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AUTOMATED REFACTORING OF LEGACY JAVA SOFTWARE TO DEFAULT METHODS

Raffi Khatchadourian[1] Hidehiko Masuhara[2]

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MOTIVATION

INTERFACES ARE TRADITIONALLY LISTS OF METHOD DECLARATIONS

- Traditionally, an **interface** is a Java type that lists method **declarations**.

```java
interface Collection<E> {
    int size();
    void add(E elem);
    boolean isEmpty();
    int capacity();
    abstract boolean atCapacity();}
```

INTERFACES ARE TRADITIONALLY LISTS OF METHOD DECLARATIONS

- Traditionally, an **interface** is a Java type that lists method **declarations**.
- Clients are guaranteed that concrete interface **implementers** provide **implementations** for all listed methods.

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interface Collection<E> {
    int size();
    void add(E elem);
    boolean isEmpty();
    int capacity();
    abstract boolean atCapacity();}
```

SOME INTERFACE METHODS ARE OPTIONAL

- Interface methods can be listed as **optional** operations.

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```
class ImmutableList<E> implements Collection<E> {
  // ...

                                                }
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SOME INTERFACE METHODS ARE OPTIONAL

- Interface methods can be listed as **optional** operations.
- Implementers may choose to support them or not.
- If operations are unsupported, they conventionally `throw` an `UnsupportedOperationException`.

```
interface Collection<E> {
  // ...
  void add(E elem); /* optional */ }}
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```
class ImmutableList<E> implements Collection<E> {
  // ...
  @Override public void add(E elem) {
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SKELETAL IMPLEMENTATION CLASSES HELP IMPLEMENT INTERFACES

- The **skeletal implementation** design pattern [Bloch, 2008] is used to make implementing interfaces easier.
- Abstract skeletal implementation class provides partial implementations.
- Implementers extend the skeletal implementation class rather than directly implementing the interface.

```java
abstract class AbstractImmutableList<E> implements
    Collection<E> {
  @Override public void add(E elem) {
    throw new UnsupportedOperationException();}}
```

```java
class ImmutableList<E> extends AbstractImmutableList<E>{
  // ...
  @Override public void add(E elem) {
    throw new UnsupportedOperationException();}}}
```

THE SKELETAL IMPLEMENTATION PATTERN HAS SEVERAL DRAWBACKS

The skeletal implementation pattern has several drawbacks:

Inheritance `ImmutableList` cannot:

- Subclass another class.
- Inherit skeletal implementations **split** over multiple classes [Horstmann, 2014].
- Inherit skeletal implementations for **multiple** interfaces.

Modularity No syntactic path between `Collection` and `AbstractCollection` (may require **global** analysis [Khatchadourian et al., 2016]).

Bloat

- Separate classes can complicate libraries, making maintenance difficult.
- Method declarations needed in **both** interface and abstract class.

JAVA 8 DEFAULT METHODS CAN REPLACE SKELETAL IMPLEMENTATIONS

- Java 8 **enhanced** interfaces allow both method declarations and **definitions**.

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- Java 8 **enhanced** interfaces allow both method declarations and **definitions**.
- Implementers inherit the (`default`) implementation if none provided.
- Original motivation to facilitate interface **evolution**.
- Can also be used as a replacement of the skeletal implementation pattern [Goetz, 2011].

```
interface Collection<E> {
  default void add(E elem) { // optional.
    throw new UnsupportedOperationException();}}
```

```
class ImmutableList<E> implements Collection<E> {}
```

~~abstract class AbstractImmutableList<E> implements Collection<E> {~~
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DEFAULT METHODS CAN COMPENSATE FOR DRAWBACKS

Using `default` methods:

Inheritance `ImmutableList` can:

- Subclass another class.
- Inherit centralized default methods for an interface.
- Inherit default methods for each interface.

Modularity No need to find default implementations (does not require **global** analysis).

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MIGRATION TO INTERFACES AS DEFAULT METHODS CAN BE DIFFICULT

Migrating **legacy code** using the skeletal implementation pattern to **instead** use default methods can require significant manual effort, especially in large and complex projects.

