Hidden GEMs: Automated Discovery of Access Control Vulnerabilities in Graphical User Interfaces

35th IEEE Symposium on Security and Privacy

Collin Mulliner, William Robertson, Engin Kirda

{crm,wkr,ek}@ccs.neu.edu
Graphical User Interfaces (GUIs)

- De facto standard to interact with most computing devices
  - Desktop, smart phone, computer-based appliances, ...
GUls → Widgets and Windows

- Widget → base UI element
  - Smallest element in a UI framework
  - On MS Windows: widget = window

- Common widgets
  - Window
  - Frame
  - Button
  - Check-box
  - Text edit field
  - Drop down box
  - Slider
Widget Attributes

- Attributes allow to change widget behavior at runtime
  - Allows user interface to be dynamic

- Common attributes

  Enabled → enable / disable widget

  Visibility → show / hide widget

  Read/Write → allow / disallow changing data stored in widget
Widget Attributes

- Attributes allow to change widget behavior at runtime
  - Allows user interface to be dynamic

- Common attributes
  - Enabled
  - Visibility
  - Read/Write

Login button disabled → indicates username required
Access Control

- Basic security requirement
- Common in any kind of enterprise application
- Especially applications that handle sensitive data
- Different privilege levels
  - Create / Add data
  - View data
  - Modify data
  - Execute privileged functionality
Access Control

- Basic security requirement
- Common in any kind of enterprise application
- Especially applications that handle sensitive data

- Different privilege levels
  - Create / Add data
  - View data
  - Modify data
  - Execute privileged functionality

- Implementing access control using the GUI is tempting
Access Control in the GUI

[Image of a GUI window with a disabled button labeled "User: text1" and an application-specific user highlighted]

- **Disabled Button**
- **Application Specific User**
Access Control in the GUI

Button used for access control

Disabled Button

Application Specific User
Access Control in the GUI

- Widgets can be manipulated
  - Feature of UI frameworks
  - No need to modify application binary

- Manipulate widget → bypass GUI-based access control
A Real World Attack

- (demo)
Access Control in the GUI

- Widgets can be manipulated
  - Feature of UI frameworks
  - No need to modify application binary

- Manipulate widget → bypass GUI-based access control

- Attacks using the UI are folklore

- We are first to systemantically investigate GUI security
Contributions

- We introduce **GUI Element Misuse (GEMs)**
  - Novel class of security vulnerabilities
  - Misuse of GUI elements for access control

- We define three classes of GEMs
  - Information Disclosure and Modification, Callback Execution

- Developed GEM Miner to automatically find GEMs
  - Find and verify GEMs in black box fashion

- We evaluated GEM Miner on applications for MS Windows
  - Found a number of GEMs in commercial software
Threat Model

- Applications with internal user management
  - Multiple users or user and administrator
  - Accounts are NOT backed by the OS

- Accounts have different privileges
  - Reading vs. writing data
  - Executing privileged functionality

- Application domain
  - Enterprise applications → users with different privileges
  - Applications that manage data → require access control
GUI Element Misuse (GEM)

- Misusing GUI elements to implement access control

- GEM vulnerability → access control bypass vulnerability

- GEM classes
  - Unauthorized Callback Execution
  - Unauthorized Information Disclosure
  - Unauthorized Information Manipulation
Unauthorized Callback Execution

- Activation of UI element results in callback execution
  - Click button → execute callback → perform operation

- Assumption
  - Disabled UI element cannot be interacted with

- Attack
  - Enable UI element
  - Interact with UI element
    - Execute callback → perform operation
Unauthorized Information Disclosure

- UI element is used to store sensitive information
  - UI element is shown only to privileged user

- Assumption
  - Hidden UI element cannot be made visible

- Attack
  - Set UI element visible
    - UI element is drawn by the UI framework
      - Data stored in UI element can be accessed
    - Access data stored in UI element programmatically
Dangling Information Disclosure

- Sensitive information is not scrubbed from UI element
  - Role-switch: user → privileged user → user

- Assumption
  - Hidden UI element cannot be made visible

- Attack
  - Set UI element visible
    - UI element is drawn by the UI framework
      - Data stored in UI element can be accessed
    - Access data stored in UI element programmatically
Unauthorized Data Modification

- UI element is used to display and edit data
  - Privileged user can edit data
  - Unprivileged user can view data

