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Recovery Reimagined: Attacking and Securing Windows Recovery

Who Are We?

Security Testing & Offensive Research at Microsoft (STORM)

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Microsoft

STORM

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Agenda

- Research Background
- WinRE Overview
- The Vulnerabilities
- WinRE Research Helpers
- Closing Remarks

July 19th, 2024 – The Global Outage

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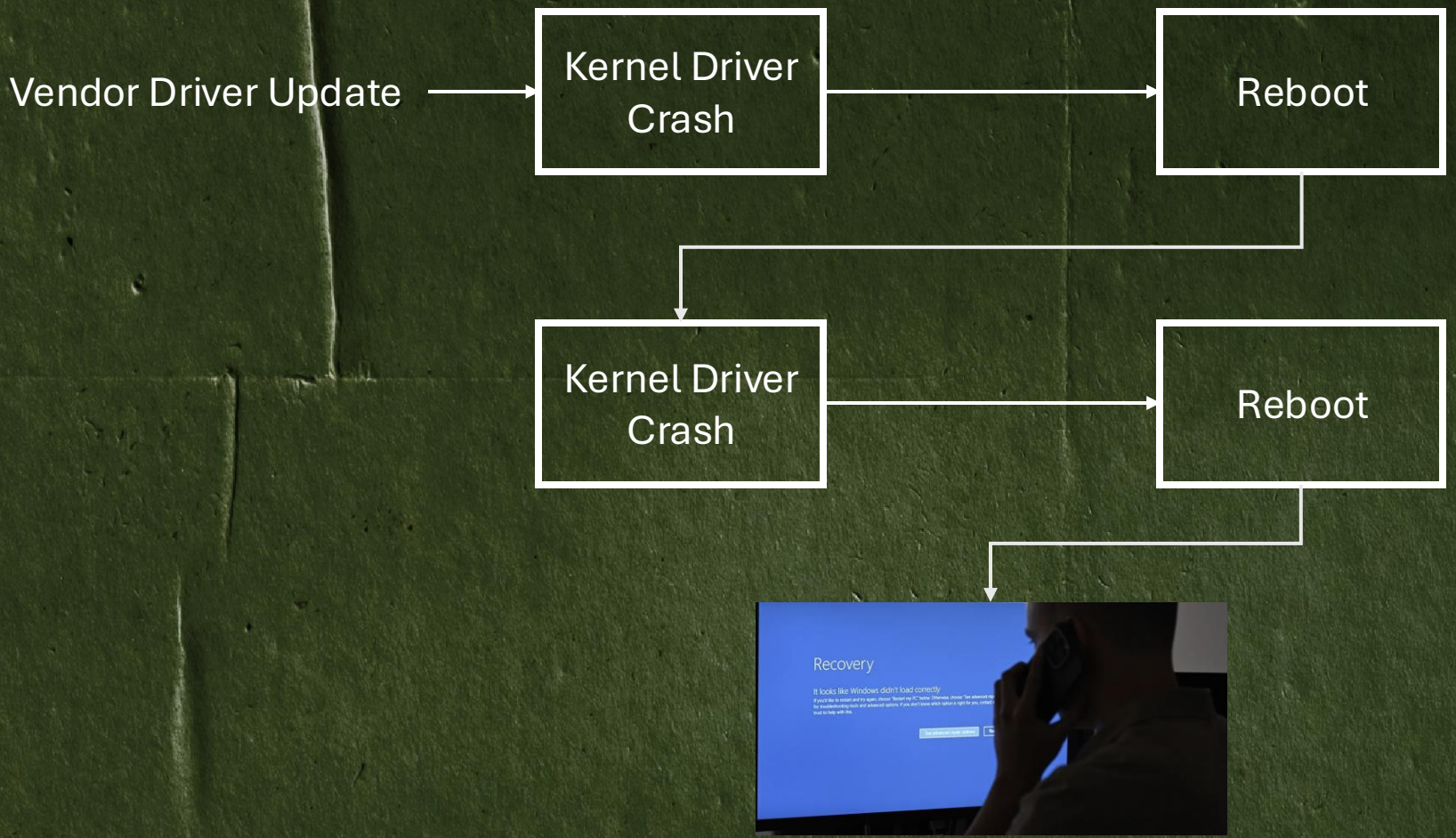
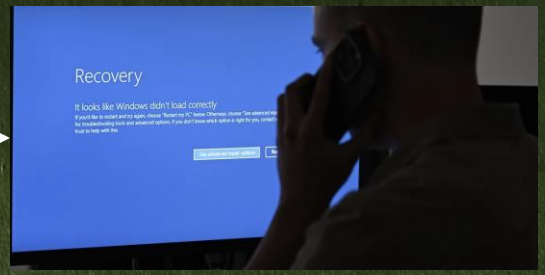
What Happened?



The Fix Procedure

Manual and physical recovery needed

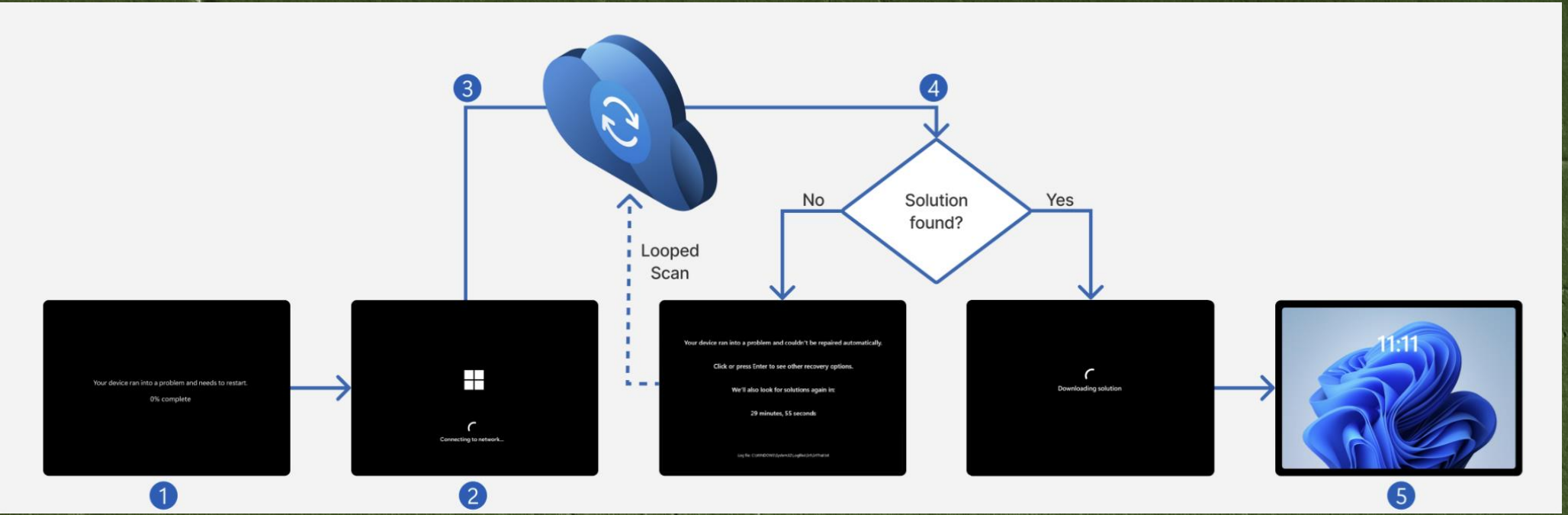


The Windows Resiliency Initiative (WRI)

- A Microsoft initiative to make Windows more resilient
- Builds stronger recovery and resiliency capabilities

WRI Feature – Quick Machine Recovery (QMR)

- Automates recovery from critical failures
- Designed to handle large-scale outage scenarios
- On failure, retrieves and applies the required fix from update services



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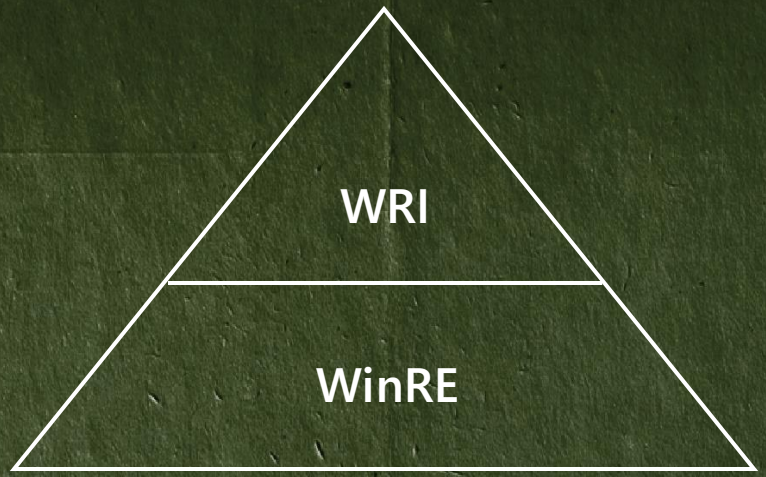
WRI Foundation – Windows Recovery

- The foundation – the Windows Recovery Environment (WinRE)

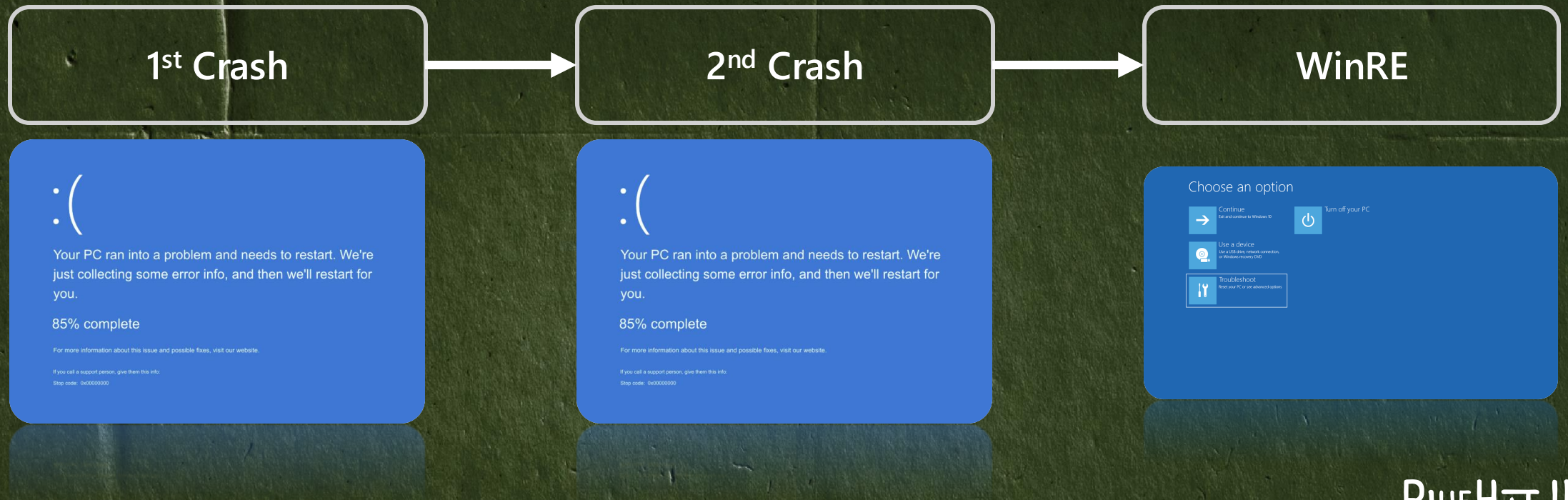


Our Task: Security Reviews

- We were tasked with reviewing both new resiliency features and the platform they rely on:
  - Forward-looking: Review new WRI features design and implementations
  - Backward-looking: Review WinRE design and implementation

WinRE Overview

- WinRE is the recovery platform of Windows
- WinRE is designed to recover from critical system issues



