Cascade: A Universal Programmer-assisted Type Qualifier Inference Tool

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Type qualifiers allow additional static type checks

```
static int oldSubindex(@Nullable MathVector ic, int l) {
   int i = 0;
   for (int k = 0; k < MathVector.NDIM; k++) {
     if (((int) ic.value(k) & 1) != 0)
       i += Cell.NSUB >> (k + 1);
   }
   return i;
 }
```

Java 8 supports custom type systems*

- Locking
- Aliasing
- Interning
- Immutability
- Tainting

*checkerframework.org

Java 8 supports custom type systems*

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+ additional static checks

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Java 8 supports custom type systems*

- Locking
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+ additional static checks

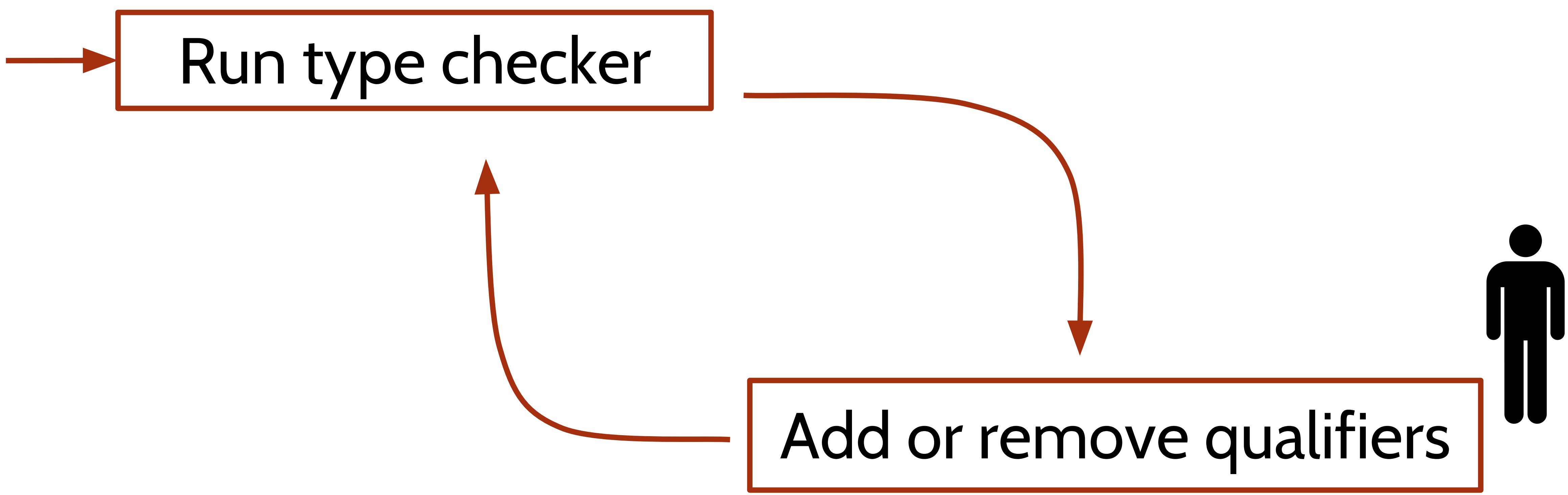
- additional code annotation

*checkerframework.org

The manual annotation process is tedious

Run type checker

The manual annotation process is tedious



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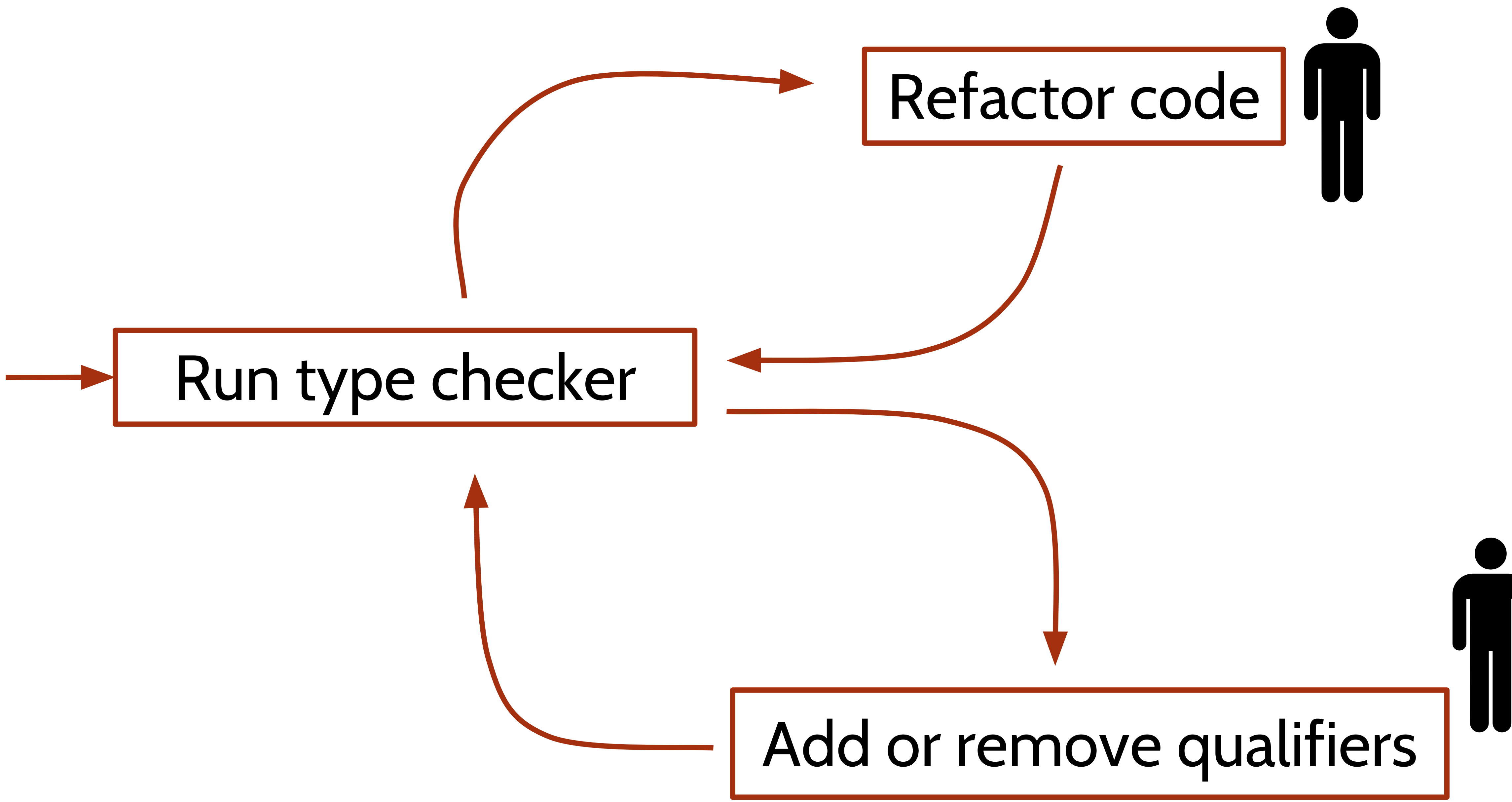
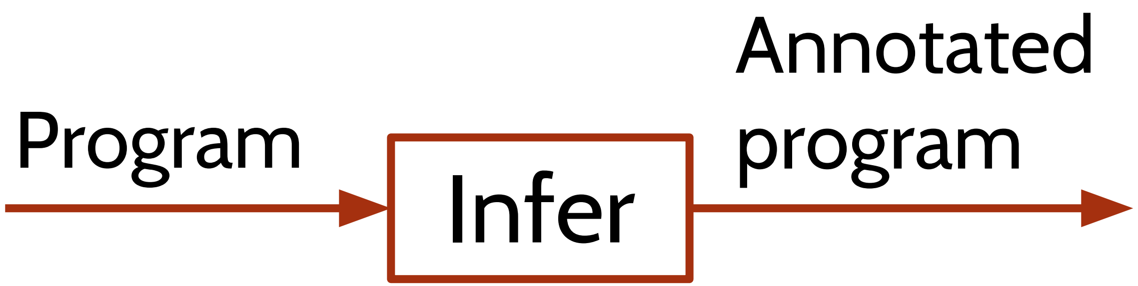


