Finding and Exploiting Access Control Vulnerabilities in Graphical User Interfaces

Collin Mulliner
crm[at]ccs.neu.edu

Black Hat USA, Las Vegas, August 2014

About

- Researcher at Northeastern University (Boston, MA)
  - Systems Security
  - Offense and Defense
  - Mobile

- This talk is based on the paper:

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

  Collin Mulliner, William Robertson, Engin Kirda

  35th IEEE Symposium Security and Privacy

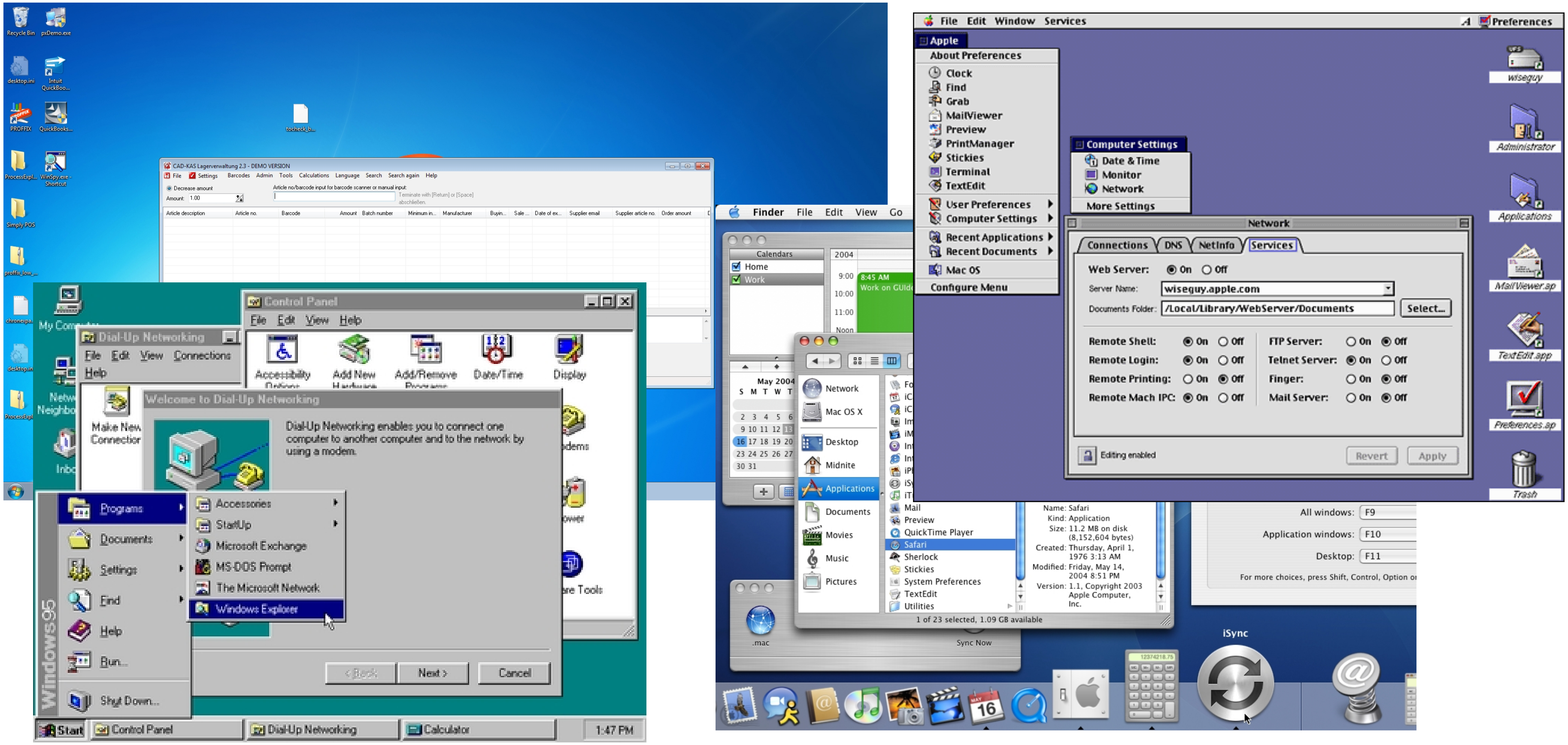
  San Jose, CA, May 2014

- Materials for this talk will be available at:

  http://mulliner.org/security/guisec

Graphical User Interfaces (GUIs)

- De facto standard to interact with most computing devices
  - Desktop, smart phone, computer-based appliances, …



Welcome to Dial-Up Networking

Dial-Up Networking enables you to connect one computer to another computer and to the network by using a modem.

Network

Web Server: ● On ○ Off

Server Name: wiseguy.apple.com

Documents Folder: /Local/Library/WebServer/Documents

Remote Shell: ● On ○ Off

Remote Login: ● On ○ Off

Remote Printing: ○ On ● Off

Remote Mach IPC: ● On ○ Off

FTP Server: ○ On ● Off

Telnet Server: ● On ○ Off

Finger: ○ On ● Off

Mail Server: ○ On ● Off

Editing enabled

Agenda

- GUI Security Background / History
- Basics of Graphical User Interfaces
- Access Control in the UI?!?!
- Introduction of GUI Element Misuse (GEMs)
- Automated app analysis to find GEM bugs
- Countermeasures
- Conclusions

GUI Security History (Shatter Attacks)

- Shatter Attacks
  - C. Paget (2002), B. Moore (2003)
- Affected platform: Windows NT/2000/XP
- <u>Remove limits of text edit fields</u>
  - Paste input to cause memory corruption → code execution
- Target: progress with system privileges
  - Code execution → privilege escalation
- Now Windows has User Interface Privilege Isolation (UIPI)
  - Can't manipulate UI of process that have higher privileges

GUI Security History (Shatter Attacks)

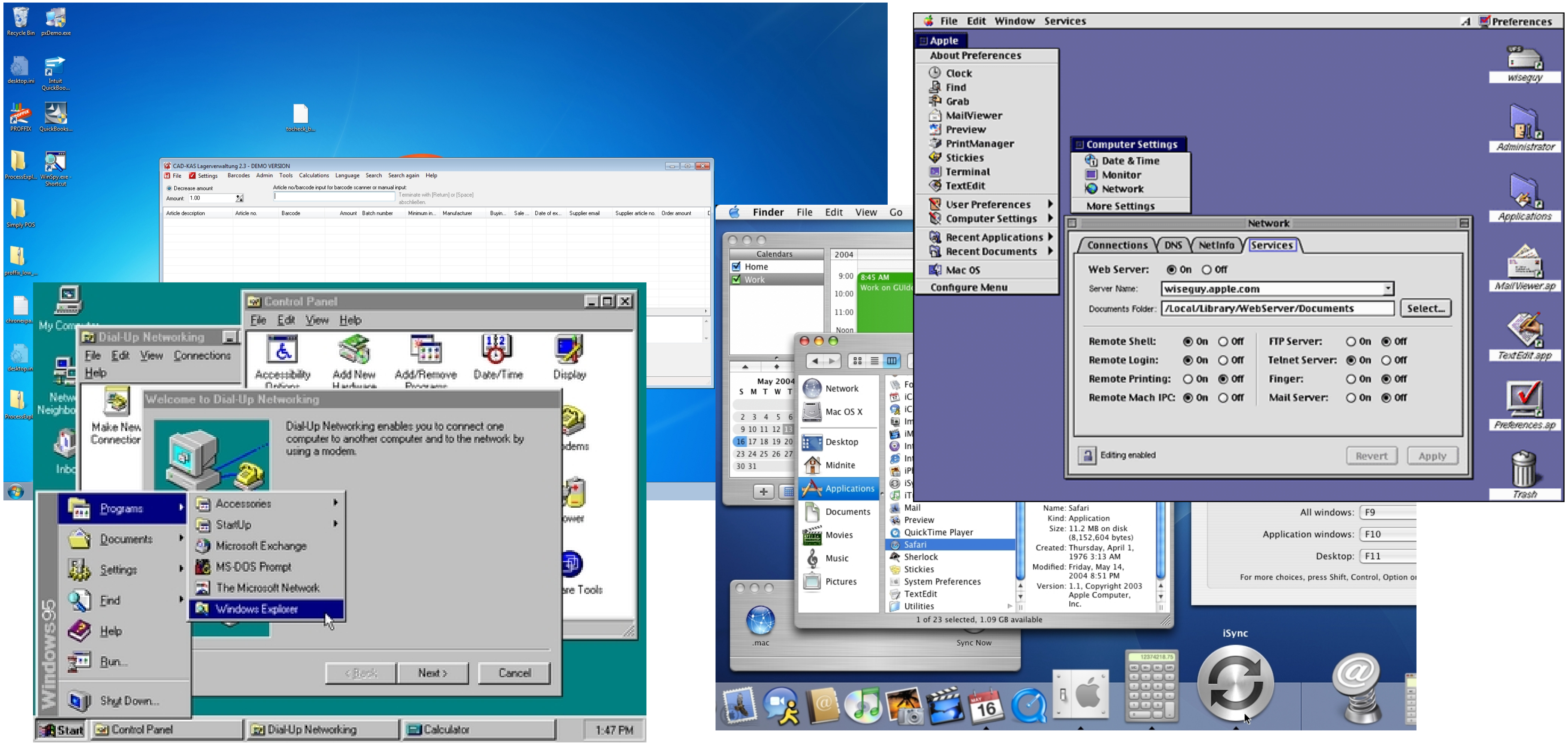
- Shatter Attacks
  - C. Paget (2002), B. Moore (2003)
- Affected platform: Windows NT/2000/XP
- Remo
  -

