ROSEAU (REED)

Fast, Accurate, Source-based API Breaking Change Analysis in Java

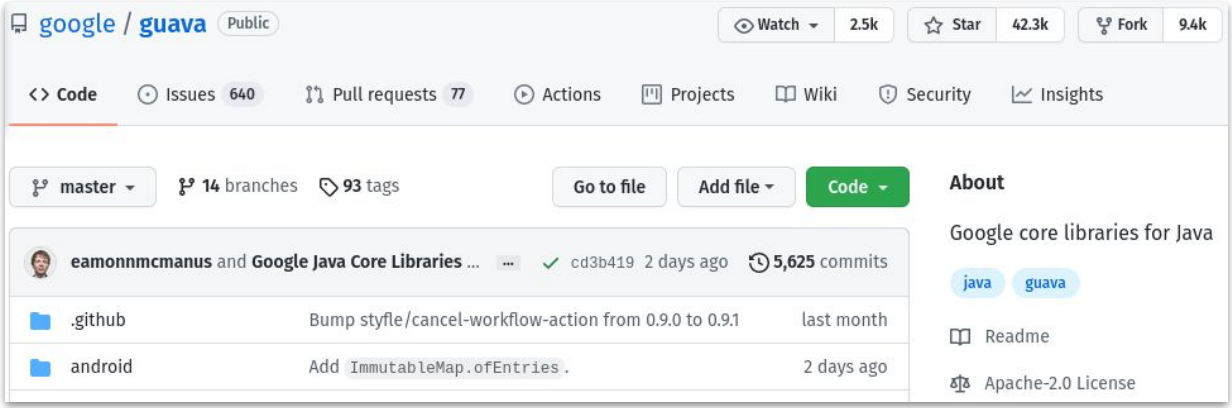
LaBRI TU/e

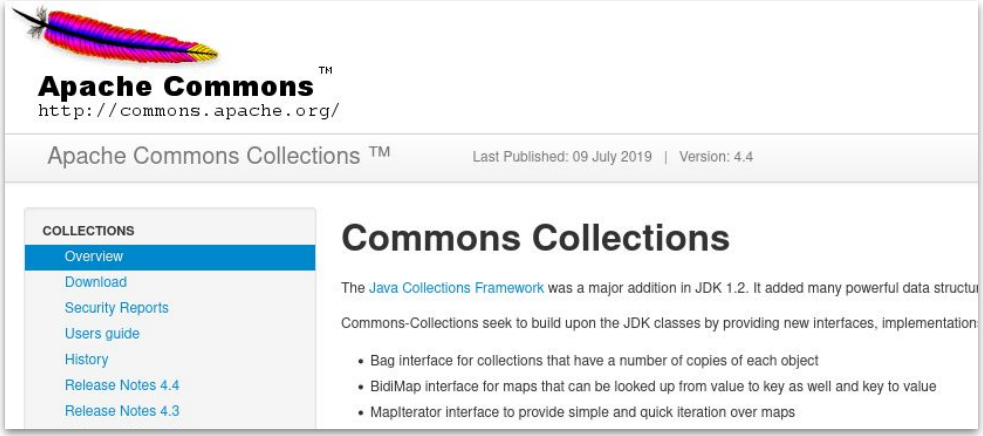




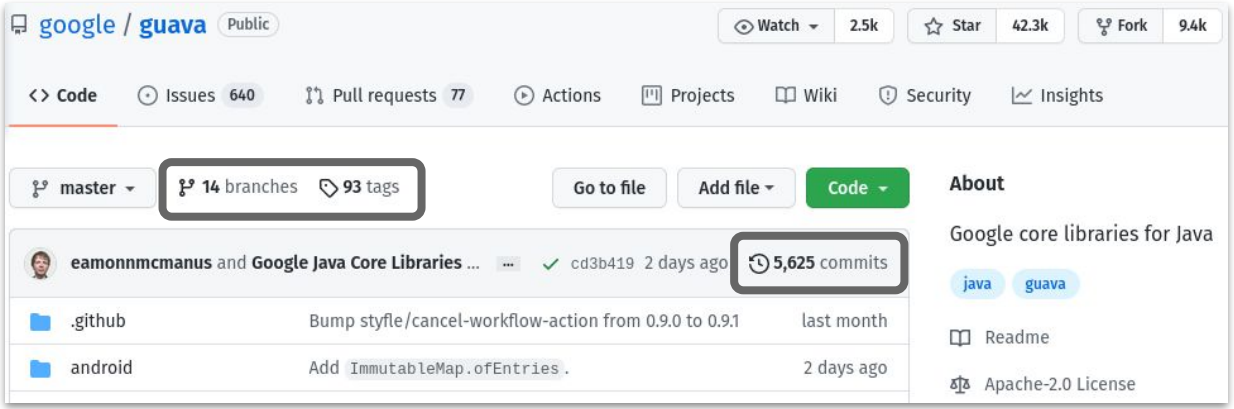
Corentin Latappy Thomas Degueule Jean-Rémy Falleri Romain Robbes Lina Ochoa Venegas

Software Libraries





Software Libraries Evolution



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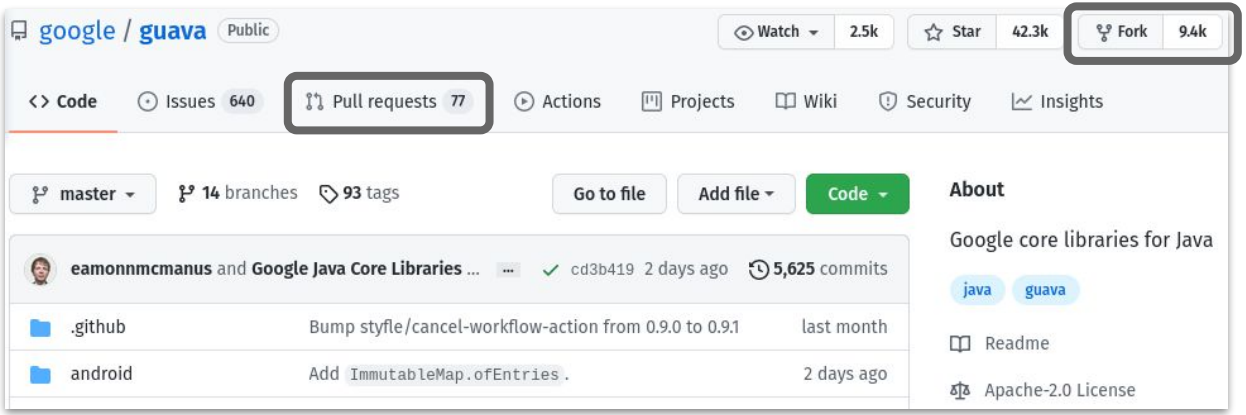

