Anti-RE Techniques in DRM Code

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Seminar on Advanced Exploitation Techniques
i4, RWTH Aachen, Germany

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Outline

1. Introduction
   - Legal Issues
   - About DRMs
   - Approaching the DRM
2. SEH Basics
   - Overview
   - Exception Dispatching
3. Anti-RE Techniques
   - Overview
   - Trampolines
   - Debug Registers
   - P-Code Machine
4. Decrypting the Content
   - The Algorithm
   - Demo

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Issues with this Talk

Legal Issues

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EFF to the Rescue!

- Electronic Frontier Foundation (EFF)[1]
- Non-profit organization dedicated to preserving free speech rights
- Discussed solution with Jennifer Granick from EFF (thx Jennifer!)
- Loophole in DMCA -> "Encryption Research"[2]
- But still too dangerous for me

Issues with this Talk (2)

Consequence

- Strip details about key setup and decryption algorithm
- Don't reveal identity of the DRM

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What it *IS*

- Show some not-so-common Anti-RE techniques
- Strategies to defeat Anti-RE

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What it *IS*

- Show some not-so-common Anti-RE techniques
- Strategies to defeat Anti-RE

What it is *NOT*

- How to hack the DRM from *********
- No tutorial for writing decryption tools

What's a DRM?

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  - Restrict access to content
  - Content encrypted
  - Decrypt online

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- Media key, hardware key, player key, content key...
- Obviously: every DRM can be broken

Possible Strategies (1)

Ultimate Goal

Find code for content decryption and the associated key setup

Obvious Approach

1. BPs on file I/O APIs (CreateFile, ReadFile, MMF)
2. Set BPM on filebuffer
   - either stops on copy operation
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Obvious approach impossible!

DRM System prevents this strategy by blocking the debug registers!

Possible Strategies (2)

Code Coverage

Runtime analysis to spot relevant code by recording execution of basic blocks / functions

Code Coverage Limitation

- Here: Impossible to find DRM code itself using code coverage!
- Gives some good starting points, though

Basic Approach Summary

Our Strategy

- Use code coverage to spot some places to investigate
- Use *obvious approach* to find decryption code

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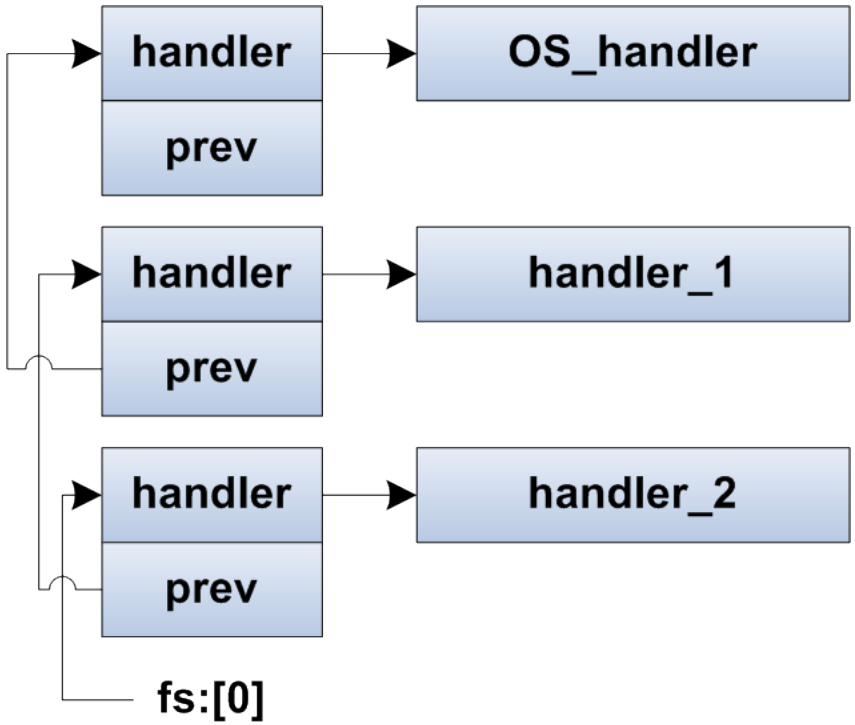
Windows SEH

Structured Exception Handling

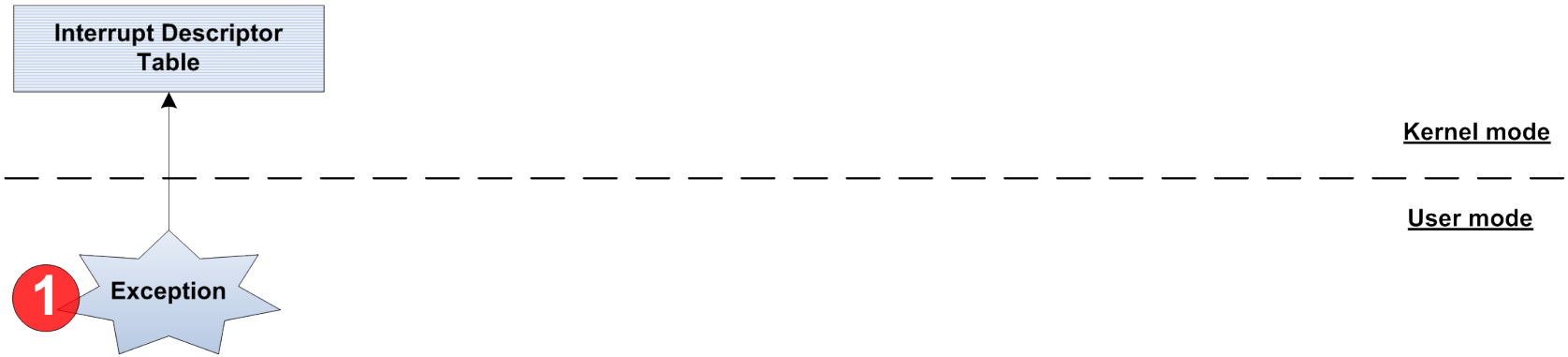
- Dispatch exception on a per-thread-basis
- Linked list of handlers starting at `fs:[0]`
- On exception OS walks list of faulting thread
- When called, a handler can:
  - Handle exception and ask OS to continue execution
  - Refuse to handle exception

SEH Handler

```
EXCEPTION_DISPOSITION _except_handler(_EXCEPTION_RECORD* ExceptionRecord,
                                      void* EstablisherFrame,
                                      _CONTEXT* ContextRecord,
                                      void* DispatcherContext);
```