This talk is about Access Control issues in the UI

- Target: progress with system privileges
  - Code execution → privilege escalation
- Now Windows has User Interface Privilege Isolation (UIPI)
  - Can't manipulate UI of process that have higher privileges

Graphical User Interfaces (GUIs)

- Windows, Widgets, …



Welcome to Dial-Up Networking

Dial-Up Networking enables you to connect one computer to another computer and to the network by using a modem.

Name: Safari
Kind: Application
Size: 11.2 MB on disk (8,152,604 bytes)
Created: Thursday, April 1, 1976 3:13 AM
Modified: Friday, May 14, 2004 8:51 PM
Version: 1.1, Copyright 2003 Apple Computer, Inc.

1 of 23 selected, 1.09 GB available

All windows: F9
Application windows: F10
Desktop: F11

Network

Web Server: ● On ○ Off
Server Name: wiseguy.apple.com
Documents Folder: /Local/Library/WebServer/Documents

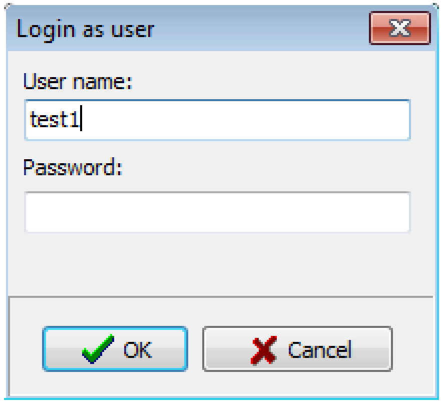
Remote Shell: ● On ○ Off
Remote Login: ● On ○ Off
Remote Printing: ○ On ● Off
Remote Mach IPC: ● On ○ Off
FTP Server: ○ On ● Off
Telnet Server: ● On ○ Off
Finger: ○ On ● Off
Mail Server: ○ On ● Off

NEU SECLAB

GUIs → 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



Login as user

User name: test1

Password:

☑ Calculate date

● Decrease amount ○ Increase amount

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

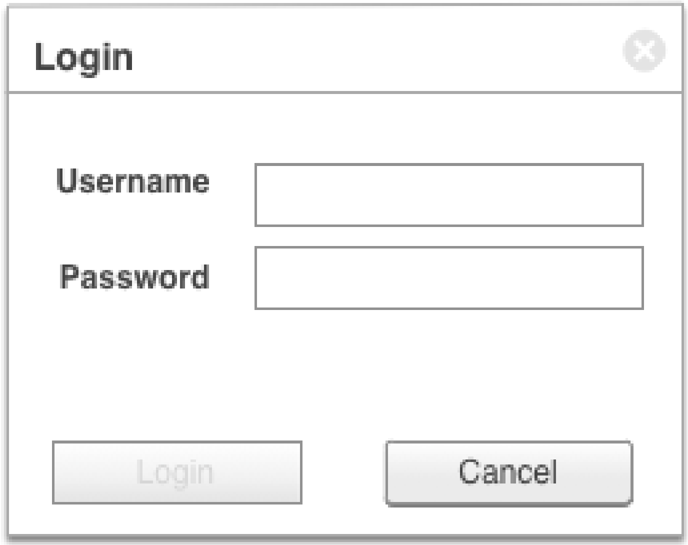
- Attributes allow to change widget behavior at runtime
  - Allows user interface to be dynamic

- Common attribut

  Enabled

  Visibility

  Read/Write



a stored in widget

Login button disabled → indicates username required

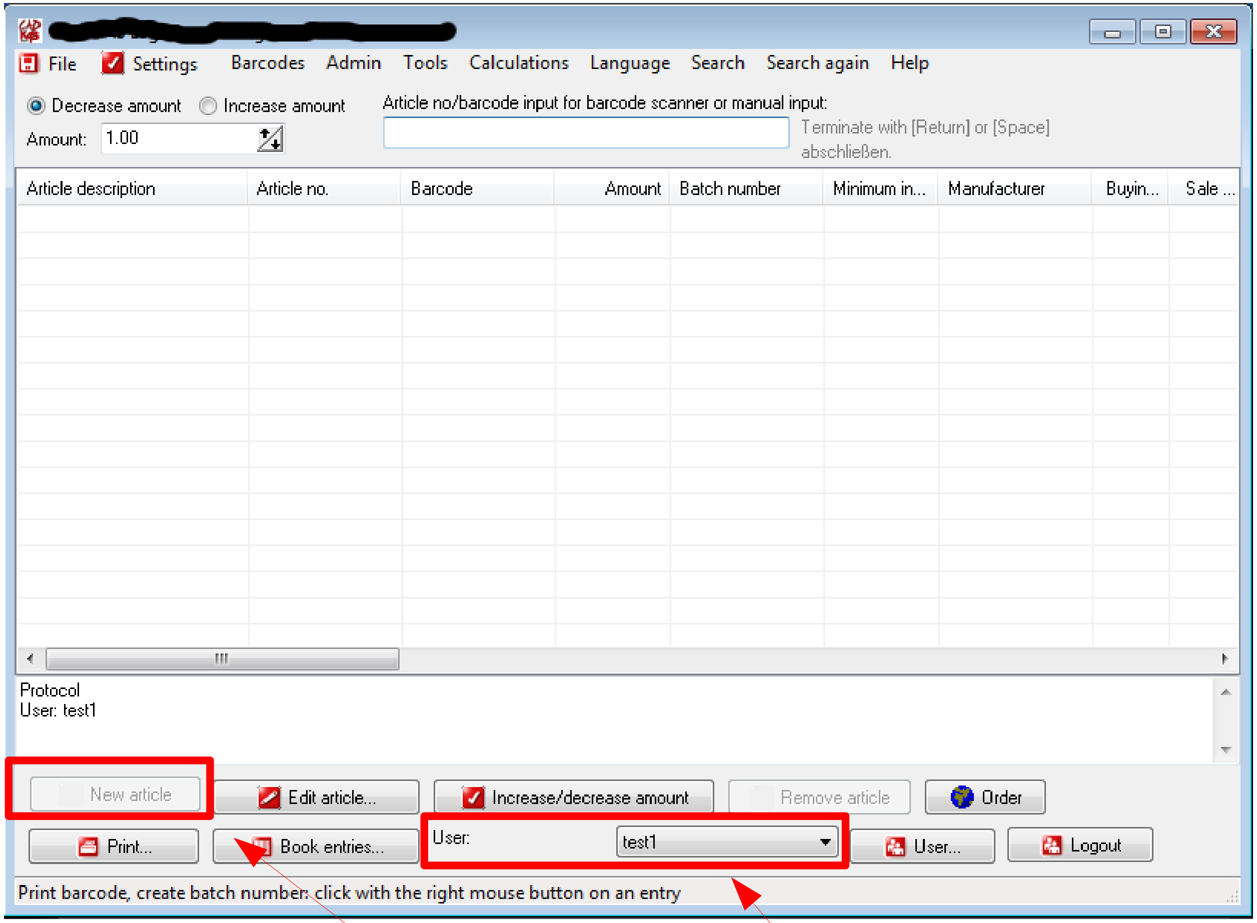
Access Control

- 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


[redacted]

● Decrease amount ○ Increase amount

Amount: 1.00

Article no/barcode input for barcode scanner or manual input:

Terminate with [Return] or [Space] abschließen.

