Effective *and* Efficient Malware Detection at the End Host

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Motivation

Why do we propose yet another malware detection scheme (yamds)?

- Binary signature based detection inherently *ineffective*
  - We all know the problems...
  - Arms-race, pretty much a lost battle

- Network based approaches *evadable*
  - Systems scan for communication artifacts
  - Encryption / blending thwart detection

Motivation

Why do we propose yet another malware detection scheme (yamds)?

- Don't rely on artifacts of malware *instances*
  - Instead focus on generic patterns

- Proposed solution:
  - Detection based on malware's behavior
  - Behavior is hard to obfuscate
  - Behavior is hard to randomize
  - Behavior is often stable across various malware version

Motivation

- Behavior-based detection received some attention over last couple of years

- Despite promising detection results, binary signatures remain the method of choice

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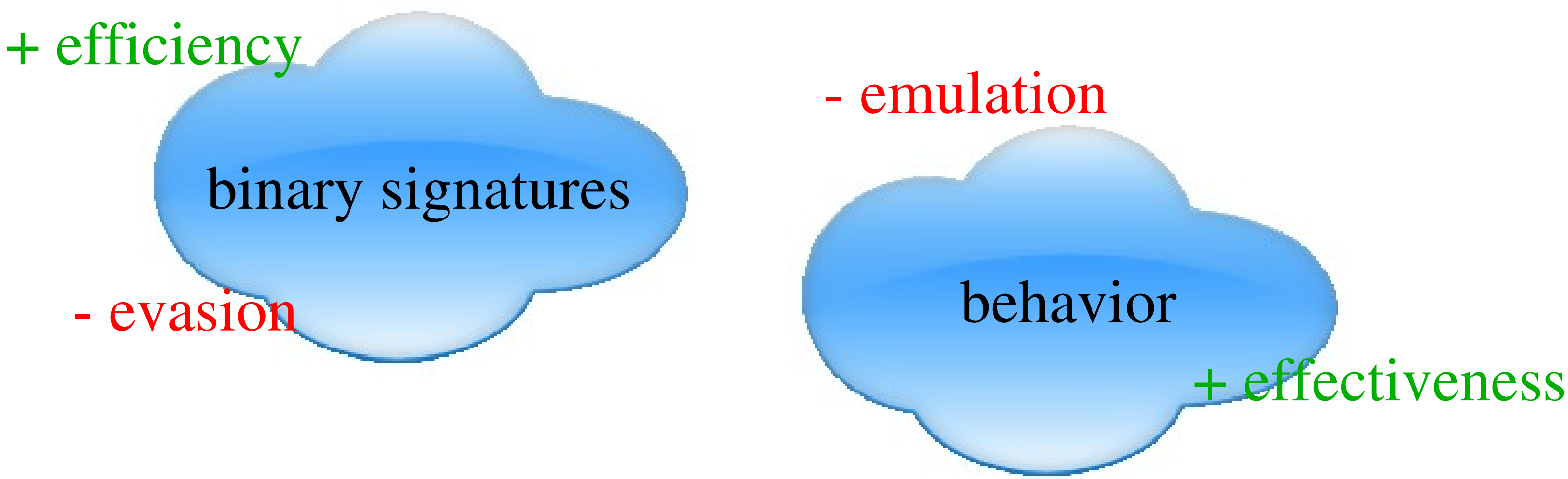
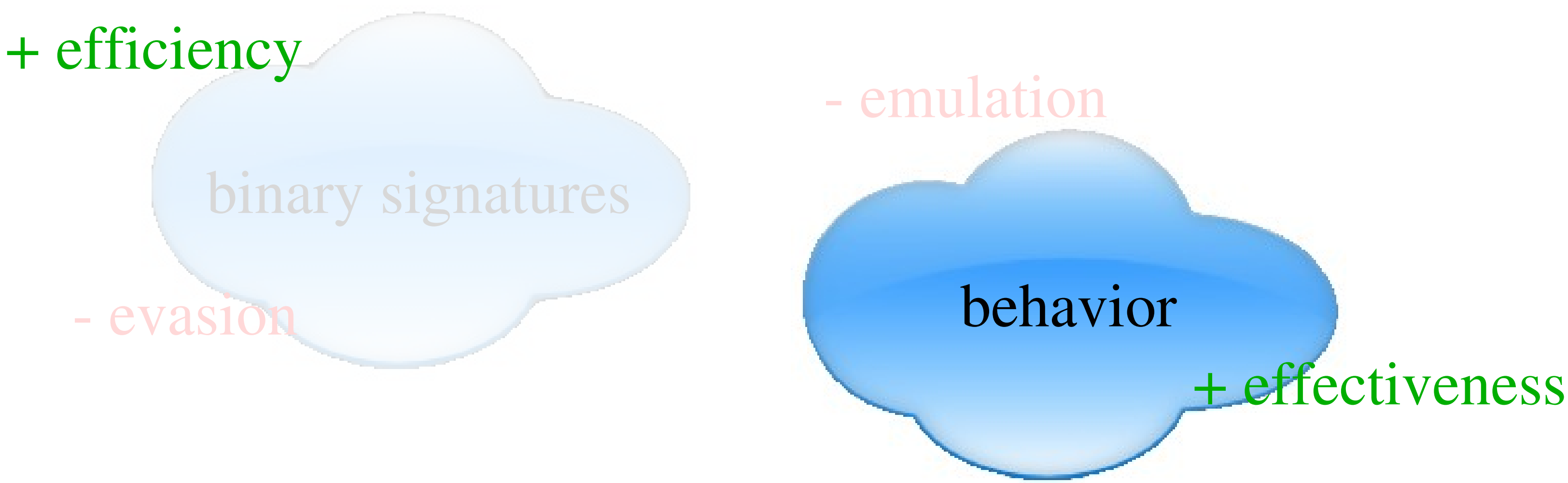