- Assumptions
  - Read-Only UI element does prevent data modification
  - Data modified only if element was writable → save data

- Attack
  - Set UI element Read-Write
    - Set/Change data
    - Click “save”
Two Corner Stones of GEM Vulnerabilities

- **False assumptions by developers**
  - GUI cannot be changed externally
    - Widget attributes are protected

- **Non sophisticated attacker**
  - Only point-and-click
  - Black box attack → change value in field OR click button
    - No reverse engineering or program understanding
    - Don't need to manually temper with files or database
    - No network protocol knowledge
The GEM Miner Analysis

- Systematically test applications for GEM vulnerabilities
  - Automated analysis
  - Complex applications cannot be tested manually

- Black box analysis
  - We do NOT require: source code, reverse engineering, etc.
The GEM Miner System

- Explore application UI and record widgets and attributes
- Identify GEM candidate widgets
- Check the GEM candidates
Application Seeding

- Create application specific users
  - Users + administrator

- Create data
  - e.g., items of an inventory management system

- Configure access control (restrict privileges of one account)
UI Exploration

- Explore the application's UI
  - Interact with widgets
    - click button, set check box, select drop down, ...

- Record
  - Widgets and attributes
  - Interactions
UI Exploration – for all privilege levels

- UI Exploration is executed once for each distinct privilege level
- Result: UI State for each privilege level
- UI State
  - Windows, contained widgets, and their attributes
GEM Candidate Identification

- Compare UI States of different privilege levels
  - Widget with different attributes → GEM candidate

<table>
<thead>
<tr>
<th>Level</th>
<th>Attributes</th>
<th>UI Element</th>
<th>Label</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Visible Disabled</td>
<td>TbitBtn</td>
<td>“New Article”</td>
</tr>
<tr>
<td>High</td>
<td>Visible Enabled</td>
<td>TbitBtn</td>
<td>“New Article”</td>
</tr>
<tr>
<td>Low</td>
<td>Visible Enabled</td>
<td>TbitBtn</td>
<td>“Help”</td>
</tr>
<tr>
<td>High</td>
<td>Visible Enabled</td>
<td>TbitBtn</td>
<td>“Help”</td>
</tr>
<tr>
<td>Low</td>
<td>Visible Enabled</td>
<td>Read EDIT</td>
<td>”’”</td>
</tr>
<tr>
<td>High</td>
<td>Visible Enabled</td>
<td>Write EDIT</td>
<td>”’”</td>
</tr>
</tbody>
</table>
GEM Candidates

- **GEM Candidate**
  - Widget that likely can be used to bypass access control

- **Candidate information**
  - Widget type and ID
  - Path to candidate widget
  - “successor” (e.g. if widget creates a new window)
GEM Checking

- Execute AUT
- Drive application to GEM candidate
- Test GEM candidate
  - Manipulate and activate widget
  - Inspect result
GEM Candidate Testing

- Different strategy for each widget and GEM type
  - Callback execution: active widget → callback executed?
  - Information disclosure: can widget contain data?
  - Information modification: modified data accepted by app?

- Black box testing
  - Manipulate the UI for testing
  - Check results by only inspecting the UI

- Tests are independent from the application
  - No application specific knowledge needed
Testing Data Modification GEMs

- Drive application to window containing GEM candidate
Testing Data Modification GEMs

- Set text edit field writable
- Change/Set test value
- Close window
Testing Data Modification GEMs

- Drive application to window containing GEM candidate
- Check if test value present
Testing Data Modification GEMs

- Drive application to window containing GEM candidate
- Check if test value present

GEM Candidate confirmed!
Result → GEMs no longer hidden!

GEM Analysis

AUT → UI Exploration → GEM Candidate Identification → GEM Checker → GEMs

Test Engineer

Widget + Type
Window
Path to Widget

Mulliner, Robertson, Kirda
"Hidden GEMs"
Evaluation

<table>
<thead>
<tr>
<th>Application</th>
<th>GEM Candidates</th>
<th>Automatically Confirmed</th>
<th>Manually Confirmed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Disclosure</td>
<td>Modification</td>
<td>Callbacks</td>
</tr>
<tr>
<td>App1</td>
<td>44</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>App2</td>
<td>1</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Proffix</td>
<td>-</td>
<td>23</td>
<td>10</td>
</tr>
<tr>
<td>Total</td>
<td>45</td>
<td>24</td>
<td>20</td>
</tr>
</tbody>
</table>