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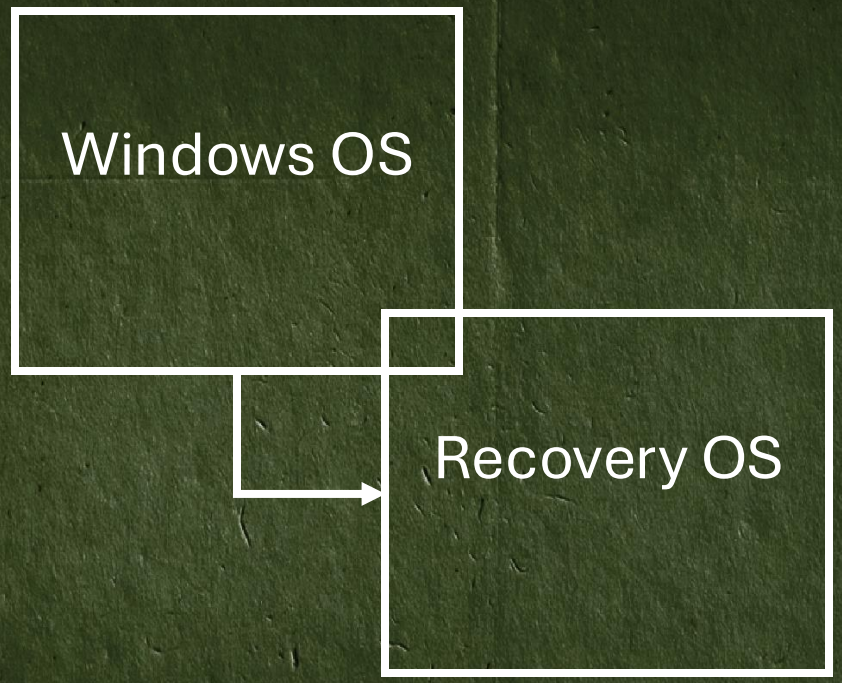
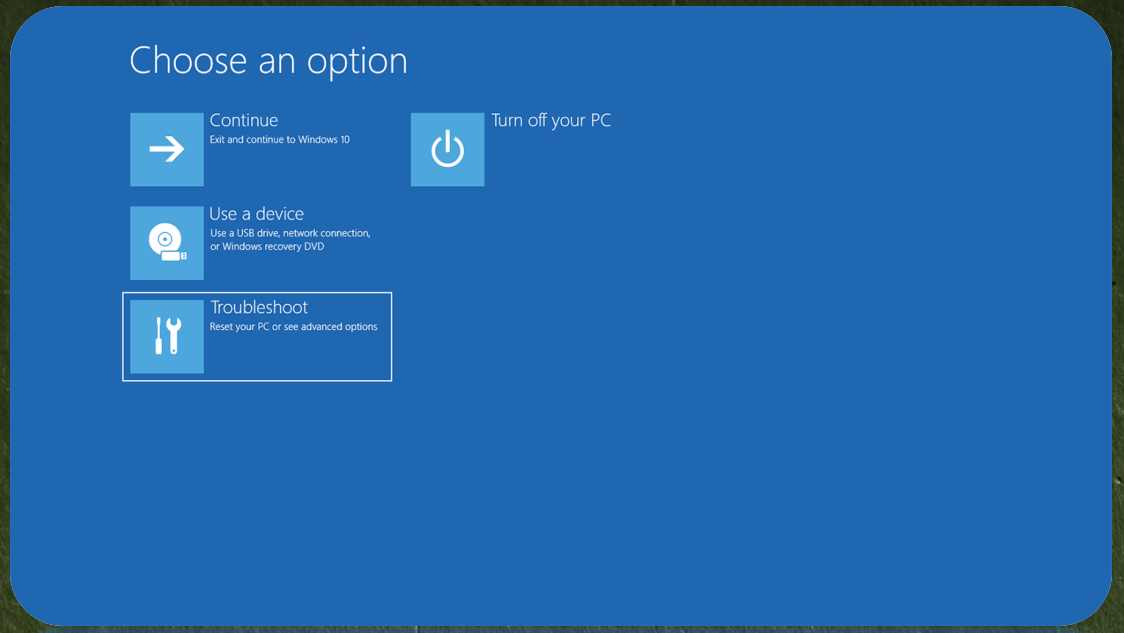
WinRE Architecture – Recovery OS

- WinRE is a lean Windows OS with recovery customizations (aka. Recovery OS)



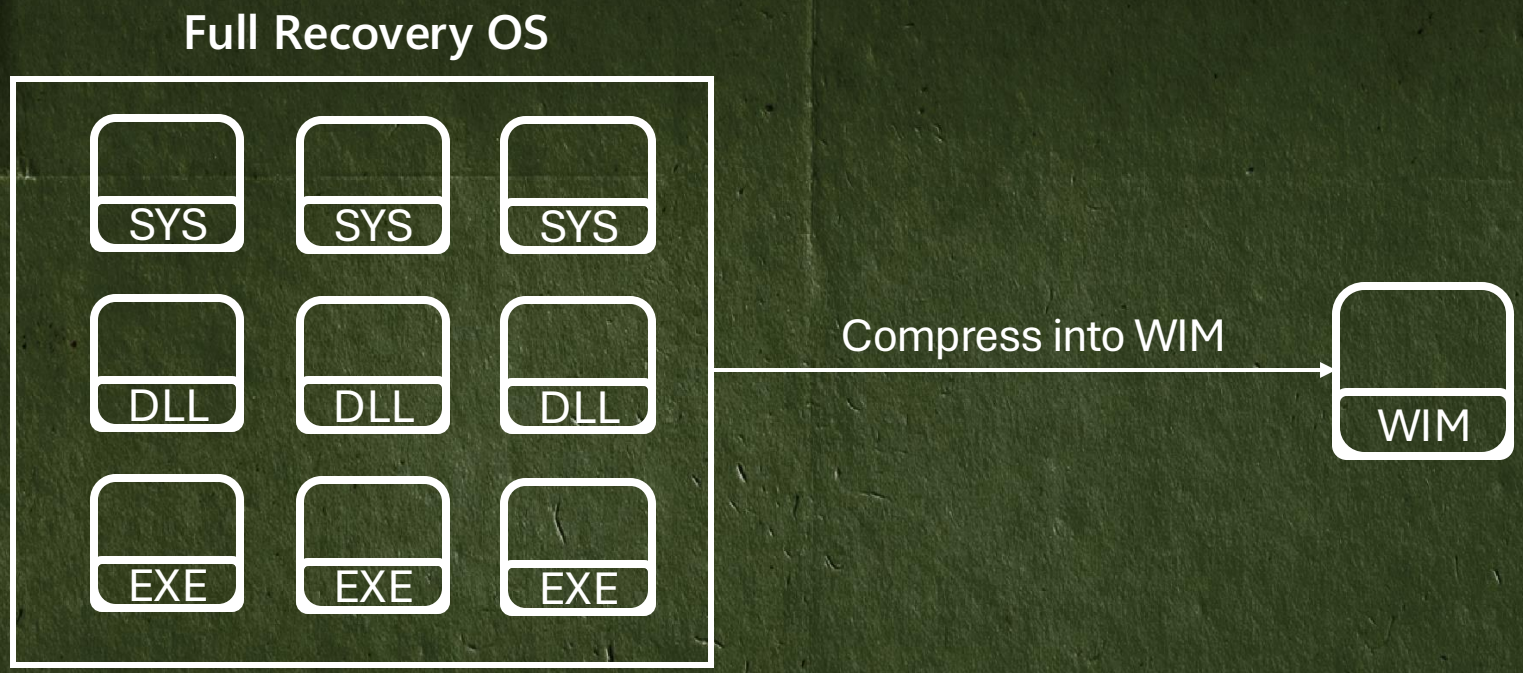
WinRE Architecture – Customizations

- The customizations include Startup Repair, System Reset, System Restore etc.