Article description	Article no.	Barcode	Amount	Batch number	Minimum in...	Manufacturer	Buyin...	Sale ...

Protocol
User: test1

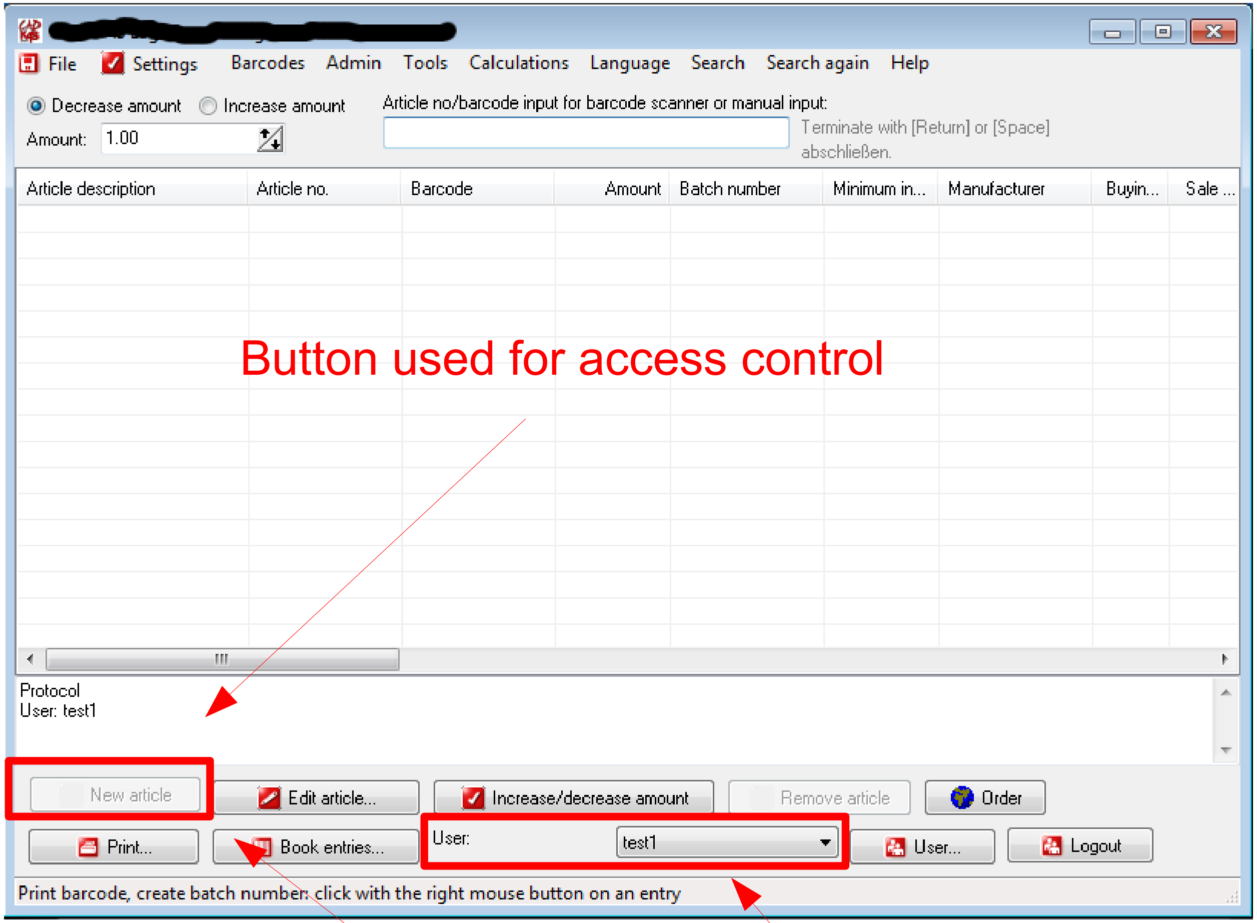
User: test1

Print barcode, create batch number: click with the right mouse button on an entry

Disabled Button

Application Specific User

Access Control in the GUI


[redacted]

● Decrease amount ○ Increase amount

Amount: 1.00

Article no/barcode input for barcode scanner or manual input:

Terminate with [Return] or [Space] abschließen.

Protocol
User: test1

User: test1

Print barcode, create batch number: click with the right mouse button on an entry

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
- **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

- Releasing some tools today!

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 Callback Execution **DEMO**

- WinSpy++
  - http://www.catch22.net/software/winspy-17
  - They provide source, thanks!

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

Unauthorized Information Disclosure **DEMO**

- gemtools_unhide.exe
  - Make all widgets of an application visible
  - Take screenshots of app windows
  - Tool is released today!

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

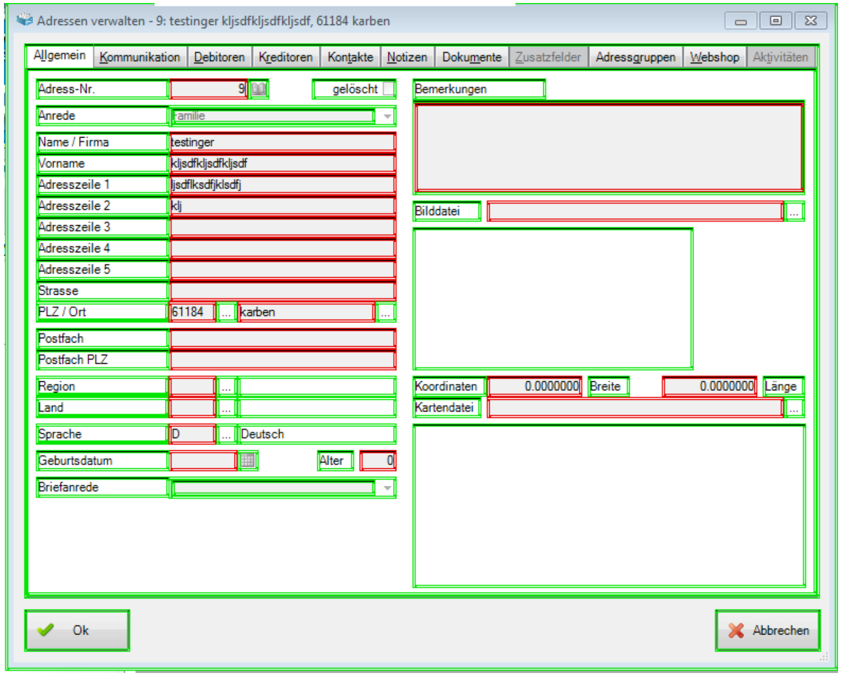
- Attack
  - Set UI element Read-Write
    - Set/Change data
      - Click “save”

Unauthorized Data Modification **DEMO**

- WinSpy++ gemcolors edition!
  - Identify R/W settings of widgets

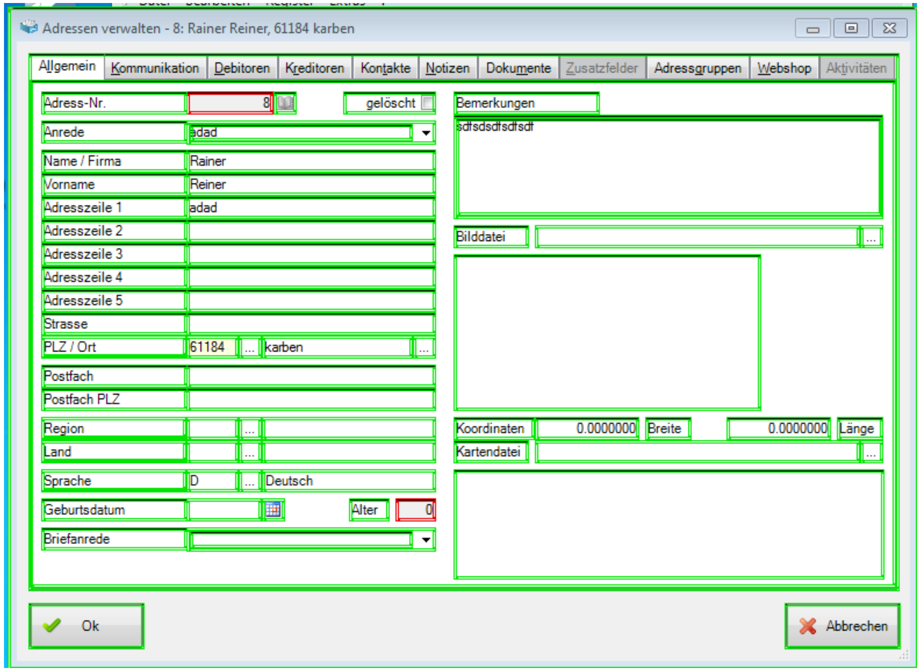
Widget Configuration

- User1 (Low Privileges) User2 (High Privileges)



Adressen verwalten - 9: testinger kljsdfkljsdfkljsdf, 61184 karben

Adress-Nr. 9
gelöscht □
Anrede Familie
Name / Firma testinger
Vorname kljsdfkljsdfkljsdf
Adresszeile 1 ljsdflksdfjklsdfj
Adresszeile 2 klj
Adresszeile 3
Adresszeile 4
Adresszeile 5
Strasse
PLZ / Ort 61184 ... karben ...
Postfach
Postfach PLZ
Region ...
Land ...
Sprache D ... Deutsch
Geburtsdatum
Alter 0
Briefanrede
Bemerkungen
Bilddatei ...
Koordinaten 0.0000000 Breite 0.0000000 Länge
Kartendatei ...



