

Using nested classes as associated types.

Authors omitted for double-bind review.

Unspecified Institution.

Abstract

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1 Introduction

Associated types are a powerful form of generics, now integrated in both Scala and Rust. They are a new kind of member, like methods fields and nested classes. Associated types behave as 'virtual' types: they can be overridden, can be abstract and can have a default. However, the user has to specify those types and their concrete instantiations manually; that is, the user have to provide a complete mapping from all virtual type to concrete instantiation. When the number of associated types is small this poses no issue, but it hinders designs where the number of associated types is large. In this paper we examine the possibility of completing a partial mapping in a desirable way, so that the resulting mapping is sound and also robust with respect to code evolution.

The core of our design is to reuse the concept of nested classes instead of relying of a new kind of member for associated types. An operation, call Redirect, will redirect some nested classes in some external types. To simplify our formalization and to keep the focus on the core of our approach, we present our system on top of a simple Java like languages, with only final classes and interfaces, when code reuse is obtained by trait composition instead of conventional inheritance. We rely on a simple nominal type system, where subtyping is induced only by implementing interfaces; in our approach we can express generics without having a polymorphic type system. To simplify the treatment of state, we consider fields to be always instance private, and getters and setters to be automatically generated, together with a `static` method `of(..)` that would work as a standard constructor, taking the value of the fields and initializing the instance. In this way we can focus our presentation to just (static) methods, nested classes and implements relationships. Expanding our presentation to explicitly include visible fields, constructors and sub-classing would make it more complicated without adding any conceptual underpinning. In our proposed setting we could write:

```
String=...
SBox={String inner;
  method String inner(){..} //implicit
  static method SBox of(String inner){..} //implicit
myTtrait={
  Box={Elem inner} //implicit Box(Elem inner) and Elem inner()
  Elem={Elem concat(Elem that)}
  static method Box merge(Box b, Elem e){return Box.of(b.inner().concat(e));}
}
Result=myTrait<Box=SBox> //equivalent to trait<Box=SBox, Elem=String>
...Result.merge(SBox.of("hello "), "world");//hello world
```



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23:2 Using nested classes as associated types.

Here class **SBox** is just a container of **Strings**, and **myTrait** is code encoding **Boxes** of any kind of **Elem** with a **concat** method. By instantiating **myTrait<Box=SBox>**, we can infer **Elem=String**, and obtain the following flattened code, where **Box** and **Elem** has been removed, and their occurrences are replaced with **SBox** and **String**.

```
Result={static method SBox merge(SBox b,String e){
return SBox.of(b.inner().concat(e));}}
```

Note how **Result** is a new class that could have been written directly by the programmer, there is no trace that it has been generated by **myTrait**. We will represent trait names with lower-case names and class/interface names with upper-case names. Traits are just units of code reuse, and do not induce nominal types.

We could have just written **Result=myTrait<Elem=String>**, obtaining

```
Result={
Box={String inner}
static method Box merge(Box b,String e){
return Box.of(b.inner().concat(e));}}
```

Note how in this case, class **Result.Box** would exist. Thanks to our decision of using nested classes as associated types, the decision of what classes need to be redirected is not made when the trait is written, but depends on the specific redirect operation. Moreover, our redirect is not just a way to show the type system that our code is correct, but it can change the behaviour of code calling static methods from the redirected classes.

This example shows many of the characteristics of our approach:

- (A) We can redirect mutually recursive nested classes by redirecting them all at the same time, and if a partial mapping is provided, the system is able to infer the complete mapping.
- (B) **Box** and **Elem** are just normal nested classes inside of **myTrait**; indeed any nested class can be redirected away. In case any of their (static) methods was implemented, the implementation is just discarded. In most other approaches, abstract/associated/generic types are special and have some restriction; for example, in Java/Scala static methods and constructors can not be invoked on generic/associated types. With redirect, they are just normal nested classes, so there are no special restrictions on how they can be used. In our example, note how **merge** calls **Box.of(..)**.
- (C) While our example language is nominally typed, nested classes are redirected over types satisfying the same structural shape. We will show how this offers some advantages of both nominal and structural typing.

A variation of redirect, able to only redirect a single nested class, was already presented in literature. While points (B) and (C) already apply to such redirect, we will show how supporting (A) greatly improves their value.

The formal core of our work is in defining

- **ValidRedirect**, a computable predicate telling if a mapping respects the structural shapes and nominal subtype relations.
- **BestRedirect**, a formal definition of what properties a procedure expanding a partial mapping into a complete one should respect.
- **ChoseRedirect**, an efficient algorithm respecting those properties.

