

# Last time

We finished up

## **Buffer overflows**

and other memory safety vulnerabilities

By looking at  
**Overflow  
Defenses**

- Buffer overflow defenses (and workarounds)
- Format string vulnerabilities
- Integer overflow vulnerabilities

# This time

Continuing with

## **Software Security**

Getting sick with

## **Malware**

- 
- Types of malware
  - How viruses work
  - Detecting viruses (and counter-measures)
  - Case studies

# Malware

**Malicious code that is stored on and runs on a *victim's system***

- How does it get to run?
  - Attacks a user- or network-facing vulnerable service
    - E.g., using techniques you learned the past couple weeks
  - Backdoor: Added by a malicious developer
  - Social engineering: Trick the user into running/ clicking/installing
  - Trojan horse: Offer a good service, add in the bad
  - Attacker with physical access downloads & runs it

# Malware

**Malicious code that is stored on and runs on a *victim's system***

- How does it get to run?
  - Attacks a user- or network-facing vulnerable service
    - E.g., using techniques you learned the past couple weeks
  - Backdoor: Added by a malicious developer
  - Social engineering: Trick the user into running/ clicking/installing
  - Trojan horse: Offer a good service, add in the bad
  - Attacker with physical access downloads & runs it

**Potentially from any mode of interaction (automated or not), provided sufficient vulnerability**

# Malware

## What can it do?

- Virtually *anything*, subject only to its permissions
  - Brag: “APRIL 1st HA HA HA HA YOU HAVE A VIRUS!”
  - Destroy:
    - Delete/mangle files
    - Damage hardware (more later this lecture)
  - Crash the machine, e.g., by over-consuming resources
    - Fork bombing or “rabbits”: `while(1) { fork(); }`
  - Steal information (“exfiltrate”)
  - Launch external attacks
    - Spam, click fraud, denial of service attacks
  - Ransomware: e.g., by encrypting files
  - Rootkits: Hide from user or software-based detection
    - Often by modifying the kernel
    - Man-in-the-middle attacks to sit between UI and reality

# Malware

## When does it run?

- Some delay based on a trigger
  - **Time bomb**: triggered at/after a certain time
    - On the 1st through the 19th of any month...
  - **Logic bomb**: triggered when a set of conditions hold
    - If I haven't appeared in two consecutive payrolls...
  - Can also include a **backdoor** to serve as ransom
    - “I won’t let it delete your files if you pay me by Thursday...”
- Some attach themselves to other pieces of code
  - **Viruses**: run when the user initiates something
    - Run a program, open an attachment, boot the machine
  - **Worms**: run while another program is running
    - No user intervention required

# Self-propagating malware

- **Virus**: propagates by arranging to have itself *eventually* executed
  - At which point it creates a new, additional instance of itself
  - Typically infects by altering *stored* code
  - User intervention required
- **Worm**: *self*-propagates by arranging to have itself *immediately* executed
  - At which point it creates a new, additional instance of itself
  - Typically infects by altering *running* code
  - No user intervention required

# Self-propagating malware

- **Virus**: propagates by arranging to have itself *eventually* executed
  - At which point it creates a new, additional instance of itself
  - Typically infects by altering *stored* code
  - User intervention required
- **Worm**: *self*-propagates by arranging to have itself *immediately* executed
  - At which point it creates a new, additional instance of itself
  - Typically infects by altering *running* code
  - No user intervention required

**The line between these is thin and blurry  
Some malware uses both styles**

# Technical challenges

- **Viruses: Detection**
  - Antivirus software wants to detect
  - Virus writers want to avoid detection for as long as possible
  - *Evade* human response
- **Worms: Spreading**
  - The goal is to hit as many machines and as quickly as possible
  - *Outpace* human response

# Viruses

# Viruses

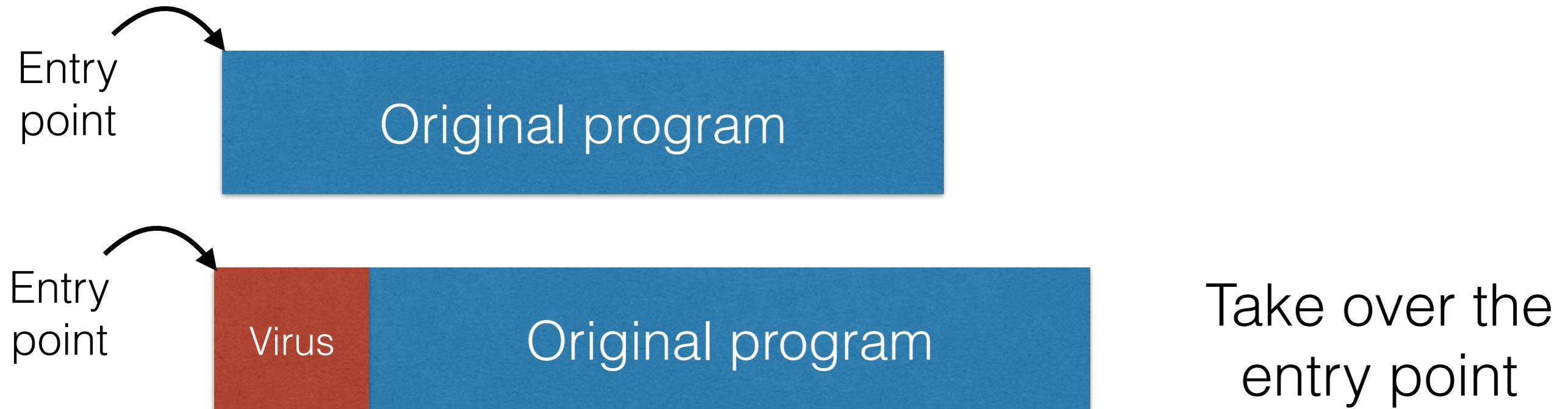
- They are opportunistic: they will *eventually* be run due to user action
- Two *orthogonal* aspects define a virus:
  1. How does it propagate?
  2. What else does it do (what is the “payload”)?
- General infection strategy:
  - Alter some existing code to include the virus
  - Share it, and expect users to (unwittingly) re-share
- Viruses have been around since at least the 70s

**They have resulted in a technological arms race**

# How viruses infect other programs



# How viruses infect other programs



# Viruses are classified by what they infect

- Document viruses:
  - Implemented within a formatted document
  - Word documents (very rich macros)
  - PDF (Acrobat permits javascript)
- Boot sector viruses:
  - Boot sector: small disk partition at a fixed location
  - If the disk is used to boot, then the firmware loads the boot sector code into memory and runs it
  - What's supposed to happen: this code loads the OS
  - Similar: AutoRun
- Memory-resident viruses:
  - “Resident code” stays in memory because it is used so often

# How viruses propagate

- First, the virus looks for an opportunity to run.  
**Increase chances** by attaching malicious code to something a user is likely to run
  - autorun.exe on storage devices
  - Email attachments
- When a virus runs, it looks for an opportunity to infect other systems.
  - User plugs in a USB thumb drive: try to overwrite autorun.exe
  - User is sending an email: alter the attachment
  - Viruses can also proactively create emails (“**I Love You**”)

# Detecting viruses

- Signature-based detection
  - Look for bytes corresponding to injected virus code
  - Protect other systems by installing a **recognizer** for a known virus
  - In practice, requires fast scanning algorithms
- This basic approach has driven the multi-billion dollar antivirus market
- #Recognized signatures is a means of marketing/competition
  - But what does that say about how important they are?

## Virus Definitions & Security Updates

To stay secure you should be running the most recent version of your licensed product and have the most up-to-date security content. Use this page to make sure your security content is current.

Select product:

Symantec Endpoint Protection 12.1.3



Need to update your  
Norton products?

[Go to Norton.com](#)

A valid support contract is required to obtain the latest content. To renew your product license, see the [License Renewal Center](#).

### File-Based Protection (Traditional Antivirus)

Definitions Created: 2/10/2014

Definitions Released: 2/10/2014

Extended Version: 2/10/2014 rev. 16

Definitions Version: 160210p

Sequence Number: 151231

Number of Signatures 23,927,535

Details: [Release History](#)

Download: [Definitions](#), Content is downloaded by your product via LiveUpdate.

Um.. thanks?

FEATURE

# Antivirus vendors go beyond signature-based antivirus

Robert Westervelt, News Director 



This article can also be found in the Premium Editorial Download "**Information Security magazine: Successful cloud migrations require careful planning.**"

[Download it now](#) to read this article plus other related content.

Security experts and executives at security vendors are in agreement that signature-based antivirus isn't able to keep up with the explosion of malware. For example, in 2009, Symantec says it wrote about 15,000 antivirus signatures a day; that number has increased to 25,000 antivirus signatures every day.

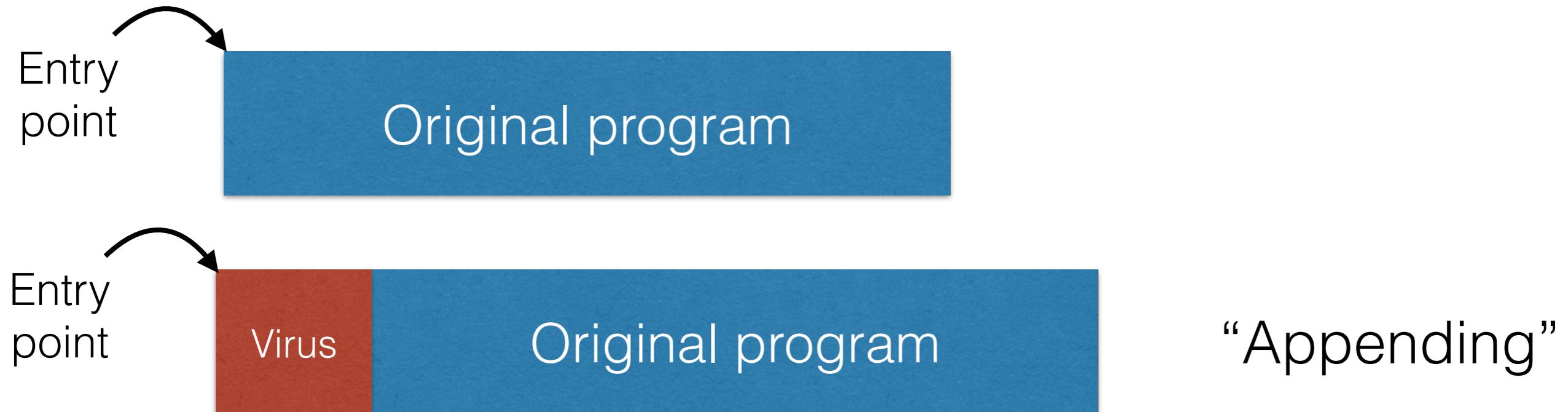
"Signatures have been dying for quite a while," says Mikko H. Hypponen, chief research officer of Finnish-based antivirus vendor, F-Secure. "The sheer number of malware samples we see every day completely overwhelms our ability to keep up with them."

