Patch Developer Manual

revision 239

https://0patch.com

Contents

1. Introduction

Welcome to the *crowdpatching* community! We're extremely happy about your interest in writing patches with 0patch. Whether you want to patch vulnerabilities or functional bugs, or you need some way to correct code flow during your reverse engineering efforts, 0patch aims to be the tool for you. We hope you'll use it to solve your, and many other people's problems.

This document will show you how to set up your environment for writing patches, explain basic mechanics of 0patch, and provide many guidelines and hints to get you started.

It is assumed that you are already familiar with 0patch Agent in terms of its user interface and general functionalities. If not, it is highly recommended that you read the 0patch User Manual available at https://0patch.com/user_manual.htm.

2. 0patch Agent for Developers

0patch Agent for Developers is a slightly modified version of *0patch Agent* (which is meant for production) and also includes a toolset needed for building your own patches. Much like *0patch Agent*, *0patch Agent for Developers* gets updates from the 0patch server when a new version becomes available. You cannot have both *0patch Agent for Developers* and *0patch Agent* installed on the same computer at the same time.

Specifically, *0patch Agent for Developers* differs from *0patch Agent* in the following ways:

1. *0patch Agent for Developers* comes with *0patch Builder*, our tool for compiling 0patch source files (*.0pp* files) into patch blobs that can get immediately applied to your local processes.
2. *0patch Agent for Developers* doesn't validate signatures on patch blobs before applying them to newly-launched or running processes. This allows you to create patches locally on your computer and also test them there without having them signed. In contrast, *0patch Agent* requires a patch to have our valid signature before applying it. Signatures are still being validated on all agents for patches that get delivered from the 0patch distribution server – we don't want you to get pwned by someone breaking into the server ;)
3. *0patch Agent for Developers* registers a 0patch icon for `.0pp` files so that you can visually identify your patch source files, and adds two actions to the Explorer menu for *.0pp* files: "Build Patch" and "Build+Debug Patch". More on these later.
4. *0patch Agent for Developers* automatically sets breakpoints on patchlet `JMP`s in WinDbg using the `.ocommand` instruction, provided that WinDbg has the correct magic word set.

3. Security Notes

Being interested in writing your own patches, you are likely sensitive to the state of security of any software you install on your computer, and any risks it brings with it. As such, here are some things you need to know about *0patch Agent for Developers*.

1. 0patch Agent for Developers does not verify digital signatures for patches when applying them to local processes. (If it did, you wouldn't be able to apply your own patches as you don't have the signing key.) As a consequence, local malware with administrative privileges[1] could store a malicious patch in the 0patch database and achieve its own persistence by using 0patch Agent for injecting malicious code into a system process such as `winlogon.exe`.
2. Beware of malicious *.0pp* files. 0patch Builder by design supports launching an executable specified in a *.0pp* file with a debugger. Inspect every *.0pp* file from an untrusted source before executing "Build + Debug" on it.
3. Beware of debugging potentially malicious processes with "Build+Debug". To allow for automatic setting of breakpoints, 0patch Builder instructs WinDbg to accept external commands from the debuggee via `.ocommand`. This means that a malicious debuggee (potentially running as a low-privileged user) could instruct WinDbg (potentially running as admin) to execute an external application with arbitrary parameters, thereby elevating its privileges. If you want to debug a malicious process, either debug it manually (not via "Build+Debug") or manually change the `.ocommand` magic word.
4. Current update procedure doesn't (yet) preserve your "unofficial" patches in the local 0patch database. Updating *0patch Agent for Developers* (when an update becomes available) will delete your own patches from the local 0patch database. (Yes, we're working on that.) Should this happen, you can simply re-build the patches from your *.0pp* files after the Agent has been updated.

4. Patches and Patchlets

0patch currently supports patches that inject X86 or X64 machine code at a desired offset in a Windows binary, and optionally jumps over a selected number of bytes to effectively remove one or more original machine code instructions in said binary.

Each patch applies to **exactly one** binary, namely the binary that has the exact crypto hash specified in the patch. (Note that you don't see this hash in the *.0pp* patch source file as patch file only specifies the path to the binary while 0patch Builder calculates the hash for you.)

A patch comprises one or more *patchlets*; each patchlet defines the code to be injected at a specific offset from the binary's base address, an optional number of original code bytes to jump over (to

[1] Yes, we know, local admin malware means game over anyway, but still…

implement removal of original code), and an optional list of functions to import from selected binaries in order to be able to call them from the patchlet code.

Some patches - like those for typical buffer overflow vulnerabilities - only need a single patchlet, while some others – like those for typical use-after-free vulnerabilities – need more than one.

Each patch has a globally unique ID, and each of its patchlets has a patch-wide unique ID. As a rule of thumb, patchlets should be identified sequentially with IDs 1, 2, 3, etc. While a patch ID needs to be globally unique when deployed to the 0patch distribution server for distribution to agents around the World, you can use any unused patch ID during local patch development. We usually give patches under development IDs above 10000 to avoid conflict with existing patches that arrive from the distribution server. (This will obviously have to be revised as the number of official patches starts to grow.)

5. Patching Guidelines

Writing a patch is a delicate endeavor. You will be changing existing machine code that was almost certainly generated by a compiler; this is good in terms of recognizing compilers' coding patterns, and bad because compilers heavily optimize the code and make it more difficult to match it to the source code (should you happen to have it).

