Virus Scanning as Model Checking

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Overview

1. The Problem:
   - Virus writers are getting smarter!
2. Smart Virus Scanner
   - Model checking
3. Encouraging Results
4. Future Directions

Why Another Virus Scanner?

Why Another Virus Scanner?

- The Problem:
  - Viruses are becoming better at hiding themselves in binaries
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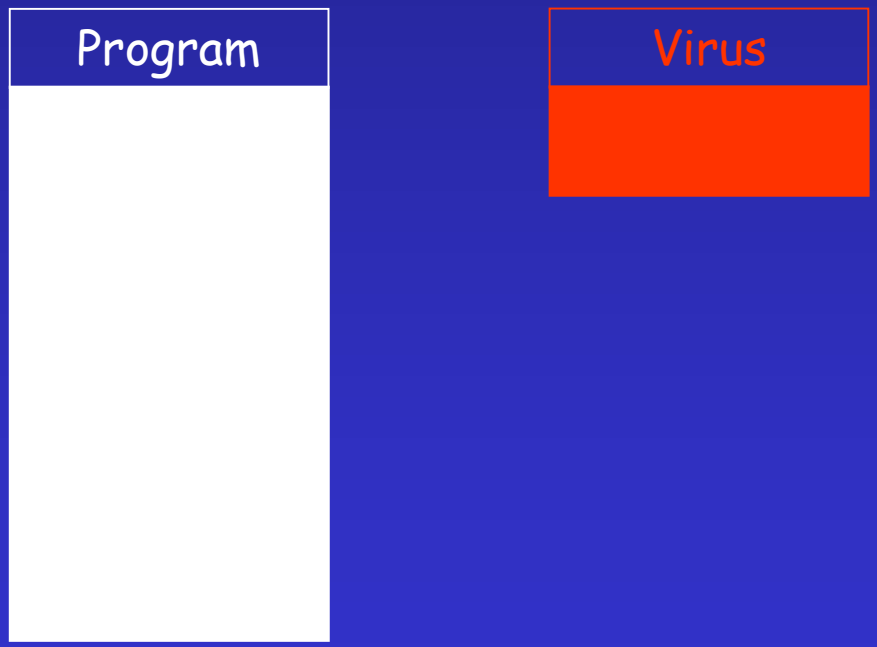
- The Problem:
  - Viruses are becoming better at hiding themselves in binaries
  - Virus writers use complex techniques to obfuscate virus code in a host program
- Current commercial virus scanners are inadequate

Obfuscation: Vanilla Virus

- Simple obfuscation methods



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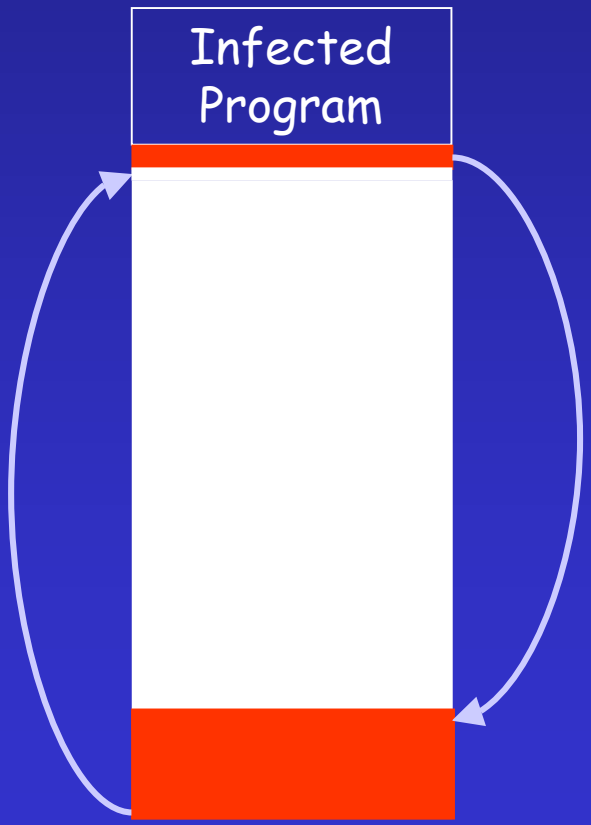

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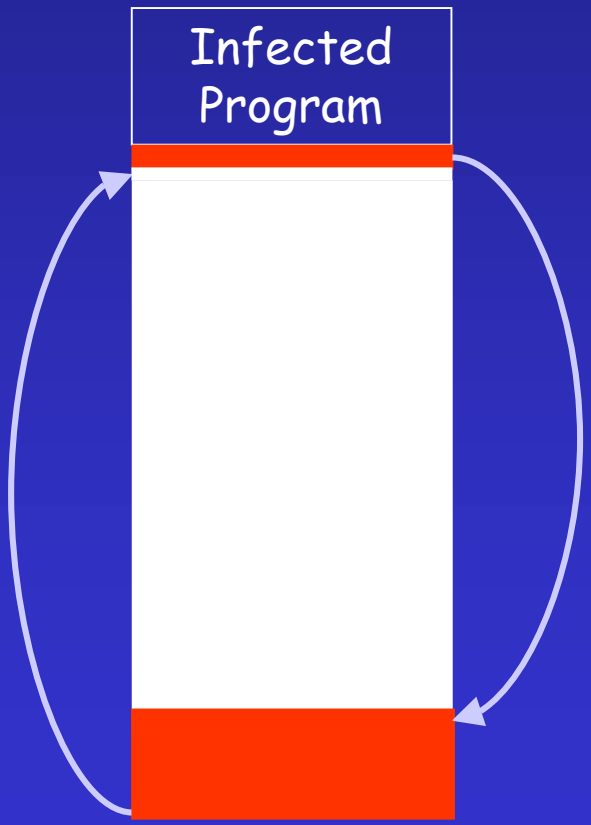

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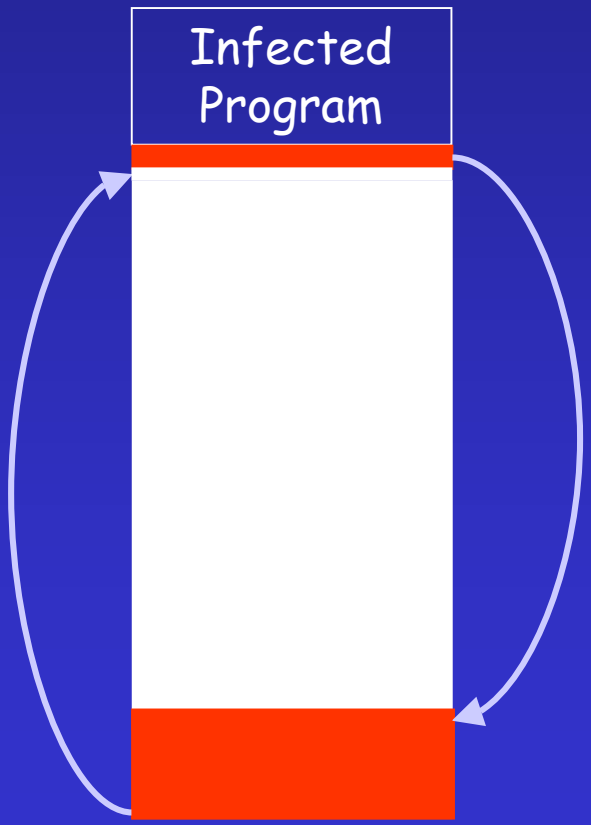

  - Signature matching

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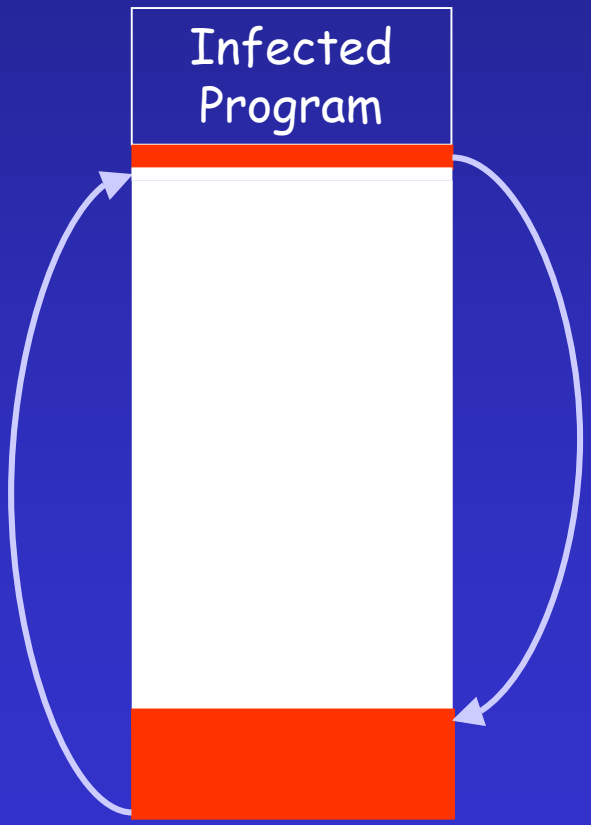
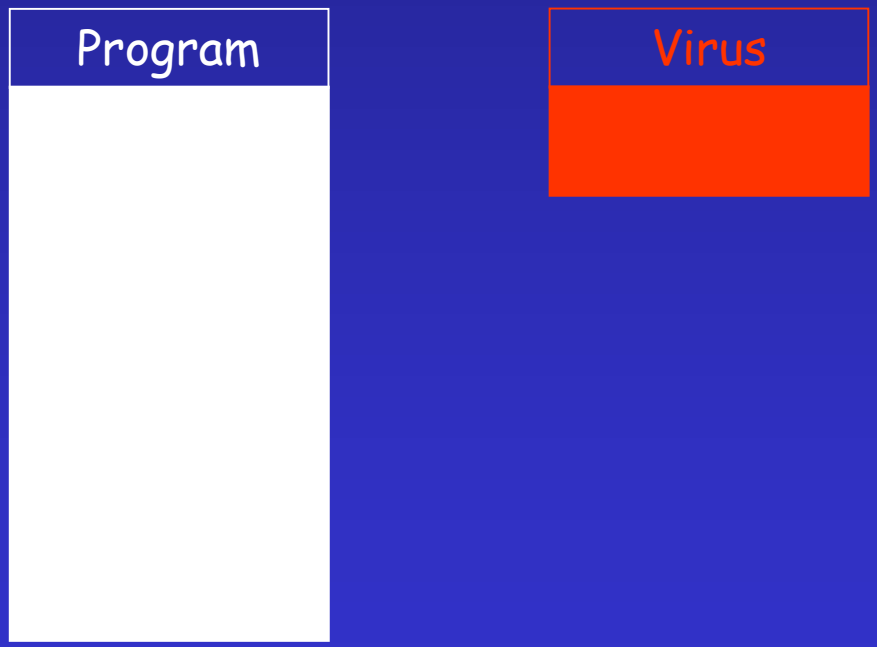


- Signature matching
- Very successful against first-gen viruses!

