AppSealer: Automatic Generation of Vulnerability-Specific Patches for Preventing Component Hijacking Attacks in Android Applications

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Motivation: Component Hijacking Attacks in Android

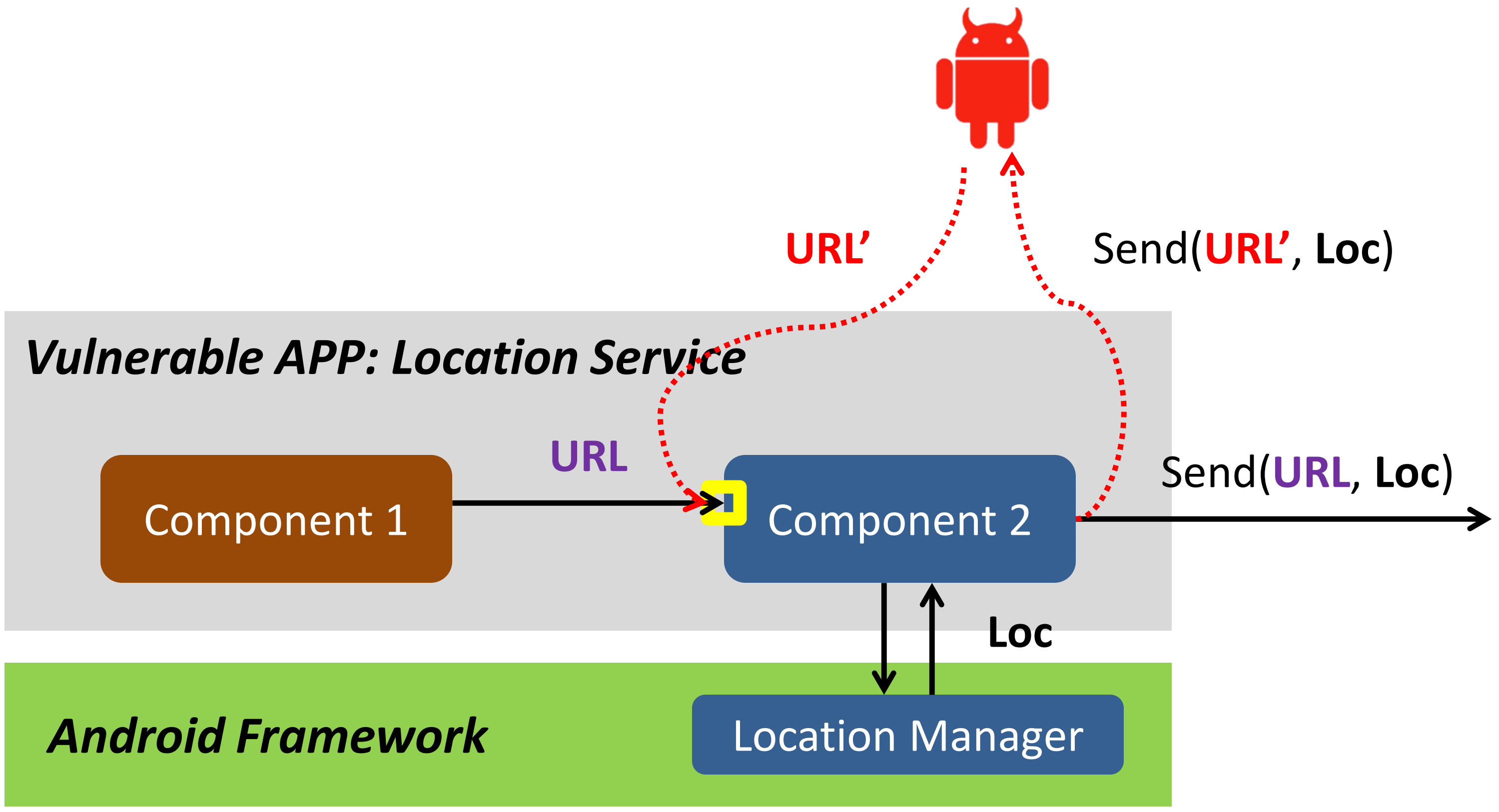
"A class of attacks that seek to

gain **unauthorized access** to protected or private resources

through **exported components** in vulnerable Android apps."