Security vendors have responded by updating their products with additional capabilities, such as file reputation and heuristics-based engines. They're also making upgrades to keep up with the latest technology trends, such as virtualization and cloud computing.

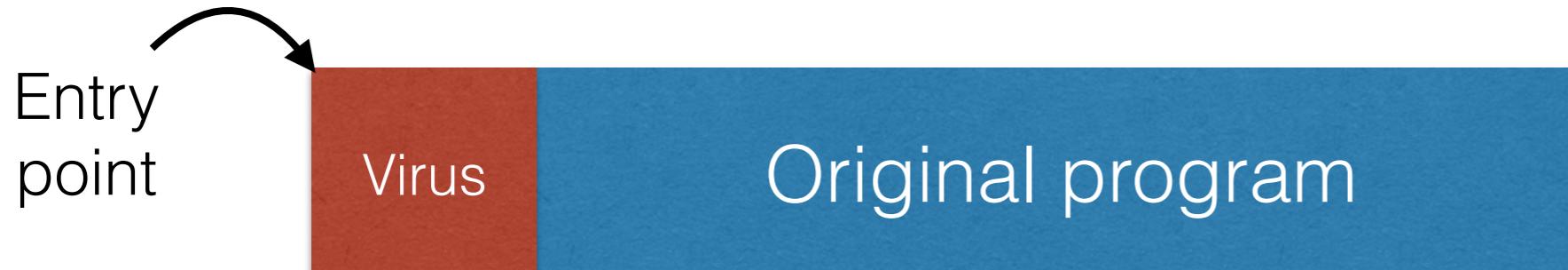
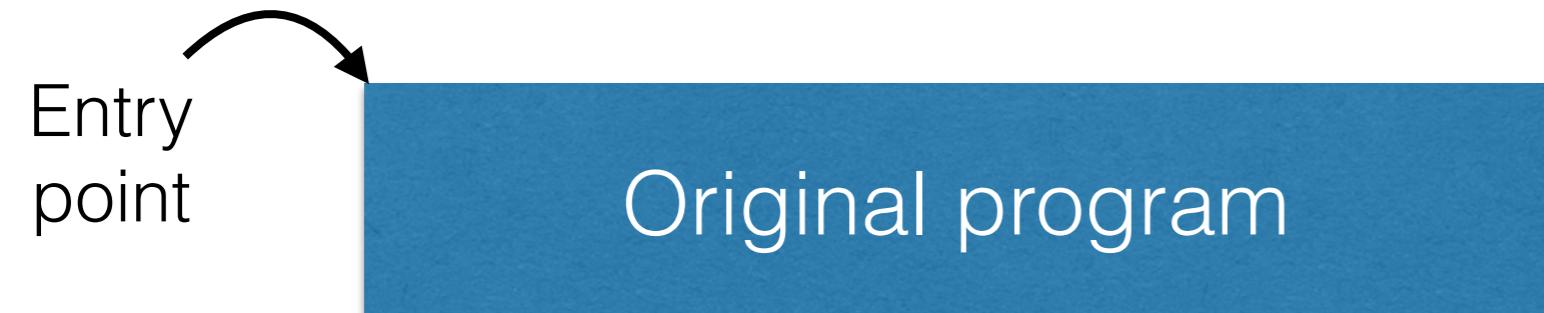
# You are a virus writer

- Your goal is for your virus to spread far and wide
- How do you avoid detection by antivirus software?
  - Give them a harder signature to find

# How viruses infect other programs



# How viruses infect other programs

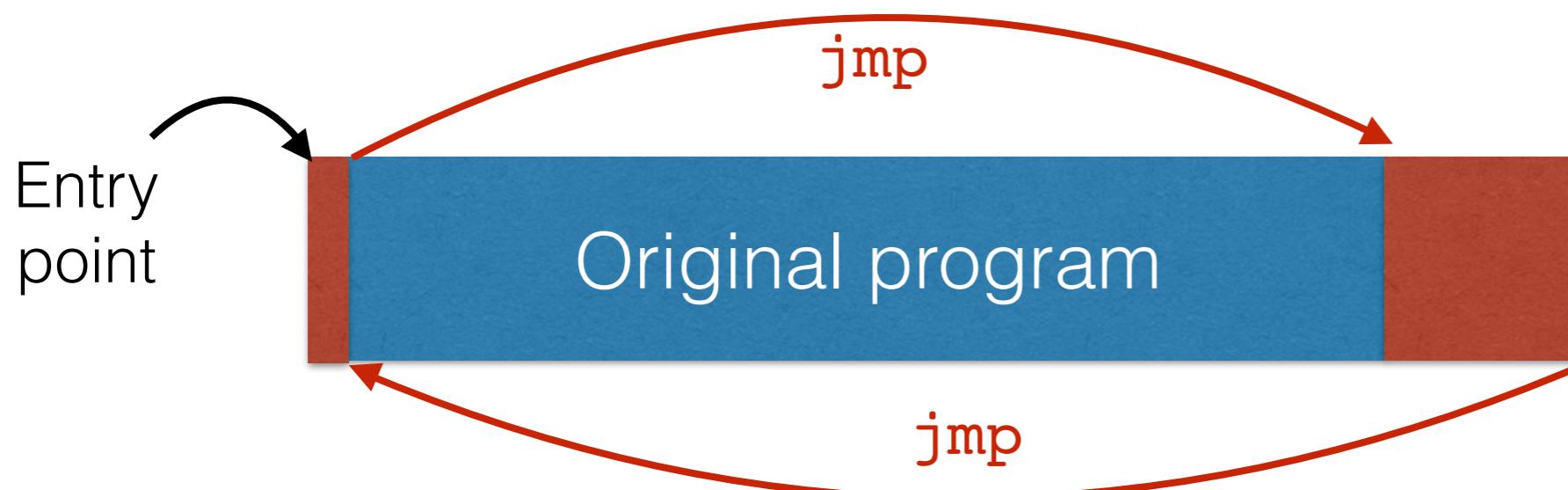
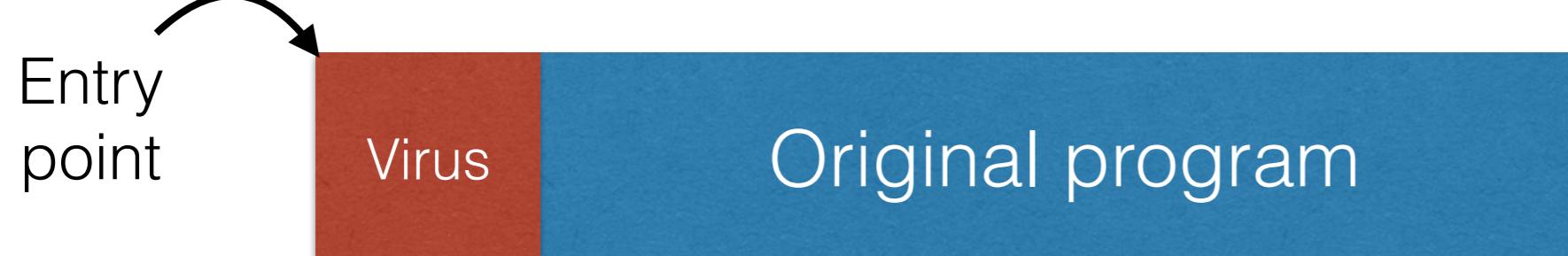
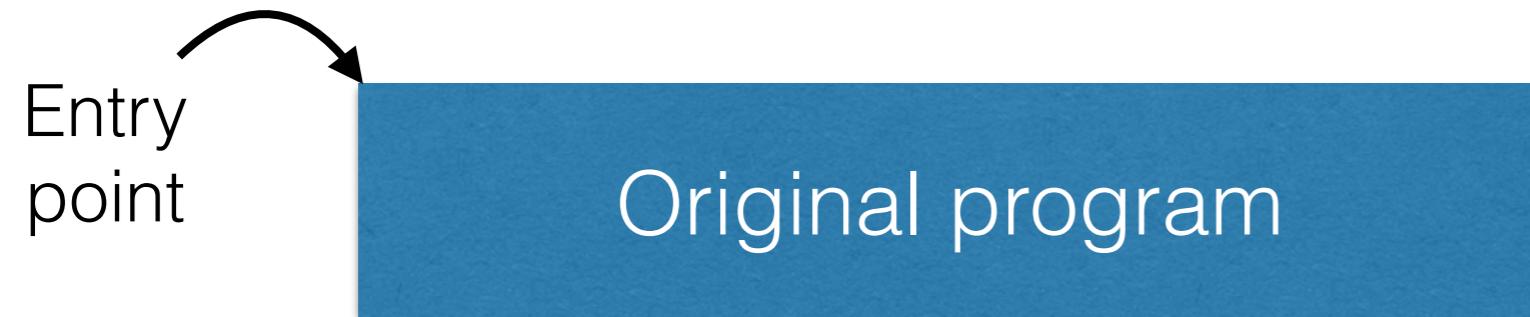


“Appending”



“Surrounding”