Type qualifier inference tools run in batch mode



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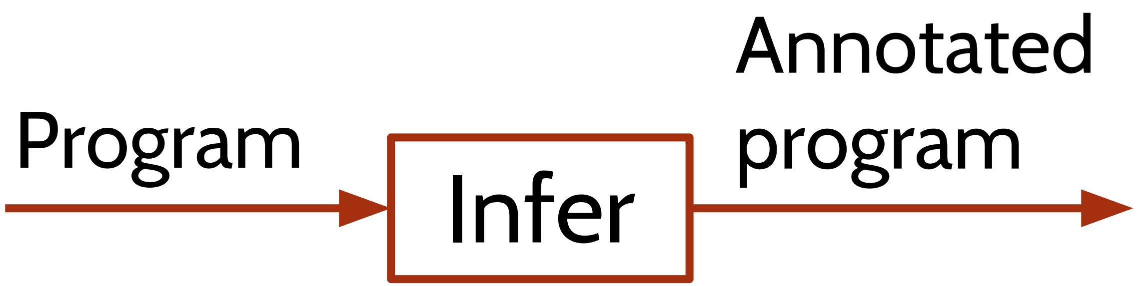
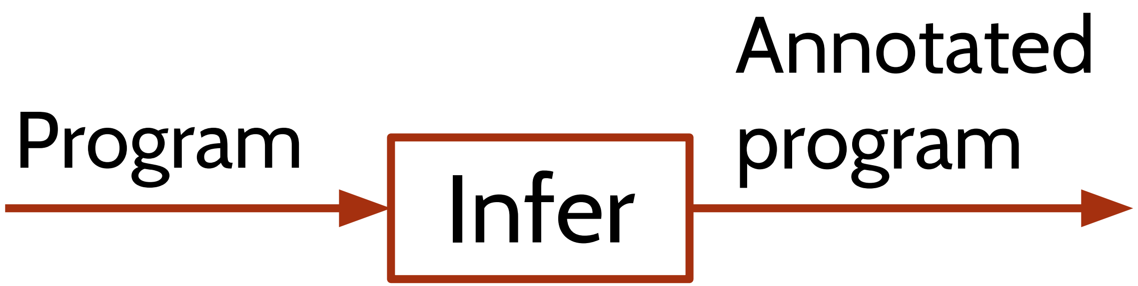


Nullness
Julia, Nit, JastAddJ Nullness, SALSA Nullness, Xylem, Daikon Nullness

Immutability
Javarifier, Pidasai, ReImInfer

Ownership
Universe and Ownership Type Inference System

Type qualifier inference tools run in batch mode



Strengths

- Optimal under certain conditions
- Large change without user involvement

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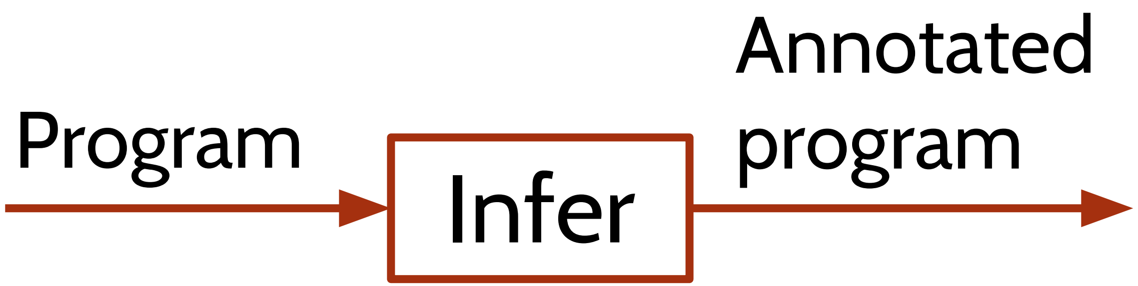
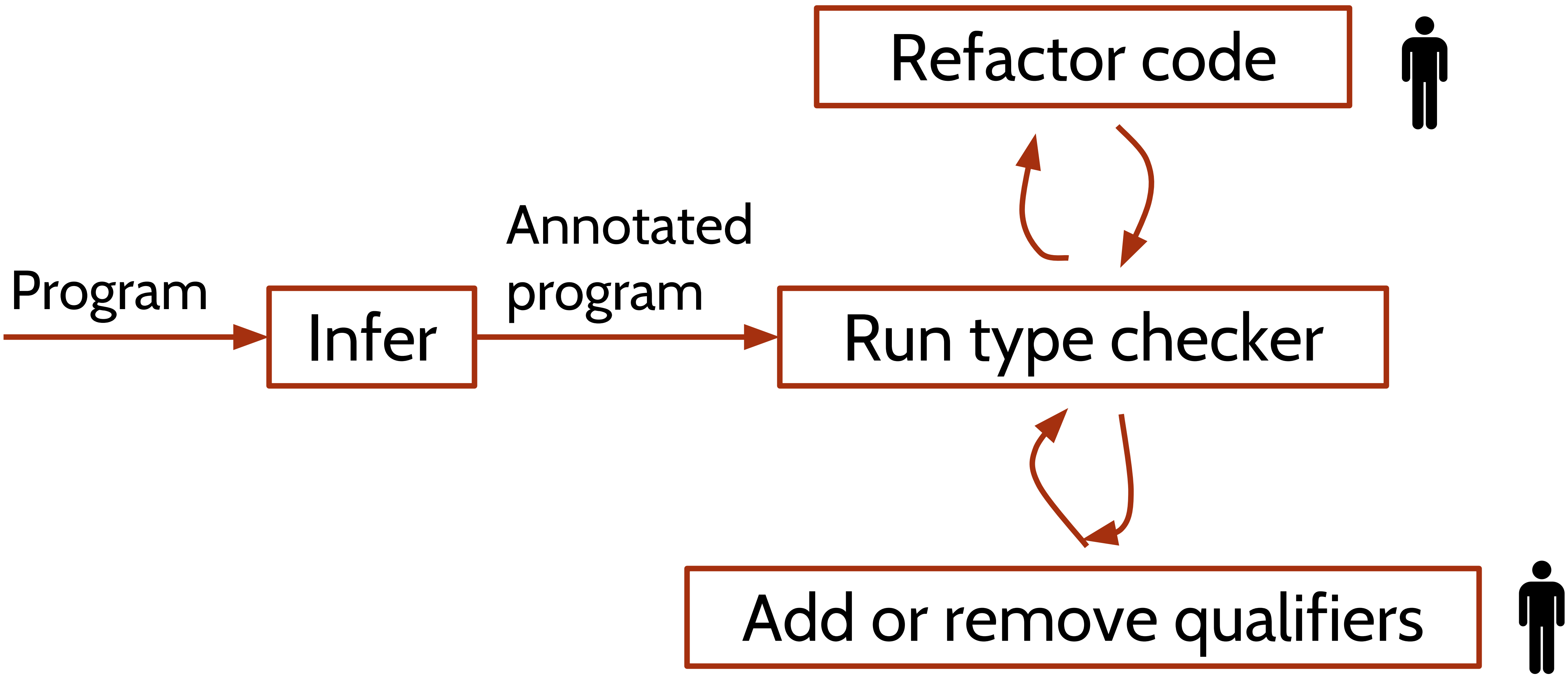


Weaknesses

- Limited to one set of qualifiers
- Unpredictable
- Rigid
- Inaccurate

Type qualifier inference tools run in batch mode



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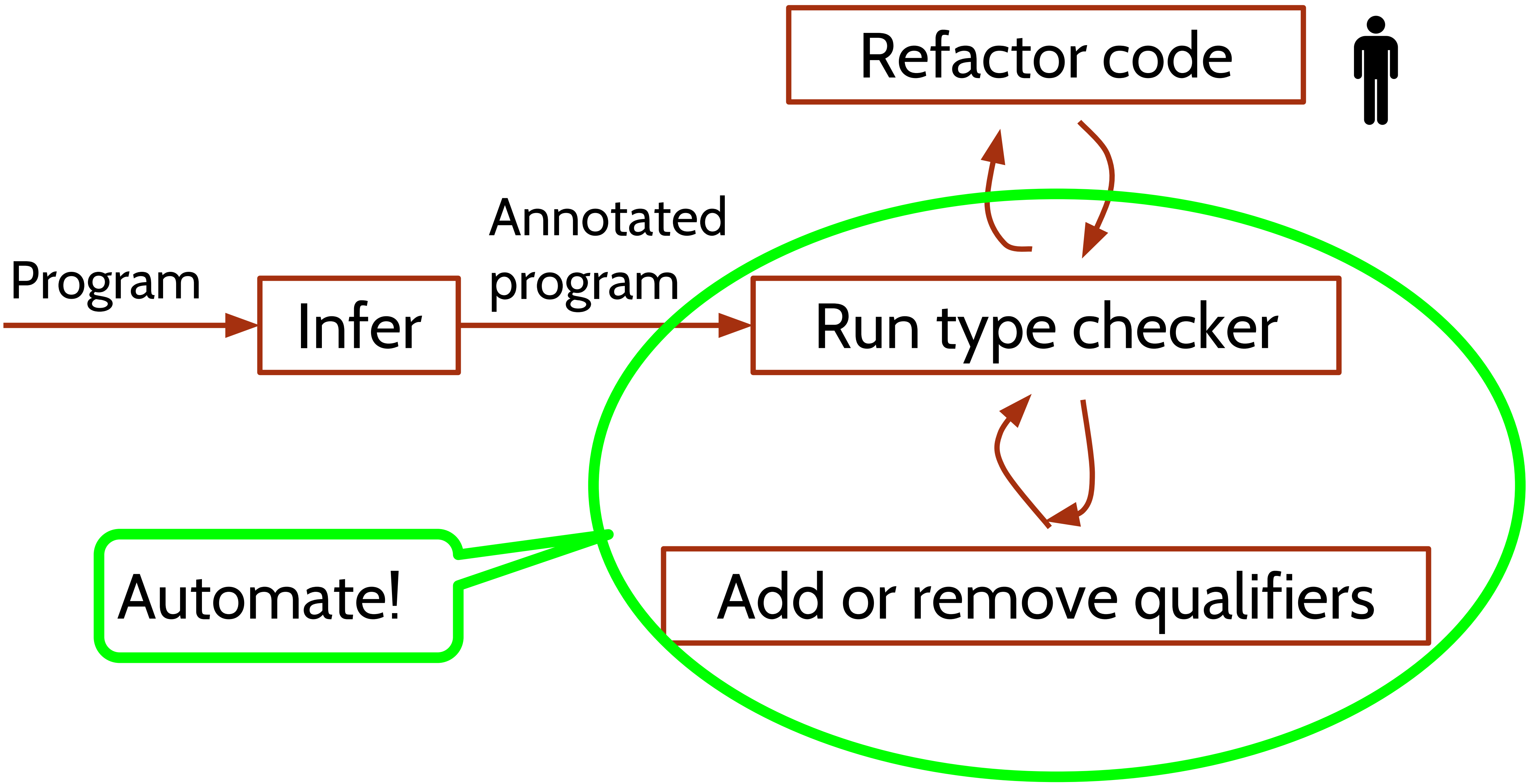