SEH Handler Invocation



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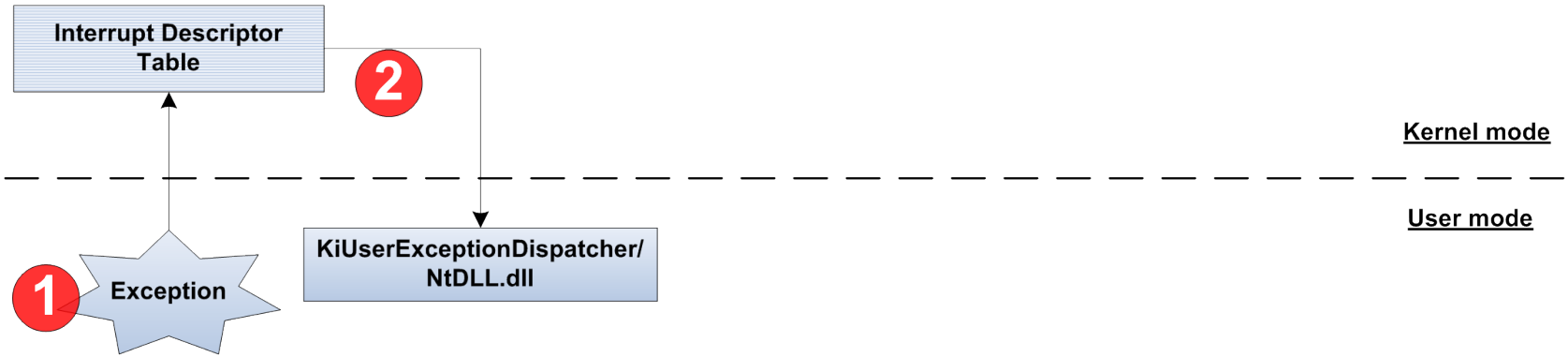

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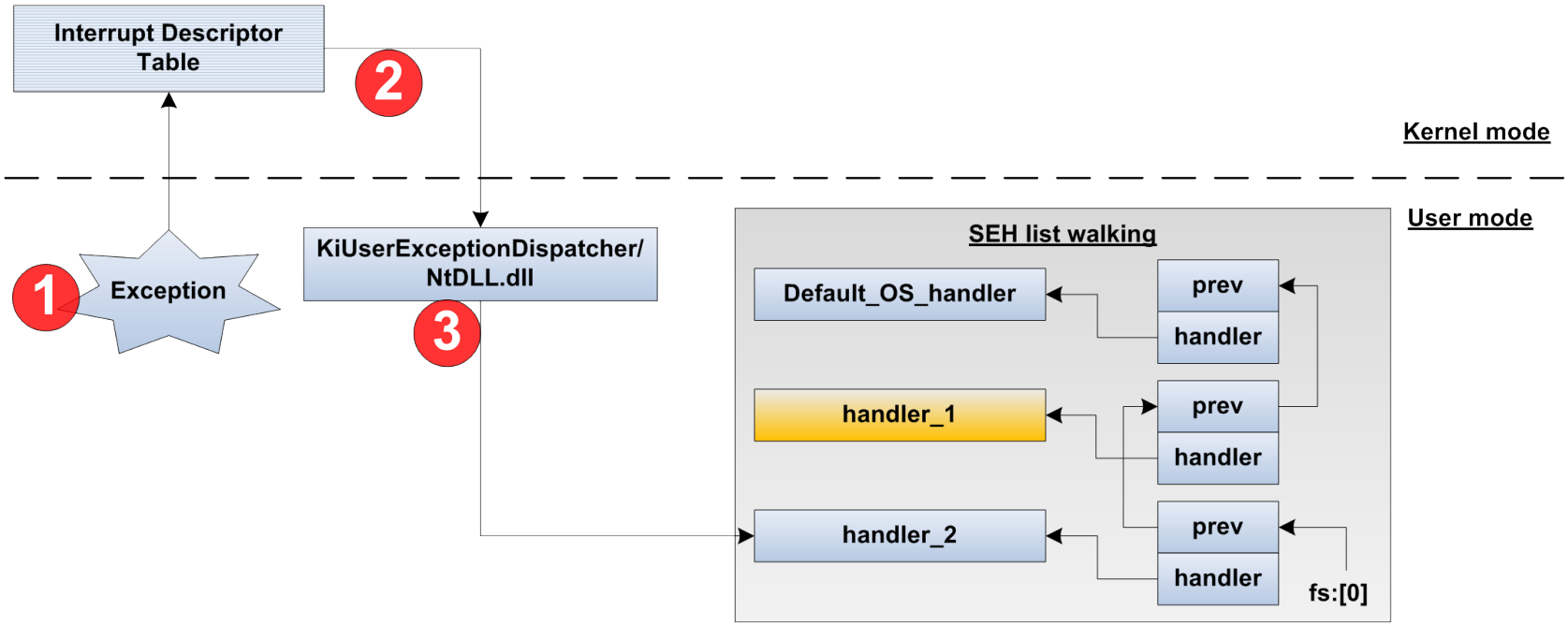

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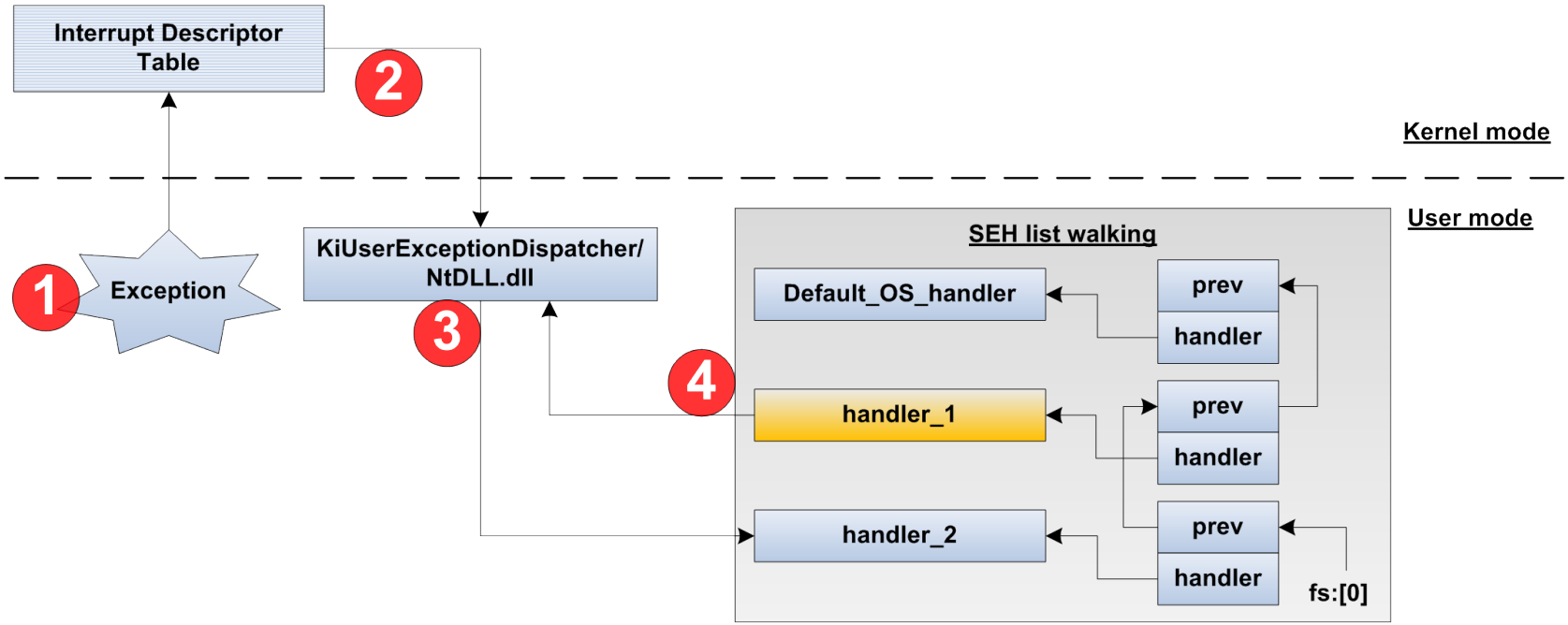