(L. Lu et al. CHEX, *CCS'12*)

Motivation: Component Hijacking Attacks in Android



Motivation: Current Countermeasures

- **Detection: Static Dataflow Analysis**
  - Conservative
- **Fix: Manual Effort**
  - Inexperienced
  - Not easy to confirm vulnerability

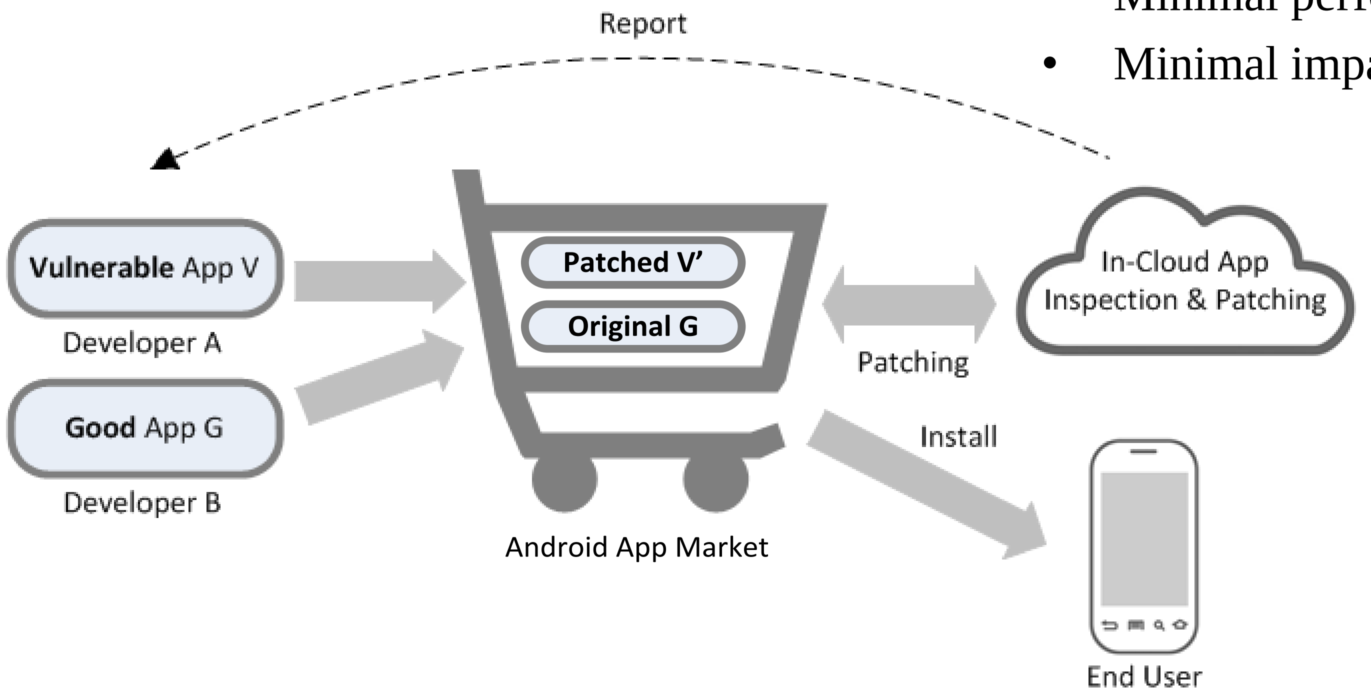
16 Reported in **Oct. 2012**
13 Not fixed until **Aug. 2013**

AppSealer: Automatic Patch Generation

- **Goal:** to automatically generate a patch that is specific to the discovered component hijacking vulnerability.

Design Requirements:

- No source code access.
- Vulnerability-specific patching.
- Minimal performance overhead.
- Minimal impact on usability.