Adressen verwalten - 8: Rainer Reiner, 61184 karben

Adress-Nr. 8
gelöscht □
Anrede adad
Name / Firma Rainer
Vorname Reiner
Adresszeile 1 adad
Adresszeile 2
Adresszeile 3
Adresszeile 4
Adresszeile 5
Strasse
PLZ / Ort 61184 ... karben ...
Postfach
Postfach PLZ
Region ...
Land ...
Sprache D ... Deutsch
Geburtsdatum
Alter 0
Briefanrede
Bemerkungen sdfsdsdfsdfsdf
Bilddatei ...
Koordinaten 0.0000000 Breite 0.0000000 Länge
Kartendatei ...

Technical

- Applications must be executed by the same OS user
  - Interaction between apps via IPC

- Attack steps:
  - Discover UI elements (widgets)
  - Obtain window HANDLE for widget
  - Manipulate widget

Technical

- All this is done through very basic Win32 APIs
  - `SendMessage..() family of functions`
  - `EnableWindow()`
  - `SendInput()`
  - `EnumChildWindows() → get all windows`
  - `SetWindowPos() → visible/hide window`
  - `GetWindowLong()`
  - `IsWindowEnabled()`
  - `IsWindowVisible()`
  - `GetClassName()`

- This stuff is very well documented

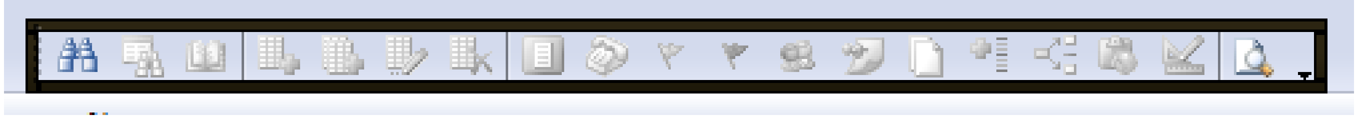
UI Frameworks

- On MS Windows a window is the basic UI element
  - Everything is a window
- Win32 API provides basic functionality
  - 'actual' window
  - Button
  - Text field
- Other UI frameworks are build on top of the Win32 UI API
  - Provide their own widget types
  - Implement drawing and receiving user input

Win32 vs. .NET

- .NET
  - Win32 windows + custom widgets
  - Implement drawing and receiving user input
  - Win32 API can see widget but not always manipulate it

- Attacker
  - Can use Win32 API to interact .NET widgets
    - Enough for most attacks
  - Using .NET API provides access to actual .NET widgets
    - e.g., see individual buttons inside a 'button bar'



.NET 'button bar' for Win32 this is one button, for .NET it is 19

Two Corner Stones of GEM Vulnerabilities

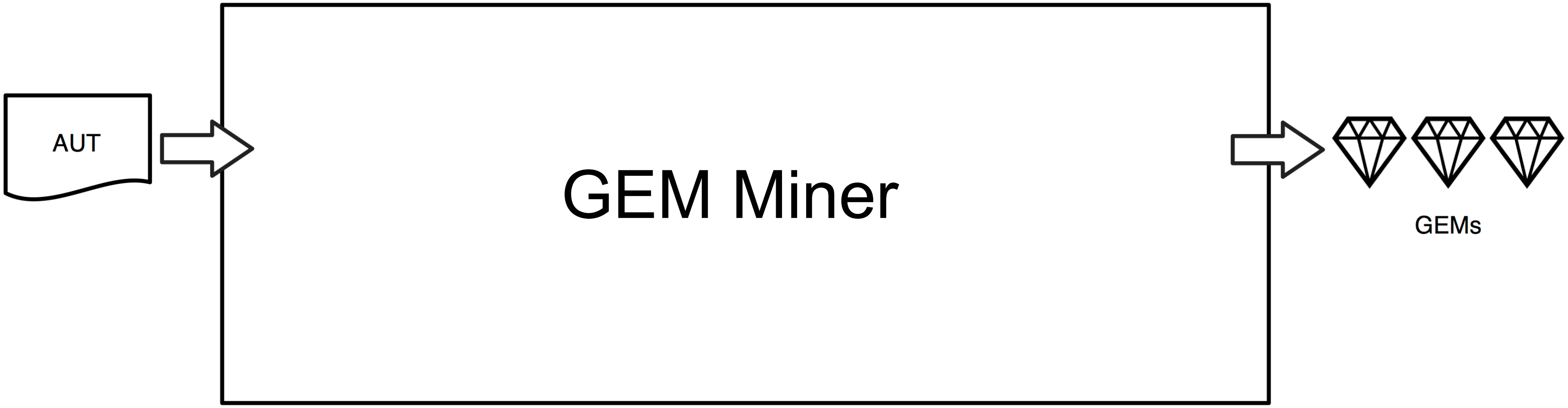
- **False assumptions by developers**
  - GUI cannot be changed externally
    - Widget attributes are protected

- **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

GEM Attacks

- Easy to carry out
    - Anybody can do it (if they know how to use a computer)
- Fast
    - Are you still trying to find the location of the binary?

