Specifications of Implemented Refactorings

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This document collects the pseudo-code specifications of all refactoring implemented in our engine. **Note:** This is work in progress; some specifications are missing, and not all implementations agree completely with the specifications.

1 Pseudocode Conventions

We give our specifications in generic, imperative pseudocode. Parameters and return values are informally typed, with syntax tree nodes having one of the types from Fig. 1. Additionally, we use an ML-like `option` type with constructors `None` and `Some` for functions that may or may not return a value.

Where convenient, we make use of ML-like lists, with list literals of the form $[1;2;3]$ and $|xs|$ indicating the length of list xs.

The names of refactorings are written in SMALL CAPS, whereas utility functions appear in `monospace`. A list of utility functions with brief descriptions is given in Fig. 2. An invocation of a refactoring is written with floor-brackets $\lfloor$LIKE THIS$\rfloor$() to indicate that any language extensions used in the output program produced by the refactoring should be eliminated before proceeding.

We write $A <: B$ to mean that type A extends or implements type B, and $m <: m'$ to mean that method m overrides method m'.

2 The Refactorings

2.1 Convert Anonymous to Local

This refactoring converts an anonymous class to a local class. Implemented in `TypePromotion/AnonymousClassToLocalClass.jrag`; see Algorithm 1.

2.2 Convert Anonymous to Nested

This refactoring converts an anonymous class to a member class. Implemented in `TypePromotion/AnonymousClassToMemberClass.jrag`; see Algorithm 2.

Note: the implementation additionally handles the case where A occurs in a field initialiser.

2.3 Convert Local to Member Class

This refactoring converts a local class to a member class. Implemented in `TypePromotion/LocalClassToMemberClass.jrag`; see Algorithms 3, 11.

2.4 Extract Class

This refactoring extracts some fields of a class into a newly created member class. Implemented in `ExtractClass/ExtractClass.jrag`; see Algorithms 4, 5, 6.

We can pass initializers to a constructor if they do not depend on values of previous initializers.

This is only a bare-bones specification. The implementation additionally allows to encapsulate the extracted fields, and to move the wrapper class W to the toplevel.

2.5 Extract Constant

This refactoring extracts a constant expression into a field. Implemented in `ExtractTemp/ExtractConstant.jrag`; see Algorithm 7.

An expression is extractible if its type is not `void`, it is not a reference to a type or package, and it is not the keyword `super`; furthermore, it cannot be on the right-hand side of a dot.

The *effective type* of an expression e is the same as the type of e, except when the type of e is an anonymous class, in which case the effective type is its superclass, or when the type of e is a captured type variable, in which case the effective type is its upper bound.

2.6 Extract Method

Implemented in `ExtractMethod/ExtractMethod.jrag`; see Algorithms 8, 9, 10, 11, 12, 13.

2.7 Extract Temp

This refactoring extracts an expression into a local variable. Implemented in `ExtractTemp/ExtractTemp.jrag`; see Algorithms 14, 15, 16, 17.

2.7.1 Insert Local Variable

The refactoring inserts a local variable before a given statement. Implemented in `ExtractTemp/IntroduceUnusedLocal.jrag`.

2.7.2 Extract Assignment

This refactoring extracts an expression into an assignment to a local variable. Implemented in `ExtractTemp/ExtractAssignment.jrag`.

Algorithm 1 CONVERT ANONYMOUS TO LOCAL(A : *AnonymousClass*, n : *Name*) : *LocalClass*

Require: Java
Ensure: Java $\cup$ locked names

```
1: $c \leftarrow$ class instance expression containing $A$
2: $d \leftarrow \lfloor$EXTRACT TEMP$\rfloor(c, \texttt{unCapitalise}(n))$
3: $b \leftarrow$ enclosing body declaration of $d$
4: $\texttt{lockNames}(b, n)$
5: convert $A$ to class named $n$, remove it from $c$
6: INSERT TYPE$(b, A)$
7: lock type access of $c$ to $A$
8: INLINE TEMP$(d)$
9: return $A$
```

Algorithm 2 CONVERT ANONYMOUS TO NESTED(A : *AnonymousClass*, n : *Name*) : *MemberType*

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Require: Java
Ensure: Java

```
1: $L \leftarrow$ CONVERT ANONYMOUS TO LOCAL$(A, n)$
2: return CONVERT LOCAL TO MEMBER CLASS$(L)$
```

Algorithm 3 CONVERT LOCAL TO MEMBER CLASS(L : *LocalClass*) : *MemberType*

Require: Java
Ensure: Java $\cup$ locked names, fresh variables

```
1: $A \leftarrow$ enclosing type of $L$
2: $\texttt{closeOverTypeVariables}(L)$
3: $\texttt{closeOverLocalVariables}(L)$
4: if $L$ is in static context then
5:     make $L$ static
6: end if
7: $\texttt{lockNames}(\texttt{name}(L))$
8: lock all names in $L$
9: remove $L$ from its declaring method
10: INSERT TYPE$(A, L)$
```

Algorithm 4 Extract Class(C : *Class*, *fs* : `list` *Field*, n : *Name*, *fn* : *Name*)

Require: Java
Ensure: Java ∪ locked names, locked dataflow, first-class array init

```
1:  $v \leftarrow$ maximum visibility of any of the $fs$
2:  $W \leftarrow$ new static class of name $n$ with visibility $v$
3:  Insert Type($C$, $W$)
4:  $w \leftarrow$ new field of type $W$ and name $fn$, initialised to a new instance of $W$
5:  Insert Field($C, w$)
6:  for all $f \in fs$ do
7:    assert $f$ is not static
8:    for all uses $v$ of $f$ do
9:      qualify $v$ with a locked access to $w$
10:   end for
11:   if $f$ has initialiser then
12:     split field declaration and initializer, leaving initializer in initializer
        block after
13:   end if
14:   remove $f$
15:   Insert Field($W, f$)
16: end for
17: $inits \leftarrow$ {initializers of $fs$}
18: Move Inits Together($inits, w$) or Id()
19: merge consecutive $inits$ to common initializer blocks
20: PassInitsToConstructor($inits, w$) or Id()
```

