Finding Architectural Flaws in Android Apps Is Easy

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50% of security vulnerabilities are architectural [McGraw, Addison-Wesley'05]

- Other 50% are coding defects: local, found by analyzing one class at a time
- Architectural flaws: non-local, found by reasoning about usage context

OWASP 2004* [web applications]
A1 - Unvalidated Input
A2 - Broken Access Control
A3 - Broken Authentication and Session Management
A4 - Cross Site Scripting
A5 - Buffer Overflow
A6 - Injection Flaws
A7 - Improper Error Handling
A8 - Insecure Storage
A9 - Application Denial of Service
A10 - Insecure Configuration Management

*https://www.owasp.org/index.php/Top_10_2004

**https://www.owasp.org/index.php/Top_10_2013-Top_10

50% of security vulnerabilities are architectural [McGraw, Addison-Wesley'05]

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OWASP 2013** [web applications]
A1 - Injection
A2 - Broken Authentication and Session Management
A3 - Cross-Site Scripting (XSS)
A4 - Insecure Direct Object References
A5 - Security Misconfiguration
A6 - Sensitive Data Exposure
A7 - Missing Function Level Access Control
A8 - Cross-Site Request Forgery (CSRF)
A9 - Using Components with Known Vulnerabilities
A10 - Unvalidated Redirects and Forwards

*https://www.owasp.org/index.php/Top_10_2004

**https://www.owasp.org/index.php/Top_10_2013-Top_10

Architectural flaws in mobile apps

- OWASP top 10 most critical risks in security of mobile applications*
- Most are architectural flaws
- >800K Android apps in Google Play store**
- >1 Billion Android devices activated*** (Sept 2013)

OWASP 2013 [mobile applications]
M1: Insecure Data Storage
M2: Weak Server Side Controls
M3: Insufficient Transport Layer Protection
M4: Client Side Injection
M5: Poor Authorization and Authentication
M6: Improper Session Handling
M7: Security Decisions Via Untrusted Inputs
M8: Side Channel Data Leakage
M9: Broken Cryptography
M10: Sensitive Information Disclosure

*https://www.owasp.org/index.php/Projects/OWASP_Mobile_Security_Project_-_Top_Ten_Mobile_Risks

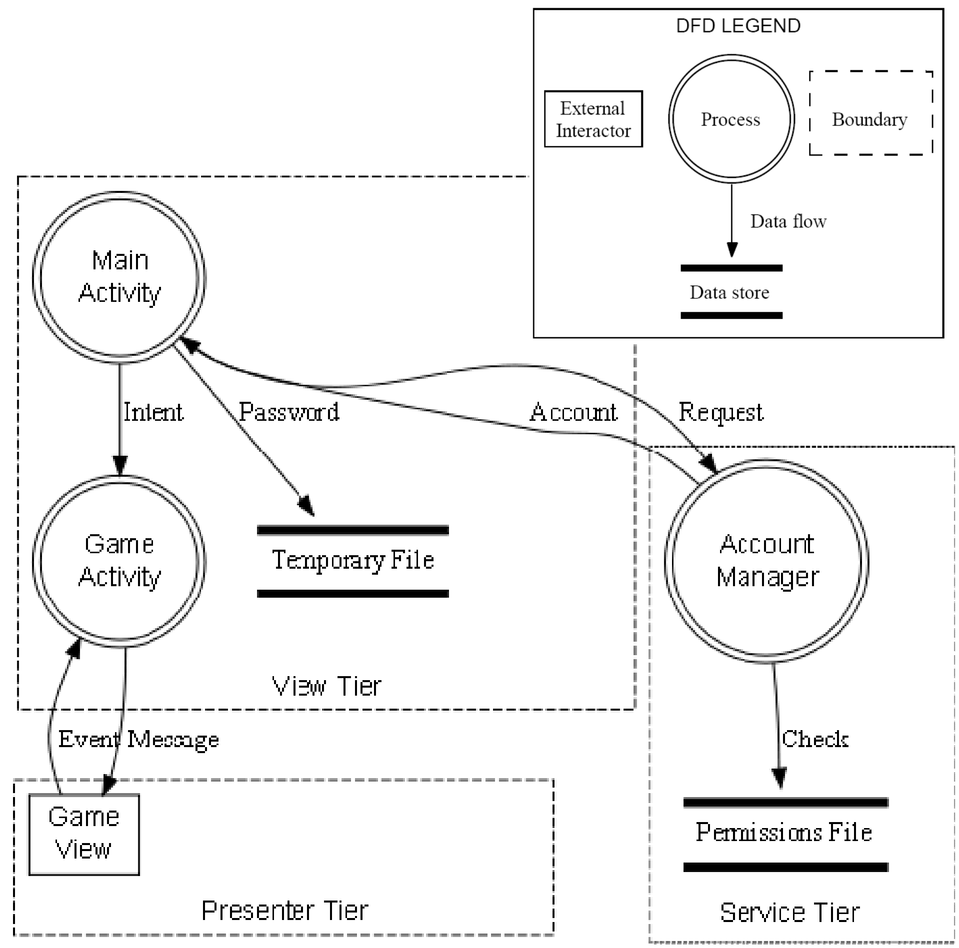
**http://www.appbrain.com/stats/number-of-android-apps

***http://www.androidcentral.com/android-passes-1-billion-activations

Architectural Risk Analysis helps to find architectural flaws [Howard and Lipner, Microsoft Press'06]

- Architects use forest-level view of system (not reading code)
  - Runtime architecture – not code architecture
  - Assign security properties to component instances

- Limitations of ARA approaches
  - Limited support for reverse engineering
  - Runtime architecture is missing or inconsistent
  - Lack of traceability to code
  - Analyses focused only on presence/absence of communication



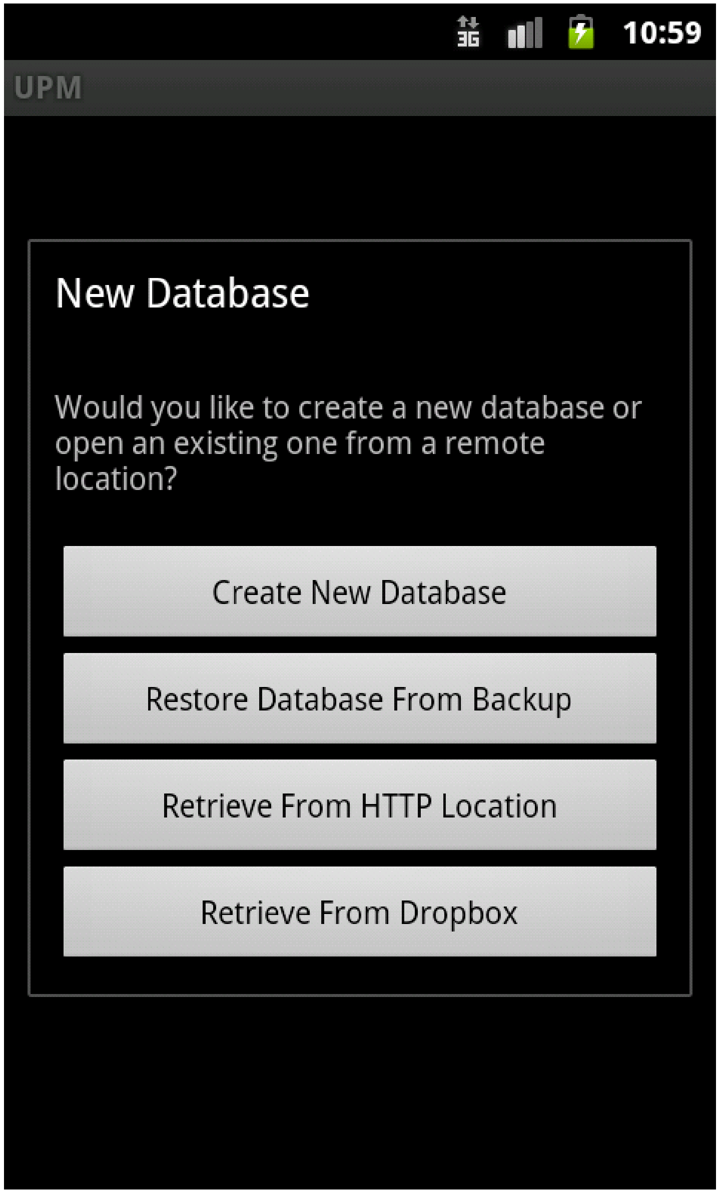
Scoria: Security Constraints On Runtime Architecture

- Extract from code runtime architecture useful for security
  - Annotations convey design intent
  - Sound approximation of the runtime architecture
  - Supports hierarchical decomposition
    - Architectural relevant objects near the top of hierarchy
    - Implementation details further down
  - Reason about dataflow communication
    - Dataflow edge refers to objects

- Scoria helps architects to find architectural flaws
  - Support architects to write constraints as unit tests

