving.*
case class TupleLike(
  field1: Int, field2: String
)
```

```
scala> Tuple.fromProductTyped(TupleLike(1, "a"))
val res0: (Int, String) = (1,a)

scala> summon[Mirror.ProductOf[TupleLike]].fromProduct(res0)
val res1: TupleLike = TupleLike(1,a)
```

- Similarly some functions can be used to convert `sealed trait` to enum like.

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- Similarly some functions can be used to convert `sealed trait` to enum like.
- Meta-programming tools in Scala 3 is reinforced rather than Scala 2 👍

TestObject implementation on Scala 3

- We'll define `derive` method as the final goal, like this:

```
inline implicit def derive[A]: TestObject[A]
```

- `derive` provides `TestObject` instances for all `A`.

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- This is an overview of the `derive` behavior:
 - ① Check if the instance for the input type has been defined.
 - ② If not found, pattern match the type into either tuple like or enum like.
 - ③ Collect the *ill-typed* list of `TestObject` for each types contained in ② using `erasedValue`.
 - ④ Finally, make the instance for the input type using ③ instances list.

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 - ④ Finally, make the instance for the input type using ③ instances list.
- Let's see the details!

① Check if the instance for the input type has been defined

- `summonFrom` searches the `TestObject` instance for type `A`.

```
inline implicit def derive[A]: TestObject[A] =  
  summonFrom {  
    case x: TestObject[A] =>  
      x  
    case _ =>  
      create[A] // we'll define next page!  
  }
```



Fig 2: Image of `summonFrom`

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 - In this case, it's unnecessary to define a new instance so `derive` returns `x`.
- In the latter case, we call `create` method to define `TestObject[A]`.

② Pattern matching if `A` is `ProductOf[A]` or `SumOf[A]`

- Since there is no `TestInstance[A]` instance yet, `create` finds `ProductOf[A]` or `SumOf[A]` instance using `summonFrom` again.

```
inline final def create[A]: TestObject[A] =  
  summonFrom {  
    case _: Mirror.ProductOf[A] =>  
      deriveProduct[A] // 1  
    case _: Mirror.SumOf[A] =>  
      deriveSum[A]      // 2  
  }
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```

- This means that:
 - ① `A` is a tuple-like type (i.e. case classes) if there is a `ProductOf[A]` instance,
 - ② `A` is an enum-like structure (i.e. sealed traits). if there is a `SumOf[A]` instance.

③ Making a list `List[TestObject[?]]` of *ill-typed* instances

- Before seeing `deriveProduct` and `deriveSum`, we need to prepare the way to collect all instances for types being contained in `A`.
- For example `TupleLike`, we need the both instances of `TestObject[Int]` and `TestObject[String]`.

```
case class TupleLike(  
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- For example `TupleLike`, we need the both instances of `TestObject[Int]` and `TestObject[String]`.
- `erasedValue` allows us to search and collect all instances recursively as follows:

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case class TupleLike(  
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```
inline def deriveRec[T <: Tuple]: List[TestObject[?]] =  
  inline erasedValue[T] match {  
    case _: EmptyTuple =>  
      Nil  
    case _: (t *: ts) =>  
      derive[t] /* mutual recursion */ :: deriveRec[ts]  
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- There is no type compatibility among the instances, `deriveRec` cannot help but to return *ill-typed* list 😊

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- There is no type compatibility among the instances, `deriveRec` cannot help but to return *ill-typed* list 😊

- Additionally, `*:` is type-level tuple constructor provided since Scala 3.

4a In deriveProduct case

- Using `deriveRec`, we define a `TestObject` instance for `A` in `deriveProduct`.

```
inline def deriveProduct[A](using a: ProductOf[A]): TestObject[A] = {  
  def p: TestObject[A] = {  
    val xs = deriveRec[a.MirroredElemTypes] // `a.MirroredElemTypes` is analogy tuple of `A`.  
    productImpl[A](xs, a)  
  }  
  p  
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- Why does `deriveProduct` only call `productImpl` through a temporary method `p` 🤔

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- This is ScalaNinja's remarkable and state-of-the-art technique to avoid:
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 - and generating too many nameless classes.