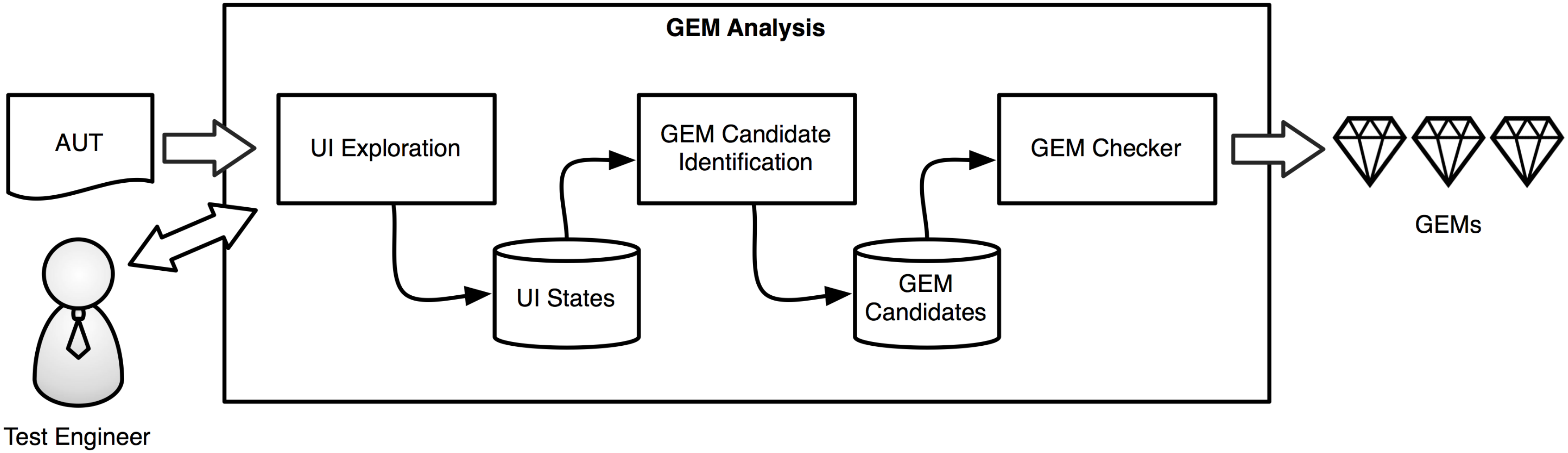
The GEM Miner Analysis



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

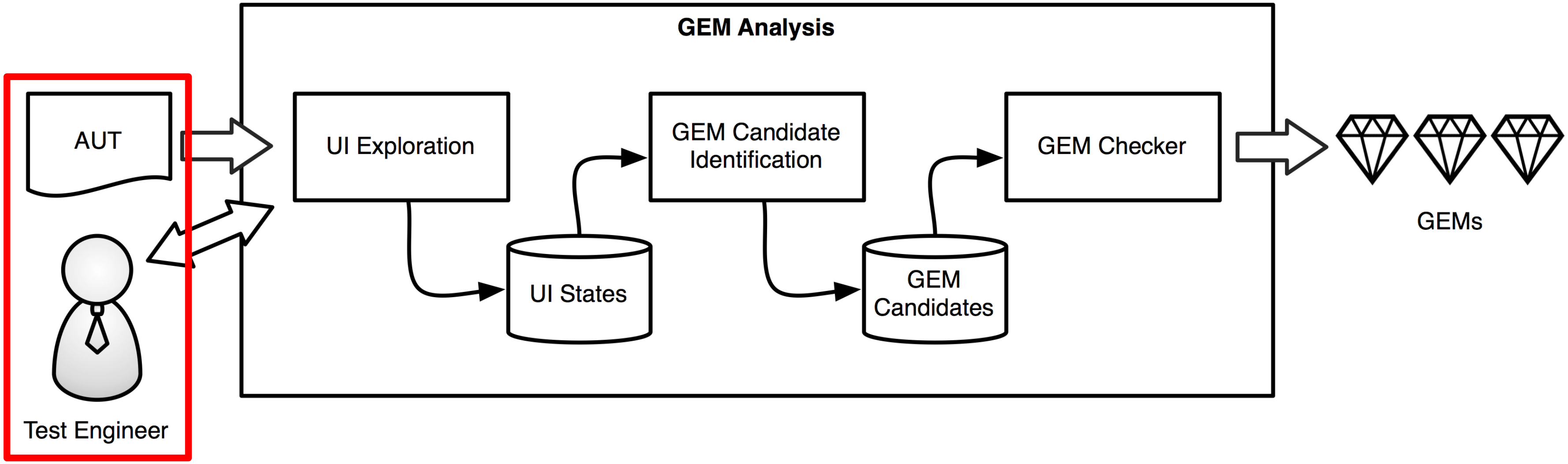
- Black box analysis
  - We do NOT require: source code, reverse engineering, etc.

The GEM Miner System



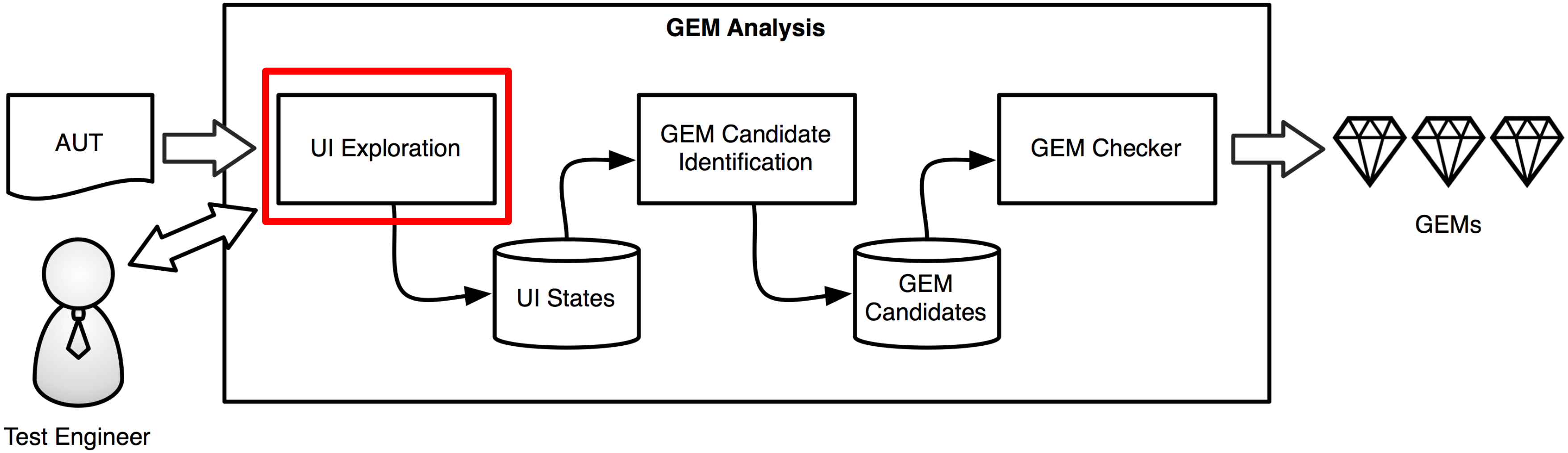
- Explore application UI and record widgets and attributes
- Identify GEM candidate widgets
- Check the GEM candidates

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)