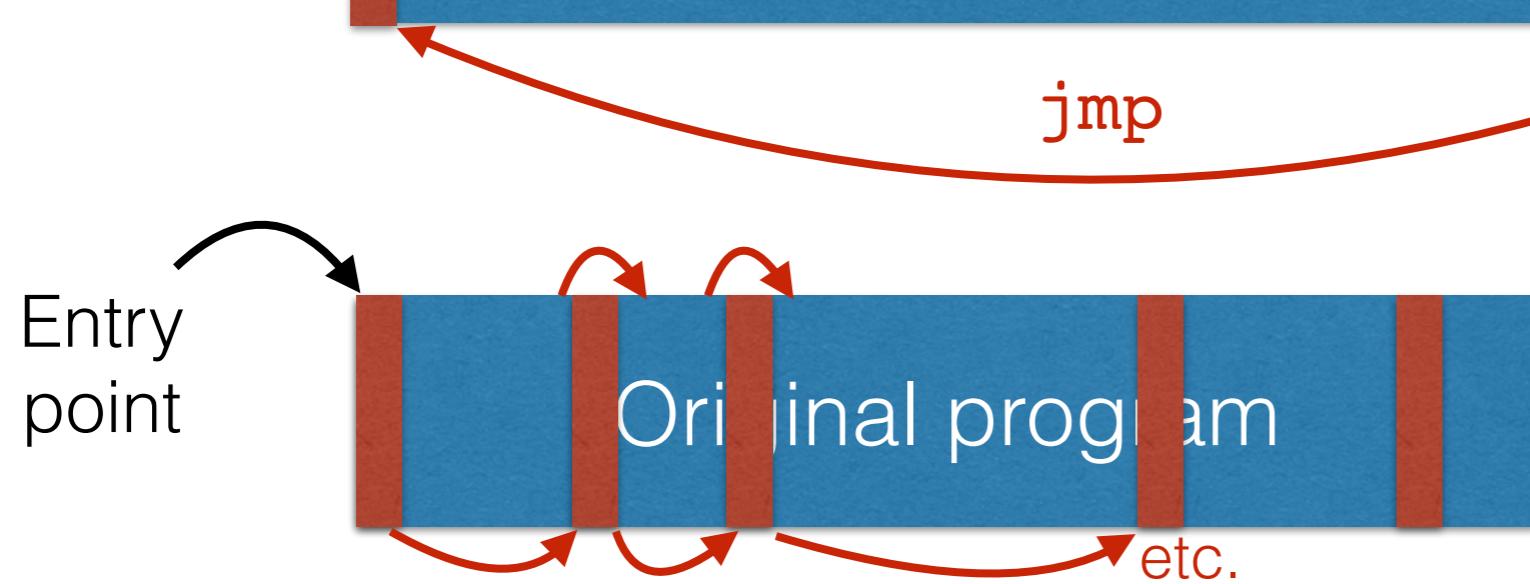
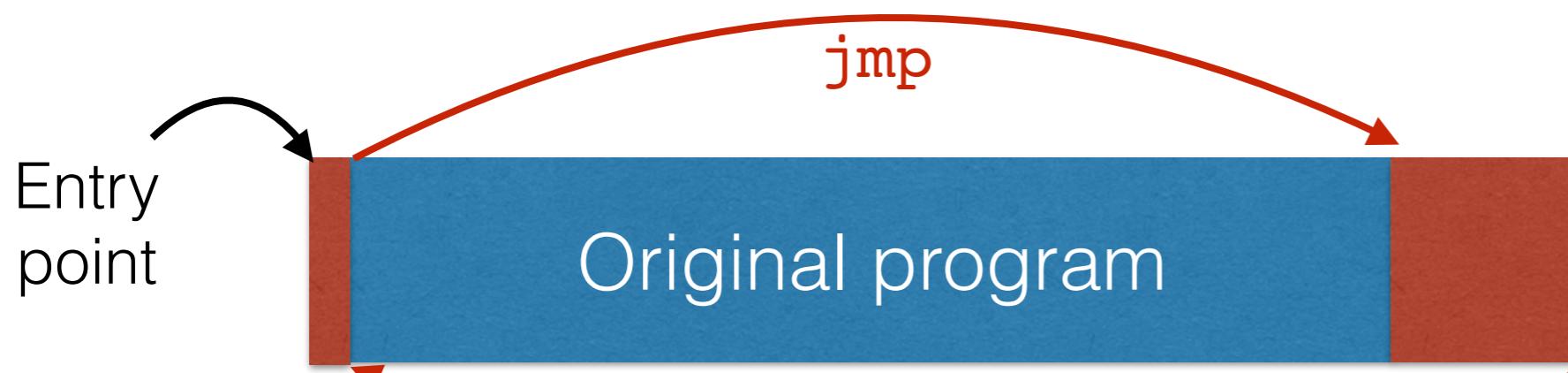
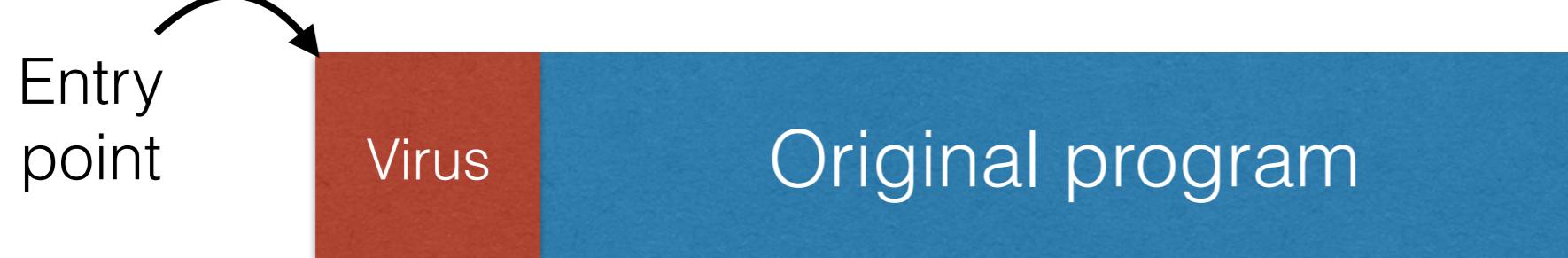
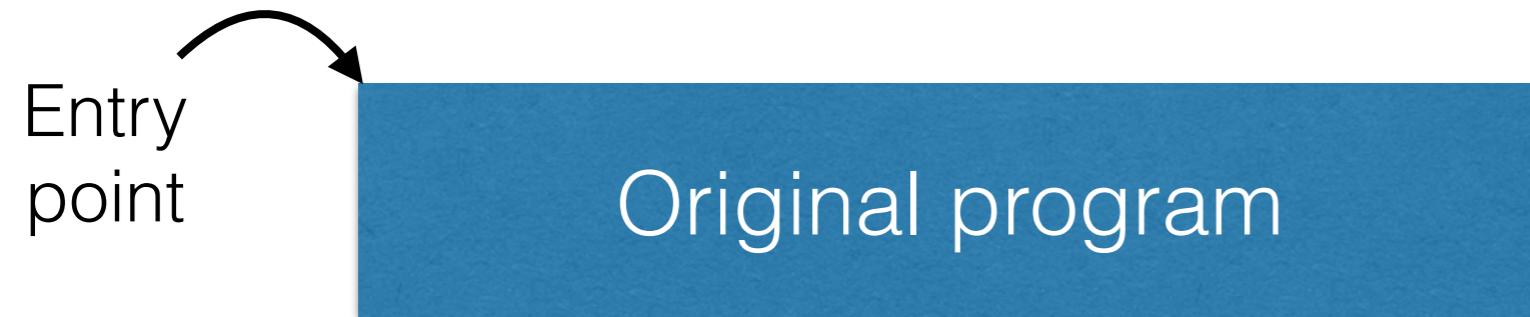
# How viruses infect other programs



“Appending”

“Surrounding”

# How viruses infect other programs



# You are a virus writer

- Your goal is for your virus to spread far and wide
- How do you avoid detection by antivirus software?
  - Give them a harder signature to find
  - *Change* your code so they can't pin down a signature
  - Writing working viruses is hard (famous bugs)

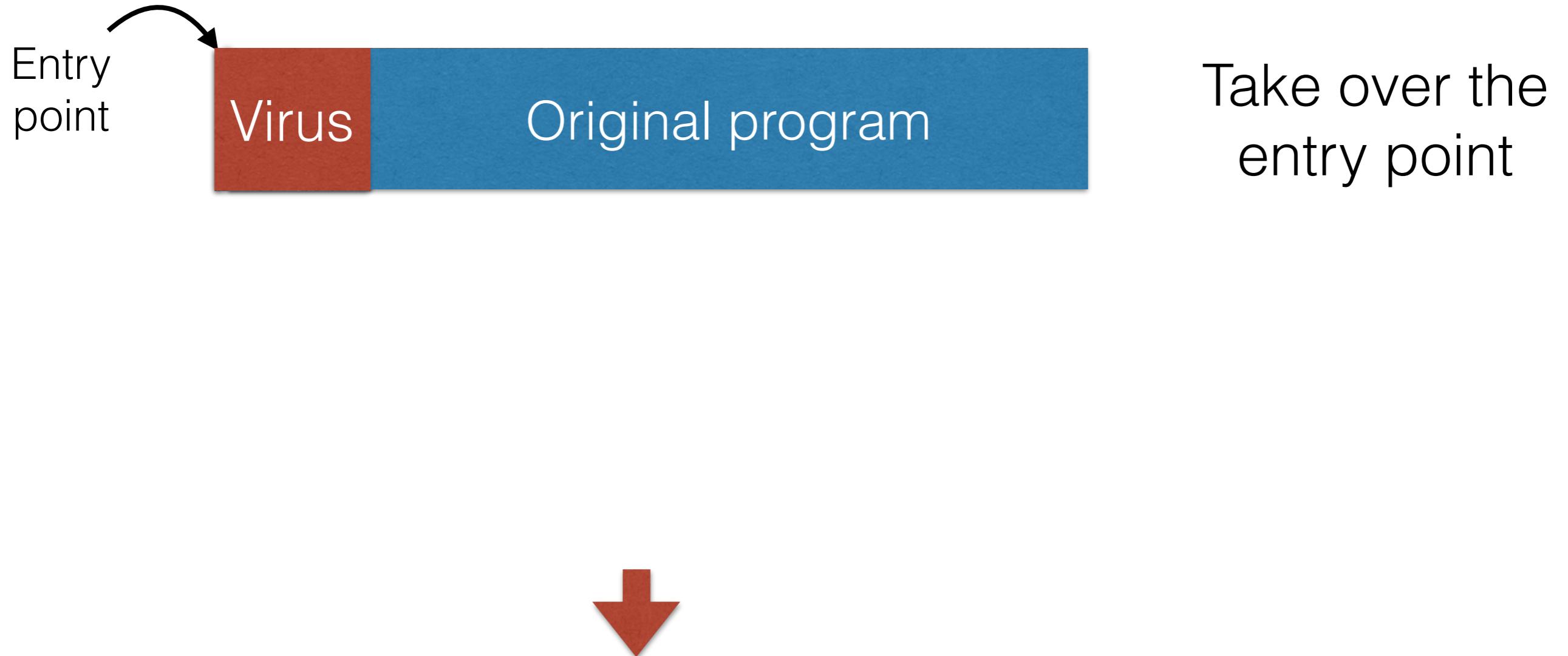
# You are a virus writer

- Your goal is for your virus to spread far and wide
- How do you avoid detection by antivirus software?
  - Give them a harder signature to find
  - *Change* your code so they can't pin down a signature
  - Writing working viruses is hard (famous bugs)