You will first have to understand the nature and context of the bug you're about to patch to the point of being able to say: "Okay, I now know exactly what the problem is," and then find a way to reliably and efficiently fix the bug. There will generally be more than one way to fix the bug, and you will want to find the one that has the least impact on the original code while fixing the problem in its entirety without allowing ways to bypass it and – importantly! - without breaking anything. In general: the less patch code the better, the fewer patchlets the better.

Always keep in mind that you're a guest in a likely huge and complex code base that you can't possibly understand as well as its original developers, and your only job is to put a plug in a tiny hole without causing any problems to original inhabitants or making their existing problems worse. This means, for example:

1. If you change a CPU register or a local variable, you have to make sure to restore it to its original value before letting the original code continue – unless you can prove that the original code will not use that value any more. (E.g., if you change `ecx` and the original code executing after your injected patch code also changes `ecx` before ever using it, it's okay not to restore it.)
2. If you make a call to some function from your patch code, you need to either completely understand its side effects (e.g., modifying registers, using blocking operations that might cause deadlocks, taking time that could cause timeouts in some other code waiting for the patched code to finish, etc.) and prove that they are inconsequential, or make sure to

neutralize these side effects (e.g., by storing relevant registers on stack before the call and restoring them after the call).

3. Take as little space as possible. Your patch code must be trivial to review by anyone understanding the bug and looking at your patch. It's not called "micropatching" for nothing. Also, do write many comments in your patch code: any instruction can be decorated with a comment using a semi-colon.

Sometimes understanding the problem or figuring out the way to fix it will take you a long time (especially if you're not experienced in reverse engineering), and sometimes this will frustrate you and make you want to give up. We're planning to release lots of material to help you with both stages of patching (you can already find some on our blog at https://0patch.blogspot.com), and we're building a patching community you'll be able to turn to for help.

6. Injecting a Patchlet

When 0patch Agent injects a patchlet into the original code, it overwrites 5 bytes of the original code with a 5-byte `JMP` instruction that transfers code execution to the patchlet code. This is a process well known from function hooking, where one or more original machine code instructions from the very beginning of a function are copied (»relocated«) to another place in memory (called a »trampoline«), while their original location is overwritten with a `JMP` instruction to injected code (in our case: patchlet code). The patchlet code ends with a `JMP` to the trampoline in order to execute the relocated original instructions, and the trampoline is then completed with a `JMP` back to the first original code instruction after the relocated instructions.

0patch takes traditional hooking to a higher level by:

1) supporting the injection almost anywhere[2] in the code, not just at the beginning of functions;
2) removing (jumping over) any number of original code instructions after the injection point, allowing you to effectively replace existing code with your patch code, or remove flawed code.

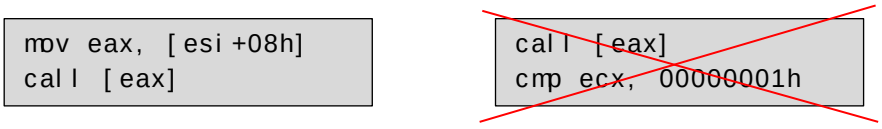
[2] Not all original instructions can be relocated to a trampoline; refer to section »Suitable Places for Injecting a Patchlet«.

7. Suitable Places for Injecting a Patchlet

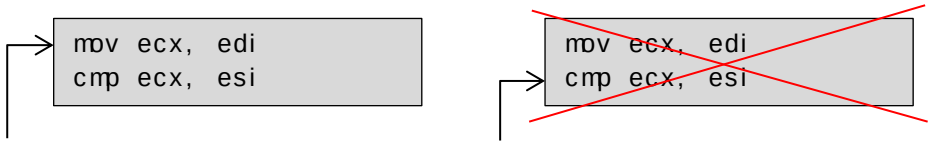
For several reasons, a patchlet cannot be injected just anywhere in the code:

1) Some original instructions cannot be safely relocated to another address. For example, a short `JZ` with a single-byte operand at address `10000000h` cannot be relocated to address `20000000h` because the recalculated relative jump offset from the new address would not fit into that single byte. The same goes for two-byte jumps, so we can only relocate 4-byte (32-bit) jumps. This also applies to relative `CALL` instructions with 2-byte (16-bit) operands. (We're planning to provide support for all these cases in the future by replacing short relative jumps and calls with 32-bit alternatives that can reside anywhere in the memory.)

2) A call instruction can only be safely relocated if it is *the last* relocated instruction; it is possible that at the moment of patching, one of the threads would be inside a relocated call (possibly already several further calls deeper down the call stack) and when it returns, it has to return to the original instruction that was there when the call was executed. If the relocated call is the last relocated instruction, we can be sure that instructions immediately after it on its original location are intact and can be safely returned to. However, if another instruction after the call was relocated to trampoline, it would mean that this instruction was also at least partly overwritten by `JMP Patchlet`, so returning to it from a thread currently executing the relocated call would result in executing unwanted code, almost certainly causing functional problems. On the left image below is a suitable code block to inject at, on the right an unsuitable code block, because the call is not the last to-be-relocated instruction.