Algorithm 5 Move Inits Together(*inits* : `list` InitializerBlock, *after* : *Field*)

Require: Java
Ensure: Java

```
1: for all $init \in inits$ do
2:   lock names and dataflow in $init$
3:   remove $init$ and insert it after already moved initializers (possibly $after$)
4:   unlock names and dataflow in $init$
5: end for
```

Algorithm 6 PassInitsToConstructor(*inits* : `list` InitializerBlock, *w* : *Field*)

```
1: assert all $inits$ are in one initializer block
2: $index \leftarrow$ possition of $w$
3: $vars \leftarrow [\,]$
4: for all $init$ in $inits$ do
5:     $v \leftarrow \lfloor$Extract Temp$\rfloor$(left side of $init$, fresh name, $index$)
6:     $vars \leftarrow v : vars$
7:     $index \leftarrow index + 1$
8: end for
9: for all $var$ in $vars$ do
10:    Inline Temp($var$)
11: end for
12: in $W$ create a constructor for initializing all fields
13: change the constructor call for $w$ to initialize the fields and remove $inits$
```

Algorithm 7 Extract Constant(*e* : *Expr*, *n* : *Name*)

Require: Java

Ensure: Java ∪ locked names, locked dataflow

```
1: assert $e$ is extractible
2: $A \leftarrow$ enclosing type of $e$
3: $t \leftarrow$ effective type of $e$
4: $f \leftarrow$ new private (public if $A$ is an interface) static final field of type $t$
   and name $n$
5: Insert Field($A, f$)
6: lock names, flow, and synchronisation of $e$
7: set initialiser of $f$ to $e$
8: replace $e$ with locked access to $f$
```

Algorithm 8 Extract Method(*b*: *Block*, *i*: *nat*, *j*: *nat*, *n*: *ident*): *Method*

Require:

Ensure:

```
1: $b' \leftarrow \lfloor$Extract Block$\rfloor(b, i, j)$
2: $a \leftarrow$ Introduce Anonymous Method($b'$)
3: Close over Variables($a$)
4: Eliminate Reference Parameters($a$)
5: return $\lfloor$Lift Anonymous Method$\rfloor(n, a)$
```

Algorithm 9 Extract Block(b: *Block*, i: *nat*, j: *nat*): *Block*

Require: no compound declarations
Ensure: locked names

```
1:  $[s_0; \dots; s_{n-1}] \leftarrow$ statements in $b$
2:  **assert** $0 \le i \le j < n$
3:  lock all variable and type names in $b$
4:  **for all** $i \le k \le j$ **do**
5:    **assert** $s_k$ is not a case or default
6:    **if** $s_k$ declares a variable referenced after $s_j$ **then**
7:      Split Declaration($s_k$)
8:      move $s_k$ before $s_i$
9:    **end if**
10: **end for**
11: $b' \leftarrow$ new block with statements $s_i, \dots, s_j$
12: set statements of $b$ to $s_0, \dots, s_{i-1}, b', s_{j+1}, \dots, s_{n-1}$
13: **return** $b'$
```

Algorithm 10 Introduce Anonymous Method(b: *Block*): *AnonymousMethod*

Require:
Ensure: locked control flow, locked names, `return void`, anonymous methods

```
1:  lock control flow successors in $b$
2:  $[e_1; \dots; e_n] \leftarrow$ locked accesses to all uncaught checked exceptions thrown in
    $b$
3:  **if** $b$ can complete normally **then**
4:    $c \leftarrow (()$: void throws $e_1, \dots, e_n \Rightarrow b)()$
5:    replace $b$ with $c$;
6:  **else**
7:    **if** $b$ is in a method $m$ **then**
8:      $T \leftarrow$ locked access to return type of $m$
9:    **else**
10:     $T \leftarrow$ void
11:   **end if**
12:   $c \leftarrow (()$: $T$ throws $e_1, \dots, e_n \Rightarrow b)()$
13:   replace $b$ with return $c$;
14: **end if**
15: **return** $c$
```

Algorithm 11 Close over Variables(a: *AnonymousMethod*)

Require:
Ensure: anonymous methods, `out` and `ref` parameters, locked names

```
1: $m \leftarrow$ body declaration enclosing $a$
2: $V \leftarrow \emptyset$; $Val \leftarrow \emptyset$; $Out \leftarrow \emptyset$; $Ref \leftarrow \emptyset$
3: for all variable accesses $va$ in $a$ do
4:   $v \leftarrow$ variable $va$ binds to
5:   assert if $va$ is a write, then $v$ is not final
6:   if $v$ is a local variable or parameter of $m$ then
7:     $V \leftarrow V \cup \{v\}$
8:     if $va$ has an incoming data flow edge then
9:       if $v \in Out$ then
10:        $Out \leftarrow Out \setminus \{v\}$
11:        $Ref \leftarrow Ref \cup \{v\}$
12:      else if $v \notin Ref$ then
13:        $Val \leftarrow Val \cup \{v\}$
14:      end if
15:    end if
16:    if $va$ has an outgoing data flow edge then
17:      if $v \in Val$ then
18:        $Val \leftarrow Val \setminus \{v\}$
19:        $Ref \leftarrow Ref \cup \{v\}$
20:      else if $v \notin Ref$ then
21:        $Out \leftarrow Out \cup \{v\}$
22:      end if
23:    end if
24:  end if
25: end for
26: for all $v \in V$ do
27:   if $v \in Val \cup Out \cup Ref$ then
28:     $p \leftarrow$ new parameter with same name and type as $v$
29:     make $p$ ref if $v \in Ref$, out if $v \in Out$
30:     add $p$ as parameter to $a$
31:     add access to $v$ as argument to $a$
32:   else
33:     $v' \leftarrow$ new local variable with same name and type as $v$
34:     add $v'$ as local variable to $a$
35:   end if
36: end for
37: for all type parameters $V$ of $m$ used in $a$ do
38:   add type parameter $V'$ with same name and bounds as $V$ to $a$
39:   add type argument $V$ to $a$
40: end for
```