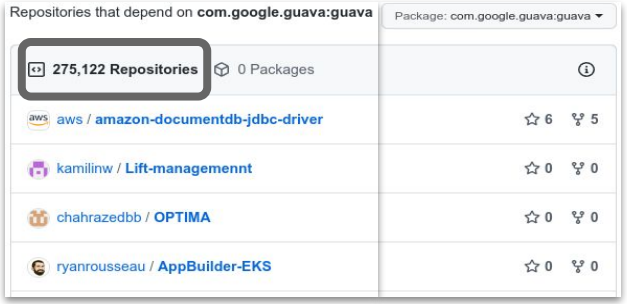

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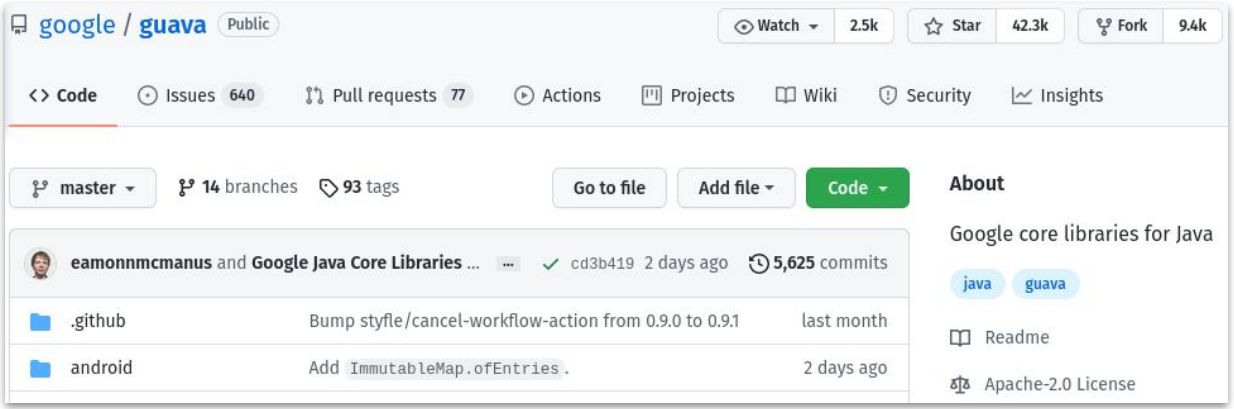
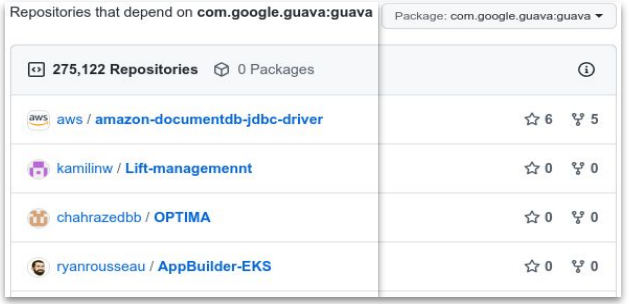
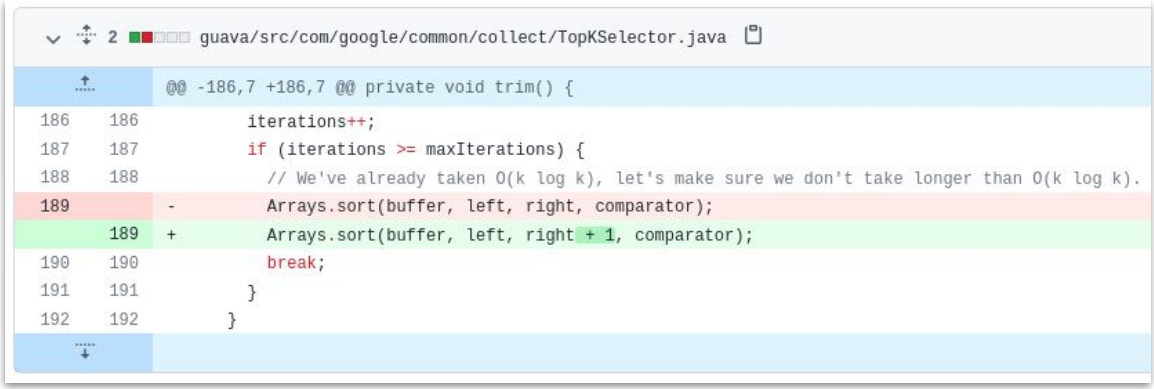




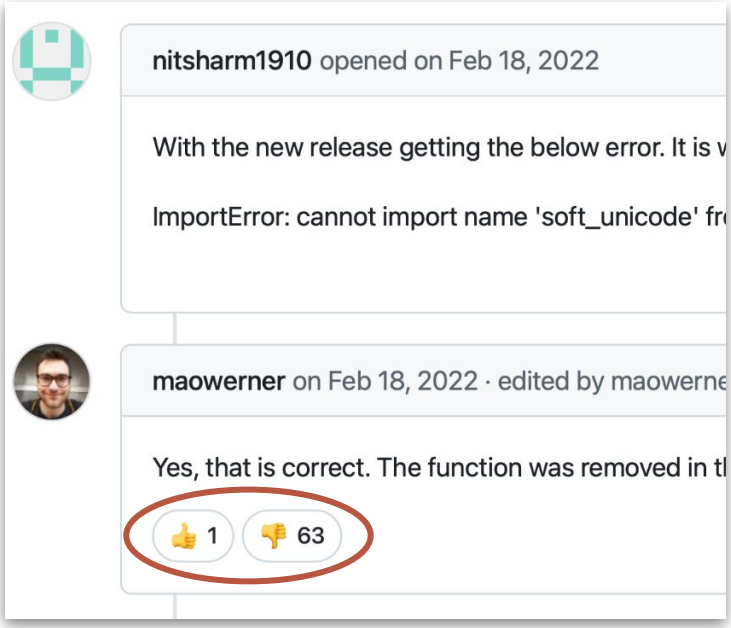


Breaking Changes in Practice

- Why?