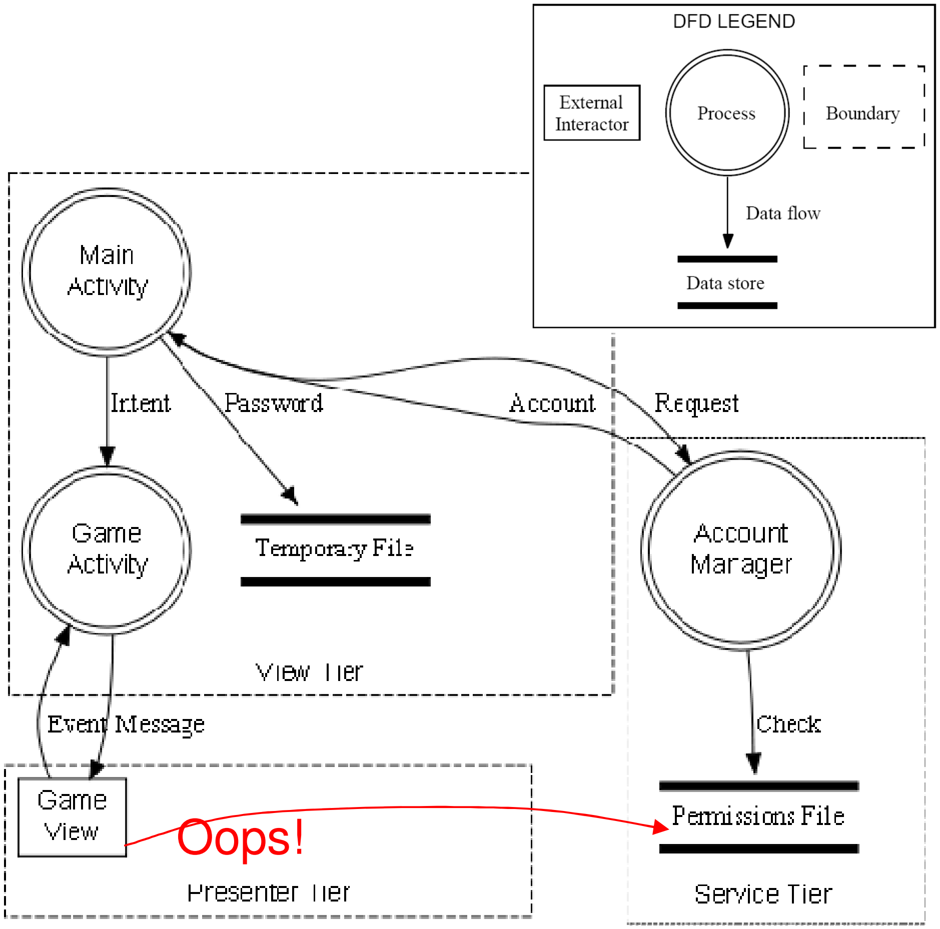
Demo

- Find architectural flaws in one open-source Android app
- Subject system: Universal Password Manager Application (UPMA) (4KLOC)
  - Stores passwords in encrypted files
  - Annotated only code of UPMA, not for Android framework
  - Downloaded > 500K



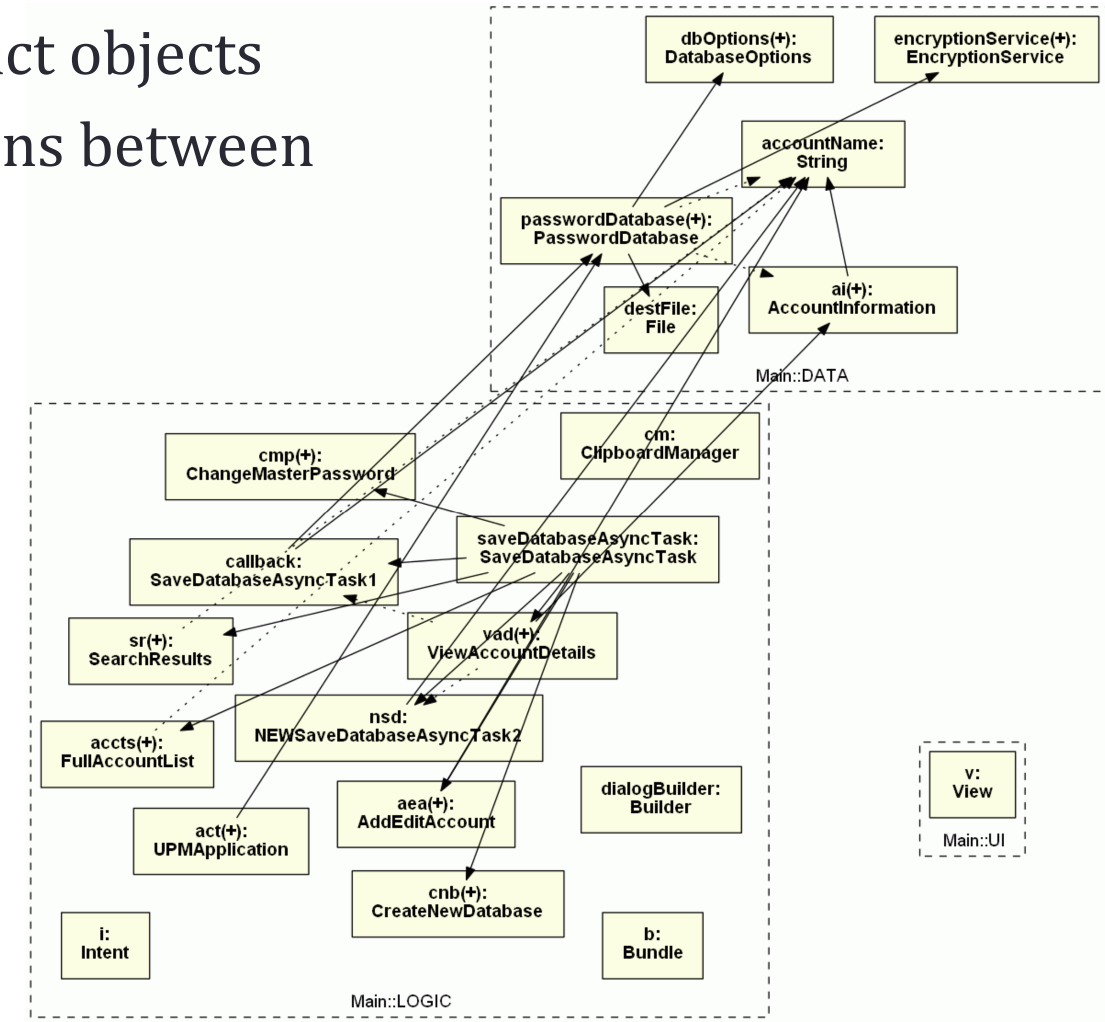
Security is a worst-case analysis and requires soundness

- **Represent all** objects and relations that may exist at runtime
- Absence of a connector means absence of communication at runtime
- Find unexpected edges that may occur in exceptional or error handling cases
- Ensure that same runtime entity is not mapped to distinct components

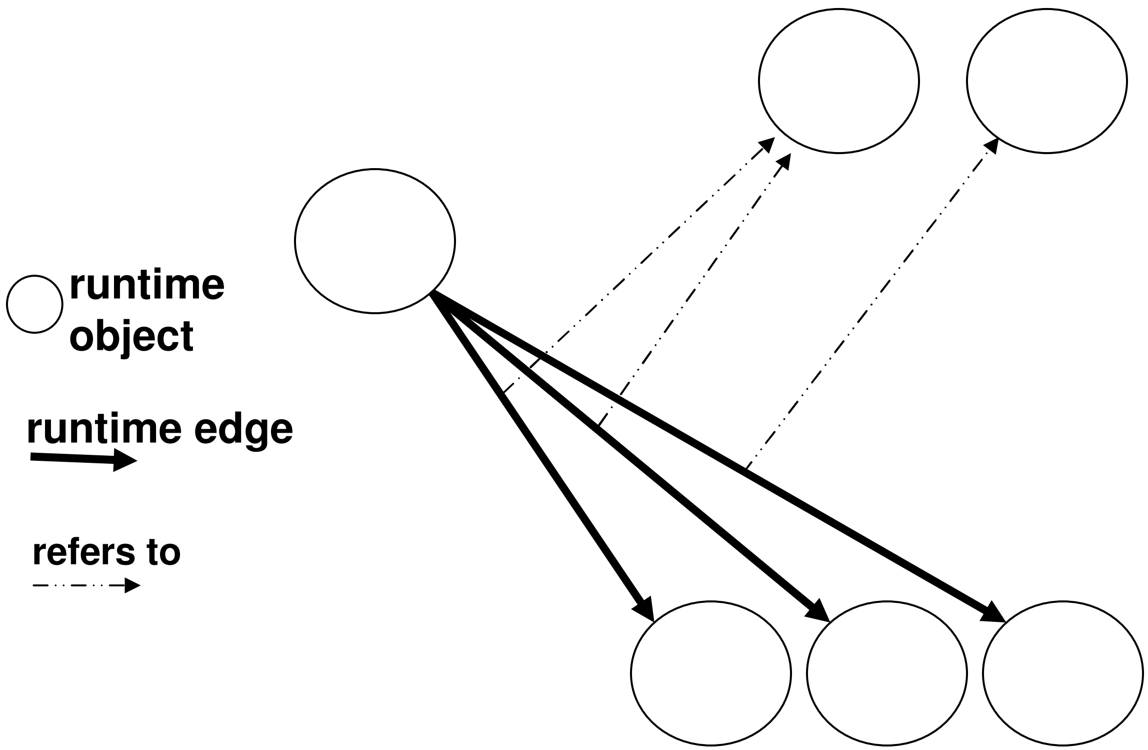


Static analysis extracts sound approximation of runtime architecture [Vanciu and Abi-Antoun, FOOL'13]

- Nodes represent abstract objects
- Edges represent relations between abstract objects
- Directed graph
- Multiple types of edges
- Multigraph