- **App1**: inventory management
  - Multiple users + admin mode

- **App2**: employee and project management
  - Multiple users + admin

- **Proffix**: customer relationship management
  - Multiple users + admin, fine-grained access control
Results – Callback GEMs

<table>
<thead>
<tr>
<th>Application</th>
<th>Disclosures</th>
<th>Modifications</th>
<th>Callbacks</th>
<th>Disclosures</th>
<th>Modifications</th>
<th>Callbacks</th>
<th>Runtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>App1</td>
<td>2</td>
<td></td>
<td>2</td>
<td>44</td>
<td></td>
<td>2</td>
<td>51 sec</td>
</tr>
<tr>
<td>App2</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td></td>
<td></td>
<td>4</td>
<td>205 sec</td>
</tr>
<tr>
<td>Proftix</td>
<td>-</td>
<td>23</td>
<td>10</td>
<td></td>
<td>17</td>
<td>7</td>
<td>666 sec</td>
</tr>
<tr>
<td>Total</td>
<td>45</td>
<td>24</td>
<td>20</td>
<td>44</td>
<td>17</td>
<td>13</td>
<td></td>
</tr>
</tbody>
</table>

- **App2**: disables button to deny export DB functionality
  - Enable button → execute export DB

- **Unconfirmed candidates**
  - Actual access control
### Results – Information Disclosure GEMs

<table>
<thead>
<tr>
<th>Application</th>
<th>GEM Candidates</th>
<th>Automatically Confirmed</th>
<th>Manually Confirmed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Disclosure</td>
<td>Modification</td>
<td>Callbacks</td>
</tr>
<tr>
<td>App1</td>
<td>44</td>
<td>-</td>
<td>2</td>
</tr>
<tr>
<td>App2</td>
<td>1</td>
<td>1</td>
<td>8</td>
</tr>
<tr>
<td>Profix</td>
<td>-</td>
<td>23</td>
<td>10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>45</td>
<td>24</td>
<td>20</td>
</tr>
</tbody>
</table>

- **App1**: creates a large number of top-level windows on startup
  - Including the user management window

- **App1**: dangling disclosure
  - Switch: user → admin → user
  - admin password in hidden window
# Results – Information Modification GEMs

<table>
<thead>
<tr>
<th>Application</th>
<th>Disclosure</th>
<th>Modification</th>
<th>Callbacks</th>
<th>Disclosure</th>
<th>Modification</th>
<th>Callbacks</th>
<th>Modification</th>
<th>Callbacks</th>
<th>Runtime</th>
</tr>
</thead>
<tbody>
<tr>
<td>App1</td>
<td>44</td>
<td>-</td>
<td>2</td>
<td>44</td>
<td>-</td>
<td>2</td>
<td>-</td>
<td>-</td>
<td>51 sec</td>
</tr>
<tr>
<td>App2</td>
<td>1</td>
<td>1</td>
<td>8</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>4</td>
<td>205 sec</td>
</tr>
<tr>
<td>Proffix</td>
<td>-</td>
<td>23</td>
<td>10</td>
<td>-</td>
<td>17</td>
<td>7</td>
<td>3</td>
<td>1</td>
<td>666 sec</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>45</td>
<td>24</td>
<td>20</td>
<td>44</td>
<td>17</td>
<td>13</td>
<td>3</td>
<td>3</td>
<td></td>
</tr>
</tbody>
</table>

- **Proffix**: R/W access control for database via text field attribute
  - Red boxes → Read-Only text fields
- **Unconfirmed candidates**
  - Field cannot be changed
  - Field relies on other value
Summary

- **GEM Vulnerabilities**
  - Exist in commercial software
  - Can be exploited by non sophisticated attackers

- **GEM Miner Analysis**
  - Systematic method to find GEM vulnerabilities
  - Independent of UI framework and application

- **The GEM Miner System**
  - Can automatically find and verify GEM bugs
  - Implemented for Windows but can be ported to other OSes
Conclusions

- We introduced GUI Element Misuse (GEMs)
  - New class of security vulnerabilities
  - Misuse of the UI to implement access control

- We defined three classes of GEMs
  - Information Disclosure and Modification, Callback Execution

- We build GEM Miner to analyze Windows applications for GEMs
  - We discovered a number of previously-unknown bugs

- First step towards including the UI in security testing
  - We specifically address access control vulnerabilities
Thank you!

Questions?