Breaking Changes in Practice

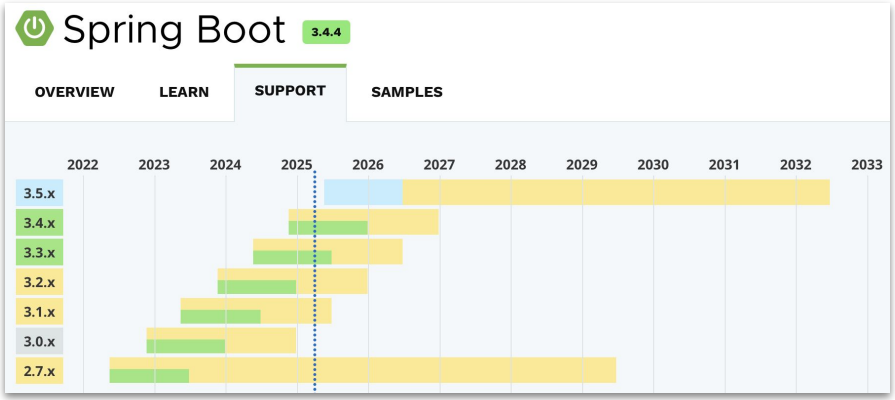
- Why?
  - Keep users confidence



https://github.com/pallets/markupsafe/issues/284

Breaking Changes in Practice

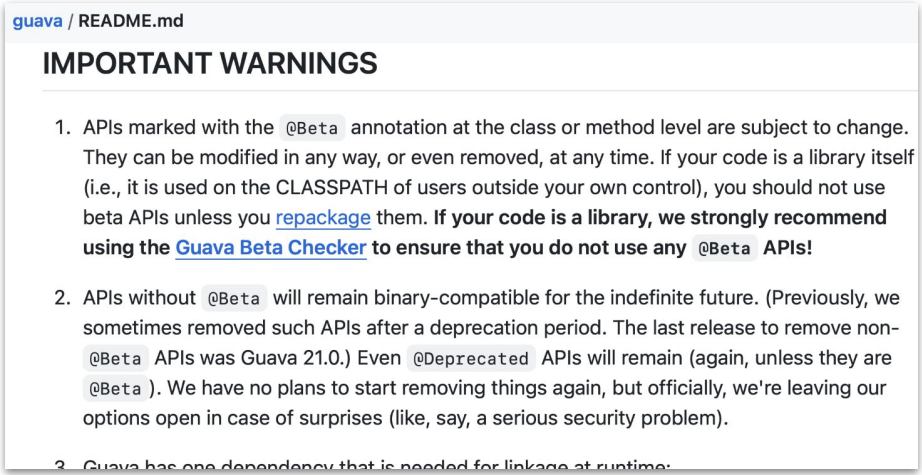
- Why?
  - Keep users confidence
  - Avoid multiple versions support



https://spring.io/projects/spring-boot#support

Breaking Changes in Practice

- Why?
  - Keep users confidence
  - Avoid multiple versions support
- How?
  - Policies



guava / README.md

IMPORTANT WARNINGS

1. APIs marked with the `@Beta` annotation at the class or method level are subject to change. They can be modified in any way, or even removed, at any time. If your code is a library itself (i.e., it is used on the CLASSPATH of users outside your own control), you should not use beta APIs unless you repackage them. **If your code is a library, we strongly recommend using the Guava Beta Checker to ensure that you do not use any `@Beta` APIs!**

2. APIs without `@Beta` will remain binary-compatible for the indefinite future. (Previously, we sometimes removed such APIs after a deprecation period. The last release to remove non-`@Beta` APIs was Guava 21.0.) Even `@Deprecated` APIs will remain (again, unless they are `@Beta`). We have no plans to start removing things again, but officially, we're leaving our options open in case of surprises (like, say, a serious security problem).

3. Guava has one dependency that is needed for linkage at runtime:

https://github.com/google/guava/blob/master/README.md#important-warnings

Breaking Changes in Practice

- Why?
  - Keep users confidence
  - Avoid multiple versions support
- How?
  - Policies
  - Tools

cargo-semver-checks

gocompat
gorelease

AexPy

JApiCmp
Revapi

Breaking Changes in SE Research

- Studies: *why*, *how*, *when* do libraries break, how does it affect clients?
  - Xavier *et al.*: 317 libraries, 9k releases[1]
  - Ochoa *et al.*: 14k libraries, 120k releases[2]
  - Jayasuriya *et al.*: 7k libraries, 18k releases[3]

[1] "*Historical and impact analysis of API breaking changes: A large-scale study*". L. Xavier; A. Brito; A. Hora, M. Valente. SANER'17
[2] "*Breaking Bad? Semantic Versioning and Impact of Breaking Changes in Maven Central*". L. Ochoa, T. Degueule, JR. Falleri, J. Vinju. EMSE'22
[3] "*An extended study of syntactic breaking changes in the wild*". D. Jayasuriya, S. Ou, S. Hegde, V. Terragni, J. Dietrich, K. Blincoe. EMSE'25

Breaking Changes in SE Research

- Studies: *why*, *how*, *when* do libraries break, how does it affect clients?
  - Xavier *et al.*: 317 libraries, 9k releases[1]
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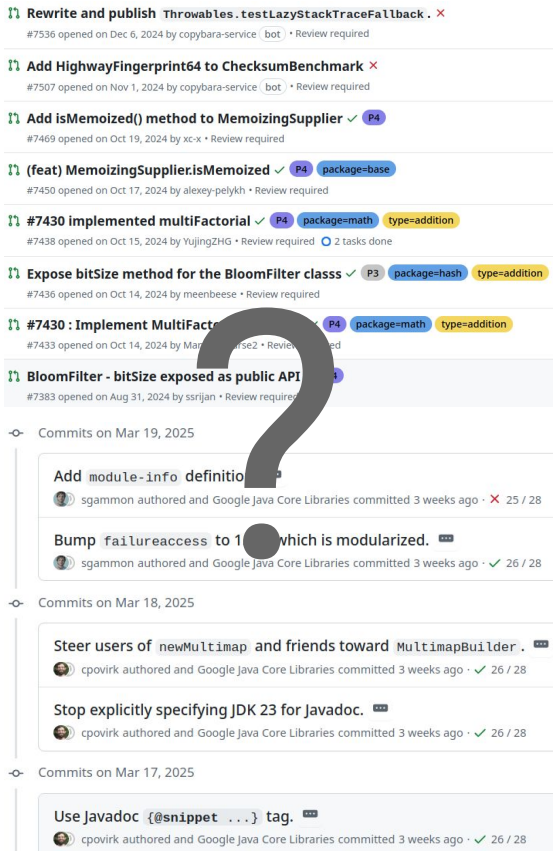
- Researchers are limited in their ability to study library evolution
  - Japicmp is the *de facto* standard, but requires compiled JAR files
    - Only about 50% of arbitrary versions on GitHub can be built automatically[4]
    - Even when possible, compilation costs are impractical for large-scale studies
  - Empirical research is limited to analyzing *pre-built releases*
- Analyzing commits, pull requests, etc. would be valuable but is impractical[5]



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[4] "*Automatic building of java projects in software repositories: A study on feasibility and challenges*". F. Hassan, M. Shaikh, E. Lam, X. Wang. ESEM'17
[5] "*BreakBot: Analyzing the Impact of Breaking Changes to Assist Library Evolution*". L. Ochoa, T. Degueule, JR. Falleri. ICSE'22 (NIER)

V1

```
public final class List<E> {
  private int size;
  public E add(int pos, E elem) {
    ...
  }
}
```

V2

```
public final class List<E T> {
  private int double size listSize;
  public E void add(int pos, E T elem) {
    ...
  }
}
```

V1

```
public final class List<E> {
  private int size;
  public E add(int pos, E elem) {
    ...
  }
}
```

Breaking Changes:
- METHOD_RETURN_TYPE_CHANGED

V2

```
public ~~final~~ class List<~~E~~ T> {
  private ~~int~~ double ~~size~~ listSize;
  public ~~E~~ void add(int pos, ~~E~~ T elem) {
    ...
  }
}
```