We first formally define our core language, then we define our redirect operator and its formal properties. Finally we motivate our model showing how many interesting examples of generics and associated types can be encoded with redirect. Finally, as an extreme application, we show how a whole library can be adapted to be injected in a different environment.

2 Language grammar and well formedness

We apply our ideas on a simplified object oriented language with nominal typing and (nested) interfaces and final classes. Instead of inheritance, code reuse is obtained by trait composition, thus the source code would be a sequence of top level declarations D followed by a main expression; a lower-case identifier t is a trait name, while an upper case identifier C is a class name. To simplify our terminology, instead of distinguishing between nested classes and nested interfaces, we will call *nested class* any member of a code literal named by a class identifier C . Thus, the term *class* may denote either an *interface class* (interface for short) or a *final class*.

$e ::= x \mid e.m(es) \mid T.m(es) \mid e.x \mid \text{new } T(es)$	expression	$T ::= \text{This}_n.Cs$	types
$L ::= \{ \text{interface } Tz; Mz \mid \{ Tz; Mz; K \}$	code literal	$Tx ::= T x$	parameter
$M ::= \text{static? } T m(Txs) e? \mid \text{private? } C=E$	member	$D ::= id=E$	declaration
$K ::= (Txz)?$	state	$id ::= C \mid t$	class/trait id
$E ::= L \mid t \mid E_1 <+ E_2 \mid E <R>$	Code Expr.	$v ::= \text{new } T(vs)$	value
$R ::= Cs_1 = T_1 \dots Cs_n = T_n$	redirect map	$LV ::= \dots$	

In the context of nested classes, types are paths. Syntactically, we represent them as relative paths of form $\text{This}_n.Cs$, where the number n identify the root of our path: This_0 is the current class, This_1 is the enclosing class, This_2 is the enclosing enclosing class and so on. $\text{This}_n.Cs$ refers to the class obtained by navigating throughout Cs starting from This_n . Thus, This_0 is just the type of the directly enclosing class. By using a larger then needed n , there could be multiple different types referring to the same class. Here we expect all types to be in the normalized form where the smallest possible n is used.

Code literals L serve the role of class/interface bodies; they contain the set of implemented interfaces Tz , the set of members Mz and their (optional) state. In the concrete syntax we will use **implements** in front of a non empty list of implemented interfaces and we will omit parenthesis around a non empty set of fields. To simplify our formalism, we delegate some sanity checks well formedness, and we assume all the fields in the state K to have different names; no two methods or nested classes with the same name (m or C) are declared in a code literal, and no nested class is named This_n for any number n ; in any method headers, all parameters have different names, and no parameter is named **this**.

A class member M can be a (private) nested class or a (static) method. Abstract methods are just methods without a body. Well formed interface methods can only be abstract and non-static. To facilitate code reuse, classes can have (static) abstract methods, code composition is expected to provide an implementation for those or, as we will see, redirect away the whole class. We could easily support private methods too, but to simplify our formalism we consider private only for nested classes. In a well formed code literal, in all types of form $\text{This}_n.Cs.C.Cs'$, if C denotes a private nested class, then Cs is empty. We assume a form of alpha-rename for private nested classes, that will consistently rename all the paths of form $\text{This}_n.C.Cs'$, where $\text{This}_n.C$ refer to such private nested class. The trivial definition of such alpha rename is given in appendix.

Expressions are used as body of (static) methods and for the main expression. They are variables x (including **this**) and conventional (static) method calls. Field access and **new** expressions are included but with restricted usage: well formed field accesses are of form **this**. x in method bodies and $v.x$ in the main expression, while well formed **new** expressions have to be of form **new This0(xs)** in method bodies and of form v in the main expression. Those restrictions greatly simplify reasoning about code reuse, since they require different

140 classes to only communicate by calling (static) methods. Supporting unrestricted fields
 141 and constructors would make the formalism much more involved without adding much of a
 142 conceptual difficulty. Values are of form `new T(vs)`.

143 For brevity, in the concrete syntax we assume a syntactic sugar declaring a static `of`
 144 method (that serve as a factory) and all fields getters; thus the order of the fields would
 145 induce the order of the factory arguments. In the core calculus we just assume such methods
 146 to be explicitly declared.

147 Finally, we examine the shape of a nested class: `private? C=E`. The right hand side
 148 is not just a code literal but a code composition expression E . In trait composition, the
 149 code expression will be reduced/flattened to a code literal L during compilation. Code
 150 expressions denote an algebra of code composition, starting from code literal L and trait
 151 names t , referring to a literal declared before by $t=E$. We consider two operators: conventional
 152 preferential sum $E_1 \lt+ E_2$ and our novel redirect $E \lt Cs = T \gt$.