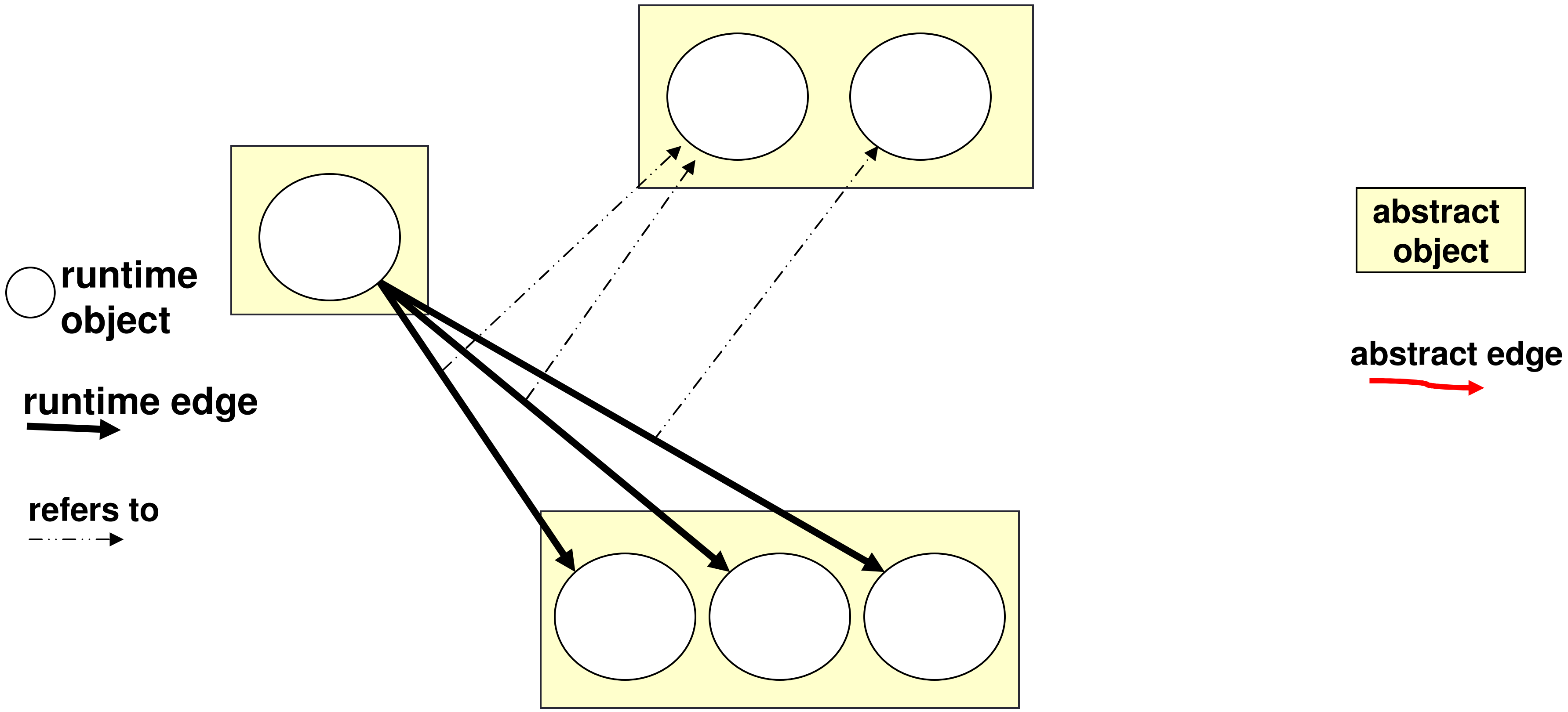


At runtime, object oriented program appears as Runtime Object Graph



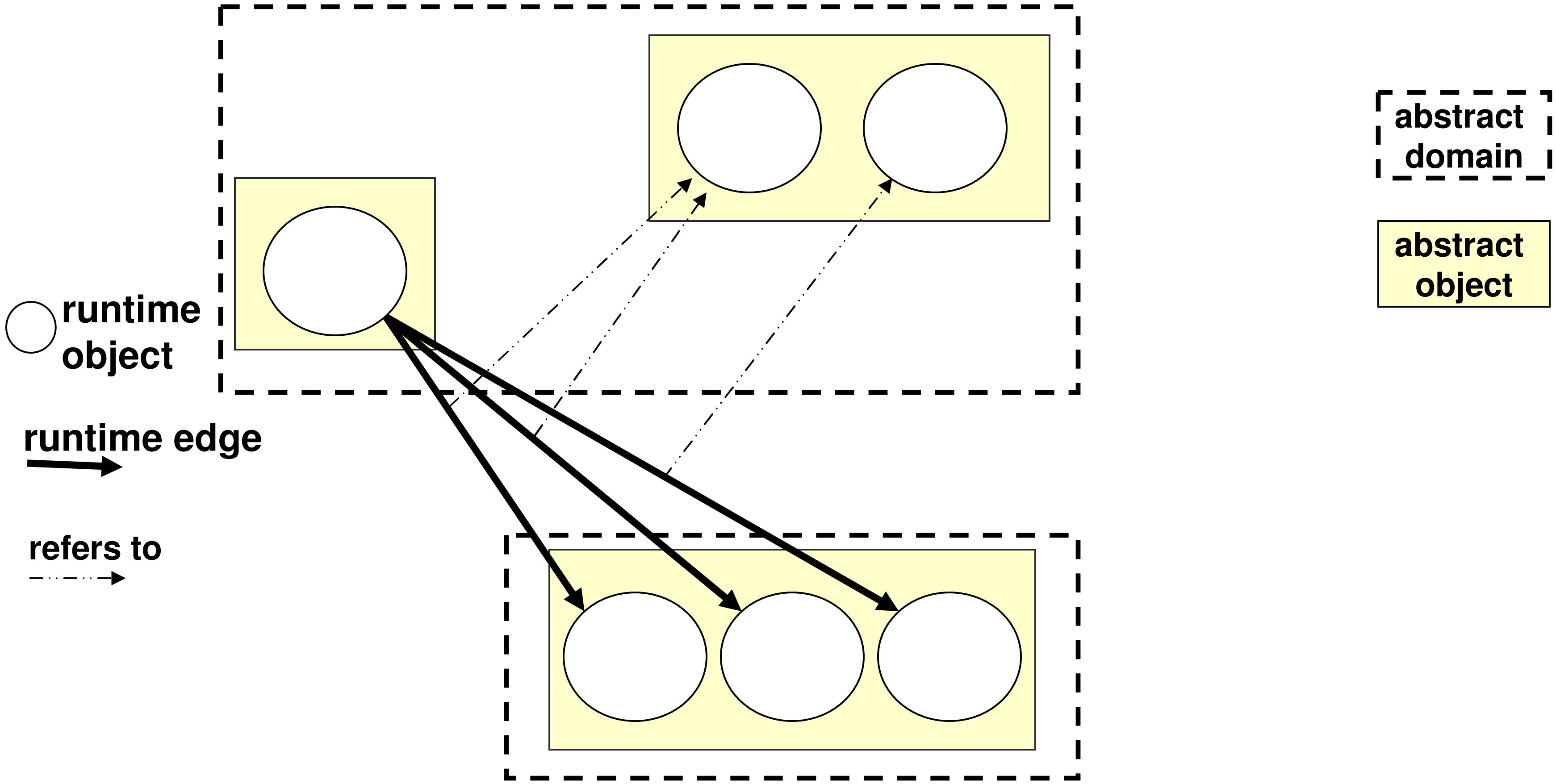
Abstract multiple runtime objects into an abstract object

- Each runtime object has **exactly one** representative in extracted object graph



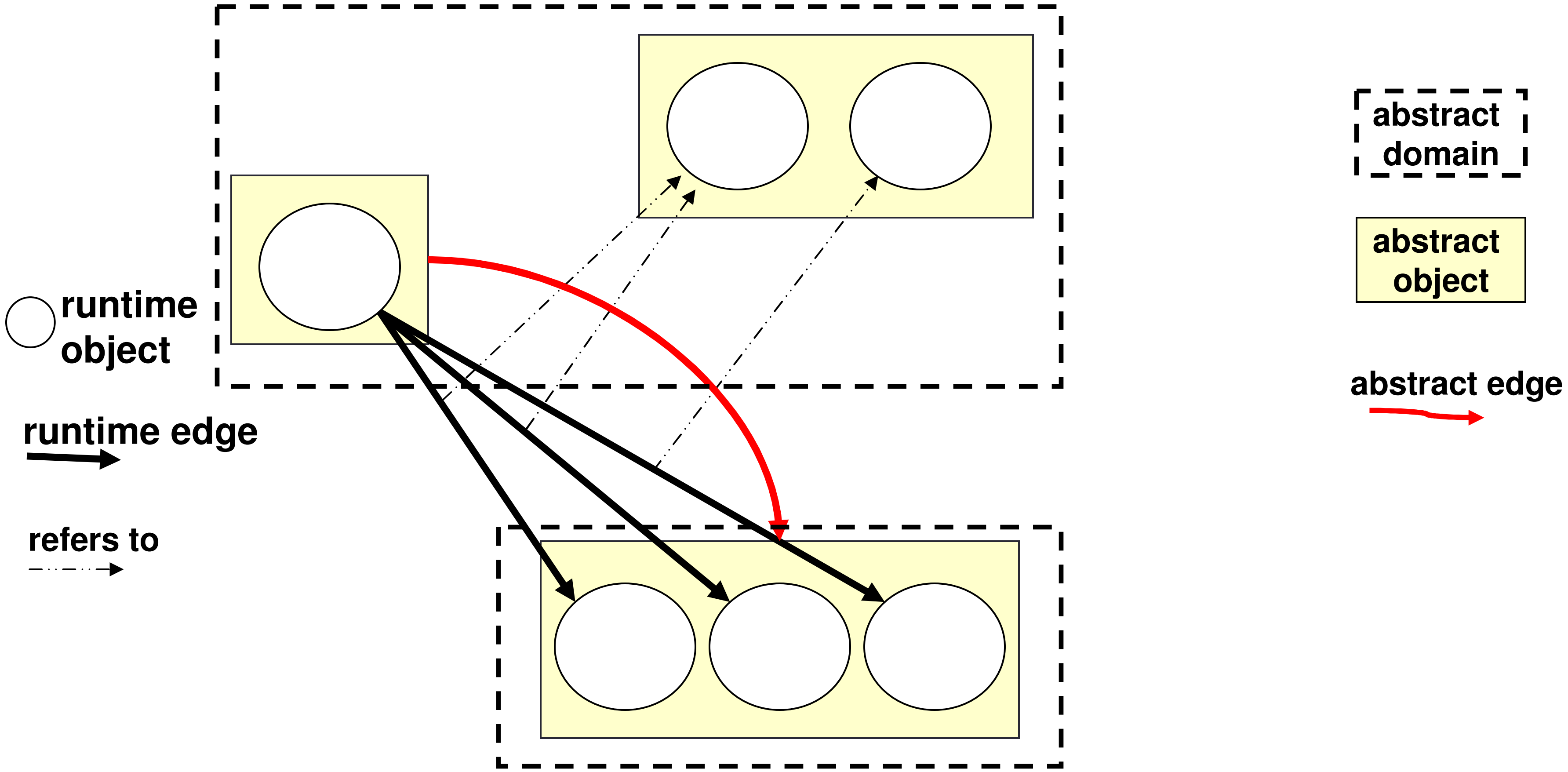
Abstract domain is a group of abstract objects