Roseau – API Model

```
public final class List<E> {
  private int size;
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    ...
  }
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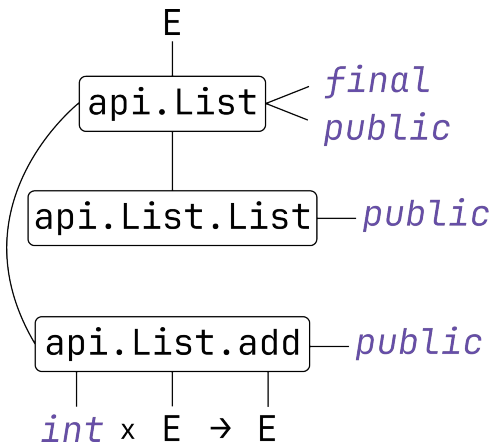
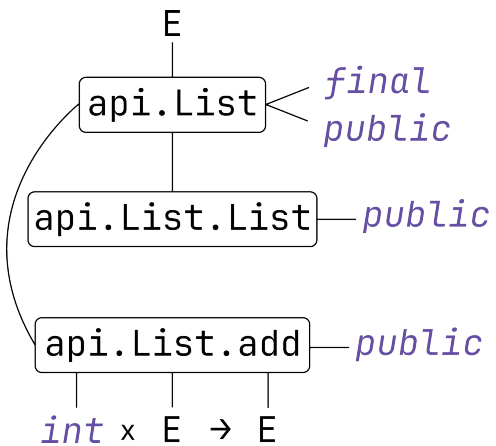


Roseau – API Model

```
public final class List<E> {
  private int size;
  public E add(int pos, E elem) {
    ...
  }
}
```

```
public final class
api.List<E> {
  public api.List();
    0: aload_0
    1: invokespecial #1
    4: return

  public E add(int, E);
    0: aconst_null
    1: areturn
}
```



Roseau

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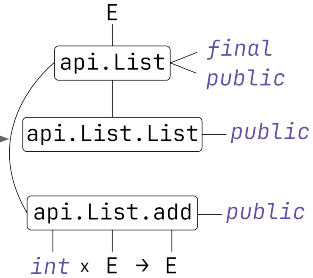

V2

```
public final class List<E> T> {
  private int double size listSize;
  public E void add(int pos, E T elem) {
    ...
  }
}
```

```
public class api.List<T> {
  public api.List();
                0: aload_0
                1: invokespecial #1
                4: return

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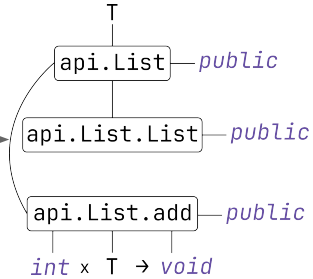
}
```



Roseau

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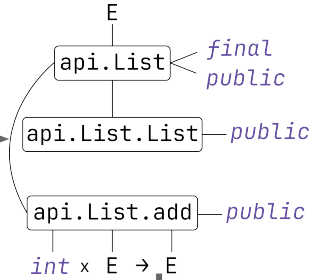

Diff

V2

```
public final class List<E T> {
  private int double size listSize;
  public E void add(int pos, E T elem) {
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  }
}
```

```
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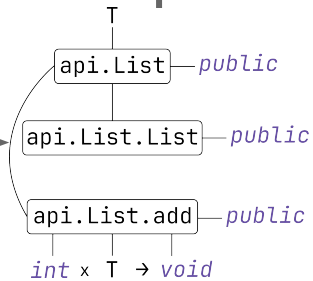

Roseau – BCs as Diffs of API Models

- Translating JLS rules as detection rules on API models
- Expressing these rules at the API level is much easier than at the AST/classfile level

Kind	Detection Rule	Binary	Source
Type removed	$T \in A \wedge \nexists\, T' \in A' \mid T \sim T'$	✗	✗
Type now protected	$T \sim T' \wedge \text{public}(T) \wedge \text{protected}(T')$	✗	✗
Type kind changed	$T \sim T' \wedge \text{typeKind}(T) \neq \text{typeKind}(T')$	✗	✗
Supertype removed	$T \sim T' \wedge \exists\, S \in \text{superTypes}(T) \mid \text{exported}(S) \wedge T' \not\sqsubseteq S$	✗	✗
Type variable removed	$T \sim T' \wedge \lvert\text{typeVars}(T)\rvert > \lvert\text{typeVars}(T')\rvert$	✓	✗
Type variable added	$T \sim T' \wedge \lvert\text{typeVars}(T')\rvert > \lvert\text{typeVars}(T)\rvert > 0$	✓	✗
Type variable changed	$T \sim T' \wedge \exists i \in [1, \lvert\text{typeVars}(T)\rvert], \exists b' \in \text{bounds}(\text{typeVar}_i(T')), \forall b \in \text{bounds}(\text{typeVar}_i(T)) \mid b \not\sqsubseteq b'$	✓	✗
Type now final	$T \sim T' \wedge \neg\text{effectivelyFinal}(T) \wedge \text{effectivelyFinal}(T')$	✗	✗
Type now abstract	$T \sim T' \wedge \neg\text{effectivelyFinal}(T) \wedge \text{effectivelyFinal}(T')$	✗	✗
Nested type now static	$T \sim T' \wedge \neg\text{static}(T) \wedge \text{static}(T')$	✗	✗
Nested type no longer static	$T \sim T' \wedge \text{static}(T) \wedge \neg\text{static}(T')$	✗	✗
Class now checked exception	$T \sim T' \wedge \text{uncheckedException}(T) \wedge \text{checkedException}(T')$	✓	✗
Abstract method added to type	$T \sim T' \wedge \exists m' \in \text{allMethods}(T') \mid \text{abstract}(m') \wedge \nexists m \in \text{allMethods}(T) \mid m \sim m'$	✓	✗
Executable removed	$e \in \text{executables}(T) \wedge \nexists\, e' \in \text{executables}(T') \mid e \sim e'$	✗	✗
Executable now protected	$e \sim e' \wedge \text{public}(e) \wedge \text{protected}(e')$	✗	✗
Executable checked exception removed	$e \sim e' \wedge \exists\, t \in \text{thrown}(e) \mid \nexists t' \in \text{thrown}(e'),\ t' \sqsubseteq t$	✓	✗
Executable checked exception added	$e \sim e' \wedge \exists\, t' \in \text{thrown}(e') \mid \nexists\, t \in \text{thrown}(e),\ t' \not\sqsubseteq t$	✓	✗
Executable parameter generics changed	$e \sim e' \wedge \exists\, i \in [1, \lvert\text{params}(e)\rvert] \mid \lvert\text{typeArgs}(\text{param}_i(e))\rvert \neq \lvert\text{typeArgs}(\text{param}_i(e'))\rvert$	✓	✗
Executable type variable removed	$e \sim e' \wedge \lvert\text{typeVars}(e)\rvert > \lvert\text{typeVars}(e')\rvert \wedge (\text{isMethod}(e) \vee \lvert\text{typeVars}(e)\rvert > 1)$	✓	✗
Executable type variable added	$e \sim e' \wedge \lvert\text{typeVars}(e')\rvert > \lvert\text{typeVars}(e)\rvert > 0$	✓	✗
Executable type variable changed	$e \sim e' \wedge \exists\, i \in [1, \lvert\text{typeVars}(e)\rvert], \exists\, b' \in \text{bounds}(\text{typeVar}_i(e')), \forall\, b \in \text{bounds}(\text{typeVar}_i(e)) \mid b \not\sqsubseteq b'$	✓	✗
Method now final	$m \sim m' \wedge \neg\text{effectivelyFinal}(m) \wedge \text{effectivelyFinal}(m')$	✗	✗
Method now static	$m \sim m' \wedge \neg\text{static}(m) \wedge \text{static}(m')$	✗	✓
Method no longer static	$m \sim m' \wedge \text{static}(m) \wedge \neg\text{static}(m')$	✗	✗
Method now abstract	$m \sim m' \wedge \neg\text{abstract}(m) \wedge \text{abstract}(m')$	✗	✗
Method return type changed	$m \sim m' \wedge \text{returnType}(m) \neq \text{returnType}(m')$	✗	✗
Field removed	$f \in \text{fields}(T) \wedge \nexists\, f' \in \text{fields}(T') \mid f \sim f'$	✗	✗
Field now protected	$f \sim f' \wedge \text{public}(f) \wedge \text{protected}(f')$	✗	✗
Field now final	$f \sim f' \wedge \neg\text{final}(f) \wedge \text{final}(f')$	✗	✗
Field now static	$f \sim f' \wedge \neg\text{static}(f) \wedge \text{static}(f')$	✗	✓
Field no longer static	$f \sim f' \wedge \text{static}(f) \wedge \neg\text{static}(f')$	✗	✗
Field type changed	$f \sim f' \wedge \text{type}(f) \neq \text{type}(f')$	✗	✗