Motivation

- Behavior-based detection received some attention over last couple of years
- Despite promising detection results, binary signatures remain the method of choice



Outline

- Motivation
- Detecting Behavior
  - Motivating example (Agent)
- Matching Behavior Graphs
- Extracting Behavior Graphs
- Evaluation

Detecting Behavior

Detecting Behavior

- Characteristic malware behavior
  - Manifest on system (i.e., survive reboot)
    - (Over-) write system executables, dlls, files
    - Create registry entries (autorun)
    - Register as Windows (startup) service
  - Conceal from being detected
    - Restart under some *stealthy* name (e.g., svchost.exe)
    - Inject into legitimate processes
  - Replicate
    - Send eMails ('*check out this picture I found: pic.jpg.exe*')
    - Copy to Samba shares, USB drives, etc.
    - Scan and exploit services on LAN or WAN

Detecting Behavior
System Overview

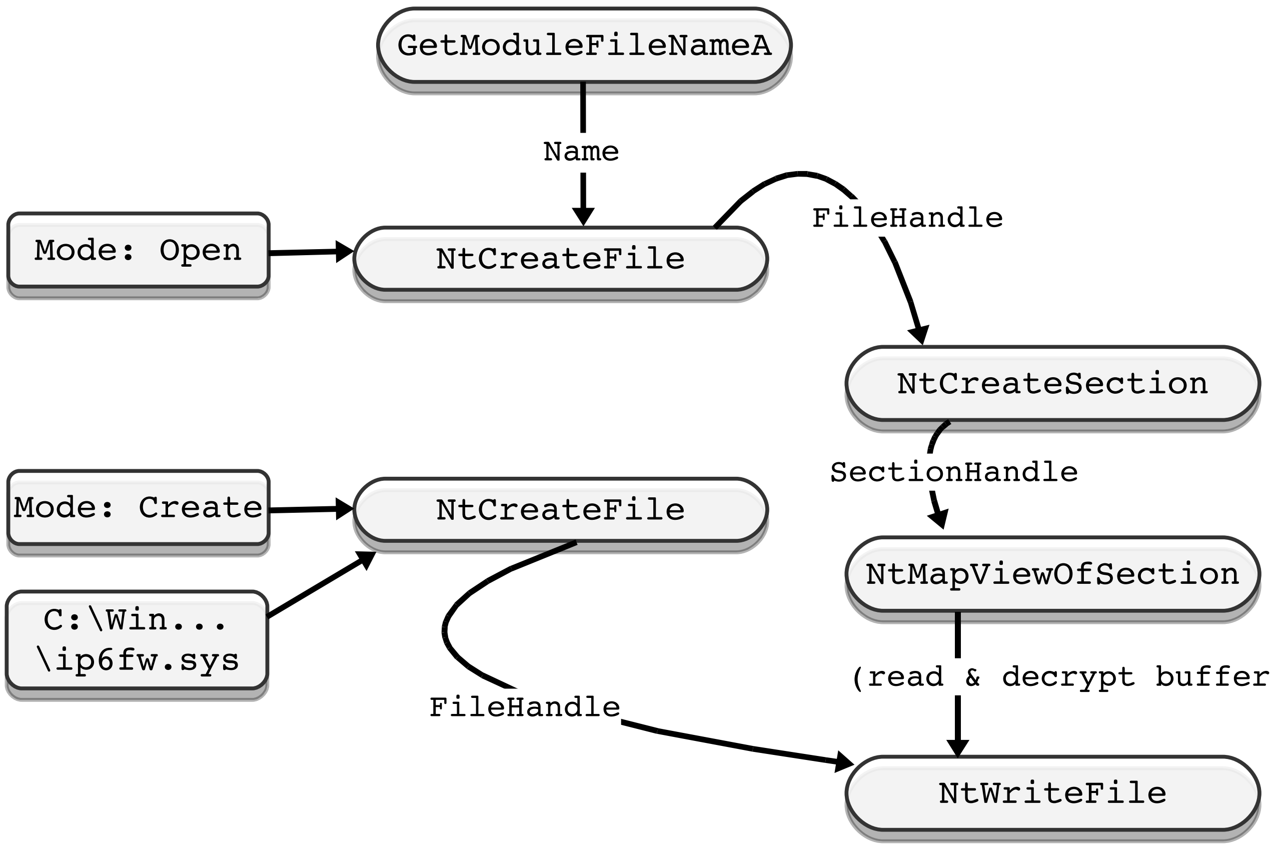
- Detection based on *execution characteristics*
  - Execute malware in full system emulator (Anubis)
  - Monitor interaction with the operating system
  - Perform detailed (taint-) analysis
  - Generate *detection graphs*
    - Describe sequence of *required* system calls leading to *security relevant* system activity
    - Include dependencies to related, previous calls (using taint dependencies)
- Detect described behavior on end host
  - Log system call activity of unknown executable
  - Match against behavior graph

Detecting Behavior
Developer Perspective

- Example: Agent (trojan horse)

- As part of its system manifestation, it
  - Reads content from binary image
  - Decrypts binary content
    - Proprietary decryption routine
    - Simple, XOR based algorithm
  - Stores binary in system file (`C:\Wind...\drivers\ip6fw.sys`)
  - Later, restarts IPv6 firewall
    - Turns itself into a system service