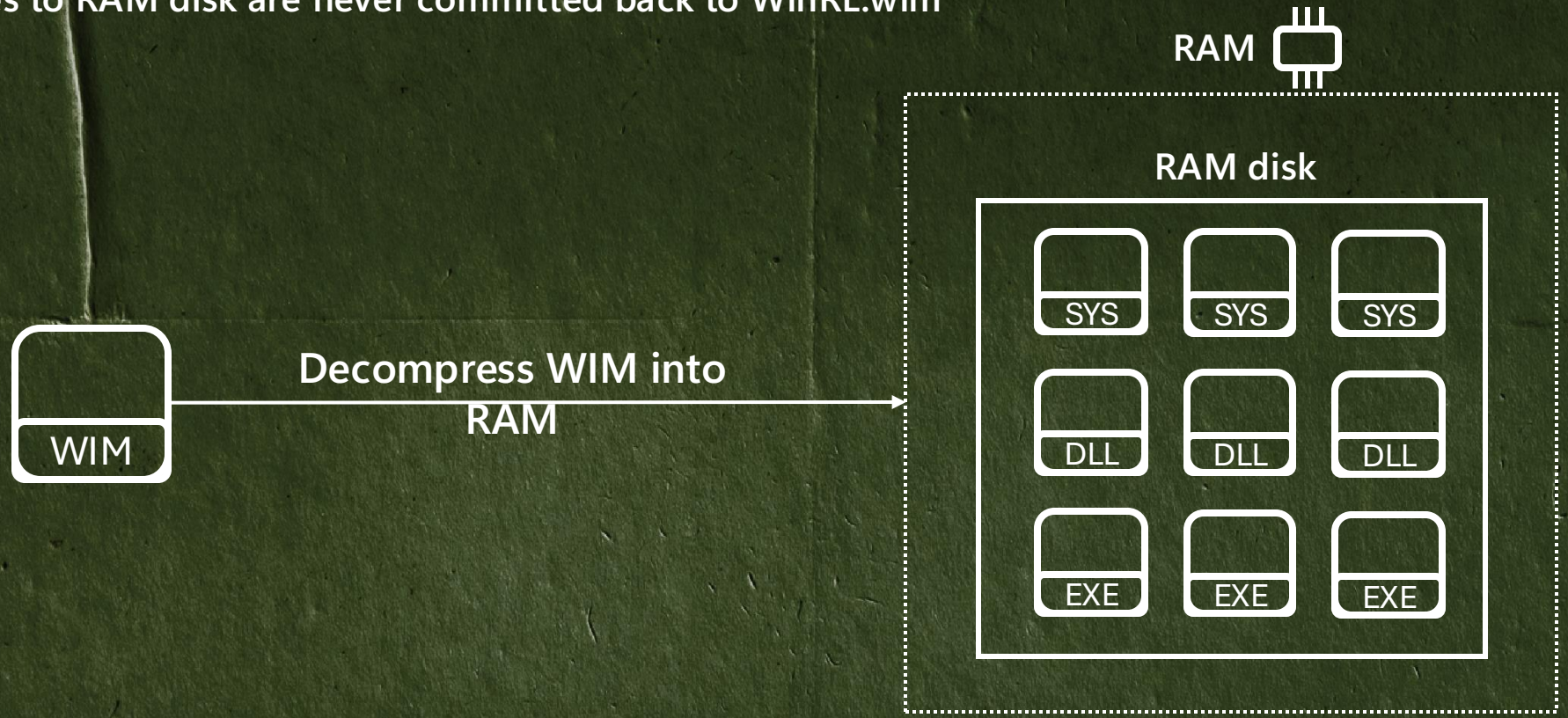
WinRE Architecture – WinRE.wim

- The recovery OS is compressed into a single WIM file – WinRE.wim



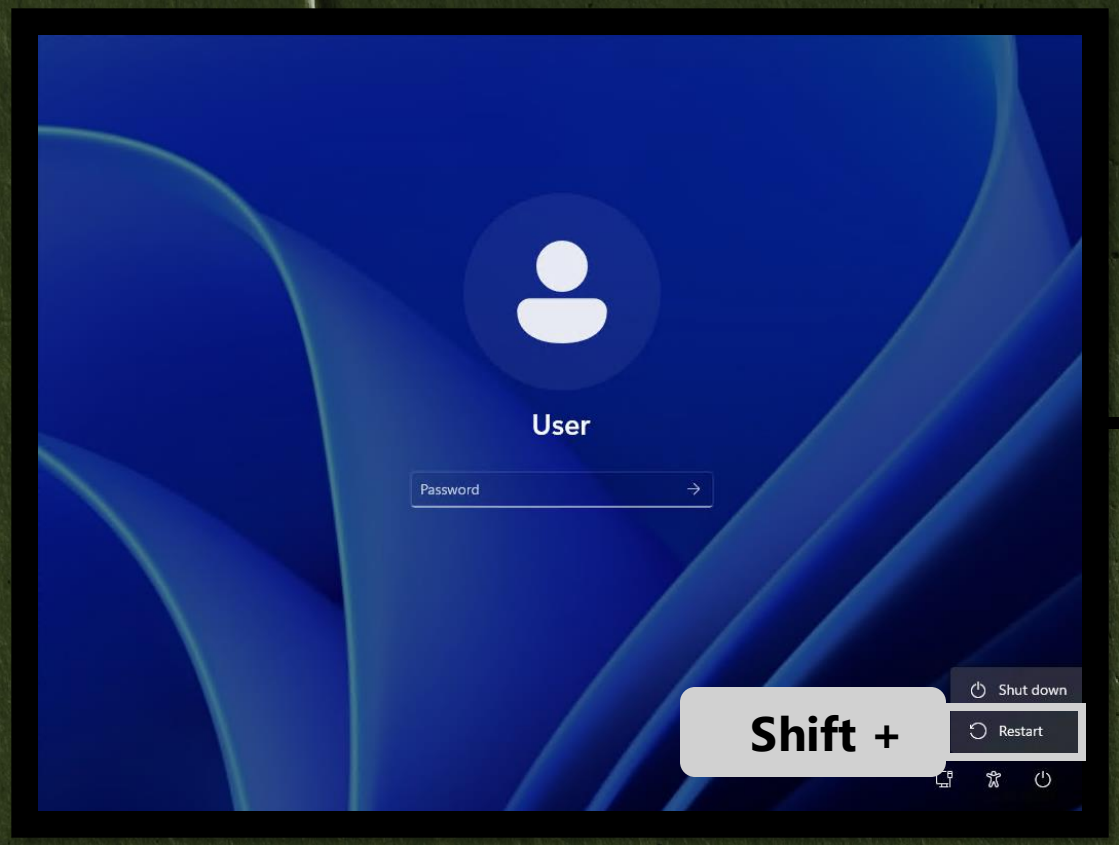
WinRE Architecture – RAM Disk Boot

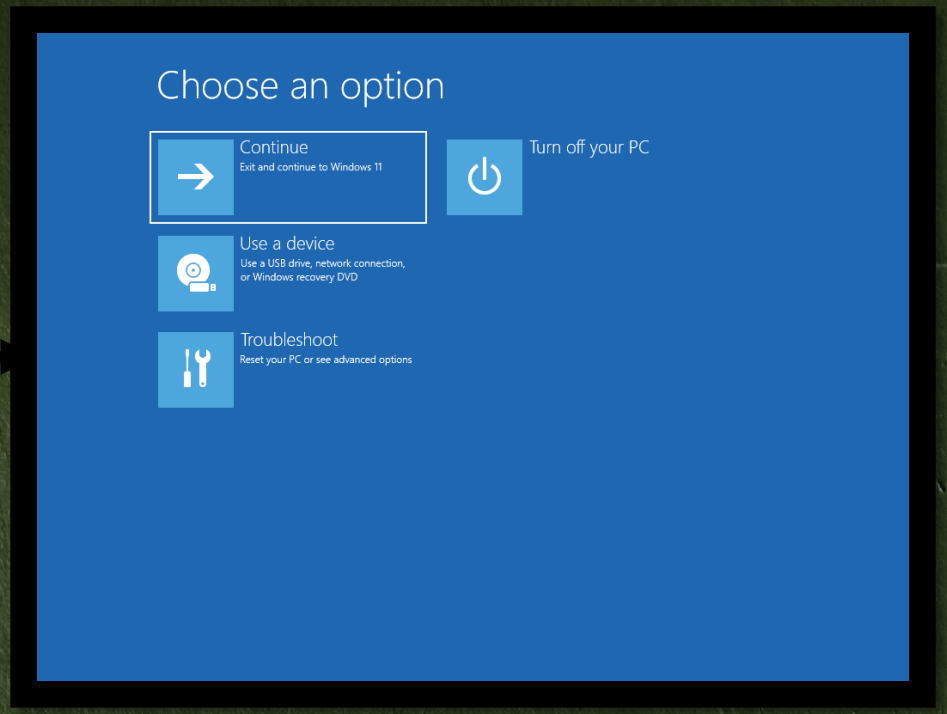
- WinRE.wim is booted from RAM disk
- Changes to RAM disk are never committed back to WinRE.wim



WinRE Interface

- A physical user can boot into WinRE by pressing Shift + Restart from the logon screen





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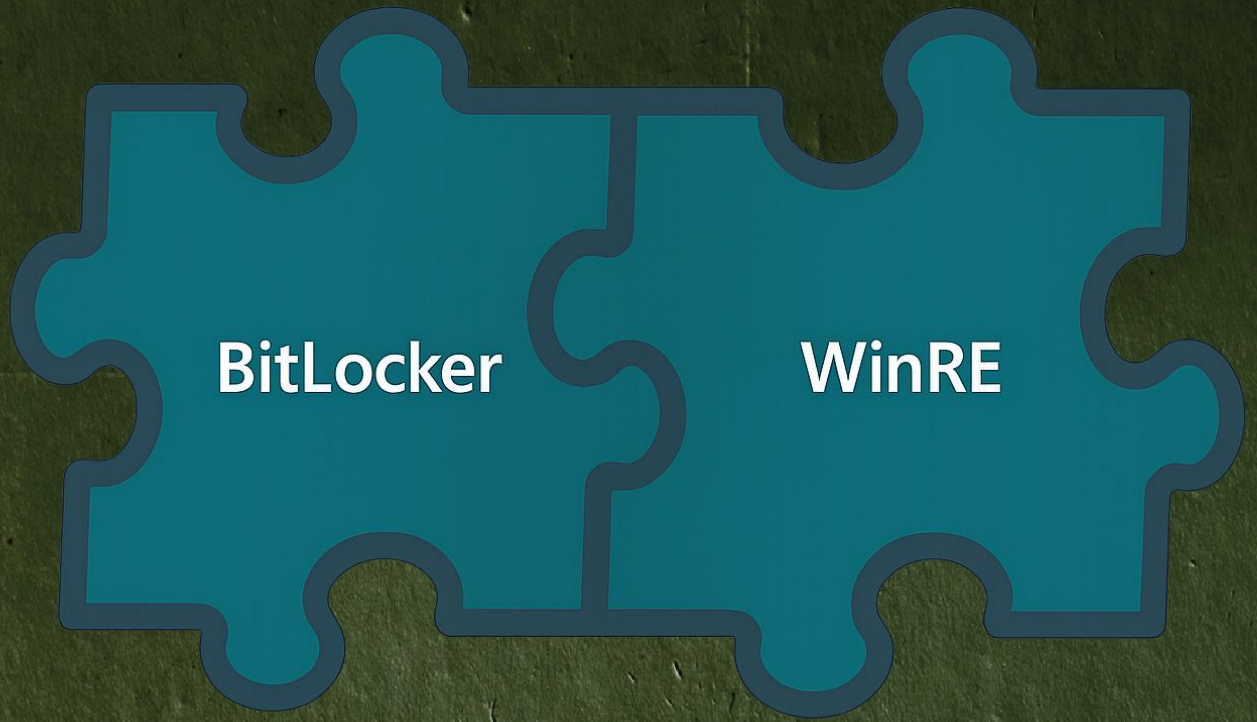
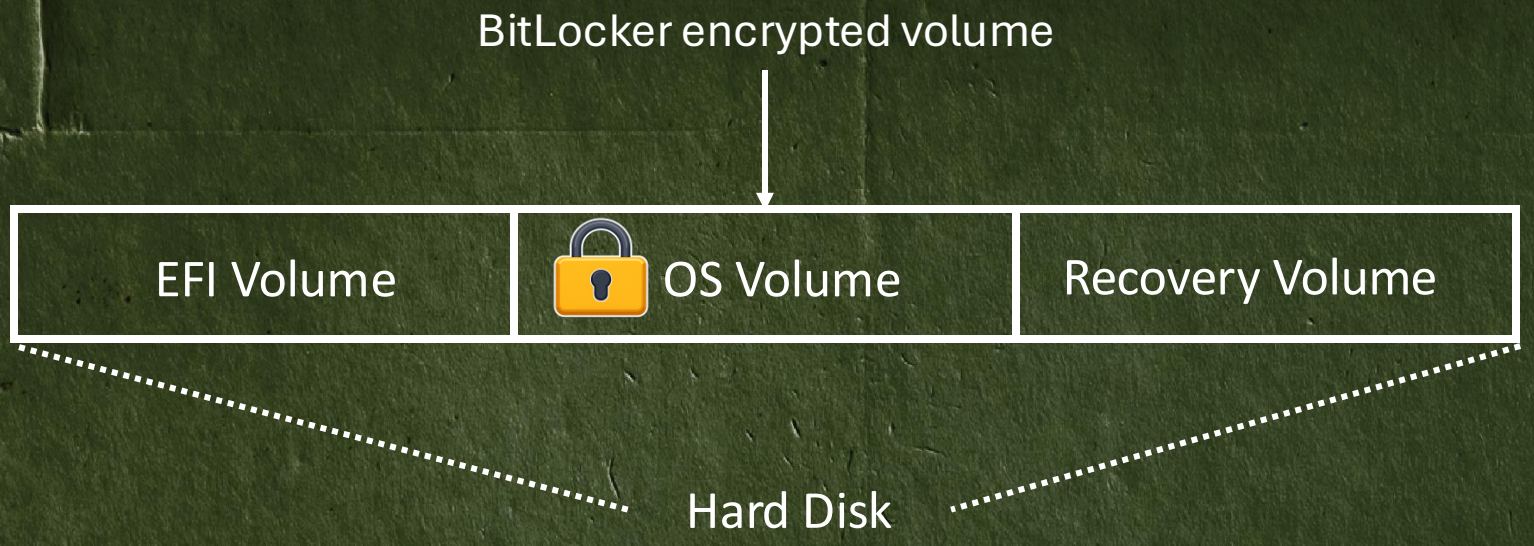
WinRE and BitLocker Intersection



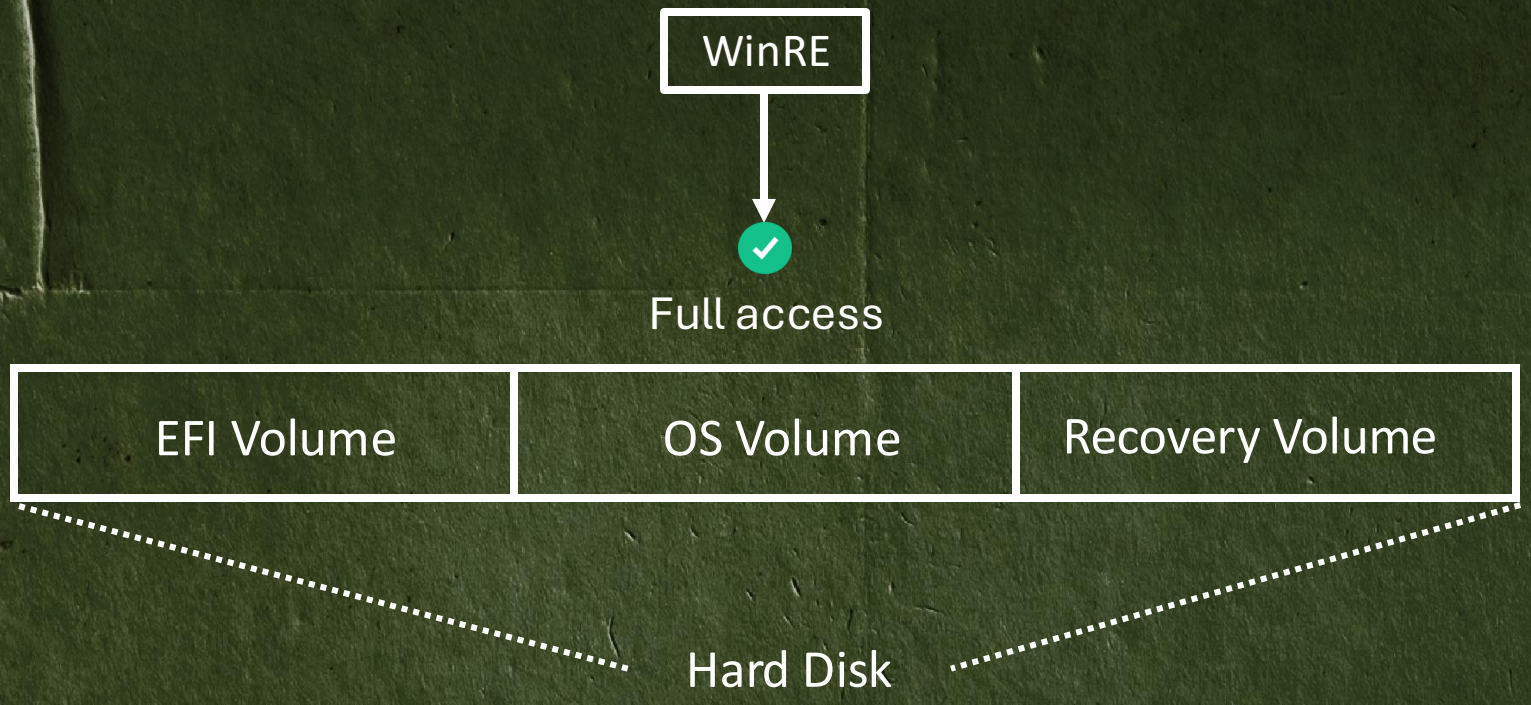
BitLocker Overview

- BitLocker is designed to protect data-at-rest and defend against theft scenarios
- It is a full volume encryption (FVE) technology