CHAPTER 13

Binary Compatibility

13.4.6 Class Body and Member Declarations

No incompatibility with pre-existing binaries is caused by adding an instance (respectively `static`) member that has the same name and accessibility (for fields), or same name and accessibility and signature and return type (for methods), as an instance (respectively `static`) member of a superclass or subclass. No error occurs even if the set of classes being linked would encounter a compile-time error.

Deleting a class member or constructor that is not declared `private` may cause a linkage error if the member or constructor is used by a pre-existing binary.

Roseau

V1

```
public final class List<E> {
  private int size;
  public E add(int pos, E elem) {
    ...
  }
}
```

```
public final class api.List<E> {
  public api.List();
                0: aload_0
                1: invokespecial #1
                4: return

  public E add(int, E);
                0: aconst_null
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}
```

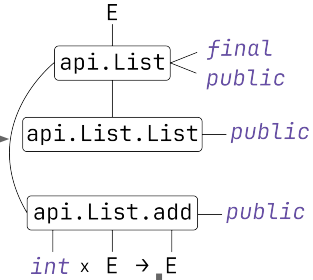

Diff

V2

```
public final class List<E T> {
  private int double size listSize;
  public E void add(int pos, E T elem) {
    ...
  }
}
```

```
public class api.List<T> {
  public api.List();
                0: aload_0
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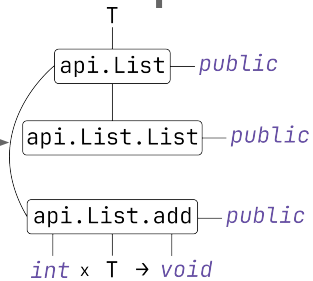

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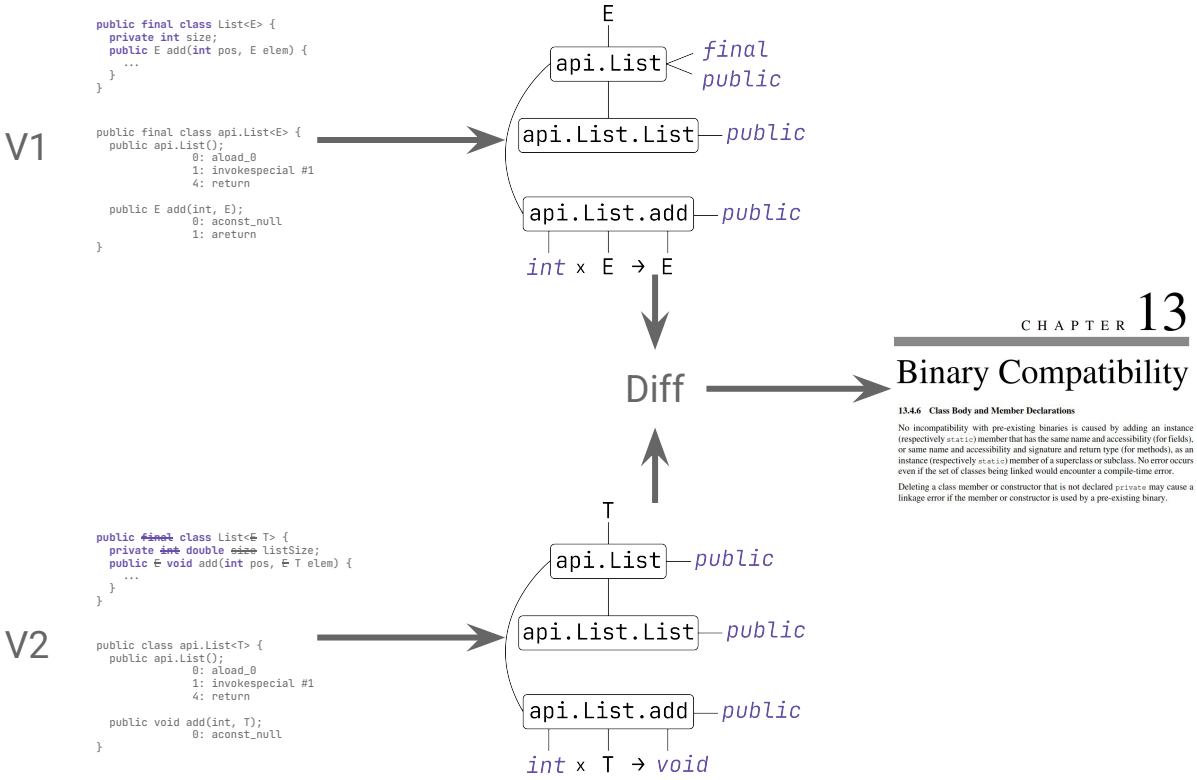
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1: invokespecial #1
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public E add(int, E);
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}
E
api.List
final
public
api.List.List
public
api.List.add
public
int x E → E
Diff
CHAPTER 13