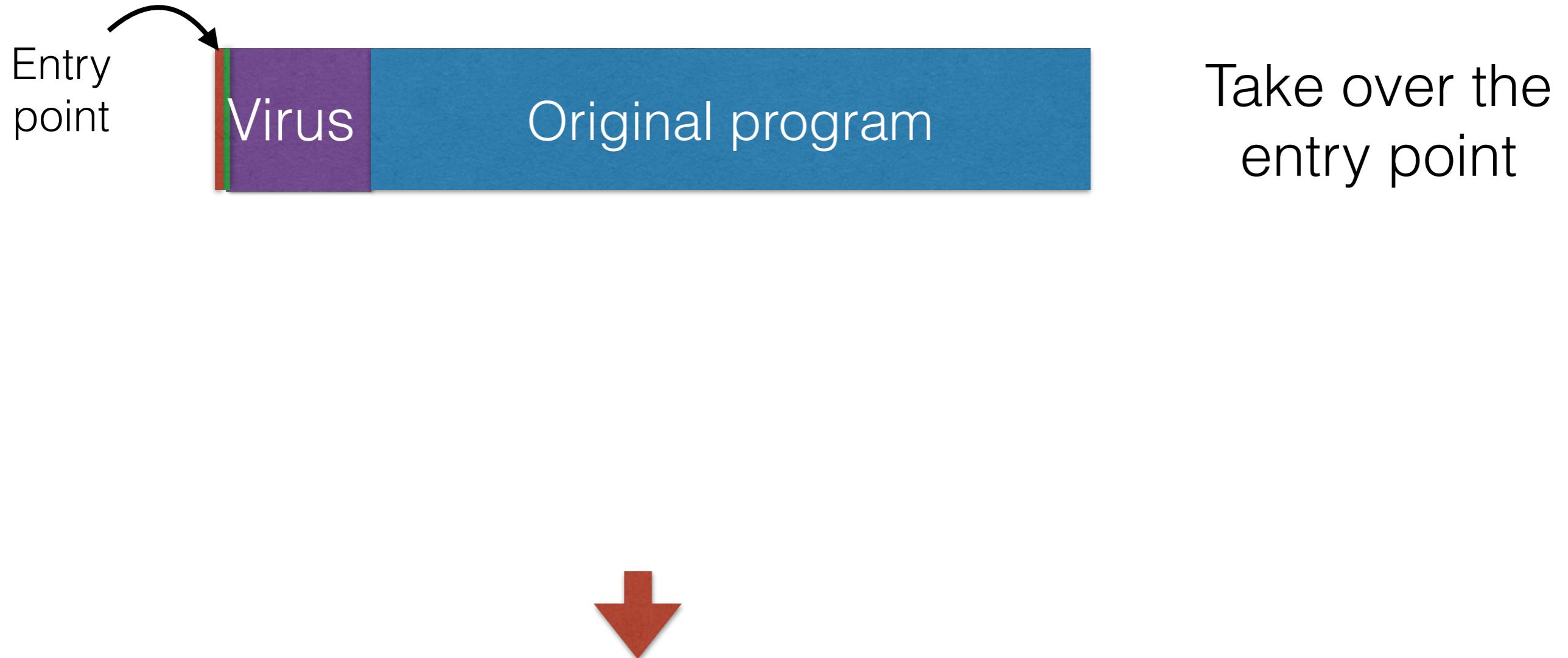
**Mechanize code changes:**

**Goal: every time you inject your code, it looks different**

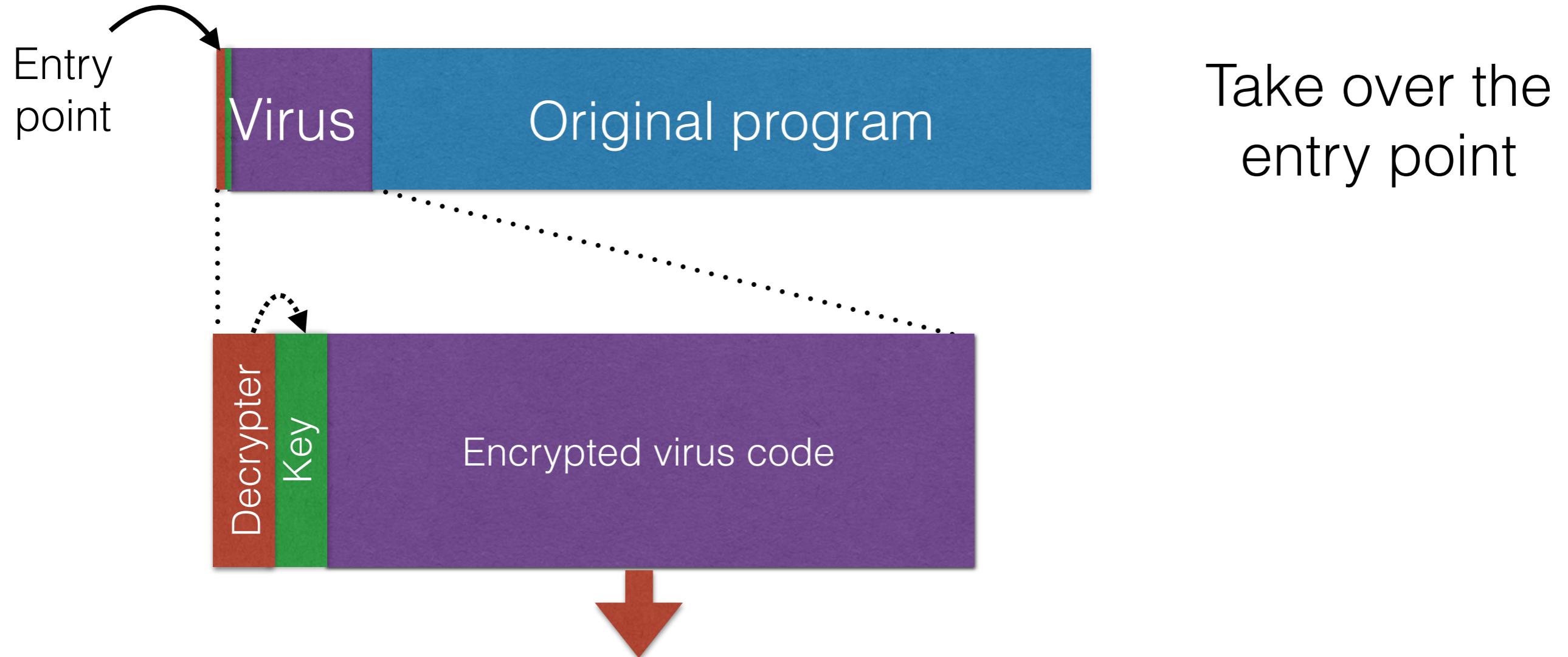
# Polymorphic viruses



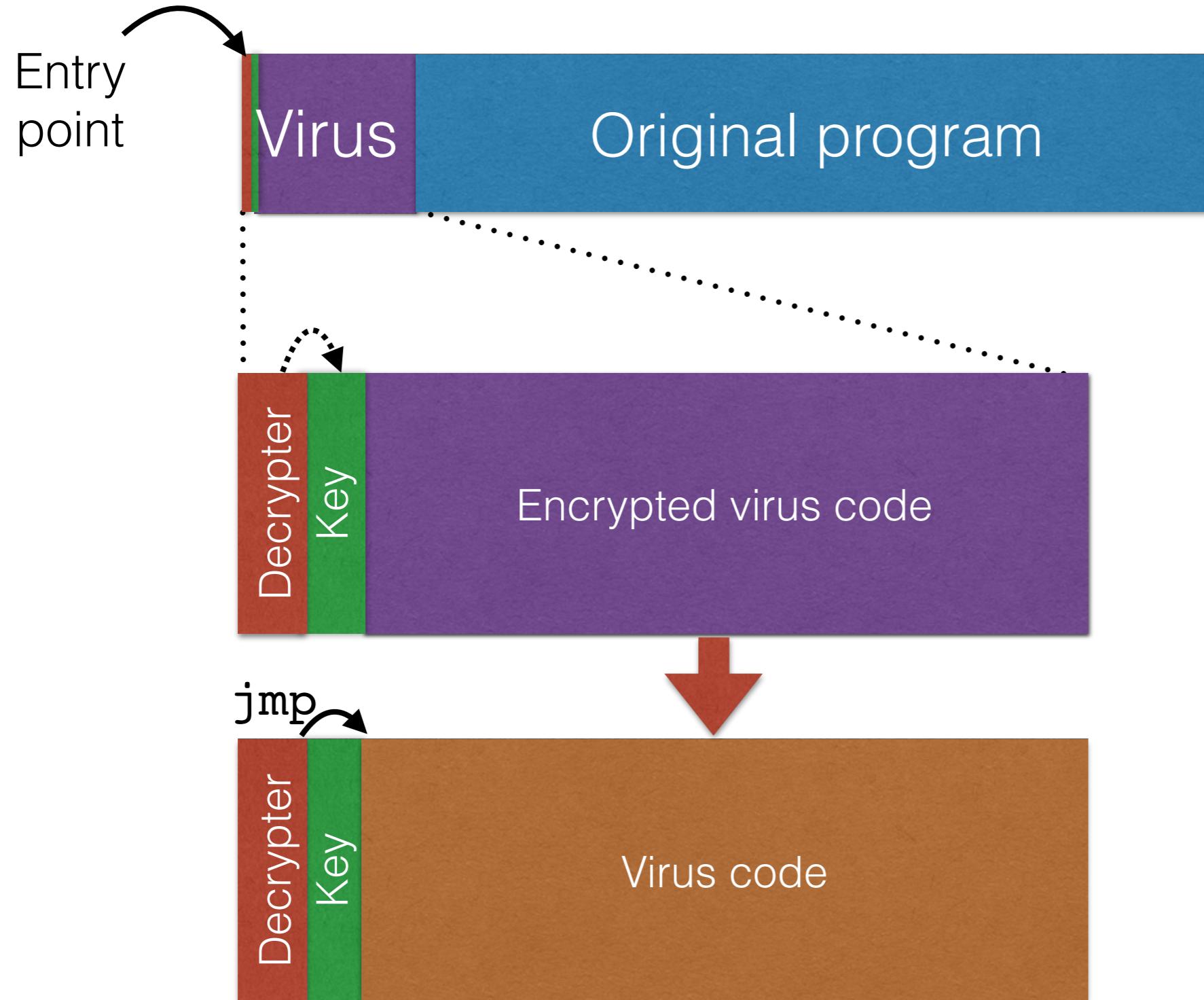
# Polymorphic viruses



# Polymorphic viruses

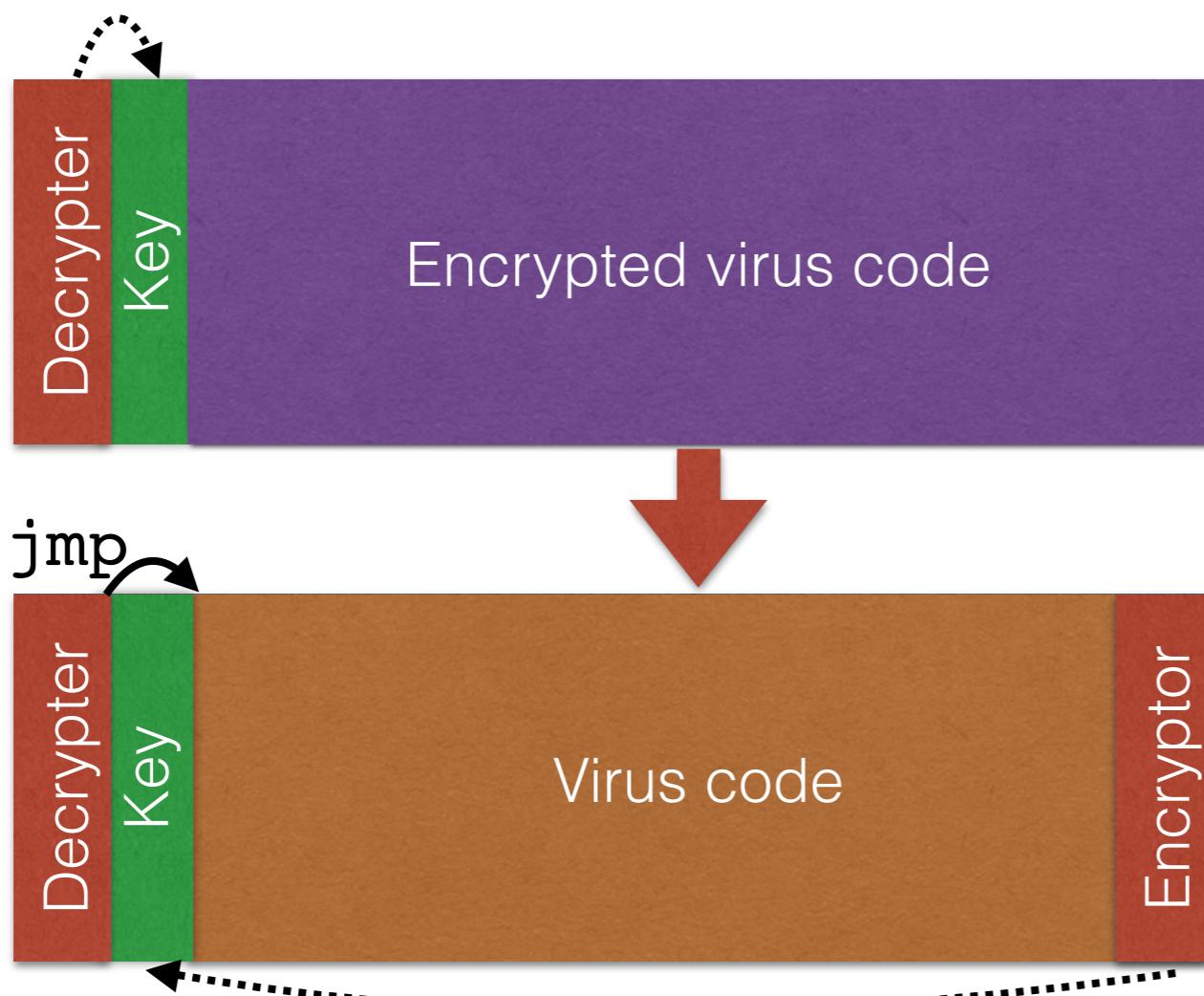


# Polymorphic viruses

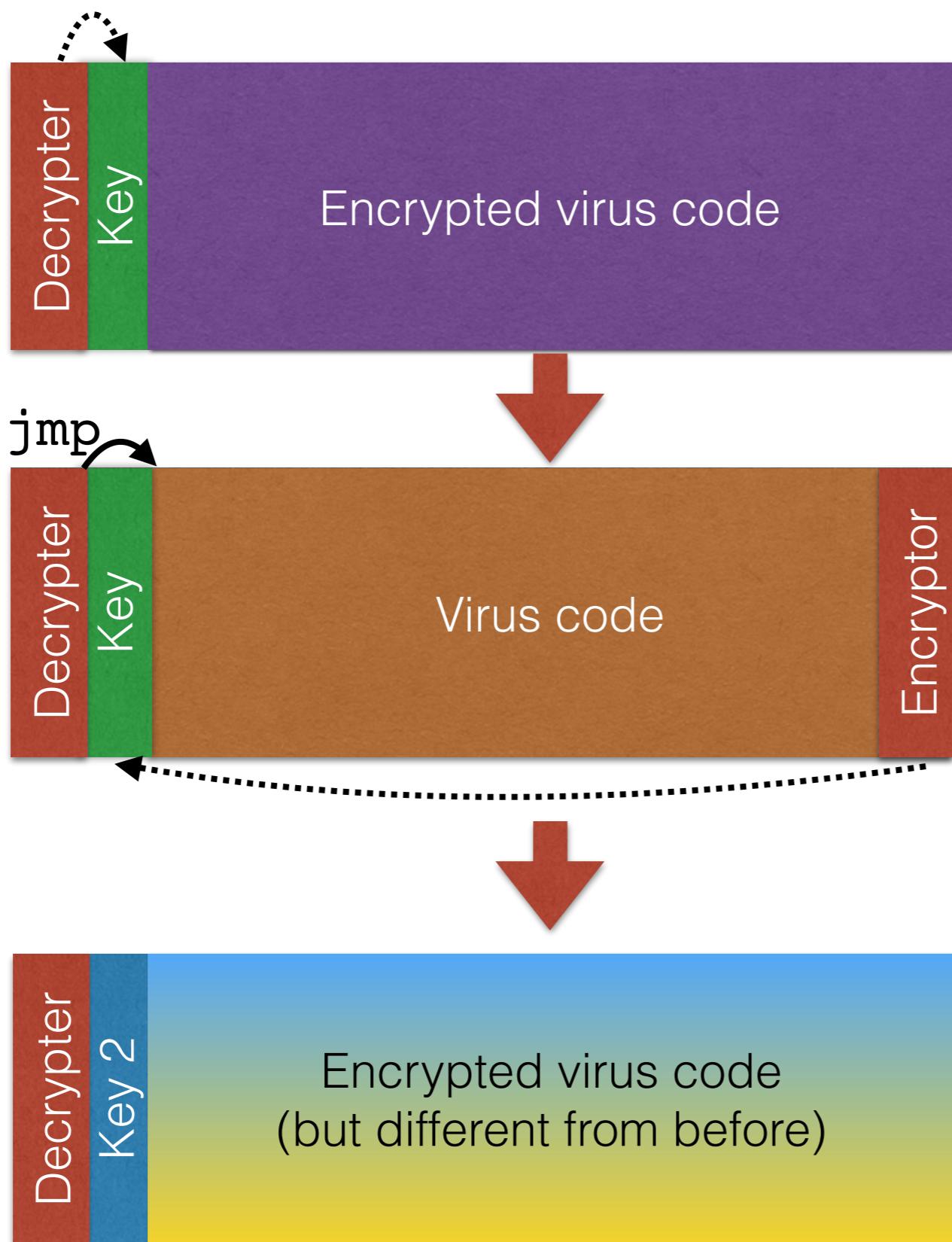


Take over the entry point

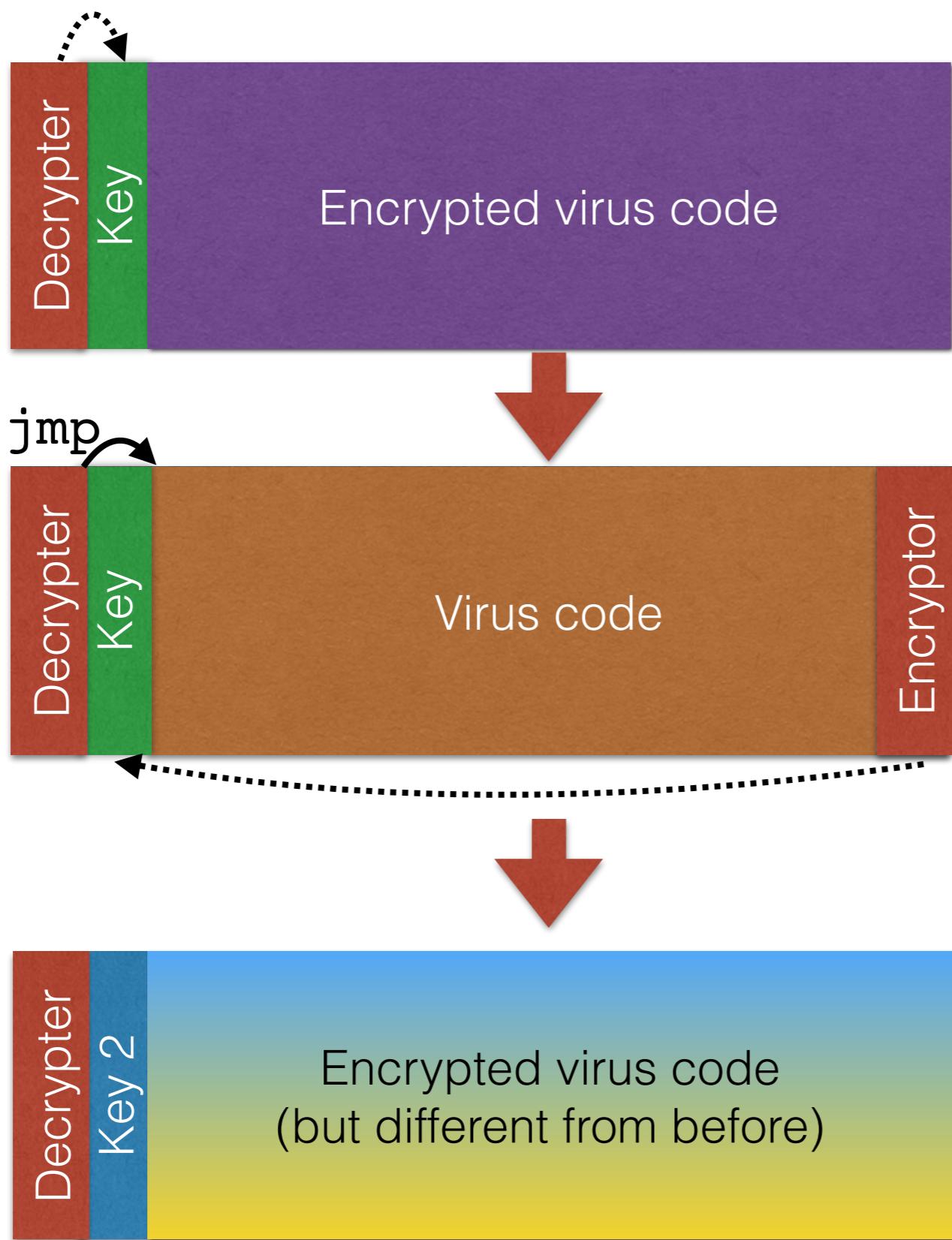
# Polymorphic viruses



# Polymorphic viruses



# Polymorphic viruses



**When used properly,  
encryption will yield  
a different, random  
output upon each  
invocation**

# Polymorphic viruses: Arms race

**Now you are the antivirus writer: how do you detect?**

# Polymorphic viruses: Arms race

## **Now you are the antivirus writer: how do you detect?**

- Idea #1: **Narrow signature** to catch the decryptor
  - Often very small: can result in many false positives
  - Attacker can spread this small code around and `jmp`
- Idea #2: **Execute** or statically analyze the suspect code to see if it decrypts.
  - How do you distinguish from common “packers” which do something similar (decompression)?
  - How long do you execute the code??

# Polymorphic viruses: Arms race

## **Now you are the antivirus writer: how do you detect?**

- Idea #1: Narrow signature to catch the decryptor
  - Often very small: can result in many false positives
  - Attacker can spread this small code around and `jmp`
- Idea #2: Execute or statically analyze the suspect code to see if it decrypts.
  - How do you distinguish from common “packers” which do something similar (decompression)?
  - How long do you execute the code??