3) Original instructions that are a destination of any jump or call elsewhere in the original code can only be safely overwritten with our 5-byte `JMP Patchlet` instruction if they are *the first* relocated instruction (as that would result in the said jump or call transferring execution to `JMP Patchlet` which would be okay). Any non-first overwritten original instructions must not be a destination of any jump or call, as such jump or call would end up executing unexpected code in the middle of the `JMP Patchlet` instruction. We recommend using some powerful disassembler (e.g., IDA) to determine whether original instructions at your potential patch location happen to be a destination of any jump or call.



4) Absolute calls and jumps can be safely relocated.

5) 32-bit relative calls can be safely relocated as we're recalculating their offset operands to work at their relocated address.

8. Patchlet Import Table

If needed, a patchlet can make calls to functions - for instance, Windows API functions or functions in the module it is patching. This is done by having desired functions imported to the *Patchlet Import Table* (PIT) using the `PIT` keyword. Let's look at some examples of imported functions in a patchlet injected into `myapp.exe`.

```
PIT user32.dll!MessageBoxW,myapp.exe!0x7798
```

The above instruction makes two functions available to the patchlet (note their names start with "`PIT_`" to avoid confusion with local labels):

1. `PIT_MessageBoxW`: The `MessageBoxW` function exported from Windows' system library `user32.dll`, and
2. `PIT_0x7798`: Location at offset `0x7798` from `myapp.exe`'s base. This can be very useful in case your patchlet implements some sanity check (e.g., for excessive height or width of an image) and the appropriate response would be to leave the patched function: using an import like this allows your patch to simply jump to the function epilog instead of having to replicate said epilog, usually comprising several `POP` instruction, `ESP` manupilation and a `RET`. Note that while you can use this notation to reference non-exported functions/locations from any binary, it is only safe to reference locations from the binary you're patching, as this guarantees that you're using the correct version of binary. You wouldn't want to reference a non-exported function from some DLL that might be different on another user's system.

In addition, there is one other function that is always available for calling from patchlet code:

3. `PIT_ExploitBlocked`: If you call this function (it takes no arguments), 0patch Agent will display an "Exploit Attempt Blocked" popup to the logged-in user. While the dialog requires manual closing, this function is not blocking and returns as soon as it sends out an instruction to show the popup. (The popup is displayed by 0patch Tray.)

Some guidelines for using imported functions:

- Avoid calling functions if possible. Any function call is likely to significantly increase the amount of code executed by your patch.
- The most safe-to-use functions are those from the module that is being patched, either exported functions or functions you specify by offset from the module base. That module's code is namely always guaranteed to be the same on all computers, as the patch will not get applied if the module's hash does not match the hash specified in the patch.
- It may sound safe to import functions from the main executable of the patched process (e.g., you're patching `lib.dll` that gets loaded by `app.exe`, and you want to import a function from `app.exe`). But there are risks here: What if another executable also loads `lib.dll` and your patchlet can't find an exported function from `app.exe`? Worse yet, what if you're importing a function from offset `0x888` from `app.exe`, and then an update replaces `app.exe` but leaves `lib.dll` intact? Your patchlet will still get applied to `lib.dll` and will call a "function" at offset `0x888` into `app.dll` – this will likely not be the function you intended to call but rather some random code.
- Even for the safest of function calls, you have to be sure that the binary you're importing a function from is already loaded when the module you're patching is loaded (so that the imported function will already be there), and that it will remain loaded until the process exits (so that you don't end up calling a function in an already-unloaded module, and crash).
- Be aware that Windows API functions may behave differently on different Windows versions (and even between service packs or monthly updates). Some functions may even only exist on newer Windows versions: `RemoveDllDirectory`, for instance, only exists on Windows 8 or later and Windows Server 2012 or later. Note that a patch will not get applied unless all imported functions from all its patchlets can be found.
- When a patched module is loaded, all its patches are copied to an internal cache, and at that time, all PIT addresses are calculated based on the current base of the modules they refer to. For example, if PIT includes `lib.dll!function`, the address of function in `lib.dll` is determined using `GetProcAddress` and stored to the PIT. This introduces some risks you need to consider:
    - If `lib.dll` gets unloaded at a later time, PIT will point to an invalid address and executing the patch code will result in a crash.
    - If `lib.dll` is not yet loaded in the process when we find it in PIT, 0patch loader will force load it – which will result in its `dllmain()` function getting executed, provided it has one. This may have unexpected results as this function may assume it

will only get executed after some other initialization has taken place, and that may not be the case now.

- If `lib.dll` is not yet loaded in the process when we find it in PIT, 0patch loader calling `LoadLibrary("lib.dll")` may result in a binary planting vulnerability.

9. Anatomy Of a Patch File

A *.0pp* patch file is formatted in the following way:

- **Patch data** section: This section specifies the main parameters for the patch, such as patch ID, the binary it patches, the vulnerability ID, and whether it's a 32-bit or 64-bit patch. This section is followed by one or more patchlet sections.
- **Patchlet** section**:** This section, beginning with `patchlet_start` and ending with `patchlet_end`, specifies two things:
  1. the main parameters for the patchlet, such as patchlet ID, offset for injecting the patchlet code, optional number of bytes of original code to jump over and optional imported functions the patchlet code is going to call;
  2. patchlet code, beginning with `code_start` and ending with `code_end`, contains patchlet's assembly code in the NASM[3] format

The following image shows an actual *.0pp* file for the *Foxit Reader FlateDecode Use-After-Free* vulnerability ZDI-16-392[4]. You can see that it begins with a Patch data section, which is followed by two Patchlet sections. (We patched this use-after-free vulnerability by sabotaging the *free* and marking the not-freed buffer with a "`BADBAFFA`" marker, then catching this marker at *use* and preventing its use.)