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13.4.6 Class Body and Member Declarations
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Deleting a class member or constructor that is not declared private may cause a linkage error if the member or constructor is used by a pre-existing binary.
V2
public final class List<E> T> {
private int double size listSize;
public E void add(int pos, E T elem) {
...
}
}
public class api.List<T> {
public api.List();
0: aload_0
1: invokespecial #1
4: return
public void add(int, T);
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}
T
api.List
public
api.List.List
public
api.List.add
public
int x T → void

Roseau

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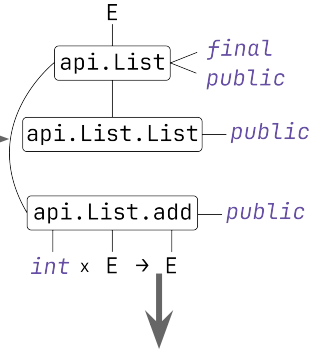

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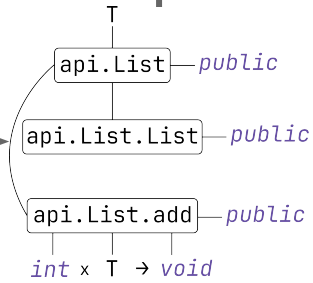

Diff

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Binary Compatibility

13.4.6 Class Body and Member Declarations

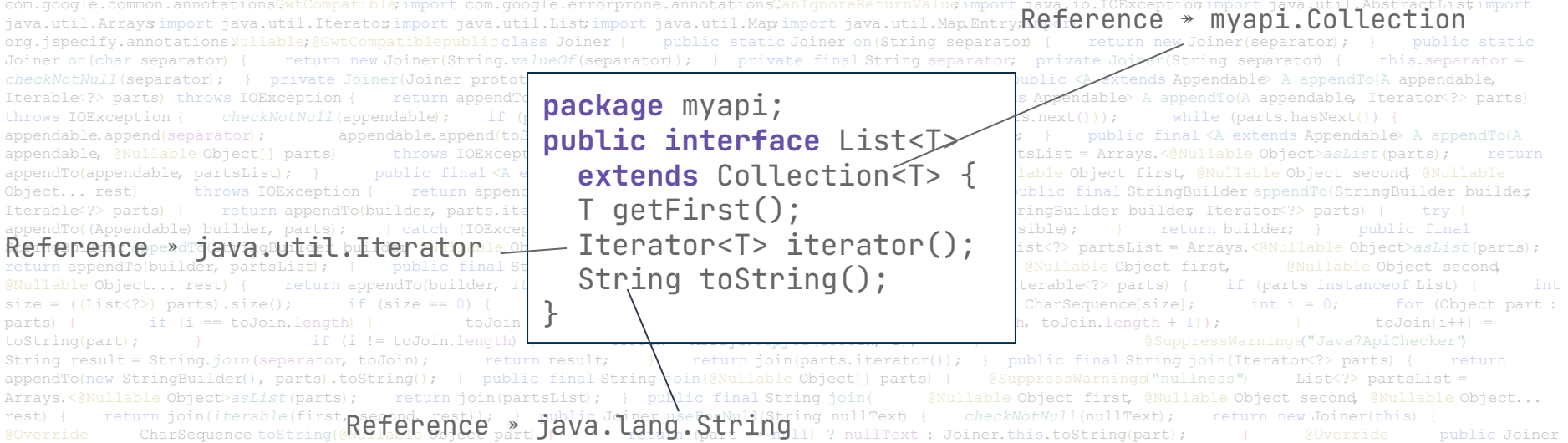
No incompatibility with pre-existing binaries is caused by adding an instance (respectively `static`) member that has the same name and accessibility (for fields), or same name and accessibility and signature and return type (for methods), as an instance (respectively `static`) member of a superclass or subclass. No error occurs even if the set of classes being linked would encounter a compile-time error.

Deleting a class member or constructor that is not declared `private` may cause a linkage error if the member or constructor is used by a pre-existing binary.

Breaking Changes:
- METHOD_RETURN_TYPE_CHANGED

Features / Optimizations

- Incremental Parsing



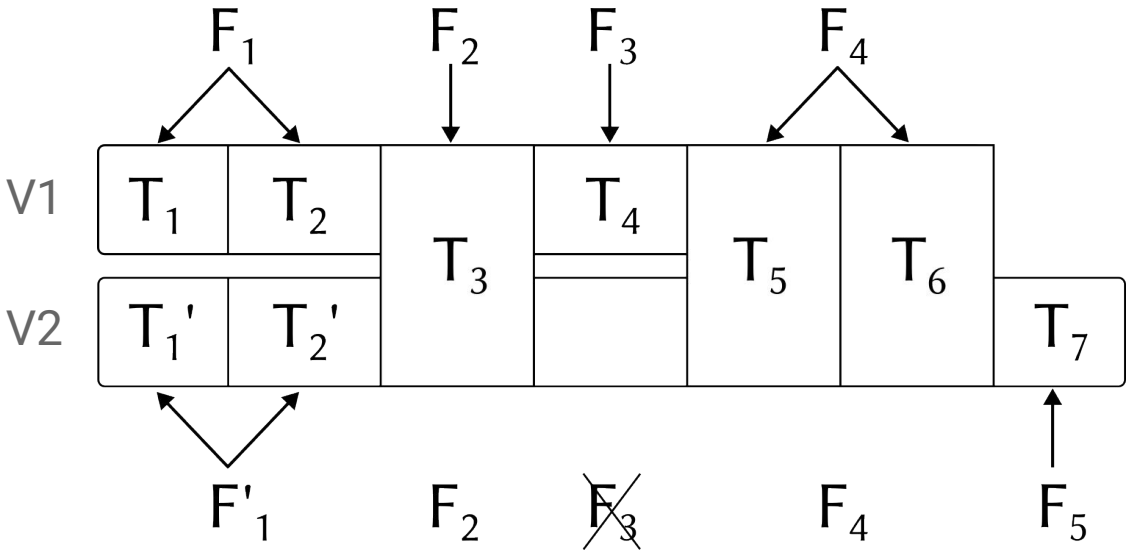
Features / Optimizations

- Incremental Parsing
- *“Diet”* Parsing

