Static Reference Analysis for GUI Objects in Android Software

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Motivation and Background

- Android software is used by millions of users
  - Requires foundational program analyses for improved performance and quality
- Static reference analysis for Java
  - What is the set of run-time objects?
  - Which variables contain references to which objects?
  - Critical component of data- and control-flow analysis
  - Prerequisite for many other techniques
- Existing work cannot be applied directly to Android
- Goal: develop a precise and efficient static reference analysis for Android-specific features

Static Reference Analysis for Android Features

- Android application
  - Driven by a graphical user interface (GUI)
  - *Activity*: on-screen window with GUI elements (*views*)
  - *Event handlers*: defined in *listeners* and associated with views to respond to user actions
- Need to model statically
  - Views and their hierarchical structure
  - Association of views with activities
  - Association of views with listeners
  - Variables that refer to views, activities, and listeners

Example

MyActivity.java:

```
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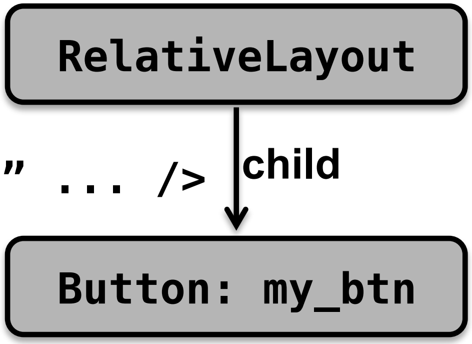

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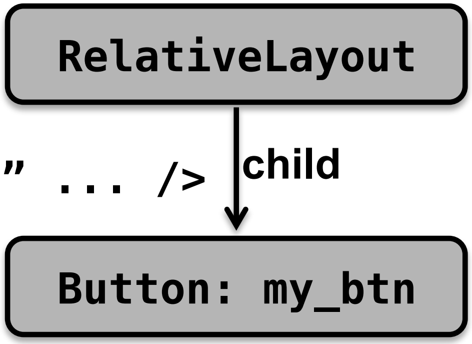

RelativeLayout

child

Button: my_btn

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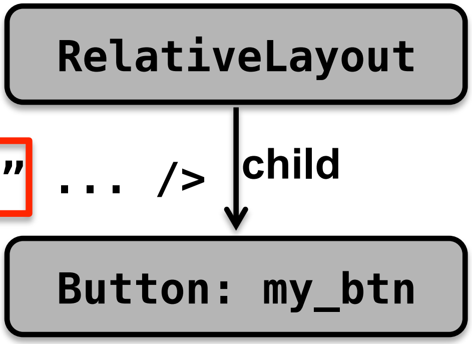

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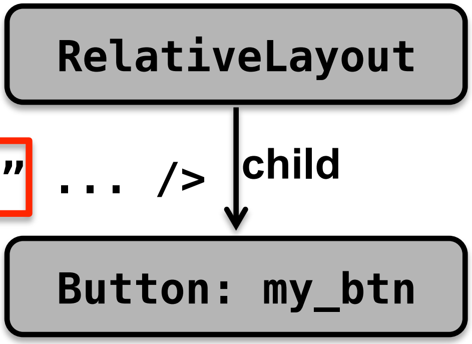