Algorithm 12 ELIMINATE REFERENCE PARAMETERS(a: *AnonymousMethod*): *AnonymousMethod*

Require: no implicit `return`

Ensure: anonymous methods

```
1:  if $a$ has ref or out parameters then
2:     assert $a$ has a single ref or out parameter
3:     assert return type of $a$ is void
4:     $x \leftarrow$ the ref or out parameter of $a$
5:     $v \leftarrow$ the variable access passed as argument into $x$
6:     replace $a$ by $v$ = $a$
7:     set return type of $a$ to type of $x$
8:     replace every return; statement with return $x$;
9:     if $x$ is a ref parameter or it is live at the entry of $a$ then
10:       make $x$ a value parameter
11:    else
12:       make $x$ a local variable
13:       remove argument $v$
14:    end if
15: end if
16: return $a$
```

Algorithm 13 LIFT ANONYMOUS METHOD(n: *ident*, a: *AnonymousMethod*): *Method*

Require:

Ensure: locked names

```
1:  assert $a$ does not reference any local variables from surrounding body dec-
    laration
2:  assert $a$ has no ref or out parameters
3:  lock all names in $a$
4:  $\overline{e} \leftarrow$ argument list of $a$
5:  $m \leftarrow$ turn $a$ into method named $n$
6:  make $m$ static if $a$ occurs in static context
7:  $T \leftarrow$ innermost type surrounding $a$
8:  assert $T$ has no member method with same signature as $m$
9:  assert no subtype of $T$ declares a method that would override or hide $m$
10: lock all calls to methods named $n$
11: insert $m$ into $T$
12: $c \leftarrow$ locked call of $m$ on arguments $\overline{e}$
13: replace $a$ with $c$
14: return $m$
```

Algorithm 14 EXTRACT TEMP(e : *Expr*, n : *Name*) : *LocalVar*

```
Require: Java
Ensure: Java ∪ locked names, locked dataflow
1: $t \leftarrow$ effective type of $e$
2: $v \leftarrow$ new local variable of type $t$ and name $n$
3: $s \leftarrow$ enclosing statement of $e$
4: INSERT LOCAL VARIABLE($s, v$)
5: EXTRACT ASSIGNMENT($v, e$)
6: MERGE DECLARATION($v$)
7: return $v$
```

Algorithm 15 INSERT LOCAL VARIABLE(s : *Stmt*, v : *LocalVar*)

```
Require: Java
Ensure: Java ∪ locked names
1: $b \leftarrow$ enclosing block of $s$
2: assert variable $v$ can be introduced into block $b$
3: lockNames($b, n$)
4: insert $v$ before $s$
```

Algorithm 16 EXTRACT ASSIGNMENT(v : *LocalVar*, e : *Expr*) : *Assignment*

```
Require: Java
Ensure: Java ∪ locked dependencies
1: assert $e$ is extractible
2: $a \leftarrow$ new assignment from $e$ to $v$
3: if $e$ is in expression statement then
4:     replace $e$ with $a$
5: else
6:     $s \leftarrow$ enclosing statement of $e$
7:     lock all names in $e$
8:     insert $a$ before $s$
9:     replace $e$ with locked access to $v$
10: end if
11: return $a$
```

2.7.3 Merge Variable Declaration

This refactoring merges a variable declaration with the assignment immediately following it, if that assignment is an assignment to the same variable. Implemented in `ExtractTemp/MergeVarDecl.jrag`.

2.8 Inline Constant

This refactoring inlines a constant field into all its uses. Implemented in `InlineTemp/InlineConstant.jrag`; see Algorithms 18, 19, 20.

2.9 Inline Method

This refactoring is inverse of EXTRACT METHOD. Implemented in `InlineMethod/`; see Algorithms 21, 22, 23, 24, 25, 26, 27.

2.10 Inline Temp

This refactoring inlines a local variable into all its uses. Implemented in `InlineTemp/InlineTemp.jrag`; see Algorithms 28, 29, 30, 31.

2.11 Insert Method

This refactoring inserts a method into a type declaration. Implemented in `Move/InsertUnusedMethod.jrag`; see Algorithms 32, 33, 34.

2.12 Introduce Factory

This refactoring introduces a static factory method as a replacement for a given constructor, and updates all uses of the constructor to use this method instead. Implemented in `IntroduceFactory/IntroduceFactory.jrag`; see Algorithm 35

We use `createFactoryMethod` (implemented in `util/ConstructorExt.jrag`) to create the factory method corresponding to constructor *cd* and insert it into the host type of *cd*. The factory method has the same signature as *cd*, but it has its own copies of all type variables of the host type used in *cd*.

2.13 Introduce Indirection

This refactoring creates a static method m' in type B that delegates to a method m in type A. Implemented in `IntroduceIndirection/IntroduceIndirection.jrag`; see Algorithm 36.

Algorithm 17 Merge Variable Declaration(v : *LocalVar*)

Require: Java $\setminus$ multi-declarations
Ensure: Java

```
1: if $v$ has initialiser then
2:     return
3: end if
4: $s \leftarrow$ statement following v
5: if $s$ is assignment to $v$ then
6:     make RHS of $s$ the initialiser of $v$
7:     remove $s$
8: end if
```

Algorithm 18 Inline Constant(f : *Field*)

Require: Java $\setminus$ implicit assignment conversion
Ensure: Java

```
1: for all uses $u$ of $f$ do
2:     Inline Constant($u$)
3: end for
4: Remove Field($f$)
```

Algorithm 19 Inline Constant(u : *FieldAccess*)

Require: Java
Ensure: Java $\cup$ locked dependencies

```
1: $f \leftarrow$ field accessed by $u$
2: assert $f$ is final and static, and has an initialiser
3: $e \leftarrow$ locked copy of the initialiser of $f$
4: assert if $u$ is qualified, then its qualifier is a pure expression
5: replace $u$ with $e$, discarding its qualifier if any
```