Detecting Behavior
Taint-Trace Perspective



Detecting Behavior

System Perspective

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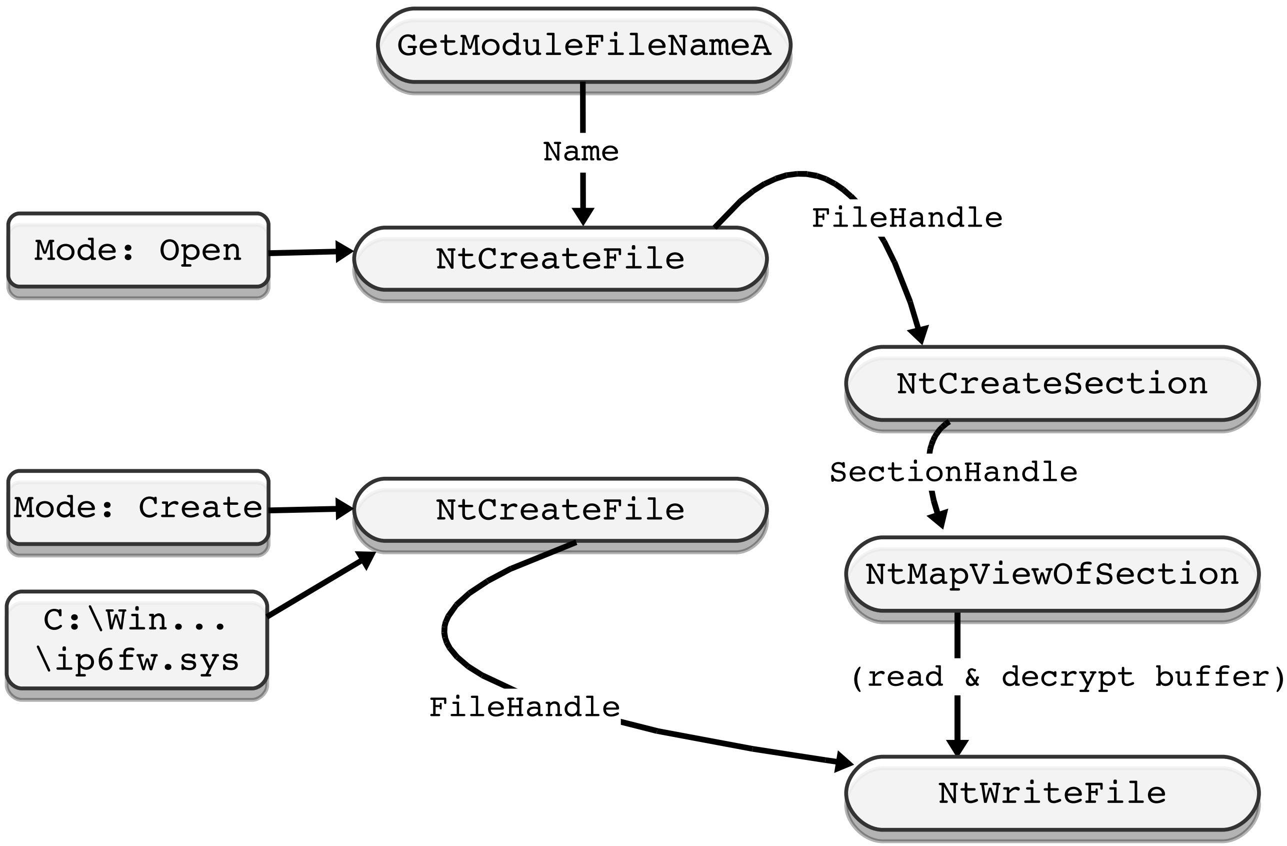