- Skeletal implementation pattern is ubiquitous, particularly in frameworks.
- Subtle language and semantic interface restrictions.
- Requires:
  - Preserving **type-correctness** by analyzing possibly complex type hierarchies.
  - Resolving issues arising from multiple inheritance.
  - Reconciling possibly minute differences between class and interface methods.
  - Ensuring tie-breakers with overriding class methods do not alter semantics.

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PULL UP METHOD REFACTORING NOT DIRECTLY APPLICABLE

- Pull Up Method refactoring [Fowler, 1999; Tip et al., 2011] safely moves methods from a subclass into a super class.
- Goal is solely to reduce redundant code.
- Java has **multiple interface** inheritance.
- More complicated type hierarchy involving interfaces.
- "Competition" with classes (tie-breaking).
- Differences between class method headers (sources) and corresponding interface method declarations (targets).

MOVE ORIGINAL METHOD TO SUPER CLASS DOES NOT DEAL WITH BODIES

- "Move Original Method to Super Class" law [Borba et al., 2004] expresses transformational semantic equivalence.
- In our case, no method **declarations** are being moved but rather **bodies**.

OUR CONTRIBUTION

TARGET METHODS WITH MULTIPLE SOURCE METHODS

```
interface Collection<E> {
  boolean isEmpty();}
```

```
abstract class AbsList<E> implements Collection<E> {
  @Override public boolean isEmpty() {
    return this.size() == 0;}}
```

```
abstract class AbsStack<E> implements Collection<E> {
  @Override public boolean isEmpty() {
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abstract class AbsSet<E> implements Collection<E> {
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INTERFACES CANNOT DECLARE INSTANCE FIELDS

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- Migrate `AbsList.size()` to `Collection` as a default method?

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In **general**, how can we guarantee that migration results in a type-correct transformation?

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- Interfaces cannot declare **instance fields**.

Question

In **general**, how can we guarantee that migration results in a type-correct transformation?

Answer

Use **type constraints** [Palsberg and Schwartzbach, 1994; Tip et al., 2011] to check refactoring preconditions.

USING TYPE CONSTRAINTS AS REFACTORING PRECONDITIONS

- Type constraints denote the subtyping relationships for each program element that must hold between corresponding expressions for that portion to be considered well-typed.

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program construct	implied type constraint(s)
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Migrating `size()` to `Collection` would imply `[this]` $=$ `Collection`.

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access E.f to field F	$[E.f] \triangleq [F]$	(1)
	$[E] \leq Decl(F)$	(2)

Migrating `size()` to `Collection` would imply [`this`] = `Collection`.

```
interface Collection<E> {
  default int size() {return this.size;}}
```

This violates constraint (2) that [`this`] ≤ [`AbsList`].