Algorithm 20 Remove Field(f : *Field*)

Require: Java
Ensure: Java

```
1: if $f$ is not used and if it has an initialiser, it is pure then
2:     remove $f$
3: end if
```

Algorithm 21 INLINE METHOD(m: *Method*)

Require: Java
Ensure: Java ∪ fresh variables, `with` statement, locked names

```
1: for all $methosAccess$ in polyUses($m$) do
2:   INLINE METHOD ACCESS($methodAccess$)
3: end for
4: REMOVE METHOD($m$) or ID()
```

Algorithm 22 INLINE METHOD ACCESS(ma: *MethodAccess*)

Require: Java
Ensure: Java ∪ fresh variables, `with` statement, locked names

```
1: $am$ ← INLINE TO ANONYMOUS METHOD($ma$)
2: INTRODUCE OUT PARAMETER($am$)
3: OPEN VARIABLES($am$)
4: $node$ ← INLINE ANONYMOUS METHOD($am$)
5: if $node$ is a $Block$ then {in particular, it does not have a label}
6:   INLINE BLOCK($node$)
7: end if
```

Algorithm 23 INLINE TO ANONYMOUS METHOD(am: *MethodAccess*) : *AnonymousMethod*

Require: Java \ `synchronized` qualifier, implicit `this` qualification
Ensure: Java ∪ `with` statement, locked names

```
1: $A$ ← host class
2: assert target($ma$) is unambiguous
3: $target$ ← target($ma$)
4: assert $target$ has a body
5: lock names in $target$
6: $am$ ← copy $target$ as anonymous method with arguments from $ma$
7: if $ma$ is a super call then
8:   assert body of $am$ does not reference enclosing instances
9:   adjust virtual calls in body of $am$ to bind to corresponding methods of $A$
10: else if $ma$ is qualified then
11:   $q$ ← qualifier
12:   add with(q) statement around the body of $am$
13:   replace qualifier and the access with $am$
14: else
15:   replace $ma$ with $am$
16: end if
17: return $am$
```

Algorithm 24 Introduce Out Parameter(am: *AnonymousMethod*)

Require:

Ensure: adds fresh variables, locked names

```
1: eliminateVarargs()
2: $parent \leftarrow$ parent($am$)
3: if $parent$ is simple assignment expression then
4:    assert destination of $parent$ assignment is a variable
5:    $v \leftarrow$ destination variable of $parent$
6:    set return type of $am$ to void
7:    add new fresh paremeter to $am$ with out modifier, type locked to type($v$)
8:    add new argument to $am$ locked to decl($v$)
9:    change return statements to assignment to the parameter and simple
      return
10:   replace $parent$ with $am$
11: end if
```

Algorithm 25 Open Variables(am: *AnonymousMethod*)

Require:

Ensure: adds fresh variables, locked names

```
1: for all ($par$, $arg$) in reverse(zip params($am$) args($am$)) do
2:    if $par$ is in parameter then
3:       $newdecl \leftarrow$ new variable declaration initialized to $arg$ with locked names
4:       insert $newdecl$ at the beginning of block of $am$
5:    else {$par$ is out parameter}
6:       assert $arg$ is a variable access
7:       lock all uses of $par$ to decl($arg$)
8:    end if
9:    remove $par$, $arg$ from $am$
10: end for
```

Algorithm 26 INLINE ANONYMOUS METHOD(*am*: *AnonymousMethod*) : *ASTNode*

Require: no implicit `return`, no `return void`
Ensure: no explicit `return`

```
 1: assert $am$ has no parameters
 2: assert one of the following three conditions is true
 3: if $am$ is the expression in an expression statement then
 4:    $l \leftarrow$ fresh label usable for block of $am$
 5:    for all $ret$ in returns($am$) do
 6:       if $ret$ has a result then
 7:          if result of $ret$ is pure then
 8:             {as $am$ is in an expression statement the result can be discarted
                and not evaluated}
 9:          else
10:             add an evaluation of the result of $ret$ before $ret$
11:          end if
12:       end if
13:       replace $ret$ with a break statement with label $l$
14:    end for
15:    replace $am$ with its block and remove useless breaks
16: else if $am$ is an expression closure, i.e. body is only a return statement
    then
17:    replace $am$ with expression from the return statement
18: else if $am$ is the expression in a return statement then
19:    replace the outer return with block of $am$
20: end if
21: return  the expression or statement we replaced with
```

Algorithm 27 INLINE BLOCK(*b*: *Block*)

Require:
Ensure: add locked names

```
1: assert $b$ is a statement in a block without a label
2: lockAllNames(parent block of $b$)
3: for all $stmt$ in $b$ do
4:    remove $stmt$ from $b$ and put it just before $b$
5: end for
6: remove $b$
```

Algorithm 28 Inline Temp(d : *LocalVar*)

Require: Java
Ensure: Java

```
1: $a \leftarrow \lfloor$Split Declaration$\rfloor(d)$
2: $\lfloor$Inline Assignment$\rfloor(a)$
3: $\lfloor$Remove Decl$\rfloor(v)$
```

Algorithm 29 Split Declaration(d : *LocalVar*) : `option` *Assignment*

Require: Java $\setminus$ compound declarations
Ensure: Java $\cup$ locked names, first-class array init

```
1: if $d$ has initialiser then
2:     $x \leftarrow$ variable declared in $d$
3:     $a \leftarrow$ new assignment from initialiser of $d$ to $x$
4:     insert $a$ as statement after $d$
5:     remove initialiser of $d$
6:     return Some $a$
7: else
8:     return None
9: end if
```

Algorithm 30 Inline Assignment(a : *Assignment*)

