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AUTOMATED REFACTORIZING OF LEGACY JAVA SOFTWARE TO DEFAULT METHODS

Raffi Khatchadourian¹ Hidehiko Masuhara²
International Conference on Software Engineering, 2017

¹Computer Science, Hunter College & the Graduate Center, City University of New York, USA
²Mathematical and Computing Science, Tokyo Institute of Technology, Japan
MOTIVATION
· Traditionally, an **interface** is a Java type that lists method declarations.
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Clients are guaranteed that concrete interface implementers provide implementations for all listed methods.

```java
interface Collection<E> {
    int size();
    void add(E elem);
    boolean isEmpty();
    int capacity();
    abstract boolean atCapacity();
}
```
· Interface methods can be listed as **optional** operations.

```java
interface Collection<E> {
    // ...
    void add(E elem); /* optional */
}
```
• Interface methods can be listed as **optional** operations.
• Implementers may choose to support them or not.

```java
interface Collection<E> {
    // ...
    void add(E elem); /* optional */ }

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

```java
interface Collection<E> {
    // ...
    void add(E elem); /* optional */
}
```

```java
class ImmutableList<E> implements Collection<E> {
    // ...
    @Override public void add(E elem) {
        throw new UnsupportedOperationException();
    }
}
```
The **skeletal implementation** design pattern [Bloch, 2008] is used to make implementing interfaces easier.
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Abstract skeletal implementation class provides partial implementations.

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

class ImmutableList<E> extends AbstractImmutableList<E> {
    // ...
    @Override public void add(E elem) {
        throw new UnsupportedOperationException();
    }
}
```
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 enhanced interfaces allow both method declarations and definitions.

interface Collection<E> {
    default void add(E elem) { // optional.
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· Java 8 enhanced interfaces allow both method declarations and definitions.
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· Original motivation to facilitate interface evolution.

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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].

```java
interface Collection<E> {
    default void add(E elem) { // optional.
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class ImmutableList<E> implements Collection<E> {
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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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- No separate classes to complicate libraries, making maintenance **easier**.
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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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  - Ensuring tie-breakers with overriding class methods do not **alter semantics**.
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” law [Borba et al., 2004] expresses transformational semantic equivalence.
· In our case, no method **declarations** are being moved but rather **bodies**.
OUR CONTRIBUTION
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() {
        return this.size() == 0;}
}

abstract class AbsSet<E> implements Collection<E> {
    @Override public boolean isEmpty() {
        int size = this.size(); return size == 0;}}
interface Collection<E> {
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abstract class AbsList<E> implements Collection<E> {
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- May not have a one-to-one correspondence between source and target methods.
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- Migrating any of the source methods passing preconditions would be safe.
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interface Collection<E> {
    int size();
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abstract class AbsList<E> implements Collection<E> {
    Object[] eles; int size;
    @Override public int size() {return this.size;}
}

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

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.
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- Migrate AbsList\(\).size\(\)() to Collection as a default method?
Interfaces cannot declare instance fields.

```java
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}

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    @Override public int size() {return this.size;}
}
```

- Migrate `AbsList.size()` to `Collection` as a default method?
- `size()` accesses instance fields; migrate them to `Collection`?
Interfaces cannot declare instance fields.

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**INTERFACES CANNOT DECLARE INSTANCE FIELDS**

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· Interfaces **cannot** declare **instance fields**.

**Question**

In **general**, how can we guarantee that migration results in a type-correct transformation?
The `Collection` interface and `AbsList` abstract class are defined as follows:

```java
interface Collection<E> {
  Object[] elems; int size;
  default int size() {return this.size;}}

abstract class AbsList<E> implements Collection<E> {
  Object[] elems; int size;
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```

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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.
• 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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• A complete program is type-correct if all constraints implied by all program elements hold.
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<tr>
<td>access E.f to field F</td>
<td>([E.f] \triangleq [F])</td>
</tr>
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<td></td>
<td>([E] \leq \text{Decl}(F))</td>
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Migrating \(\text{size()}\) to \(\text{Collection}\) would imply \([\text{this}] = \text{Collection}\).

\begin{verbatim}
interface Collection<E> {
default int size() {return this.size;}
}
\end{verbatim}

This violates constraint (2) that \([\text{this}] \leq \text{Decl}(F)\).

\begin{verbatim}
abstract class AbsList<E> implements Collection<E> {
@override public int size() {return this.size;}
\end{verbatim}
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Migrating `size()` to Collection would imply `[this] = Collection`.