153 2.1 Compilation process/flattening

154 The compilation process consists in flattening all the E into L , starting from the innermost
 155 leftmost E . This means that sum and redirect work on LV s: a kind of L , where all the
 156 nested classes are of form $C=LV$. The execution happens after compilation and consist in
 157 the conventional execution of the main expression e in the context of the fully reduced
 158 declarations, where all trait composition has been flatted away. Thus, execution is very
 159 simple and standard and behaves like a variation of $FJ\Box$ with interfaces instead of inheritance,
 160 and where nested classes are just a way to hierarchically organize code names. On the
 161 other side, code composition in this setting is very interesting and powerful, where nested
 162 classes are much more than name organization: they support in a simple and intuitive way
 163 expressive code reuse patterns. To flatten an E we need to understand the behaviour of the
 164 two operators, and how to load the code of a trait: since it was written in another place,
 165 the syntactic representation of the types need to be updated. For each of those points we
 166 will first provide some informal explanation and then we will proceed formalizing the precise
 167 behaviour.

168 2.1.1 Redirect

169 Redirect takes a library literal and produce a modified version of it where some nested classes
 170 has been removed and all the types referencing such nested classes are now referring to an
 171 external type. It is easy to use this feature to encode a generic list:

```
172 list={
173   Elem={}
174   static This0 empty()= new This0(Empty.of())
175   boolean isEmpty()= this.impl().isEmpty()
176   Elem head()= this.impl.asCons().tail()
177   This0 tail()=this.impl.asCons().tail()
178   This0 cons(Elem e)=new This0(Cons.of(e, this.impl)
179   private Impl={interface Bool isEmpty() Cons asCons()}
180   private Empty={implements This1
181     Bool isEmpty()=true Cons asCons()=../*error*/
182     ()//() means no fields
183   private Cons={implements This1
184     Bool isEmpty()=false Cons asCons()=this
185     Elem elem Impl tail }
186   Impl impl
187   }
188 }
189 IntList=list<Elem=Int>
```

```

190 ...
191 IntList.Empty.of().push(3).top()==4 //example usage
192

```

193 This would flatten into

```

194 list={/*as before*/
195 //IntList=list<Elem=Int>
196 IntList={
197   //Elem={} no more nested class Elem
198   static This0 empty()= new This0(Empty.of())
199   boolean isEmpty()= this.impl().isEmpty()
200   Int head()= this.impl.asCons().tail()
201   This0 tail()=this.impl.asCons().tail()
202   This0 cons(Int e)=new This0(Cons.of(e, this.impl)
203   private Impl={interface Bool isEmpty() Cons asCons()}
204   private Empty={/*as before*/}
205   private Cons={implements This1
206     Bool isEmpty()=false Cons asCons()=this
207     Int elem Impl tail }
208   Impl impl
209 } //everywhere there was "Elem", now there is "Int"
210

```

212 Redirect can be propagated in the same way generics parameters are propagate: For
 213 example, in Java one could write code as below,

```

214 class ShapeGroup<T extends Shape>{
215   List<T> shapes;
216   ..}
217 //alternative implementation
218 class ShapeGroup<T extends Shape,L extends List<T>>{
219   L shapes;
220   ..}
221

```

223 to denote a class containing a list of a certain kind of **Shapes**. In our approach, one could
 224 write the equivalent

```

225 shapeGroup={
226   Shape={implements Shape}
227   List=list<Elem=Shape>
228   List shapes
229   ..}
230

```

232 With redirect, **shapeGroup** follow both roles of the two Java examples; indeed there are two
 233 reasonable ways to reuse this code

234 **Triangulation=shapeGroup<Shape=Triangle>**, if we have a **Triangle** class and we would
 235 like the concrete list type used inside to be local to the **Triangulation**, or **Triangulation=shapeGroup<List=Triangles>**,
 236 if we have a preferred implementation for the list of triangles that is going to be used by our
 237 **Triangulation**. Those two versions would flatten as follow:

```

238 //Triangulation=shapeGroup<Shape=Triangle>
239 Triangulation={
240   List=/*list with Triangle instead of Elem*/
241   List shapes
242   ..}
243
244 //Triangulation=shapeGroup<List=Triangles>
245 //expands to shapeGroup<List=Triangles,Shape=Triangle>
246 Triangulation={
247   Triangles shapes
248   ..}
249

```

251 As you can see, with redirect we do not decide a priori what is generic and what is not in a
 252 class.

Redirect can not always succeed. For example, if we was to attempt `shapeGroup<List=Int>` the flattening process would fail with an error similar to a invalid generic instantiation. Subtype is a fundamental feature of object oriented programming. Our proposed redirect operator do not require the type of the target to perfectly match the structural type of the internal nested classes; structural subtyping is sufficient. This feature adds a lot of flexibility to our redirect, however completing the mapping (as happens in the example above) is a challenging and technically very interesting task when subtyping is took into account. This is strongly connected with ontology matching and will be discussed in the technical core of the paper later on.