Require: Java $\setminus$ implicit assignment conversion
Ensure: Java $\cup$ locked dependencies

```
1: $x \leftarrow$ LHS of $a$
2: assert $x$ refers to local variable
3: $U \leftarrow$ all $u$ such that $a$ is a reaching definition of $u$
4: for all $u \in U$ do
5:     assert $a$ is the only reaching definition of $u$
6:     assert $u$ is not an lvalue
7:     assert $u, a$ are in same body declaration
8:     replace $u$ with a locked copy of the RHS of $a$
9: end for
10: if $U \neq \emptyset$ then
11:     remove $a$
12: end if
```

Algorithm 31 Remove Decl(d : *LocalVar*)

Require: Java $\setminus$ compound declarations
Ensure: Java

```
1: if $d$ is not used and has no initialiser then
2:     remove $d$
3: end if
```

Algorithm 32 Insert Method(m : *Method*, T : *Type*)

Require: Java
Ensure: Java ∪ locked method names

```
1: lockMethodNames(name($m$))
2: assert canIntroduceMethod($m$, $T$)
3: assert not isDynamicallyCallable($m$)
4: assert $\{\texttt{name}(td) | \mathit{TypeDecl}\ td \in \texttt{below}(m)\}$
          $\cap \{\texttt{name}(t) | t \text{ is enclosing type of } T \vee t = T\} = \emptyset$
5: insert method $m$ into the type $T$
6: if $m$ is abstract then
7:   for all $type$ in typesToMakeAbstract($m$) do
8:     Make Type Abstract($type$)
9:   end for
10: end if
```

Algorithm 33 canIntroduceMethod(m : *Method*, T : *Type*)

```
1: assert $m$ is not static or $T$ is not inner
2: assert there is no local method in $T$ with same signature errasure as $m$
3: assert if there are any like-named methods in superclasses, we must be able
   to override or hide them, and similarly for subclasses
```

Algorithm 34 typesToMakeAbstract(m : *Method*) : set Type

```
1: do DFS from hostType($m$) through child types
   but do not visit a type that declares a method that overrides $m$
   (in particular, visit a type in a different package, even if it can't override $m$)
2: return  set of all visited types
```

Algorithm 35 Introduce Factory(cd : *ConstructorDecl*)

Require: Java
Ensure: Java ∪ locked names

```
1: $f \leftarrow$ static factory method for $cd$
2: for all uses $u$ of $cd$ and its parameterised copies do
3:   if $u$ is a class instance expression without anonymous class and it is not
     in $f$ then
4:     replace $u$ with a call to $f$
5:   end if
6: end for
```

2.14 Introduce Parameter

This refactoring turns an expression into a parameter of the surrounding method. Implemented in `ChangeMethodSignature/IntroduceParameter.jrag`; see Algorithm 37.

2.15 Introduce Parameter Object

This refactoring wraps a set P of parameters of a method m into a single parameter n of type w, where w is a newly created wrapper class containing fields corresponding to all the parameters in P. Implemented in `IntroduceParameterObject/IntroduceParameterObjec` see Algorithm 38.

Note that we need to perform the transformation for all relatives of m, *i.e.* for all methods r such that there exists a method m' with $m <:^* m'$ and $r <:^* m'$. We also lock all calls to methods of the same as m in the whole program; this ensures that if overloading resolution changes due to the transformation, the name binding framework will insert appropriate casts to rectify the situation.

Note: the implementation actually: eliminates variable arity parameter for this method and adjusts all calls; does not require p_i to be contiguous and adds new argument at the beginning. (This can be unsound for parameters with side effects!!!)

2.16 Make Method Static

This refactoring makes a method static. Implemented in `MakeMethodStatic/MakeMethodStatic.jrag`; see Algorithm 39.

2.17 Move Inner To Toplevel

This refactoring converts a member type to a toplevel type. Implemented in `TypePromotion/MoveMemberTypeToToplevel.jrag`; see Algorithms 40, 41, 42.

2.18 Move Instance Method

This refactoring moves a method into a variable, which is either a parameter of that method or an accessible field. Implemented in `Move/MoveMethod.jrag`; see Algorithm 43.

2.19 Move Members

In order to move Field, static methods, and member types, we simply lock all references to them, as well as all names contained in them, and (for fields) the flow dependencies of their initialiser, and then move them inside the AST.

We include specification only for MOVE STATIC METHOD; see Algorithm 44. They are all implemented in `Move/MoveMembers.jrag`.

Algorithm 36 INTRODUCE INDIRECTION(m : *Method*, B : *ClassOrInterface*)

```
Require: Java
Ensure: Java ∪ locked names, return void
 1: assert $B$ is non-library
 2: $fn \leftarrow$ fresh method name
 3: $m' \leftarrow$ copy of $m$ with locked names and empty body
 4: set name of $m'$ to $fn$
 5: $xs \leftarrow$ locked accesses to parameters of $m'$
 6: set body of $m'$ to return $m(xs)$;
 7: INSERT METHOD(hostType($m$), $m'$)
 8: MAKE METHOD STATIC($m'$)
 9: MOVE STATIC METHOD($m'$, $B$)
```

Algorithm 37 INTRODUCE PARAMETER(e : *Expr*, n : *Name*)

```
Require: Java
Ensure: Java ∪ locked names
 1: assert $n$ is a valid name
 2: assert $e$ is extractible and constant
 3: assert $e$ appears within a method $m$
 4: assert $m$ is not overridden by and does not override any other methods
 5: assert $m$ has no parameter or local variable $n$
 6: lockMethodCalls(name($m$))
 7: $t \leftarrow$ effective type of $e$
 8: $p \leftarrow$ new parameter of type $t$ and name $n$
 9: insert $p$ as the first parameter of $m$
10: replace $e$ with locked access to $p$
11: for all calls $c$ to $m$ do
12:     insert a locked copy of $e$ as first argument of $c$
13: end for
```

Algorithm 38 Introduce Parameter Object(m : *Method*, P : `set` *Parameter*, w : `set` Name, n : `set` Name)