- Place each abstract object in exactly one conceptual group (abstract domain)



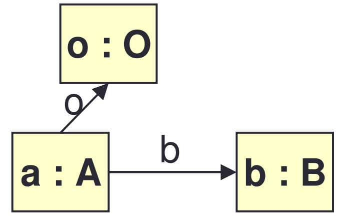
Abstract edge is between abstract objects

- Runtime edge between two objects maps to the abstract edge between the representatives of two objects



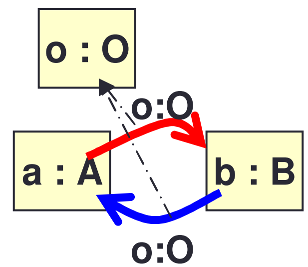
Edges between objects

- Points-to [label is field name]



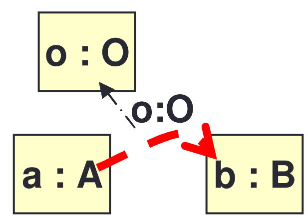

```
class A{
  B b; O o;
```

- Dataflow [label refers to object]




```
O m1(){
 return b.add(o);
}
```

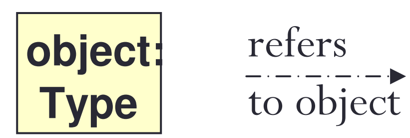
- Creation [label refers to object]




```
void m2(){
 new B(o);
}
```

- Control flow [label is method name]

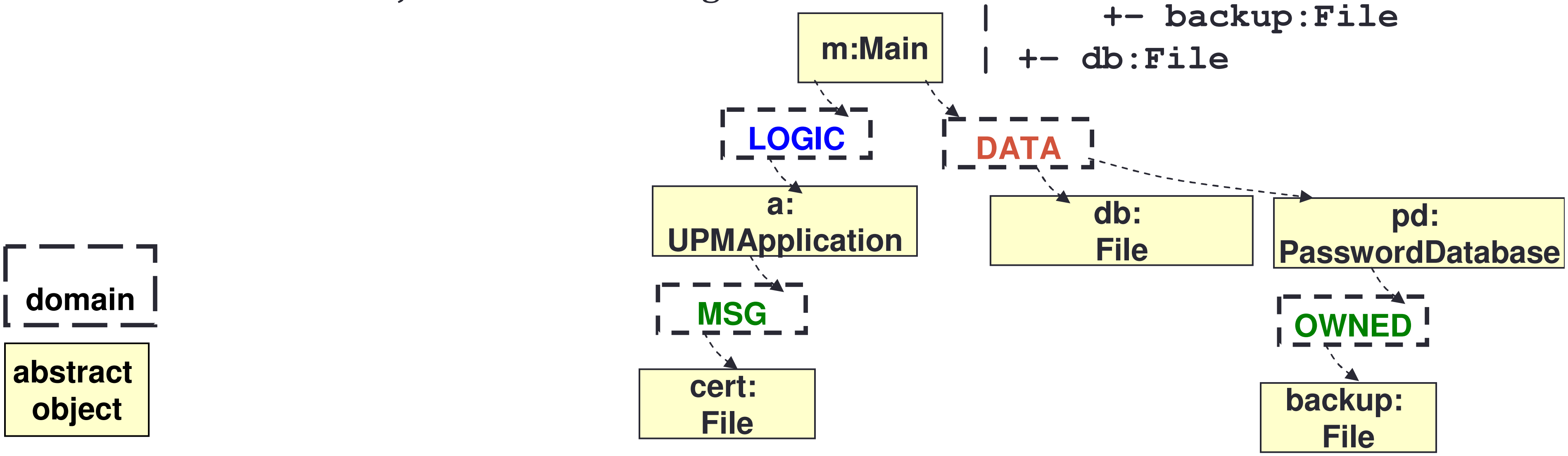

```
void m3(){
  b.start()
 }
}
```



Objects are organized hierarchically

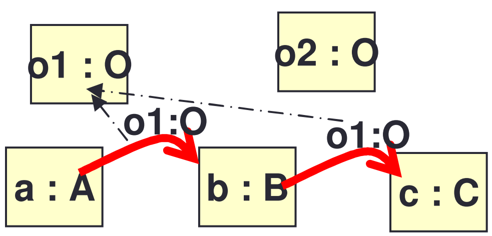
- Abstract object can have abstract domains
- Each domain can have objects
- Hierarchy of objects extracted by analyzing code with annotations
- Domains provides precision
  - Distinguish between objects of same type in different domains
  - At runtime object does not change domain

```
+-m:Main
  +- LOGIC
  | +- a:UPMApplication
  |   +- MSG
  |     +- i:Intent
  |       +- OWNED
  |         +- map:HashMap
  |     +- cert:File
  +- DATA
  | +- pd:PasswordDatabase
  |   +- OWNED
  |     +- backup:File
  | +- db:File
```

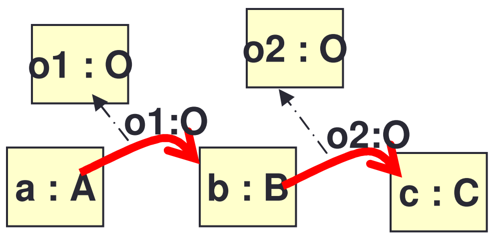


Architects distinguish between copying and sharing of object → Object identity

- Every abstract object is uniquely identified
- Enable comparison of references



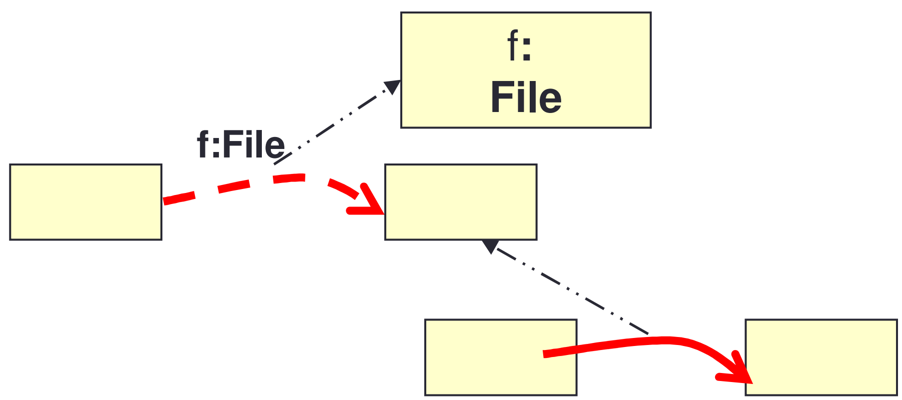
Edges refer to same abstract object



Edges refer to distinct abstract objects of same type

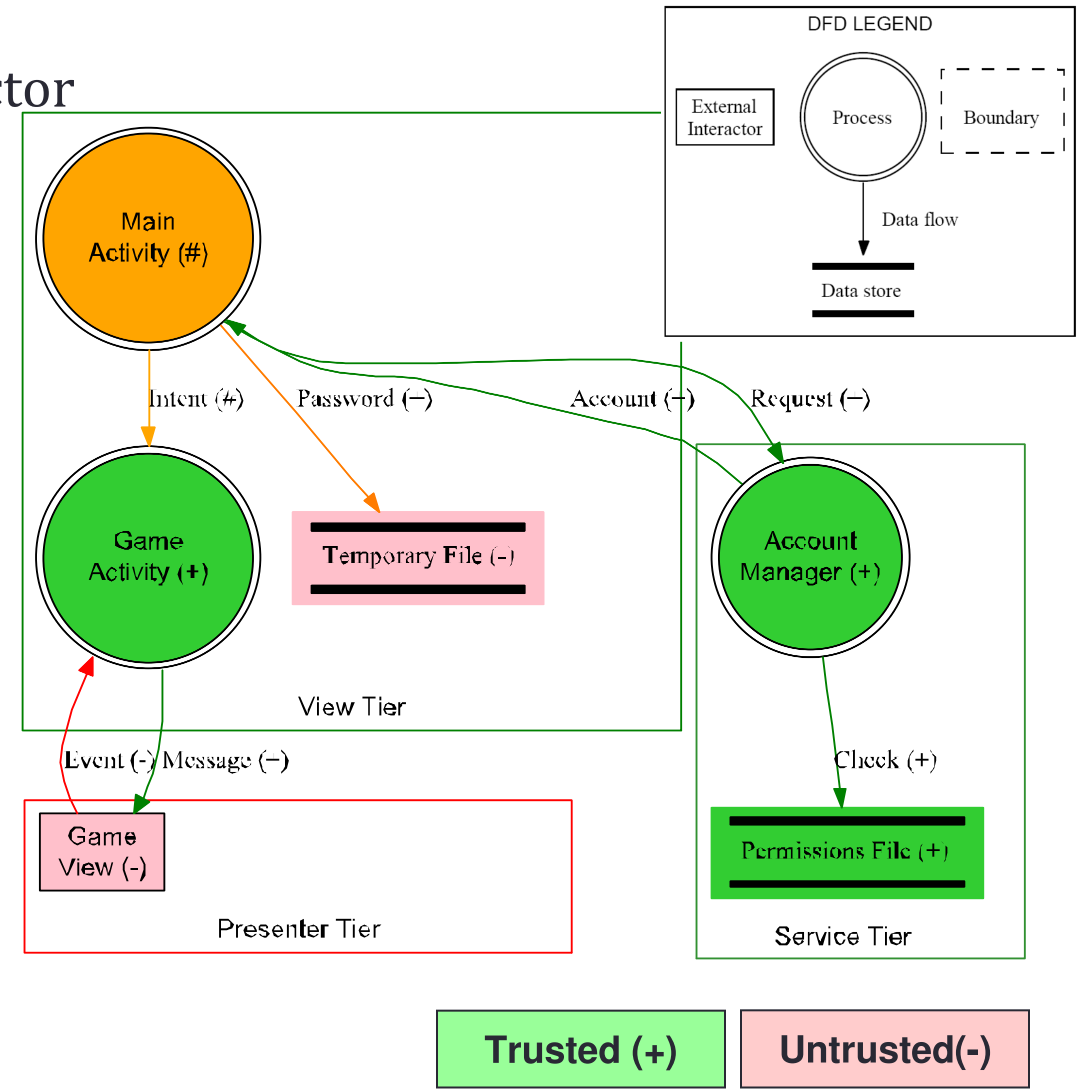
Distinguish between objects of type File