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Modeled Android Operations

- **Inflate**
  - Create GUI structure from XML and attach to activity/view
- **CreateView**
  - Programmatically create a view through **new V**
- **FindView**
  - Lookup a view from activity or ancestor view (e.g., by ID)
- **SetListener**
  - Associate view and listener
- **AddView**
  - Establish parent-child relationship between two views
- **SetId**
  - Programmatically set the ID of a view

Our Proposal

- Define *formal semantics* of GUI-related Android constructs
- Encode semantics of an Android application in a *constraint graph*
- Perform constraint-based static reference analysis

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Propagation edges and relevant nodes

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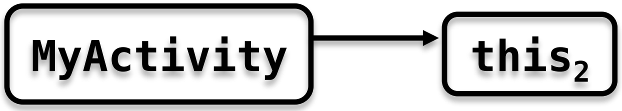

MyActivity

this_2

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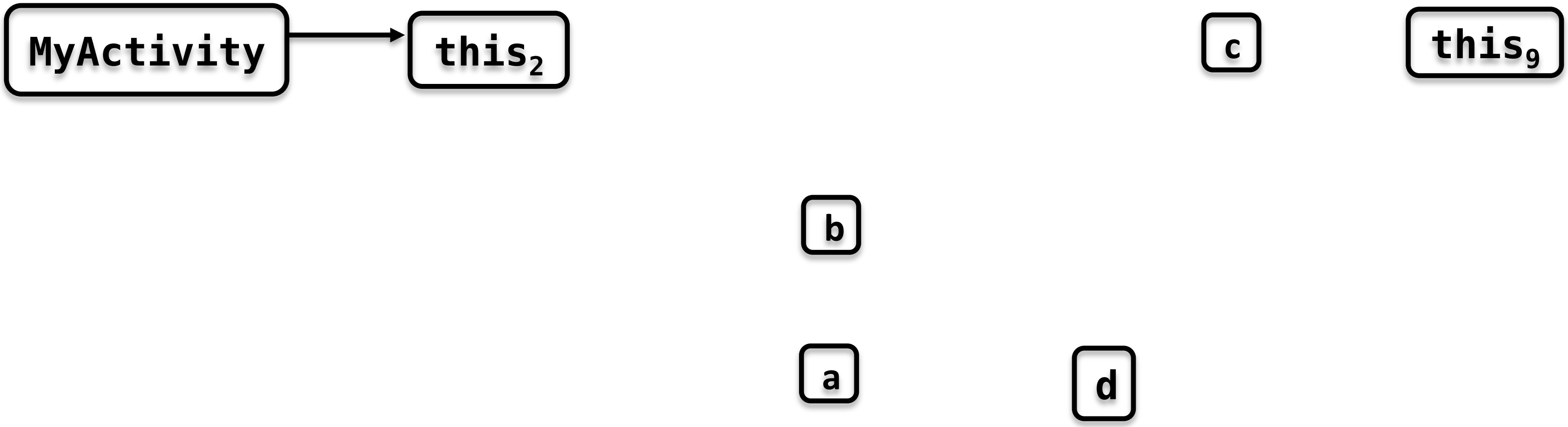

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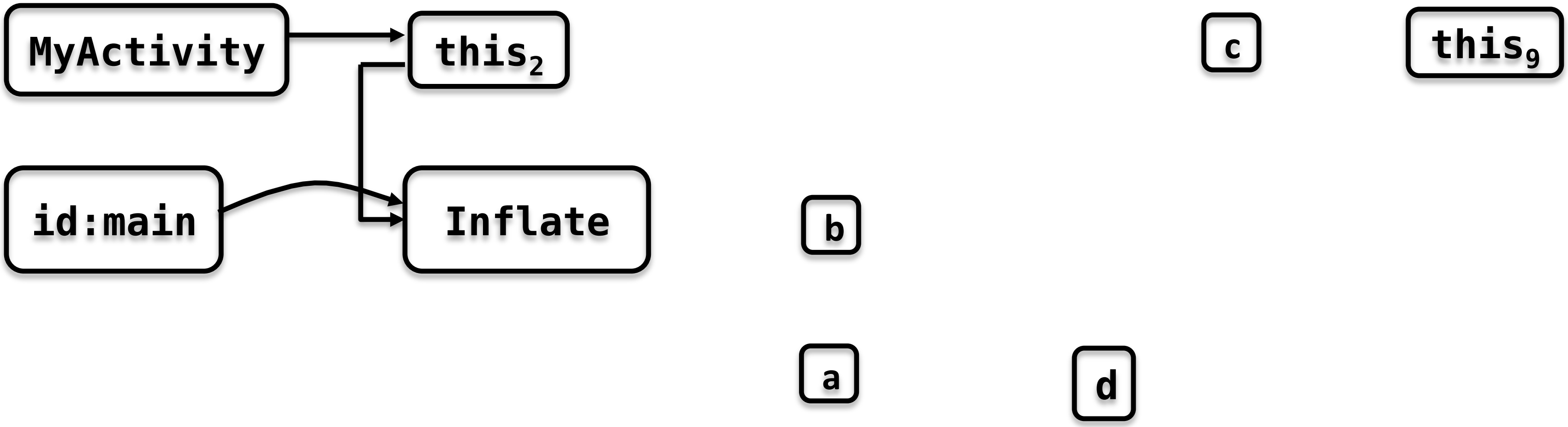

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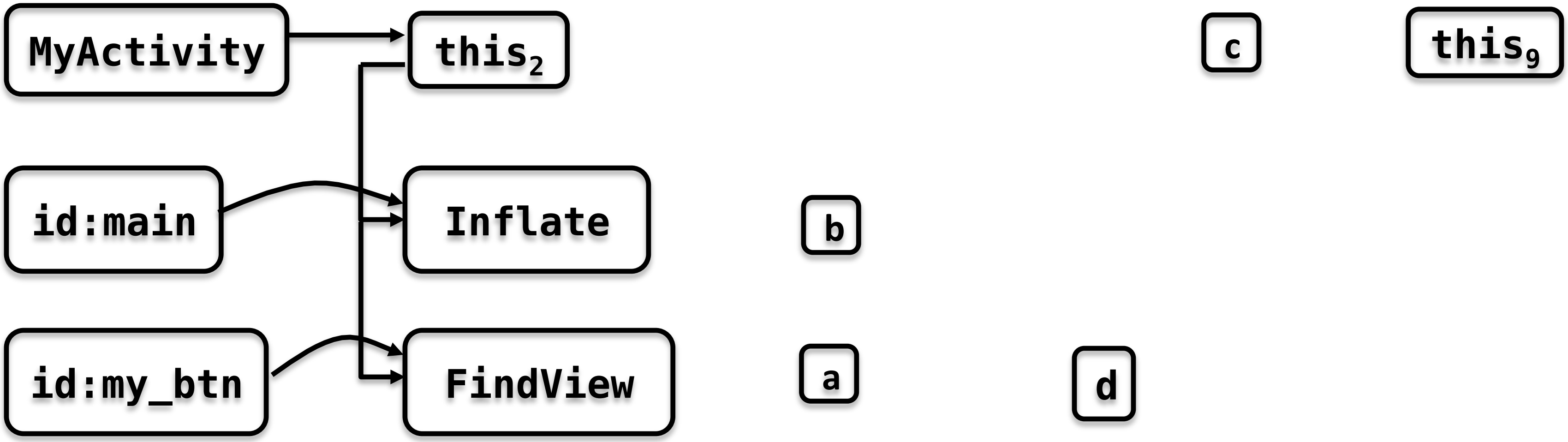

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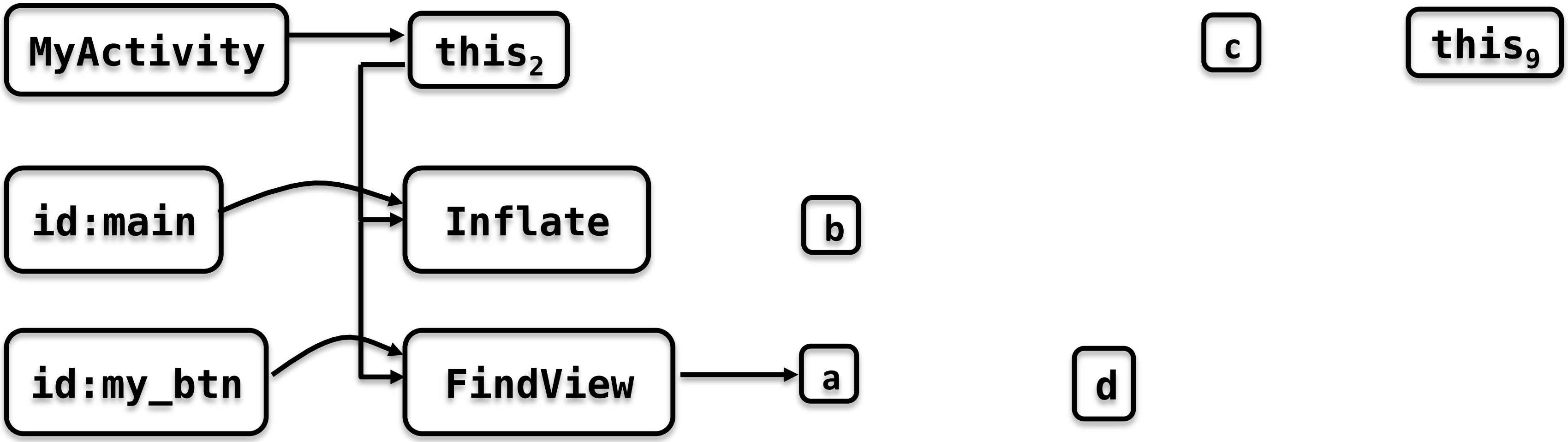

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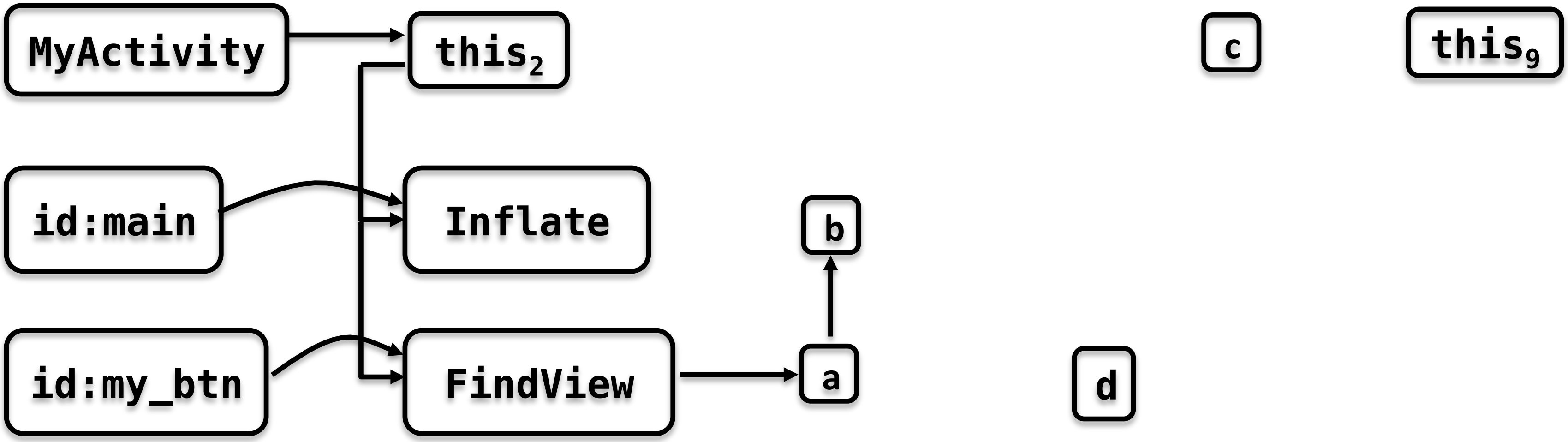

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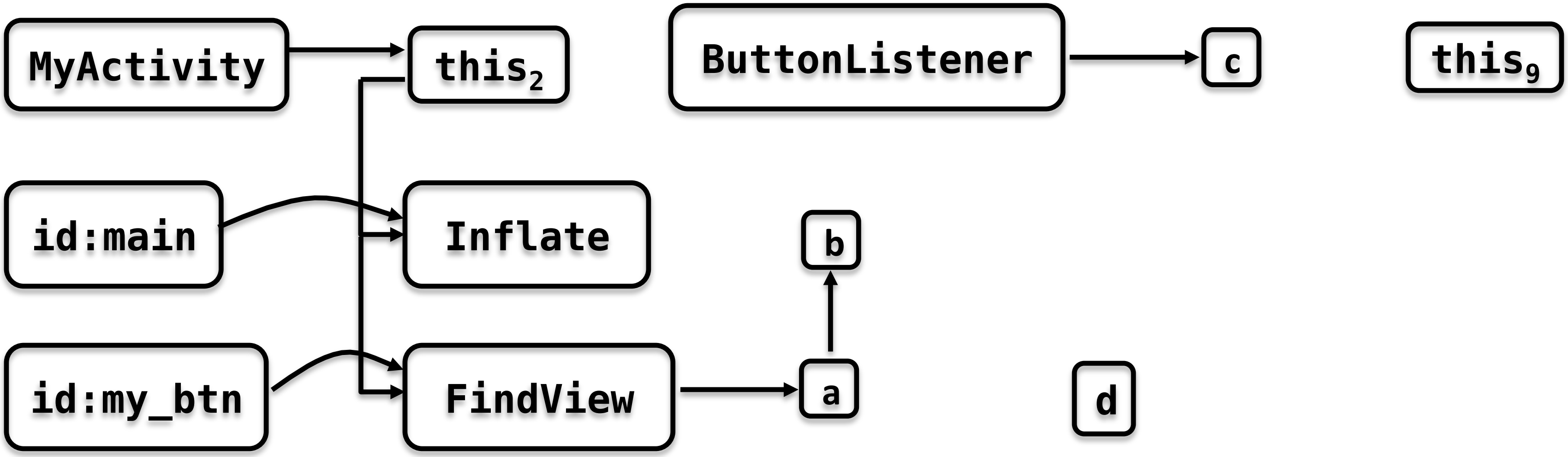

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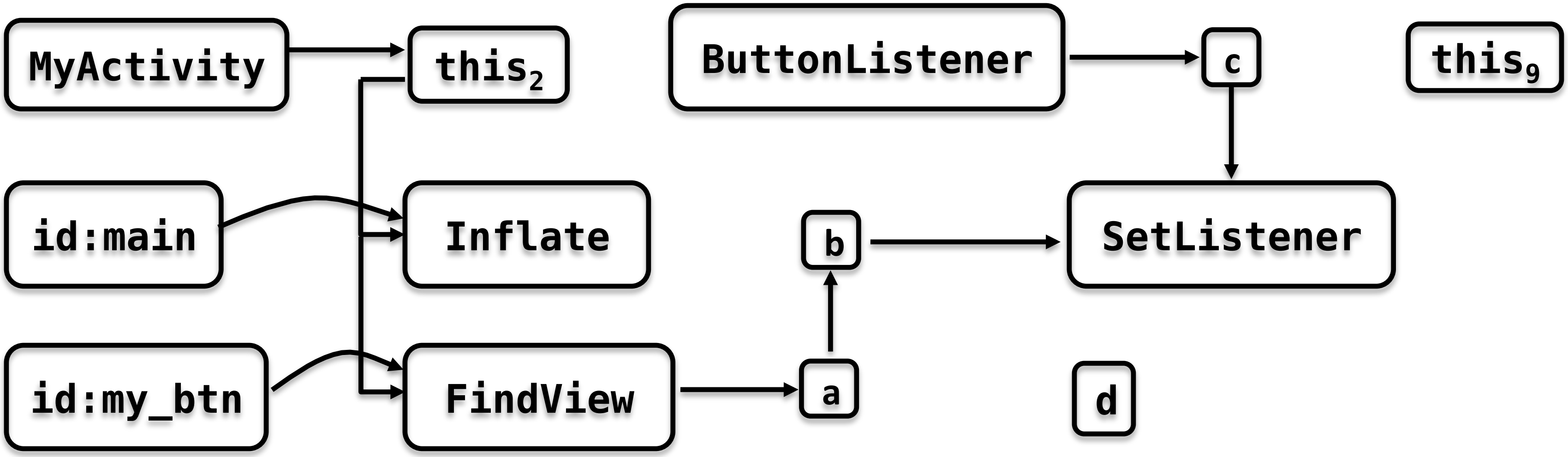