[3] http://www.nasm.us
[4] http://www.zerodayinitiative.com/advisories/ZDI-16-392/

```
MODULE_PATH "C:\Program Files (x86)\Foxit Software\Foxit Reader\FoxitReader.exe"
PATCH_ID 250
PATCH_FORMAT_VER 2
VULN_ID 1448
PLATFORM win32
```

Patch data

```
patchlet_start
  PATCHLET_ID 1
  PATCHLET_TYPE 2
  PATCHLET_OFFSET 0x00493AB6
  N_ORIGINALBYTES 5
  JUMPOVERBYTES 2

  code_start
    jz RETURN    ; if ecx is 0, return
                 ; (remember that the last instruction before entering this patch
                 ; code was "test ecx, ecx", and that the JZ we removed was just
                 ; going to jump to retn, which we can do here as well
    cmp dword [ecx+8], 0xBADBAFFA    ; does ecx point to a previously "freed" buffer?
    jz RETURN                        ;if so, return
    jmp RESUME
  RETURN:
    retn
  RESUME:

  code_end

patchlet_end
```

Patchlet 1

Patchlet code

```
patchlet_start

  PATCHLET_ID 2
  PATCHLET_TYPE 2
  PATCHLET_OFFSET 0x00495663
  N_ORIGINALBYTES 5
  JUMPOVERBYTES 5; we eliminate the 5-byte call to free as we will write BADBAFFA to it

  code_start
    mov dword [esi], 0xBADBAFFA  ; instead of freeing esi, we write BADBAFFA to it
  code_end

patchlet_end
```

Patchlet 2

10. Patch File Keywords

Patch Data		
Keyword	**Mandatory**	**Description**
RUN_CMD	No	Full path to the executable you want to have launched when selecting “Build+Debug” from the shortcut menu on a *.Opp* file. 0patch Builder will launch this executable

		in WinDbg debugger.
MODULE_PATH	Yes	Full path to the binary to be patched. 0patch Builder calculates a crypto hash from the content of this file and stores both filename (without path) and this hash to the patch blob. The patch will only be applied to binaries with the same name **and** the same hash.
PATCH_ID	Yes	Unique identifier for this patch. If a patch with this ID already exists in your local 0patch Agent's database, that patch will be overwritten with this one when you build it.
PATCH_FORMAT_VER	Yes	The only supported format version at this time is **2**.
VULN_ID	Yes	ID of the vulnerability this patch is fixing. If a vulnerability with this ID exists in your local 0patch Agent's database, its title and CVE ID will be shown in the 0patch Console and on 0patch popups. If you don't know this ID, we recommend using some arbitrary large value such as 10000.
PLATFORM	Yes	**win32** for 32-bit binaries or **win64** for 64-bit binaries

Patchlet Data

Keyword	Mandatory	Description
PATCHLET_ID	Yes	Unique identifier for this patchlet inside the patch. Make sure that each patchlet in a patch has a different ID; we recommend using 1, 2, 3…
PATCHLET_TYPE	Yes	The only supported patchlet type at this time is **2**.
PATCHLET_OFFSET	Yes	Offset from the base of the module where the patchlet is to be injected. The patchlet gets injected **before** the instruction at this offset, while the said instruction (and if needed, subsequent instructions) gets relocated to another place in memory where it will be executed after the patchlet code. This value can be either in hex (0xAAAAAAAA format) or decimal (AAAAAAAA format). We recommend using hex format.
N_ORIGINALBYTES	No	The number of original bytes at the PATCHLET_OFFSET location that get verified before the patchlet is applied. Default value is 5, which is all bytes overwritten by our "jump to patchlet" instruction. The only use cases for setting this value we know of are:

		1) injecting at a location of a JUMP or CALL that gets relocated by Windows according to the PE relocation table (in this case we set `N_ORIGINALBYTES` to 1 as only the instruction code is constant); 2) injecting at a location where the to-be-patched code does not exist in its final form at module load time – e.g., is either decrypted or decoded after the module loads (in this case we set `N_ORIGINALBYTES` to 0).
`JUMPOVERBYTES`	No	The number of bytes of the original code we want to jump over (i.e., effectively remove) after the execution of patchlet code is completed. Default value is 0, which means we want to keep all of the original code. If you set this value, you must make sure that the number of bytes you specify corresponds to the actual length of original instructions from the `PATCHLET_OFFSET` location forward. For instance, you can use `JUMPOVERBYTES 3` for jumping over two instructions `xor eax, eax` (2-byte instruction) and `inc esi` (1-byte instruction) located at `PATCHLET_OFFSET`.

`PIT`	No	Patchlet import table – allows you to specify exported functions or offset-based locations, either in the module you're patching or some other module. Format is:
		
		`PIT`
		`<module_name1>!<function_name_or_offset1>,`
		`<module_name2>!<function_name_or_offset2>,`
		`...`
		
		See section 8 for more information.

`code_start` `code_end`	Yes	Non-empty patchlet code (to be injected right after the original code instruction at `PATCHLET_OFFSET`) must be located between these two keywords; the code must be in NASM format as it's being compiled by NASM.

