Case Study: Existential and Higher-Order Types for Polymorphic Embedding of DSLs

based on Hofer, Ostermann, Rendel, Moors, *Polymorphic Embedding of DSLs*, ACM Conference on Generative Programming and Component Engineering, 2008

The Traditional Approach

- P. Hudak, Modular Domain Specific Languages and Tools
- DSL as library, not as a separate language
- DSL as an algebra, not via building ASTs
- Example: A Regions language

```
type Region = Vector ⇒ boolean

def univ : Region = p ⇒ true
def circle : Region
  = p ⇒ p._1 * p._1 + p._2 * p._2 < 1
def union(x : Region, y : Region) : Region
  = p ⇒ x(p) || y(p)
...
```

Pros and Cons

- Pros
  - Reuse of language infrastructure (incl. type checking)
  - Interpretation is compositional (defined by an algebra)
  - Allows combining several DSLs
- Cons
  - The interpretation is integral part of the language
    - Alternative interpretations cannot be supplied
  - Interpretations are not components
    - In particular: Optimizations cannot be applied to them

Contributions

- Pure Embedding with multiple interpretations
  - Analyses and optimizations as "yet another" interpretation
- Interpretations and languages as components
- Scala as implementation language in OO context
  - Show-case for existential and higher-order types in the form of abstract (higher-kinded) type members

Explicit language interface

```
trait Regions {
  // Ordinary type synonyms
  type Vector = (double, double)

  // Abstract domain types
  type Region

  // Abstract domain operations
  def univ : Region
  def circle : Region
  def union(x : Region, y : Region) : Region
  def scale(v : Vector, r : Region) : Region
  ...
}
```

Explicit language interface II

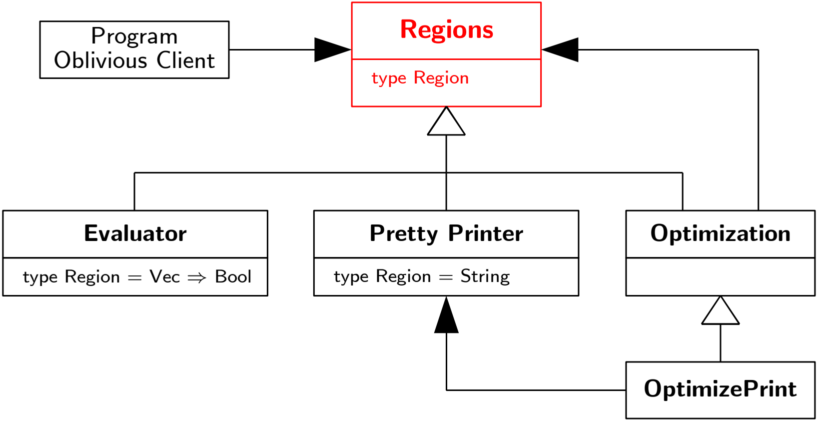
- Abstract type members are existential types that represent domain types

```
type Region
```

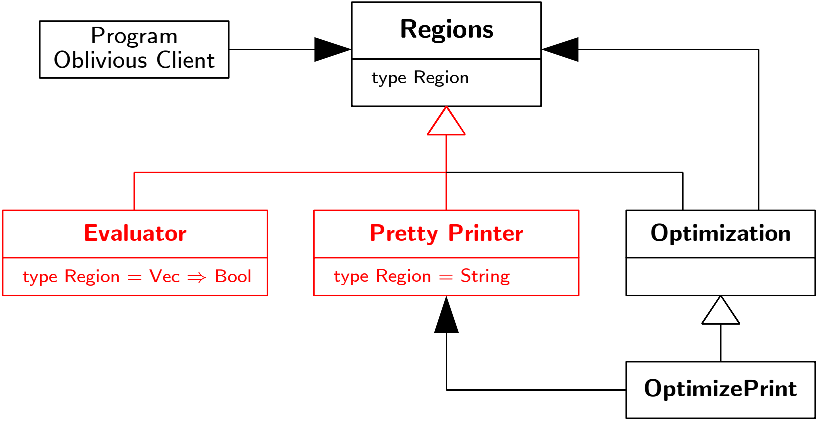
- Compositional by construction:
  Interface is the signature of the algebra

```
def union(x : Region, y : Region) : Region
```

Architecture Overview



Architecture Overview



An Evaluator

```
trait Evaluation extends Regions {
  type Region = Vector => boolean

  def univ : Region  = p => true
  def circle : Region
    = p => p._1 * p._1 + p._2 * p._2 < 1
  def union(x : Region, y : Region) : Region
    = p => x(p) || y(p)
  ...
}
object Eval extends Evaluation
```