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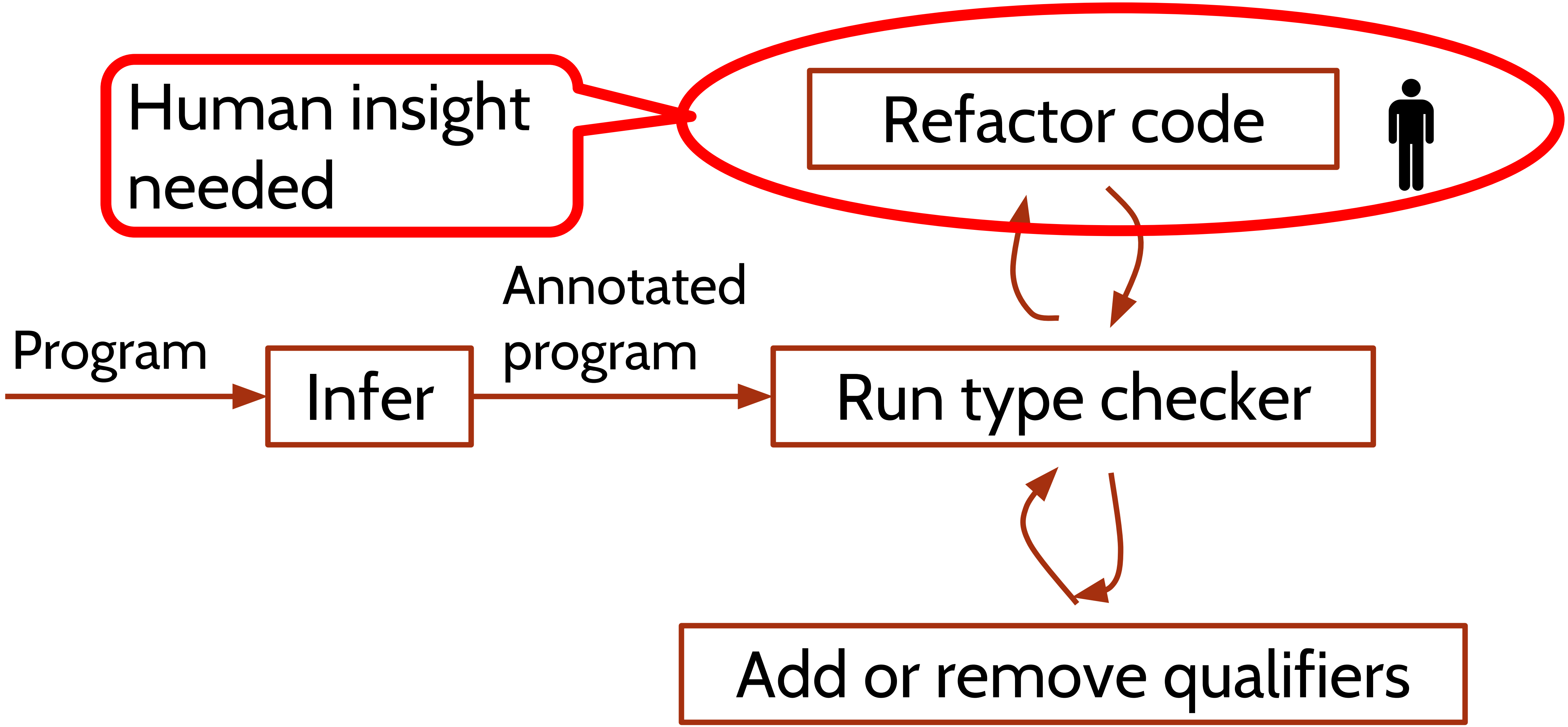

Batch-mode tools make arbitrary decisions

```
class Tree {
  //...
  @Nullable Node root;

  void makeTree(int nstep) {
    for (Enumeration e = bodiesRev(); e.hasMoreElements();) {
      Body q = (Body) e.nextElement();
      if (q.mass != 0.0) {
        q.expandBox(this, nstep);
        MathVector xqic = intcoord(q.pos);
        if (root == null) {
          root = q;
        } else {
          root = root.loadTree(q, xqic, Node.IMAX >> 1, this);
        }
      }
    }
    root.hackcofm();
  }

  @Nullable MathVector intcoord(MathVector vp) {
    MathVector xp = new MathVector();
    //..
    xsc = (vp.value(2) - rmin.value(2)) / rsize;
    if (0.0 <= xsc && xsc < 1.0) {
      xp.value(2, Math.floor(Node.IMAX * xsc));
    } else {
      return null;
    }
    return xp;
  }
}
```

```
class Node {
  //...
  Node loadTree(Body p, @Nullable MathVector xpic, int l, Tree tree) {
    int si = oldSubindex(xpic, l);
    //...
  }

  static int oldSubindex(@Nullable MathVector ic, int l) {
    int i = 0;
    for (int k = 0; k < MathVector.NDIM; k++) {
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BUG

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      }
    }
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    return i;
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```

BUG

Type qualifier inference is a refactoring

- Adding type qualifiers preserves the program behavior
- Adding maintainable type qualifiers
  that match the programmer's intention
  requires code refactoring

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Compositional Refactoring

+

Speculative Analysis

→

Cascade

Inferring Primitive Changes from Error Messages

	Type Checker Error	Fix
Nullness	see below	

```
incompatible types in argument.
  root = root.loadTree(q, xqic);
                          ^
found   : @Nullable MathVector
required: @NonNull MathVector
```

Inferring Primitive Changes from Error Messages

Type Checker Error

Fix

Nullness

```
incompatible types in argument.
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Change parameter `xpic` of `loadTree()` to `@Nullable MathVector`

Inferring Primitive Changes from Error Messages

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Change parameter `xpic` of `loadTree()` to `@Nullable MathVector`

Mutability

```
call to value(int) not allowed
on the given receiver.
      ic.value(k);
              ^
  found   : @ReadOnly MathVector
  required: @Mutable MathVector
```

Inferring Primitive Changes from Error Messages

	Type Checker Error		Fix

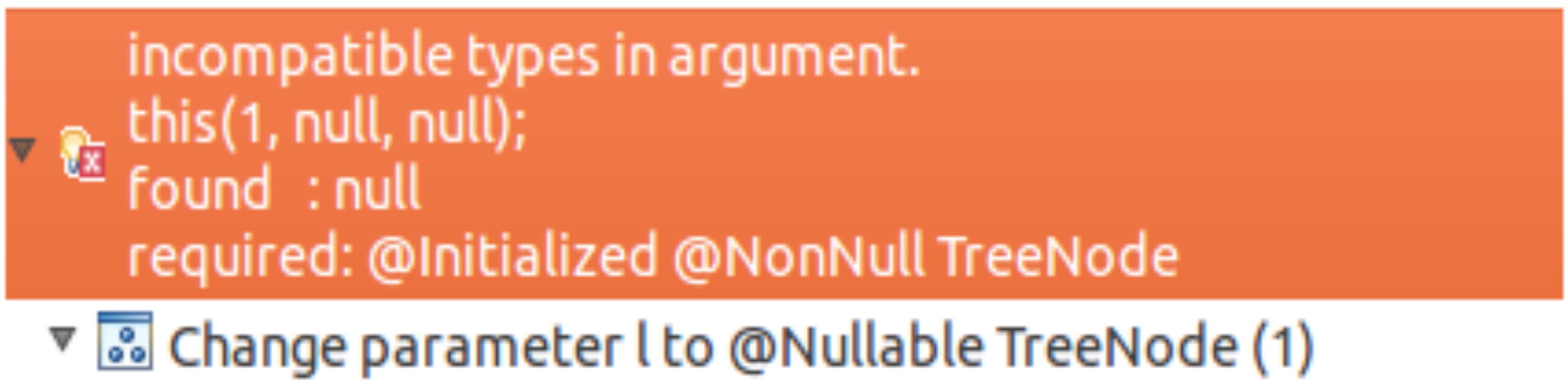
Nullness	`incompatible types in argument.`
	`  root = root.loadTree(q, xqic);`
	`                           ^`
	`found   :` **`@Nullable`** `MathVector`
	`required:` **`@NonNull`** `MathVector`
		➡	Change parameter `xpic` of `loadTree()` to `@Nullable MathVector`