- Selection queries
  getObjectsByCondition,
  getEdgesByCondition
  - Return objects or edges that satisfy condition
- Condition based on:
  - Type + object hierarchy: *IsInDomain, isChildOf*
  - Type + object reachability: *IsInstOfRchblFromInstOf*
  - Type: *InstanceOf*



For information not directly extracted from code → assign security properties

- Security property values for each component and connector
  - **TrustLevel**
    - **Trusted(+)**
    - **Untrusted(-)**
    - **Unknown**
  - **IsConfidential**
    - **True**
    - **False**
    - **Unknown**
  - **IsEncrypted**
- Using security properties
  - **Tampering**: **Untrusted(-) → Trusted(+)**
  - **Information Disclosure**: **Trusted(+) → Untrusted(-)**



Finding Architectural Flaws in Android app

- Intents are like command line arguments used to start an activity [Burns, Black Hat'09]

- Security policy: *Don't put sensitive data into Intents used to start Activities. Callers can't easily require Manifest permissions of the Activities they start, and so your data might be exposed.*
  - *For example processes with the GET_TASKS permission are able to see ActivityManager.RecentTaskInformation which includes the –base Intent used to start Activities.*

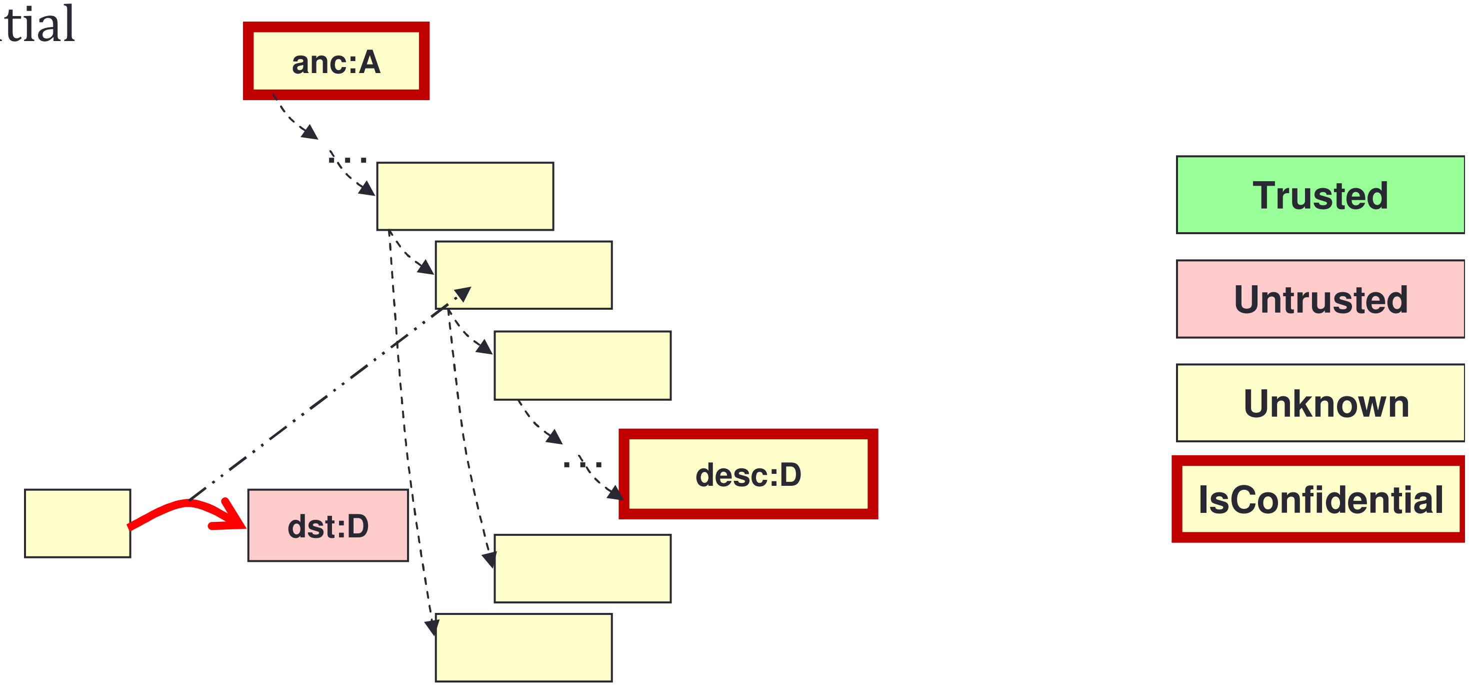
Automating security reasoning →queries

- Property queries: *setObjectsProperty(props, condition), setEdgesProperty(props, condition)*
  - Assign property values to objects or edges that satisfy condition

- Condition based on:
  - Type + object hierarchy: *IsInDomain, isChildOf*
  - Type + object reachability: *IsInstOfRchblFromInstOf*
  - Type: *InstanceOf*

Some objects that carry confidential data may be part of some other object → object hierarchy

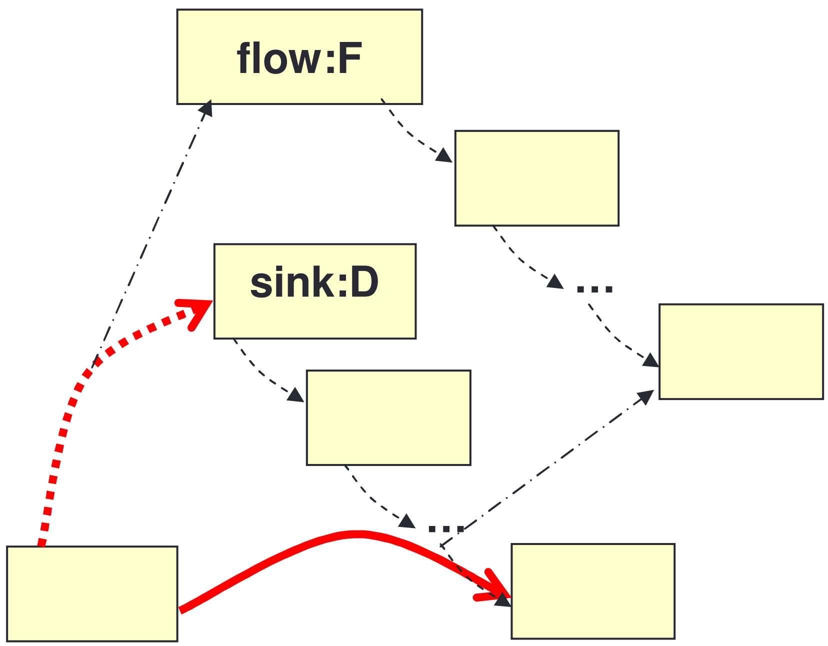
- Only some objects are confidential, but architects also consider:
  - Descendant of object referred from dataflow edge is confidential
  - Ancestor of object referred from dataflow edge is confidential



Selection query in terms of architecturally relevant objects →Indirect communication

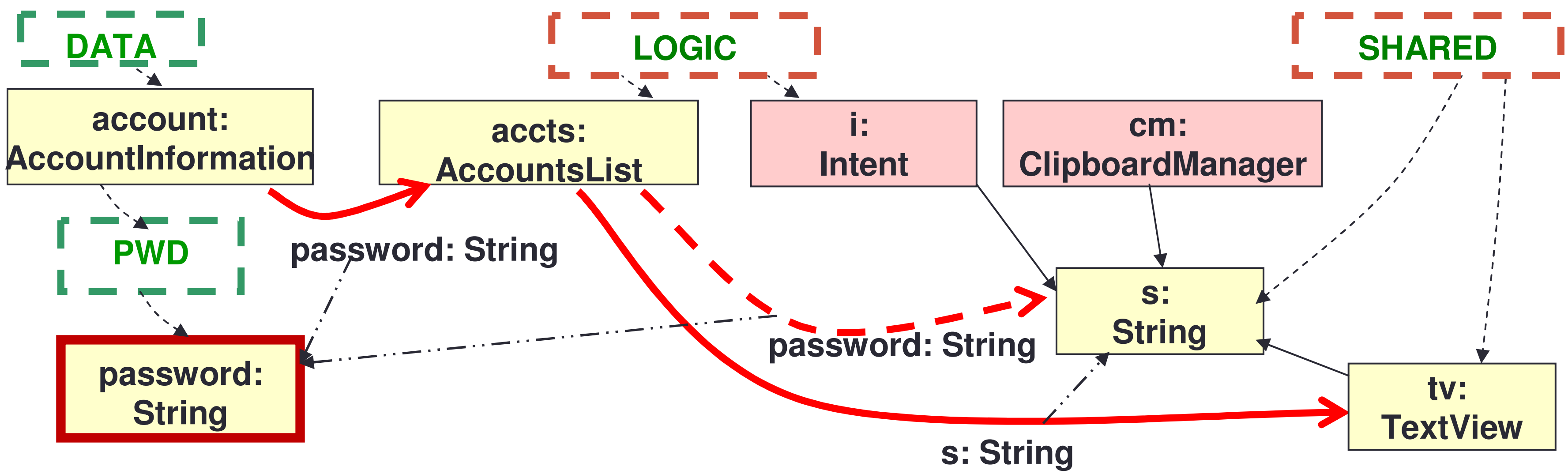
getFlowIntoSink(flow, sink)