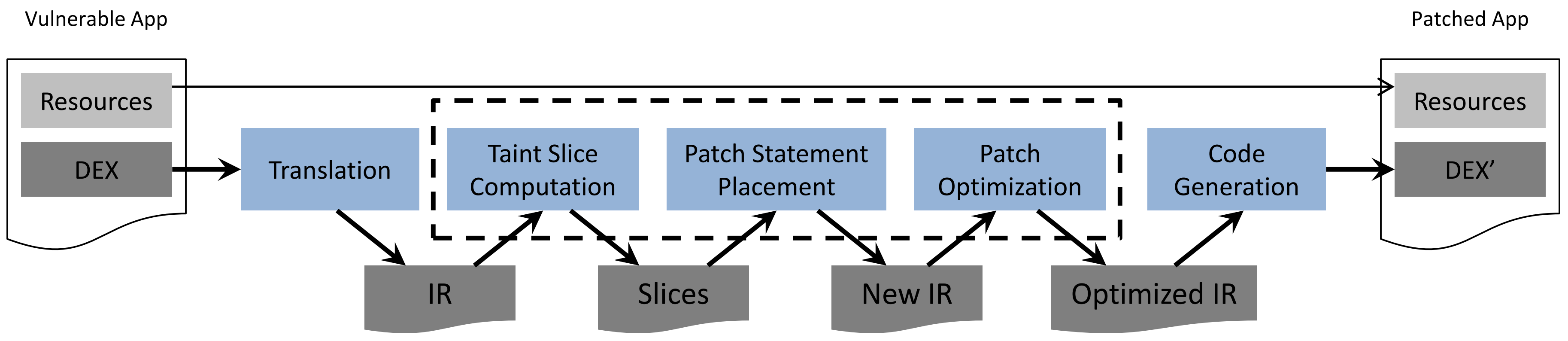


Related Work: Automatic Patch Generation

- **Data Patch**
  - W. Cui et al. ShieldGen, *Oakland'07*
  - D. Brumley et al. *Oakland'06*
  - M. Costa et al. Vigilante, *SOSP'05*
  - M. Costa et al. Bouncer, *SOSP'07*
  - J. Caballero et al. *RAID'09*
- **Code Patch**
  - Z. Lin et al. AutoPaG, *ASIACCS'07*
  - C. Zhang et al. IntPatch, *ESORICS'10*
  - Sidiroglou and Keromytis, *IEEE Security and Privacy*
  - J. Newsome et al. VSEF, *NDSS'06*

Technical Approach

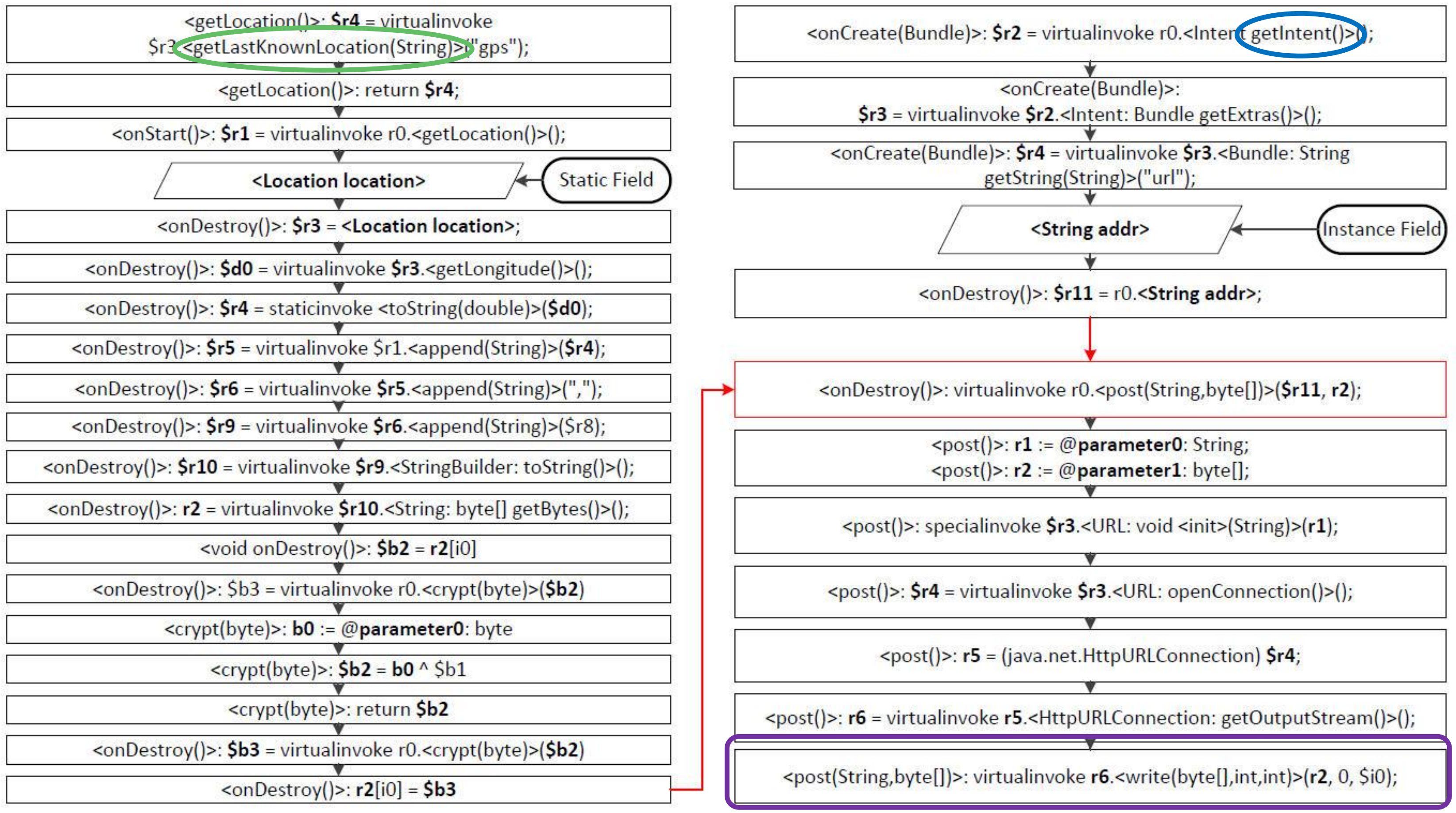
- Key: to place ***minimally*** required code into the vulnerable program to ***accurately*** keep track of dangerous information.