Require: Java \ variable arity parameters
Ensure: Java ∪ locked names

```
1:  assert $m$ has a body
2:  assert the parameters in $P$ are in contiguous positions $i, \dots, i+k$
3:  $W \leftarrow$ new class containing fields for all the $P$ and a standard constructor
    to initialise them
4:  Insert Type(hostType($m$), $W$)
5:  lockMethodCalls(name($m$))
6:  for all relatives $r$ of $m$ do
7:     assert $r$ has no parameter or local variable with name $n$
8:     $[p_1; \dots; p_n] \leftarrow$ parameters of $r$
9:     $p \leftarrow$ new parameter of type $W$ and name $n$
10:    replace parameters $p_i, \dots, p_{i+k}$ with $p$
11:    for all $j \in \{i, \dots, i+k\}$ do
12:       $v_j \leftarrow$ new variable of same name, type, and finality as $p_j$
13:       insert assignment from $p.f_j$ to $v_j$ at beginning of $m$
14:    end for
15:    for all calls $c$ to $r$ do
16:       $[a_1; \dots; a_n] \leftarrow$ arguments of $c$
17:       replace arguments $a_i, \dots, a_{i+k}$ with new $W$($a_i$, ..., $a_{i+k}$)
18:    end for
19: end for
```

Algorithm 39 Make Method Static(m : *Method*)

Require: Java
Ensure: Java ∪ return `void`, fresh variables, `with` statement, locked names, demand `final` modifier

```
1:  assert $m$ has a body
2:  $newMethod \leftarrow$ copy($m$)
3:  $delegator \leftarrow m$
4:  lockMethodNames(name($delegator$))
5:  add static modifier to $newMethod$
6:  add new parameter to $newMethod$ with fresh name, type locked to
    hostType($m$), and demand final
7:  put a with statement around the body of $newMethod$ mapping this to the
    new parameter
8:  Close Over Variables($newMethod$)
9:  change the block of $delegator$ method to a call to $newMethod$
    with this and parameters of $delegator$ as arguments
10: Insert Method(hostType($delegator$), $newMethod$)
```

2.20 Promote Temp to Field

This refactoring turns a local variable into a field. Implemented in `PromoteTempToField/PromoteTempToField.`
see Algorithms 45, 46.

2.21 Pull Up

This refactoring pulls up a method m from its host class B to the super class A. Implemented in `PullUp/PullUpMethod.jrag`; see Algorithm 47.

TODO: explain translation of type variables; this is basically a right-inverse of the type variable substitution that happens when inheriting a method

Note that Insert Method ensures that the inserted method is not called from anywhere.

2.22 Push Down

This refactoring pushes a method down to all subclasses of its defining class. Implemented in `PushDown/PushDownMethod.jrag`; see Algorithms 48, 49, 50, 51, 52.

Types that inherit a method m include the host type of m.

2.23 Rename

This family of refactorings is used for renaming named program entities. Implemented in `Renaming/`.

Refactoring Rename Field (Algorithm 53) changes the name of a field f to n. It ensures that n is indeed a valid name and that the host type of f contains no other field called n. It then globally locks all accesses to variables, types, or packages named either n or `name`(f), and changes the name of f to n.

Refactoring Rename Local (Algorithm 54) changes the name of a local variable or parameter v to n. It ensures that n is indeed a valid name and that the renaming v to n will not violate the rule that scopes of local variables of the same name cannot be nested. It then again locks all accesses to variables, types, or packages named either n or `name`(v), but only within the enclosing block of v, and changes the name of v to n.

Refactoring Rename Method (Algorithm 55) changes the name of a method m to n. It ensures that n is a valid name, then locks all calls to methods of name `name`(m) or n, and their overriding dependencies. Now it changes the names of all methods m' related to m (*i.e.*, such that m and m' both transitively override the same method), checking that the resulting program will be well-formed: in particular, there cannot be another local method with the same signature, and any methods that the renamed m' would override or hide must, in fact, be overridable or hidable by m', and vice versa for methods that would override or hide m'. If there is a static import that only imports m' (and not also another static member of the surrounding class), then remove that import. We could, of course, try to adjust it, but changing imports is a tricky business.

Refactoring RENAME TYPE (Algorithm 56) changes the name of a type T to n. It is fairly straightforward, except for the well-formedness checks and the treatment of import declarations.

Refactoring RENAME PACKAGE (Algorithm 57) changes the name of a package P to n and renames also all subpackages.

2.24 Self-Encapsulate Field

This refactoring makes a field private, rerouting all accesses to it through getter and setter methods. Implemented in `SelfEncapsulateField/SelfEncapsulateField.jrag`; see Algorithm 58.

By "abbreviated assignment" we mean `x+=y` and friends, as well as increment and decrement expressions. The language restriction tries to expand these into normal assignments, but may fail if the data flow is too complicated. If it succeeds, every lvalue will appear on the left hand side of a (simple) assignment.

Note that even when f is final there may still be assignments to f from within constructors; we cannot encapsulate these assignments, so we skip them.

Algorithm 40 MOVE MEMBER TYPE TO TOPLEVEL(M : *MemberType*)

Require: Java

Ensure: Java $\cup$ locked names

```
1: if $M$ is not static then
2:     $\lfloor$MAKE TYPE STATIC$\rfloor(M)$
3: end if
4: $p \leftarrow$ hostPkg($M$)
5: lock all names in $M$
6: remove $M$ from its host type
7: INSERT TYPE($p, M$)
```

Algorithm 41 INSERT TYPE(p : *Package*, T : *ClassOrInterface*)

Require: Java

Ensure: Java $\cup$ locked names

```
1: assert no type or subpackage of same name as $T$ in $p$
2: lockNames(name($T$))
3: remove modifiers static, private, protected from $T$
4: insert $T$ into $p$
```

Algorithm 42 MAKE TYPE STATIC(M : *MemberType*)