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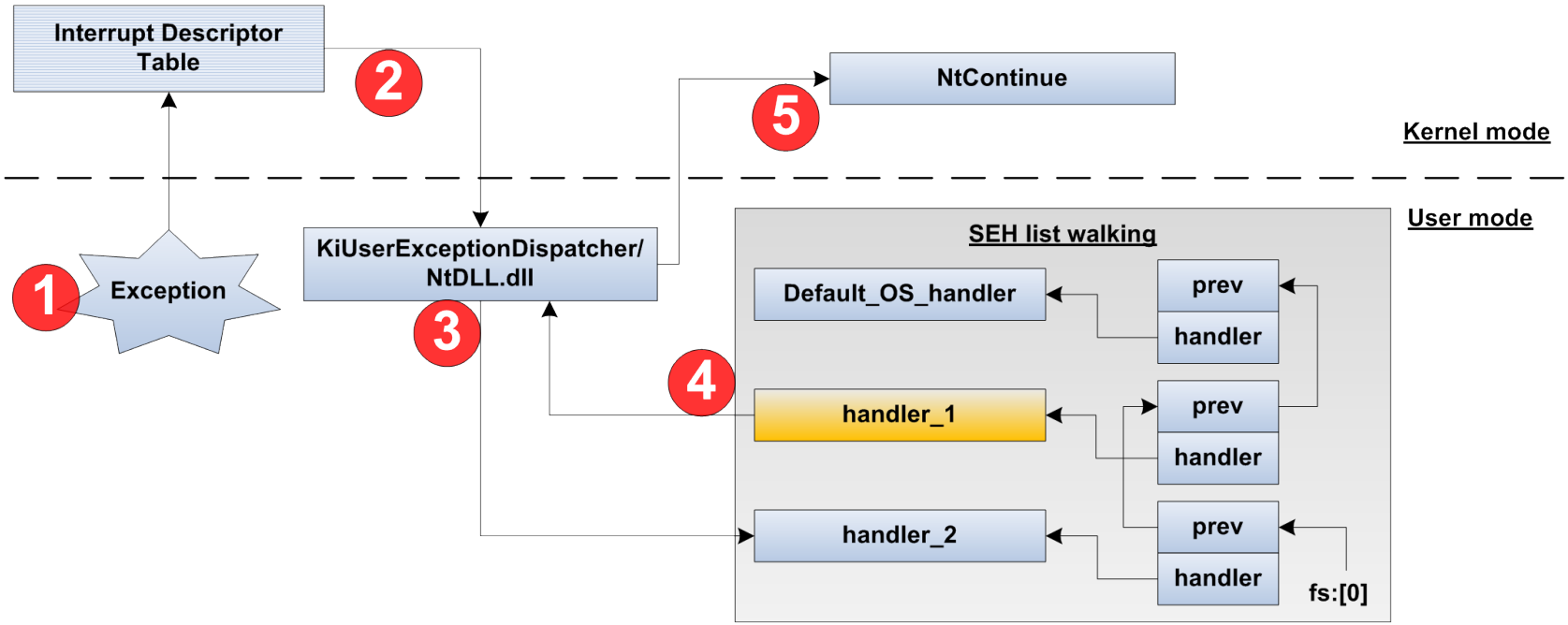

Remarks

SEH Handler Invocation

Simplified view, because

- No stack unwinding
- No collided unwind, nested exceptions
- Handler can decide not to return (C++, try...except)

But good enough for our analysis!

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The DRM Protection (1)

Control Flow Obfuscation

- Use fake exceptions to interrupt control flow
- Handlers change thread context
- Inter-/intra-modular calls through call tables
- Use dynamically allocated trampolines
- P-Code machine

The DRM Protection (2)

Anti-Debugging

- Check PEB flag
- Scan APIs for `0xCC`
- Usage of debug registers (no BPM/BPX)
- Special files contain code uncompressed at runtime
- Use fake exceptions to detect debugger

Trampolines Overview

Trampoline Definition

- Copy code at runtime to randomized location (`RDTSC`), execute from there

Trampoline Execution

1. Change control flow via fake exceptions (single step exception)
2. Exception handler modifies `EIP` based on debug register values
3. Execution resumes at next trampoline

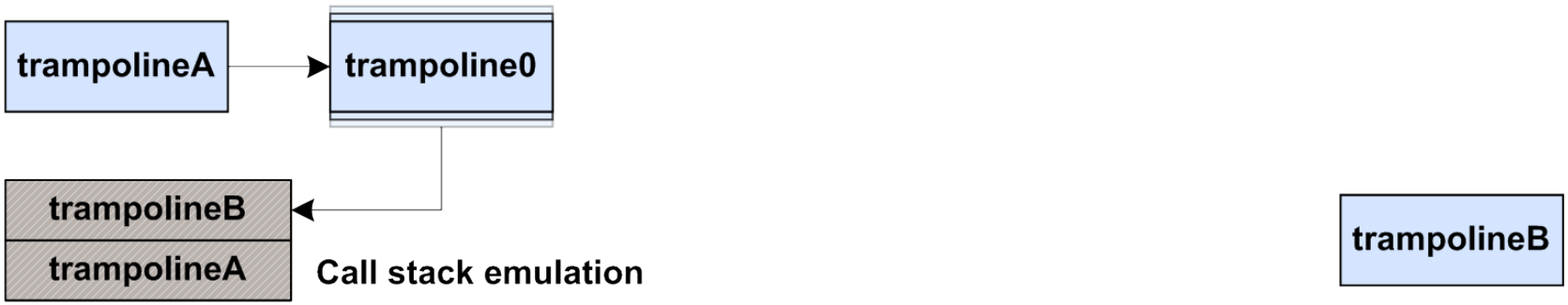
Trampoline Details



Trampoline Control Flow

- Trampoline A transfers control flow to trampoline B
- Control flow entirely depends on jumps and exceptions
- No `call` or `ret` instructions, no direct control flow between trampolines
- Therefore, a call hierarchy emulation is implemented

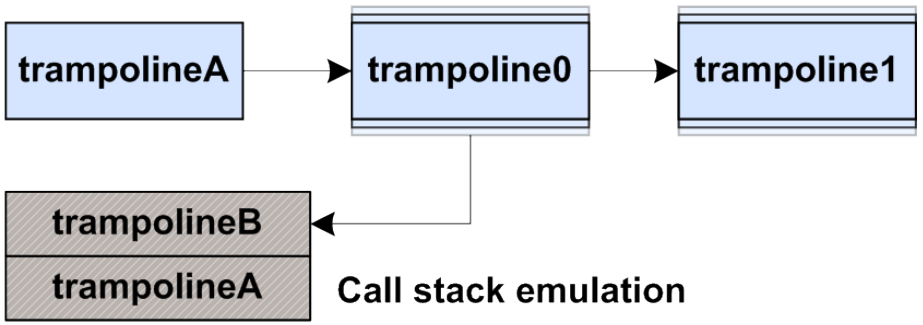
Trampoline Details



Trampoline0

- TrampolineA copies trampoline0 and jumps to it
- Trampoline0 manages internal call hierarchy
- Put destination trampoline on stack
- Copies next trampoline to random location