2.1.2 Preferential sum and examples of sum and redirect working together

The sum of two traits is conceptually a trait with the sum of the traits members, and the union of the implemented interfaces. If the two traits both define a method with the same name, some resolution strategy is applied. In the symmetric sum[] the two methods need to have the same signature and at least one of them need to be abstract. With preferential sum (sometimes called override), if they are both implemented, the left implementation is chosen. Since in our model we have nested classes, nested classes with the same name will be recursively composed.

We chose preferential sum since is simpler to use in short code examples.¹ Since the focus of the paper is the novel redirect operator, instead of the well known sum, we will handle summing state and interfaces in the simplest possible way: a class with state can only be summed with a class without state, and an interface can only be summed with another interface with identical methods signatures.

In literature it has been shown how trait composition with (recursively composed) nested classes can elegantly handle the expression problem and a range of similar design challenges. Here we will show some examples where sum and redirect cooperate to produce interesting code reuse patterns:

```
listComp=list<+{
  Elem:{ Int geq(Elem e)}//-1/0/1 for smaller, equals, greater
  static Elem max2(Elem e1, Elem e2)=if e1.geq(e2)>0 then e1, else e2
  Elem max(Elem candidate)=
    if This.isEmpty() then candidate
    else this.tail().max(This.max2(this.head(),candidate))
  Elem min(Elem candidate)=...
  This0 sort()=...
}
```

As you can see, we can *extends* our generic type while refining our generic argument: `Elem` of `listComp` now needs a `geq` method.

While this is also possible with conventional inheritance and F-Bound polymorphism, we think this solution is logically simpler then the equivalent Java

```
class ListComp<Elem extends Comparable<Elem>> extends LinkedList<Elem>{
  ../*body as before*/
}
```

¹ symmetric sum is often presented in conjunction with a restrict operator that makes some methods abstract.

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```

355 C={D={E=t}}
356 H=t<B=A>

```

the flattened version for $C.D.E$ will be $\{ B=\{()\} \text{ This3.A m(This0.B b)}\}$, where the path This1.A is now This3.A while the path This0.B stays the same: types defined internally will stay untouched. The program p in the observation point $E=t$ is

```

361 A={()}
362 t={ B={()} This1.A m(This0.B b)}
363 C={D={E=t}};
364 C={D={E=t}}, //this means, we entered in C
365 D={E=t} //this means, we entered in D

```

In order to fetch code literals from the program, while transforming the types so that they keep referring to the same nested classes, we rely on notations $p[T]$ and $p[t]$. Those notations extract a class or a trait from a program while consistently transforming types. We also use notation $L[C = E]$ to update the code expression in C to E . For space reasons, those notations are defined in the appendix.

3 Flattening

Aside from the redirect operation itself, compilation/flattening is the most interesting part, it is defined by reduction arrow $Ds \Rightarrow Ds'$, where eventually Ds' is going to reach form DVs and $p; id \vdash E \Rightarrow E'$, where eventually E' is going to reach form LV . The id represents the identifier of the type/trait that we are currently compiling, it is needed since it will be the name of This0 , and we use that fact that that is equal to This1.id to compare types for equality. Rule (TOP) selects the leftmost $id=E$ where E is not of form LV and DVz : a well typed subset of the preceeding declarations. E is flattened in the context of such DVz , thus by rule (TRAIT) DVz must contain all the trait names used in E . In the judgement $p; id \vdash E \Rightarrow E'$ id is only used in order to grow the program p in rule (L-ENTER), and p itself is only needed for (REDIRECT). The (CTXV) rule is the standard context, the (L-ENTER) rule propagates compilation inside of nested-classes, (TRAIT) merely evaluates a trait reference to it's defined body, finally (SUM) and (REDIRECT) perform our two meta-operations by propagating to corresponding auxiliary definitions. We will present those two rules in the two sections below. Note how we require that they are already in the *minimized* form, that is, all the T uses the shortest way to refer to their corresponding nested class. This prevents the programmer from expressing some difficult cases. Consider for example using two different ways to refer to A , redirect A and then adding it back:

```

391 B=...
392 X={ A:{} Void m(This1.X.A p1, This0.A p2)} <A=B> <+ {A:{}}
393 //should flattening redirect only p2
394 X={ A:{} Void m(This1.X.A p1, This1.B p2)}
395 //or both occurrences?
396 X={ A:{} Void m(This1.B p1, This1.B p2)}

```

The complete L42 language solves those issues, but here we present a simplified version.

3.1 Sum

Rule (SUM) just delegate the work on the auxiliary notation defined below:

Def: $L_1 \ltimes L_2 = \text{interface? } \{Tz_1 \cup Tz_2; Mz \ltimes Mz', Mz_1, Mz_2; K?\}$
 $L_1 = \text{interface? } \{Tz_1; Mz, Mz_1; K?_1\}$ $L_2 = \text{interface? } \{Tz_2; Mz', Mz_2; K?_2\}$
 $\{empty, K?_1, K?_2\} = \{empty, K?\}$
 if $\text{interface?} = \text{interface}$ then $m\text{dom}(L_1) = m\text{dom}(L_2)$
Def: $Tm(Txs)e? \ltimes Tm(Txs)e = Tm(Txs)e$
Def: $Tm(Txs)e? \ltimes Tm(Txs) = Tm(Txs)e?$
Def: $(C=L) \ltimes (C=L') = C = L \ltimes L,$

As usual in definitions of sum operators, the implemented interfaces is the union of the interfaces of L_1 and L_2 , the members with the same domain are recursively composed while the members with disjoint domains are directly included. Since method and nested class identifiers must be unique in a well formed L and $M_1 \ltimes M_2$ being defined only if the identifier is the same, our definition forces $\text{dom}(Mz) = \text{dom}(Mz')$ and $\text{dom}(Mz_1)$ disjoint $\text{dom}(Mz_2)$. For simplicity here we require at most one class to have a state; if both have no state, the result will have no state, otherwise the result will have the only present state (the set $\{empty, K?\}$ mathematically express this requirement in a compact way); we also allow summing only interfaces with interfaces and final classes with final classes. When two interfaces are composed both sides must define the same methods. This is because other nested classes inside L_1 may be implementing such interface, and adding methods to such interface would require those classes to somehow add an implementation for those methods too. In literature there are expressive ways to soundly handle merging different state, composing interfaces with final classes and adding methods to interfaces, but they are out of scope in this work.

Member composition $M_1 \ltimes M_2$ uses the implementation from the right hand side, if available, otherwise if the right hand side is abstract, the body is took from the left side. Composing nested classes, not how they can not be **private**; it is possible to sum two literals only if their private nested classes have different private names. This constraint can always be obtained by alpha-renaming them.

3.2 Redirect

Rule (REDIRECT) is the centre of our interest for this work. As for sum we check that the LV is in minimize form. Moreover, to have a single data structure p' where all the types correctly points to the corresponding nested classes, we add the L to the top of our current program. Notation R/id is defined as

$Cs_0 = \text{This}_n.C.Cs = Cs_0 = \text{This}_{n+1}.C.Cs$, where either $C \neq id$ or $n > 0$

In addition of adding 1 to all the types provided in the redirect map, since they was relative to p and not p' , it also checks that R actually refers to types external of LV , by preventing types of form $\text{This}_0.id.$

Notation $p.\text{redirectSet}(R)$ computes the set of nested classes that need to be redirected if R is redirected. This is information depend just from LV (the top of the program) and the domain of R .

$$\text{dom}(R) \subseteq p.\text{redirectSet}(R)$$

$$\text{internals}(\text{reachables}(p[\text{This}_0.Cs])) \subseteq p.\text{redirectSet}(R)$$

$$\text{with } Cs \in p.\text{redirectSet}(R)$$

We use $p'.\text{bestRedirection}()$ in order to complete the provided mapping R into a complete mapping. Such mapping must be of the correct Something does not work: either we check $\text{dom}(R') = \text{Csz}$ or we use $\text{dom}(R')$ instead of Csz . What is the right one?

We will comment on the formal definitions used in (REDIRECT) in the next section, that is going to be the formal core of the paper.

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■ **Figure 1** Flattening

Def: $Ds \Rightarrow Ds'$ and $p; id \vdash E \Rightarrow E'$, where $\mathcal{E}_V ::= \square \mid \mathcal{E}_V <+ E \mid LV <+ \mathcal{E}_V \mid \mathcal{E}_V < Cs = T >$
(TOP)

$$\frac{DVz \subseteq DVs \quad DVz \vdash \mathbf{Ok}}{empty; DVz; id \vdash E \Rightarrow E'} \quad \frac{}{DV_s id=EDs \Rightarrow DV_s id=E'Ds} \quad \frac{}{(L-ENTER) \quad \frac{p.\mathbf{push}(id=L[C=E]); C \vdash E \Rightarrow E'}{p; id \vdash L[C=E] \Rightarrow L[C=E']}} \quad \frac{}{(TRAIT) \quad \frac{}{p; id \vdash t \Rightarrow p[t]}}$$

$$\frac{}{(SUM) \quad \frac{LV_i = p.\mathbf{min}(id=LV_i) \quad LV_1 <+ LV_2 = LV}{p; id \vdash LV_1 <+ LV_2 \Rightarrow LV}} \quad \frac{}{(REDIRECT) \quad \frac{LV = p.\mathbf{min}(id=LV) \quad p' = p.\mathbf{push}(id=LV) \quad Csz = p'.\mathbf{redirectSet}(R/id) \quad p'.\mathbf{redirectable}(Csz) \quad R' = p'.\mathbf{bestRedirection}(R/id)}{p; id \vdash LV <R> \Rightarrow R'(L.\mathbf{remove}(Csz))}}$$

441 For space reason, the type system and the reduction of the main program are in appendix.
442 They are very straight forward: thanks to flattening, they are a simple nominal type system
443 and reduction over a FJ-like language, with no generics or special method dispatch rules.

4 Appendix?

444 $\mathcal{E}_V ::= \square \mid \mathcal{E}_V <+ E \mid LV <+ \mathcal{E}_V \mid \mathcal{E}_V < Cs = T >$ context of library-evaluation
445 $\mathcal{E}_v ::= \square \mid \mathcal{E}_v.m(es) \mid v.m(vs \mathcal{E}_v es) \mid T.m(vs \mathcal{E}_v es)$

5 Type System

447 The type system is split into two parts: type checking programs and class literals, and the
448 typechecking of expressions. The latter part is mostly convential, it involves typing judgments
449 of the form $p; Txs \vdash e : T$, with the usual program p and variable environement Txs (often
450 called Γ in the literature). rule $(Dsok)$ type checks a sequence of top-level declarations by
451 simply push each declaration onto a program and typecheck the resulting program. Rule pok
452 typechecks a program by check the topmost class literal: we type check each of it's members
453 (including all nested classes), check that it properly implements each interface it claims to,
454 does something weird, and finanly check check that it's constructor only referenced existing
455 types,

456

457

458 Define $p \vdash \mathbf{Ok}$

459 =====

460

461 $D1; Ds \vdash \mathbf{Ok} \dots Dn; Ds \vdash \mathbf{Ok}$

462 $(Ds \text{ ok}) \text{ ----- } Ds = D1 \dots Dn$

463 $Ds \vdash \mathbf{Ok}$

464

465 $p \vdash M1 : \mathbf{Ok} \dots p \vdash Mn : \mathbf{Ok}$