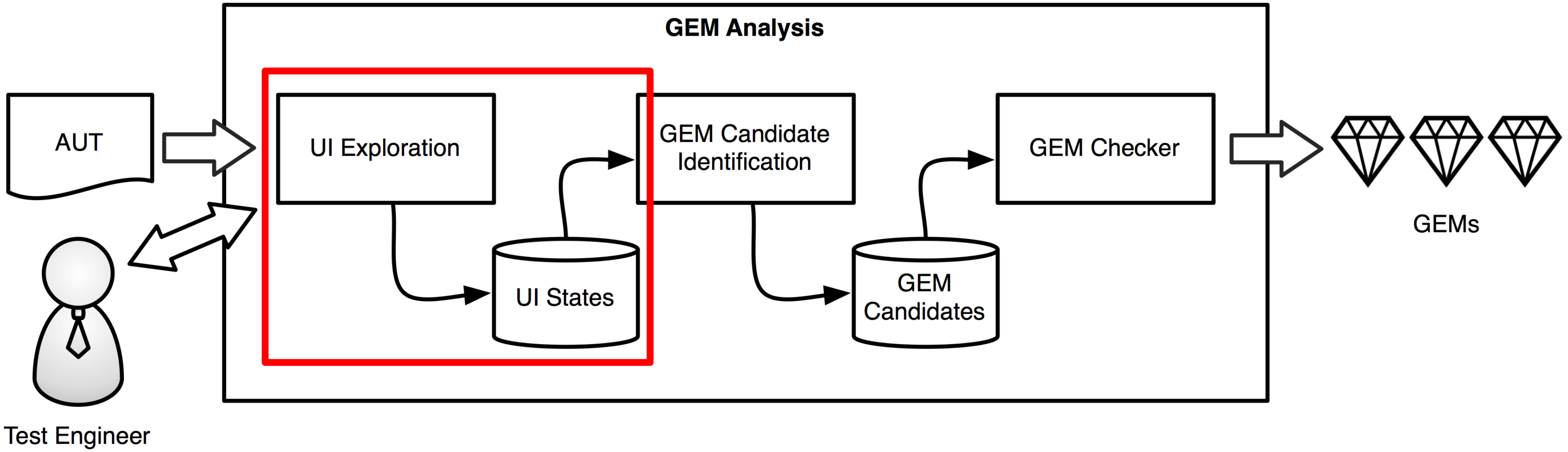
UI Exploration



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

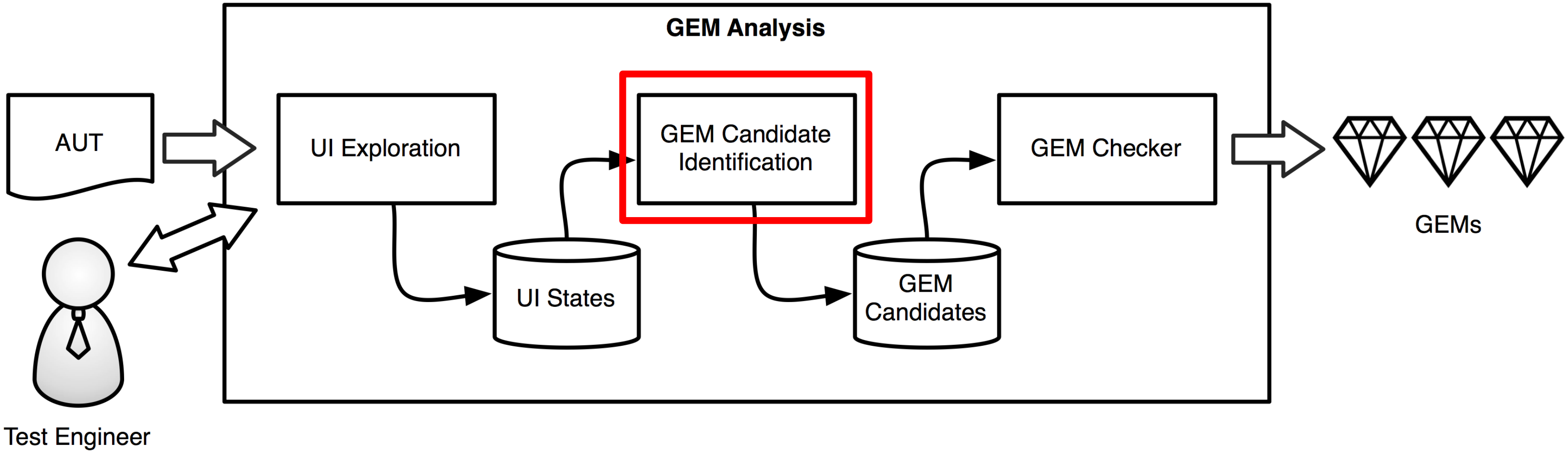
- Record
  - Widgets and attributes
  - Interactions

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

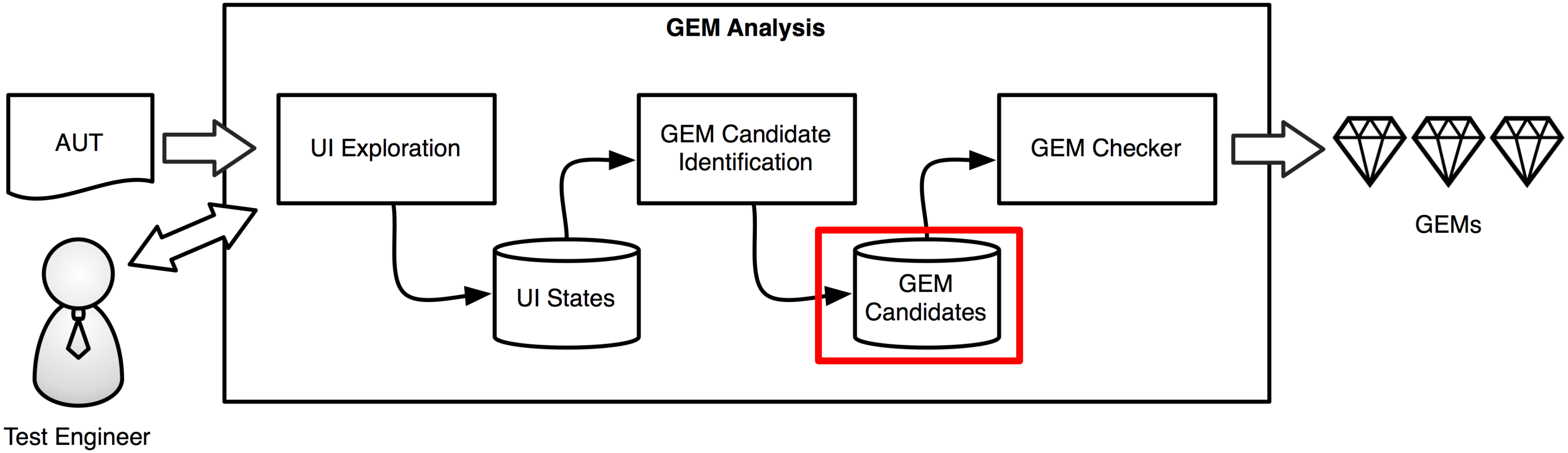
GEM Candidate Identification



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

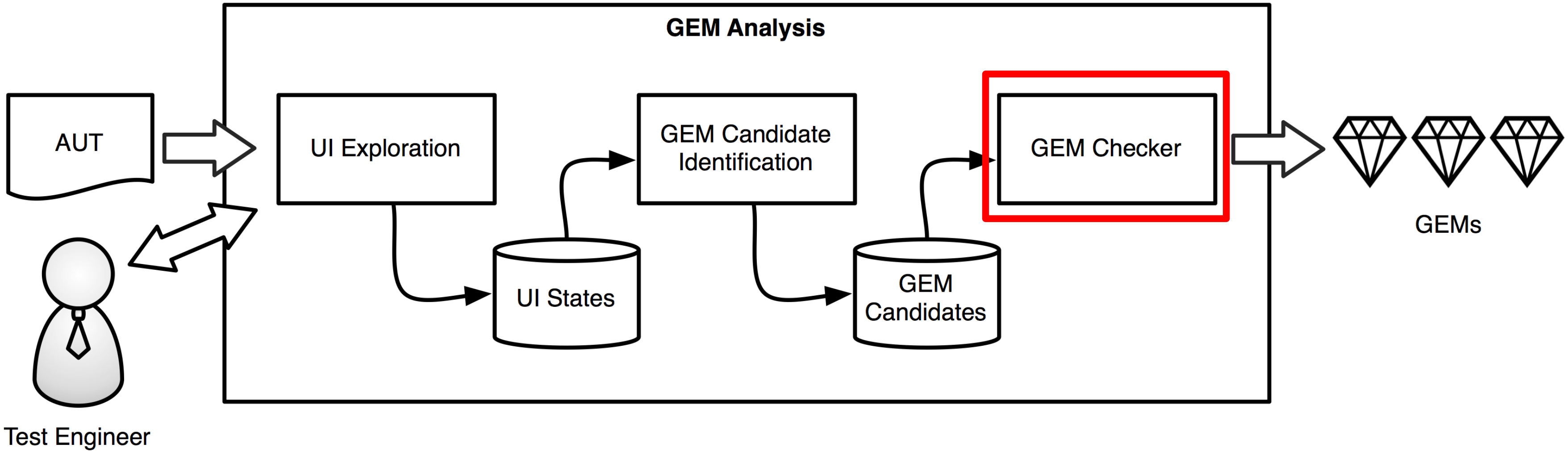
Level	Attributes	UI Element	Label
Low	Visible Disabled	TbitBtn	“New Article”
High	Visible Enabled	TbitBtn	“New Article”
Low	Visible Enabled	TbitBtn	“Help”
High	Visible Enabled	TbitBtn	“Help”
Low	Visible Enabled Read	EDIT	“”
High	Visible Enabled Write	EDIT	“”

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 Callback Widgets

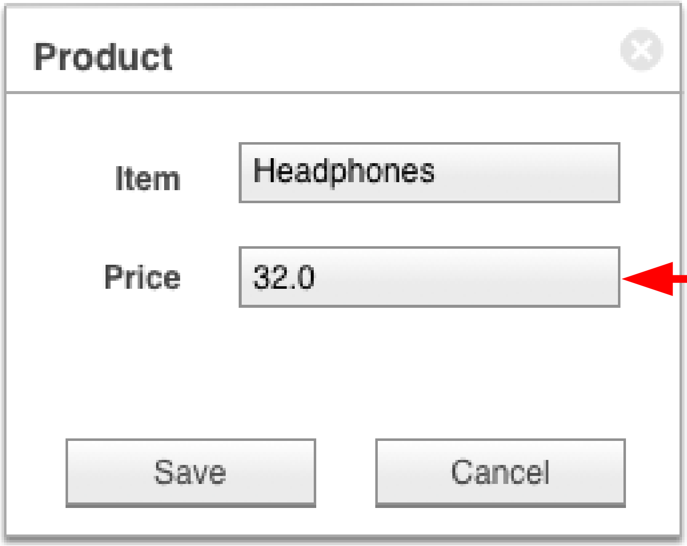
- What effect does 'activation' of widget have?
  - e.g. new window / popup?