Trampoline Details

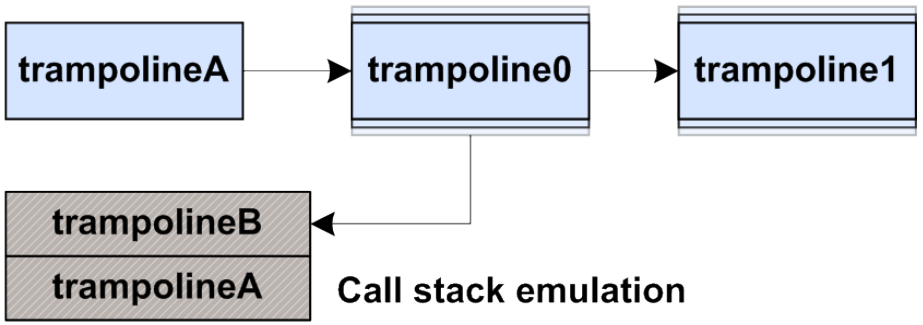




Trampoline1

- Copy trampoline0 to random location
- Install SEH frame and trigger single step exception

Trampoline Details





Trampoline1

- Copy trampoline0 to random location
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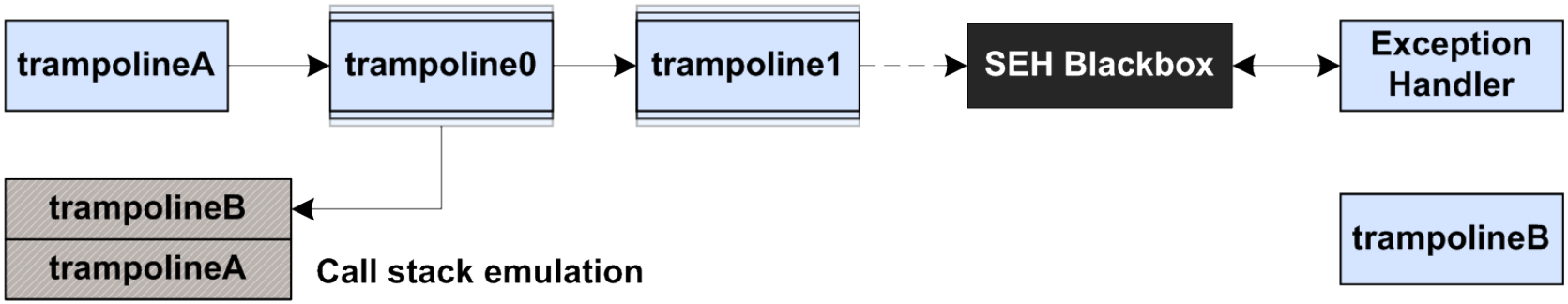
Trigger Exception

```
pushf
pop eax
or eax, 100h
push eax
popf
```

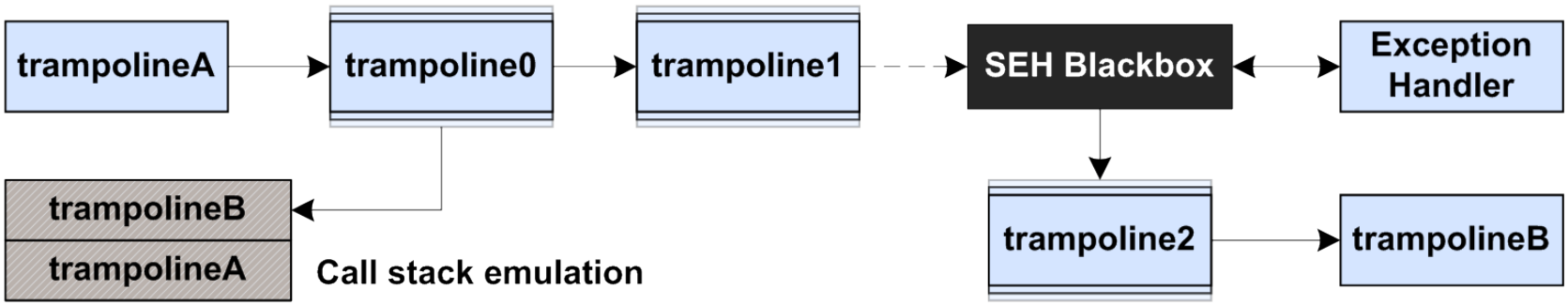
Trampoline Details



Exception Handler

- Changes EIP based on debug register values
- Clear TF bit, remove SEH frame, clean stack

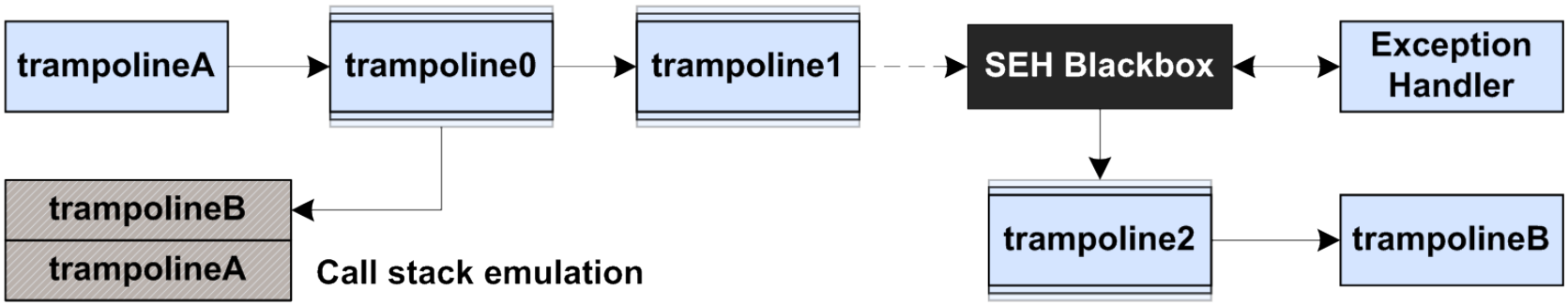
Trampoline Details



Trampoline2

- Copy destination trampoline
- Jump to destination trampoline

Trampoline Details



Call Stack Emulation

The `ret` instruction is emulated by a similar mechanism!

- Special exception handler removes trampoline from internal call stack
- Modifies context, execution resumes

More Trampoline Details

Use of the Debug Registers

- DR0 and DR6 are zeroed out
- DR1 contains pointer to a shared stack area to pass data between trampolines
- DR2 holds trampoline address, which is used to perform return emulation
- DR3 holds the address of the starting trampoline (trampoline0)
- DR7 is used to turn hardware breakpoints on and very frequently

Impact of Trampolines

Impact on RE

- Debugging pretty annoying, trampoline addresses jitter
- Control flow depends on DRs, so no BPM/BPX
- No call stack, i.e. back tracing difficult
- We can´t *execute until return*, difficult to tell who called us
- No direct *call* between subs, less X-Refs
- Absence of `ret` instructions confuses disassembler

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- Absence of `ret` instructions confuses disassembler
- But: Once understood we get perfect call stack

Ease Impact of Trampolines

Idea

- *Fix* trampoline addresses
- Use kernel mode driver

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Driver

1. Turn `RDTSC` into privileged instruction (`TSD` flag, `CR4` register)
2. Hook `IDT`
3. Return zero upon exception if
   - Exception from user mode
   - Instruction was `RDTSC`

   else jump to original handler

Reclaiming the Debug Registers (1)

Usage of DRs

- DRM system uses DRs for storage
- Uses `SetThreadContext` API
- Debugger cannot use hardware breakpoints (crash or no break)

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Strategy

But we need BPMs for our strategy!