A Running Example

```java
public class VulActivity extends Activity{
  private String DEFAULT_ADDR = "http://default.url";
  private byte DEFAULT_KEY = 127;

  private String addr;
  private static Location location;
  private byte key;

  /* Entry point of this Activity */
  public void onCreate(Bundle savedInstanceState){
    this.key = DEFAULT_KEY;

    this.addr = getIntent().getExtras().getString("url");
    if(this.addr == null){
      this.addr = DEFAULT_ADDR;
    }
  }

  public void onStart(){
    VulActivity.location = getLocation();
  }

  public void onDestroy(){
     String location =
       Double.toString(location.getLongitude())
      + "," + Double.toString(location.getLatitude());
    byte[] bytes = location.getBytes();
    for(int i=0; i<bytes.length; i++)
      bytes[i] = crypt(bytes[i]);
    String url = this.addr;
    post(url, bytes);
  }


  public byte crypt(byte plain){
    return (byte)(plain ^ key);
  }

  public Location getLocation(){
    Location location = null;
    LocationManager locationManager = (LocationManager)
      getSystemService(Context.LOCATION_SERVICE);
    location = locationManager.getLastKnownLocation
      (LocationManager.GPS_PROVIDER);
    return location;
  }

  public void post(String addr, byte[] bytes){
    URL url = new URL(addr);
    HttpURLConnection conn =
      (HttpURLConnection)url.openConnection();
    ...
    OutputStream output = conn.getOutputStream();
    output.write(bytes, 0, bytes.length);
    ...
  }
}
```

Taint Slice Computation



```
<getLocation()>: $r4 = virtualinvoke $r3.<getLastKnownLocation(String)>("gps");
<getLocation()>: return $r4;
<onStart()>: $r1 = virtualinvoke r0.<getLocation()>();
<Location location>
<onDestroy()>: $r3 = <Location location>;
<onDestroy()>: $d0 = virtualinvoke $r3.<getLongitude()>();
<onDestroy()>: $r4 = staticinvoke <toString(double)>($d0);
<onDestroy()>: $r5 = virtualinvoke $r1.<append(String)>($r4);
<onDestroy()>: $r6 = virtualinvoke $r5.<append(String)>(",");
<onDestroy()>: $r9 = virtualinvoke $r6.<append(String)>($r8);
<onDestroy()>: $r10 = virtualinvoke $r9.<StringBuilder: toString()>();
<onDestroy()>: r2 = virtualinvoke $r10.<String: byte[] getBytes()>();
<void onDestroy()>: $b2 = r2[i0]
<onDestroy()>: $b3 = virtualinvoke r0.<crypt(byte)>($b2)
<crypt(byte)>: b0 := @parameter0: byte
<crypt(byte)>: $b2 = b0 ^ $b1
<crypt(byte)>: return $b2
<onDestroy()>: $b3 = virtualinvoke r0.<crypt(byte)>($b2)
<onDestroy()>: r2[i0] = $b3
```

```
<onCreate(Bundle)>: $r2 = virtualinvoke r0.<Intent getIntent()>();
<onCreate(Bundle)>:
$r3 = virtualinvoke $r2.<Intent: Bundle getExtras()>();
<onCreate(Bundle)>: $r4 = virtualinvoke $r3.<Bundle: String
getString(String)>("url");
<String addr>
<onDestroy()>: $r11 = r0.<String addr>;
<onDestroy()>: virtualinvoke r0.<post(String,byte[])>($r11, r2);
<post()>: r1 := @parameter0: String;
<post()>: r2 := @parameter1: byte[];
<post()>: specialinvoke $r3.<URL: void <init>(String)>(r1);
<post()>: $r4 = virtualinvoke $r3.<URL: openConnection()>();
<post()>: r5 = (java.net.HttpURLConnection) $r4;
<post()>: r6 = virtualinvoke r5.<HttpURLConnection: getOutputStream()>();
<post(String,byte[])>: virtualinvoke r6.<write(byte[],int,int)>(r2, 0, $i0);
```