## **Now you are the *virus* writer again: how do you evade?**

# Polymorphic countermeasures

- Change the decryptor
  - **Oligomorphic viruses**: change to one of a fixed set of decryptors
  - **True polymorphic viruses**: can generate an endless number of decryptors
    - e.g., brute force key break
    - Downside: inefficient

# Metamorphic code

# Metamorphic code

- Every time the virus propagates, generate a *semantically different* version
  - Higher-level semantics remain the same
  - But the way it does it differs
    - Different machine code instructions
    - Different algorithms to achieve the same thing
    - Different use of registers
    - Different constants....

# Metamorphic code

- Every time the virus propagates, generate a *semantically different* version
  - Higher-level semantics remain the same
  - But the way it does it differs
    - Different machine code instructions
    - Different algorithms to achieve the same thing
    - Different use of registers
    - Different constants....
- How would you do this?
  - Include a code rewriter with your virus
  - Add a bunch of complex code to throw others off (then just never run it)

## Symantec HUNTING FOR METAMORPHIC

```
5A          pop  edx
BF04000000  mov   edi,0004h
8BF5        mov   esi,ebp
B80C000000  mov   eax,000Ch
81C288000000 add   edx,0088h
8B1A        mov   ebx,[edx]
899C8618110000 mov  [esi+eax*4+00001118],ebx

58          pop  eax
BB04000000  mov   ebx,0004h
8BD5        mov   edx,ebp
BF0C000000  mov   edi,000Ch
81C088000000 add   eax,0088h
8B30        mov   esi,[eax]
89B4BA18110000 mov  [edx+edi*4+00001118],esi
```

Figure 4 Win95/Regswap using different registers in new generations

a. An early generation:

```
C7060F000055  mov      dword ptr [esi],5500000Fh  
C746048BEC5151  mov      dword ptr [esi+0004],5151EC8Bh
```

b. And one of its later generations:

```
BF0F000055      mov      edi,5500000Fh  
893E            mov      [esi],edi  
5F              pop     edi  
52              push    edx  
B640            mov      dh,40  
BA8BEC5151      mov      edx,5151EC8Bh  
53              push    ebx  
8BDA            mov      ebx,edx  
895E04          mov      [esi+0004],ebx
```

c. And yet another generation with recalculated ("encrypted") "constant" data.

```
BB0F000055      mov      ebx,5500000Fh  
891E            mov      [esi],ebx  
5B              pop     ebx  
51              push    ecx  
B9CB00C05F      mov      ecx,5FC000CBh  
81C1C0EB91F1    add      ecx,F191EBC0h ; ecx=5151EC8Bh  
894E04          mov      [esi+0004],ecx
```

Figure 6: Example of code metamorphosis of Win32/Evol

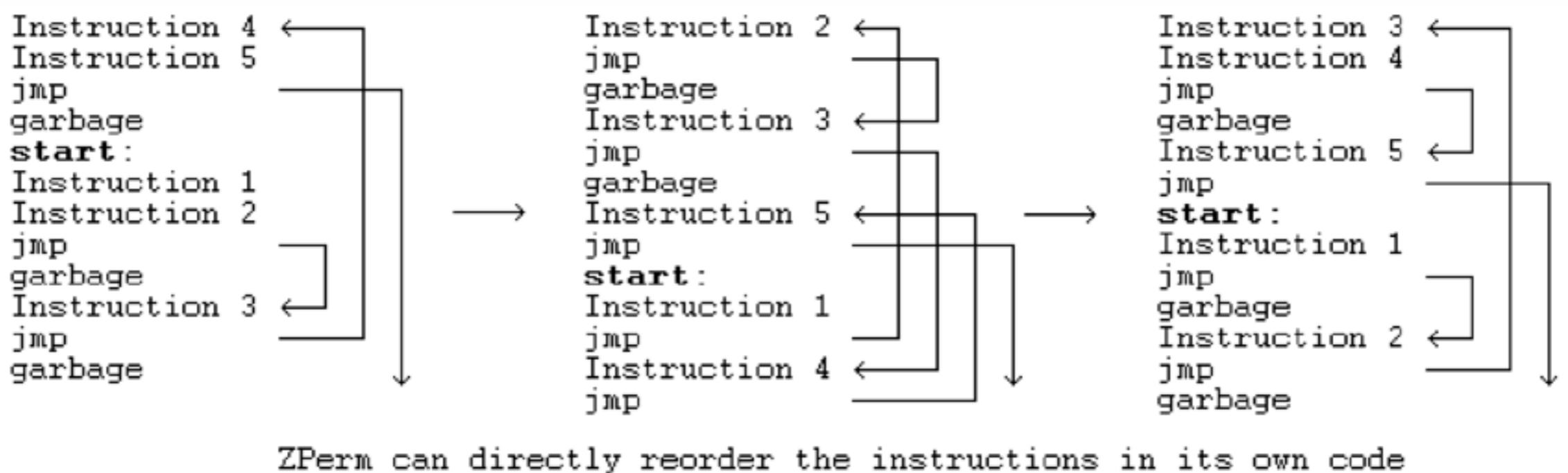
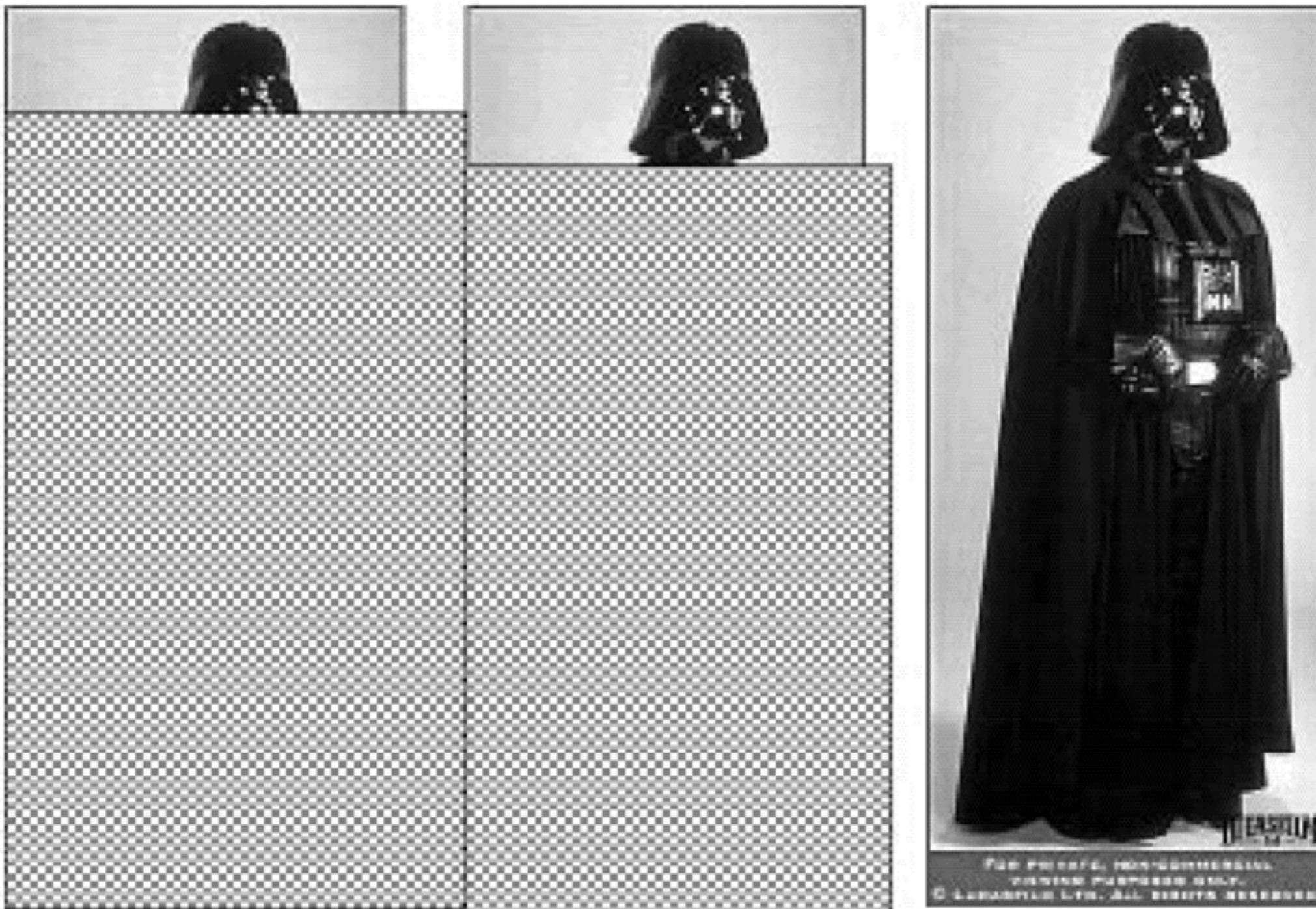


Figure 7. Zperm.A inserts JMP instruction into its code

# Polymorphic



**When can you successfully scan?**

Figure 8: A partial or complete snapshot of polymorphic virus during execution cycle

# Metamorphic



**When can you successfully scan?**

Figure 10: T-1000 of Terminator 2

# Detecting metamorphic viruses

- Scanning isn't enough: need to **analyze execution behavior**
- Two broad stages in practice (both take place in a safe environment, like gdb or a virtual machine)
  1. AV company analyzes new virus to find **behavioral signature**
  2. AV system at the end host analyzes suspect code to see if it matches the signature

# Detecting metamorphic viruses

- Countermeasures
  - Have your virus change slowly (hard to create a proper behavioral signature)
  - Detect if you are in a safe execution environment (e.g., gdb) and act differently
- Counter-countermeasures
  - Detect detection and skip those parts
- Counter-counter-counter.... Arms race

# Detecting metamorphic viruses

- Countermeasures
  - Have your virus change slowly (hard to create a proper behavioral signature)
  - Detect if you are in a safe execution environment (e.g., gdb) and act differently
- Counter-countermeasures
  - Detect detection and skip those parts
- Counter-counter-counter.... Arms race

**Attackers have the upper hand:**

**AV systems hand out signatures, thus serving as an oracle**

# Putting it all together sounds hard

- Coming up with these things can be really difficult
- Any **scriptkiddy** can use them