Detecting Behavior

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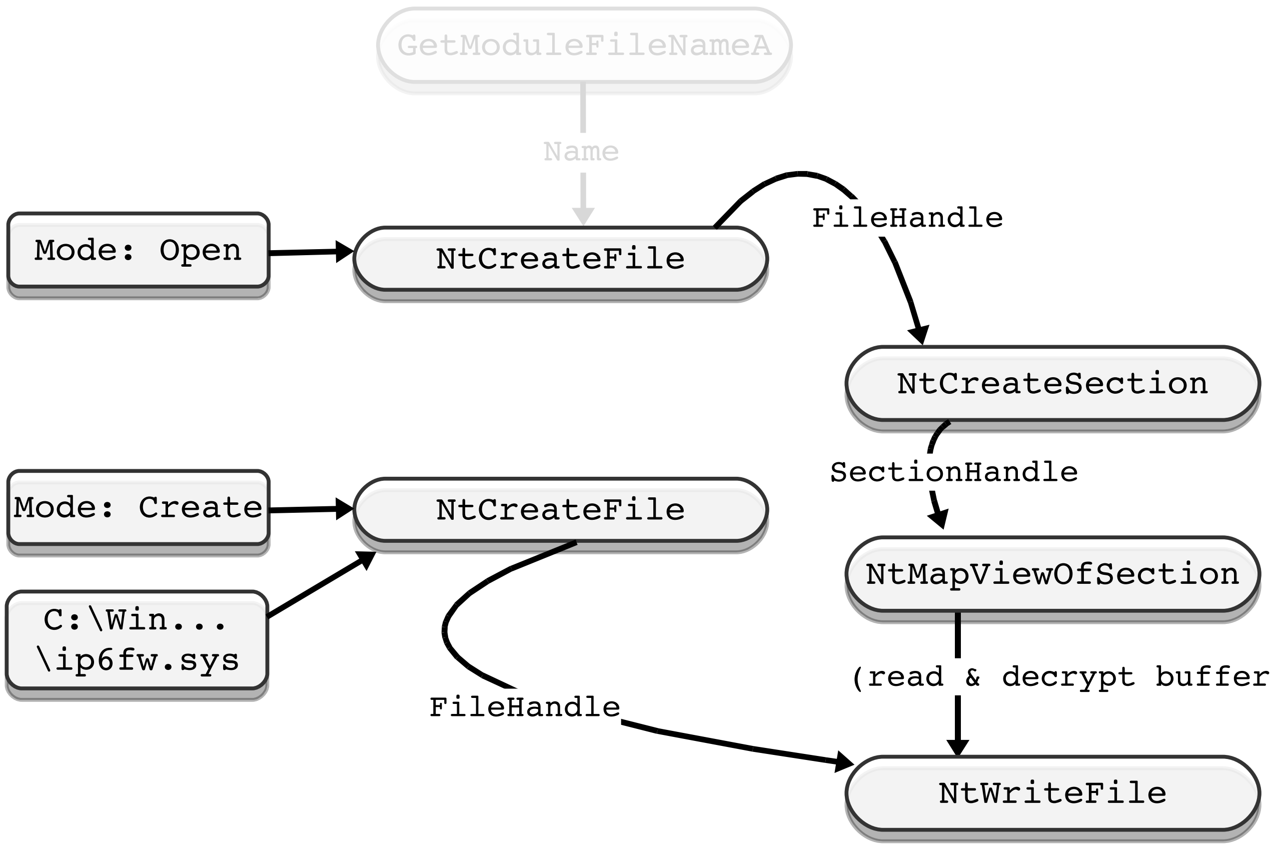