WinRE and BitLocker Intersection

- If certain conditions are met – WinRE has full access to the OS volume

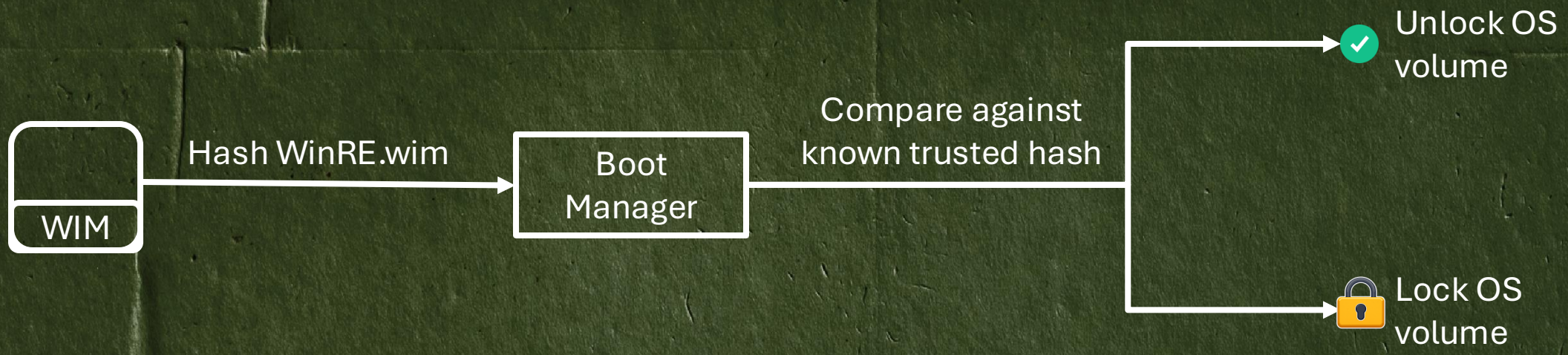


WinRE OS Volume Access Conditions

1. WinRE.wim is trusted
2. Overly permissive recovery tools aren’t selected

Condition #1 – WinRE is Trusted

- Trusted WIM boot compares the WinRE.wim hash against a known trusted hash

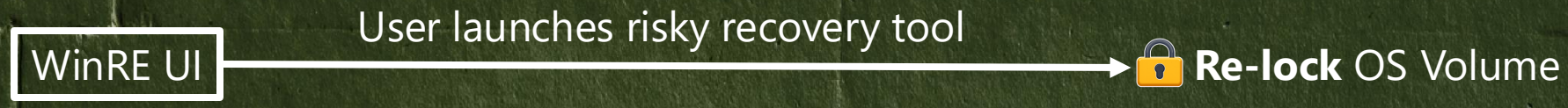


Condition #1 – WinRE is Trusted

- In Unlocked state – WinRE can fully access the OS volume
- In Locked state – WinRE cannot access the OS volume

Condition #2 – Risky Recovery Tools

- If a risky recovery tool is selected from the recovery UI – OS volume is re-locked
- For example: Command Prompt



Research Rules

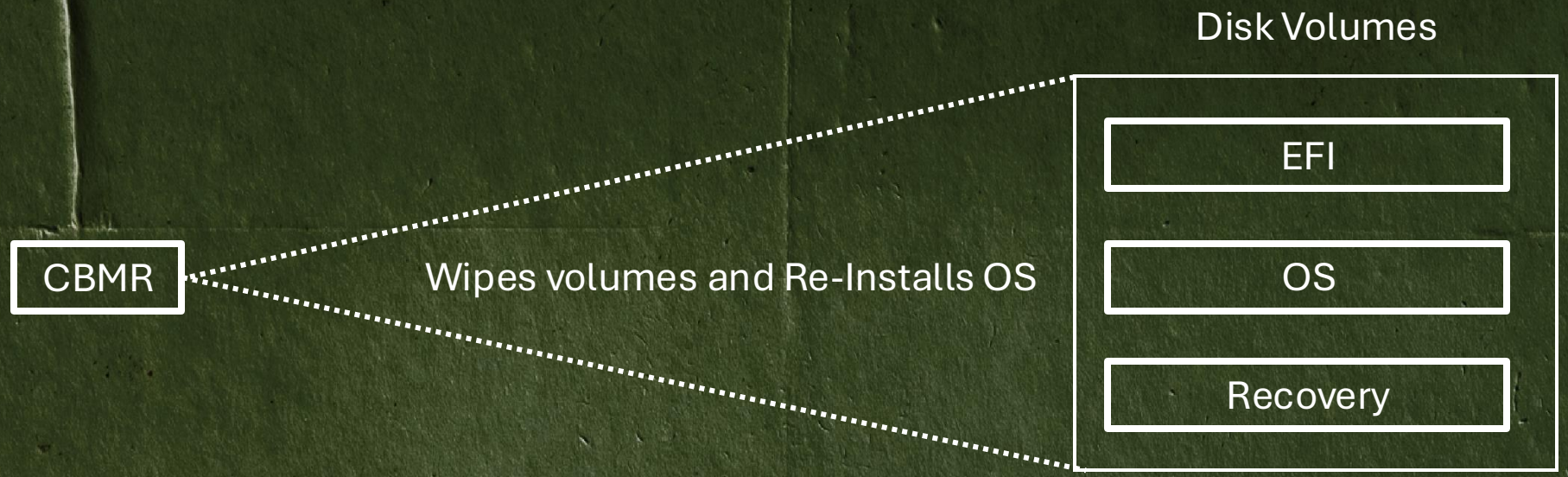
1. Static WinRE.wim image cannot be modified – due to trusted WIM boot
2. Recovery tools that trigger re-lock are out-of-scope

Our Focus Today

- We will dive into:
  -  CVE-2025-55330 – BitLocker Security Feature Bypass
    - CVE-2025-55332 – BitLocker Security Feature Bypass

Cloud Bare Metal Recovery (CBMR) Overview

- Cloud-based bare-metal recovery that reinstalls Windows from scratch via WinRE



CBMR Execution Path – Pseudo Code

- CBMR executes only if:
  - “CBMR” folder exists on the recovery volume
  - There’s no associated OS

```
if (AssociatedOS == nullptr)
{
    AppendPath(RecoveryDrive,
               L"CBMR",
               CbmrFolderPath,
               szCbmrFolderPath);

    if (PathExists(CbmrFolderPath))
    {
        ShouldLaunchCBMR = TRUE;
    }
}

// [REDACTED SNIP]

if (ShouldLaunchCBMR)
{
    LaunchCBMR();
}
```

Triggering CBMR

- CBMR executes only if:
  - ✅ “CBMR” folder exists on the recovery volume
  - 👀 There’s no associated OS

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if (ShouldLaunchCBMR)
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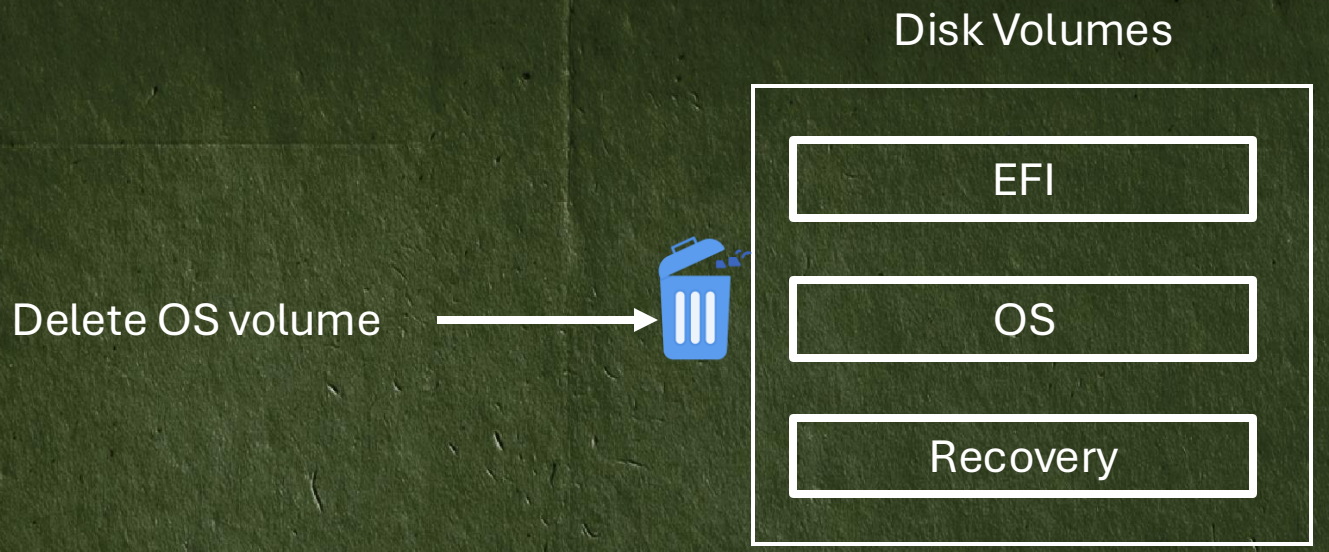
}
```

No OS Volume, No Prize

- If we delete OS volume – we have nothing to attack

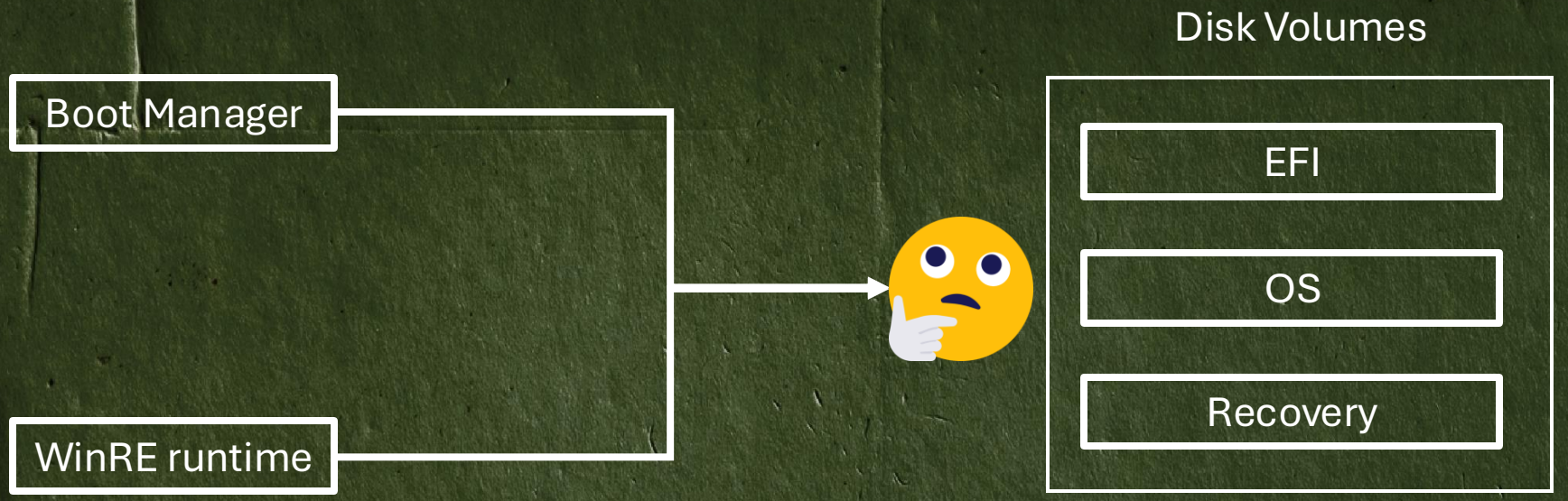


What’s Needed?

1. No OS volume found by WinRE → CBMR triggers
2. OS volume must still exist → target data
3. OS volume must stay unlocked → data accessible

OS Lookups – Happens Twice

- Boot phase – decides what to unlock
- OS phase – decides what to recover
- The lookup logics aren’t shared!



OS Lookups – BCD based

- BCD – Boot Configuration Data
- BCD represents Windows Boot configuration
- BCD is stored on the EFI volume

```
C:\Windows\System32>bcdedit /enum {f227cc65-aa4d-11f0-806c-28a06b34d7de} /v

Windows Boot Loader
-------------------
identifier              {f227cc65-aa4d-11f0-806c-28a06b34d7de}
device                  partition=C:
path                    \WINDOWS\system32\winload.efi
description             Windows 11
locale                  en-US
inherit                 {6efb52bf-1766-41db-a6b3-0ee5eff72bd7}
recoverysequence        {f227cc67-aa4d-11f0-806c-28a06b34d7de}
displaymessageoverride  Recovery
recoveryenabled         Yes
isolatedcontext         Yes
allowedinmemorysettings 0x15000075
osdevice                partition=C:
systemroot              \WINDOWS
resumeobject            {f227cc64-aa4d-11f0-806c-28a06b34d7de}
nx                      OptIn
bootmenupolicy          Standard
hypervisorlaunchtype    Auto
claimedtpmcounter       0x10002
```

Boot Phase Lookup Exclusive Addition

- Boot phase lookups support a dedicated BCD element that specifies the associated OS
- OS phase lookups do not support this BCD element

