Datatype Generic Programming with Scala 3

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https://github.com/y-yu/scalamatsuri2023 (771be2e)

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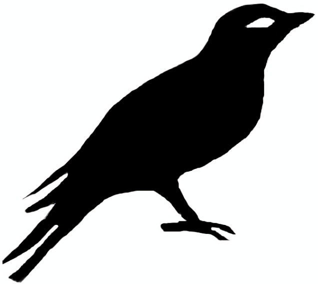
Who am I ?



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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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trait TestObject[A] {
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}
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implicit val strInstance: TestObject[String] = new TestObject {
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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.

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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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  - For instance, it's difficult for us to write *sbt* settings even if we know Scala 😇
- Almost every data structure can be classified as either "tuple"-like or "enum"-like:

```scala
case class TupleLike(
  field1: Int, field2: String
)
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```scala
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.
- Datatype generic programming provides us with the following two functions: ❶ converting a value to the analogy tuple or enum ❷ 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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- Almost all meta-programming can be done using such datatype abstraction and ad-hoc polymorphism, without the need to edit syntax trees.
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  2. Then, find some implicit instances based on the types included in the tuple or enum.
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- `case class TupleLike(field1: Int, field2: String)` example:

$$\dfrac{\texttt{TupleLike} \Leftrightarrow \texttt{(Int, String)} \qquad \dfrac{\texttt{TestObject[Int]} \qquad \texttt{TestObject[String]}}{\texttt{TestObject[(Int, String)]}}\ \text{2}}{\texttt{TestObject[TupleLike]}}\ \text{1}$$

where `TupleLike ⇔ (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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- 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 😇
- Eventually we (mainly *ScalaNinja*) began to develop another `TestObject` implementation for Scala 3

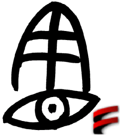

Fig 1: ScalaNinja

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

```scala
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)
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- 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:

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

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

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

```scala
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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- If `summonFrom` finds a `TestObject[A]` instance, then the instance will be assigned to the variable `x`.
  - 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]`.

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

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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.

❸ 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]`.

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- `erasedValue` allows us to search and collect all instances recursively as follows:

```scala
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:
  - 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 😇

```scala
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:

```scala
sealed trait X
case object X3 extends X
case object X2 extends X
case object X1 extends X
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- shapeless 2 returns `X1 :+: X2 :+: X3`, which is sorted by alphabetical order,
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- 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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- 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.

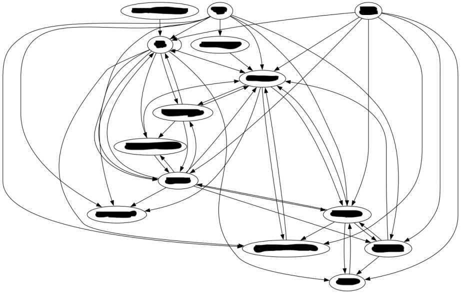

Fig 3: Very complicated micro services

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!