Detecting Behavior
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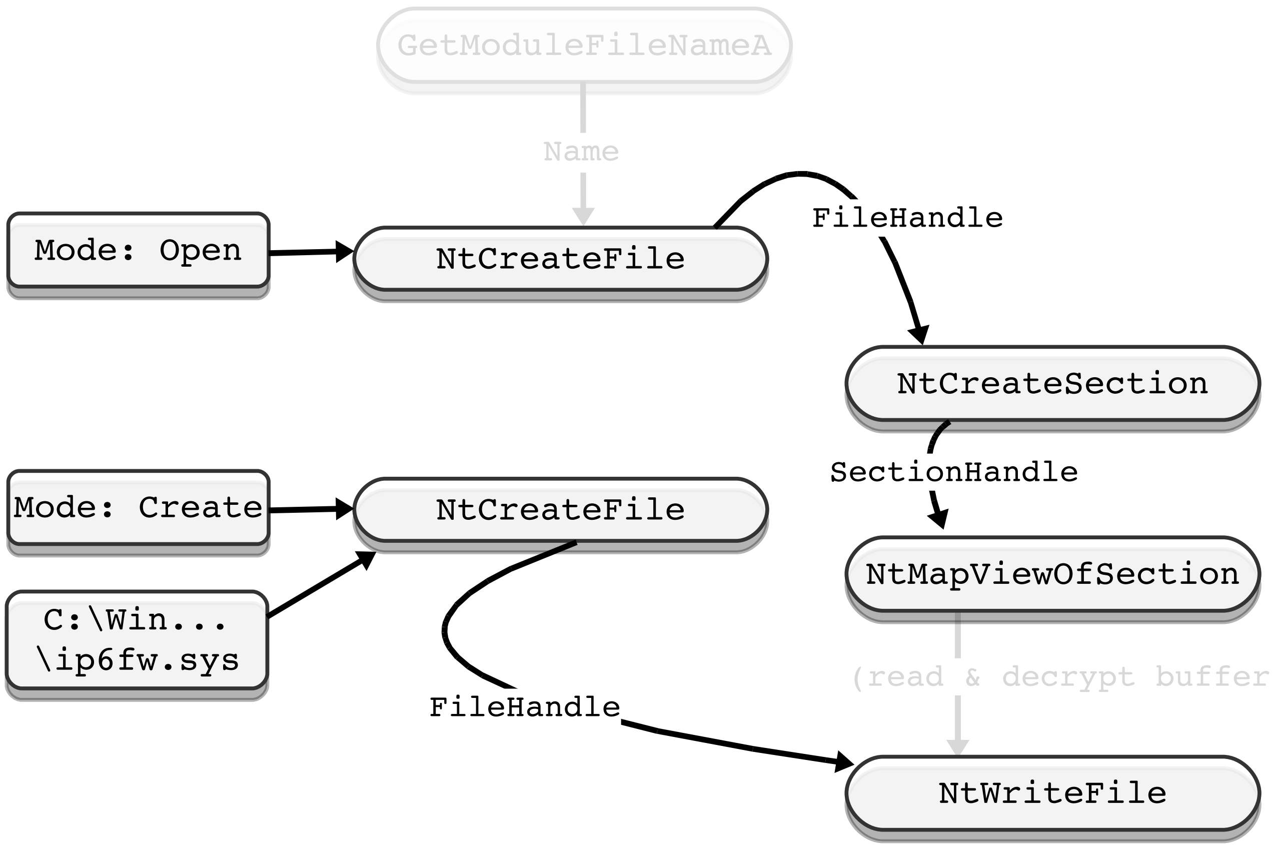