Require: Java

Ensure: Java $\cup$ `with`, locked names

```
1:  $[A_n; \ldots; A_1] \leftarrow$ enclosing types of $M$
2:  for all $i \in \{1, \ldots, n\}$ do
3:      $f \leftarrow$ new field of type $A_i$ with name this$i
4:      INSERT FIELD($M$, $f$)
5:      for all constructors $c$ of $M$ do
6:          $p \leftarrow$ parameter of type $A_i$ with name this$i
7:          assert no parameter or variable this$i in $c$
8:          insert $p$ as first parameter of $c$
9:          if $c$ is chaining then
10:             add this$i as first argument of chaining call
11:         else
12:             $a \leftarrow$ new assignment of $p$ to $f$
13:             insert $a$ after super call
14:         end if
15:     end for
16: end for
17: for all constructors $c$ of $M$ do
18:     for all non-chaining invocations $u$ of $c$ do
19:         $es \leftarrow$ enclosing instances of $u$
20:         assert $|es| = n$
21:         insert $es$ as initial arguments to $u$
22:         discard qualifier of $u$, if any
23:     end for
24: end for
25: if $M$ not in inner class then
26:     put modifier static on $M$
27: end if
28: for all non-static callables $m$ of $M$ do
29:     if $m$ has a body then
30:         surround body of $m$ by
            with(this$n, ..., this$1, this) {...}
31:     end if
32: end for
```

Algorithm 43 MOVE METHOD(m : *InstanceMethod*, v : *Variable*)

Require: Java

Ensure: Java ∪ locked names, `return void`, fresh variables, demand `final`

```
1: assert $v$ is either a parameter of $m$ or a field
2: $T \leftarrow$ type of $v$
3: assert $T$ is a non-library class
4: assert $m$ has a body and is not from library
5: $m' \leftarrow$ copy of $m$ with synchronized removed and all names locked
6: $xs \leftarrow$ list of locked accesses to parameters of $m$
7: if $v$ is a parameter then
8:     $i \leftarrow$ position of $v$ in parameter list of $m$
9:     remove $i$th parameter from $m'$
10:    remove $i$th element of $xs$
11: else
12:    $i \leftarrow 0$
13: end if
14: $v' \leftarrow$ final local variable declaration with same name and type as $v$, initialised to this
15: insert $v'$ as first statement into $m'$
16: lock all uses of $v$ inside $m'$ to $v'$
17: $qs \leftarrow []$
18: for all enclosing classes $C$ of $m$ do
19:    $p_C \leftarrow$ demand final parameter with fresh name, of type $C$
20:    make $p_C$ the $i$th parameter of $m'$
21:    $e \leftarrow$ access to $C$.this
22:    insert $e$ as $i$th element into $xs$
23:    $qs \leftarrow [\![p_C]\!] :: qs$
24: end for
25: wrap body of $m'$ into with($qs$) {...}
26: set body of $m$ to return $[\![v]\!]$.$[\![m]\!]$($xs$);
27: INSERT METHOD($T, m'$)
28: eliminate with statement in $m'$
29: INLINE TEMP($v'$)
30: for all $p_C$ do
31:    REMOVE PARAMETER($p_C$) or ID()
32: end for
```

Algorithm 44 MOVE STATIC METHOD(m : *StaticMethod*, *target* : *Type*)

Require: Java

Ensure: Java ∪ locked names

```
1: lockAllNames() in $m$
2: lockNames(name($m$))
3: remove $m$ from hostType($m$) and insert it into the target
```

Algorithm 45 Promote Temp to Field(d : *LocalVar*)

Require: Java

Ensure: Java $\cup$ locked dependencies

```
1: $\lfloor$Split Declaration$\rfloor(d)$
2: $d' \leftarrow$ new private field of same type and name as $d$
3: make $d'$ static if $d$ is in static context
4: $\lfloor$Insert Field$\rfloor$(hostType($d$), $d'$)
5: for all uses $u$ of $d$ do
6:     lock $u$ onto $d'$
7:     lock reaching definitions of $u$
8: end for
9: Remove Decl($d$)
```

Algorithm 46 Insert Field(T : *ClassOrInterface*, d : *Field*)

Require: Java

Ensure: Java $\cup$ locked names

```
1: assert $T$ has no local field with same name as $d$
2: assert $d$ has no initialiser
3: assert if $T$ is inner and $d$ is static, then $d$ is a constant
4: lockNames(name($d$))
5: insert field $d$ into $T$
```

Algorithm 47 Pull Up Method(m : *Method*)

Require: Java

Ensure: Java $\cup$ locked names

```
1: assert the host type of $m$ $B$ is a non-library class
2: assert the superclass $A$ of $B$ is also non-library
3: $m' \leftarrow$ copy of $m$ with locked names
4: translate type variables in $m'$ from $B$ to $A$
5: Insert Method($A, m'$)
6: remove $m$ from $B$
```

Algorithm 48 TRIVIALLY OVERRIDE($B : \mathit{Type}, m : \mathit{VirtualMethod}$) : `option` *MethodCall*

Require: Java \ implicit method modifiers
Ensure: Java + locked names, `return void`

```
1:  assert $m$ is not final
2:  if $m$ not a member method of $B$ then
3:      return None
4:  end if
5:  $m' \leftarrow$ copy of $m$ with locked names
6:  if $m$ is abstract then
7:      INSERT METHOD($B, m'$)
8:      return None
9:  else
10:     $xs \leftarrow$ list of locked accesses to parameters of $m'$
11:     $c \leftarrow$ super.$m$($xs$)
12:     set body of $m'$ to return $c$;
13:     INSERT METHOD($B, m'$)
14:     return Some c
15: end if
```

Algorithm 49 REMOVE METHOD($m : \mathit{Method}$)

Require: Java
Ensure: Java

```
1: assert $(\texttt{uses}(m) \cup \texttt{calls}(m)) \setminus \texttt{below}(m) = \emptyset$
2: $o \leftarrow \{m' \mid m <: m'\}$
3: if $o \neq \emptyset \wedge \forall m' \in o.m'$ is abstract then
4:     for all $B$ in typesToMakeAbstract($m$) do
5:         MAKE TYPE ABSTRACT($B$)
6:     end for
7: end if
8: remove $m$
```