Testing for Information Disclosure

- No actual testing required
- Conditions
  - Widget is not visible in “low privileged” mode
  - Widget can store data

Testing Data Modification GEMs 1/4

- Drive application to window containing GEM candidate



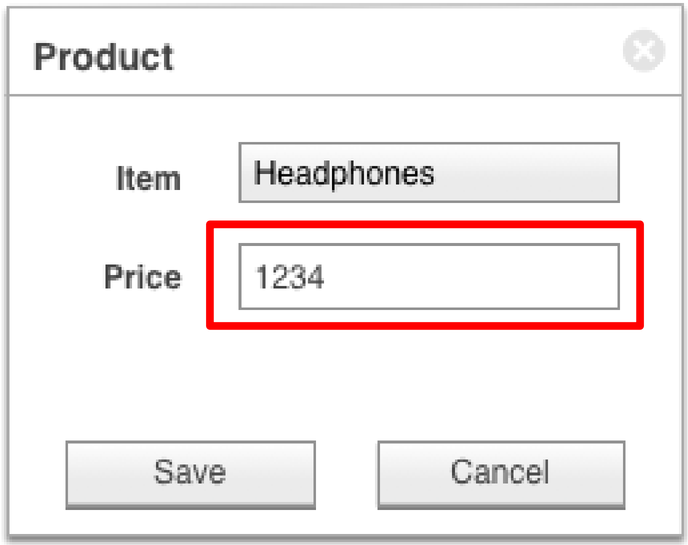
Item: Headphones

Price: 32.0

Candidate

Testing Data Modification GEMs 2/4

- Set text edit field writable
- Change/Set test value
- Close window

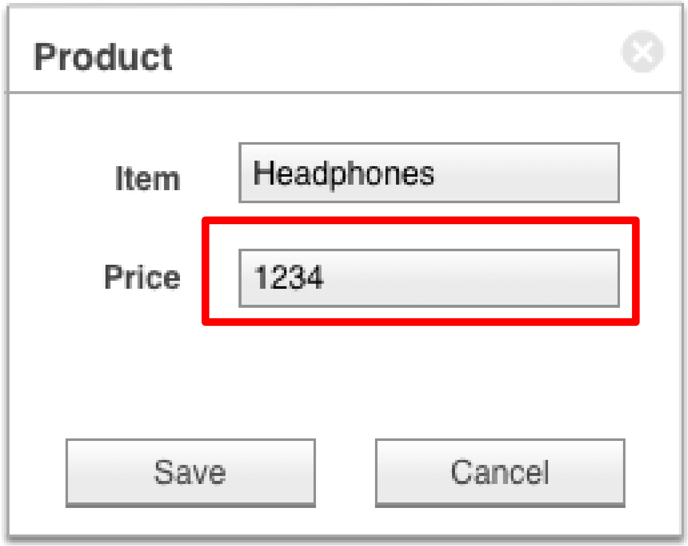


Item: Headphones

Price: 1234

Testing Data Modification GEMs 3/4

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



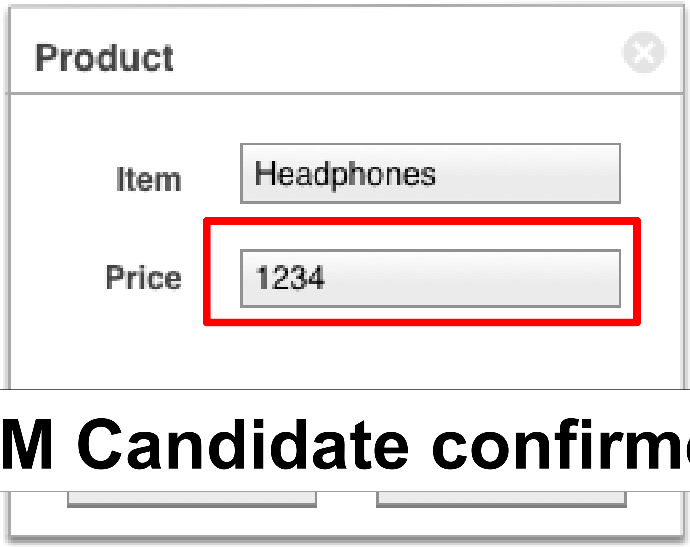
Product

Item: Headphones

Price: 1234

Testing Data Modification GEMs 4/4

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



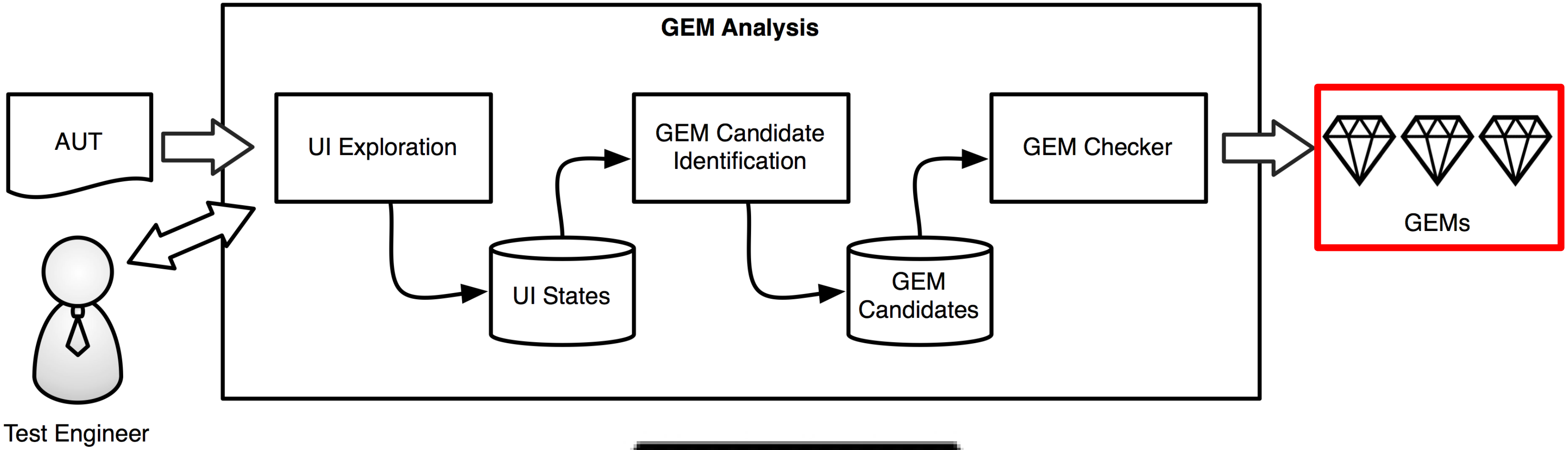
Product

Item: Headphones

Price: 1234

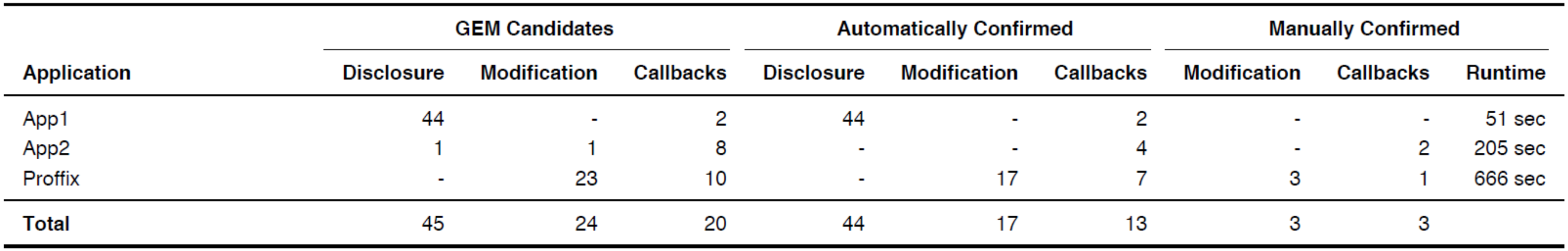
GEM Candidate confirmed!

Result → GEMs no longer hidden!