Reclaiming the Debug Registers (2)

Use API Hooking

- Hook into Set/GetThreadContext API
- Redirect modifications to internal storage
- DRM System cannot modify DRs anymore!
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Really?

- Hardware breakpoints still don't work!
- Why?

Context Emulation

Problem

- Modification of `EIP` depends on DRs
- Two thread contexts: kernel mode vs. internal storage

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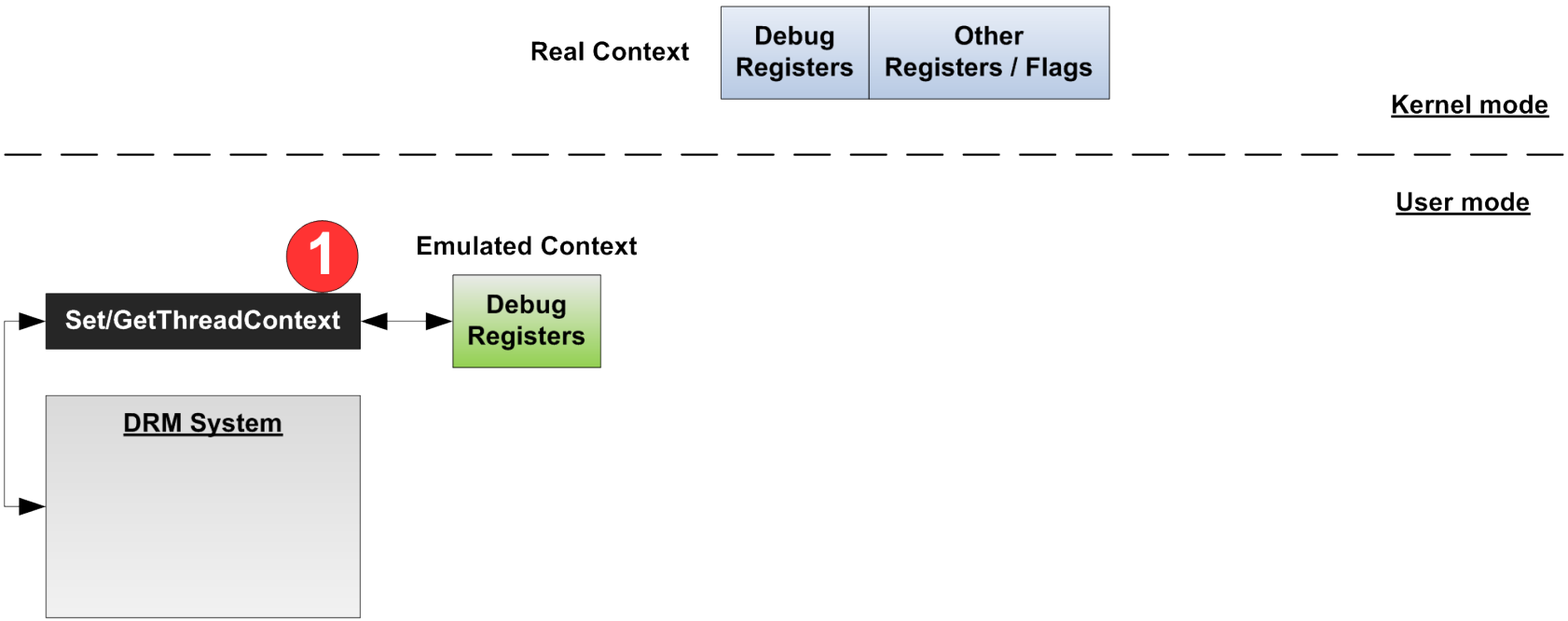
Hook KiUserExceptionDispatcher

If *fake exception*, execute re-implemented KiUserExceptionDispatcher:

1. Pass fake context, DR values from internal storage
2. On return copy modifications to real context
3. Apply context via `NtContinue`

KiUserExceptionDispatcher - Re-implemented



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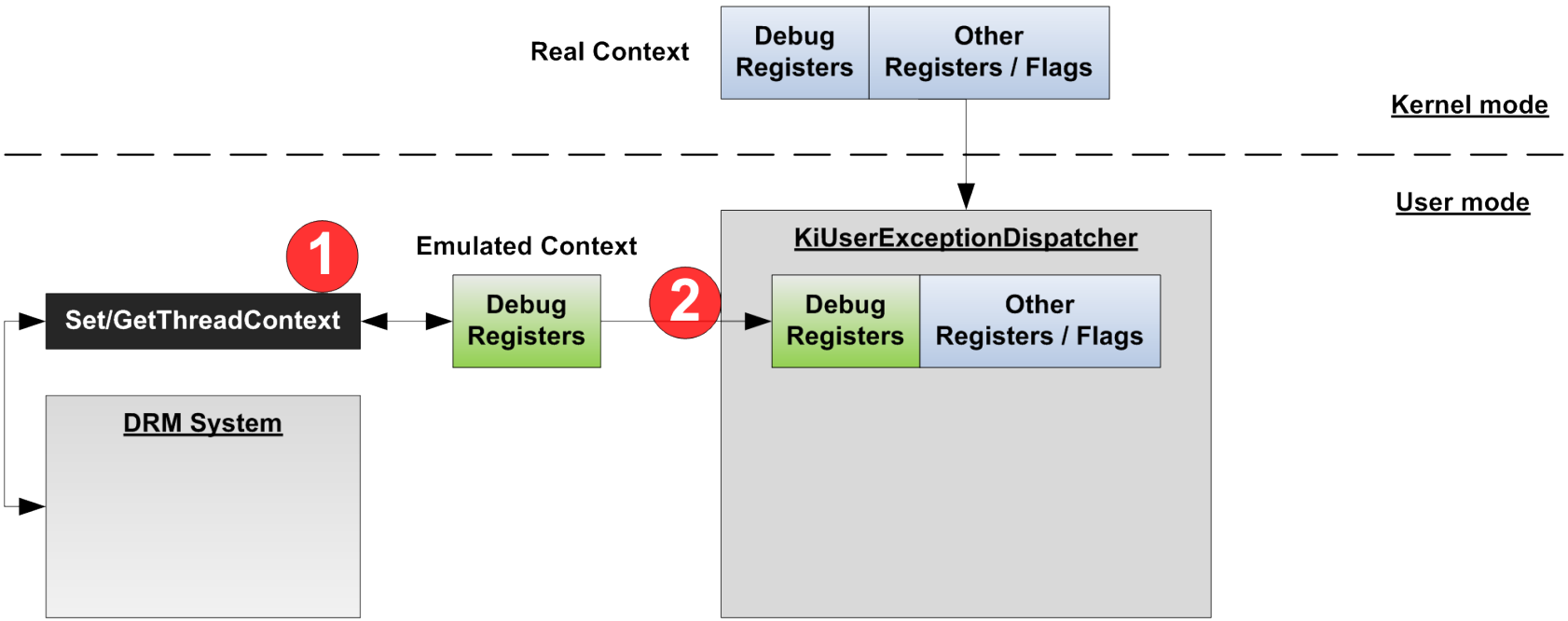