- Returns dataflow or creation edges
- Destination is descendant of *sink*, or object reachable from *sink*
- Edge refers to descendant of *flow* or object reachable from *flow*



Use queries to assign security properties

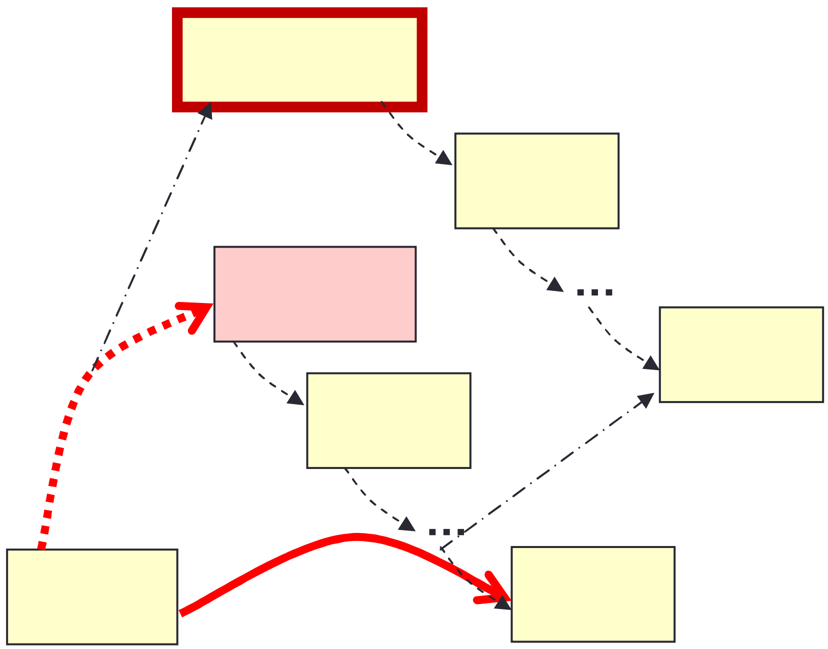
- *setObjectsProperty*(*TrustLevel.**Untrusted*** , InstanceOf(OuptutStream))
- setObjectsProperty(*IsConfidential.**true,*** IsChildOf(String, AccountInformation))
- setObjectsProperty(*IsConfidential.**true,*** IsInDomain(String, PWD))



Automating security reasoning → machine checkable constraints on query results

*getFlowIntoSink(IsConfidential.**true**, TrustLevel.**Untrusted**)*

- Query in terms of security properties only
  - Return edges that refer to confidential object with an untrusted destination
  - Returned set is empty means: no confidential data flows to untrusted destination
  - Written in general terms — not system specific

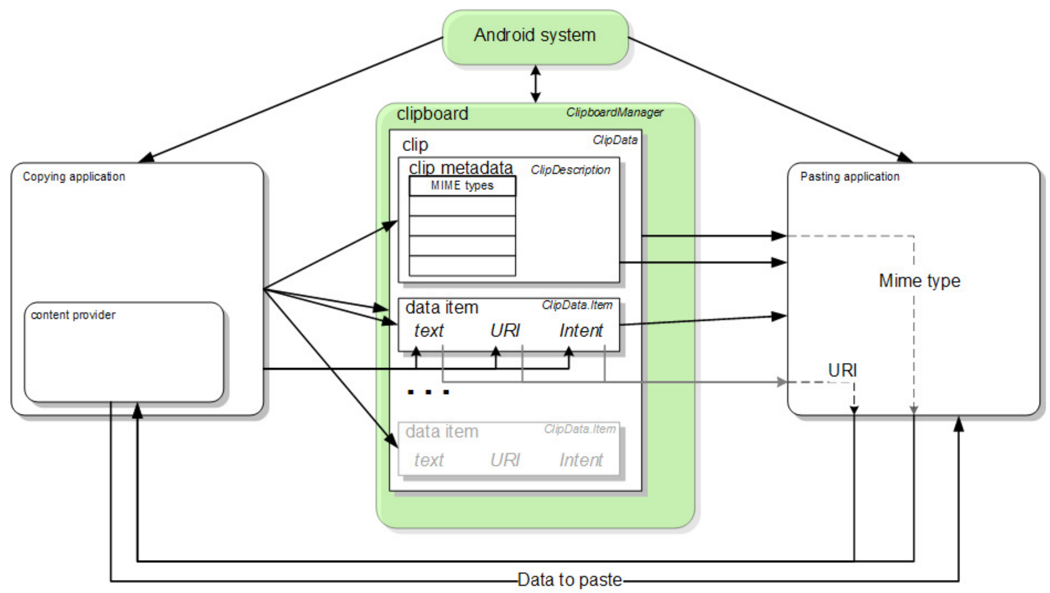


Security Test: No confidential data flows to untrusted object

```
@Test
public void checkInfDisclosureIntentPolicy() {
    secGraph.setObjectProperty(TrustLevelType.Low,
        new InstanceOf(Intent.class));
    secGraph.setObjectProperty(IsConfidential.True,
        new IsChildOf(AccountInformation.class, String.class));
    Property[] snkProps = { TrustLevelType.Low };
    Property[] flwProps = { IsConfidential.True };
    if (secGraph.checkFlowIntoSink(snkProps, flwProps)) {
        Set<IEdge> sEdges = secGraph.getFlowIntoSink(snkProps, flwProps);
        scoria.displayWarnings(sEdges);
        Assert.fail("Information disclosure found");
    }
}
```

Multiple communication mechanisms for ClipboardManager in Android

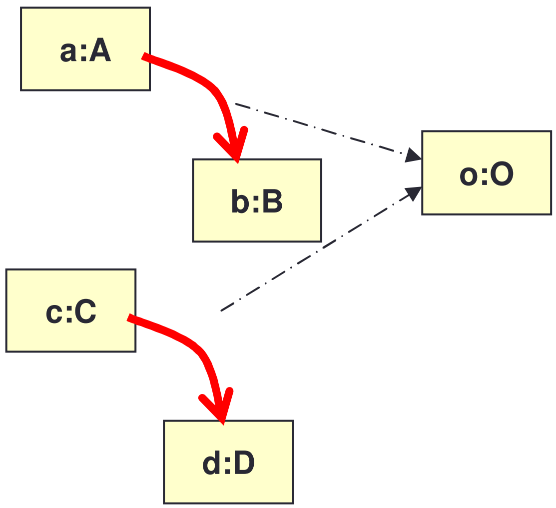
- No explicit permissions needed to access clipboard
  - Most Password manager apps expose password in plaintext to clipboard
  - Developers criticized Android's missing support for password manager apps [Fahl et al. FCDS'13]



http://developer.android.com/guide/topics/text/copy-paste.html

Architects can reason about object provenance → return dataflow edges that refer to same object

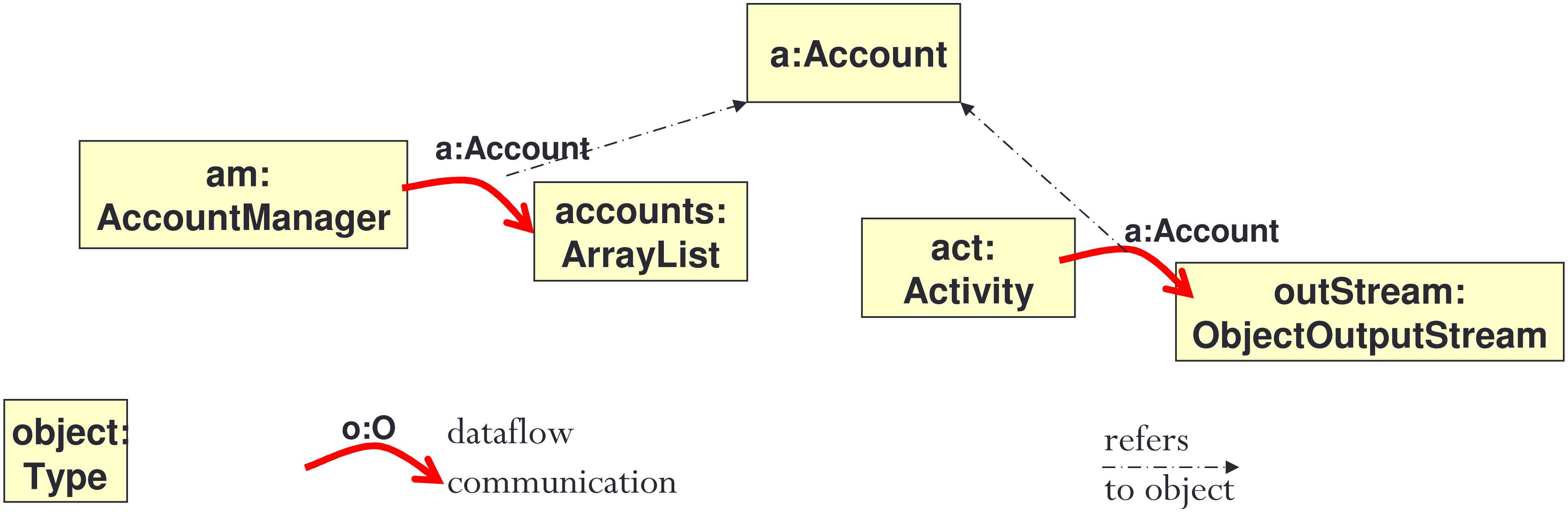
- Query: object provenance



- Constraint: return set is empty
  - No object that flows from **a:A** to **b:B** also flows from **c:C** to **d:D**