Obfuscation: Polymorphism

- Encrypted virus body + morphed decryption routine



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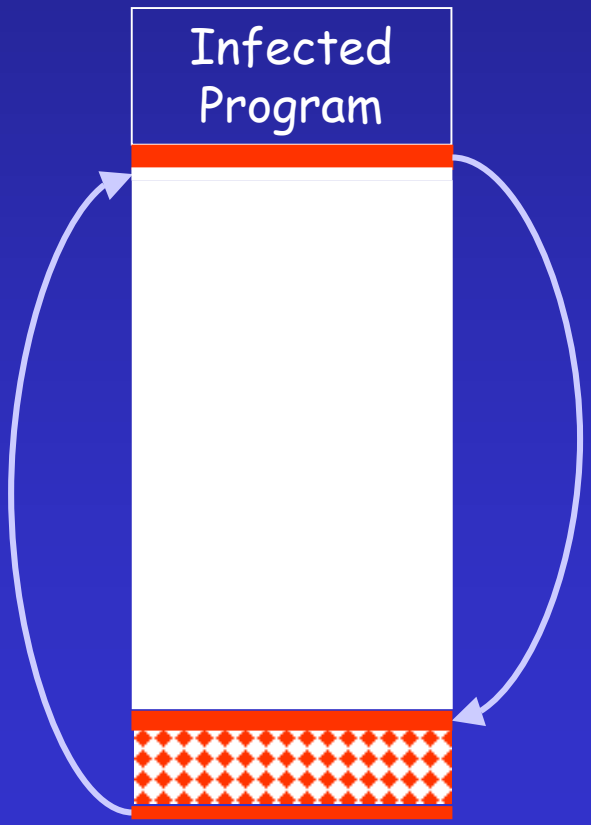

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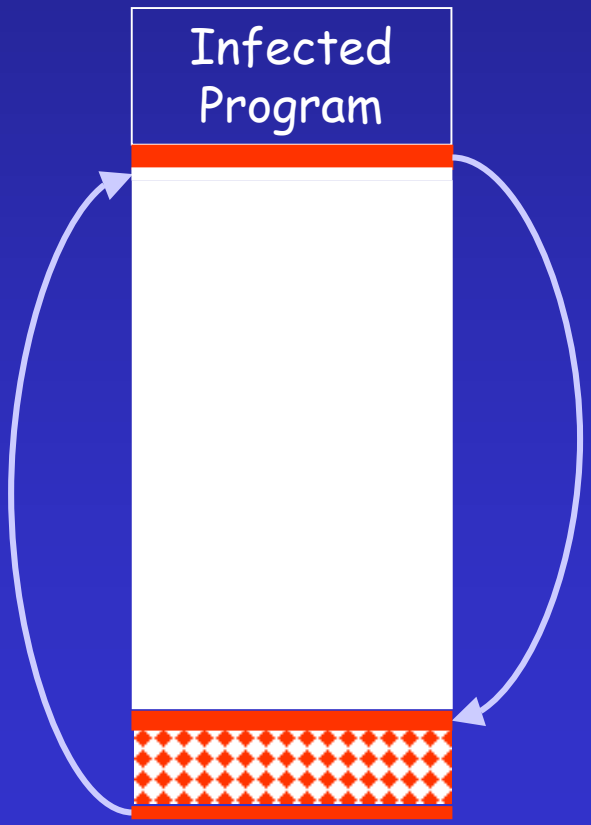

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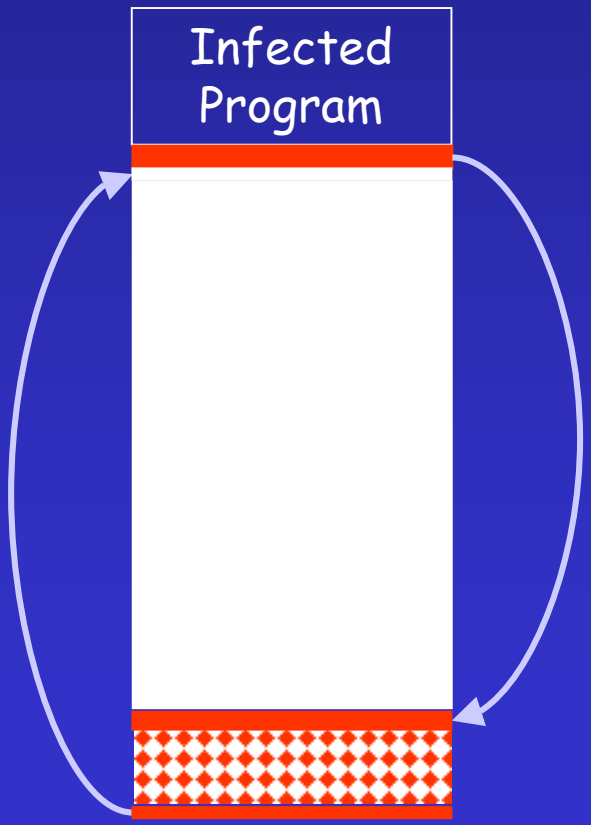

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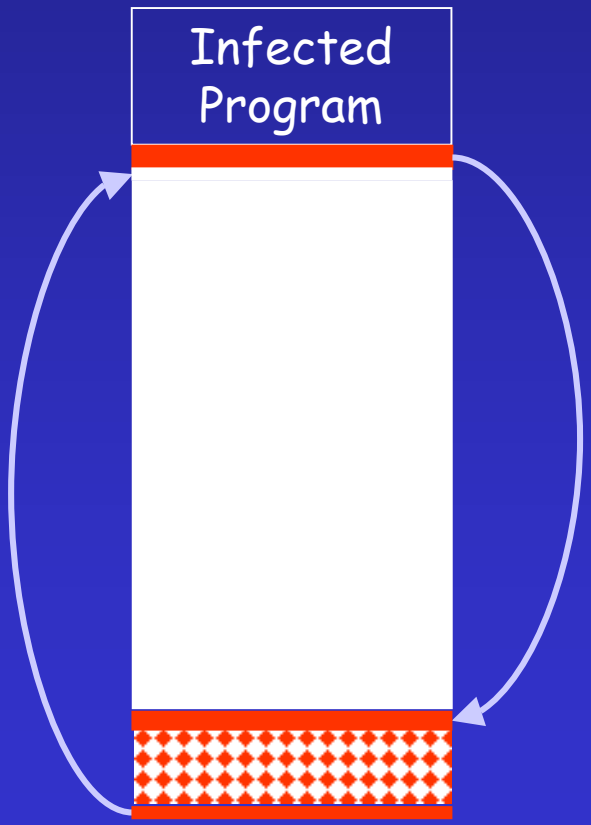

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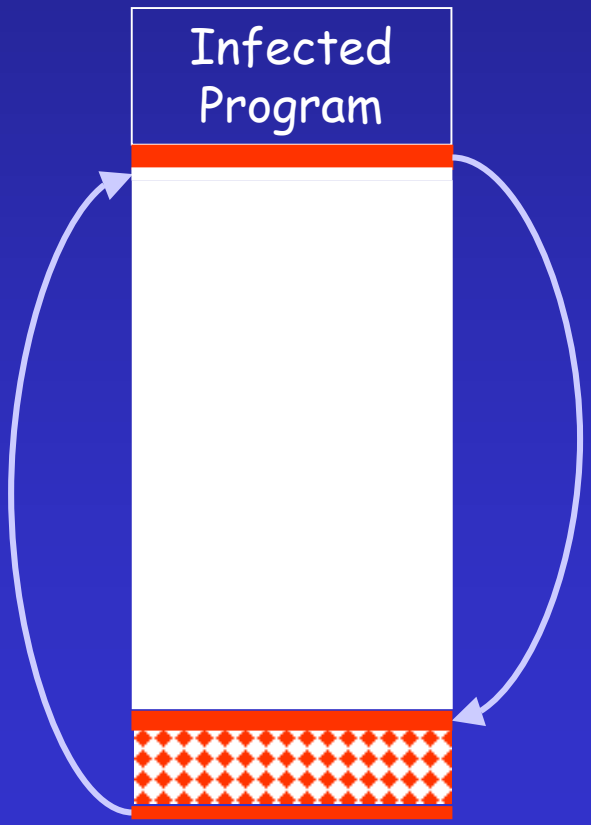

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- Current state-of-the-art

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- Metamorphic viruses:
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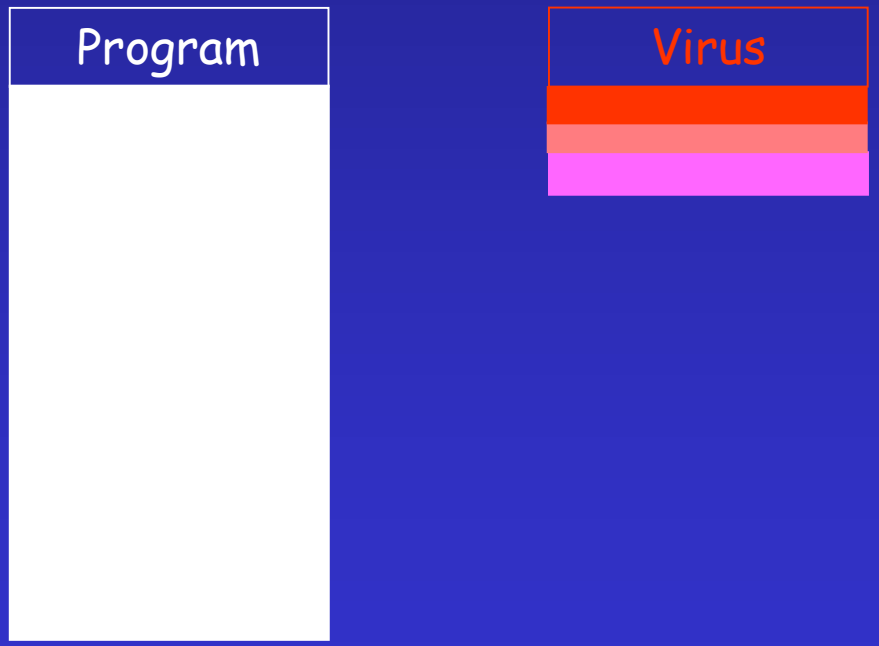