# Putting it all together sounds hard

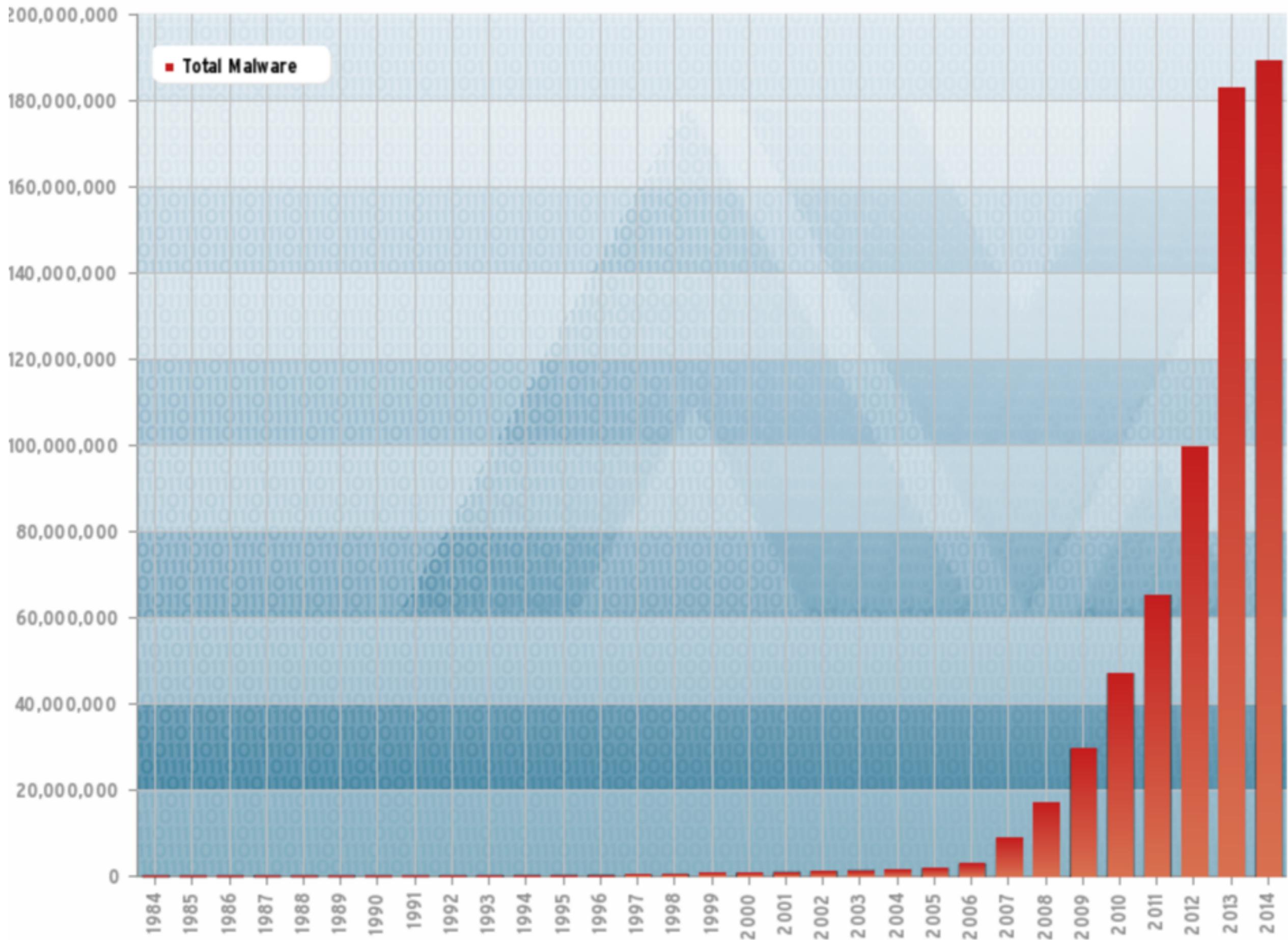
- Coming up with these things can be really difficult
- Any **scriptkiddy** can use them

```
^ ~ x root@bt: /opt/framework3/msf3
File Edit View Terminal Help
root@bt:/opt/framework3/msf3# msfcli windows/smb/ms08_067_netapi RHOST=192.168.1.100 P
[*] Please wait while we load the module tree...

Compatible payloads
=====
Name                                     Description
----                                     -----
generic/debug_trap                      Generate a debug trap in the target process
generic/shell_bind_tcp                  Listen for a connection and spawn a command shell
generic/shell_reverse_tcp               Connect back to attacker and spawn a command shell
generic/tight_loop                     Generate a tight loop in the target process
windows/adduser                        Create a new user and add them to local administration group
windows/dllinject/bind_ipv6_tcp        Listen for a connection over IPv6, Inject a Dll via a reflective loader
windows/dllinject/bind_nonx_tcp       Listen for a connection (No NX), Inject a Dll via a reflective loader
windows/dllinject/bind_tcp            Listen for a connection, Inject a Dll via a reflective loader
windows/dllinject/reverse_ipv6_tcp    Connect back to the attacker over IPv6, Inject a Dll via a reflective loader
windows/dllinject/reverse_nonx_tcp   Connect back to the attacker (No NX), Inject a Dll via a reflective loader
windows/dllinject/reverse_ord_tcp    Connect back to the attacker, Inject a Dll via a reflective loader
windows/dllinject/reverse_tcp        Connect back to the attacker, Inject a Dll via a reflective loader
windows/dllinject/reverse_tcp_allports Try to connect back to the attacker, on all possible ports (1-65535, slowly), Inject a Dll via a reflective loader
windows/dllinject/reverse_tcp_dns   Connect back to the attacker, Inject a Dll via a reflective loader
windows/download_exec                 Download an EXE from an HTTP URL and execute it
```

# So how much malware is out there?

- Polymorphic and metamorphic viruses can make it easy to *miscount* viruses
- Take numbers with a grain of salt
  - Large numbers are in the AV vendors' best interest



# How do we clean up an infection?

- Depends what the virus did, but..
- May require restoring / repairing files
  - A service that antivirus companies sell
- What if the virus ran as root?
  - May need to rebuild the entire system
- So what, just recompile it?
  - What if the malware left a backdoor in your compiler?
    - Compile the malware back into the compiler
  - May need to use original media and data backups

# Virus case studies

# Brain

## First IBM PC virus (1987)

- Propagation method
  - Copies itself into the boot sector
  - Tells the OS that all of the boot sector is “faulty” (so that it won’t list contents to the user)
    - Thus also one of the first examples of a stealth virus
  - Intercepts disk read requests for 5.25” floppy drives
    - Sees if the 5th and 6th bytes of the boot sector are 0x1234
    - If so, then it’s already infected, otherwise, infect it
- Payload:
  - Nothing really; goal was just to spread (to show off?)
  - However, it served as the template for future viruses

Path=H:

## Absolute sector 0000000, System BOOT

Displacement	Hex codes																							
0020K(00000)	FA	E9	4A	01	34	12	00	07	14	00	01	00	00	00	00	00	00	00	00	00	00	00	20	
0016K(00100)	20	20	20	20	20	20	57	65	6C	63	6F	6D	65	20	74	6F								
0032K(00200)	20	74	68	65	20	44	75	6E	67	65	6F	6E	20	20	20	20	20	20	20	20	20	20	20	
0048K(00300)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	
0054K(00400)	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	
0060K(00500)	20	20	63	29	20	31	39	38	36	20	42	61	73	69	74	20								
0096K(00600)	26	20	41	6D	6A	61	64	20	28	70	76	74	29	20	4C	74								
0112K(00700)	64	2E	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	
0128K(00800)	20	42	52	41	49	4E	20	43	4F	4D	50	55	54	45	52	20								
0144K(00900)	53	45	52	56	49	43	45	53	2E	2E	37	33	38	20	4E	49								
0160K(00A00)	5A	41	4D	20	42	4C	4F	43	4B	20	41	4C	4C	41	4D	41								
0176K(00B00)	20	49	51	42	41	4C	20	54	4F	57	4E	20	20	20	20	20	20	20	20	20	20	20	20	
0192K(00C00)	20	20	20	20	20	20	20	20	20	20	20	20	20	4C	41	48	4F	52						
0208K(00D00)	45	20	58	41	4B	49	53	54	41	4E	2E	2E	50	48	4F	4E								
0224K(00E00)	45	20	3A	34	33	30	37	39	31	2C	34	34	33	32	34	38								
0240K(00F00)	2C	32	38	30	35	33	30	2E	20	20	20	20	20	20	20	20								

ASCII value  
 -8J04† e† e  
 Welcome to  
 the Dungeon  
 (c) 1996 Basit  
 & Amjad (put) Lt  
 d.  
 BRAIN COMPUTER  
 SERVICES.. 730 MI  
 2AM BLOCK ALLAMA  
 IBN TOWNS  
 LAHORE  
 E-PAKISTAN.. PHON  
 E :438791, 443248  
 , 280530.

Home=eg of file/disk End=end of file/disk

ESC=exit PgUp=forward PgDn=back F2=chg sector num F3=edit F4=get name

# Rootkits

- Recall: a rootkit is malicious code that takes steps to go undiscovered
  - By intercepting system calls, patching the kernel, etc.
  - Often effectively done by a man in the middle attack
- **Rootkit revealer**: analyzes the disk offline and through the online system calls, and compares
- Mark Russinovich ran a rootkit revealer and found a rootkit in 2005...

# Rootkits

- Recall: a rootkit is malicious code that takes steps to go undiscovered
  - By intercepting system calls, patching the kernel, etc.
  - Often effectively done by a man in the middle attack
- **Rootkit revealer**: analyzes the disk offline and through the online system calls, and compares
- Mark Russinovich ran a rootkit revealer and found a rootkit in 2005... **installed by a CD he had bought.**

# Sony XCP rootkit

**Detected 2005**

# Sony XCP rootkit

**Detected 2005**

- Goal: keep users from copying copyrighted material

# Sony XCP rootkit

**Detected 2005**

- Goal: keep users from copying copyrighted material
- How it worked:
  - Loaded thanks to autorun.exe on the CD
  - Intercepted read requests for its music files
  - If anyone but Sony's music player is accessing them, then garble the data
  - Hid itself from the user (to avoid deletion)

# Sony XCP rootkit

**Detected 2005**

- Goal: keep users from copying copyrighted material
- How it worked:
  - Loaded thanks to autorun.exe on the CD
  - Intercepted read requests for its music files
  - If anyone but Sony's music player is accessing them, then garble the data
  - Hid itself from the user (to avoid deletion)
- How it messed up
  - Morally: violated trust
  - Technically: Hid *all files* that started with “\$sys\$”
  - Seriously?: The uninstaller did not check the integrity of the code it downloaded, and would not delete it afterwards.