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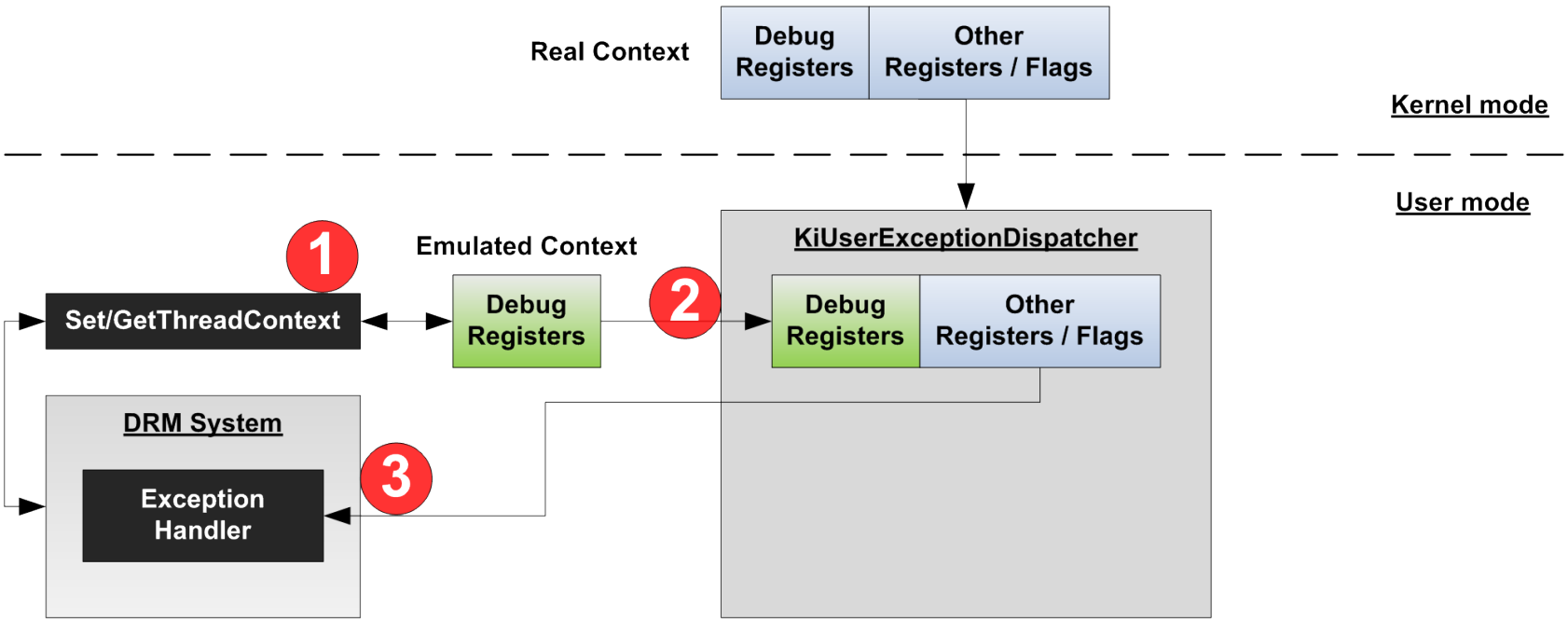

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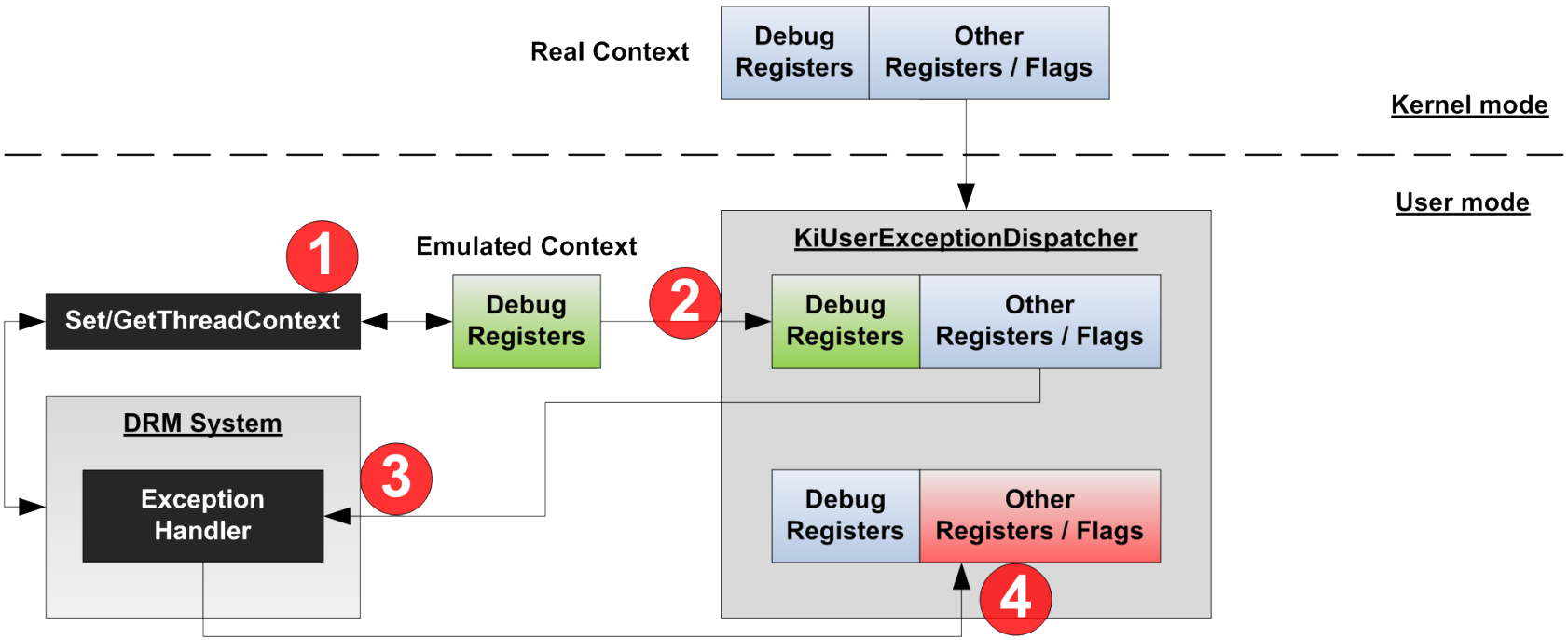