Algorithm 50 MAKE METHOD ABSTRACT($m : \mathit{Method}$)

Require: Java
Ensure: Java

```
1: assert $m$ is not native, static, private, nor final
2: assert there are no static calls to $m$ (e.g., super-call)
3: for all $B$ in typesToMakeAbstract($m$) do
4:     MAKE TYPE ABSTRACT($B$)
5: end for
6: make $m$ abstract
```

Algorithm 51 Make Type Abstract(T : *Type*)

```
Require: Java
Ensure: Java
1: if $T$ is interface then
2:     return
3: end if
4: assert $T$ is class and never instantiated
5: make $T$ abstract
```

Algorithm 52 Push Down Virtual Method(m : *VirtualMethod*)

```
Require: Java
Ensure: Java $\cup$ locked names
1: for all types $B$ <: hostType($m$) do
2:     $c \leftarrow \lfloor$Trivially Override$\rfloor(B, m)$
3:     if $c \neq$ None then
4:         Inline Method($c$)
5:     end if
6: end for
7: Remove Method($m$)
8:         or Make Method Abstract($m$)
9:         or Id()
```

Algorithm 53 Rename Field(f : *Field*, n : *Name*)

```
Require: Java
Ensure: Java $\cup$ locked names
1: assert $n$ is a valid name
2: assert host type of $f$ contains no other field of name $n$
3: lockNames({$n$, name($f$)})
4: set name of $f$ to $n$
```

Algorithm 54 Rename Local(v : *Local*, n : *Name*)

```
Require: Java
Ensure: Java $\cup$ locked names
1: assert $n$ is a valid name
2: assert scope of $v$ does not intersect scope of any other Local named $n$
3: lockNames(block($v$), {$n$, name($f$)})
4: set name of $v$ to $n$
```

Algorithm 55 RENAME METHOD(m : *Method*, n : *Name*)

Require: Java
Ensure: Java $\cup$ locked names, locked overriding

```
1: assert $n$ is a valid name
2: lockMethodNames($\{$name$(m), n\}$)
3: lockOverriding($\{$name$(m), n\}$)
4: for all $m'$ such that $\exists m''.m <:^* m'' \wedge m' <:^* m''$ do
5:     assert $m'$ is not native
6:     $s \leftarrow$ signature of $m'$ after renaming
7:     assert host type of $m'$ contains no local method of signature $s$
8:     assert $m'$ can override or hide any ancestor method of signature $s$
9:     assert $m'$ can be overridden or hidden by any descendant method of
       signature $s$
10:    set name of $m'$ to $n$
11:    remove any static import of $m'$ if it would become vacuous
12: end for
```

Algorithm 56 RENAME TYPE(T : *Type*, n : *Name*)

Require: Java
Ensure: Java $\cup$ locked names

```
1: assert $n$ is a valid name
2: assert no native method is nested in $T$
3: assert there is no nesting or enclosing type of name $n$
4: assert if $T$ is a toplevel type, there is no other toplevel type $n$ in the
   enclosing package, and it has no subpackage of name $n$
5: assert if $T$ is a type parameter, there is no type parameter of name $n$ in
   the parameter list where it occurs
6: lockNames($\{$name$(T), n\}$)
7: set name of $T$ to $n$
8: set names of constructors of $T$ to $n$
9: if $T$ is public, change the name of its compilation unit to match
10: remove any single type import declaration of $T$ that would clash with a
    visible type or with another import declaration
11: remove any static import of $T$ if it would become vacuous
```

Algorithm 57 RENAME PACKAGE(P : *Package*, n : *Name*)

Require: Java
Ensure: Java $\cup$ locked names

```
1: assert $n$ is a valid name
2: assert there is no package with name $n$
3: lockAllPackageAccesses()
4: for all $package$ in {packages with name starting with name($P$)} do
5:   RENAME PACKAGE($package$, name($package$).replaceFirst(name($P$), $n$))
6: end for
7: set name of $P$ to $n$
```

Algorithm 58 SELF-ENCAPSULATE FIELD(f : *Field*)

Require: Java $\setminus$ abbreviated assignments
Ensure: Java $\cup$ locked names

```
1: create getter method $g$ for $f$
2: if $f$ is not final, create setter method $s$ for it
3: for all all uses $u$ of $f$ and its substituted copies do
4:   if $u \notin$ below($g$) $\cup$ below($s$) then
5:     if $u$ is an rvalue then
6:       replace $u$ with locked access to $g$
7:     else
8:       if $f$ is not final then
9:         $q \leftarrow$ qualifier of $u$, if any
10:        $r \leftarrow$ RHS of assignment for which $u$ is LHS
11:        replace $u$ with locked access to $s$ on argument $r$, qualified with $q$
           if applicable
12:      end if
13:    end if
14:  end if
15: end for
```

3 Node Types

See Fig. 1. We also use the non-node type *Name* to represent names.

Node Type	**Description**
ClassOrInterface	either a class or an interface; is a *Type*
Field	field declaration
LocalVar	local variable declaration
MemberType	type declared inside another type; is a *Type*
Method	method declaration
MethodCall	method call
Package	package
Type	type declaration
VirtualMethod	non-`private` instance method; is a *Method*

Figure 1: Node Types

4 Utility Functions

See Fig. 2.

Name	**Description**
`below`(n)	returns the set of all nodes below n in the syntax tree
`calls`(m)	returns all calls that may dynamically resolve to method m; can be a conservative over-approximation
`hostPkg`(e)	returns the package of the compilation unit containing e
`hostType`(e)	returns the closest enclosing type declaration around e
`lockMethodCalls`(n)	locks all calls to methods named n anywhere in the program
`lockNames`(n)	locks all names anywhere in the program that refer to a declaration with name n
`name`(e)	returns the name of program entity e
`uses`(m)	returns all calls that statically bind to method m

Figure 2: Utility Functions

List of Algorithms