Mutability	`call to value(int) not allowed`
	`on the given receiver.`
	`      ic.value(k);`
	`              ^`
	`found   :` **`@ReadOnly`** `MathVector`
	`required:` **`@Mutable`** `MathVector`
		➡	Change receiver parameter of `value()` to `@ReadOnly MathVector`

Speculative analysis suggests a change composition

```
incompatible types in argument.
this(1, null, null);
found   : null
required: @Initialized @NonNull TreeNode
```

Speculative analysis suggests a change composition



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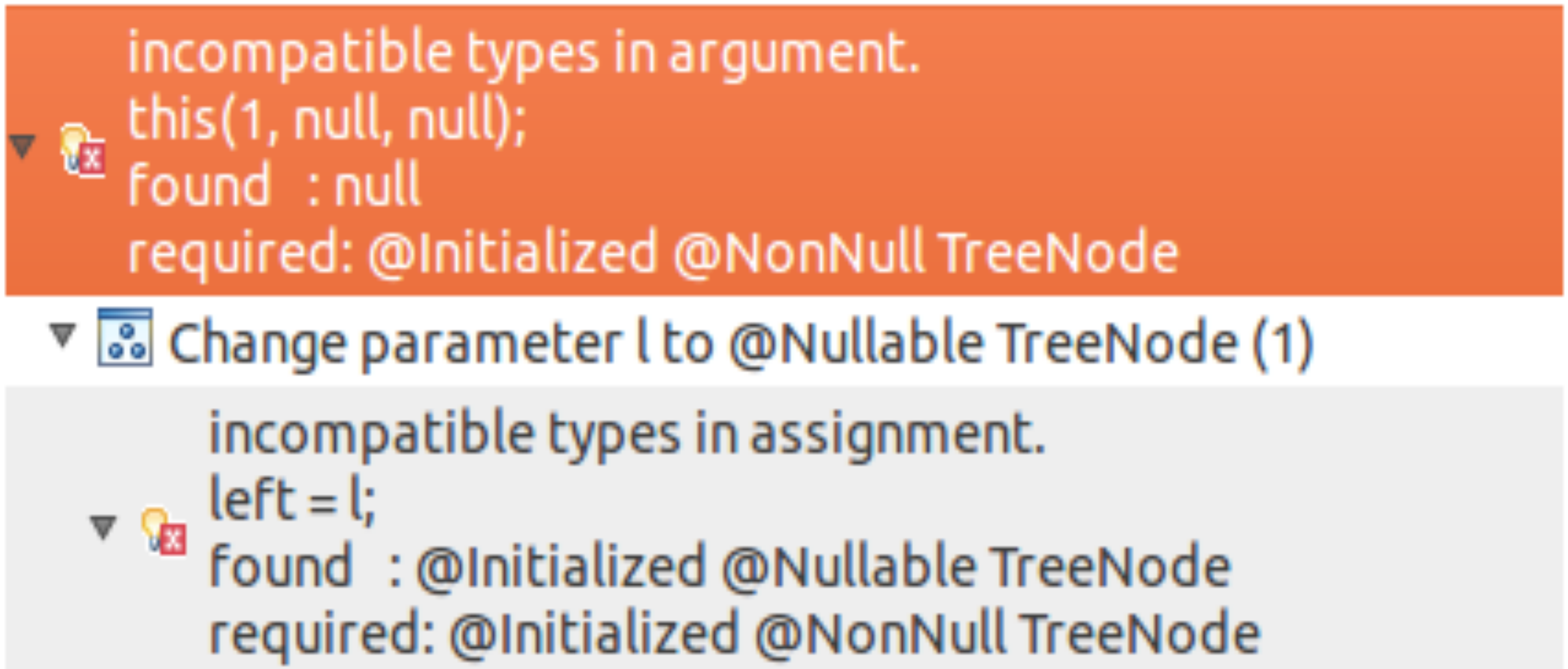