Patch Statement Placement

```
1   public class VulActivity extends Activity{
      ...
5     private String addr;
P     public boolean addr_s0_t;
6     private static Location location;
P     public static boolean location_s1_t;
      ...
10    public void onCreate(Bundle savedInstanceState){
        ...
13      this.addr=getIntent().getExtras().getString("url");
P       if(isExternalIntent()){
P         this.addr_s0_t = true;
P       }else{
P         this.addr_s0_t = false;
P       }
14      if(this.addr == null){
15        this.addr = DEFAULT_ADDR;
P         this.addr_s0_t = false;
16      }
17    }
18
19    public void onStart(){
20      VulActivity.location = getLocation();
P       VulActivity.location_s1_t = true;
21    }
22
```

```
23    public void onDestroy(){
        ...
29      String url = this.addr;
P       BoolWrapper bytes_s1_w = new BoolWrapper();
P       bytes_s1_w.b = VulActivity.location_s1_t;
P       BoolWrapper url_s0_w = new BoolWrapper();
P       url_s0_w.b = this.addr_s0_t;
30      post(url, bytes, url_s0_w, bytes_s1_w);
31    }
      ...
44    public void post(String addr, byte[] bytes,
        BoolWrapper addr_s0_w, BoolWrapper bytes_s1_w){
P       boolean output_s0_t = addr_s0_w.b;
P       boolean bytes_s1_t = bytes_s1_w.b;
        ...
48      OutputStream output = conn.getOutputStream();
P       if(output_s0_t == true && bytes_s1_t == true)
P         promptForUserDecision();
49      output.write(bytes, 0, bytes.length);
50      ...
51    }
52  }
```

Patch Optimization

```
public byte crypt(byte, BoolWrapper, BoolWrapper, BoolWrapper) {
    r0 := @this: VulActivity;
    b0 := @parameter0: byte;

    w_p0 := @parameter1: BoolWrapper;
    w_t := @parameter2: BoolWrapper;
    w_r := @parameter3: BoolWrapper;

    r0_t = w_t.<BoolWrapper: boolean b>;
    b0_t = w_p0.<BoolWrapper: boolean b>;
    $b2_t = w_r.<BoolWrapper: boolean b>;

    $b1 = r0.<VulActivity: byte key>;
    $b2 = b0 ^ $b1;
    $b2_t = b0_t | 0;

    w_t.<BoolWrapper: boolean b> = r0_t;
    w_p0.<BoolWrapper: boolean b> = b0_t;
    w_r.<BoolWrapper: boolean b> = $b2_t;

    return $b2;
}
```

O1: Removing Redundant BoolWrapper Statements
O2: Removing Redundant Function Parameters