11. Building A Sample Patch

This section will guide you through the process of building a sample patch. You'll need the following setup before you begin:

1) **A Windows computer with one of the following Windows versions**[5]:
   a. Windows 10 64-bit
   b. Windows 8.1 64-bit
   c. Windows 7 64-bit
   d. Windows 7 32-bit
   e. Windows XP 32-bit

2) **The latest version of *0patch Agent for Developers*** must be installed and registered on your computer. You can download the agent installer from https://dist.0patch.com/download/latestagentdev. After successful installation, you will be prompted to register your agent when the 0patch Console is launched for the first time. Use your existing 0patch account credentials if you already have one, or register a new account at https://dist.0patch.com/User/Register.
   (Note that if you currently have *0patch Agent* installed, you will need to manually uninstall it and install *0patch Agent for Developers*; while they share much of the code base, these are two distinct products. If unsure about which Agent you have installed, look at its version number: if the last five digits look like "2xxxx", it is *0patch Agent for Developers*, otherwise it is the production *0patch Agent*.)

3) ***0patch Agent for Developers sample package*** must be unpacked on your computer in a folder of your choice. The package can be downloaded from https://0patch.com/files/DevAgentSamplePackage.zip.

4) **WinDbg must be installed** if you want to use the "Build+Debug" feature. On 64-bit systems, we recommend installing both 32-bit and 64-bit WinDbg. We are officially supporting the following WinDbg versions[6]:
   a. WinDbg 6.12.2.633 on pre-Windows 7 systems
   b. WinDbg 6.3.9600.16384 on Windows 7 and newer systems

5) **System-wide `WinDbgDir_` environment variable(s)** must be set if you want to use the "Build+Debug" feature:
   a. On 32-bit and 64-bit systems, `WinDbgDir_x86` environment variable must be set to the directory of 32-bit `windbg.exe`; for the default installation location of 32-bit WinDbg 6.3.9600.16384, you can use the following command to set this variable:

[5] Other Windows versions back to Windows XP and Windows Server 2003 likely work as well, although we have experienced problems with deploying a patch to registry on Vista.
[6] Other WinDbg versions are likely to work well too, but there may be some differences in options, flags or features that could cause incompatibility issues.

```
setx WinDbgDir_x86 "C:\Program Files (x86)\Windows Kits\8.1\Debuggers\x86"
```

b. On 64-bit systems, `WinDbgDir_x64` environment variable must be set to the directory of 64-bit `windbg.exe`; for the default installation location of 64-bit WinDbg 6.3.9600.16384, you can use the following command to set this variable:

```
setx WinDbgDir_x64 "C:\Program Files\Windows Kits\8.1\Debuggers\x64"
```

Having all the above, you're ready to start. Let's go!

Step #1: Launch SmokeTest_x86.exe

`SmokeTest_x86.exe` (part of the sample package you have downloaded) is our sample executable that does one thing only: it pops up a "Hello World!" message box. Double-click this executable and notice the message, then close it.

Step #2: Build a patch

`ZP-SmokeTest_x86.0pp` is a patch source file for patching `SmokeTest_x86.exe` by simply injecting a call to `PIT_ExploitBlocked`, which should result in displaying a 0patch "Exploit Attempt Blocked" popup when the test executable is executed.

Right-click on `ZP-SmokeTest_x86.0pp` and select "Build Patch". A command interpreter (`cmd.exe`) window shortly appears, then a UAC prompt is displayed asking your permission to launch Registry Editor. Confirm the UAC prompt. The command interpreter window closes.

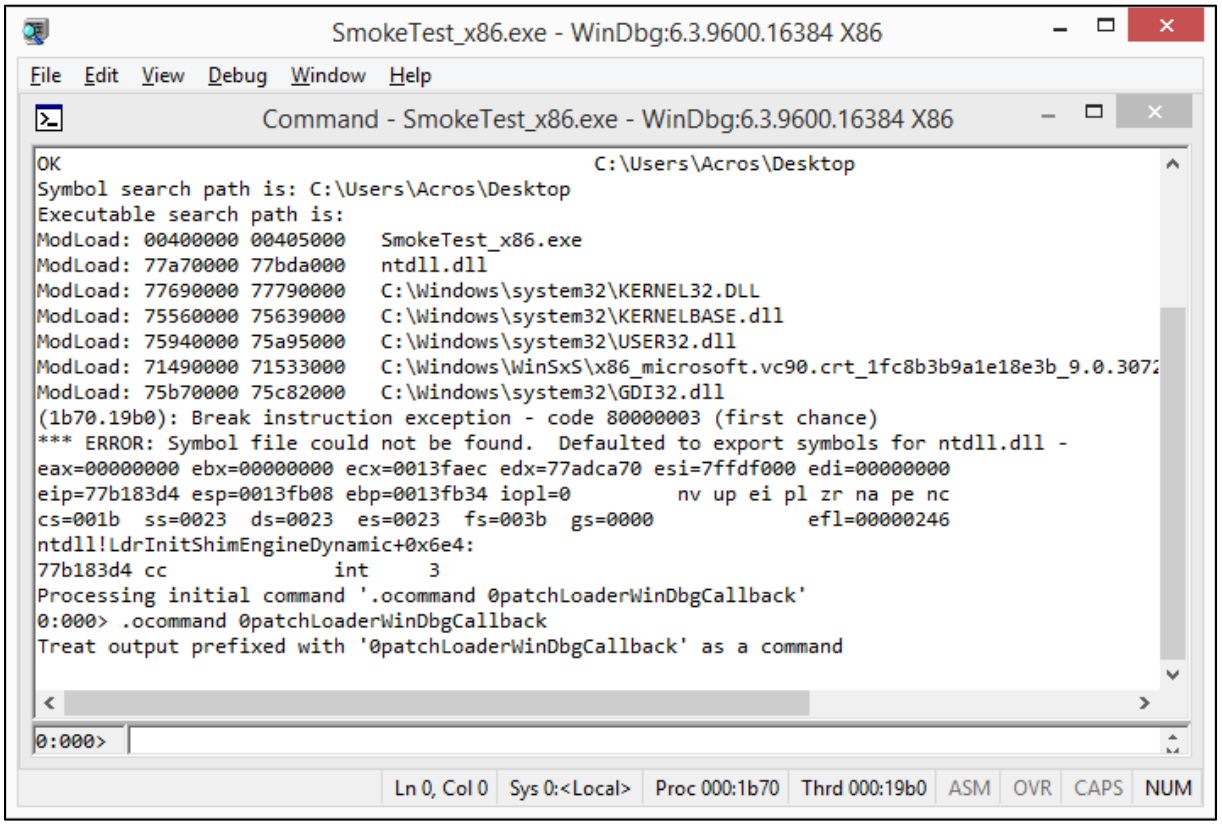
If everything went well, you have just created a patch with ID 20000 for `SmokeTest_x86.exe`. Open the 0patch Console and find patch #20000 at the end of the list in the "PATCHES" tab. You'll be able to disable and enable this patch there from now on.