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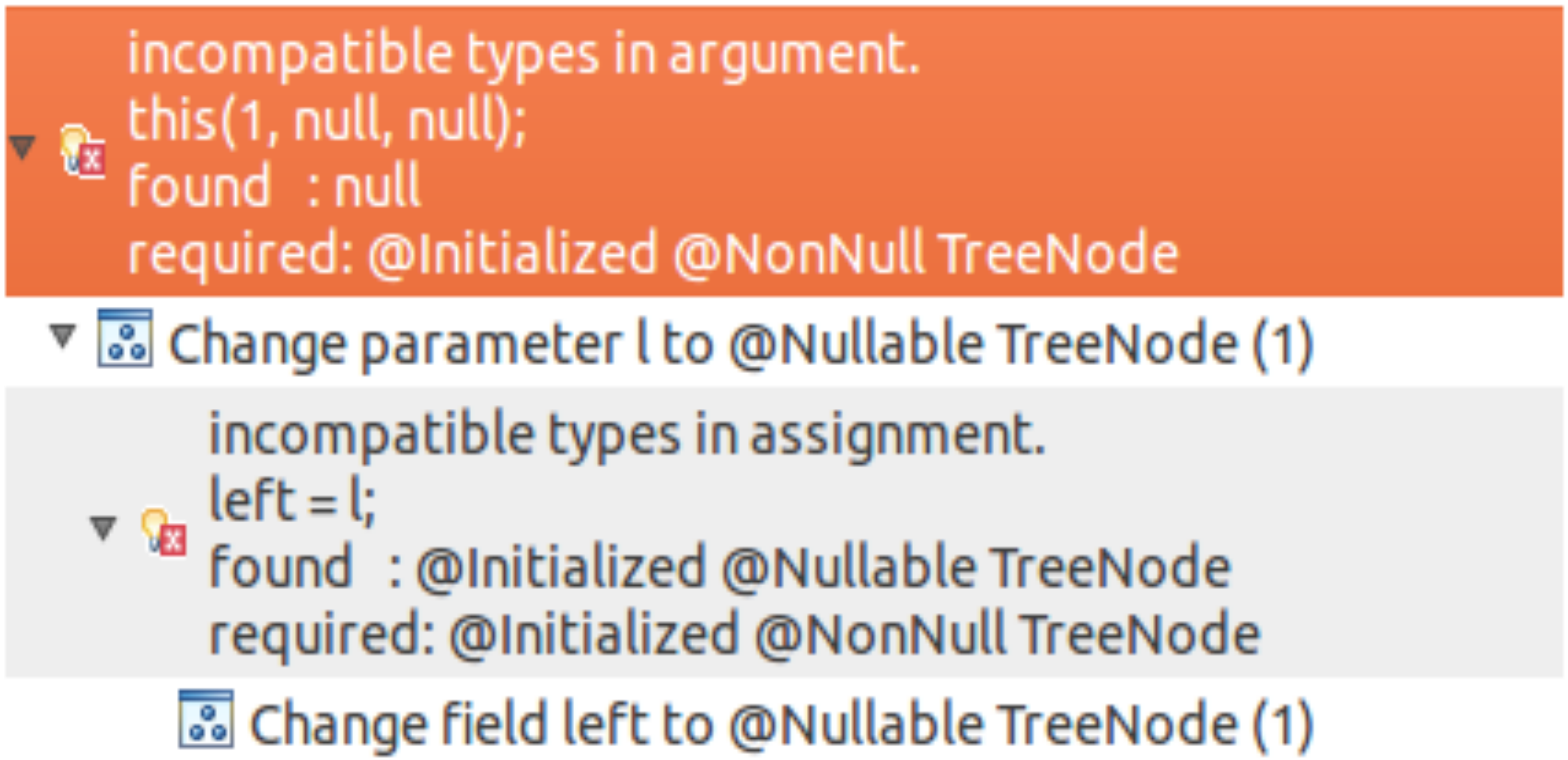
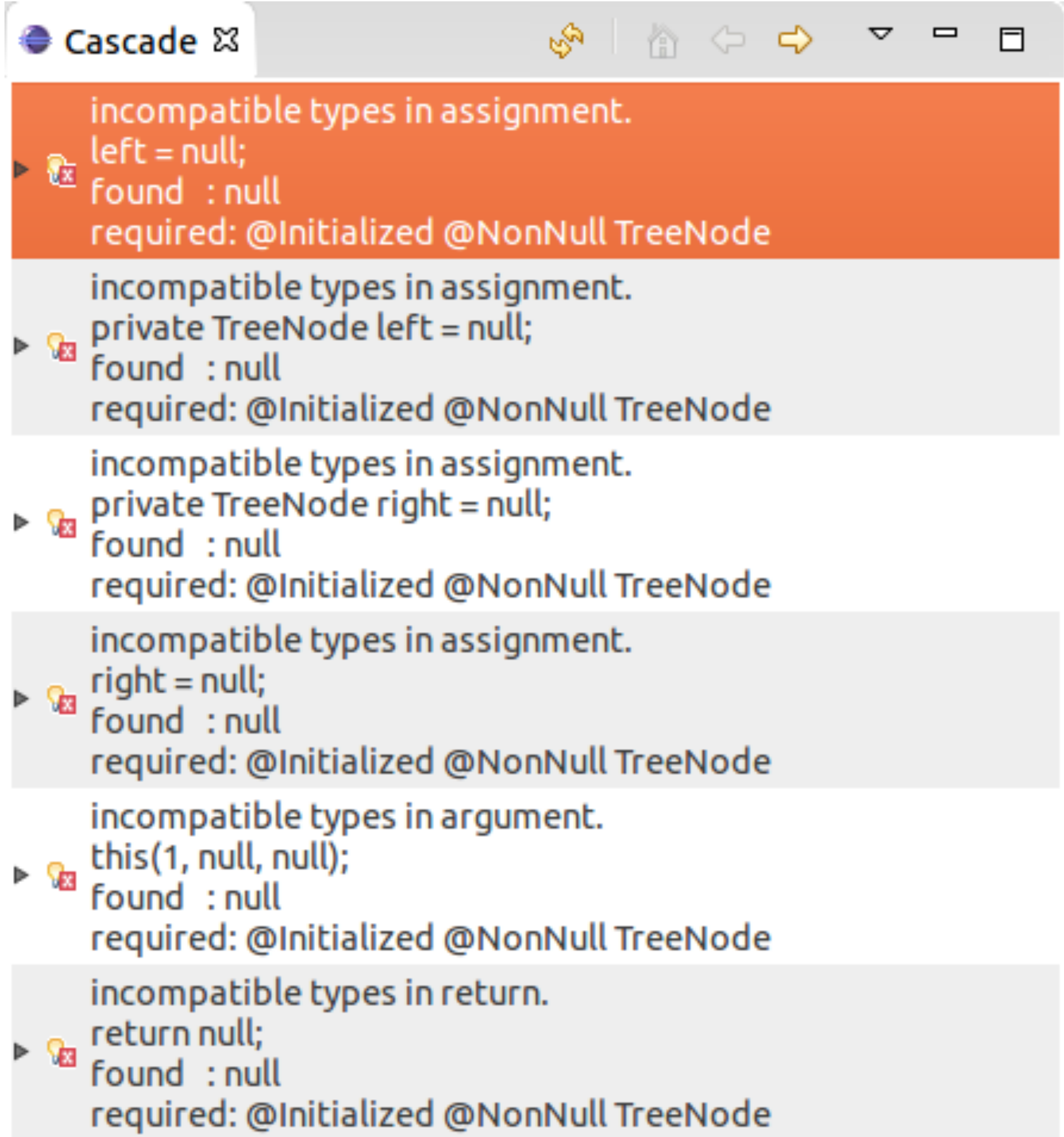
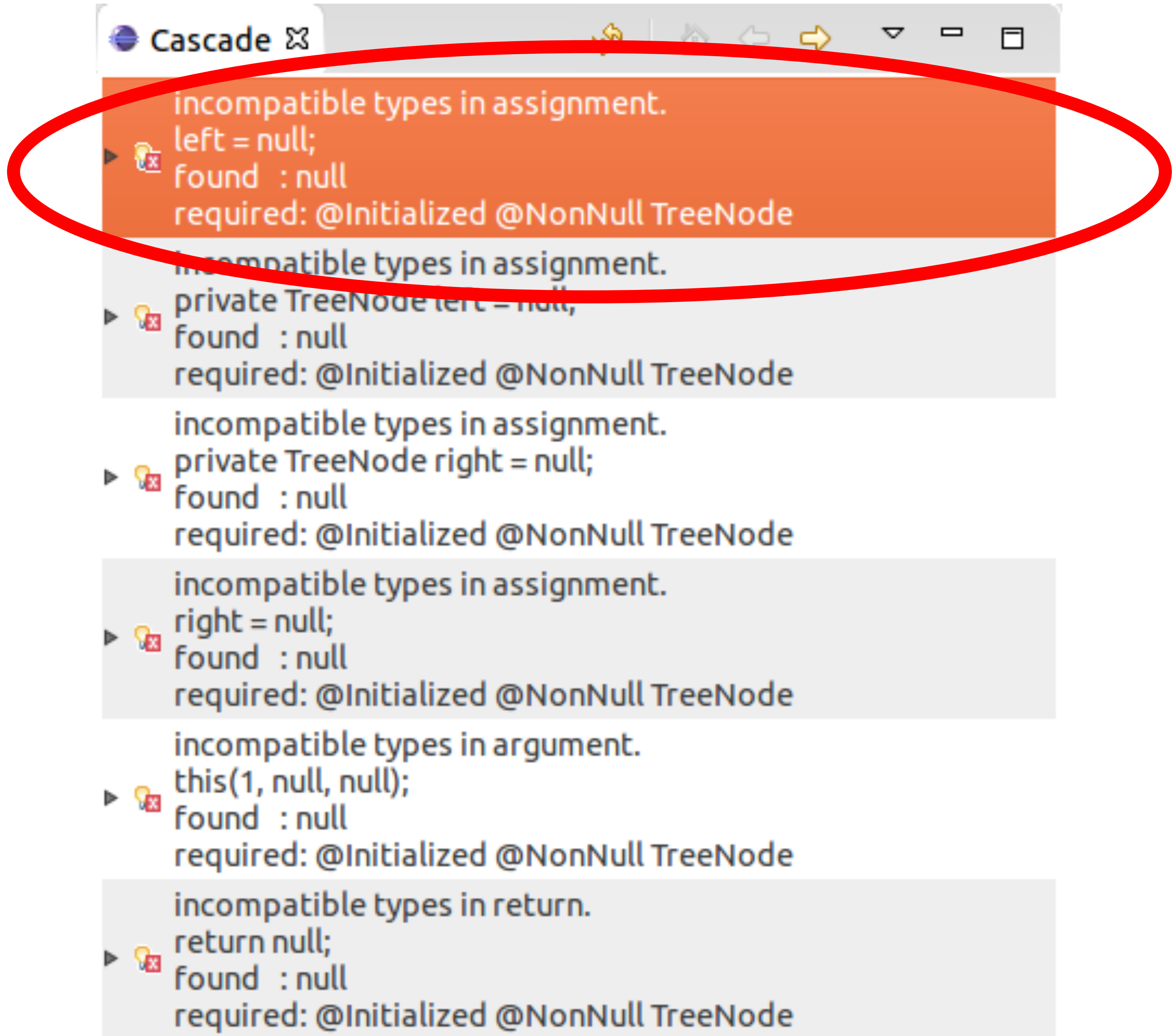