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

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interface Collection<E> {
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```

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

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abstract class AbsList<E> implements Collection<E> {
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### NEW TYPE CONSTRAINTS, DEFINITIONS, AND SEMANTICS PRESERVATION

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<td>assignment $E_i = E_j$</td>
<td>$[E_i] \leq [E_j]$ (1)</td>
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<tr>
<td>method call $E.m(E_1, \ldots, E_n)$ to a virtual method $M$ (throwing exceptions $E_{x1}, \ldots, E_{xn}$)</td>
<td>$[E.m(E_1, \ldots, E_n)] \leq [M]$ (2) $[E_i] \leq [\text{Param}(M,i)]$ (3) $[E] \leq \text{Decl}(M_1) \lor \cdots \lor [E] \leq \text{Decl}(M_k)$ (4) where $\text{RootDefs}(M) = {M_1, \ldots, M_k}$ $\forall E_i \in {E_{x1}, \ldots, E_{xn}}$ $\exists E_h \in \text{Handle}(E.m(E_1, \ldots, E_n))[[E_{x1}] \leq [E_h]]$ (5)</td>
</tr>
<tr>
<td>access $E.f$ to field $F$</td>
<td>$[E.f] \equiv [F]$ (6) $[E] \leq \text{Decl}(F)$ (7)</td>
</tr>
<tr>
<td>return $E$ in method $M$</td>
<td>$[E] \leq [M]$ (8)</td>
</tr>
<tr>
<td>$M'$ overrides $M$, $M' \neq M$</td>
<td>$[\text{Param}(M',i)] = [\text{Param}(M,i)]$ (9) $[M'] \leq [M]$ (10) $\text{Decl}(M') \not\subseteq \text{Decl}(M)$ (11)</td>
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<tr>
<td>for every class (and enum) $C$</td>
<td>$C \subseteq \text{java.lang.object}$ (12)</td>
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<td>for every interface $I$</td>
<td>$I \not\subseteq \text{java.lang.object} \wedge \forall M [\text{Decl}(M) \equiv \text{java.lang.object}\wedge \text{Public}(M) \Rightarrow \exists M' [\text{Decl}(M') \equiv I \wedge \text{NOptOverrides}(M', M)]]$ (13)</td>
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<td>for every functional interface $I$</td>
<td>$\exists M [\text{Decl}(M) \equiv I \wedge \text{Abstract}(M) \wedge \forall M' [\text{Decl}(M') \equiv I \wedge M' \neq M \Rightarrow \neg\text{Abstract}(M')]]$ (14)</td>
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<td>implicit declaration of $\textbf{this}$ in method $M$</td>
<td>$[\textbf{this}] \equiv \text{Decl}(M)$ (15)</td>
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<td>implicit declaration of $\textbf{super}$ in method $M$</td>
<td>$\neg\text{Interface}(\text{Decl}(M)) \Rightarrow [\textbf{super}] \equiv \text{super}(\text{Decl}(M))$ (16)</td>
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<td>implicit declaration of $1.$ $\textbf{super}$ in method $M$</td>
<td>$\text{Decl}(M) &lt; I \Rightarrow [1.\textbf{super}] \equiv I$ (17)</td>
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<tr>
<td>expression $\textbf{new} T(E_1, \ldots, E_n) \ldots$</td>
<td>$\text{Decl}(M') \equiv T$ (19)</td>
</tr>
<tr>
<td>declaration of method $M$ (declared in type $T$)</td>
<td>$\text{Decl}(F) \equiv T$ (20)</td>
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<tr>
<td>declaration of field $F$ (declared in type $T$)</td>
<td>$[e] \equiv T$ (21)</td>
</tr>
<tr>
<td>explicit declaration of variable or method parameter $T$</td>
<td>$[M] \equiv T$ (22)</td>
</tr>
<tr>
<td>declaration of method $M$ with return type $T$</td>
<td>$[F] \equiv T$ (23)</td>
</tr>
<tr>
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<td>$[[F]E] \equiv T$ (24)</td>
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<tr>
<td>cast $(T)E$</td>
<td>$\exists J, M' [\text{Interface}(J) \wedge J \not\subseteq I \wedge J \not\subseteq \text{Decl}(M') \wedge \text{NOptOverrides}(M', M) \wedge (\text{Default}(M') \lor \text{Default}(M))] \Rightarrow \forall C \mid \text{Class}(C) \wedge C &lt; I \wedge C &lt; J\exists M'' [M'' \neq M' \wedge M'' \neq M \wedge \text{Decl}(M'') \wedge \text{Decl}(M') \wedge \text{Public}(M'') \wedge \text{NOptOverrides}(M', M'')]$ (25)</td>
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<tr>
<td>declaration of method $M$ declared in interface $I$</td>
<td>$\exists M' [\text{Decl}(M') \wedge \text{NOptOverrides}(M', M') \wedge \neg\text{Abstract}(M') \wedge \forall M'' [T &lt; \text{Decl}(M'') &lt; \text{Decl}(M') \wedge \text{NOptOverrides}(M'', M')] \Rightarrow \neg\text{Abstract}(M'')]]$ (26)</td>
</tr>
</tbody>
</table>

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.
abstract class AbsList<E> implements Collection<E> {
    @Override public void removeLast() {
        throw new UnsupportedOperationException();
    }
}

interface Queue<E> extends Collection<E> {
    void removeLast();
    void setSize(int i);
}

abstract class AbsQueue<E> extends AbsList<E> implements Queue<E> {
    @Override public void removeLast() {
        if (!isEmpty()) this.setSize(this.size() - 1);
    }
}

new AbsQueue<Integer>() {}.removeLast(); // to AbsQueue.
abstract class AbsList<E> implements Collection<E> {
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        throw new UnsupportedOperationException();}
}

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new AbsQueue<Integer>() {}.removeLast(); // to AbsQueue.