Step #3: Launch patched SmokeTest_x86.exe

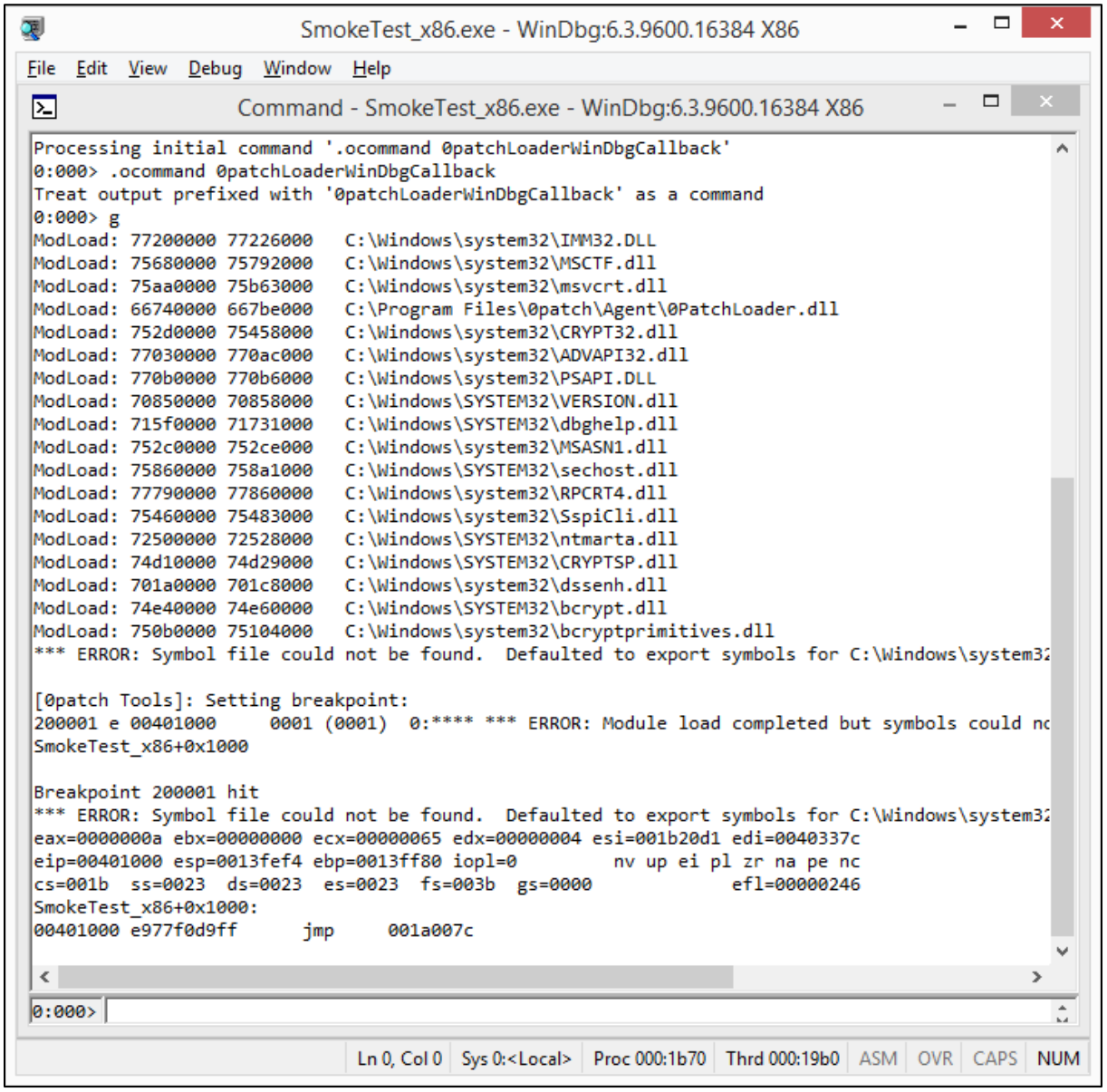
Double-click `SmokeTest_x86.exe` and notice that, in addition to the "Hello World!" message box, an "Exploit Attempt Blocked" popup also appears as a result of your patch injecting a call to `PIT_ExploitBlocked` in the code of the testing executable.