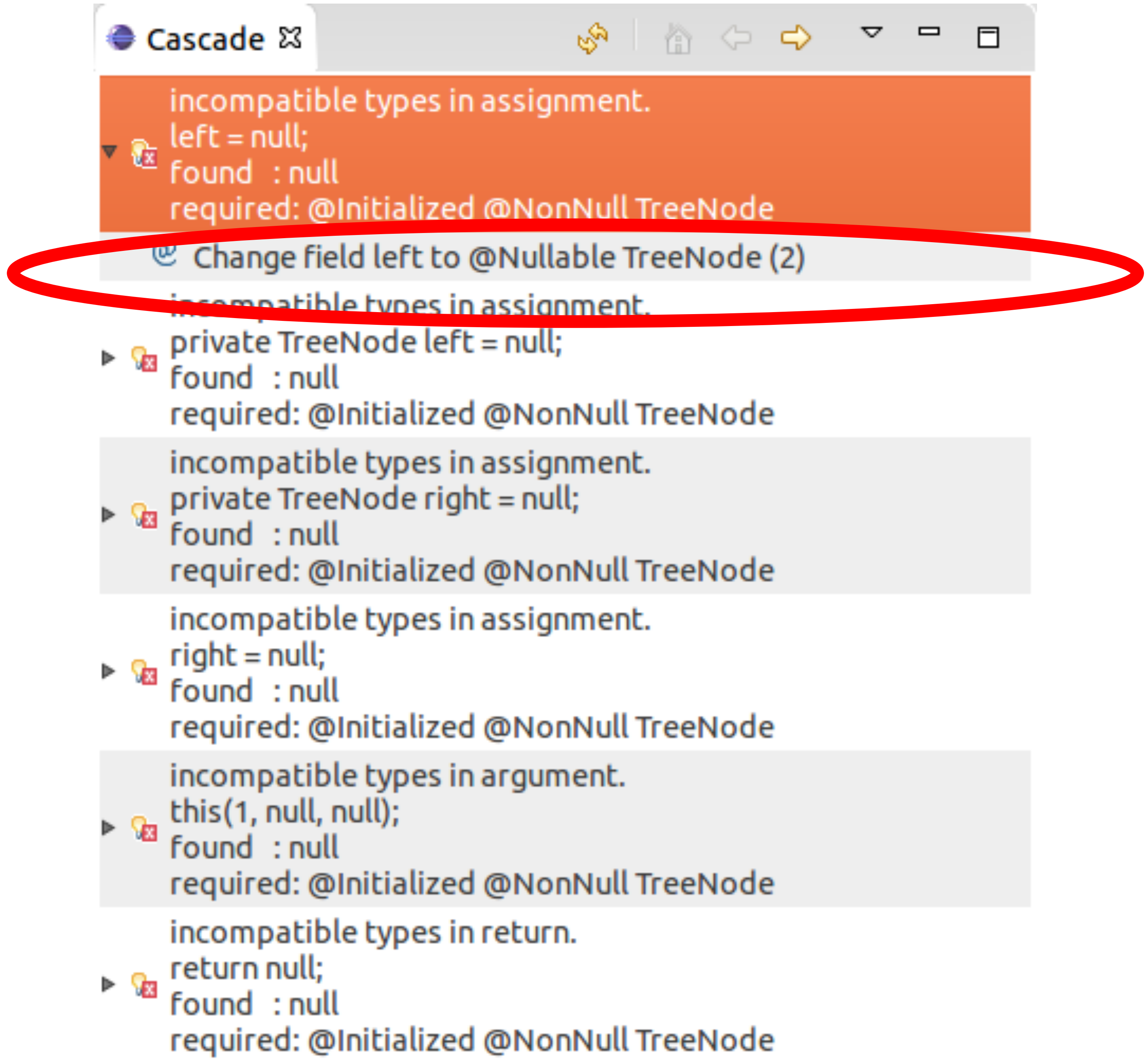
Cascade Tree



Cascade Tree



Cascade Tree



TreeNode.java

```java
 * Create a tree node given the two children. The initial node value is 1.
 **/
public TreeNode() {
  this(1, null, null);
}

/**
 * Construct a subtree with the specified number of levels. We recursively call the c
 * create the tree.
 *
 * @param levels the number of levels in the subtree
 **/
public TreeNode(int levels) {
  value = 1;
  if (levels <= 1) {
    if (levels <= 0) throw new RuntimeException("Number of levels must be positive no
    left = null;
    right = null;
  } else {
    left = new TreeNode(levels - 1);
    right = new TreeNode(levels - 1);
  }
}

/**
 * Set the children of the tree
 *
 * @param l the left child
 * @param r the right child
 **/
public void setChildren(TreeNode l, TreeNode r) {
  left = l;
  right = r;
}
```

Cascade | Outline

incompatible types in assignment.
left = null;
found : null
required: @Initialized @NonNull TreeNode