Widget + Type
Window
Path to Widget

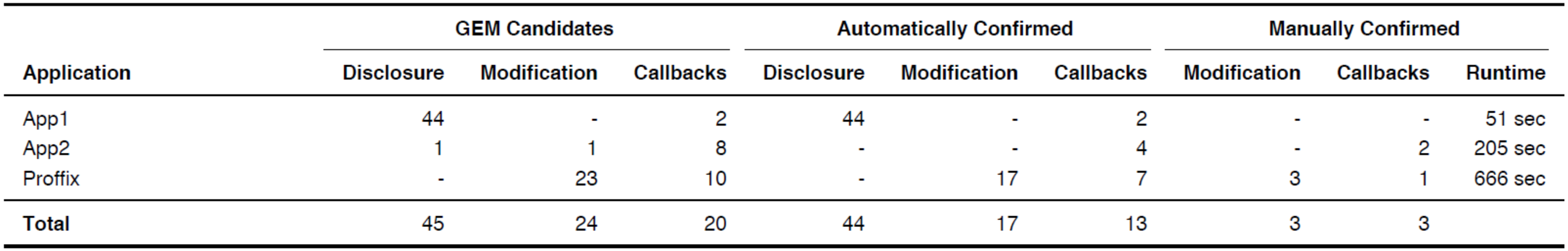
Analyzing Real World Apps (Evaluation)



	GEM Candidates			Automatically Confirmed			Manually Confirmed		
Application	Disclosure	Modification	Callbacks	Disclosure	Modification	Callbacks	Modification	Callbacks	Runtime
App1	44	-	2	44	-	2	-	-	51 sec
App2	1	1	8	-	-	4	-	2	205 sec
Proffix	-	23	10	-	17	7	3	1	666 sec
Total	45	24	20	44	17	13	3	3	

- 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

Analyzing Real World Apps (Evaluation)



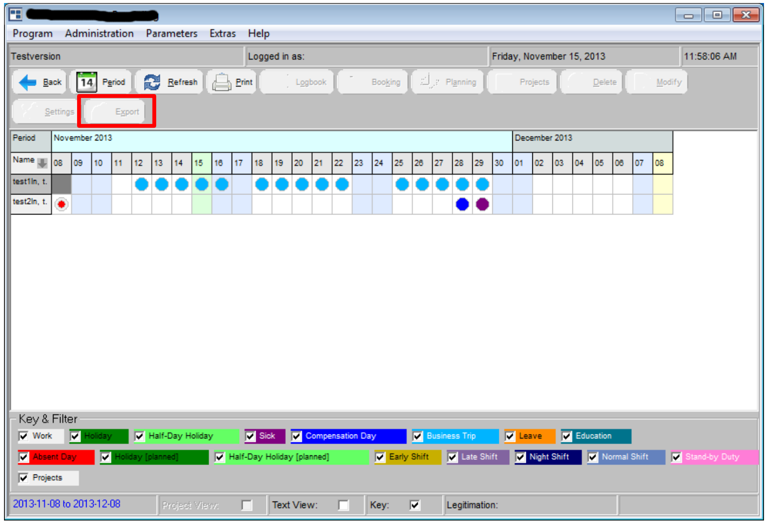
	GEM Candidates			Automatically Confirmed			Manually Confirmed		
Application	**Disclosure**	**Modification**	**Callbacks**	**Disclosure**	**Modification**	**Callbacks**	**Modification**	**Callbacks**	**Runtime**
App1	44	-	2	44	-	2	-	-	51 sec
App2	1	1	8	-	-	4	-	2	205 sec
Proffix	-	23	10	-	17	7	3	1	666 sec
Total	45	24	20	44	17	13	3	3	

- App1 : **Win32** management
  - ers + admin mode
- App2 : **Win32** and project management
  - ers + admin
- Proffix : **.NET** r relationship management
  - ers + admin, fine-grained access control

Results – Callback GEMs

	GEM Candidates			Automatically Confirmed			Manually Confirmed		
Application	**Disclosure**	**Modification**	**Callbacks**	**Disclosure**	**Modification**	**Callbacks**	**Modification**	**Callbacks**	**Runtime**
App1	44	-	2	44	-	2	-	-	51 sec
App2	1	1	8	-	-	4	-	2	205 sec
Proffix	-	23	10	-	17	7	3	1	666 sec
Total	45	24	20	44	17	13	3	3	

- App2 : disables button to deny export DB functionality
  - Enable button → execute export DB
- Unconfirmed candidates
  - Actual access control


[redacted]

Testversion

Logged in as:

Friday, November 15, 2013

11:58:06 AM

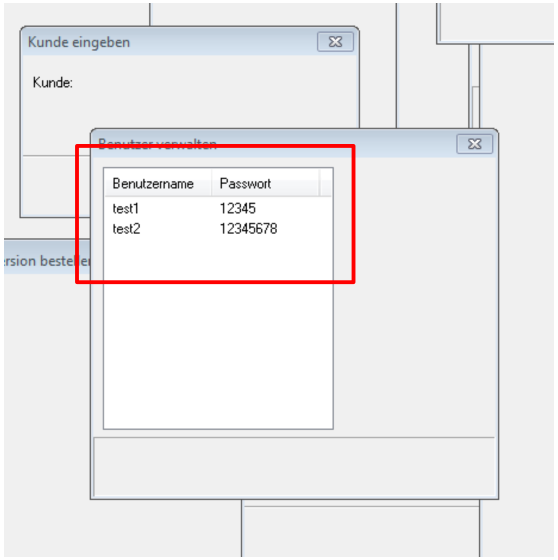
2013-11-08 to 2013-12-08

NEU SECLAB

Results – Information Disclosure GEMs

	GEM Candidates			Automatically Confirmed			Manually Confirmed		
Application	Disclosure	Modification	Callbacks	Disclosure	Modification	Callbacks	Modification	Callbacks	Runtime
App1	44	-	2	44	-	2	-	-	51 sec
App2	1	1	8	-	-	4	-	2	205 sec
Proffix	-	23	10	-	17	7	3	1	666 sec
Total	45	24	20	44	17	13	3	3	

- 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



Kunde eingeben

Kunde:

Benutzer verwalten

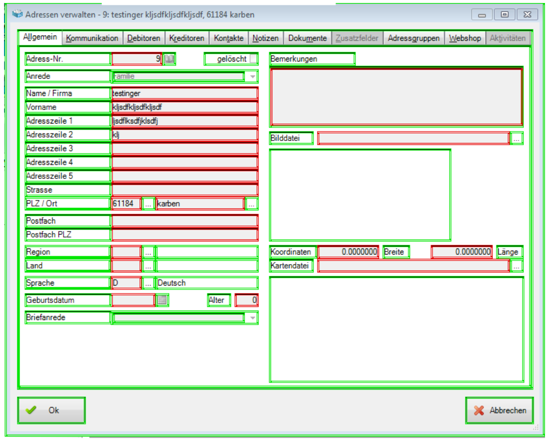
Benutzername	Passwort
test1	12345
test2	12345678

Results – Information Modification GEMs

	GEM Candidates			Automatically Confirmed			Manually Confirmed		
Application	**Disclosure**	**Modification**	**Callbacks**	**Disclosure**	**Modification**	**Callbacks**	**Modification**	**Callbacks**	**Runtime**
App1	44	-	2	44	-	2	-	-	51 sec
App2	1	1	8	-	-	4	-	2	205 sec
Proffix	-	23	10	-	17	7	3	1	666 sec
Total	45	24	20	44	17	13	3	3	

- 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



Adressen verwalten - 9: testinger kljsdfkljsdfkljsdf, 61184 karben

Adress-Nr.: 9
gelöscht ☐
Anrede: Familie
Name / Firma: testinger
Vorname: kljsdfkljsdfkljsdf
Adresszeile 1: ljsdflksdfjklsdfj
Adresszeile 2: klj
Adresszeile 3:
Adresszeile 4:
Adresszeile 5:
Strasse:
PLZ / Ort: 61184 karben
Postfach:
Postfach PLZ:
Region:
Land:
Sprache: D Deutsch
Geburtsdatum:
Alter: 0
Briefanrede:
Bemerkungen:
Bilddatei:
Koordinaten: 0.0000000 Breite 0.0000000 Länge
Kartendatei:

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

Other OSes and GUI Toolkits

- GEM bugs can be exploited if:
  - GUI of application can be inspected
  - GUI elements can be manipulated

- Proof-of-Concept for GTK+ on Linux
  - (just because it is totally different)
  - LD_PRELOAD a library into GTK+ application
    - Discover widgets
    - Modify widget attributes

Countermeasures

- Application developers should not rely on the GUI framework
  - Don't store runtime information in UI elements
  - Treat data stored in widgets as untrusted user input
  - Create and destroy widgets and windows as needed

- Remove unused UI elements from the UI
  - Can't manipulate non-existent elements
  - “Partial fix only”

- Run vulnerable application as different OS user
  - This will prevent manipulating the UI
  - This is a an easy to deploy HOT FIX

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

EOF

Thank you!

Any Questions?

http://mulliner.org/security/guisec/

Future Work

- Look at more applications!
- Appliances that run custom UI apps on standard Oses
- Detailed investigation of other OSes and GUI frameworks