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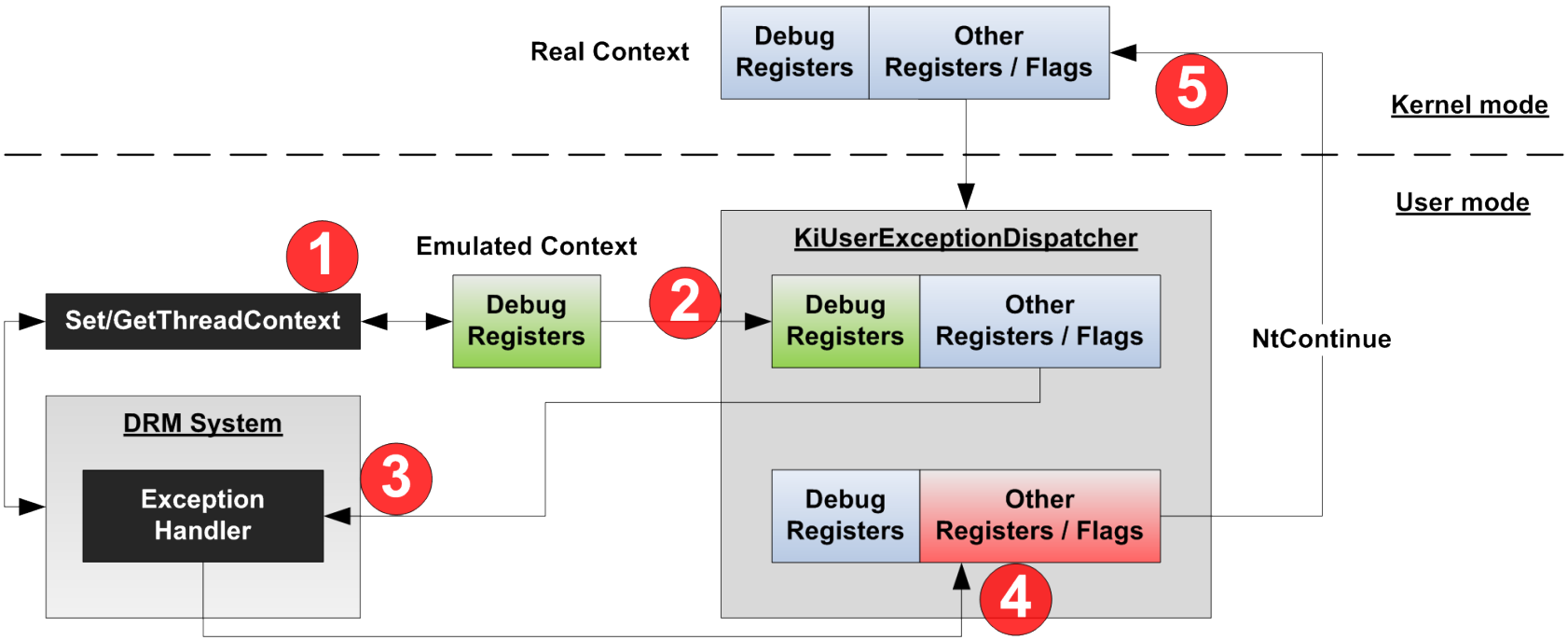

Summary

Situation after Countermeasures

- DRM System cannot modify DRs - API hook
- Exception handler gets expected values - KiUserExceptionDispatcher patch
- Our debugger can use hardware breakpoints!
- Implementation available as IDA plugin (IDA Stealth[3])

P-Code Machine Overview

Machine Properties

- Stack based with result register
- 256 fixed size opcodes (1 byte)
- Opcodes interleaved with data (ASN.1)
- Allocate memory in host machine
- High-level opcodes (load opcodes, call into other modules, music decoding)
- Low level opcodes, emulate virtual CPU

Loading of Opcodes

Opcode Module Files

- Special module which contains P-Code machine
- Contain native code + opcodes
- Decompressed at runtime
- No PE, no IAT, no sections, etc.
- Relocation table + some fixed imports (MSVCRT)

Obfuscation in the P-Code Machine

Executing Opcodes

- Per-module random pool
- Randomize opcode <-> opcode handler
- Descramble opcodes with PRNG in machine
- Garbage data interleaved with opcodes
- Data parsed via ASN.1

Impact of the P-Code Machine

Static RE Difficult

- Understand machine itself first
- Different meaning of opcodes per module
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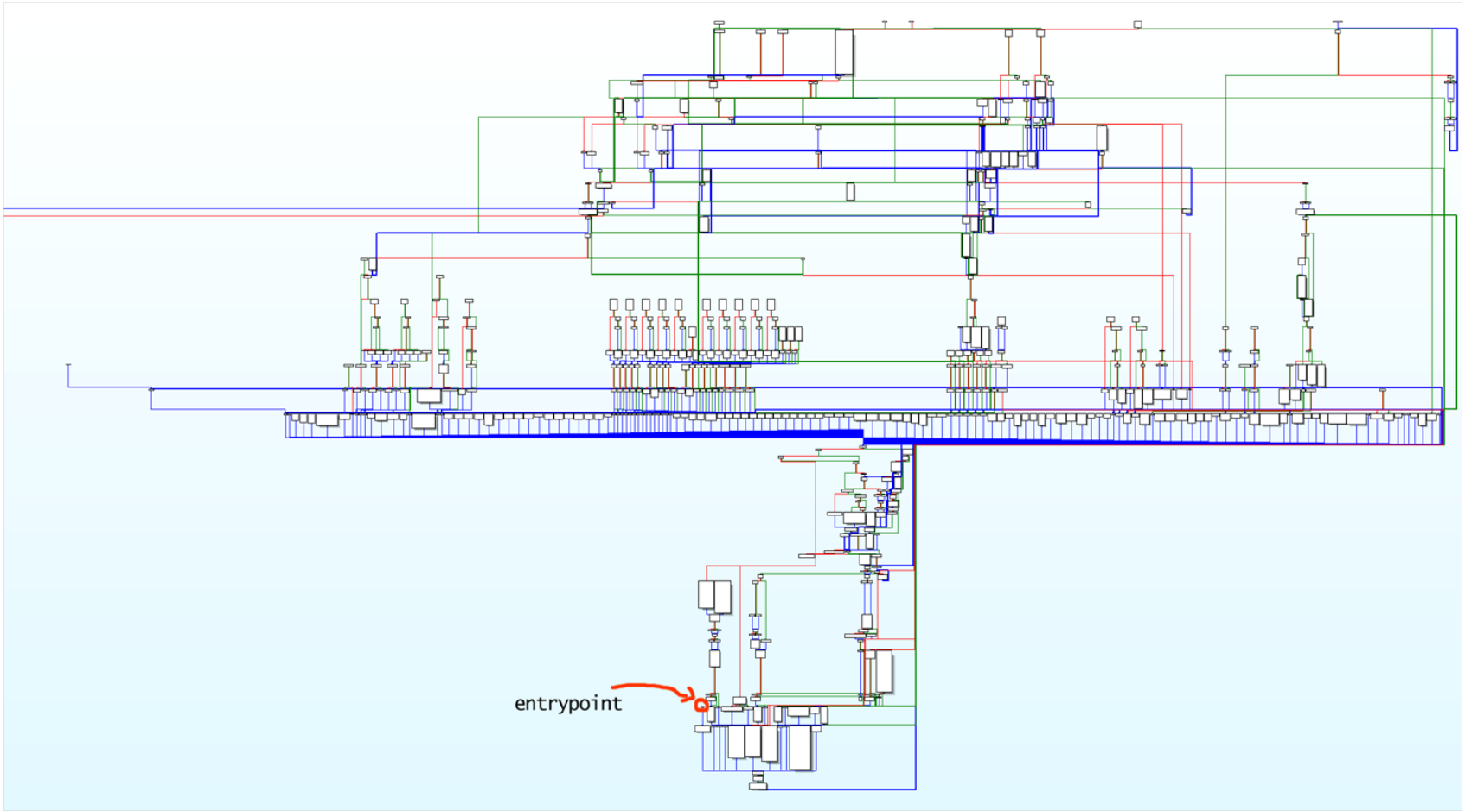
Debugging Difficult

- Low signal to noise ratio (big "handler loop")
- Even lower due to opcode descrambling

P-Code Machine in IDA



Strategies to find Decryption Algorithm + Keysetup

1. Write custom Disassembler (*Expensive Strategy*)
   - Many handlers
   - Long and complex high level handlers
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   - Single-step via debugger script
   - Slow, but reaches code writing key
   - Not so clever

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   - Not so clever
3. Use emulation (*Cool Strategy*)
   - Use CPU emulation (PyEmu[4], x86 Emu for IDA[5], ...)
   - Fast, very flexible

Strategies to find Decryption Algorithm + Keysetup

4. Use BPMs / Attack machine memory (*Lazy Strategy*)
   - Use what we have
   - Exploit machine memory management
   - Filebuffer size 0x1800, DES keyschedule size 0x80
   - Set BP, fire when keysetup memory allocated
   - Set BPM, fire when keysetup written
   - Back-trace from there

Strategies to find Decryption Algorithm + Keysetup

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Keen Disappointment

Decryption and keysetup in native code! High-level handlers!