Step #4: Build + Debug a patch

Right-click on `ZP-SmokeTest_x86.0pp` and select “Build+Debug Patch”. A command interpreter (`cmd.exe`) window shortly appears, then a UAC prompt is displayed asking your permission to launch Registry Editor. Confirm the UAC prompt. The command interpreter window closes and WinDbg is launched, attached to a newly-launched `SmokeTest_x86.exe`, as shown on the image below.

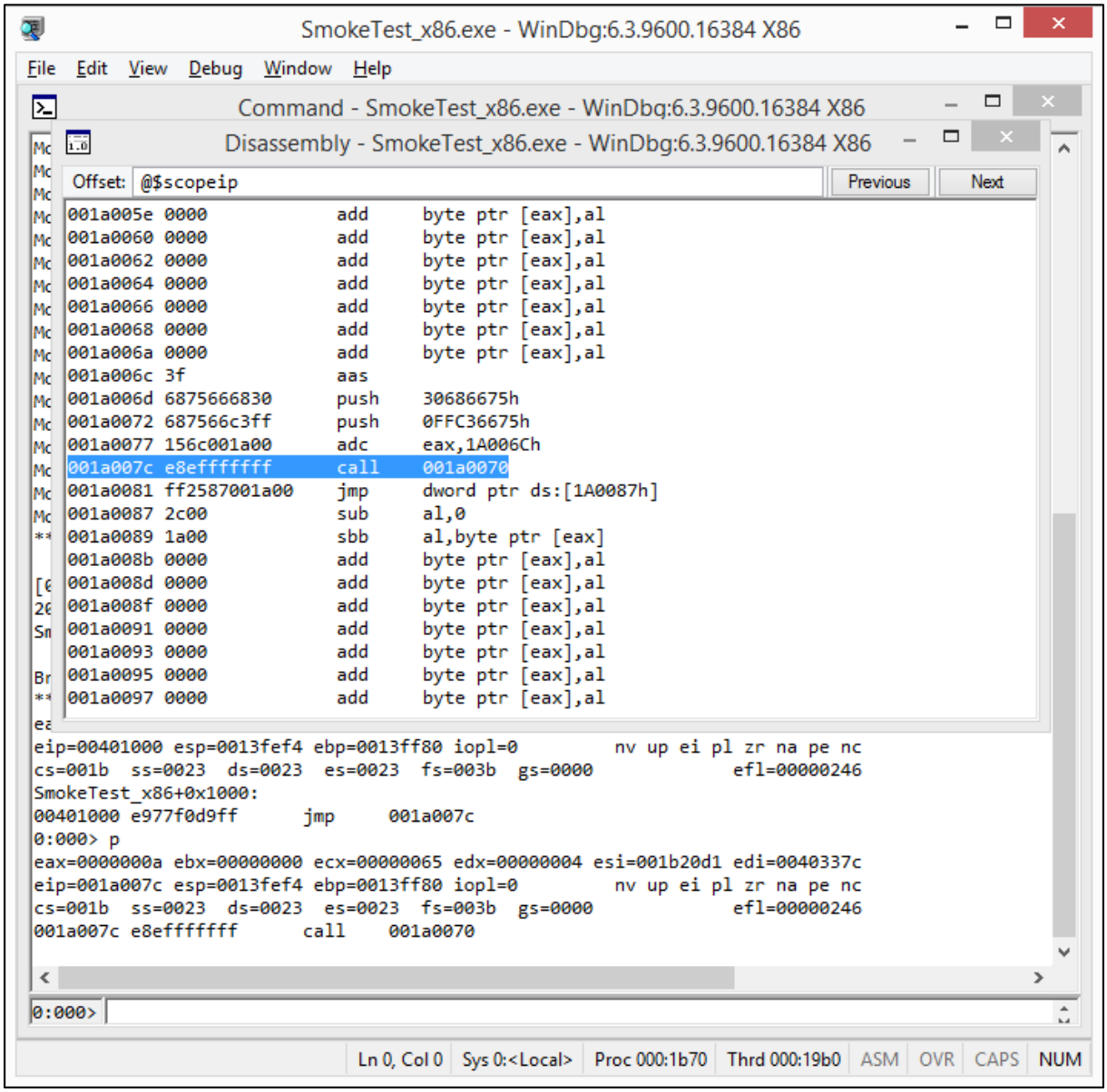


Make sure the focus is on WinDbg's Command window and press F5; WinDbg should continue with execution and stop on breakpoint 200001 at a `JMP` instruction, as shown on the image below. This is the exact `JMP` instruction 0patch Agent has put in the original code to inject the patchlet code.