```
abstract class AbsList<E> implements Collection<E> {
  @Override public int size() {return this.size;}}
```

program construct	implied type constraint(s)	
assignment $E_i = E_j$	$[E_j] \leq [E_i]$	(1)
method call $E.m(E_1, \ldots, E_n)$ to a virtual method M (throwing exceptions $Ext_1, \ldots, Ext_j$)	$[E.m(E_1, \ldots, E_n)] \triangleq [M]$ $[E_i] \leq [\mathit{Param}(M, i)]$ $[E] \leq \mathit{Decl}(M_1) \vee \cdots \vee [E] \leq \mathit{Decl}(M_k)$ where $\mathit{RootDefs}(M) = \{M_1, \ldots, M_k\}$ $\forall Ext \in \{Ext_1, \ldots, Ext_j\}$ $\exists Ex_h \in \mathit{Handle}(E.m(E_1, \ldots, E_n))[[Ex_t] \leq [Ex_h]]$	(2) (3) (4) (5)
access $E.f$ to field F	$[E.f] \triangleq [F]$ $[E] \leq \mathit{Decl}(F)$	(6) (7)
return E in method M	$[E] \leq [M]$	(8)
M' overrides M, $M' \neq M$	$[\mathit{Param}(M', i)] = [\mathit{Param}(M, i)]$ $[M'] \leq [M]$ $\mathit{Decl}(M') < \mathit{Decl}(M)$	(9) (10) (11)
for every class (and enum) C	$C \leq \texttt{java.lang.Object}$	(12)
for every interface I	$I \not\leq \texttt{java.lang.Object} \wedge \forall M[\mathit{Decl}(M) \triangleq \texttt{java.lang.Object} \wedge$ $\mathit{Public}(M) \implies \exists M'[\mathit{Decl}(M') \triangleq I \wedge \mathit{NOverrides}(M', M)]]$	(13)
for every functional interface I	$\exists M[\mathit{Decl}(M) \triangleq I \wedge \mathit{Abstract}(M)$ $\wedge \forall M'[\mathit{Decl}(M') \triangleq I \wedge M' \neq M \implies \neg \mathit{Abstract}(M')]]$	(14)
implicit declaration of **this** in method M	$[\textbf{this}] \triangleq \mathit{Decl}(M)$	(15)
implicit declaration of **super** in method M	$\neg \mathit{Interface}(\mathit{Decl}(M)) \implies [\textbf{super}] \triangleq \mathit{super}(\mathit{Decl}(M))$	(16)
implicit declaration of `I.super` in method M	$\mathit{Decl}(M) < I \implies [\texttt{I.}\textbf{super}] \triangleq I$	(17)
expression **new** $T(E_1, \ldots, E_n)$ ...	$[\textbf{new}\ T(E_1, \ldots, E_n)\ \ldots] \leq [T]$	(18)
declaration of method M (declared in type T)	$\mathit{Decl}(M) \triangleq T$	(19)
declaration of field F (declared in type T)	$\mathit{Decl}(F) \triangleq T$	(20)
explicit declaration of variable or method parameter $T\ v$	$[v] \triangleq T$	(21)
declaration of method M with return type T	$[M] \triangleq T$	(22)
declaration of field F with type T	$[F] \triangleq T$	(23)
cast $(T)E$	$[(T)E] \triangleq T$	(24)
declaration of method M declared in interface I	$\exists J, M'[\mathit{Interface}(J) \wedge J \not\leq I \wedge I \nless J \wedge J \leq \mathit{Decl}(M')$ $\wedge \mathit{NOverrides}(M', M) \wedge (\mathit{Default}(M') \vee \mathit{Default}(M))]$ $\implies \forall C \mid \mathit{Class}(C) \wedge C < I \wedge C < J[\exists M''[M'' \neq M' \wedge M'' \neq M$ $\wedge \mathit{Class}(\mathit{Decl}(M'')) \wedge C \leq \mathit{Decl}(M'') \wedge \mathit{Public}(M'')$ $\wedge \mathit{NOverrides}(M'', M')]]$	(25)
declaration of concrete type T implementing interface I declaring method M	$\exists M'[T \leq \mathit{Decl}(M') \wedge \mathit{NOverrides}(M, M')$ $\wedge \neg \mathit{Abstract}(M') \wedge \forall M''[T < \mathit{Decl}(M'') < \mathit{Decl}(M') \wedge$ $\mathit{NOverrides}(M'', M') \implies \neg \mathit{Abstract}(M'')]]$	(26)

Fig. 4. Type constraints for a subset of core Java features.

- Extend [Tip et al., 2011] with **new** constraints, **new** definitions, and **semantics preservation** for **default methods**.
- See paper for more details.

PRESERVING SEMANTICS IN LIGHT OF MULTIPLE INHERITANCE

```java
abstract class AbsList<E> implements Collection<E> {
  @Override public void removeLast() {
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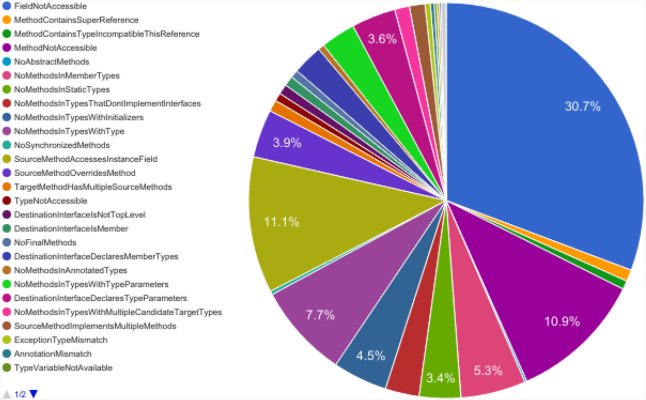
- `Queue` **loses** “tie” with `AbsList`.
- Disallow methods that override in **both** classes and interfaces.