```
> bcdedit /set {recovery_os_object} custom:0x11000083 partition=TARGET_PARTITION
```

Failing OS Phase Lookups

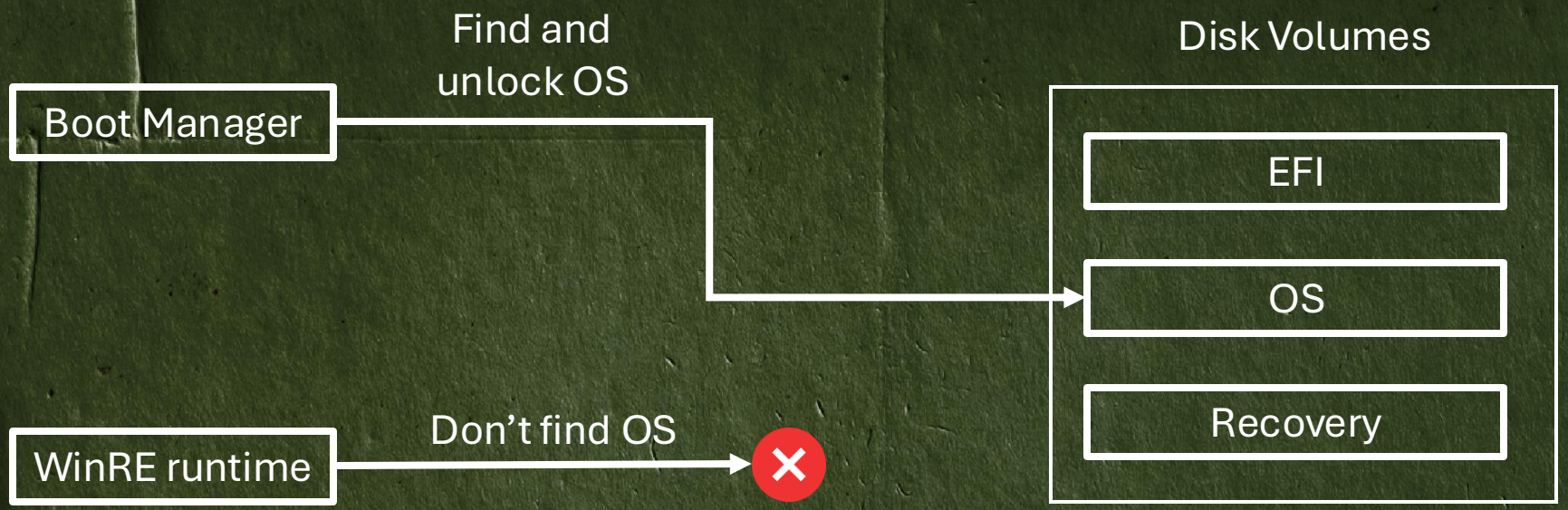
- OS phase lookups heavily rely on the recovery sequence BCD element
- Deleting this element from the target OS BCD object will cause all lookups to fail

```
> bcdedit /deletevalue {target_os_object} recoverysequence
```

The Result of This Setup

```
> bcdedit /set {recovery_os_object} custom:0x11000083 partition=TARGET_PARTITION
```

```
> bcdedit /deletevalue {target_os_object} recoverysequence
```



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}

// [REDACTED SNIP]

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{
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}
```
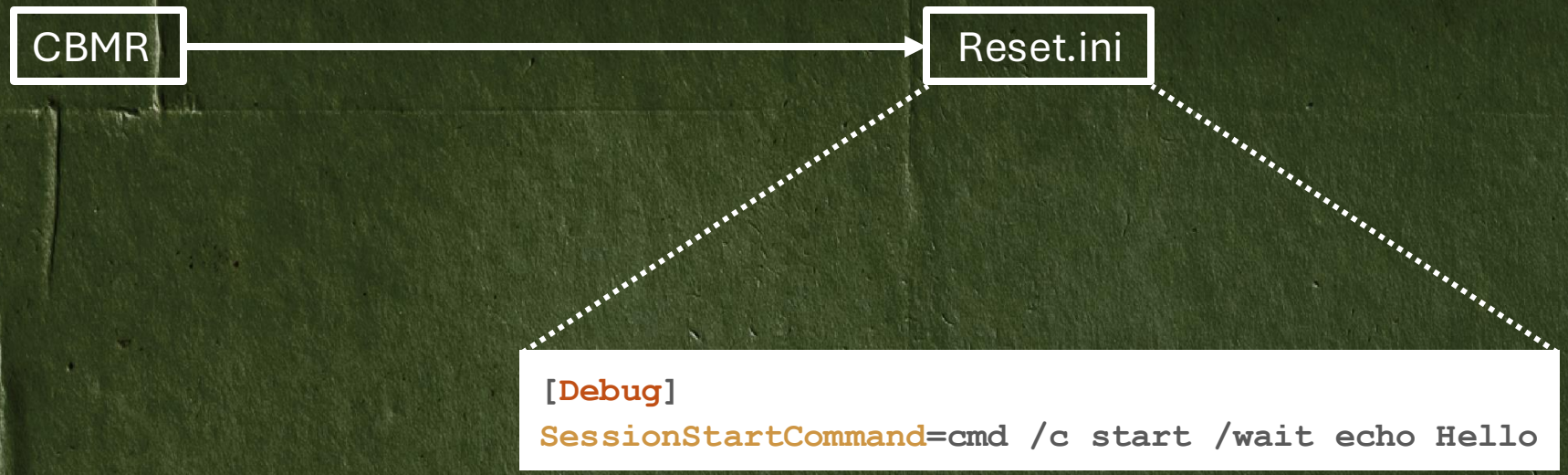
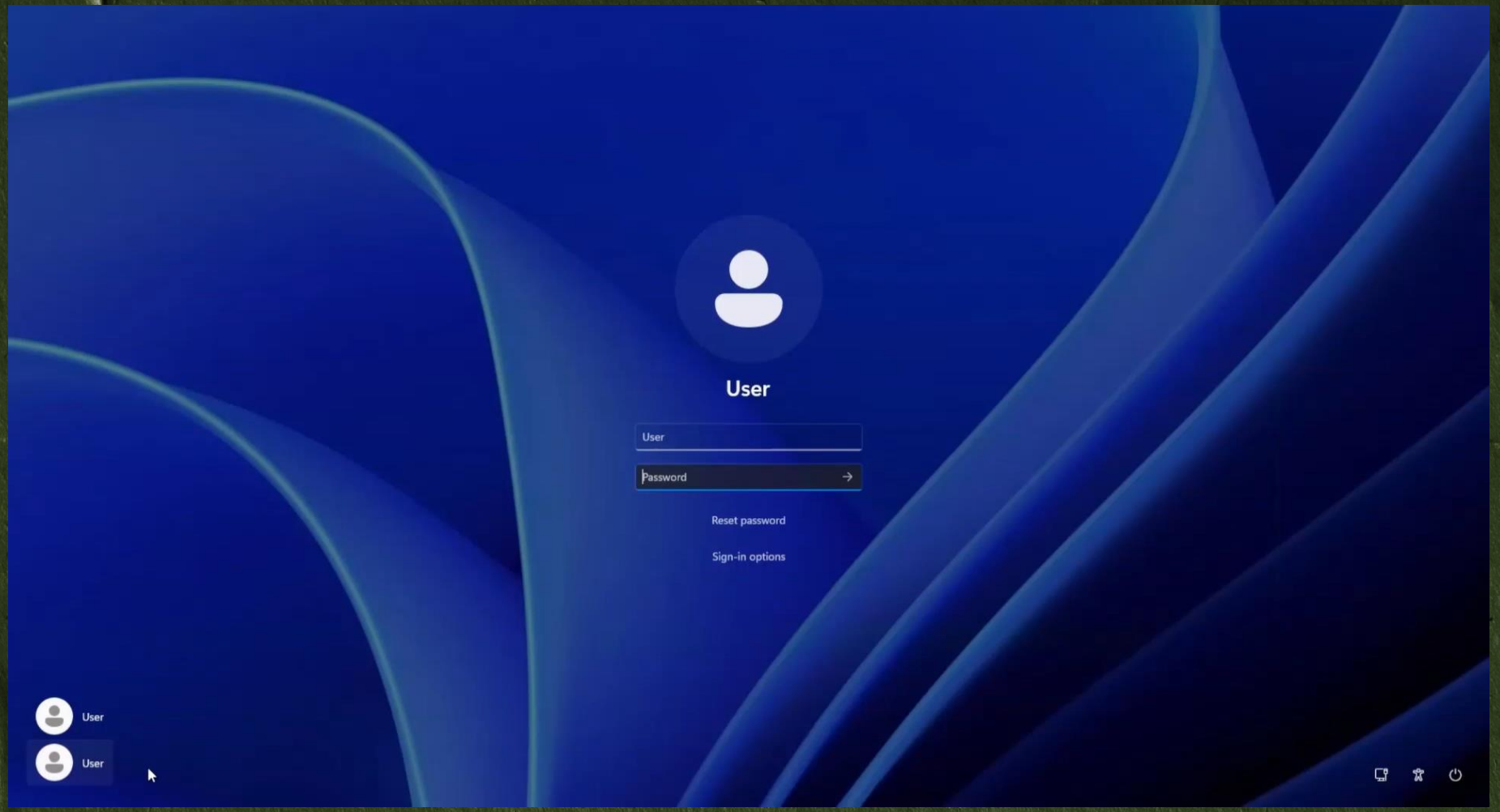

Configuration Files Is All We Need

- CBMR loads Reset.ini from the Recovery volume
- This file contains debug hooks that can be used to run arbitrary commands



Demo for Vulnerability #1



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Our Focus Today

- We will dive into:
  - ✅ CVE-2025-55330 – BitLocker Security Feature Bypass
  -  CVE-2025-55332 – BitLocker Security Feature Bypass

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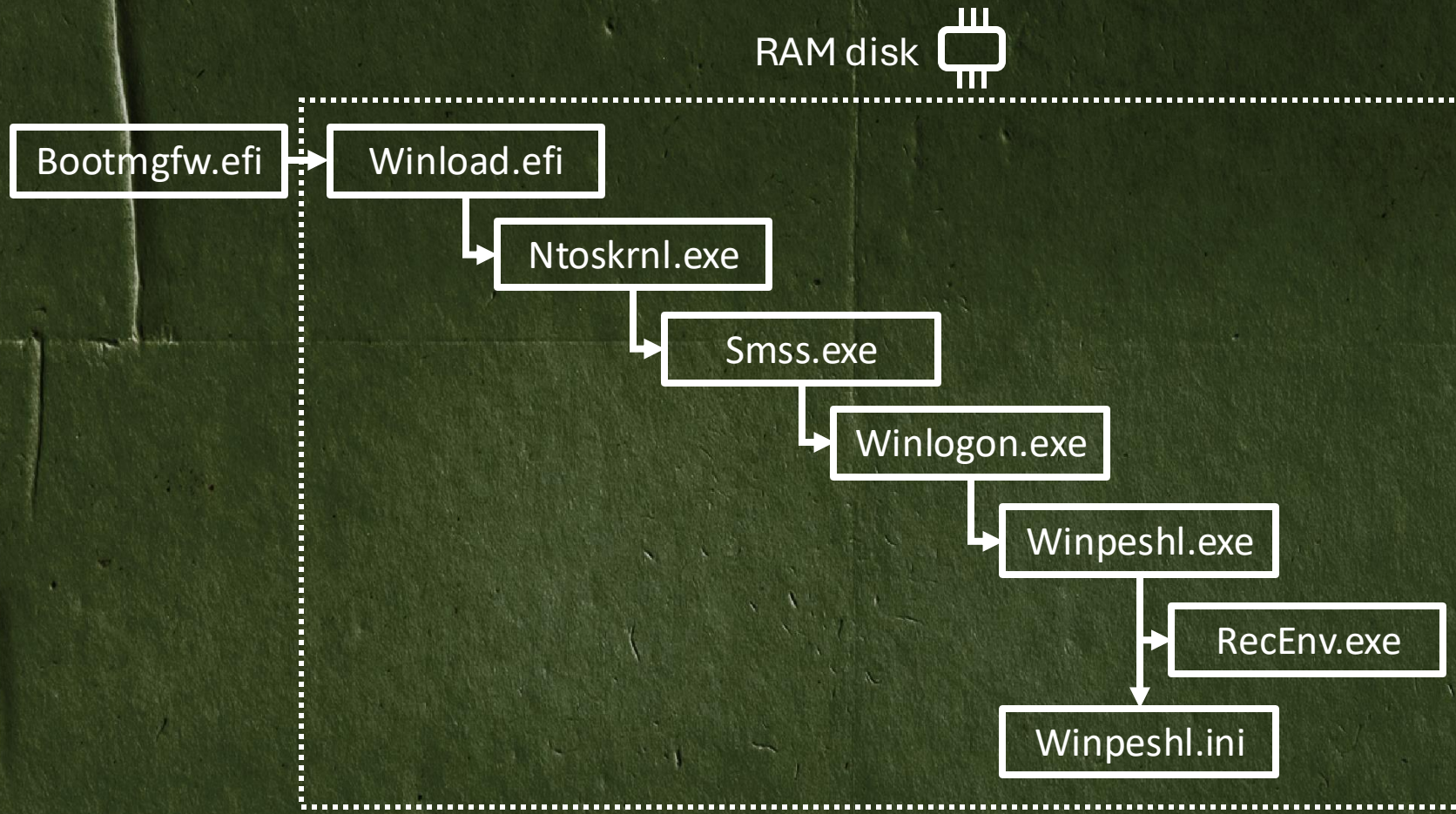
WinPE Overview