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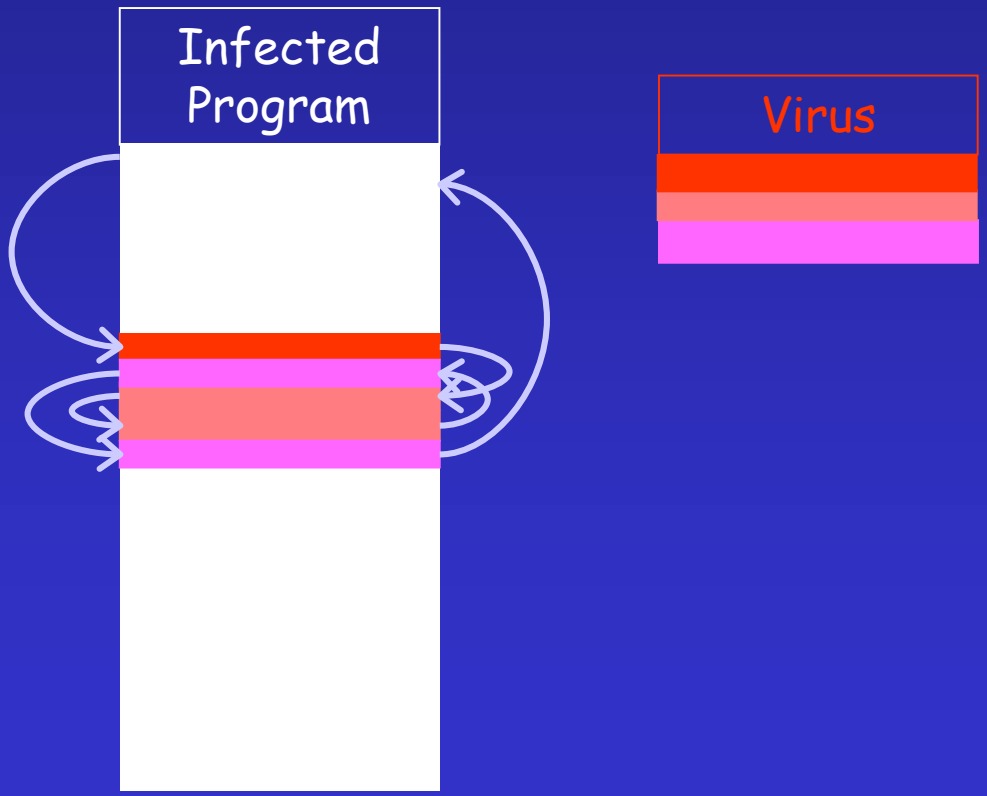

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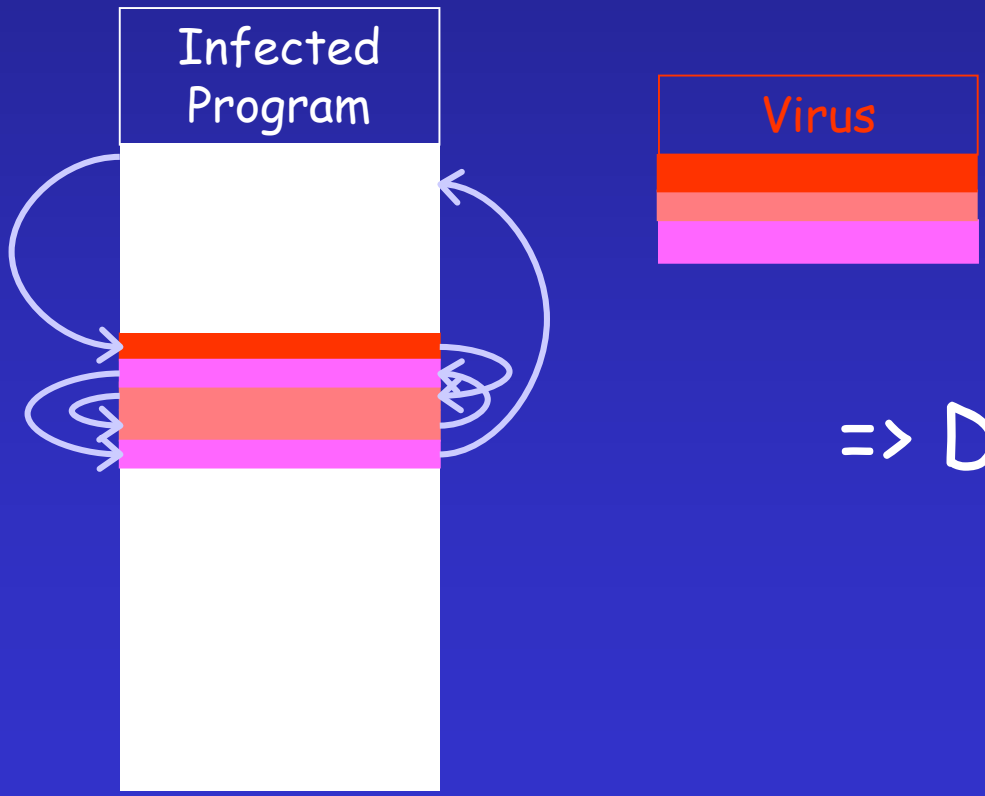

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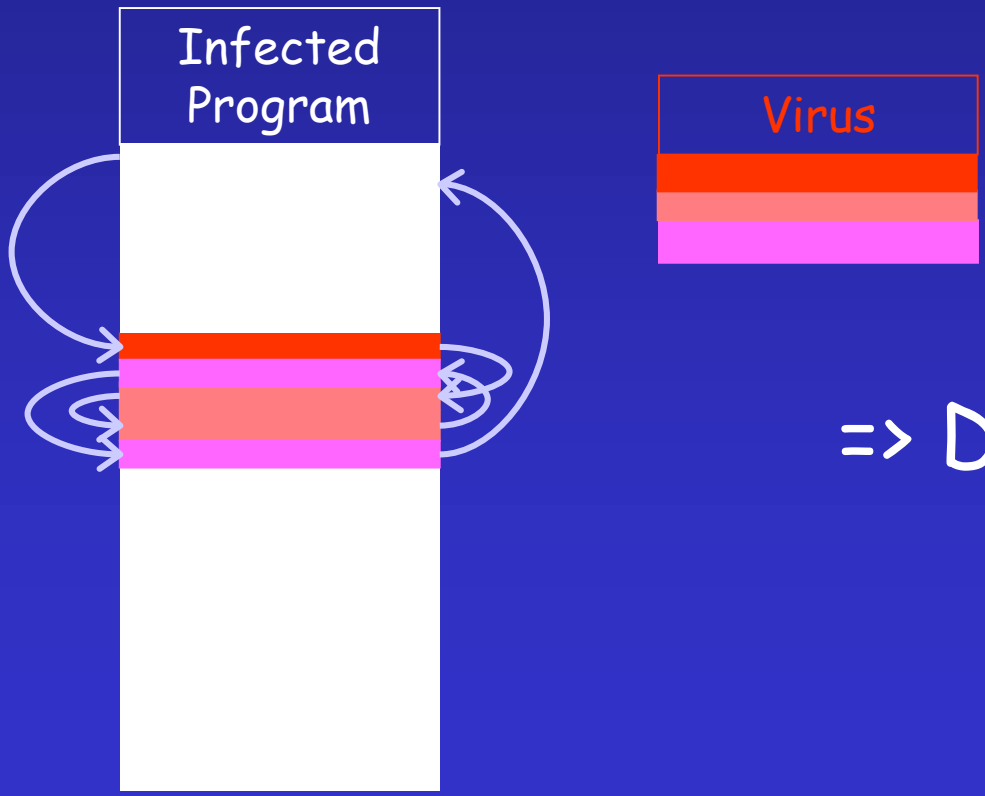

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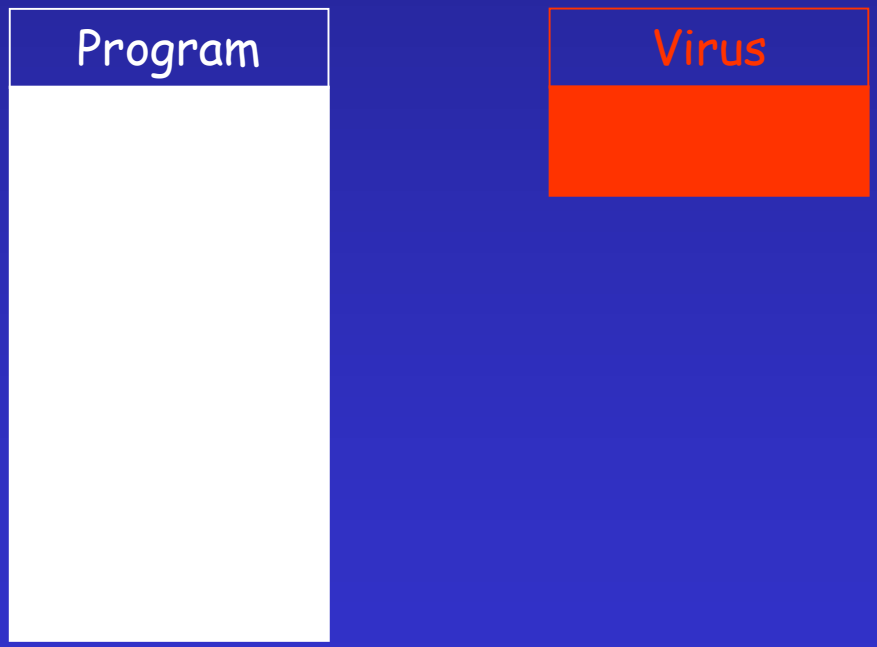
- Integration of virus and program
  - e.g. Mistfall Virus Engine



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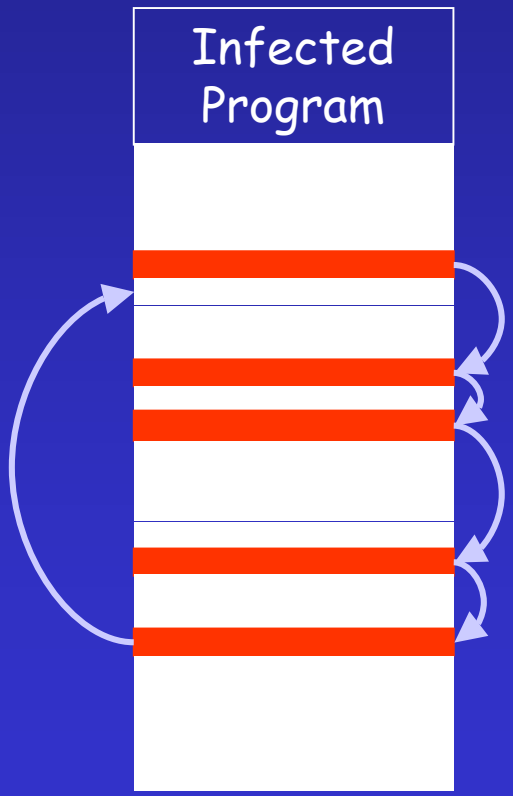