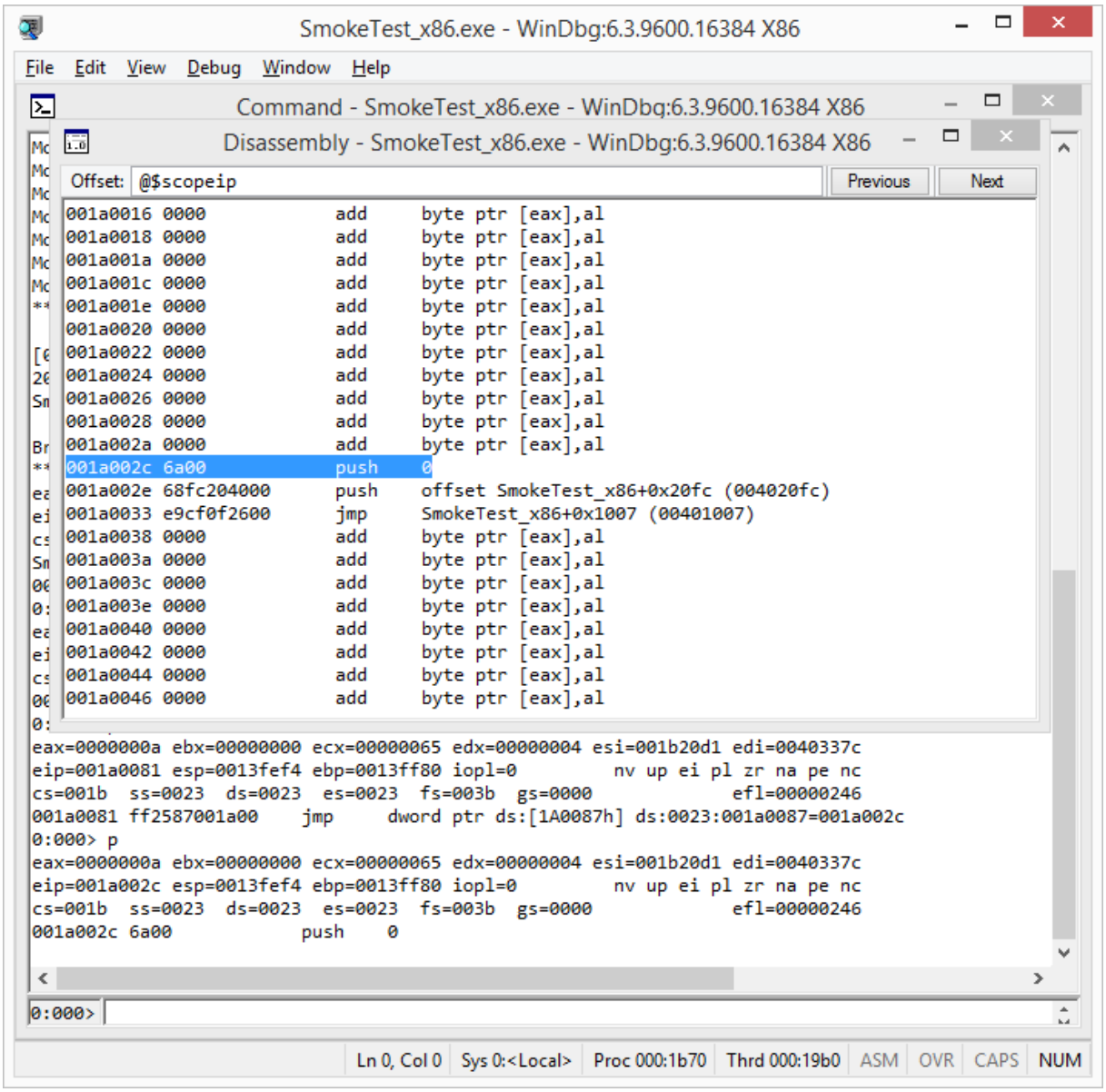
As you can see, WinDbg first received an external command (via `.ocommand` from 0patch Agent running inside the debuggee) for setting breakpoint #200001 at location `0x00401000`, which is the location where we inject our patchlet code. Subsequently, as execution continued, this breakpoint was hit.

Step over the `JMP` instruction to get into the patchlet code, as shown on the image below. As you can see, the patchlet code consists of a single call (to `PIT_ExploitBlocked`), after which there if a `JMP` to the original instructions that were relocated before the Agent overwrote them with the `JMP` to patchlet code.



Step over the `CALL` to see the “Exploit Attempt Blocked” popup.

Finally, step over the `JMP` to see how execution continues with the relocated original code. As you can see on the image below, the original code consists of two `PUSH` instructions; 0patch Agent had to relocate them both as the first one takes up only 2 bytes and the `JMP` to patchlet code needs 5 bytes. After the relocated `PUSH` instructions, you can see a `JMP` to the original code immediately following the original location of these two relocated instructions.



12. Final Notes

If you're as passionate about fixing vulnerabilities as we are, you will want to get to the point of writing production-quality patches that can actually be distributed to millions of endpoints around the World and potentially applied even before the attackers had enough time to build reliable exploits. We're working hard on building the infrastructure to allow you to submit your patches for an independent quality and security review, and finally have them distributed to users for a decent compensation.

Do let us know about your experience with building patches. We'll appreciate your suggestions, ideas, criticism and bug reports, as well as words of encouragement. We're building this product for you and we need your input to make your work easier and more efficient. Your comments on our documentation are also highly welcome. Email us at support@0patch.com.