- WinRE is built on WinPE
- Windows Preinstallation Environment (WinPE) – small Windows OS
- Used for -
  - Deploy captured Windows image
  - Modify existing Windows OS
  - Recover data from unbootable devices
- Custom shell or GUI

WinRE Execution Flow



WinPEShl.ini Launch App

- winpeshl.ini determines which application launches next (typically recenv.exe)

Pseudo Code: App execution

```
void ExecuteStartupApps() {
    bool started = false;

    char* iniPath = LocateConfigFile("winpeshl.ini");

    if (iniPath != NULL) {
        // Case 1: Single app from [LaunchApp] section
        char* app = ReadIniValue(iniPath, "LaunchApp", "AppPath");
        if (app) {
            started = ExecuteApp(app);
        }

        // [REDACTED SNIP]

        // Case 2: INI found but nothing started -> error prompt
        if (!started)
            ExecuteApp("cmd.exe", "/k \"echo <bad INI error>\"");
    }
}
```

- winpeshl.exe attempts to load winpeshl.ini

Pseudo Code: App execution

```
void ExecuteStartupApps() {
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    }
}
```

- If valid, the specified application is launched

Pseudo Code: App execution

```
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    bool started = false;

    char* iniPath = LocateConfigFile("winpeshl.ini");

    if (iniPath != NULL) {
        // Case 1: Single app from [LaunchApp] section
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        // Case 2: INI found but nothing started -> error prompt
        if (!started)
            ExecuteApp("cmd.exe", "/k \"echo <bad INI error>\"");
    }
}
```
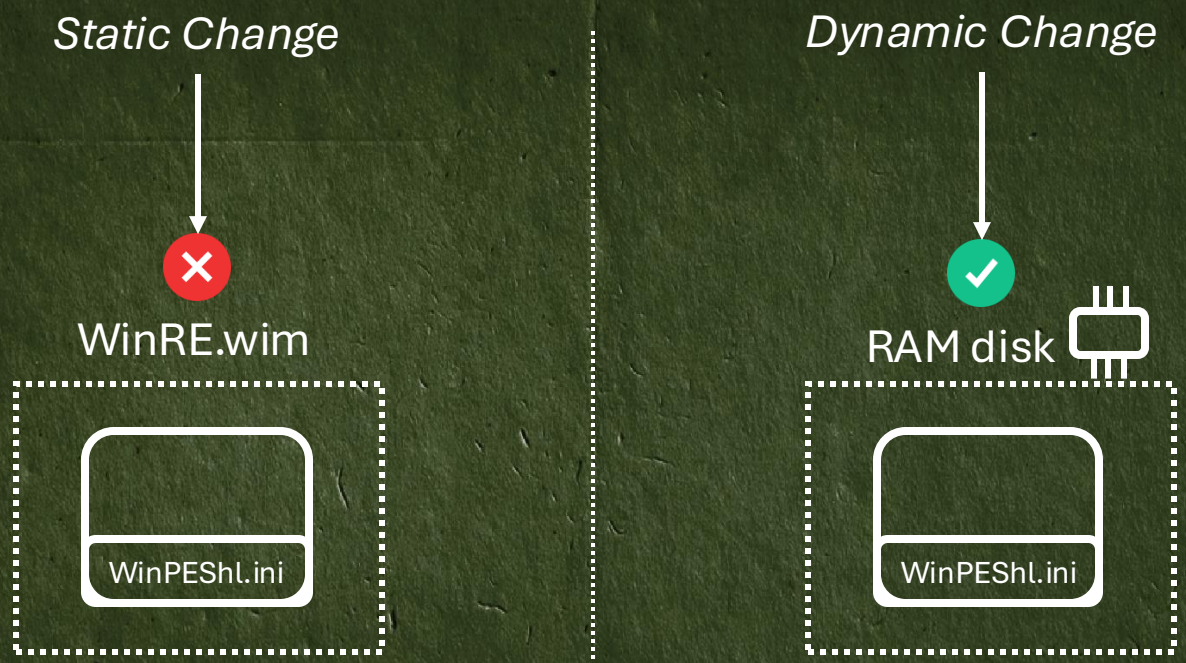

- malformed INI triggers cmd.exe launch
- OS volume remains unlocked – can be used to bypass BitLocker

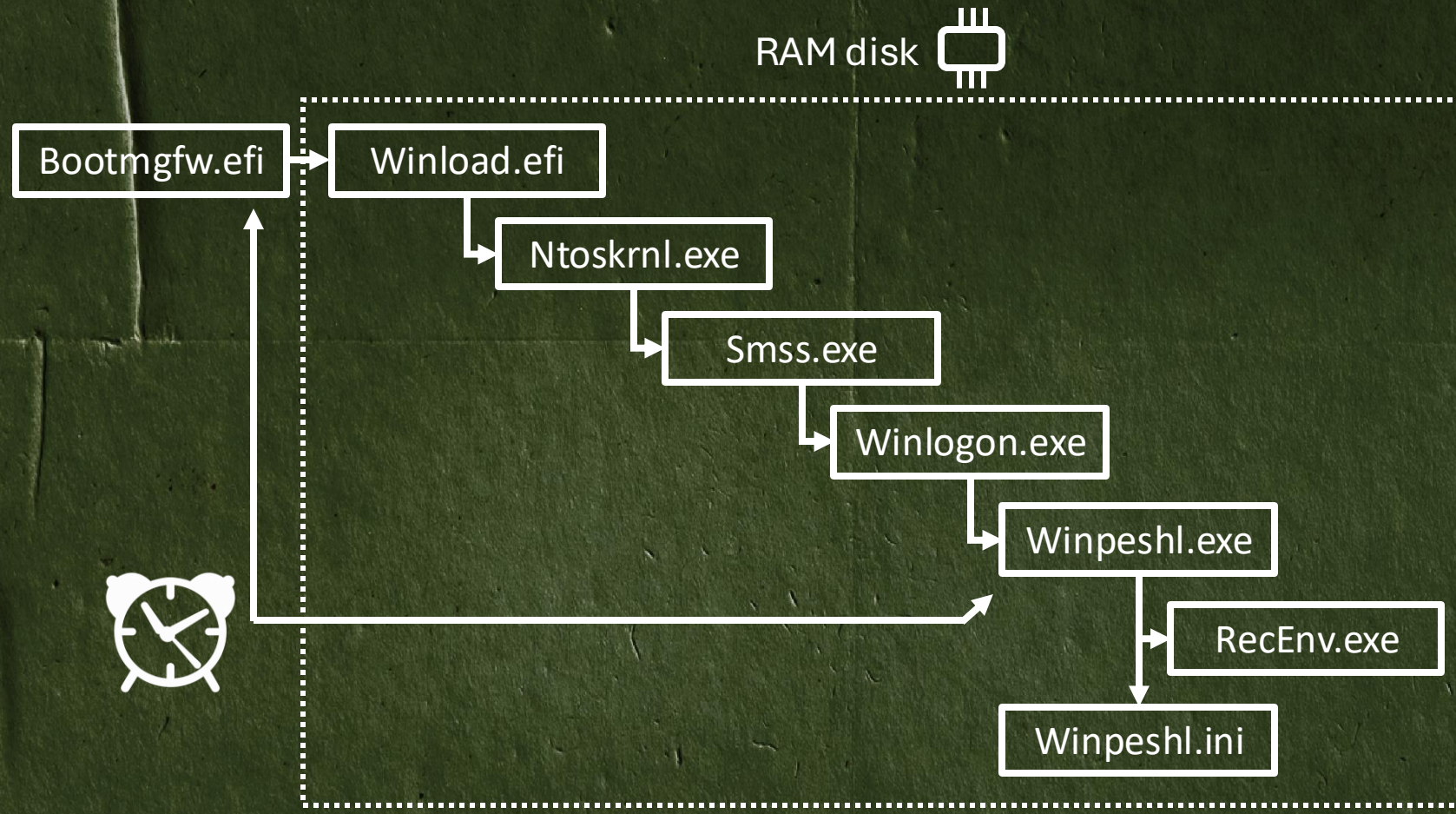
Our Target: Dynamic File Corruption Primitive

- Winpeshl.ini resides in WinRE.wim
  - On-disk modification – impossible due to Trusted WIM boot
  - RAM disk modification – requires a post-boot file corruption primitive



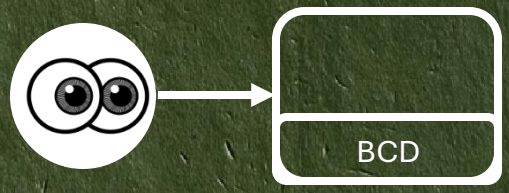
The Opportunity Window

- After bootmgfw.efi, before winpeshl.exe



Where Do We Look?

- Boot Configuration Data (BCD) is a great candidate
- There are more then 250 BCD elements!
- We manually inspected the usage of elements that:
  - Contain a file path
  - Likely not boot-critical
  - Likely written to during boot



Potential Candidate: bootstatfilepath

- The bootstatfilepath element controls the BootStat.dat file path

0x12000044	file path for boot status data log		string	6.0 and higher
	BcdLibraryString_BsdLogPath			6.2 and higher
	BCDE_LIBRARY_TYPE_BSD_LOG_PATH	**bootstatfilepath**		1803 and higher

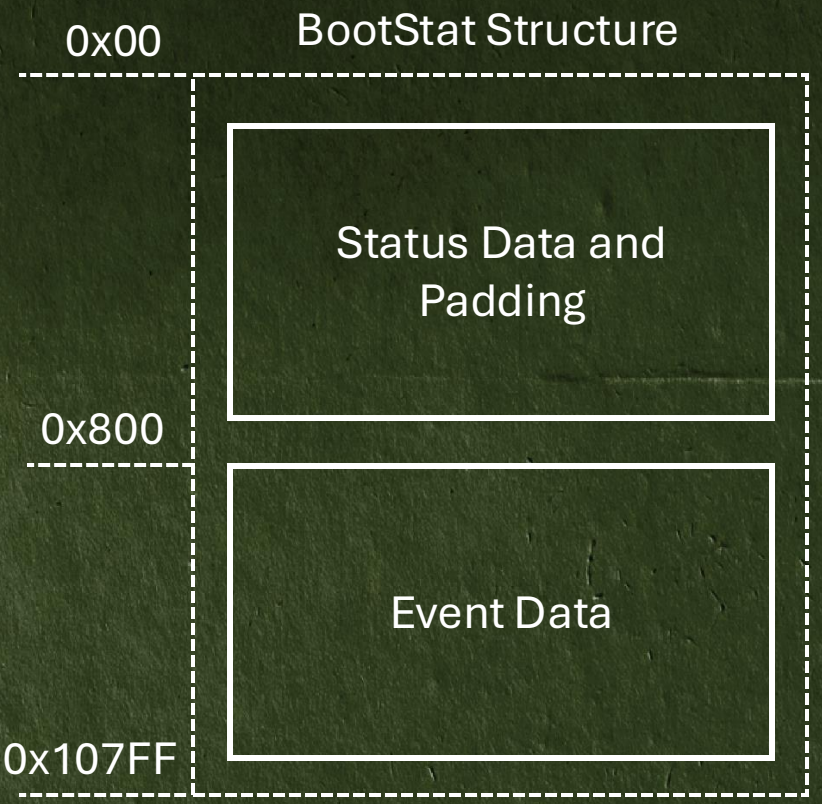
[* Geoff Chappell - BCD Elements]

BootStat.dat Instances

- There are two BootStat.dat instances:
  - Boot Manager Instance: logged to only by Boot Manager
  - OS instance: logged to by Boot Loader, Kernel and System Processes
- The bootstatfilepath BCD element is only applicable for the OS instance