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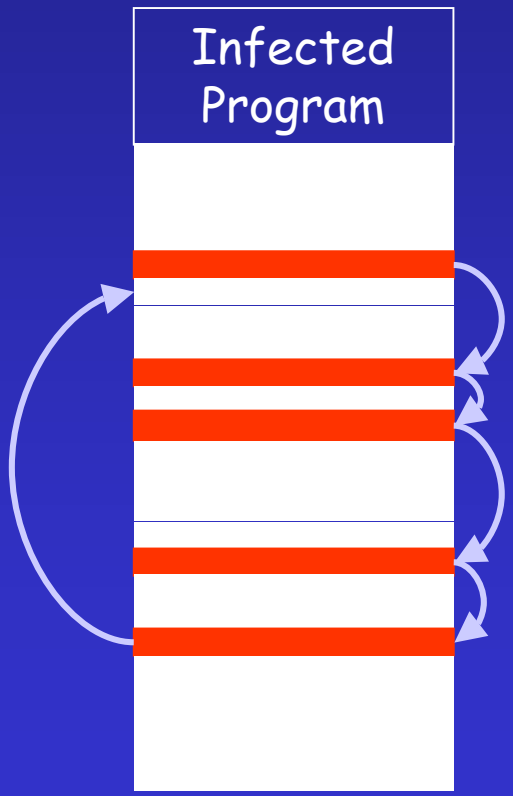

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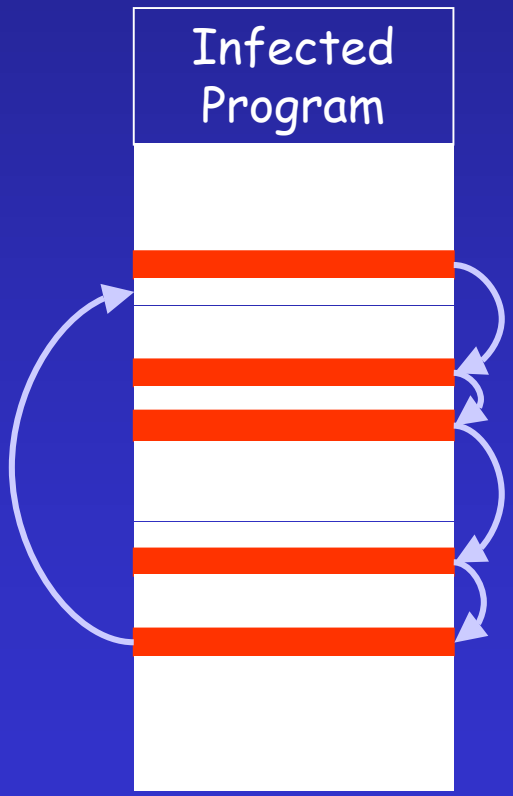