```

466 p |- P1 : Implemented .... p |- Pn : Implemented
467 p |- implements(Pz; Ms) /*WTF?*/ if K? = K: p.exists(K.Txs.Ts)
468 (p ok) ----- p.top() = interface? {P1...Pn; M1, ..., Mn; K?
469 p |- Ok
470
471 p.minimize(Pz) subseq p.minimize(p.top().Pz)
472 amt1 _ in p.top().Ms ... amtn _ in p.top().Ms
473 (P implemented) ----- p[P] = interface {Pz; amt1 ... am
474 p |- P : Implemented
475
476 (amt-ok) ----- p.exists(T, Txs.Ts)
477 p |- T m(Tcs) : Ok
478
479 p; This0 this, Txs |- e : T
480 (mt-ok) ----- p.exists(T, Txs.Ts)
481 p |- T m(Tcs) e : Ok
482
483 C = L, p |- Ok
484 (cd-Ok) -----
485 p |- C = L : OK
486

```

Rule (*Pimplemented*) checks that an interface is properly implemented by the program-top, we simply check that it declares that it implements every one of the interfaces super-interfaces and methods. Rules (*amt - ok*) and (*mt - ok*) are straightforward, they both check that types mentioned in the method signature exist, and ofcourse for the latter case, that the body respects this signature.

To typecheck a nested class declaration, we simply push it onto the program and typecheck the top-of the program as before.

The expression typesystem is mostly straightforward and similar to feartherwiegth Java, notable we use $p[T]$ to look up information about types, as it properly 'from's paths, and use a classes constructor definitions to determine the types of fields.