∙ Can we migrate removeLast() from AbsQueue to Queue?
abstract class AbsList<E> implements Collection<E> {  
  @Override public void removeLast() {  
    throw new UnsupportedOperationException();}}

interface Queue<E> extends Collection<E> {  
  default void removeLast();  
  void setSize(int i);}

abstract class AbsQueue<E> extends AbsList<E> implements Queue<E> {  
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new AbsQueue<Integer>() {}.removeLast(); // to AbsQueue.

Can we migrate removeLast() from AbsQueue to Queue?
Preserving semantics in light of multiple inheritance

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    }
}

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    default void removeLast() {
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- Now dispatches to AbsList as classes take precedence!
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new AbsQueue<Integer>() {}.removeLast(); // to AbsList.

- Can we migrate removeLast() from AbsQueue to Queue?
- **Now** dispatches to AbsList as **classes take precedence!**
- Queue loses “tie” with AbsList.
abstract class AbsList<E> implements Collection<E> {
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• Can we migrate removeLast() from AbsQueue to Queue?
• Now dispatches to AbsList as classes take precedence!
• Queue loses “tie” with AbsList.
• Disallow methods that override in both classes and interfaces.
## ECLIPSE PLUG-IN AND CASE STUDY

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<td>166</td>
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</table>

- 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 ~0.144 secs/KLOC.
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)).
· 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).
SUMMARY

- Efficient, fully-automated, semantics-preserving refactoring approach based on type constraints that migrates the skeletal implementation pattern in legacy Java code to instead use default methods.

- Implemented as an Eclipse IDE plug-in (available at http://cuny.is/interefact) and evaluated on 19 open source projects.

- Tool scales and refactored 19.63% of methods possibly participating in the pattern.

- 4 pull requests merged into GitHub repositories, including large, widely used frameworks from reputable organizations.

- Studies highlight pattern usage and gives possible insight to language designers on construct applicability to existing software.

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EFFICIENT, FULLY-AUTOMATED, SEMANTICS-PRESERVING REFACCTORING APPROACH BASED ON TYPE CONSTRAINTS THAT MIGRATES THE SKELETAL IMPLEMENTATION PATTERN IN LEGACY JAVA CODE TO INSTEAD USE DEFAULT METHODS.

IMPLEMENTED AS AN ECLIPSE IDE PLUGIN (AVAILABLE AT HTTP://CUNY.IS/INTEREFACT) AND EVALUATED ON 19 OPEN SOURCE PROJECTS.

TOOL SCALES AND REFACTORED 19.63% OF METHODS POSSIBLY PARTICIPATING IN THE PATTERN.

4 PULL REQUESTS MERGED INTO GITHUB REPOSITORIES, INCLUDING LARGE, WIDELY USED FRAMEWORKS FROM REPUTABLE ORGANIZATIONS.

STUDIES HIGHLIGHT PATTERN USAGE AND GIVE POSSIBLE INSIGHT TO LANGUAGE DESIGNERS ON CONSTRUCT APPLICABILITY TO EXISTING SOFTWARE.

GRADUATE POSITIONS AVAILABLE! HTTP://BIT.LY/CUNYGRAD
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Graduate positions available! http://bit.ly/cunygrad
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<th>#</th>
<th>Precondition</th>
<th>Fails</th>
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<tr>
<td>P2</td>
<td>MethodContainsCallToProtectedObjectMethod</td>
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<td>P3</td>
<td>TypeVariableNotAvailable</td>
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<td>P4</td>
<td>DestinationInterfaceIsFunctional</td>
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<td>P5</td>
<td>TargetMethodHasMultipleSourceMethods</td>
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<td>MethodContainsIncompatibleParameterTypeParameters</td>
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<td>NoMethodsWithMultipleCandidateDestinations</td>
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<td>SourceMethodImplementsMultipleMethods</td>
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<td>P10</td>
<td>SourceMethodProvidesImplementationsForMultipleMethods</td>
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<td>MethodContainsTypeIncompatibleThisReference</td>
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<td>IncompatibleMethodReturnType</td>
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Table: Precondition failures.
FOR FURTHER READING