=> Detection methods

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Example

Virus Code

(from Chernobyl CIH 1.4):

```
Loop:
        pop     ecx
        jecxz   SFModMark
        mov     esi, ecx
        mov     eax, 0d601h
        pop     edx
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        call    edi
        jmp     Loop
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Loop:
            pop     ecx
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            xor     ebx, ebx
            beqz    N1
N1:         mov     esi, ecx
            nop
            mov     eax, 0d601h
            pop     edx
            pop     ecx
            nop
            call    edi
            xor     ebx, ebx
            beqz    N2
N2:         jmp     Loop
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L3:     call    edi
        xor     ebx, ebx
        beqz    N2
N2:     jmp     Loop
        jmp L4
L2:     nop
        mov     eax, 0d601h
        pop     edx
        pop     ecx
        nop
        jmp L3
L1:     jecxz   SFModMark
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        beqz    N1
N1:     mov     esi, ecx
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  - More flexible

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- Better virus detection tool
  - Analyze the program structure (instead of signature matching)
  - More flexible
- Check whether viral properties are present in a given program
  - e.g.: "program writes to an executable file"
  - e.g.: "program monitors as executables are loaded into memory and changes them"
  - e.g.: "program behaves just like virus XYZ"

Overview

1. The Problem:
   - Virus writers are getting smarter!

☞ 2. Smart Virus Scanner
   - Model checking

3. Encouraging Results

4. Future Directions

Use Model Checking

- Consider the vanilla virus code as a set of one or more properties