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- This is ScalaNinja's remarkable and state-of-the-art technique to avoid:
 - throwing `MethodTooLargeException` due to `inline`
 - and generating too many nameless classes.
- In meta-programming, we have to also consider compiling efficiency, not only runtime. That's maybe the why meta-programming is difficult 😊

4a In deriveProduct case

- First, we create a tuple naming `values` which are containing all values required by `A`.

```
final def productImpl[A](xs: List[TestObject[?]], a: ProductOf[A]): TestObject[A] =  
  new TestObject[A] {  
    def generate: IntState[A] =  
      for {  
        values <- xs.traverse(_.generate.widen[Any])  
      } yield a.fromProduct(new SeqProduct(values))  
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```

- It's important that `productImpl` doesn't have `inline`.
- Then, we create a `A` value using `a.fromProduct`.

4b In deriveSum case

- In `SumOf` case, we generate a value in `values`.

```
inline def deriveSum[A](using a: SumOf[A]): TestObject[A] = {  
  def s: TestObject[A] = {  
    val values = deriveRec[a.MirroredElemTypes]  
    sumImpl[A](values)  
  }  
  s  
}
```

- It's very similar to `deriveProduct`.

4b In deriveSum case

- `sumImpl` is a very complicated function 😊

```
final def sumImpl[A](values: List[TestObject[?]]): TestObject[A] =  
  new TestObject[A] {  
    def generate: IntState[A] =  
      for {  
        allResults <- values.traverse(_.generate.widen[Any])  
        l = allResults.minBy(_.getClass.getName)  
        rOpt = allResults.tail.headOption.flatMap(  
          _ => allResults.maxByOption(_.getClass.getName)  
        )  
        s <- State.get  
      } yield rOpt match {  
        case Some(r) => if (s % 2 == 0) l.asInstanceOf[A] else r.asInstanceOf[A]  
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- What's the purpose of `minBy(_.getClass.getName)` and `maxByOption(_.getClass.getName)`?

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- For instance:

```
sealed trait X  
case object X3 extends X  
case object X2 extends X  
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- shapeless 2 returns `X1 :+: X2 :+: X3`, which is sorted by alphabetical order,
- but `MirroredElemTypes` is `X3 *: X2 *: X1` 😊

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- I don't know why, but anyway shapeless 2 sorts the instances by their type name[3].
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- shapeless 2 returns `X1 :+: X2 :+: X3`, which is sorted by alphabetical order,
 - but `MirroredElemTypes` is `X3 *: X2 *: X1` 😊
- So the `minBy` and `maxByOption` are needed for the compatibility of shapeless 2 behavior.

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 - <https://github.com/y-yu/test-object>
 - It may be useful as proof-of-concept to compare Scala 2(shapeless 2) with Scala 3.

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 - And shapeless 2 and 3 don't have the same interface.

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- Scala 3 supports datatype generic programming initially.
 - Is there any ways how not using ill-typed list? 🤔

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 - It may be useful as proof-of-concept to compare Scala 2(shapeless 2) with Scala 3.
- There is no macro compatibility between Scala 3 and 2 😇
 - And shapeless 2 and 3 don't have the same interface.
- Scala 3 supports datatype generic programming initially.
 - Is there any ways how not using ill-typed list? 🤔
- Happy datatype generic programming!

- As March 1st, the number of lines of Scala 2 & 3 source code is 878,434 in our product.
 - This does not include generated code (such as protobuf & gRPC), so the total is approximately over 1,000,000.
- There are many microservices (Fig.3), making it a very complicated system 😊
- The number of our server-side team members is about 16.
- Meta-programming, which includes not only datatype generic programming but also *scalafix* and so on, is very useful for us.

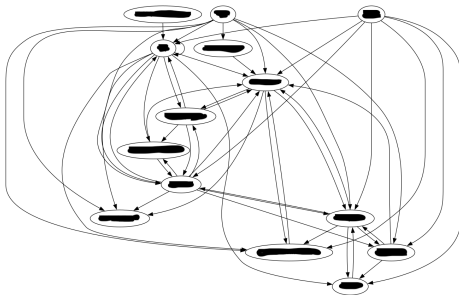


Fig 3: Very complicated micro services

References

- [1] shapeless: generic programming for Scala (GitHub).
<https://github.com/milessabin/shapeless>.
Accessed: 2023-03-13.
- [2] shapeless 3 for Scala 3 (GitHub).
<https://github.com/typelevel/shapeless-3>.
Accessed: 2023-03-13.
- [3] shapeless 2 sorts subclasses by alphabetical order.
<https://github.com/milessabin/shapeless/blob/da31eced505d3df9637a3a28825ff31c65a99ffe/core/shared/src/main/scala/shapeless/generic.scala#L412>.
Accessed: 2023-03-13.

Thank you for the attention!