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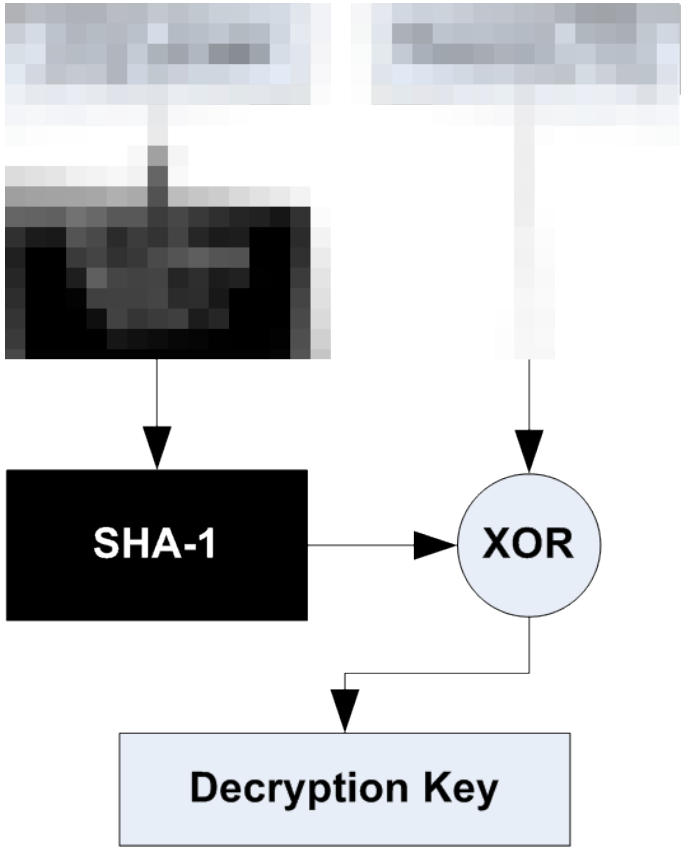
Keysetup Algorithm

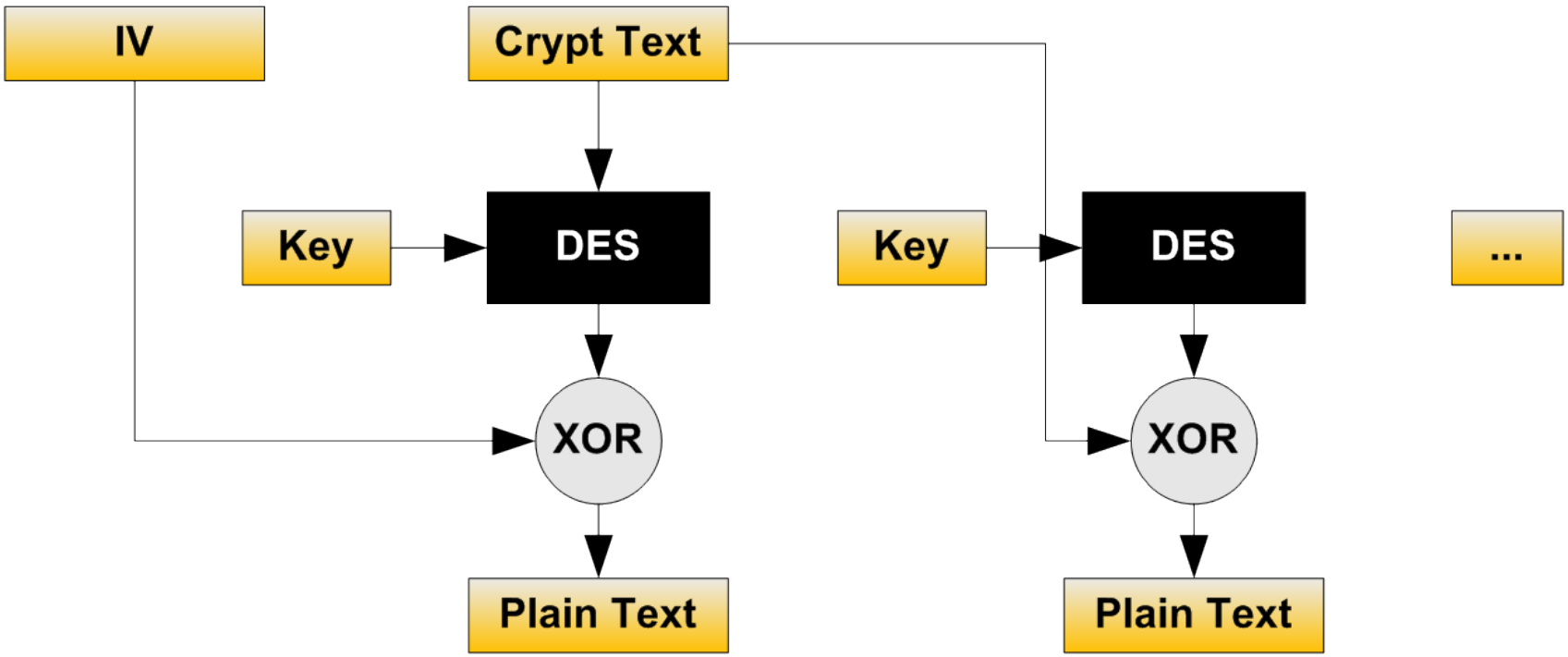
Key Derivation

- Hash some files
- Use different hash algorithms
- Different key for every music file



Decryption Algorithm

- Decrypt content with DES-CBC (Cipher Block Chaining)
- IV from DRM file



Demo

Demo

or

"Han shot first!"

Conclusion

Summary

- Overall: good protection
- BPMs led us to success, P-Code machine almost useless!
- Implementation weaknesses

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Room for Improvements

1. Transform more native code to P-Code
2. Make P-Code machine more complex (nesting, polymorphic handlers, self-modifying machine, ...)
3. Improve (very) weak debugger detection
4. *Use* DRs, let control flow depend on BPM/BPX firing
5. ...

Thanks for your Attention!

Questions?

Contact: jan.newger@newgre.net


Electronic Frontier Foundation.
Electronic Frontier Foundation.
http://www.eff.org/.


DMCA.
DMCA Encryption Research Paragraph.
http://www.law.cornell.edu/uscode/html/uscode17/usc_sec_17_00001201----000-.html.


Jan Newger.
IDA Stealth.
http://www.newgre.net/idastealth.


Cody Pierce.
PyEmu: A Multi-Purpose Scriptable x86 Emulator.
http://dvlabs.tippingpoint.com/team/cpierce.


Chris Eagle.

The x86 Emulator plugin for IDAPro.

http://www.idabook.com/x86emu/.