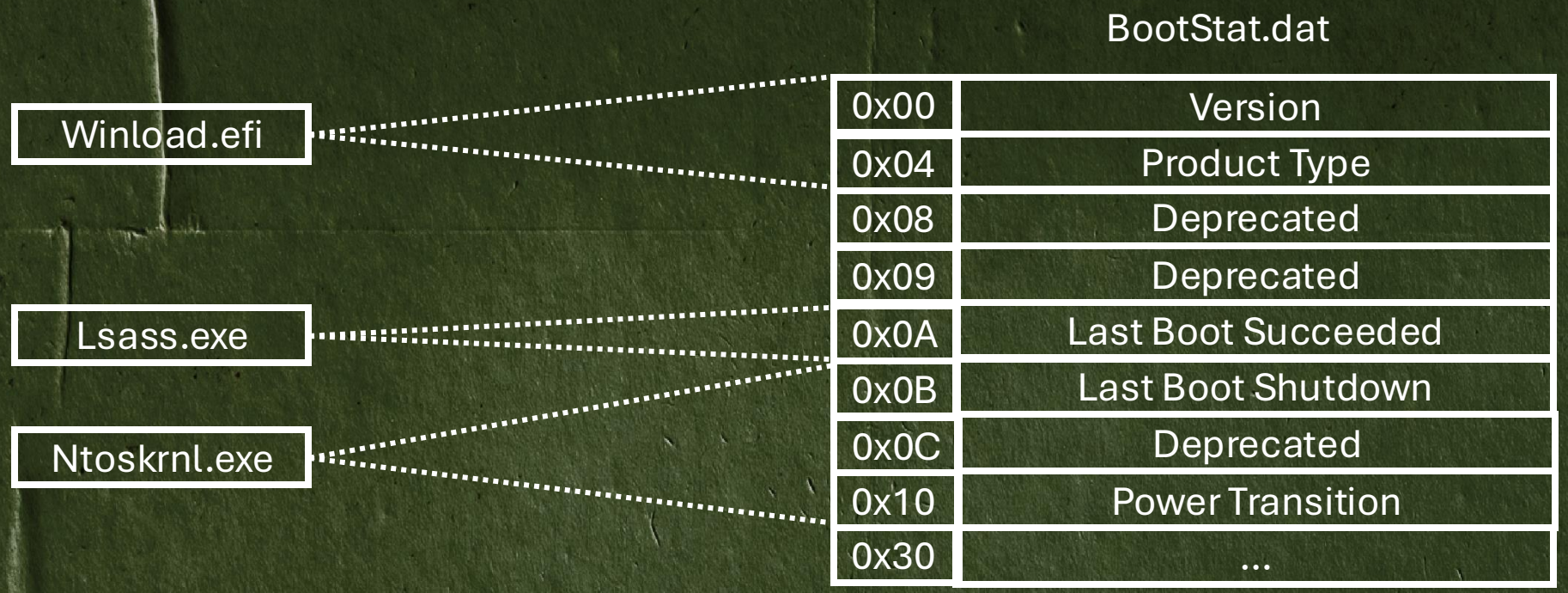
OS Instance BootStat.dat Format

- The OS instance BootStat.dat is separated to two separate sections
  - 0x00 – 0x800 – Status Data and Padding
  - 0x800 – 0x107FF – Event Data



What Do We Care About in BootStat.dat

- WinPEShl.ini size is 0x30 – we only care about status data from 0x00 to 0x30
- The components writing to 0x00 to 0x30 BootStat.dat events are Winload.efi, Ntoskrnl.exe and Lsass.exe



Boot Phase BootStat.dat Writing

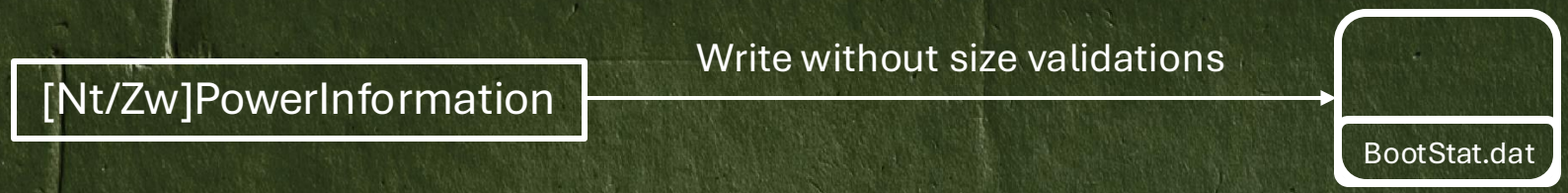
- Winload.efi validates that BootStat.dat is of an expected size
- WinPEShl.ini is much smaller than expected, so all Winload.efi writes will fail

Log Read and Write API (Pseudo Code)

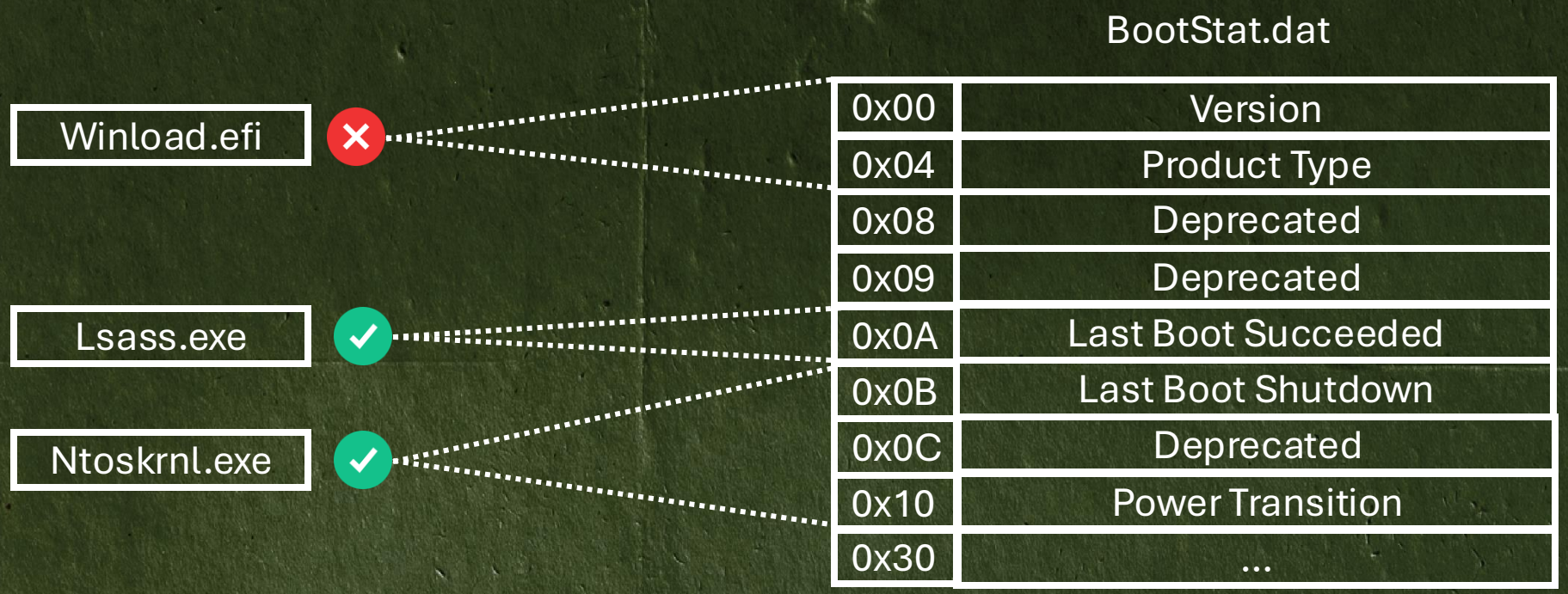
```
// [SNIP REDACTED]
if (BsdFileSize < sizeof(BSD_MIN_FILE_RECORD)) {
    Status = STATUS_BSD_MIN_SIZE_VIOLATION;
    goto BsdMinSizeCheckEnd;
}
// [SNIP REDACTED]
```

OS Phase BootStat.dat Writing

- Kernel and User Mode process writing to BootStat.dat are using the [Nt/Zw]PowerInformation system call
- This system call doesn't perform validations before writing to BootStat.dat



How Does it Look Like?



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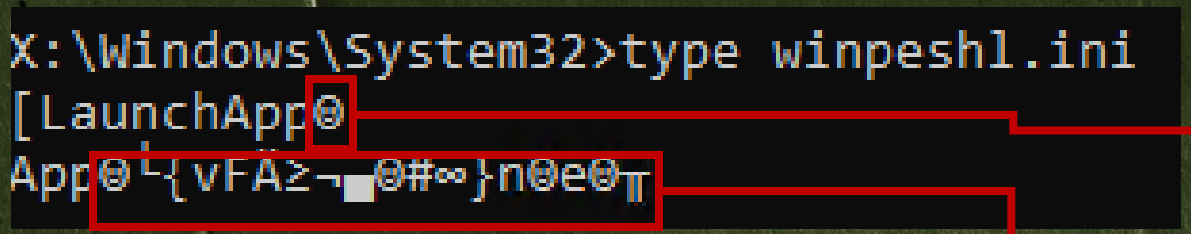
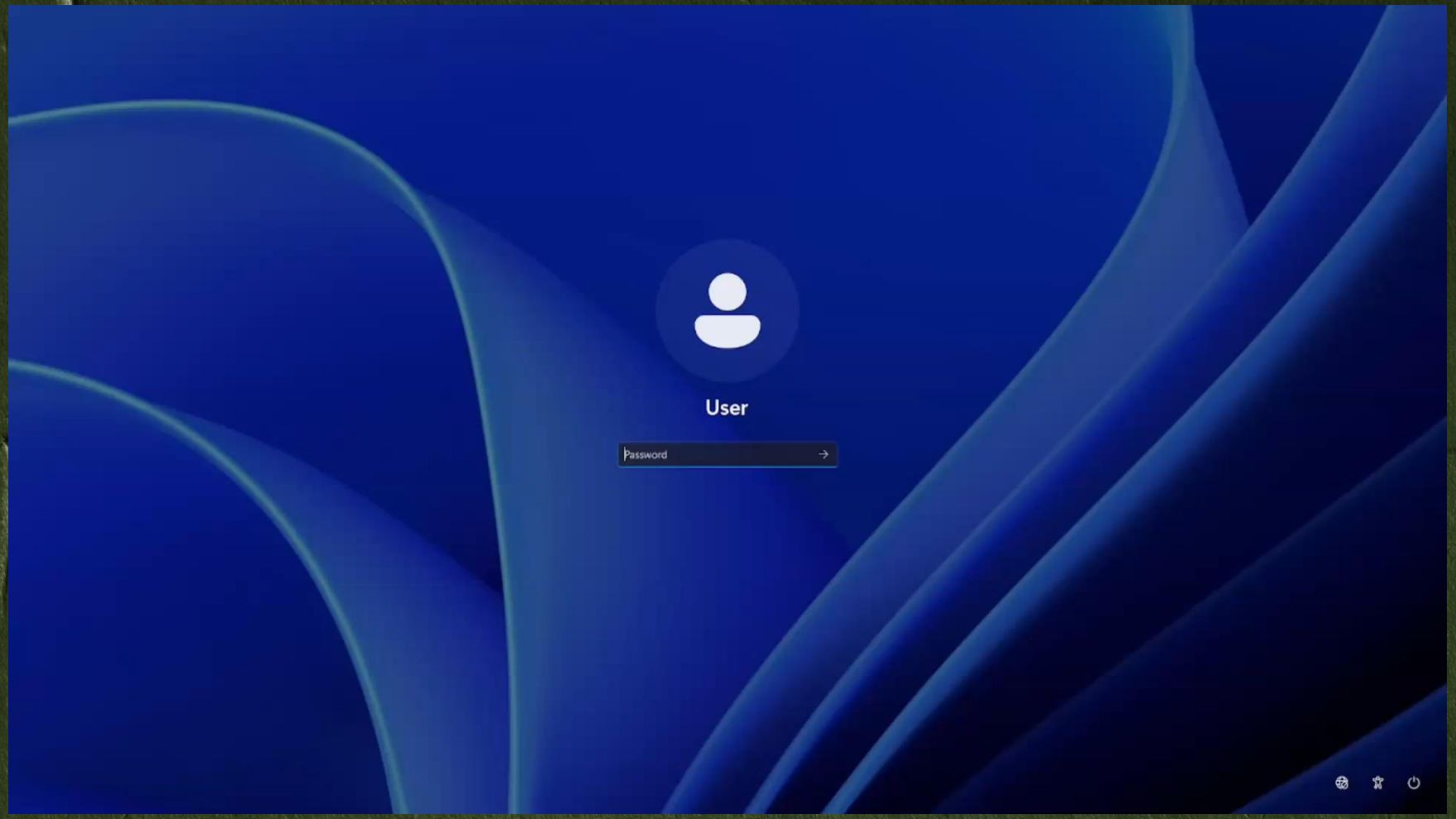


BootStat.dat

0x00	Version
0x04	Product Type
0x08	Deprecated
0x09	Deprecated
0x0A	Last Boot Succeeded
0x0B	Last Boot Shutdown
0x0C	Deprecated
0x10	Power Transition
0x30	...