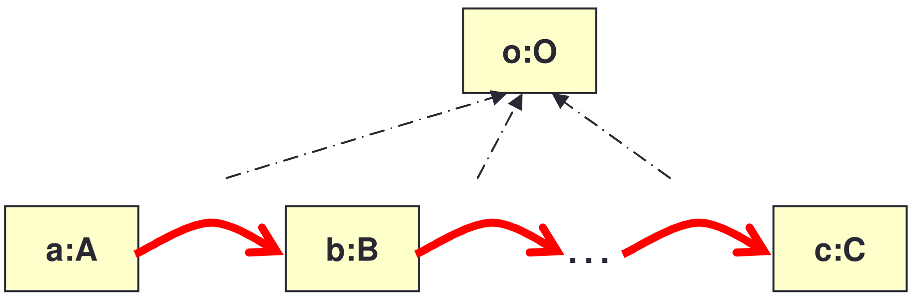
Example of object provenance

- Same object a:Account that flows from mgr:AccountManager is saved by act:Activity into outputStream:ObjectOutputStream



Special case of object provenance → object transitivity

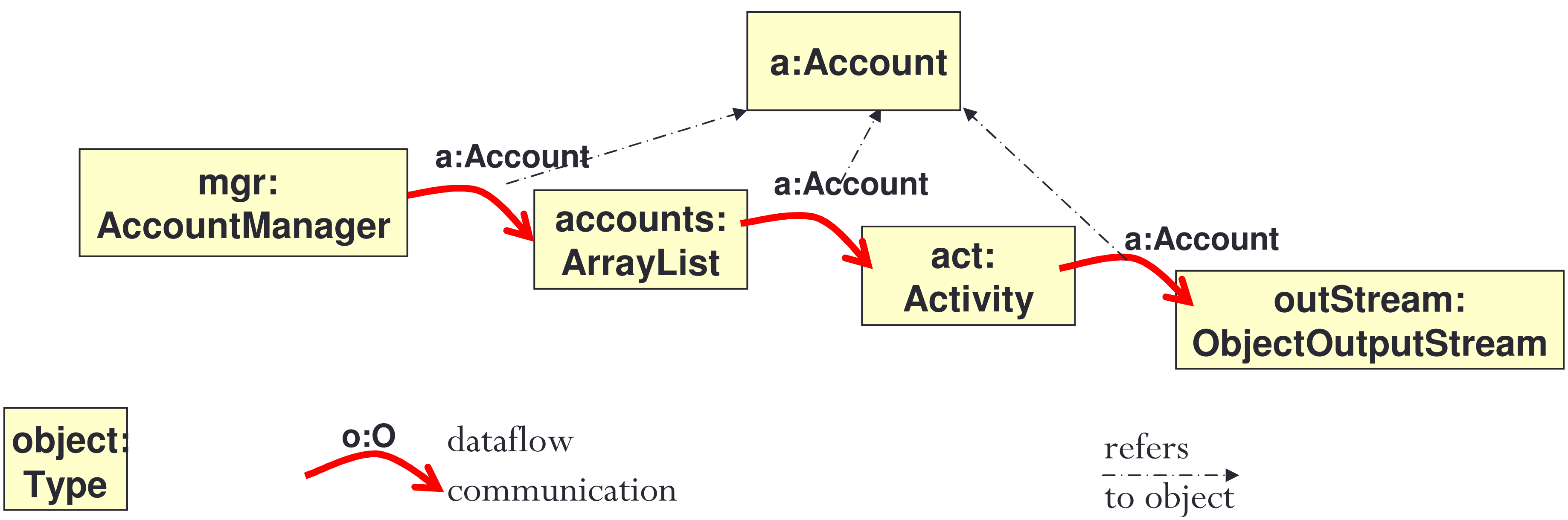
- Destination of e1 is source of e2



- Constraint: return set is empty
  - Object that flows from a:A to b:B does not flow to c:C

Example of object transitivity

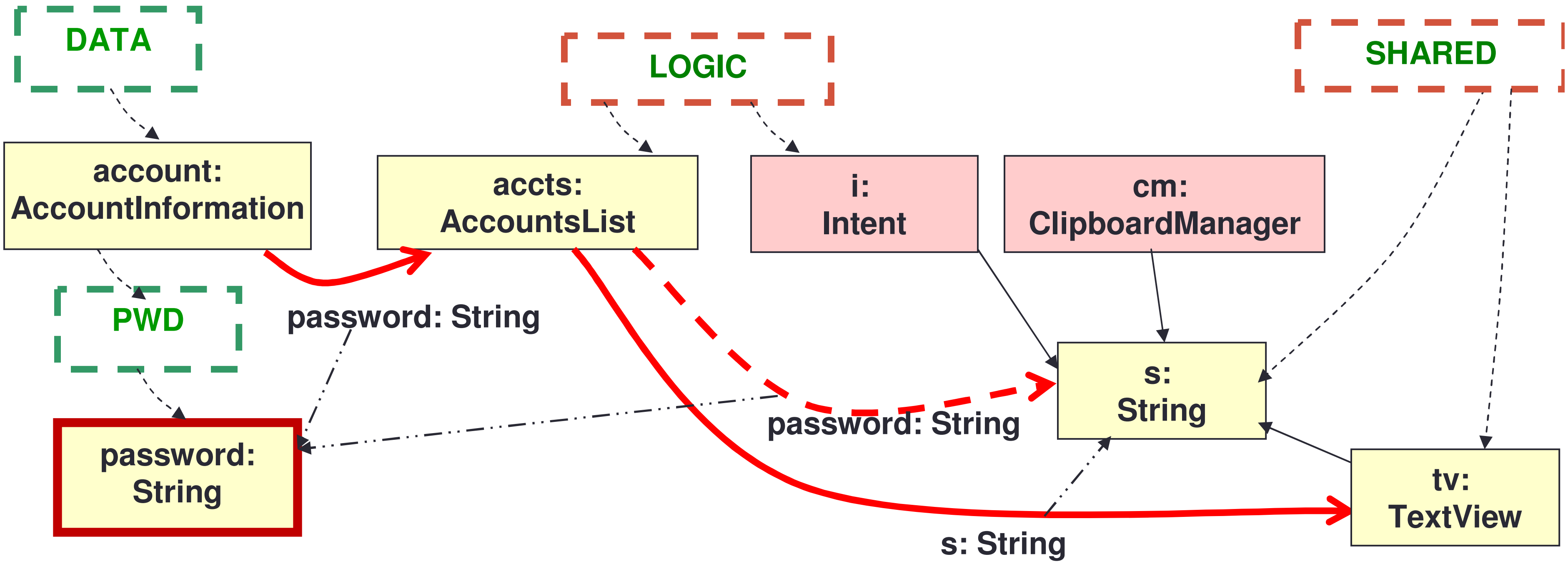
- Object a:Account flows from mgr:AccountManager to outStream:ObjectOutputStream through some intermediate objects



Limitation: false positives

- UPMA - password is sent to a text view for a user to see
- This is the intended feature in UPMA, not an architectural flaw

```
Class ViewAccountDetails{
 accountPasswordTextView.setText(new String(account.getPassword()));
}
```



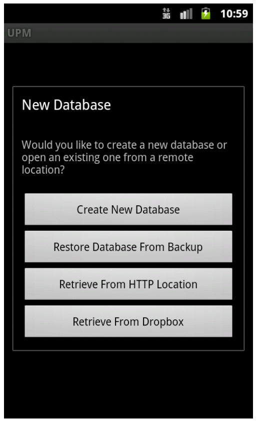
Other limitations

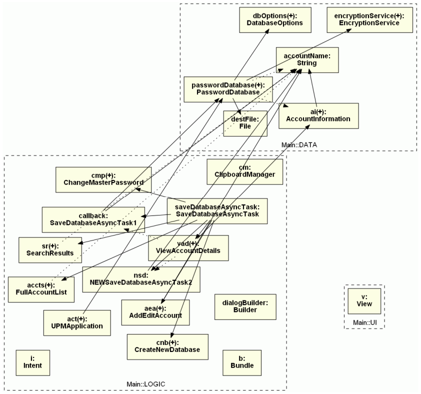
- Scoria supports architectural flaws that deal with structure, rather than behavior (no protocols, no states of objects)
  - **S**poofing
  - ✓**T**ampering
  - **R**epudiation
  - ✓**I**nformation disclosure
  - **D**enial of service
  - **E**levation of privilege

Some related tools

- AST based analysis
  - SecureAssist
  - FindBugs
- Static Analysis
  - Fortify, IBMScan, FlowDroid, Blue Seal
- Reasoning about code architecture
  - Bauhaus
- Query object graph
  - VisualVM
- Monitoring
  - TaintDroid