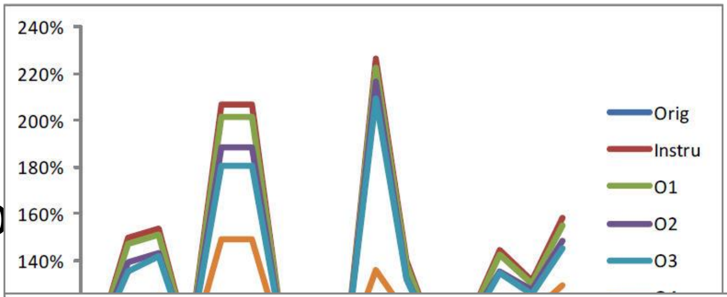
Patch Optimization

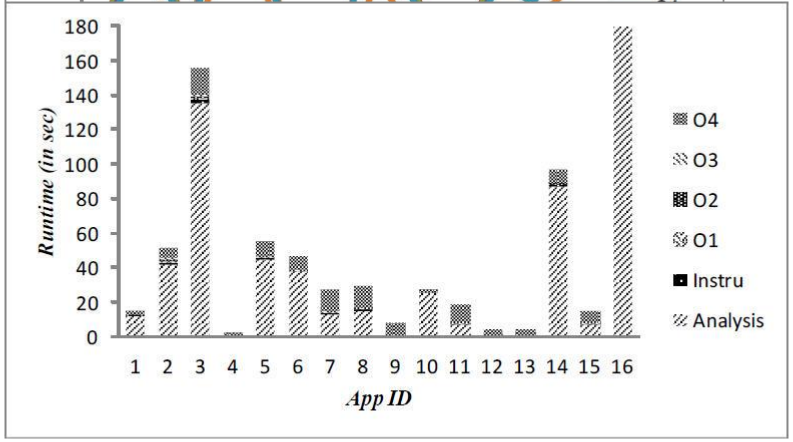
```
public byte crypt(byte, BoolWrapper, BoolWrapper) {
    r0 := @this: VulActivity;
    b0 := @parameter0: byte;
    w_p0 := @parameter1: BoolWrapper;
    w_r := @parameter2: BoolWrapper;
    $b3 = virtualinvoke r0.<VulActivity: byte crypt(byte)>($b2);
    b0_t = w_p0.<BoolWrapper: boolean b>;
    tmp21 = $b2;
    $b1 = r0.<VulActivity: byte key>;
    $b2 = b0 ^ $b1;
    $b2_t = b0_t | 0;
    $b3 = tmp21 | 0;
    tmp23 = tmp21 | 0;
    w_r.<BoolWrapper: boolean b> = $b2_t;
    $b3 = tmp23;
    return $b2;
}
```

O3: Inlining Instrumentation Code
O4: Soot Built-in Optimizations

Evaluation: Overview

- **16 real-world apps with component hijacking vulnerabilities**
  - Increase of Program Size
  - Performance of Patch Generatio
  - Runtime Overhead
    - Average: 2%
    - Worst Case: 9.6%
  - Effectiveness
    - Benign Context: No Interruption
    - Under Attack: Warning





Evaluation: Case Study

- **6** apps with **Pop-up Dialogs**
- **3** apps with **Selection Views**
- **3** apps with Multiple **Threads**

Related Work

[1] W. Cui, M. Peinado, and H. J. Wang, "ShieldGen: Automatic Data Patch Generation for Unknown Vulnerabilities with Informed Probing," in Proceedings of Oakland'07.

[2] D. Brumley, J. Newsome, D. Song, H. Wang, and S. Jha, "Towards Automatic Generation of Vulnerability-Based Signatures," in Proceedings of Oakland'06.

[3] M. Costa, J. Crowcroft, M. Castro, A. Rowstron, L. Zhou, L. Zhang, and P. Barham, "Vigilante: End-to-End Containment of Internet Worms," in Proceedings of SOSP'05.

[4] M. Costa, M. Castro, L. Zhou, L. Zhang, and M. Peinado, "Bouncer: Securing Software by Blocking Bad Input," in Proceedings of SOSP'07.

[5] J. Caballero, Z. Liang, Poosankam, and D. Song, "Towards Generating High Coverage Vulnerability-Based Signatures with Protocol-Level Constraint-Guided Exploration," in Proceedings of RAID'09.

[6] Z. Lin, X. Jiang, D. Xu, B. Mao, and L. Xie, "AutoPaG: Towards automated Software Patch Generation with Source Code Root Cause Identification and Repair," in Proceedings of ASIACCS'07.

[7] C. Zhang, T. Wang, T. Wei, Y. Chen, and W. Zou, "IntPatch: Automatically Fix Integer-Overflow-to-Buffer-Overflow Vulnerability at Compile-Time," in Proceedings of ESORICS'10.

[8] S. Sidiroglou and A. D. Keromytis, "Countering Network Worms Through Automatic Patch Generation," IEEE Security and Privacy, vol. 3, no. 6, pp. 41–49, Nov. 2005.

[9] J. Newsome, D. Brumley, and D. Song, "Vulnerability-specific execution filtering for exploit prevention on commodity software," in Proceedings of NDSS'06.

Conclusion

- We developed a technique to ***automatically*** generate patch for Android applications with **component hijacking vulnerability**.
- The key is to place ***minimally*** required code into the vulnerable program to ***accurately*** keep track of dangerous information and effectively block the attack at the security sensitive APIs.

Questions?

Discussion

- **Soundness of Patch Generation**
  - Static analysis: standard, FP
  - Taint tracking: taint policy of TaintDroid, FP
  - Optimization: compiler algorithms
  - In theory, FP; In practice, no FP observed.