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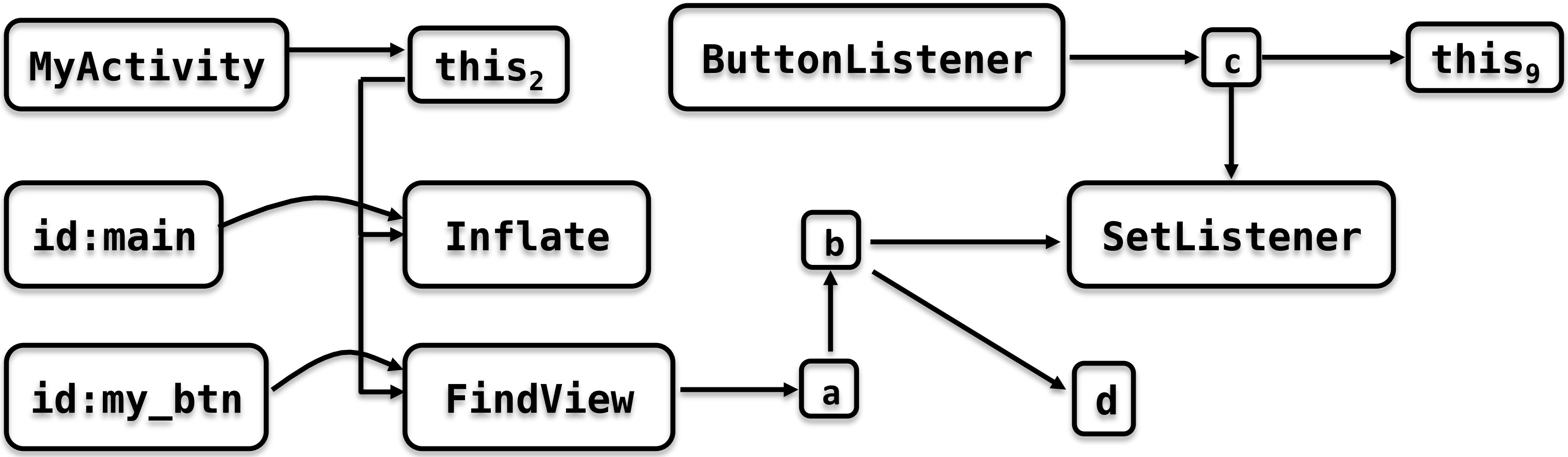

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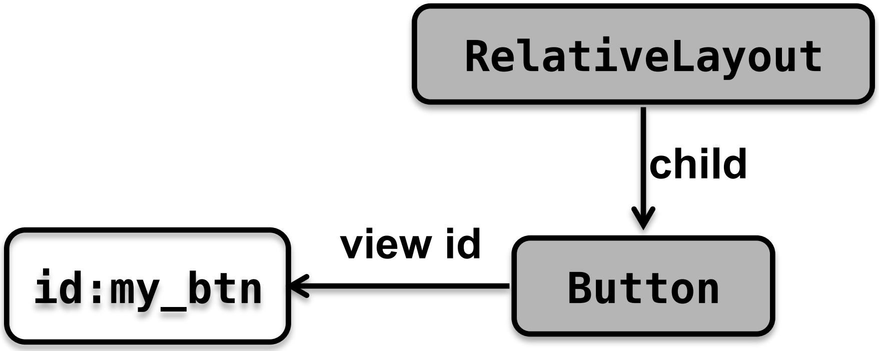

RelativeLayout

child

Button

view id

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Property edges and relevant nodes

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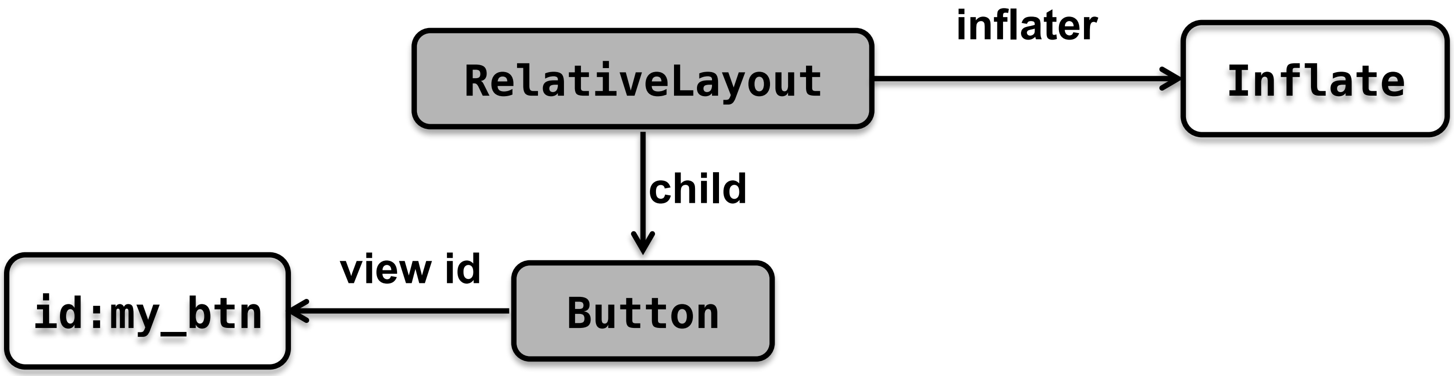

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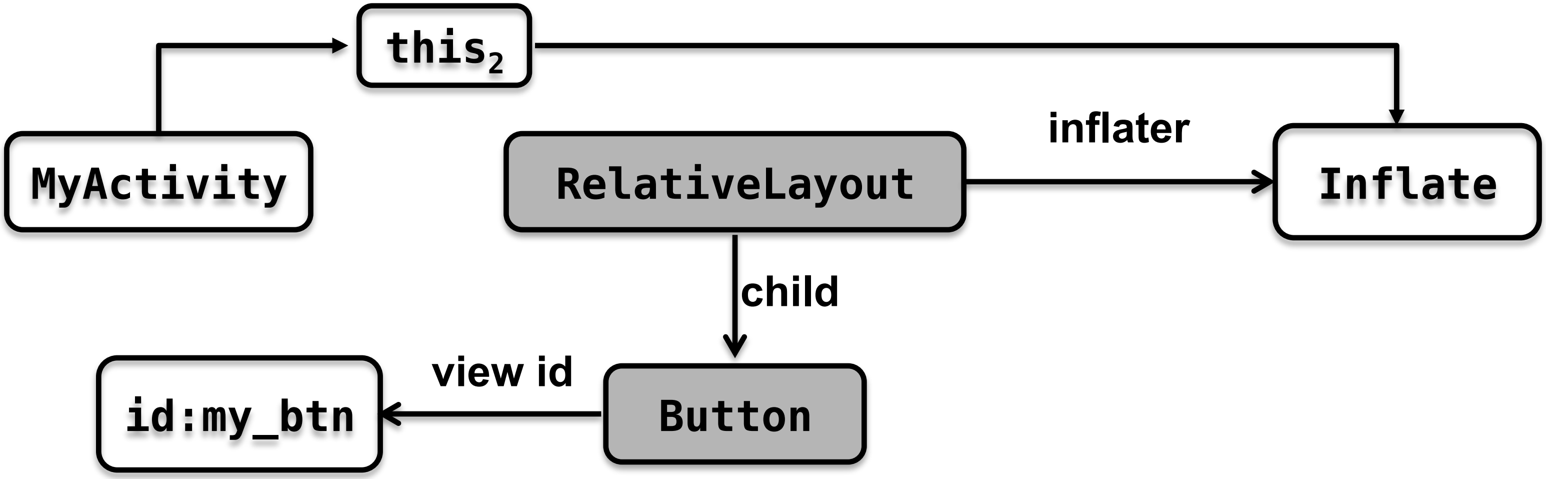

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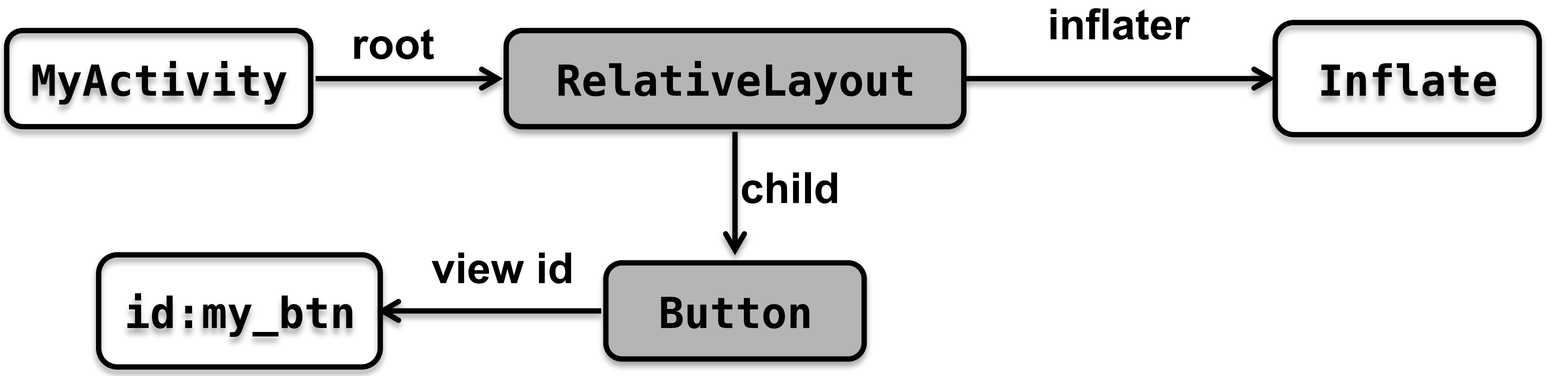

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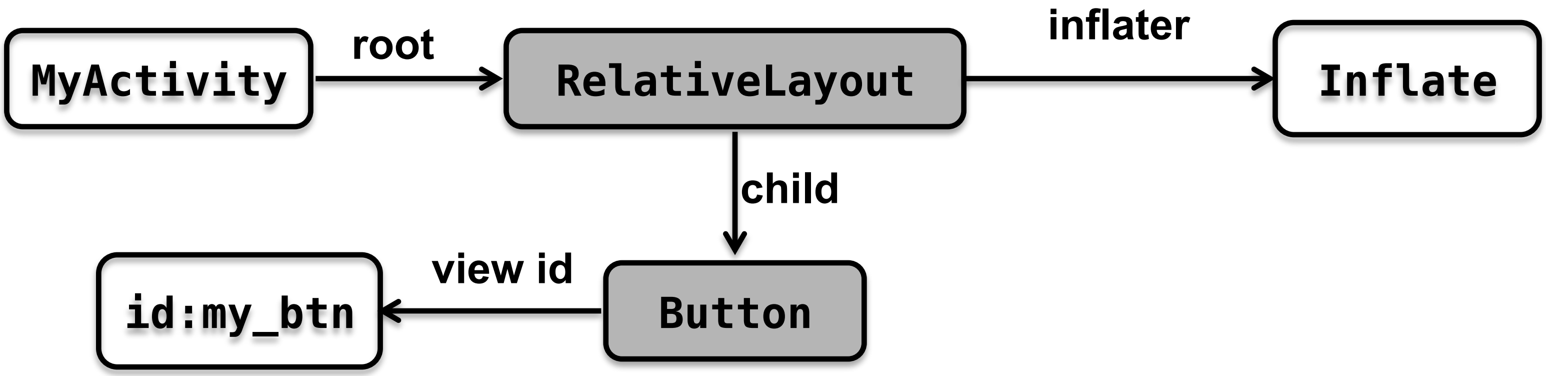