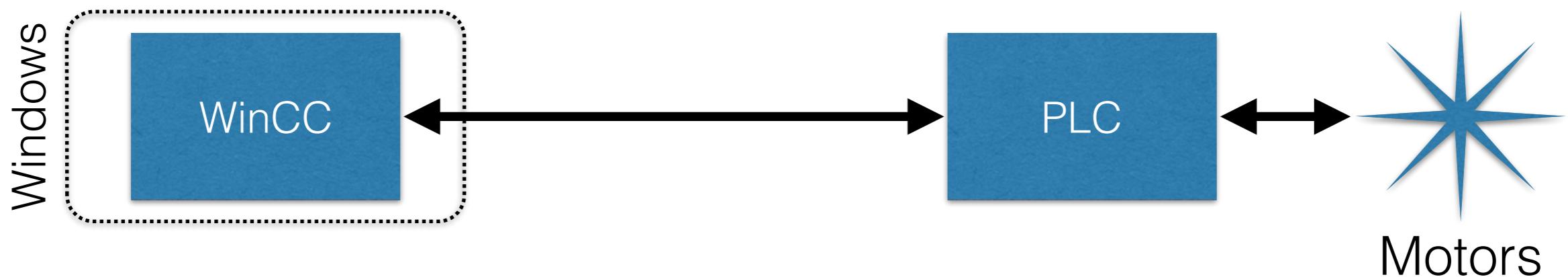
# Stuxnet: Propagation

June 2010

- Virus in that it initially spread by infected USB stick
  - Once inside a network, it acted as a worm, spreading quickly
- Exploited **four** zero-day exploits
  - Zero-day: Known to only the attacker until the attack
  - Typically, one zero-day is enough to profit
  - Four was unprecedented
    - Immense cost and sophistication on behalf of the attacker
- Rootkit: installed *signed* device drivers
  - Thereby avoiding user alert when installing
  - Signed with certificates stolen from two Taiwanese CAs

# Stuxnet: Payload

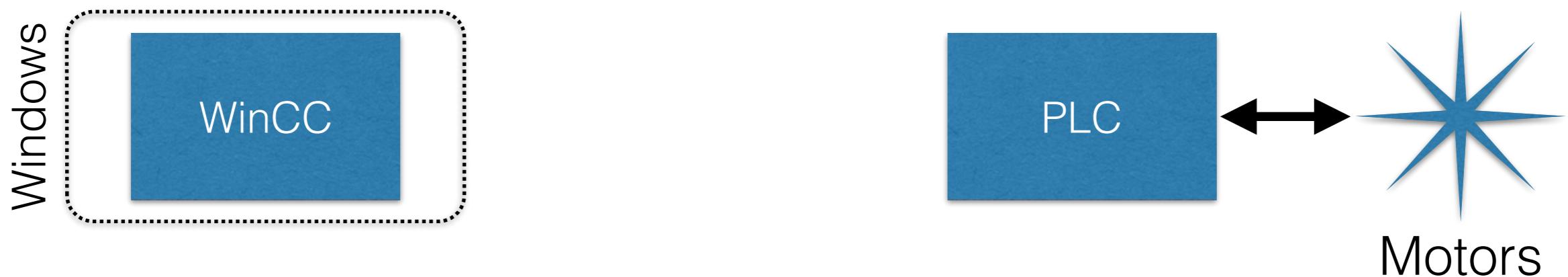
- Targets industrial control systems by overwriting programmable logic boards
- Man-in-the-middle between Windows and Siemens control systems; looked like it was working properly to the operator



- In reality, it sped up and slowed down the motors
- Result: Destroy (or at least decrease the productivity of) nuclear centrifuges

# Stuxnet: Payload

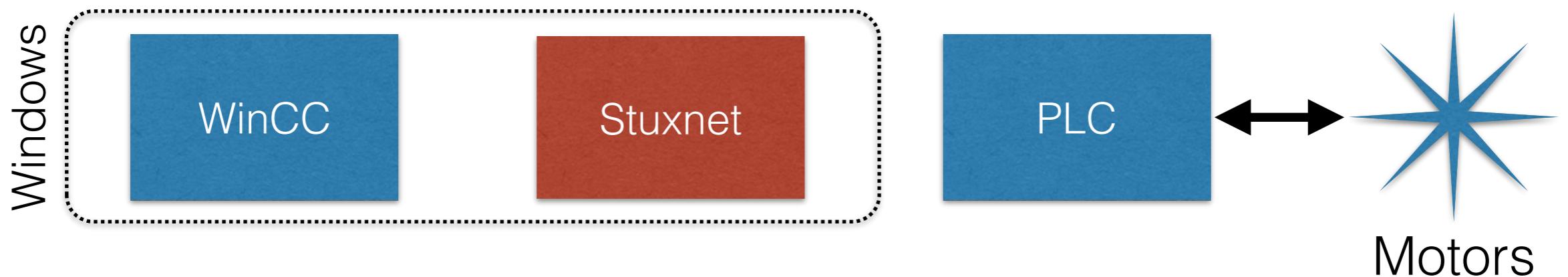
- Targets industrial control systems by overwriting programmable logic boards
- Man-in-the-middle between Windows and Siemens control systems; looked like it was working properly to the operator



- In reality, it sped up and slowed down the motors
- Result: Destroy (or at least decrease the productivity of) nuclear centrifuges

# Stuxnet: Payload

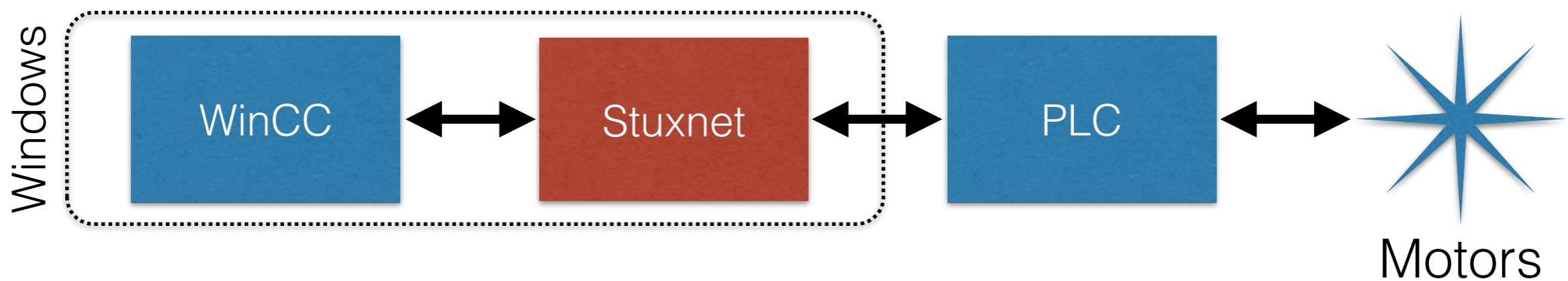
- Targets industrial control systems by overwriting programmable logic boards
- Man-in-the-middle between Windows and Siemens control systems; looked like it was working properly to the operator



- In reality, it sped up and slowed down the motors
- Result: Destroy (or at least decrease the productivity of) nuclear centrifuges

# Stuxnet: Payload

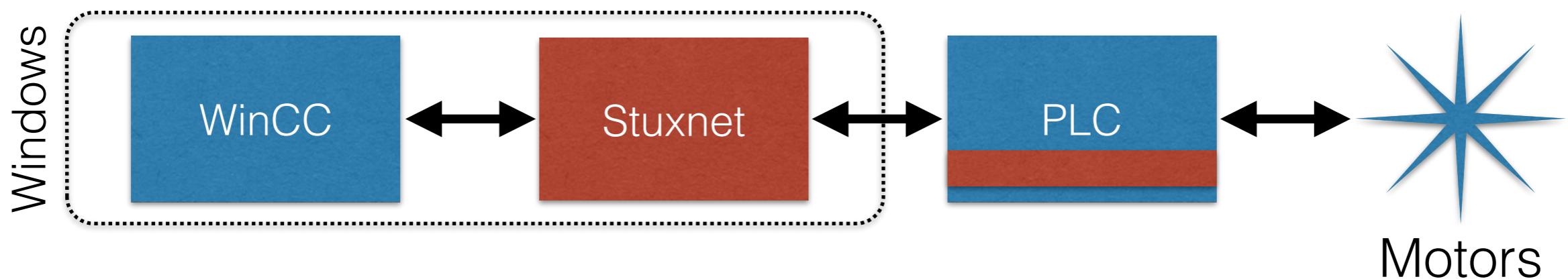
- Targets industrial control systems by overwriting programmable logic boards
- Man-in-the-middle between Windows and Siemens control systems; looked like it was working properly to the operator



- In reality, it sped up and slowed down the motors
- Result: Destroy (or at least decrease the productivity of) nuclear centrifuges

# Stuxnet: Payload

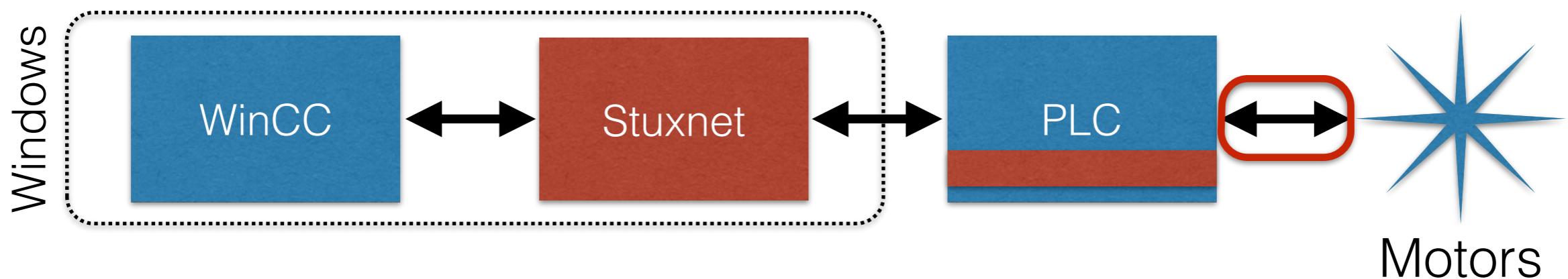
- Targets industrial control systems by overwriting programmable logic boards
- Man-in-the-middle between Windows and Siemens control systems; looked like it was working properly to the operator



- In reality, it sped up and slowed down the motors
- Result: Destroy (or at least decrease the productivity of) nuclear centrifuges

# Stuxnet: Payload

- Targets industrial control systems by overwriting programmable logic boards
- Man-in-the-middle between Windows and Siemens control systems; looked like it was working properly to the operator



- In reality, it sped up and slowed down the motors
- Result: Destroy (or at least decrease the productivity of) nuclear centrifuges

# Stuxnet: Fallout

- Iran denied they had been hit by Stuxnet
- Then claimed they were, but had contained it
- Understood now that it took out 1k of Iran's 5k centrifuges
- Security experts believe the U.S. did it (possibly along with Israel) due to its sophistication and cost
- Legitimized cyber warfare

# Viruses

- Technological arms race between those who wish to detect and those who wish to evade detection
- Started off innocuously, capable by only a few very clever people
- But viruses have become commoditized; any scriptkiddy can launch one (creation remains hard)
- No longer purely of academic interest
  - Economic pursuits (zero-day markets)
  - Cyber warfare

# Worms

Due to the snow storm,  
we'll cover worms when we get to networking

# This time

Continuing with

## **Software Security**

Getting sick with

## **Malware**

- 
- Types of malware
  - How viruses work
  - Detecting viruses (and counter-measures)
  - Case studies