Demo for Vulnerability #2



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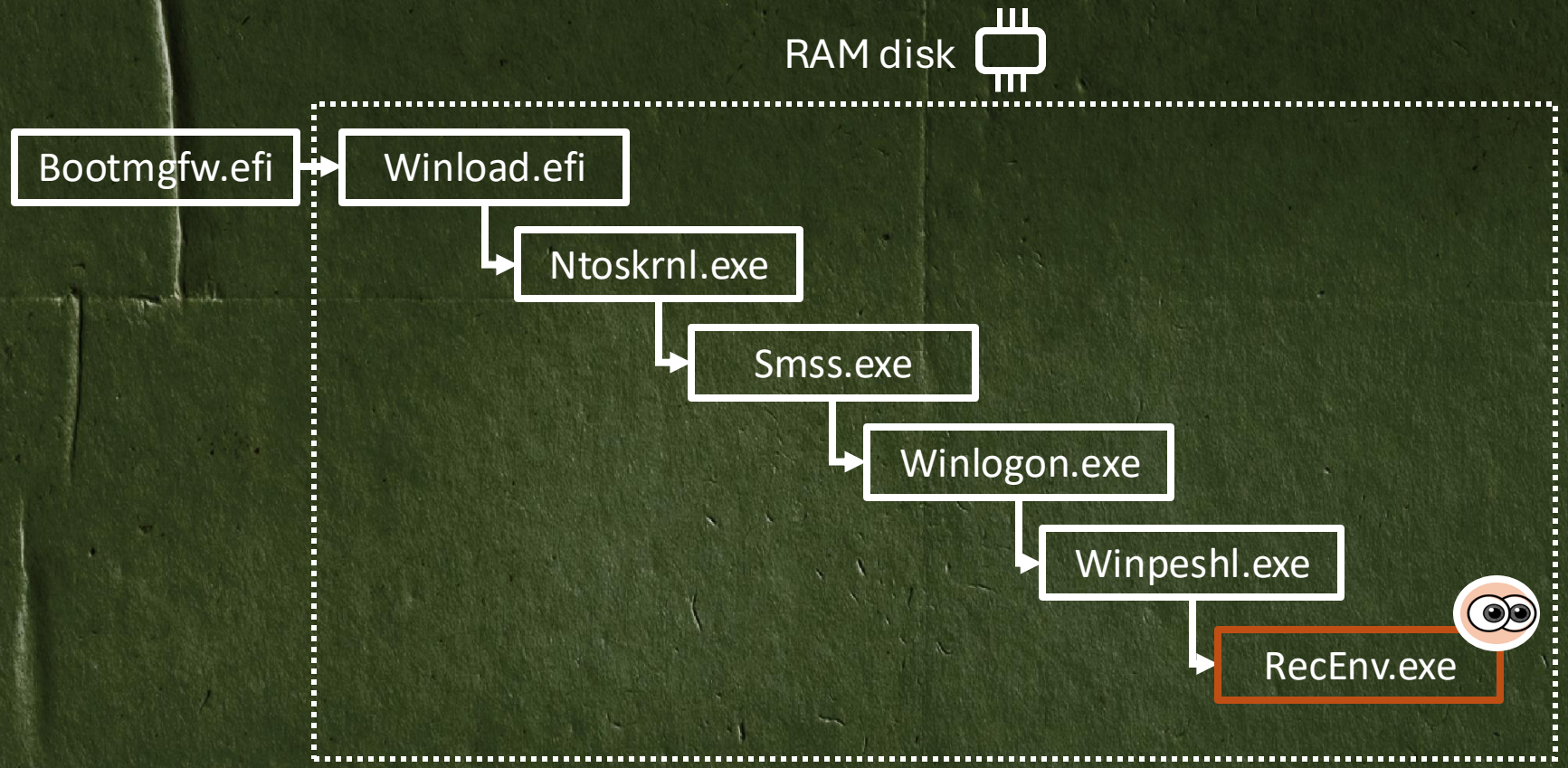
Debugging WinRE

- Our debugging target: RevEnv.exe



RecEnv.exe Debugging Options

- Kernel debugging and attaching to RecEnv.exe
  - Requires turning off security features
  - Requires inserting the BitLocker recovery key every time
- Targeted user-mode debugging via DbgSrv.exe
  - Works without turning off security features

RecEnv.exe Debugging via DbgSrv

- **Run these commands from logged-in OS, as Administrator**

  - mkdir c:\mnt
  - reagentc /mountre /path C:\mnt
  - reg load HKLM\tempmount C:\mnt\windows\system32\config\system
  - reg add HKLM\tempmount\Setup /v CmdLine /t REG_SZ /d "cmd.exe" /f
  - reg unload HKLM\tempmount
  - reagentc /unmountre /path C:\mnt /commit
  - reagentc /disable
  - reagentc /enable
  - reagentc /boottore
  - shutdown –r -t 0

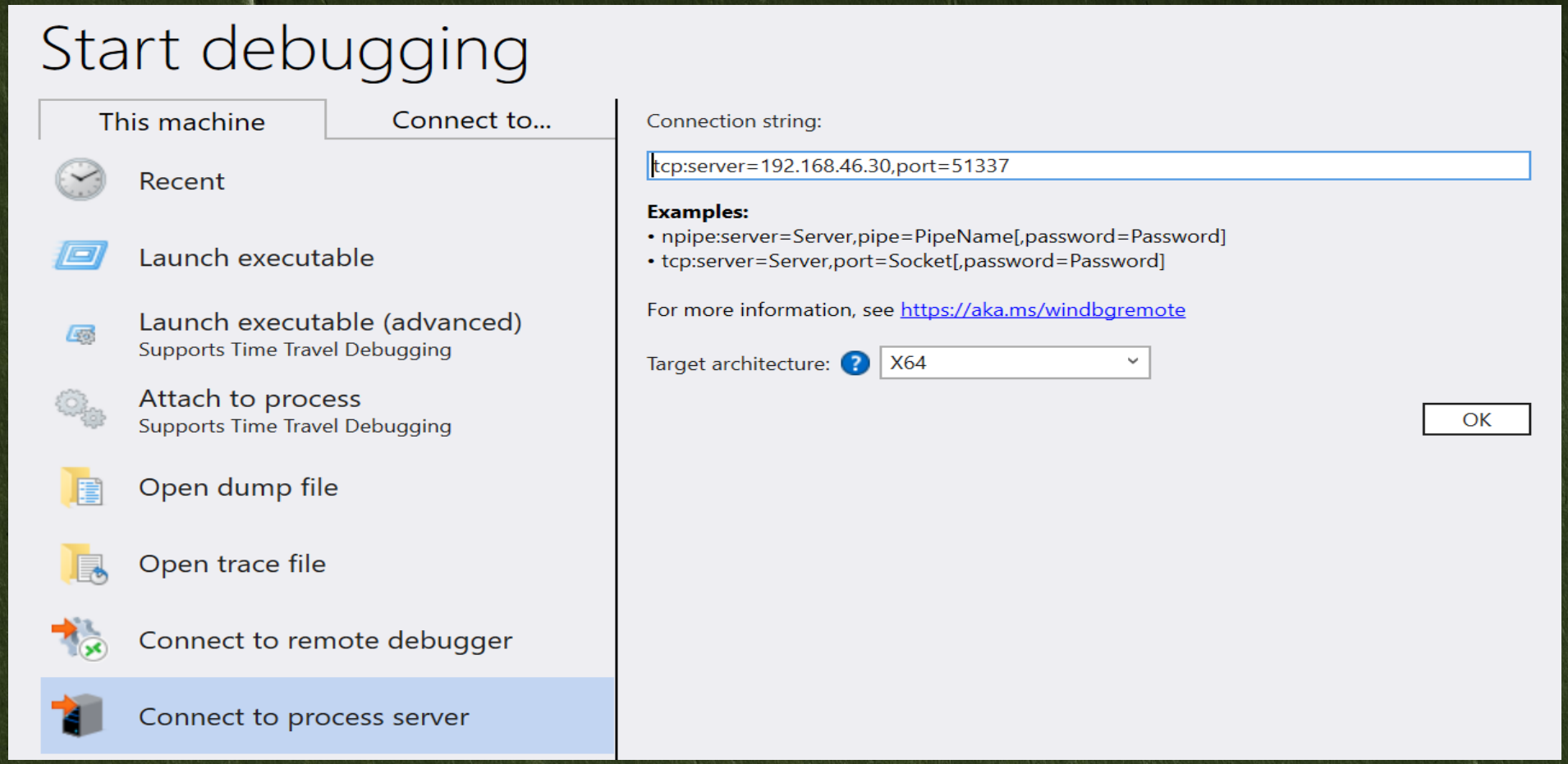
RecEnv.exe Debugging via DbgSrv

- Run these commands from WinRE spawned Command Prompt

  - wpeinit
  - wpeutil disablefirewall
  - D:\DbgSrv.exe –t tcp:port=51337

RecEnv.exe Debugging via DbgSrv

- Connect to the DbgSrv via WinDbg



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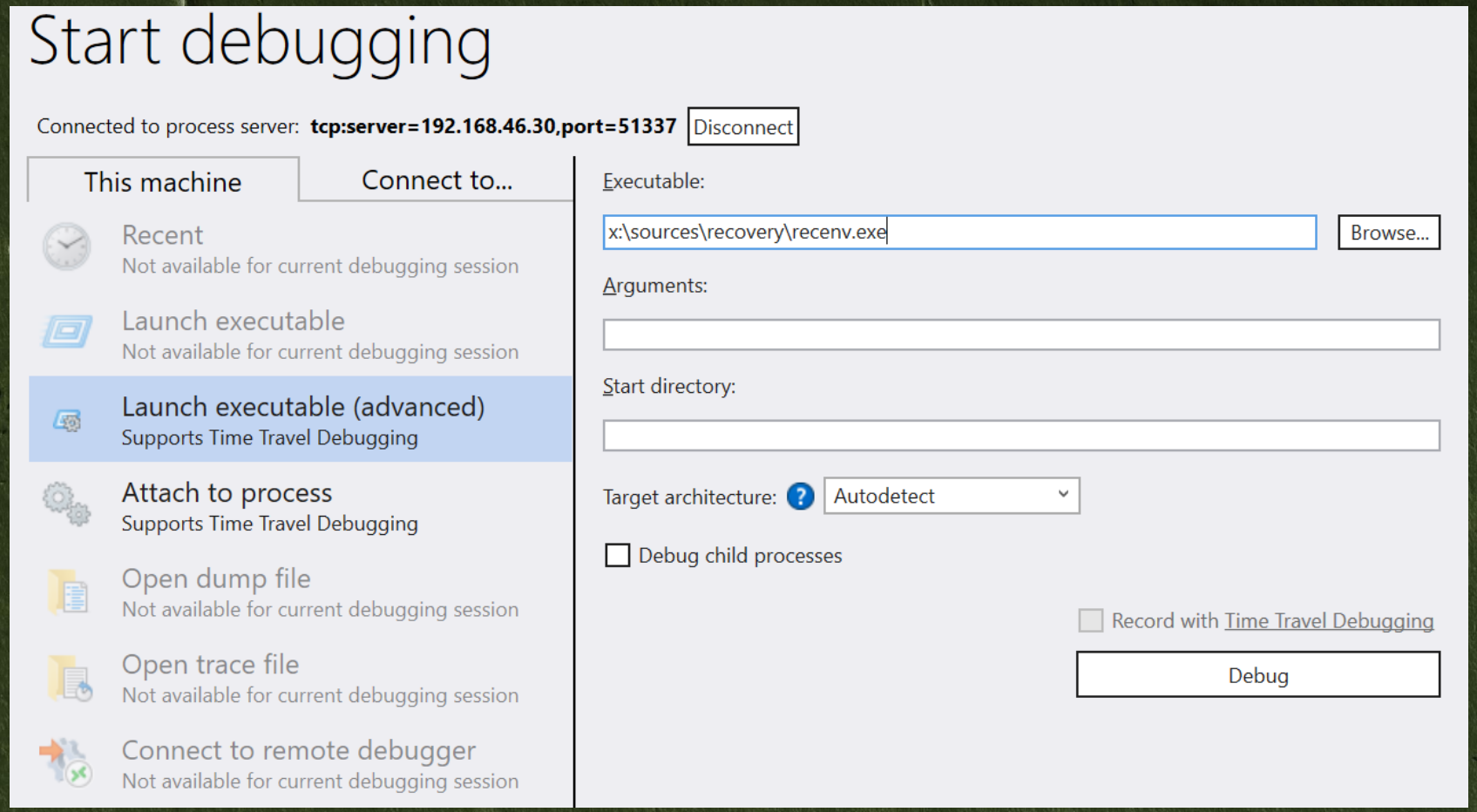
RecEnv.exe Debugging via DbgSrv

- Launch RecEnv.exe via WinDbg



Research Findings and Results

- We found 11 BitLocker bypasses originating from WinRE
  - CVE-2025-48001, CVE-2025-48003, CVE-2025-48800, CVE-2025-48804, CVE-2025-48818, CVE-2025-55330, CVE-2025-55332, CVE-2025-55333, CVE-2025-55337, CVE-2025-55338, CVE-2025-55682
- Fixes were shipped in July and October Patch Tuesday's
- Fuzzers were implemented to fuzz parsing of attacker-facing inputs
- Hardenings were implemented to harden and decrease exposed attack surfaces

Key Takeaway

Overlooked components can hide high-value security research opportunities

Thank You

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