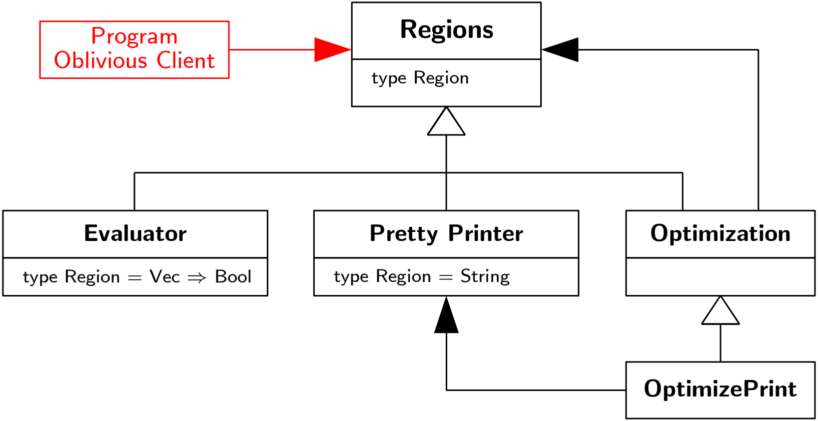
- Same definitions as in the traditional approach

A Pretty Printer

```
trait Printing extends Regions {
  type Region = String

  def univ : Region = "univ"
  def circle : Region = "circle"
  def union(x : Region, y : Region) : Region
    = "union(" + x + ",␣" + y + ")"
  ...
}
object Print extends Printing
```

Architecture Overview

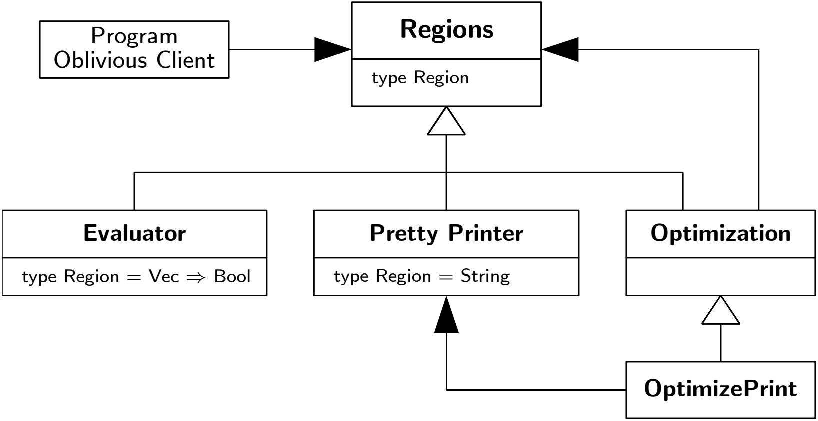


Programs as Oblivious Clients

```
// A simple program
def program(semantics : Regions)
                           : semantics.Region = {
  import semantics._
  val ellipse24 = scale((2, 4), circle)
  union(univ, ellipse24)
}
```

- A DSL program has path-dependent type: semantics.Region
- `println(program(Eval)((1, 2)))` prints `true`
- `println(program(Print))` prints `union(univ, scale((2, 4), circle)`

Architecture Overview



A DSL with Polymorphism

- Example: Functions language (inspired by Carette et al.)
- User-defined bindings

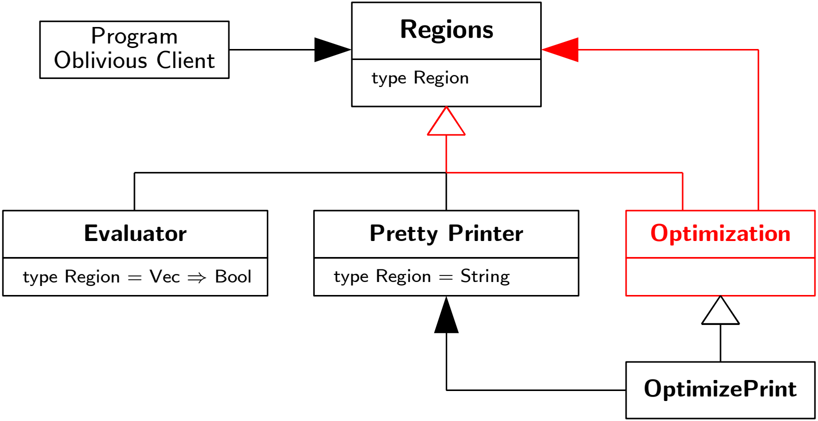
```
trait Functions {
  // Abstract domain types
  type Rep[X]
  // Abstract domain operations
  def fun[S, T](f :  Rep[S] ⇒ Rep[T])
              : Rep[S ⇒ T]
  def app[S, T](f : Rep[S ⇒ T], v : Rep[S])
              : Rep[T]
}
```

- Using higher-kinded abstract type member Rep
- Using higher-order abstract syntax (HOAS)

Two Example Interpretations

```
trait FunEval extends Functions {
  type Rep[T] = T
  def fun[S,T](f : S ⇒ T) = f
  def app[S,T](f : S ⇒ T, v : S) : T = f(v)
}
trait FunPrinting extends Functions {
  type Rep[X] = String
  def fun[S,T](f : String ⇒ String) : String
    =
  {
    val v = variables.next
    "fun(" + v + " ⇒ " + f(v) + ")"
  }
  ...
}
```