- Check that the program exhibits those properties
  - If YES => infected

Model Checking

- Technique for checking program properties

1. Build automaton for the desired property
2. Extract program model
3. Compare the model against the automaton

Model Checking

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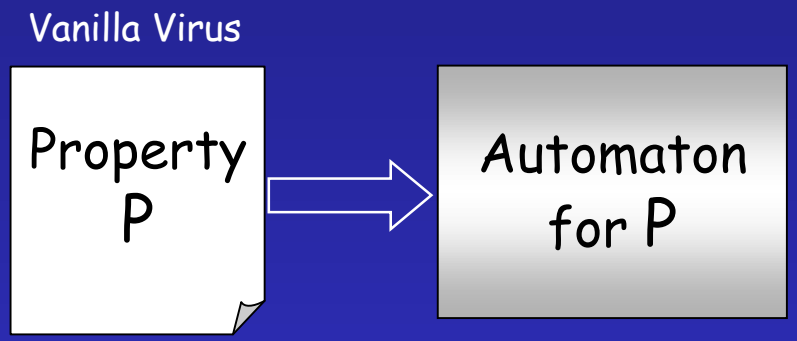

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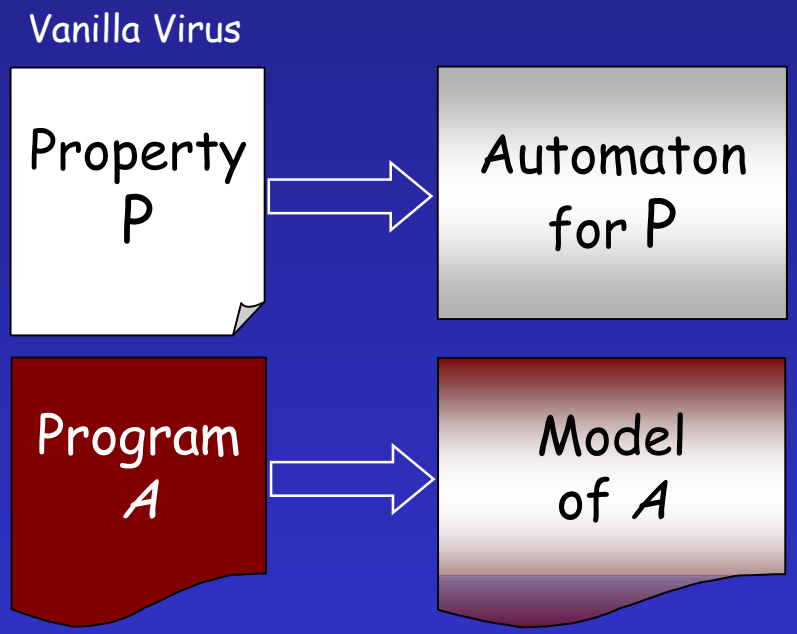

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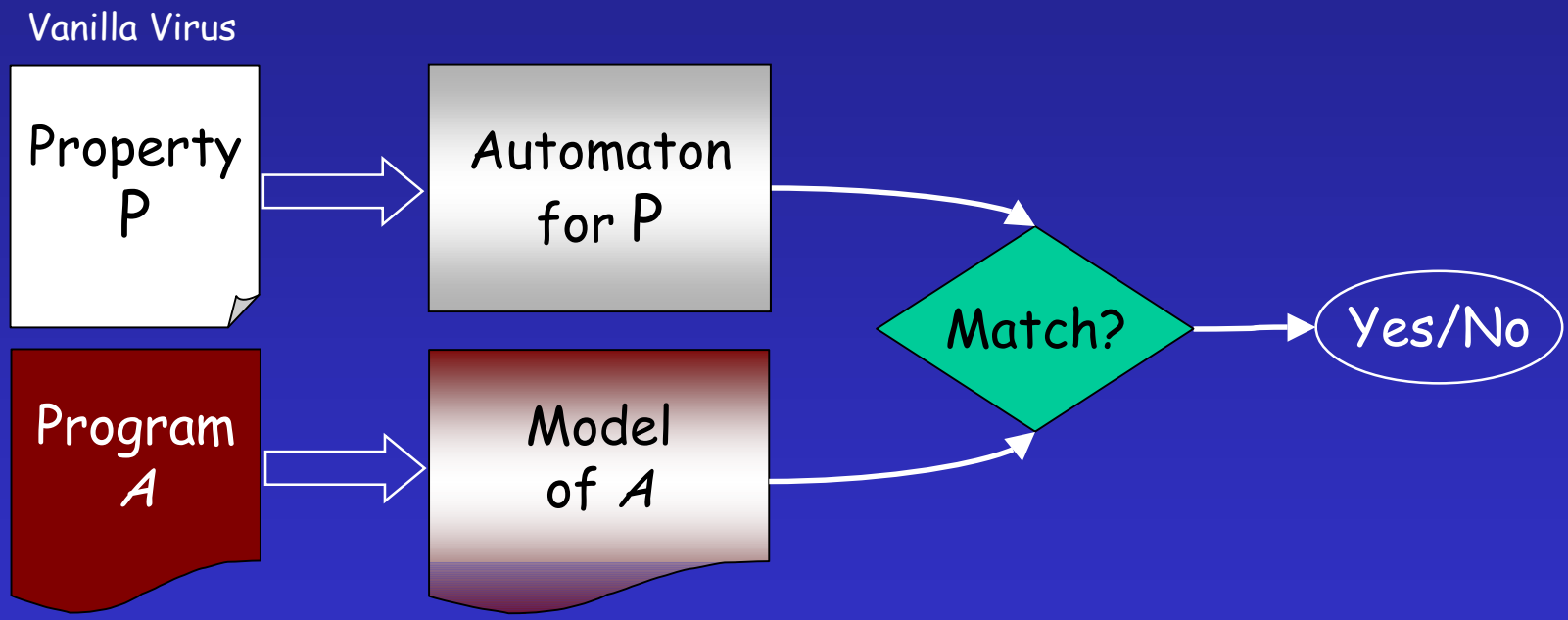

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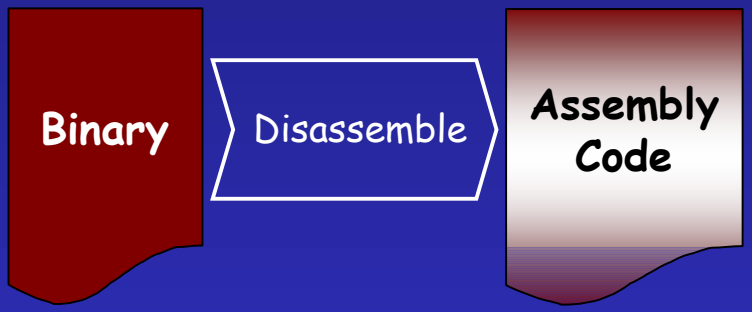

IDA Pro

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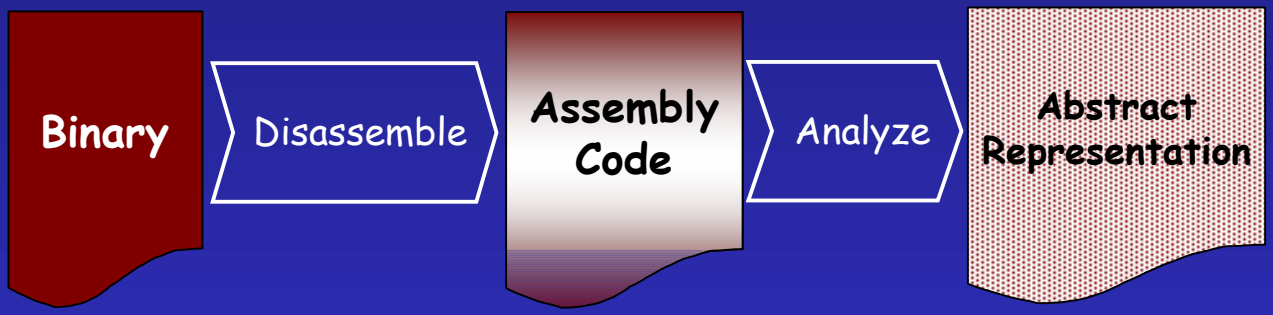

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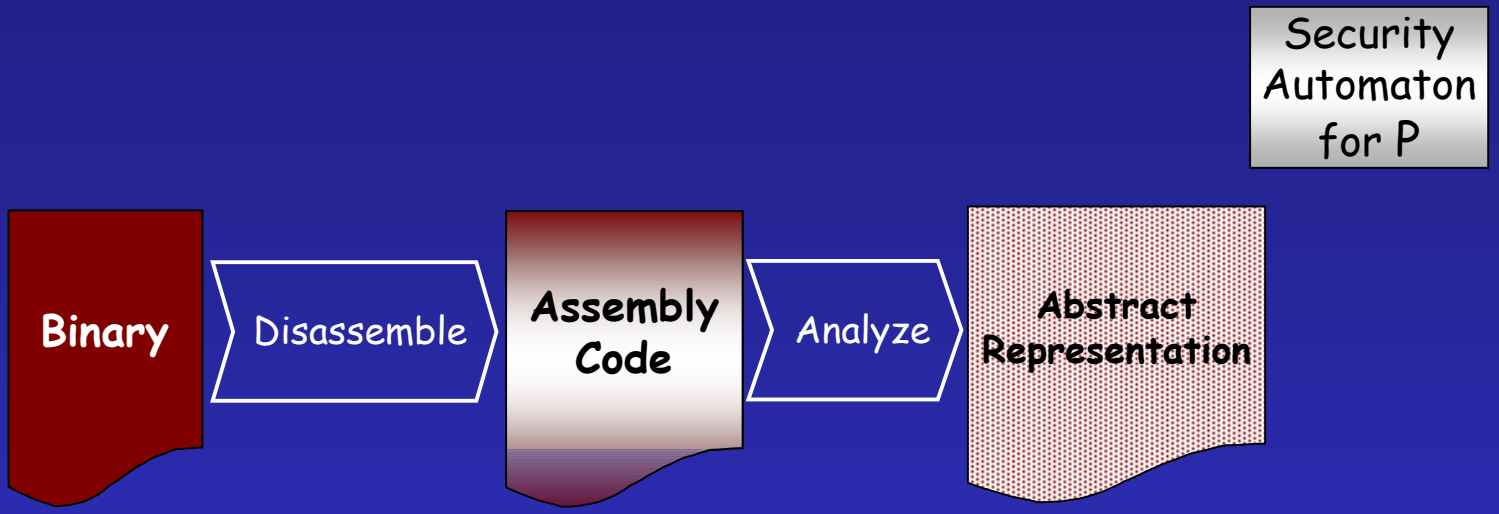

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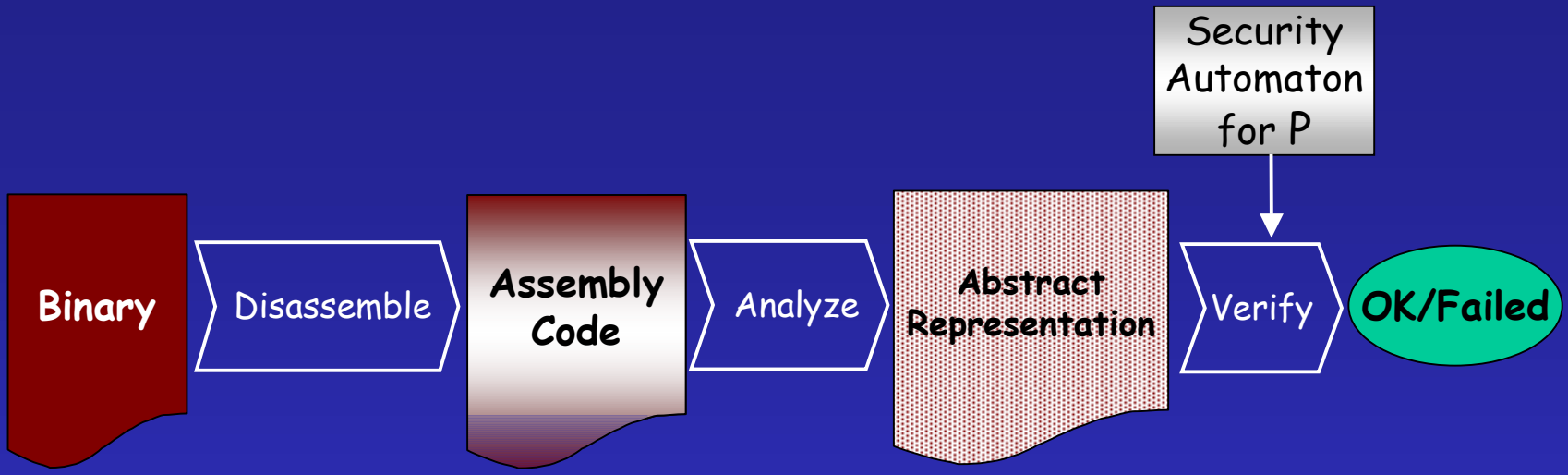

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2. Build a model of the program
3. Verify that model does not match the blueprint

Smart Virus Scanner Example

Virus Code:

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push    eax
sidt    [esp-02h]
pop     ebx
add     ebx, HookNo * 08h + 04h
cli
mov     ebp, [ebx]
mov     bp, [ebx-04h]
lea     esi, MyHook - @1[ecx]
push    esi
mov     [ebx-04h], si
shr     esi, 16
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(from Chernobyl CIH 1.4 virus)

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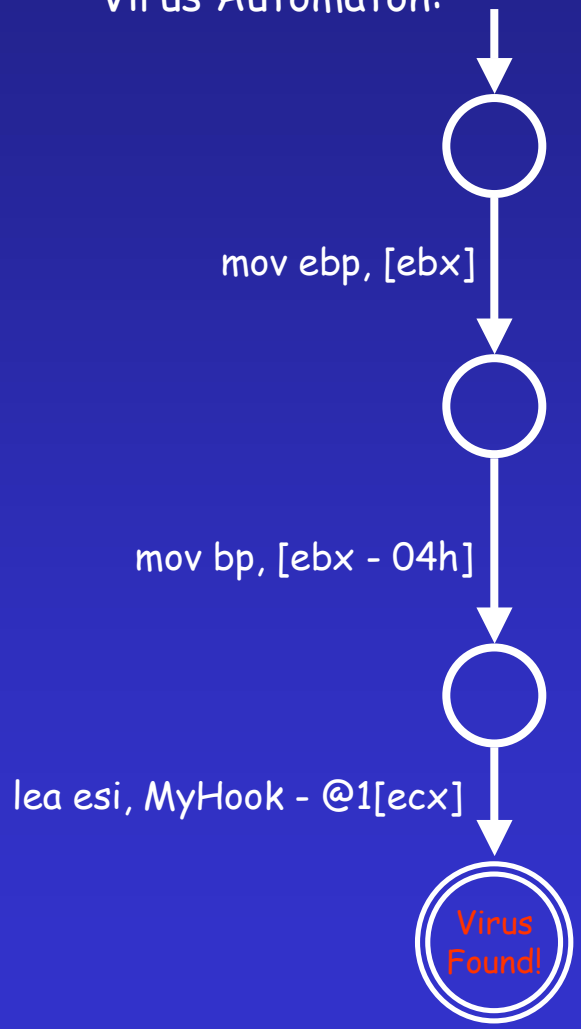

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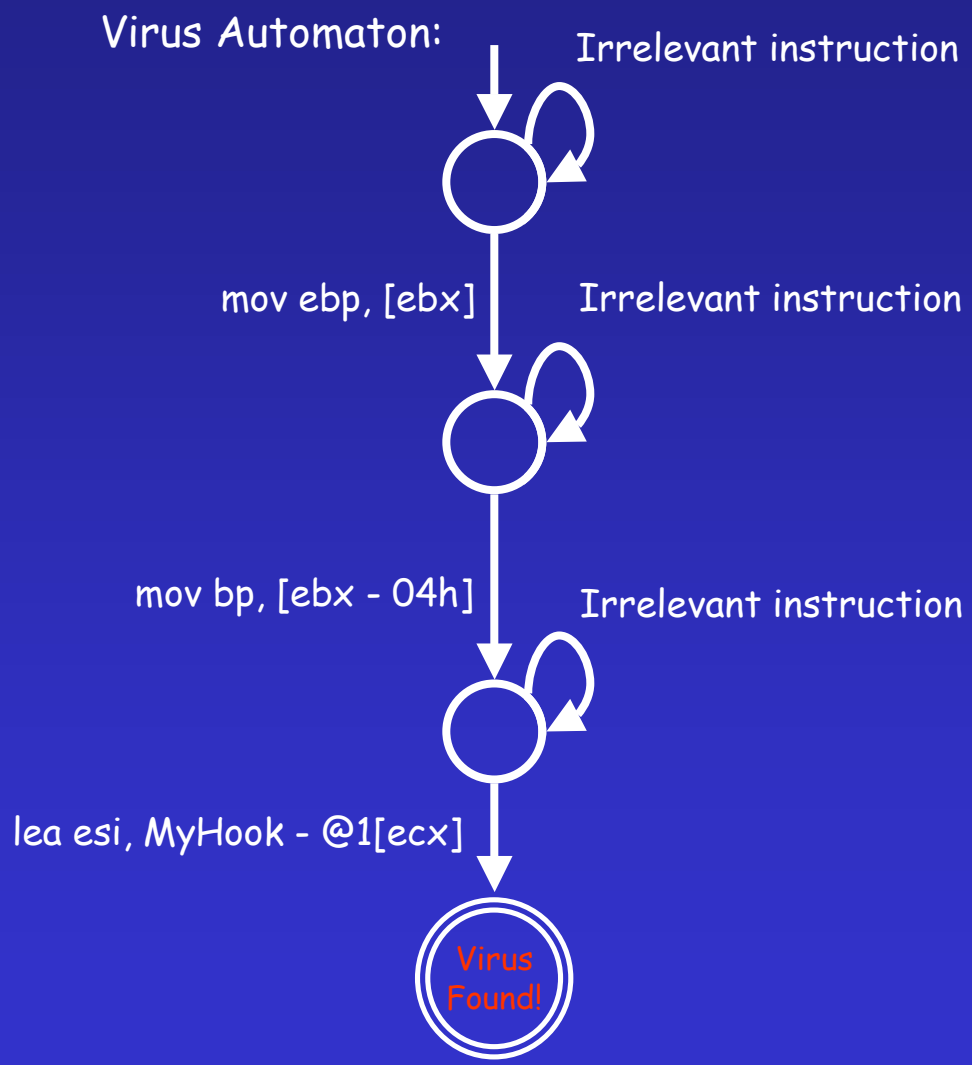

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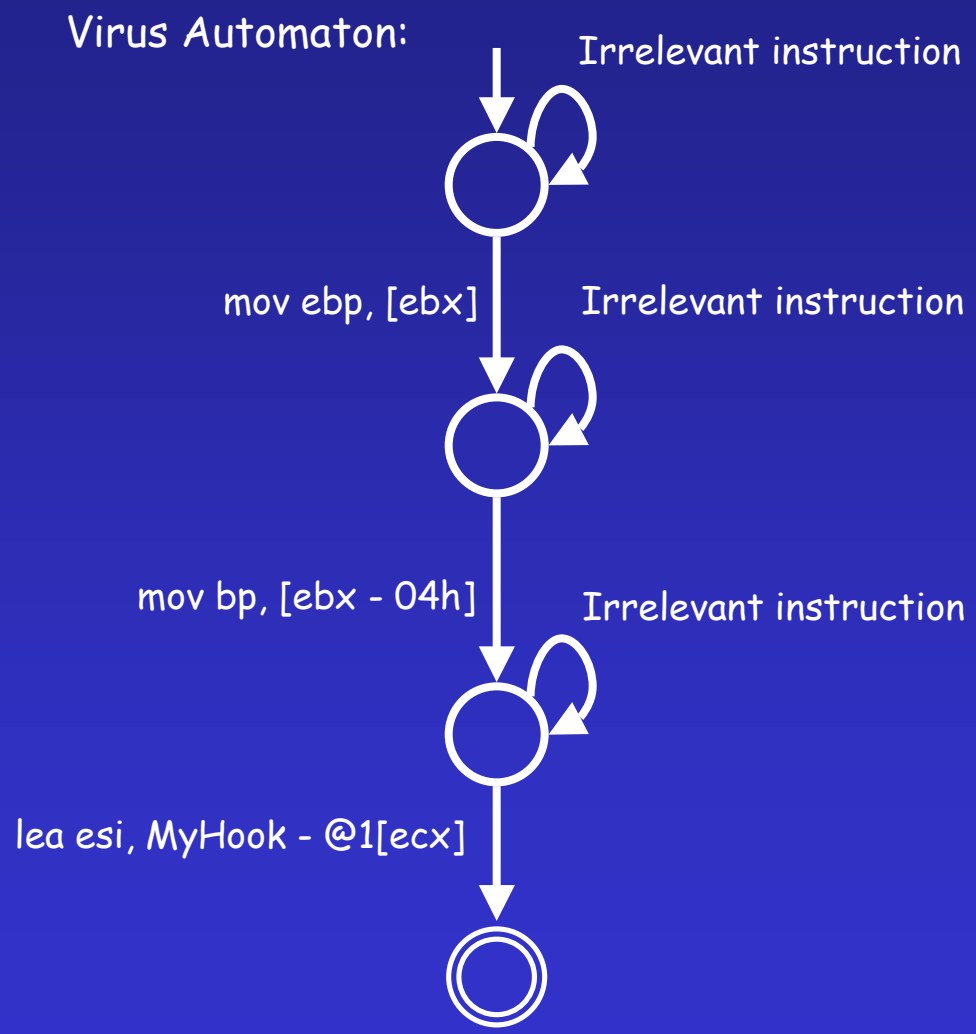

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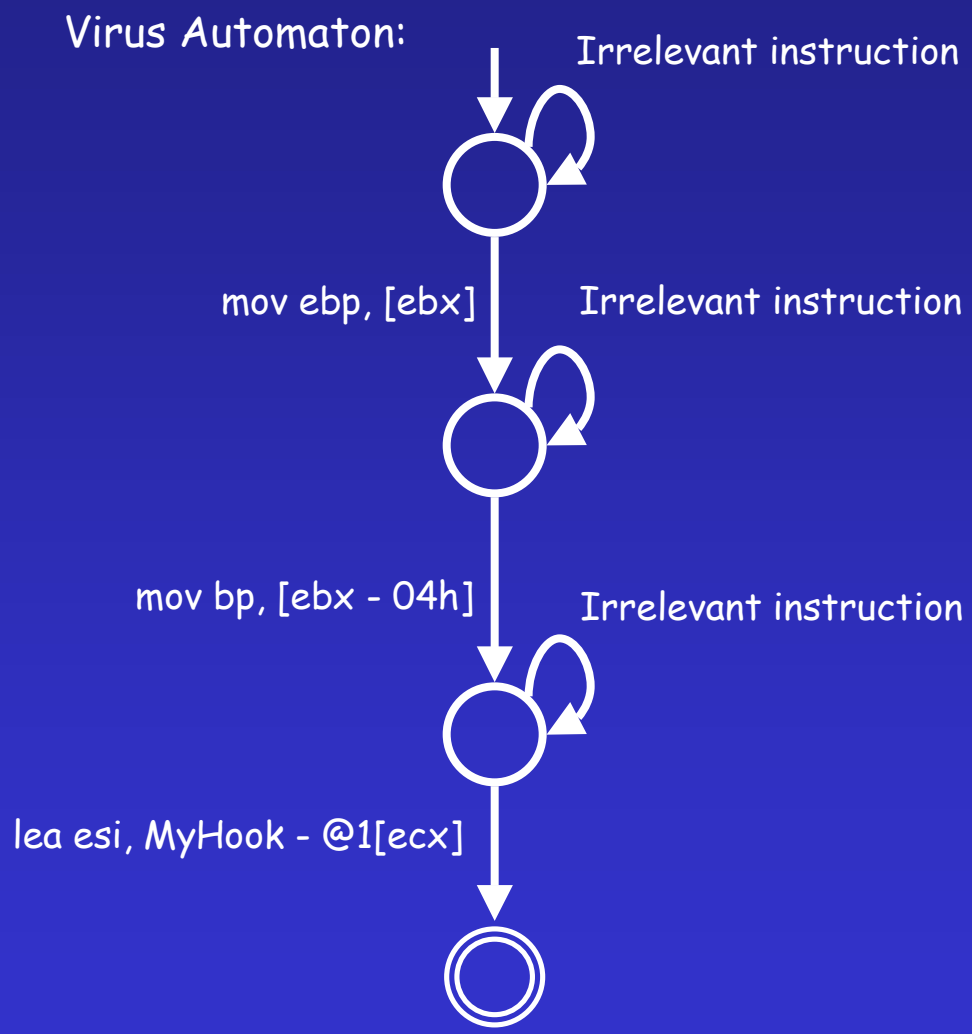
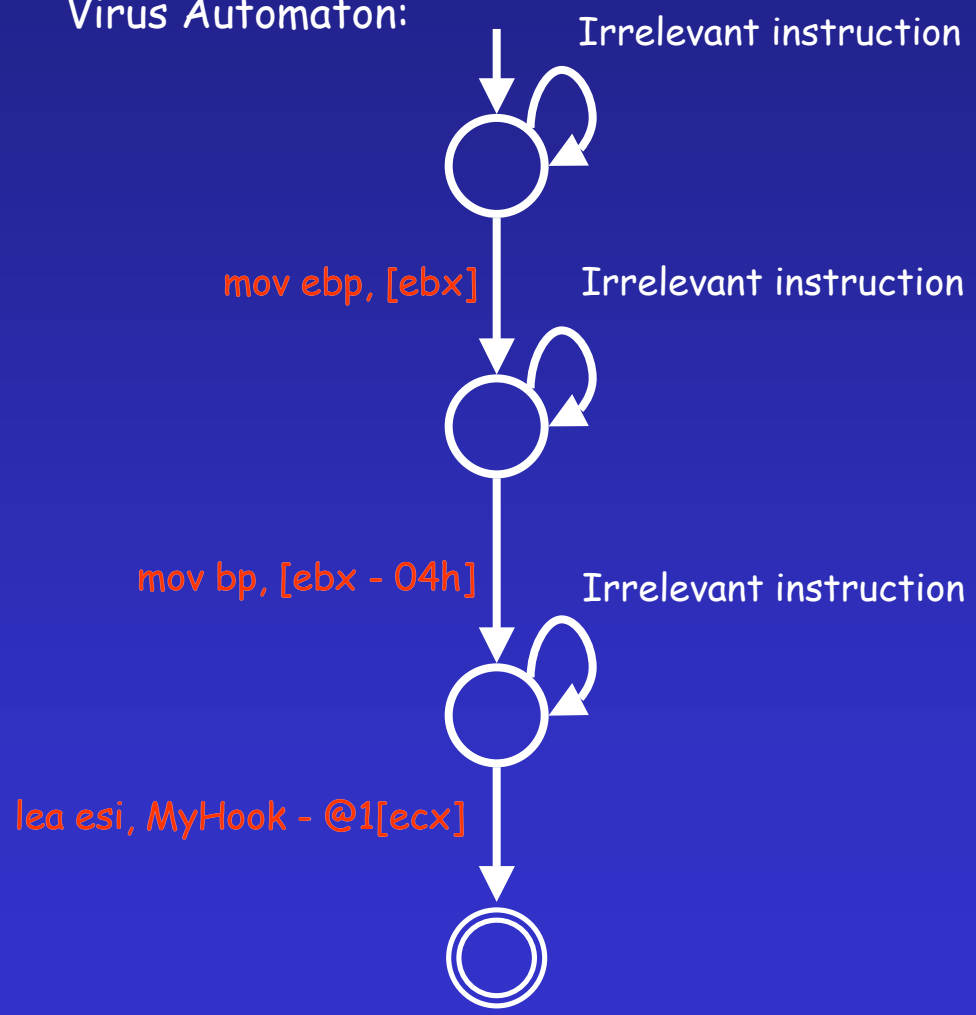


Program to be checked:

```
        mov ebp, [ebx]
        nop
        mov bp, [ebx-04h]
        test ebx
        beqz next
next:   lea esi, MyHook - @1[ecx]
```

Smart Virus Scanner Example

Virus Automaton:



Program to be checked:

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next:   lea esi, MyHook - @1[ecx]
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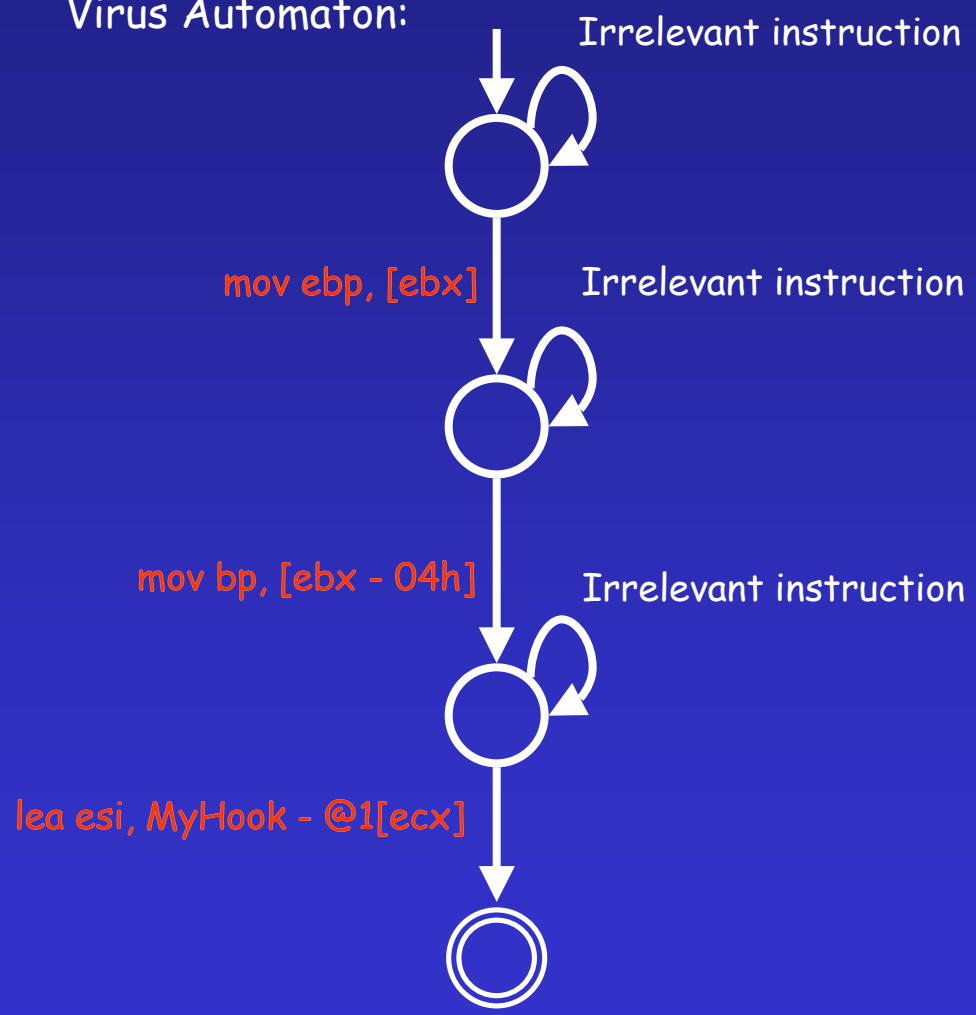

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  - Control flow instructions that do not change the control flow
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  - Instructions that modify dead registers
  - Sequences of instructions that do not modify architectural state
    - e.g.:

      add ebx, 1
      sub ebx, 1

Overview

1. The Problem:
   - Virus writers are getting smarter!
2. Smart Virus Scanner
   - Model checking
3. Encouraging Results
4. Future Directions

Current Status

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- We disassemble and analyze program structure

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- We can detect viruses morphed in a simple manner
  - Irrelevant instructions = NOPs

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  - AntiVirus utilities
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☺ Our Smart Virus Scanner catches "NOP"-morphed viruses

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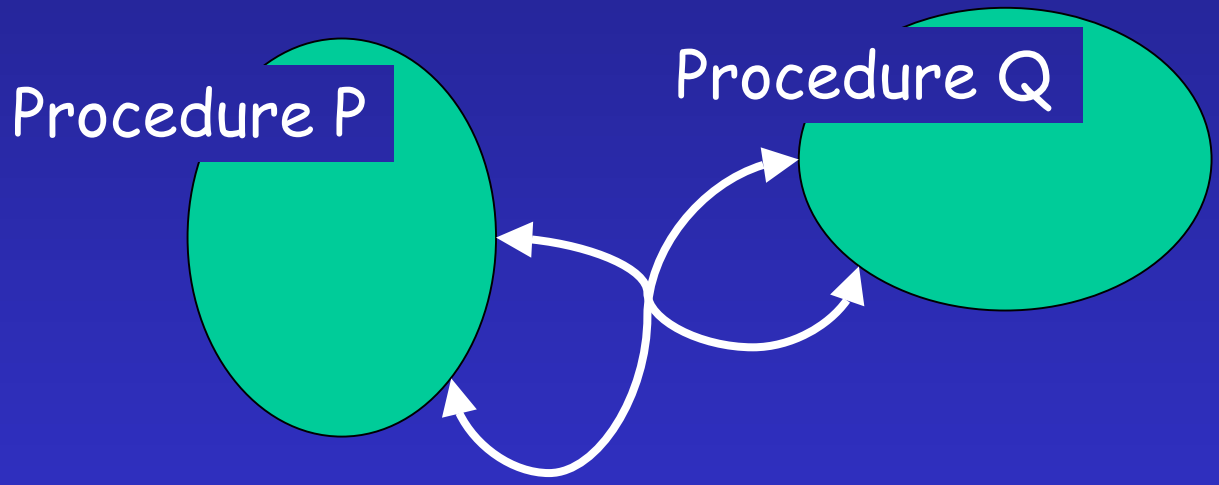

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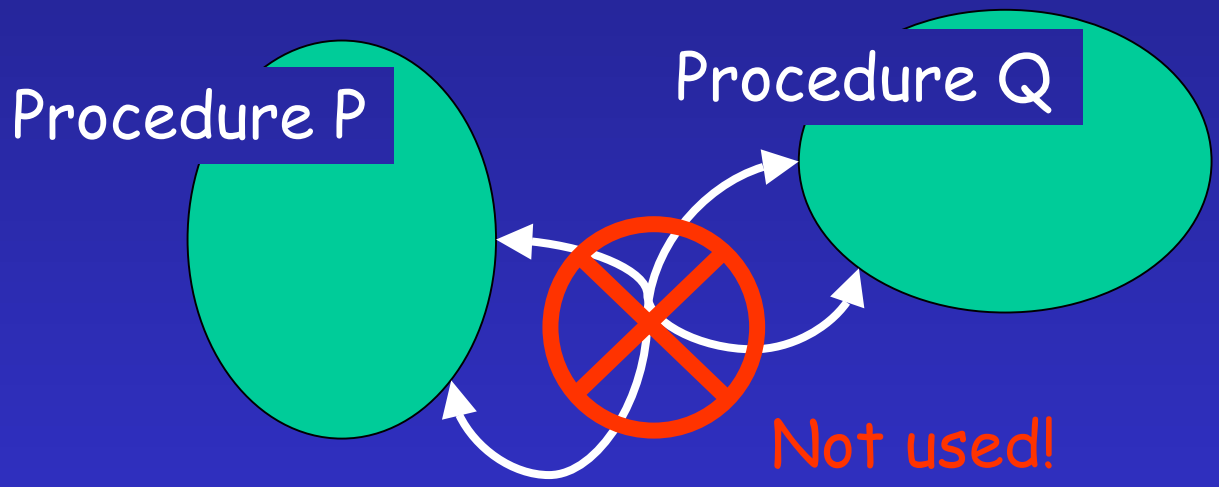

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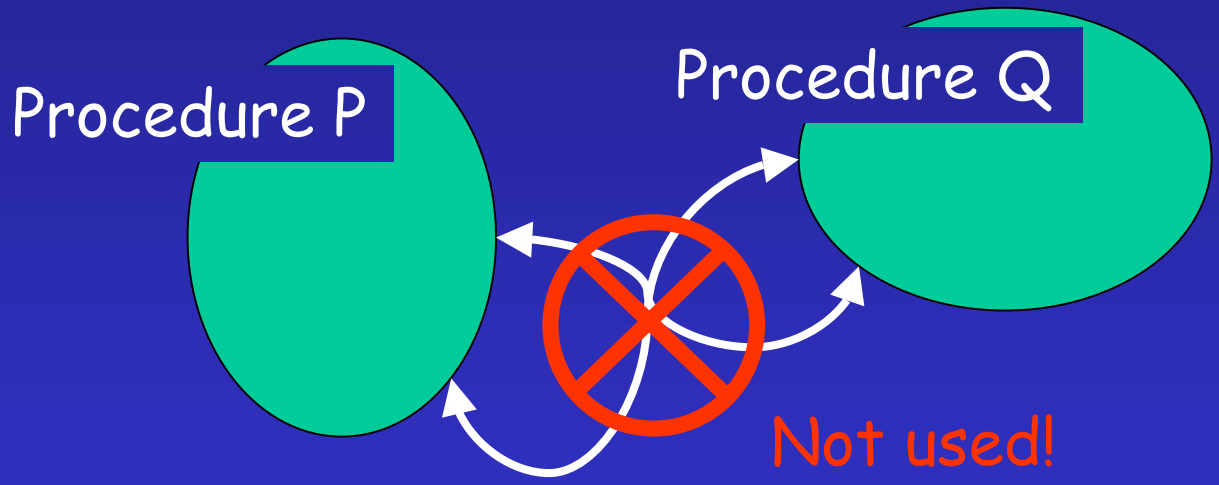

  - Cannot detect equivalent instruction sequences

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Future Work

- Main focus:
  - Improve detection of "irrelevant insn's"