```

497 Define p; Txs |- e : T
498 =====
499 (var)
500 ----- T x in Txs
501 p; Txs |- x : T
502
503 (call)
504 p; Txs |- e0 : T0
505 ...
506 p; Txs |- en : Tn
507 ----- T' m(T1 x1 ... Tn xn) _ in p[T0].Ms
508 p; Txs |- e0.m(e1 ... en) : T'
509
510 (field)
511 p; Txs |- e : T
512 ----- p[T].K = constructor(_ T' x _)

```

23:12 Using nested classes as associated types.

```

513 p; Txs |- e.x : T'
514
515
516 (new)
517 p; Txs |- e1 : T1 ... p; Txs |- en : Tn
518 ----- p[T].K = constructor(T1 x1 ... Tn xn)
519 p; Txs |- new T(e1 ... en)
520
521
522 (sub)
523 p; Txs |- e : T
524 ----- T' in p[T].Pz
525 p; Txs |- e : T'
526
527
528 (equiv)
529 p; Txs |- e : T
530 ----- T =p T'
531 p; Txs |- e : T'

```

532 6 Graph example

533 We now consider an example where Redirect simplifies the code quite a lot: We have a **Node**
534 and **Edge** concepts for a graph. The **Node** have a list of **Edges**. A **isConnected** function takes
535 a list of **Nodes**. A **getConnected** function takes **Node** and return a set of **Nodes**.

```

536 graphUtils={
537   Edges:list<+{Node start() Node end()}
538   Node:{Edges connections()}
539   Nodes:set<Elem=Node> //note that we do not specify equals/hash
540   static Bool isConnected(Nodes nodes)=
541     if(nodes.size()==0) then true
542     else getConnected(nodes.asList().head()).size()==nodes.size()
543   static Nodes getConnected(Node node)=getConnected(node,Nodes.empty())
544   static Nodes getConnected(Node node,Nodes collected)=
545     if(collected.contains(node)) then collected
546     else connectEdges(node.connections(),collected.add(node))
547   static Nodes connectEdges(Edges e,Nodes collected)=
548     if( e.isEmpty()) then collected
549     else connectEdges(e.tail(),collected.add(e.head().end()))
550 }
551
552

```

553 We have shown the full code instead of omitting implementations to show that the code
554 inside of an highly general code like the former is pretty conventional. Just declare nested
555 classes as if they was the concrete desired types. Note how we can easily create a new **Nodes@**
556 by doing **Nodes.empty()**.

557 Here we show how to instantiate **graphUtils** to a graph representing cities connected by
558 streets, where the streets are annotated with their length, and **Edges** is a priority queue, to
559 optimize finding the shortest path between cities.

```

560 Map:{
561   Street:{City start, City end, Int size}
562   City:{}
563   Streets:priorityQueue<Elem=Street><+{
564     Int geq(Street e1, Street e2)=e1.size()-e2.size()}
565 }

```