Architecture Overview



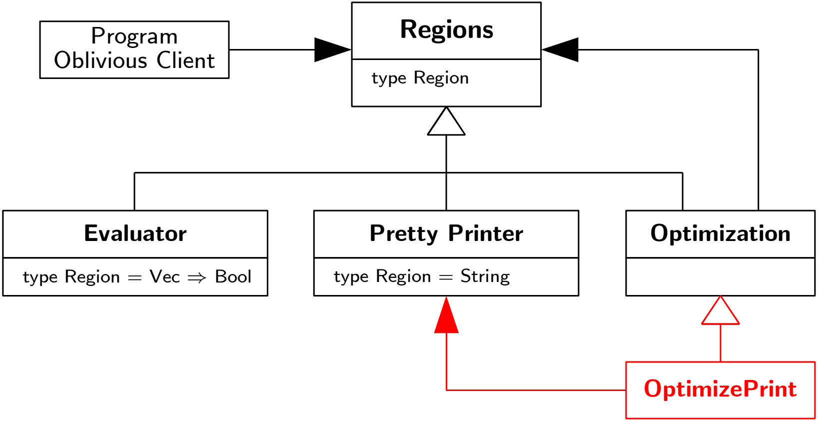
Interpretations as Components

- Example: Optimization

```
trait Optimization extends Regions {
  val semantics : Regions

  type Region = (semantics.Region, boolean)
  def univ : Region = (semantics.univ, true)
  def circle : Region =
                  (semantics.circle, false)
  def union(x : Region, y : Region) : Region
    =
     if (x._2 || y._2) (semantics.univ, true)
        else (semantics.union(x._1, y._1), false)
  ...
```

Architecture Overview



Reuse of Interpretations

- Interpretations can be regarded as reusable components
  - Odersky / Zenger: Scalable Component Abstractions
- Example: An optimizing interpretation can work on several interpretations

```
object OptimizePrint extends Optimization {
  val semantics = Print
}
```

- `println(program(OptimizePrint))` prints `(univ, true)`
- while `println(program(Print))` prints `union(univ, scale((2, 4), circle))`

Hierarchical Composition

- Example: A Vectors sublanguage

```
trait Vectors {
  type Vector
  ...
}

trait Regions {
  val vec : Vectors
  import vec._
  ...
}
```

Interplay with Interpretation Components

- Example: Optimization for refactored Regions language
- Needs singleton types

```
trait Optimization extends Regions {
  val semantics : Regions
  val vec :  semantics.vec.type = semantics.vec
  import vec._
  ...
}
```

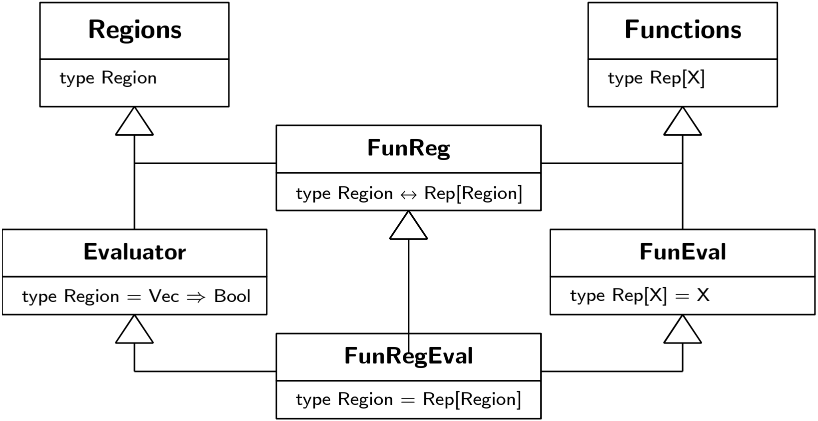
Peer Composition

- Example: Combine Regions with Functions language
- Problem: Representations have to be translated

```
trait FunReg extends
               Regions with Functions {
  implicit def fromRegion(r : Region)
                               : Rep[Region]
  implicit def toRegion(r : Rep[Region])
                               : Region
}
```

- Using Scala's *implicit* conversions for less verbosity

Peer Composition: Overview



Peer Composition of Interpretations

- Integration for both evaluation and printing semantics
- Example: Evaluation

```
object FunRegEval extends FunReg
          with Evaluation with FunEval {
  implicit def fromRegion(r : Region)
                    : Rep[Region] = r
  implicit def toRegion(r : Rep[Region])
                    : Region = r
}
```

Summary

- Reuse of the language infrastructure in pure embedding style
- Interpretation components
  - In particular: Application of optimizations on them
- Language components

- Outlook
  - Compositionality can be limiting
  - Regard Scala arithmetics, etc. as language interfaces
  - Alternative approaches
    - Type classes (Haskell)
    - Virtual classes (gbeta)