- More (precise) information from static analysis
  - live range information
  - alias/points-to analysis
- Library of equivalent instructions sequences

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  - Recognize virus code spread across subroutines
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  - Recognize virus code with different register usage
- Virus scanning for component-based systems
  - Recognize virus code distributed across components
- Scan for multiple viruses at the same time

References

- Schneider, F.B. *Enforceable Security Policies*. TR99-1759, July 27, 1999.
- Dawson Engler, Benjamin Chelf, Andy Chou, and Seth Hallem. *Checking System Rules Using System Specific, Programmer-Written Compiler Extensions*. In Proceedings of the Fourth Symposium on Operating Systems Design and Implementation, San Diego, CA, October 2000. http://citeseer.nj.nec.com/engler00checking.html
- Péter Ször, and Peter Ferrie. *Hunting For Metamorphic*. In Proceedings of Virus Bulletin Conference, September 2001. Pp. 123 – 154. http://www.geocities.com/szorp/metamorp.pdf
- Zombie. *Zombie's Homepage*. http://z0mbie.host.sk

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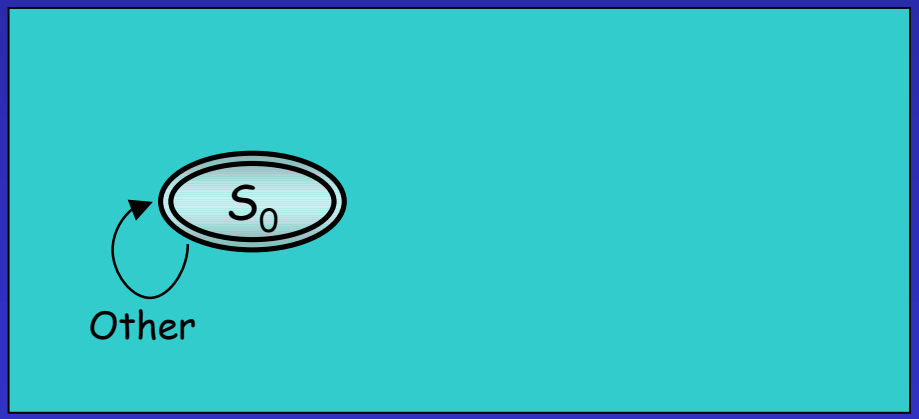

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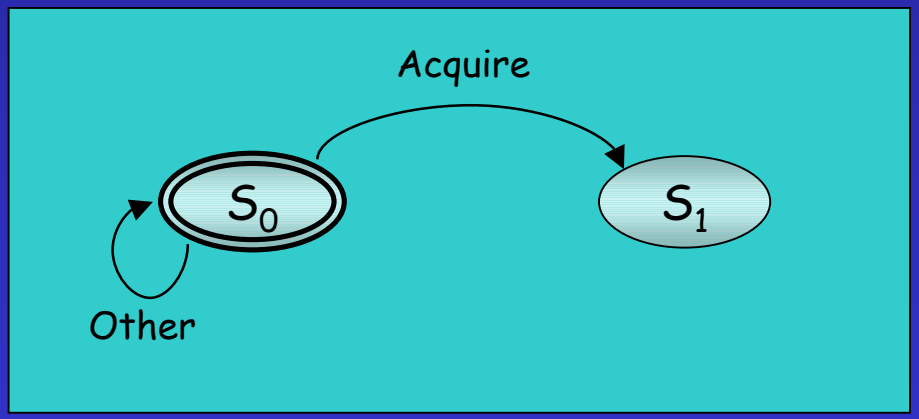

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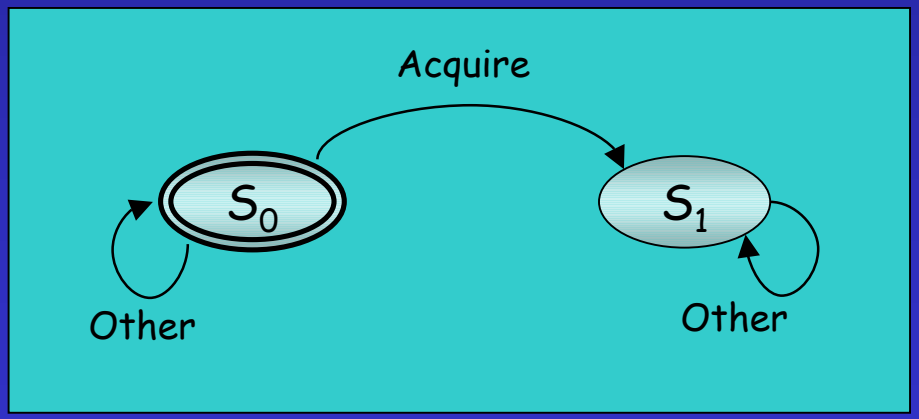

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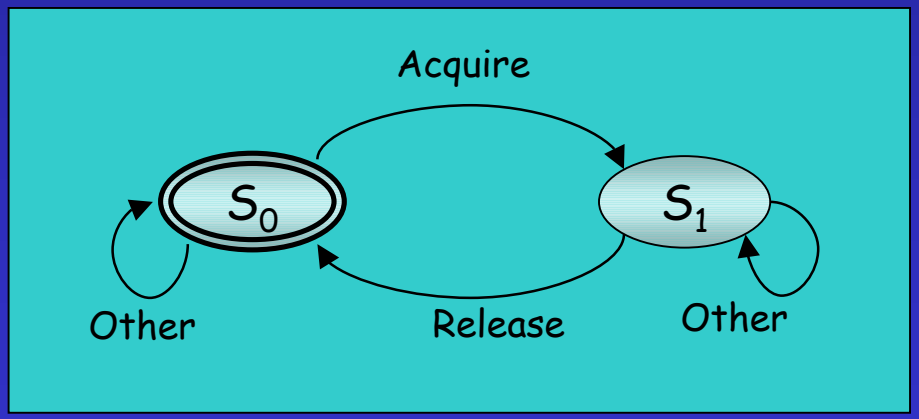

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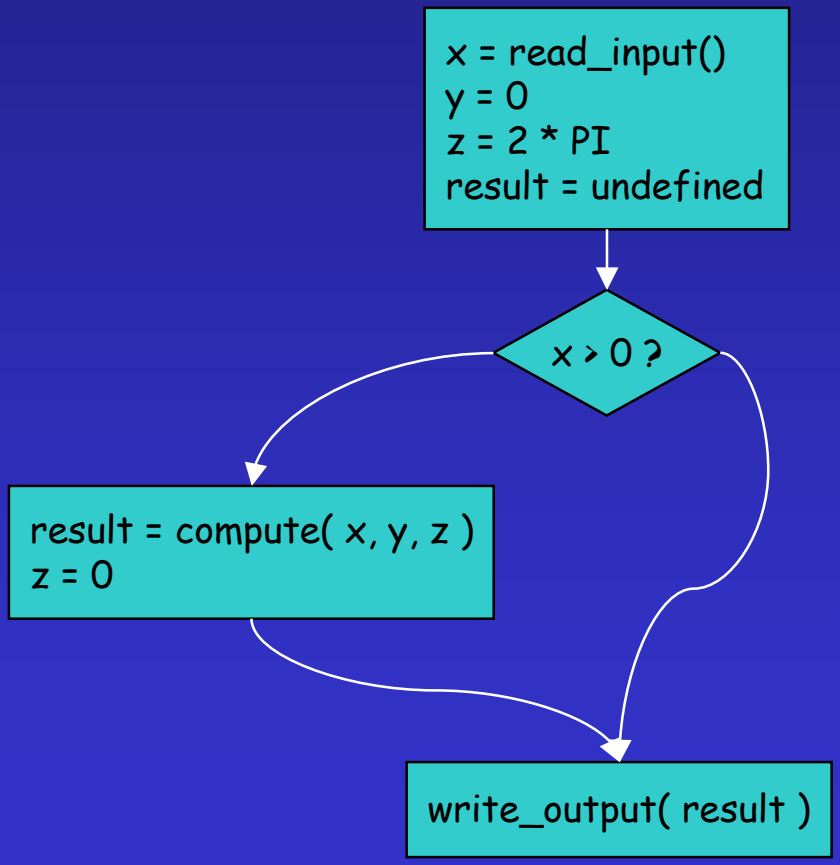

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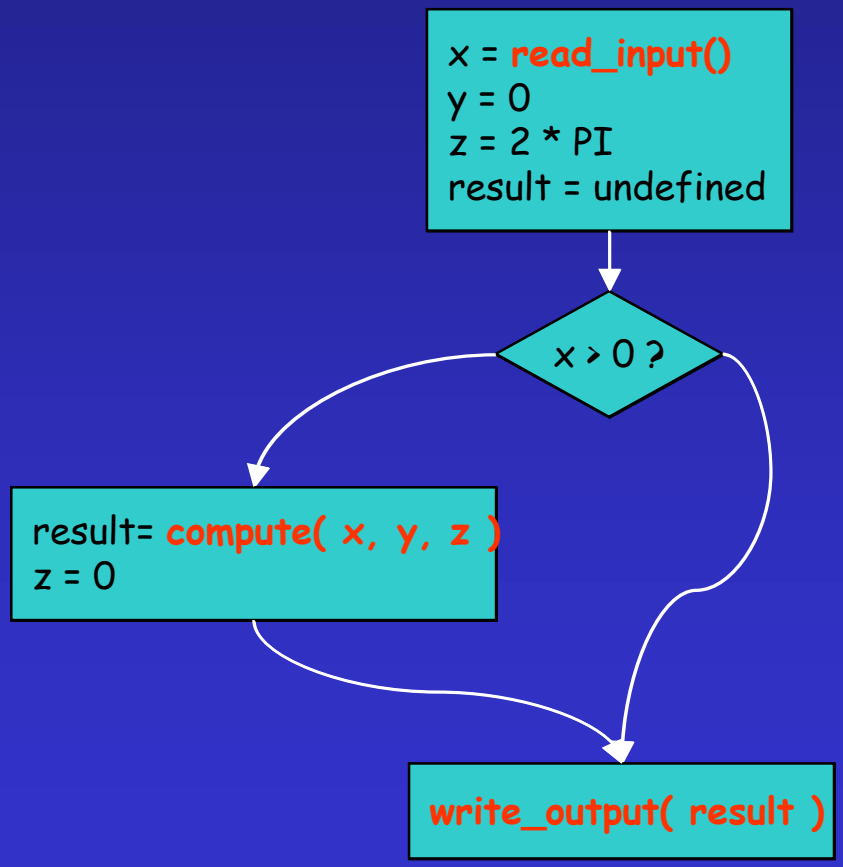

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