```
public class ArrayList {
  public int indexOf(Object o) {
    E[] a = this.a;
    if (o == null) {
      for (int i = 0; i < a.length; i++)
        if (a[i] == null)
          return i;
    } else {
      for (int i = 0; i < a.length; i++)
        if (o.equals(a[i]))
          return i;
    }
    return -1;
  }
}
```

Features / Optimizations

- Incremental Parsing
- *“Diet”* Parsing
- Partial Updates



Evaluation

Accuracy

API Evolution Data Corpus (*Jezek et al.*[1] and *Ochoa et al.*[2])

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	All			Source			Binary		
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JAPICMP	0.90	0.82	0.86	0.78	0.80	0.79	0.90	**0.98**	**0.94**
REVAPI	0.85	0.97	0.91	0.77	0.96	0.85	0.89	0.95	0.92
ROSEAU	**0.98**	**0.99**	**0.99**	**0.88**	**1.00**	**0.94**	**0.91**	**0.98**	**0.94**

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Performance

Dataset w/ Top 100 Artifacts from Maven

⏱️ Artifact last stable version on itself

Java Microbenchmark Harness (JMH)
→ **50** measures by artifact and tool

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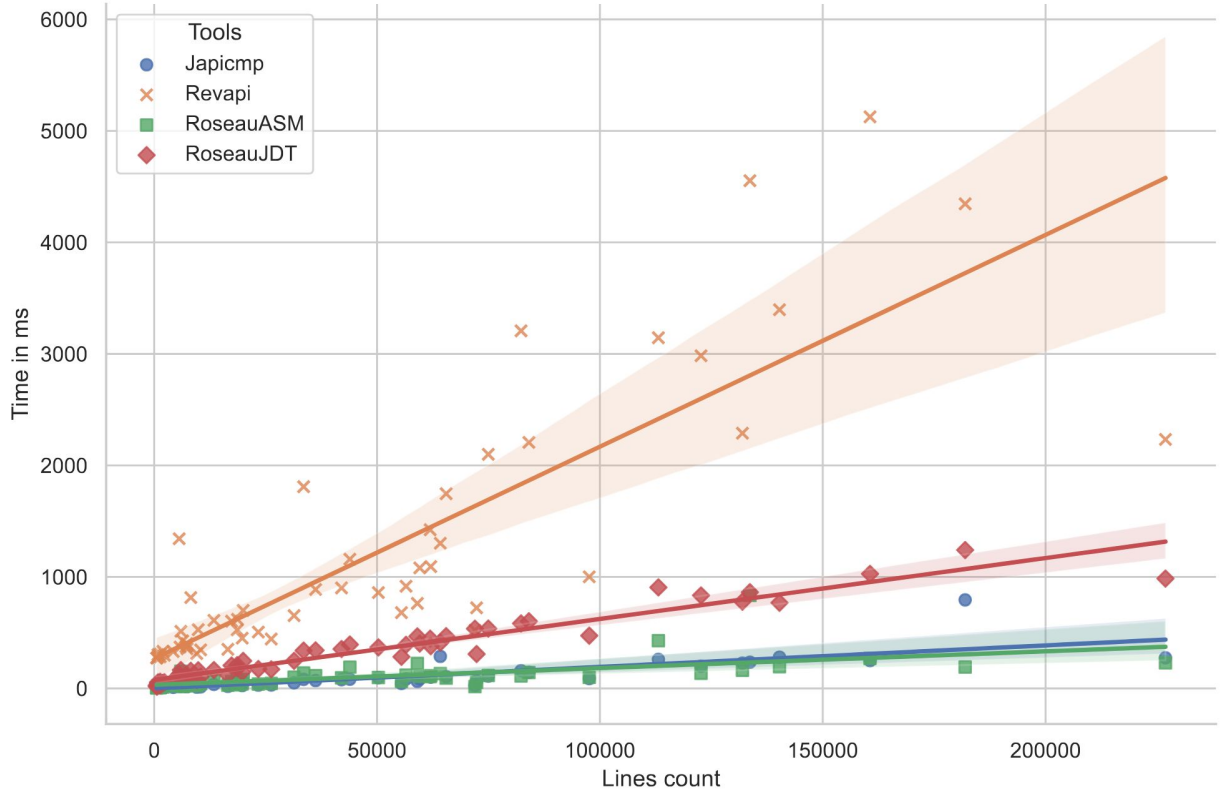
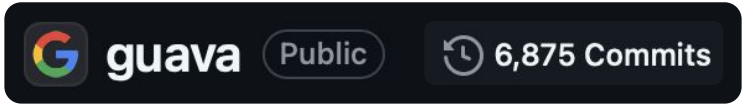


Large-scale Longitudinal Studies



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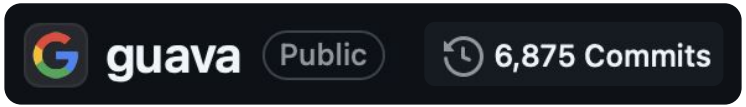

Preliminary study: 100 latest commits of Google's Guava

Method	Mean commit time (ms)	Total time (minutes)
Packaging JAR	68,750	7,836
Roseau w/o incremental	1,065	121
Roseau w/ incremental	81	9

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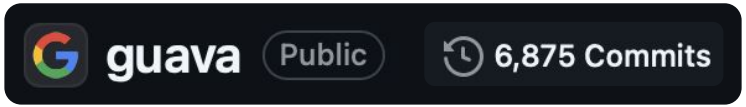

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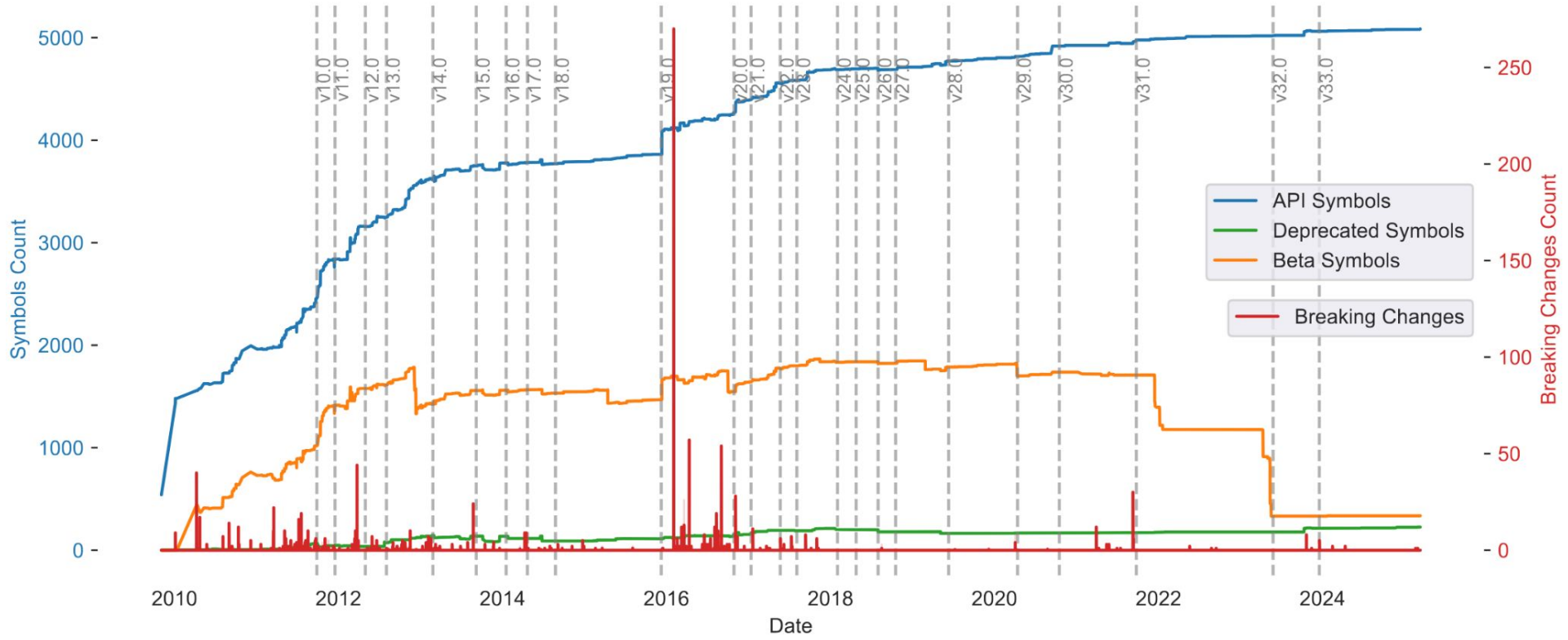
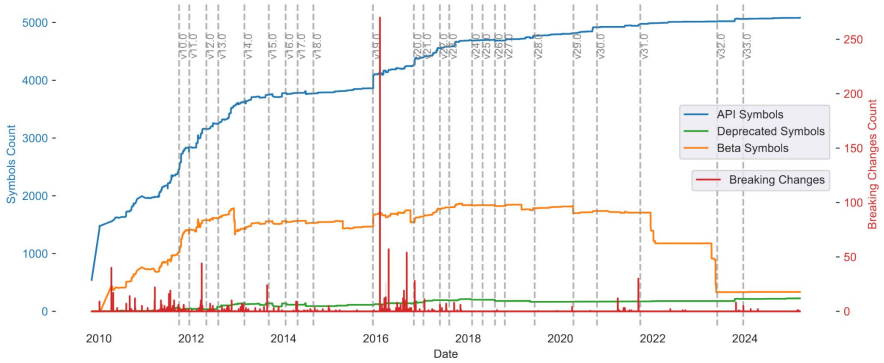


Evolution of Guava API and introduction of Breaking Changes over time

Future Work

Qualitative case studies of some popular libraries



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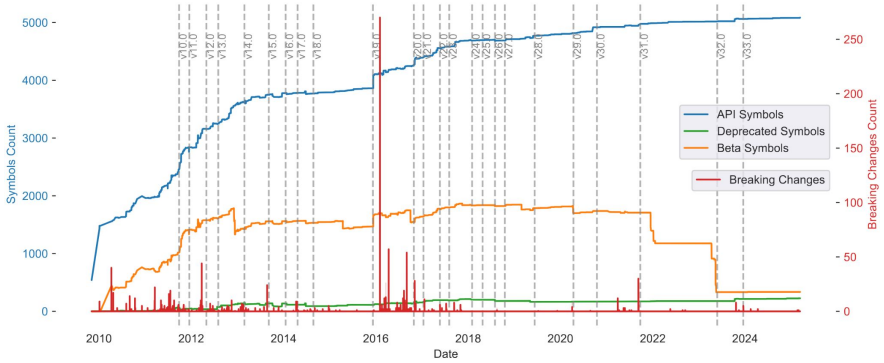

Maintain and improve Roseau

junit-team / **junit-framework**

Commit `465a06f`

marcphilipp committed on Jul 11 Verified