incompatible types in assignment.
private TreeNode left = null;
found : null
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incompatible types in return.
return null;
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TreeNode.java

```java
package treeadd;
/**
 * A Tree node data structure.
 **/
public class TreeNode {
  private int value = 0;
  private TreeNode left = null;
  private TreeNode right = null;

  /**
   * Create a node in the tree with a given value and two children.
   *
   * @param v the node's value
   * @param l the left child.
   * @param r the right child.
   **/
  public TreeNode(int v, TreeNode l, TreeNode r) {
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Cascade | Outline

incompatible types in assignment.
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Change field left to @Nullable TreeNode (2)

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*TreeNode.java

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Cascade | Outline

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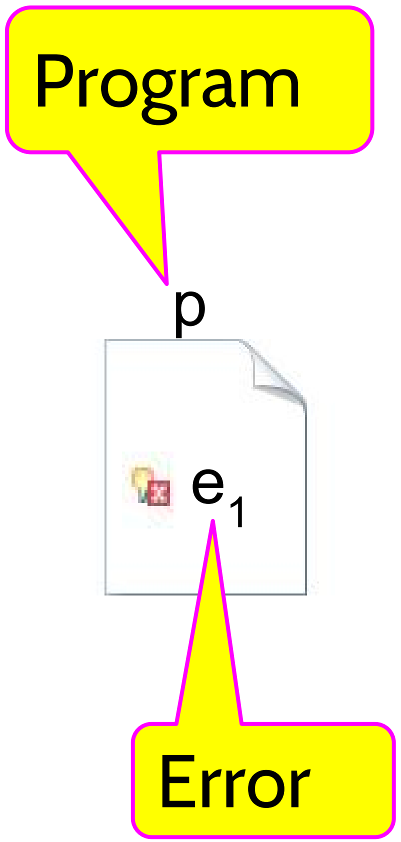
The speculative analysis computes a tree recursively



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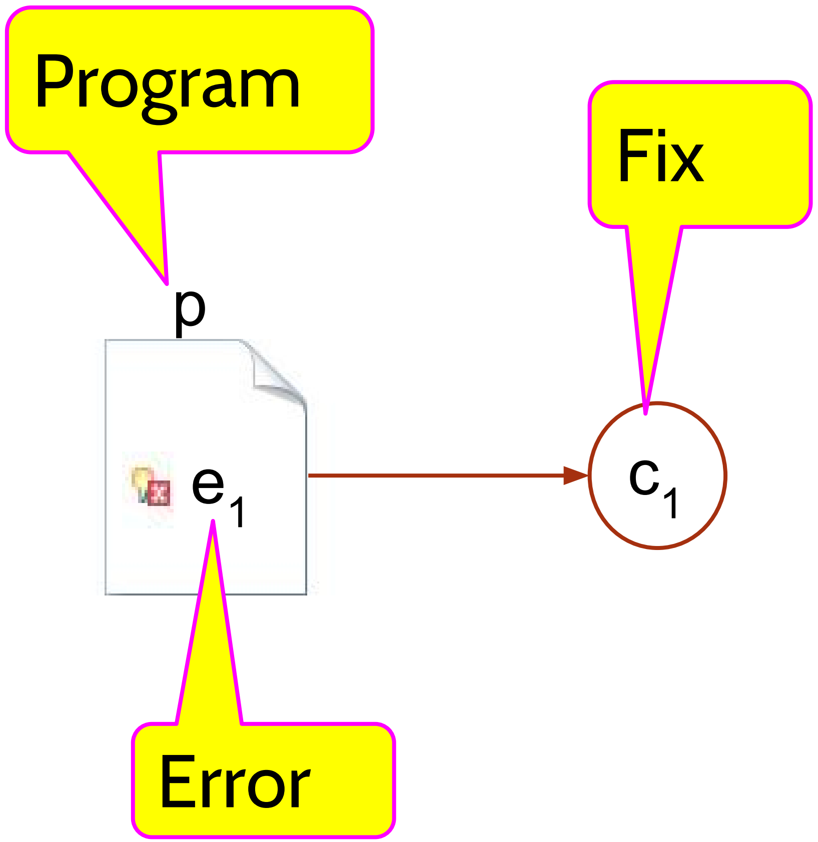

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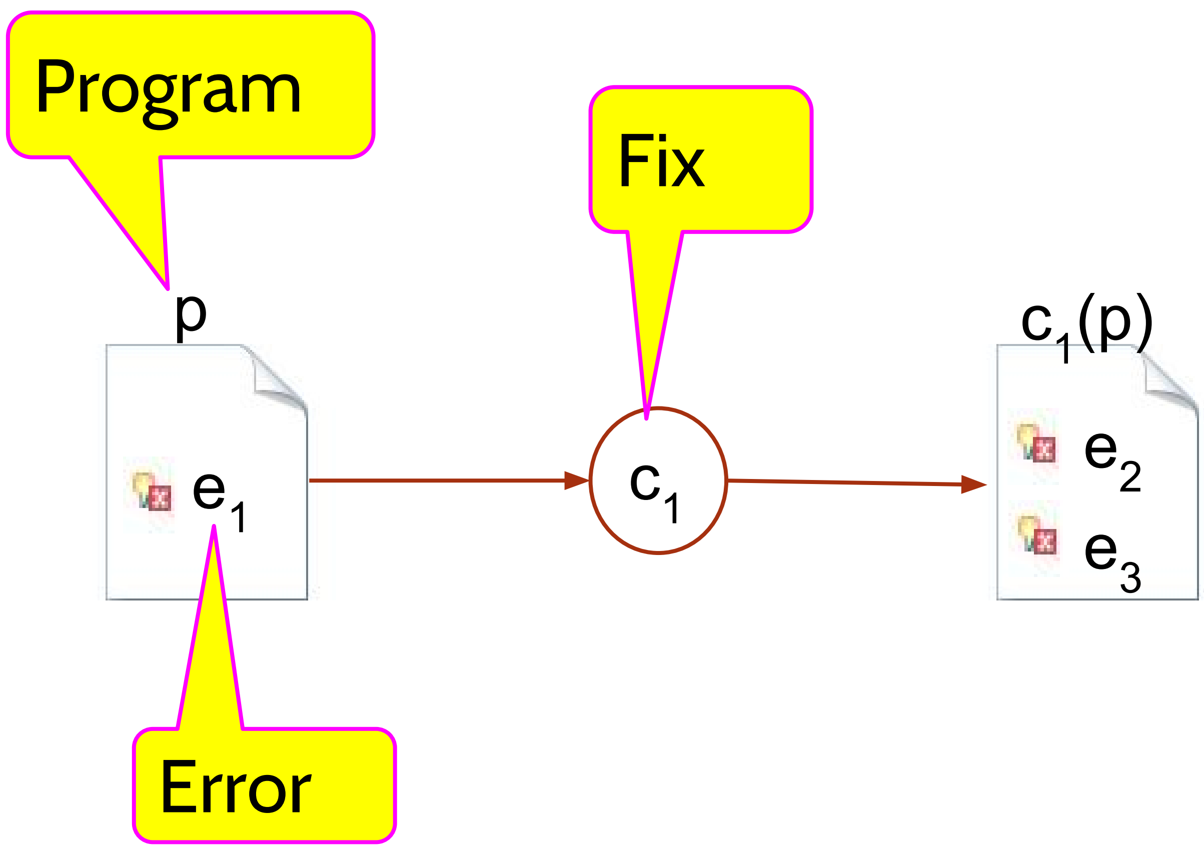

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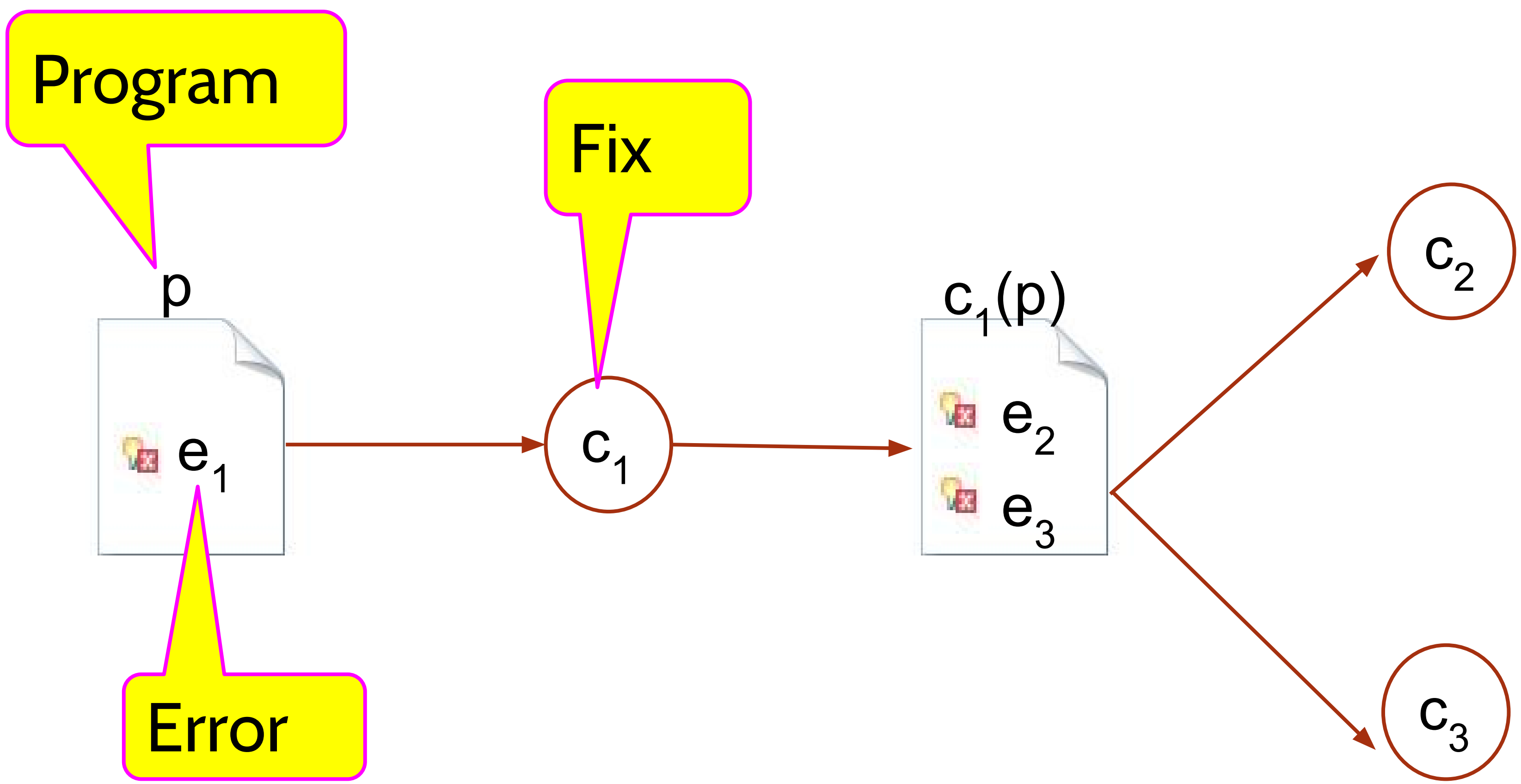

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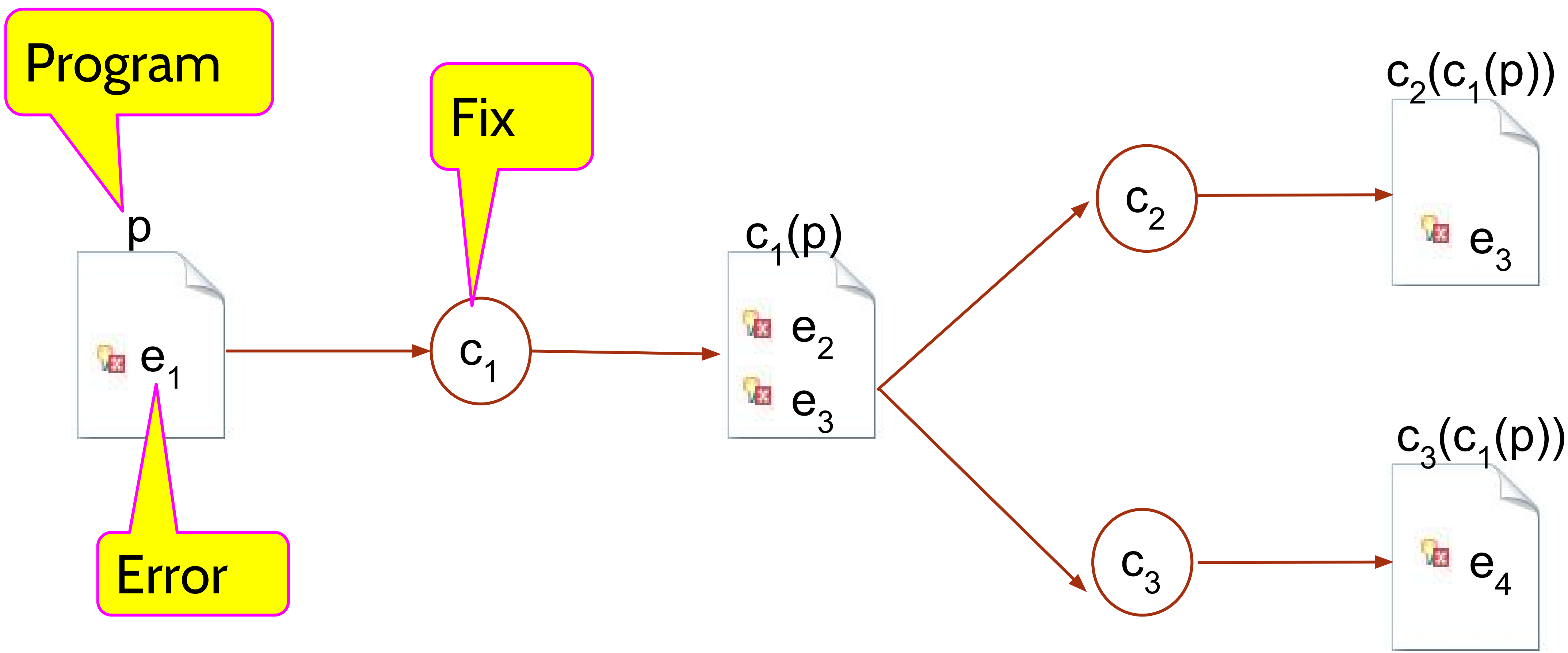


A change is represented as an AST path

Primitive Change	**Representation**
Variable Decl. Fixer	Compilation Unit + Variable Decl. + New Type
Method Return Fixer	Compilation Unit + Method Decl. + New Type
Method Receiver Fixer	Compilation Unit + Method Decl. + New Type

Research Questions

How does **Cascade** compare with **Julia**, a batch qualifier inference tool?

- Learnability
- Quality of results
- Task completion time
- Control over process
- Willingness to use

User study