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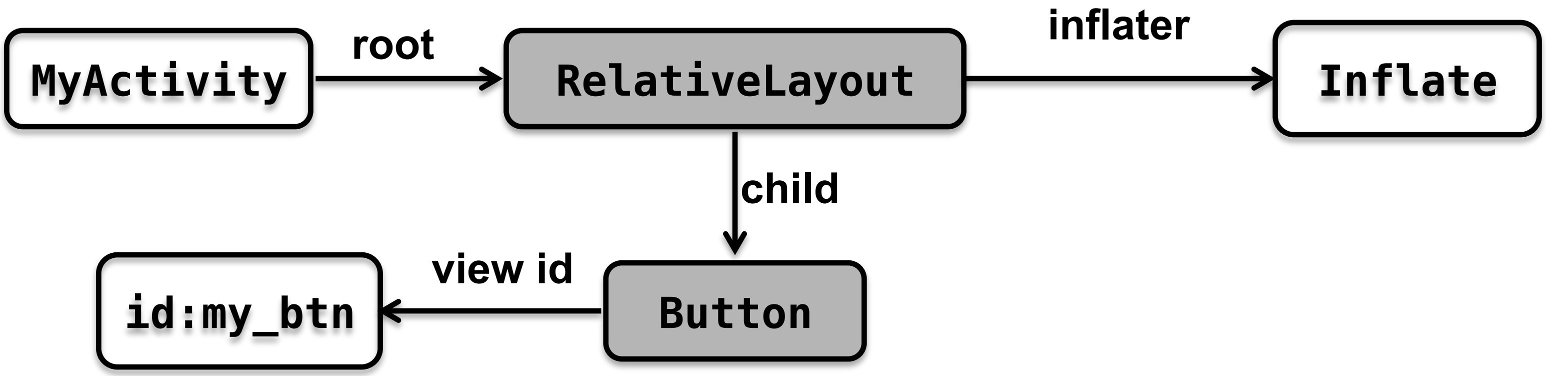

MyActivity

root

RelativeLayout

inflater

Inflate

child

Button

view id

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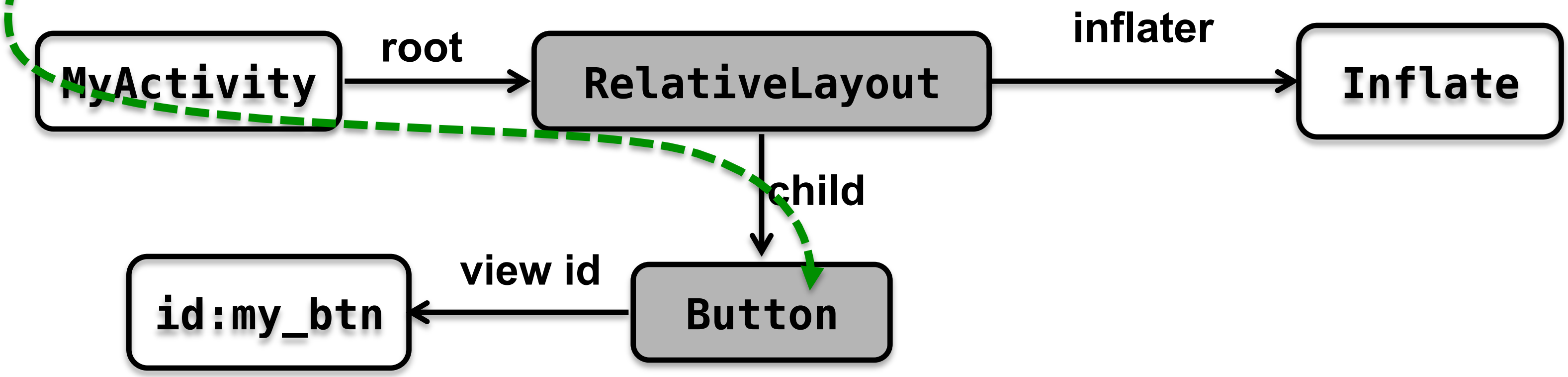
lookup performed by **FindView**



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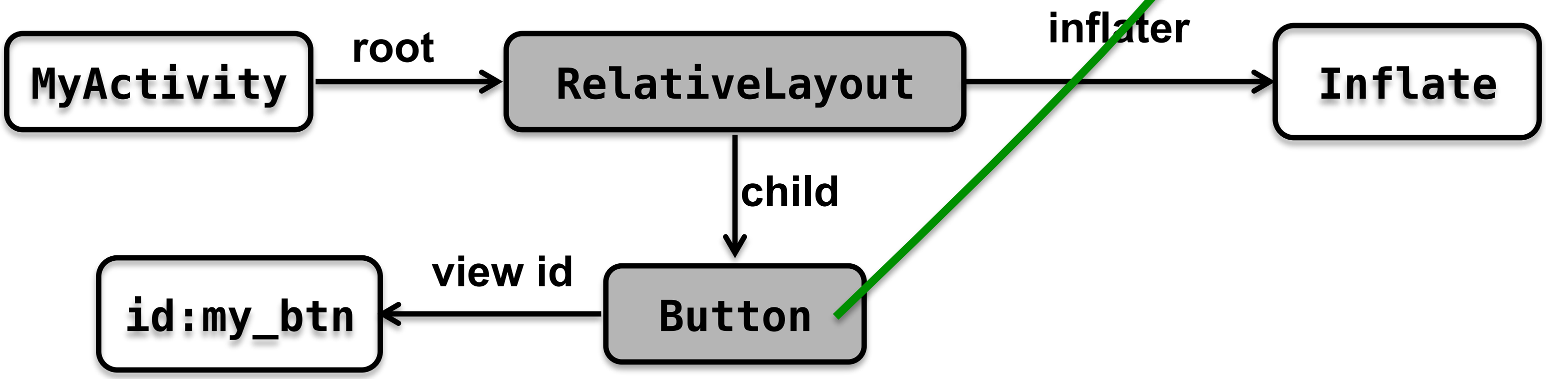

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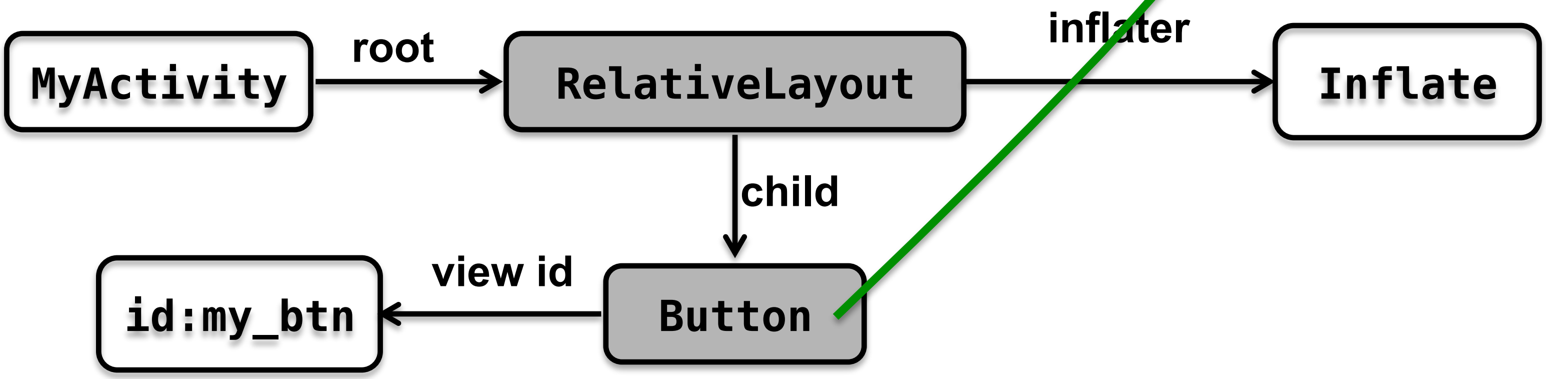

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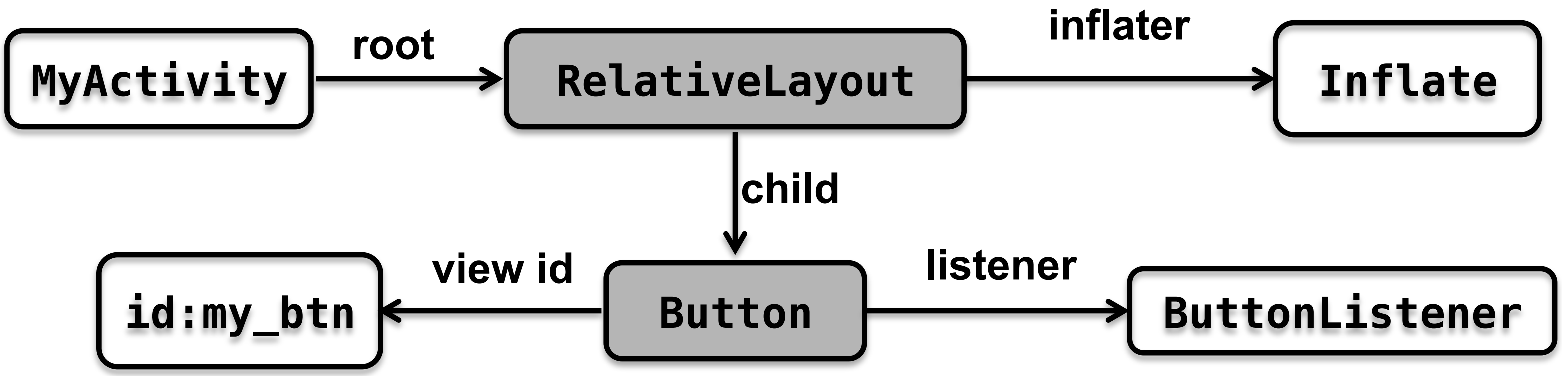


Property edges and relevant nodes

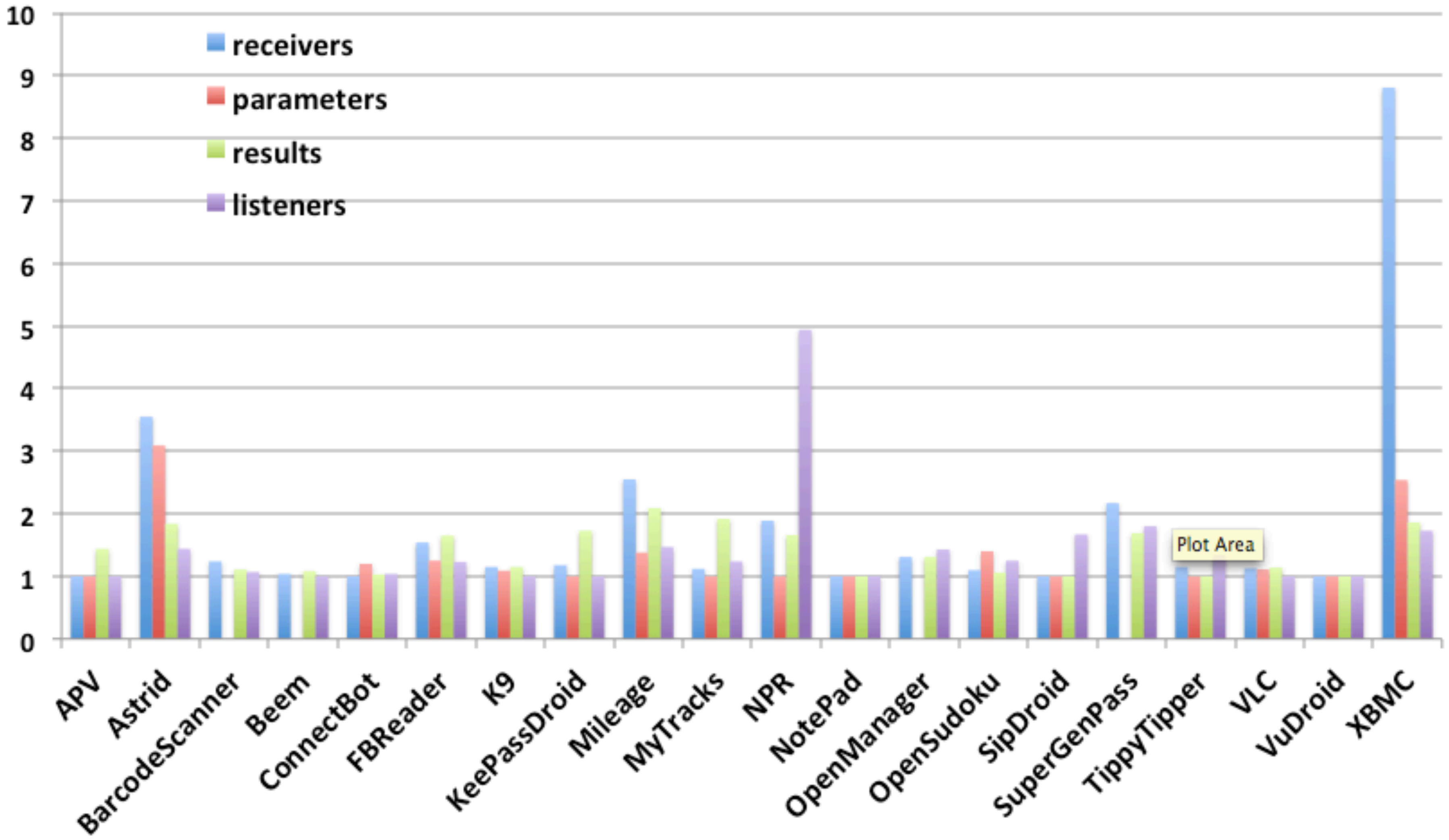
Implementation

- Input
  - Java bytecode of the application
  - Relevant XML files
- Output
  - Parent-child relationships between views