```
Try out roseau to analyze API changes between versions
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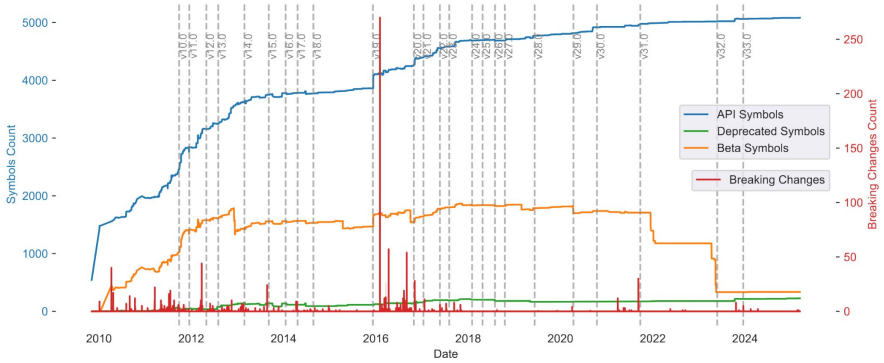

Combinatorial benchmark

V1 API :

288 types

47K members → 1,5M V2

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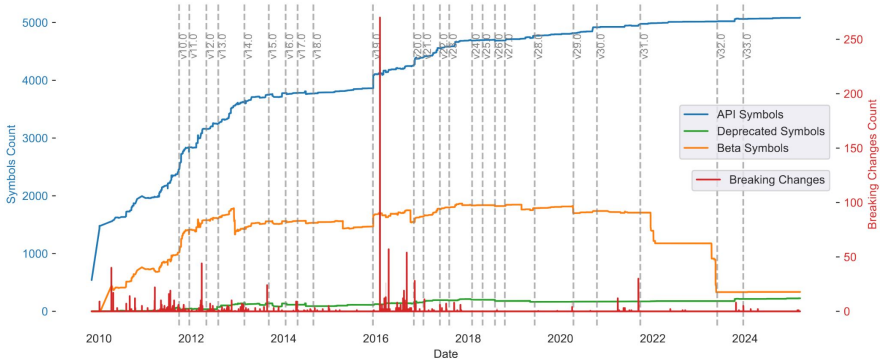

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Live feedback in IDEs

```
boolean isEffectivelyFinal() {   6 clients   1 broken   Revert
  return isFinal()
      || isNative()
      || containingType.isEffectivelyFinal();
}
```

ROSEAU (REED)

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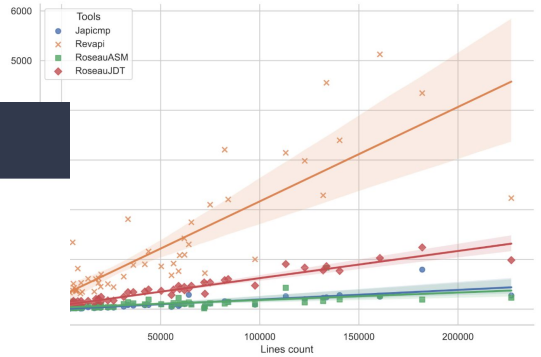

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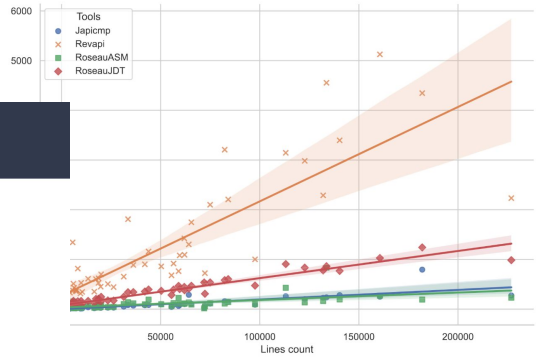

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"I bend and do not break."

The Oak and the Reed
by Jean de La Fontaine