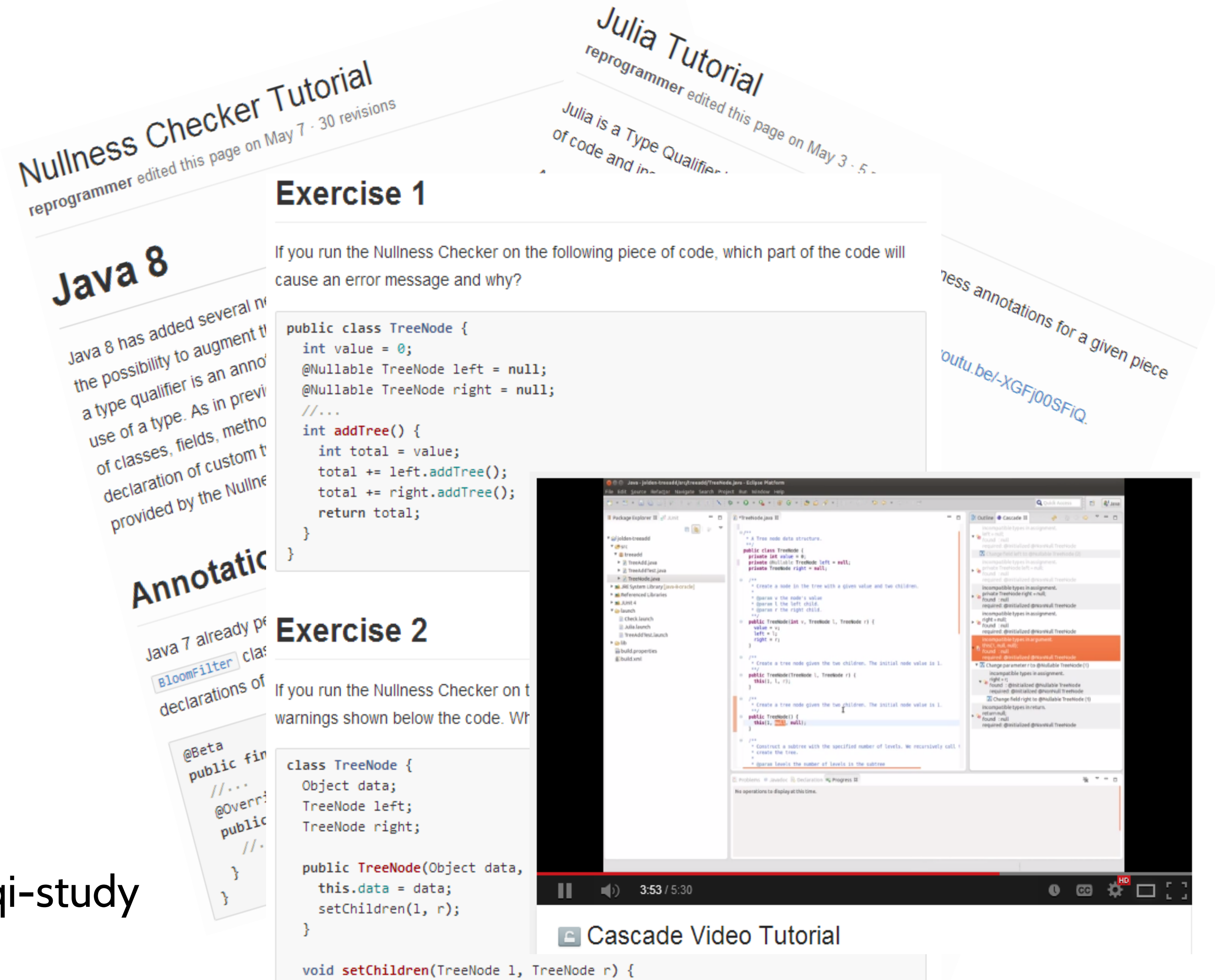
Subjects:

- **12** computer science graduate students from 9 different research labs
- Familiar with Java and Eclipse
- Average of 10 years of programming experience

Training

- Nullness Checker
- Julia
- Cascade

github.com/reprogrammer/tqi-study

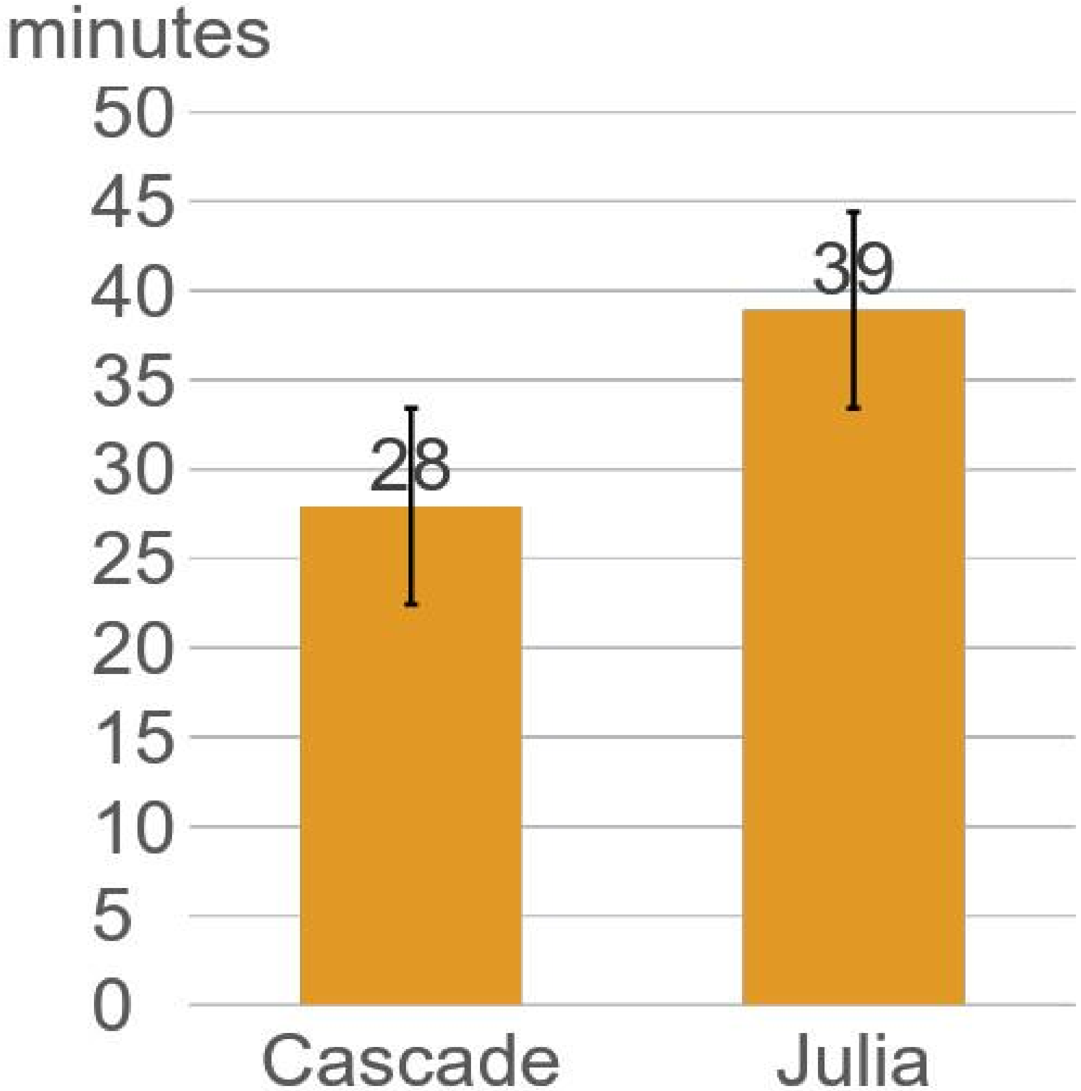


Task Design

	Julia then Cascade	Cascade then Julia
MST then BH	3 participants	3 participants
BH then MST	3 participants	3 participants

BH	Barnes-Hut, a hierarchical force-calculation algorithm
MST	Bentley's algorithm for finding the minimum spanning tree of a graph

Users complete tasks faster with Cascade



t test

- $p = 0.01$
- Cohen's $d = 1.13$

Users added less inaccurate annotations with Cascade

	BH + MST	
	Julia	**Cascade**
Correct	13.9	9.6
Incorrect	2.8	0.1
Redundant	1.7	0.4
Unnecessary warning suppressions	7.2	0

Postquestionnaire Results

Questions *(T = Julia or Cascade)*	**Cascade better**	**Equal Rating**	**Julia better**
I found T easy to **learn**.	3	6	3
I know **why** T inserted each annotation.	8	4	0
Using T, I have **control** over the process of annotating the code.	9	0	3
I'm willing to **use** T in the future	11	0	1

Qualitative Interview Results

The participants believe that:

- Cascade's **speculative analysis** is useful (N = 8).
- Cascade is more **predictable** (N = 7).
- Cascade's tree computation is **slow** (N = 5).
- The **overhead** of fixing Julia's annotations is high (N = 7).

Future Work

- Improve the **performance** of Cascade.
- Evaluate compositional refactoring and Cascade in the **field**.
- Make Cascade support **bidirectional** speculative analysis.

Cascade: A Universal Type Qualifier Inference Tool

- Cascade is **easy to use** and helps users complete tasks **fast**.
- **Compositional refactoring** and **speculative analysis**.
- **Less** is sometimes **more** in the automation of software evolution tasks.
  - More automation is not always better
  - Some tasks need problem-solving and creativity
  - Applicable to other fields