ECLIPSE PLUG-IN AND CASE STUDY

subject	KL	KM	cnds	dflts	fps	δ	-δ	tm (s)
ArtOfIllusion	118	6.94	16	1	34	1	0	3.65
Azureus	599	3.98	747	116	1366	31	2	61.83
Colt	36	3.77	69	4	140	3	0	6.76
elasticsearch	585	47.87	339	69	644	21	4	83.30
Java8	291	30.99	299	93	775	25	10	64.66
JavaPush	6	0.77	1	0	4	0	0	1.02
JGraph	13	1.47	16	2	21	1	0	3.12
JHotDraw	32	3.60	181	46	282	8	0	7.75
JUnit	26	3.58	9	0	25	0	0	0.79
MWDumper	5	0.40	11	0	24	0	0	0.29
osgi	18	1.81	13	3	11	2	0	0.76
rdp4j	2	0.26	10	8	2	1	0	1.10
spring	506	53.51	776	150	1459	50	13	91.68
Tomcat	176	16.15	233	31	399	13	0	13.81
verbose	4	0.55	1	0	1	0	0	0.55
VietPad	11	0.58	15	0	26	0	0	0.36
Violet	27	2.06	104	40	102	5	1	3.54
Wezzle2D	35	2.18	87	13	181	5	0	4.26
ZKoss	185	15.95	394	76	684	0	0	33.95
Totals:	2677	232.2	3321	652	6180	166	30	383.17

- Implemented as an open source Eclipse plug-in.
- Evaluated on 19 Java programs of varying size and domain.
- Automatically migrated 19.63% (column **dflts**) of candidate despite conservatism.
- Running time (column **tm (s)**) averaged $\sim$0.144 secs/KLOC.

REFACTORING PRECONDITION FAILURE DISTRIBUTION



- Field and method **inaccessibility** from the destination interface accounted for largest number of errors.
- Next largest failure due to **instance field accesses** (failures of constraint (2)).

PRELIMINARY PULL REQUEST STUDY

- Submitted 19 pull requests to Java projects on GitHub.
- 4 were successfully merged, 5 are still open, and 10 were closed without merging.
- Merged projects totaled 163 watches, 1071 stars, and 180 forks.
- Projects rejecting requests citing reasons such as:
    - They had not yet moved or were in the process of moving to Java 8.
    - Needed to support older Java clients (Android).

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- Graduate positions available! `http://bit.ly/cunygrad`

PRECONDITION FAILURES BREAKDOWN

#	Precondition	Fails
P1	MethodContainsInconsistentParameterAnnotations	1
P2	MethodContainsCallToProtectedObjectMethod	1
P3	TypeVariableNotAvailable	10
P4	DestinationInterfaceIsFunctional	17
P5	TargetMethodHasMultipleSourceMethods	19
P6	MethodContainsIncompatibleParameterTypeParameters	42
P7	NoMethodsWithMultipleCandidateDestinations	53
P8	TypeNotAccessible	64
P9	SourceMethodImplementsMultipleMethods	72
P10	SourceMethodProvidesImplementationsForMultipleMethods	79
P11	MethodContainsTypeIncompatibleThisReference	79
P12	IncompatibleMethodReturnTypes	104
P13	ExceptionTypeMismatch	105
P14	MethodContainsSuperReference	147
P15	SourceMethodOverridesClassMethod	258
P16	AnnotationMismatch	305
P17	SourceMethodAccessesInstanceField	463
P18	MethodNotAccessible	1,679
P19	FieldNotAccessible	2,565

Table: Precondition failures.

FOR FURTHER READING

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