Conclusion





```
@Test
public void checkInfDisclosureIntentPolicy() {
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        new IsChildOf(AccountInformation.class, Stri
    Property[] snkProps = { TrustLevelType.Low };
    Property[] flwProps = { IsConfidential.True };
    if (secGraph.checkFlowIntoSink(snkProps, flwProp
        Set<IEdge> sEdges = secGraph.getFlowIntoSink
        scoria.displayWarnings(sEdges);
        Assert.fail("Information disclosure found");
    }
```
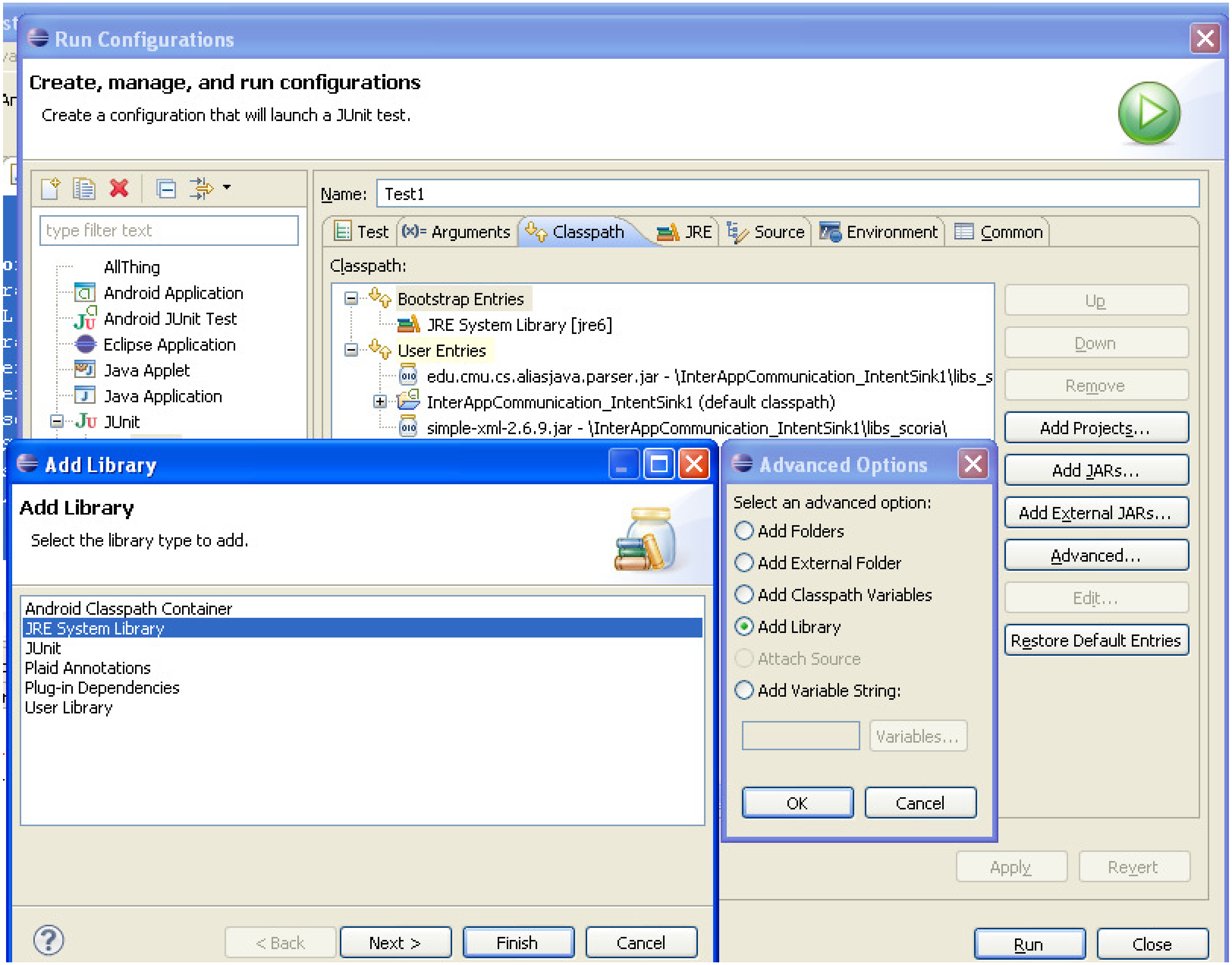

- Found information disclosure in Android app
- Constraints implementing Java CERT rules for which automatic support is unavailable [Vanciu and Abi-Antoun, ASE’13]
- Future work
    - Compare Scoria to related approaches based on benchmarks
    - Study how security architects use Scoria



Run Configurations
Create, manage, and run configurations
Create a configuration that will launch a JUnit test.
type filter text
AllThing
Android Application
Android JUnit Test
Eclipse Application
Java Applet
Java Application
JUnit
Name:
Test1
Test
Arguments
Classpath
JRE
Source
Environment
Common
Classpath:
Bootstrap Entries
JRE System Library [jre6]
User Entries
edu.cmu.cs.aliasjava.parser.jar - \InterAppCommunication_IntentSink1\libs_s
InterAppCommunication_IntentSink1 (default classpath)
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Up
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Add External JARs...
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Android Classpath Container
JRE System Library
JUnit
Plaid Annotations
Plug-in Dependencies
User Library
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Advanced Options
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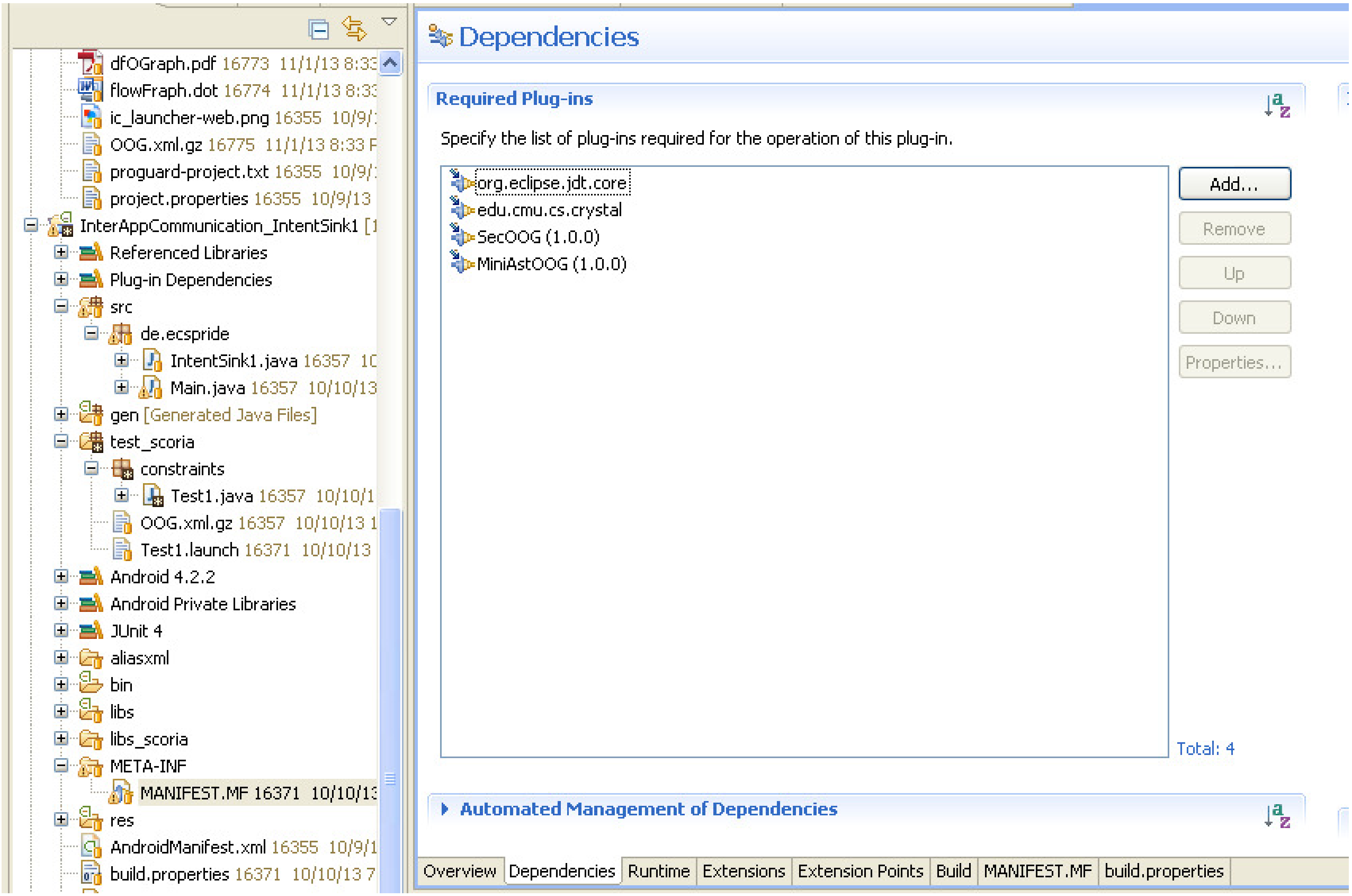

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flowFraph.dot 16774 11/1/13 8:33
ic_launcher-web.png 16355 10/9/1
OOG.xml.gz 16775 11/1/13 8:33 F
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project.properties 16355 10/9/13
InterAppCommunication_IntentSink1 [1
Referenced Libraries
Plug-in Dependencies
src
de.ecspride
IntentSink1.java 16357 10
Main.java 16357 10/10/13
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test_scoria
constraints
Test1.java 16357 10/10/1
OOG.xml.gz 16357 10/10/13 1
Test1.launch 16371 10/10/13
Android 4.2.2
Android Private Libraries
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aliasxml
bin
libs
libs_scoria
META-INF
MANIFEST.MF 16371 10/10/13
res
AndroidManifest.xml 16355 10/9/1
build.properties 16371 10/10/13 7
Dependencies
Required Plug-ins
Specify the list of plug-ins required for the operation of this plug-in.
org.eclipse.jdt.core
edu.cmu.cs.crystal
SecOOG (1.0.0)
MiniAstOOG (1.0.0)
Add...
Remove
Up
Down
Properties...
Total: 4
Automated Management of Dependencies
Overview
Dependencies
Runtime
Extensions
Extension Points
Build
MANIFEST.MF
build.properties