```

566 }<+{
567 Streets: {}
568 City: {Streets connections, Int index} //index identify the node
569 Cities: set<Elem=City><+{
570   Bool eq(City e1, City e2) e1.index == e2.index
571   Int hash(City e) e.index
572 }
573 Cities cities
574 //more methods
575 }
576 MapUtils = graphUtils<Nodes=Map.Cities>
577 //infers Nodes.List, Node, Edges, Edge

```

579 In Appending 2 we will show our best attempt to encode this graph example in Java,
580 Rust and Scala. In short, we discovered...

581 FROM and minimize that will go in the appendix:

582 To fetch a trait from a program, we will use notation $p(t) = LV$, to fetch a class we will
583 use $p(T)$.

584 To look up the definition of a class in the program we will use the notation $p(T) = LV$,
585 which is defined by the following:

$$\begin{aligned}
 (DLs; DVs).push(id=L) &:= id=L, DLs; DVs \\
 (; _, C=L, _)(\text{This}_0.C.Cs) &:= L(Cs) \\
 p.push(_=L)(\text{This}_0.Cs) &:= L(Cs) \\
 p.push(_)(\text{This}_{n+1}.Cs) &:= p(\text{This}_n.Cs) \\
 LV(\emptyset) &:= LV \\
 \text{interface? } \{ _, _, C=L_0, _, _ \}(C.Cs) &:= L_0(Cs)
 \end{aligned}$$

587 where $L = a$

588 This notation just fetch the referred LV without any modification. To adapt the paths
589 we define $T_0.\text{from}(T_1, j)$, $L.\text{from}(T, j)$ and $p.\text{minimize}(T)$ as following:

$$\begin{aligned}
 \text{This}_n.Cs.\text{from}(T, j) &:= \text{This}_n.Cs \quad \text{with } n < j \\
 \text{This}_{n+j}.Cs.\text{from}(\text{This}_m.C_1 \dots C_k, j) &:= \text{This}_{m+j}.C_1 \dots C_{k-n} \quad \text{with } n \leq k \\
 \text{This}_{n+j}.Cs.\text{from}(\text{This}_m.C_1 \dots C_k, j) &:= \text{This}_{m+j+n-k}.C_1 \dots C_{k-n}Cs \quad \text{with } n > k \\
 \{\text{interface? } Tz; Mz; K\}.\text{from}(T, j-1) &:= \{\text{interface? } Tz.\text{from}(T, j); Mz.\text{from}(T, j); K.\text{from}(T, j)\} \\
 p.\text{minimize}(T) &:= T' \dots
 \end{aligned}$$

592 Finally, we we combine those to notation for the most common task of getting the value of a
593 literal, in a way that can be understand from the current location: $p[t]$ and $p[T]$:

$$\begin{aligned}
 (DL_1 \dots DL_n; _, t=LV, _)[t] &:= LV.\text{from}(\text{This}_n) \\
 p[T] &:= p.\text{minimize}(p(T).\text{from}(T))
 \end{aligned}$$

596 - towel1:.. //Map: towel2:.. //Map: lib: T:towel1 f1 ... fn

598 MyProgram: T:towel2 Lib:lib[T=This0.T] ... -

599 7 extra

600 Features: Structural based generics embedded in a nominal type system. Code is Nominal,
601 Reuse is Structural. Static methods support for generics, so generics are not just a trik to
602 make the type system happy but actually change the behaviour Subsume associate types.
603 After the fact generics; redirect is like mixins for generics Mapping is inferred-> very large

604 maps are possible -> application to libraries

605 In literature, in addition to conventional Java style F-bound polymorphism, there is
 606 another way to obtain generics: to use associated types (to specify generic paramaters) and
 607 inheritance (to instantiate the paramaters). However, when parametrizing multiple types,
 608 the user to specify the full mapping. For example in Java interface A B m(); inteface
 609 BString f(); class G<TA extends A<TB>, TB> //TA and TB explicitly listed String g(TA
 610 a TB b) return a.m().f(); class MyA implements A<MyB>.. class MyB implements B ..
 611 G<MyA,MyB> //instantiation Also scala offers genercs, and could encode the example in
 612 the same way, but Scala also offers associated types, allowing to write instead....

613 Rust also offers generics and associated types, but also support calling static methods
 614 over generic and associated types.

615 We provide here a foundational model for genericity that subsume the power of F-bound
 616 polimorphims and associated types. Moreover, it allows for large sets of generic parameter
 617 instantiations to be inferred starting from a much smaller mapping. For example, in our
 618 system we could just write g= A= method B m() B= method String f() method String g(A a
 619 B b)=a.m().f() MyA= method MyB m()= new MyB(); .. MyB= method String f()="Hello";
 620 .. g<A=MyA> //instantiation. The mapping A=MyA,B=MyB

621 We model a minimal calculus with interfaces and final classes, where implementing an
 622 interface is the only way to induce subtyping. We will show how supporting subtyping
 623 constitute the core technical difficulty in our work, inducing ambiguity in the mappings.
 624 As you can see, we base our generic matches the structor of the type instead of respect-
 625 ing a subtype requirement as in F-bound polymorphis. We can easily encode subtype
 626 requirements by using implements: Print=interface method String print(); g= A:implements
 627 Print method A printMe(A a1,A a2) if(a1.print().size())>a2.print.size())return a1; return a2;
 628 MyPrint=implements Print .. g<A=MyPrint> //instantiation g<A=Print> //works too
 629 ————— example showing ordering need to strictly improve EI1: interface EA1: imple-
 630 ments EI1

631 EI2: interface EA2: implements EI2

632 EB: EA1 a1 EA1 a1

633 A1: A2: B: A1 a1 A2 a2 [B = EB] // A1 -> EI1, A2 -> EA2 a // A1 -> EA1, A2 ->
 634 EI2 b // A1 -> EA1, A2 -> EA2 c

635 a <=b b <=a c<= a,b a <= c

636 hi Hi class

a ::= b c

637 aaHiHi class qaq a ::= b c

a ::= b c

638 }}[()]
 (TOP)

a \xrightarrow{b} c $\forall i < 3 a \vdash b : \text{OK}$

639
$$\frac{\forall i < 3 a \vdash b : \text{OK}}{1 + 2 \rightarrow 3} \begin{matrix} a \\ b \\ c \end{matrix}$$