  - Association of activities with root views
  - Association of views with listeners
  - Variables and fields referring to views, activities, listeners
- Analysis algorithm
  1. Create initial constraint graph from app code
  2. Solve propagation constraints for IDs, activities, listeners
  3. Fixed-point computation for flow of views between operation nodes

Evaluation

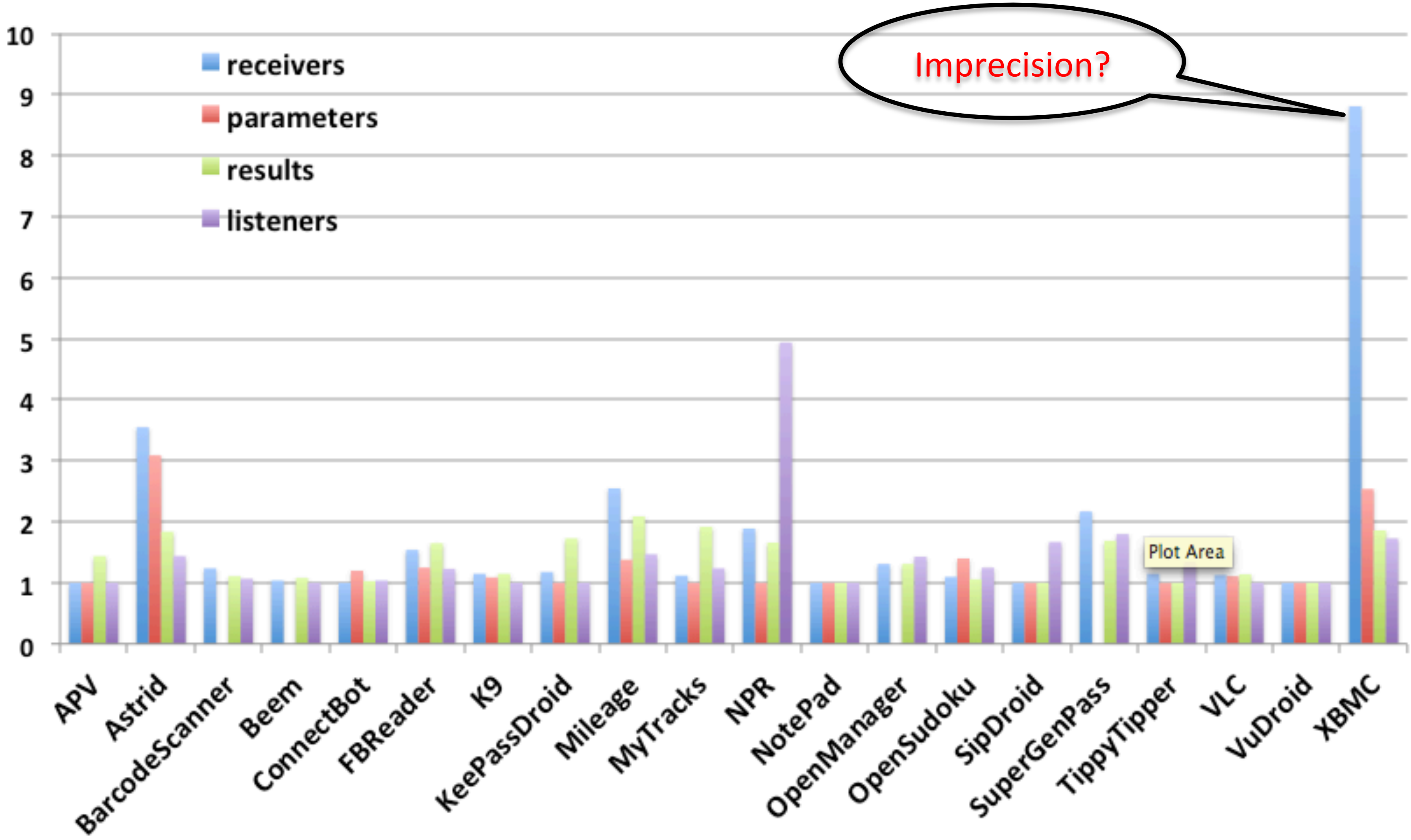
- Experiments on 20 open-source Android apps
- Experiment I – application characterization
    - Constraint graph: number of various types of nodes
    - Result: Android-specific features are widely used
- Experiment II – analysis performance and precision
    - Running time to perform the constraint analysis
        - Less than 5 seconds for each app
    - Average number of objects for variables at relevant operations – e.g.
        - v1.addChild(v2) – receiver v1, parameter v2
        - v = x.findViewById(…) – result v
        - v.setListener(m) – receiver v, listener m

Precision Measurements



Average number of objects for variables at relevant operations

Precision Measurements



Average number of objects for variables at relevant operations

Conclusions

- First static analysis to focus on GUI-related Android constructs
- Proposed constraint-based algorithm exhibits high precision and low cost
- Critical building block for other analyses and tools for Android
- Software release
  - GATOR: Pro***g***ram ***A***nalysis ***T***oolkit F***o***r And***r***oid
  - http://www.cse.ohio-state.edu/presto/software/

Thank you