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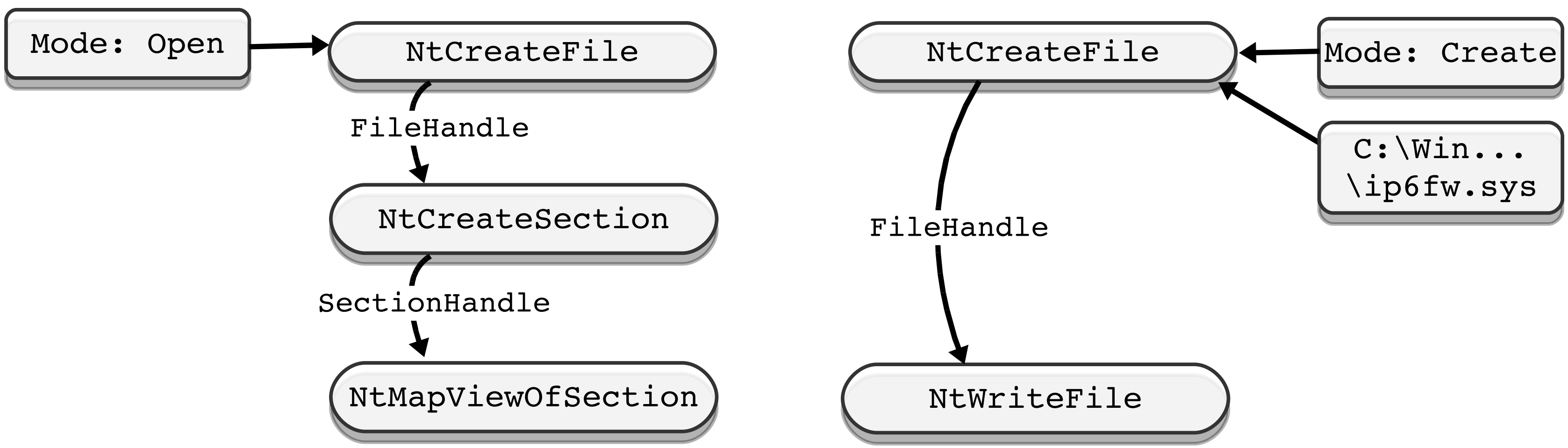
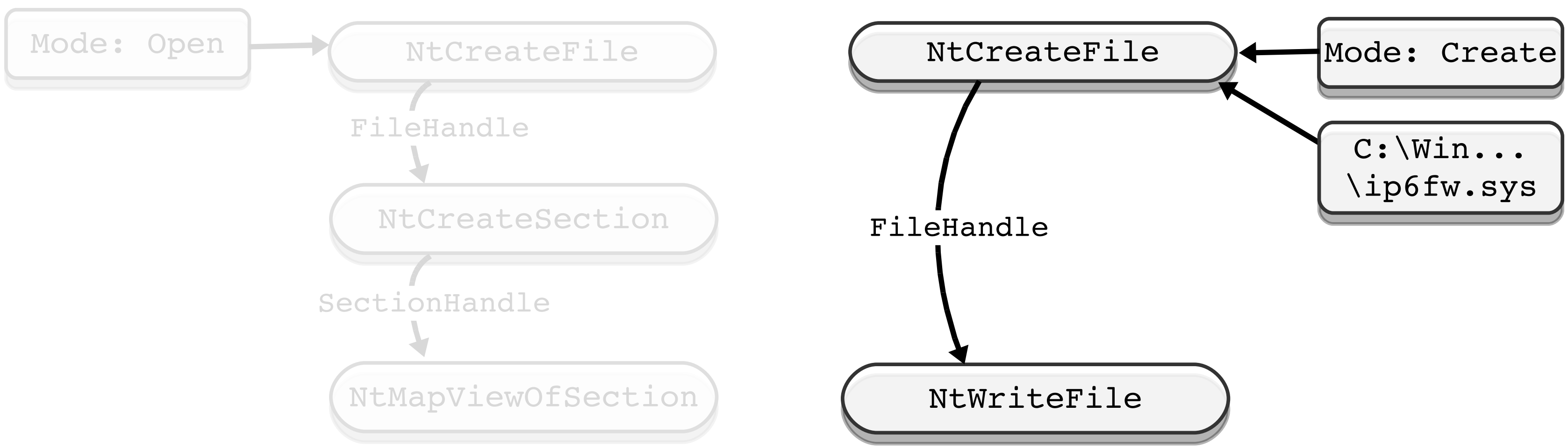


Detecting Behavior
System Perspective



Detecting Behavior

- Detection based on *execution characteristics*
  - Works well as long as we can see *all types of* dependencies between system calls
  - *Handle* dependencies
    - Insufficient for detection
    - Behavior graphs break into trivial subgraphs
  - *Data* dependencies
    - *Convenient* for behavior graph generation
    - *Necessary* for behavior detection

Matching Behavior Graphs

Matching Behavior Graphs

- Maintaining dependencies using taint propagation
  - Performance overhead: Extended emulation engine
  - Memory overhead: Shadow memory
  - Not applicable to production systems / end hosts

- Maintaining dependencies *without* taint propagation
  - *Handle* dependencies
    - Direct value propagation
    - System provided identifiers
      - File, section, process, thread handles
      - Registry keys
      - Socket identifiers
  - *Must* be constant between call invocations

Matching Behavior Graphs

- Maintaining dependencies *without* taint propagation
  - *Data* dependencies
    - Arbitrary data (& control) dependency between system calls
    - Might modify values between system calls
  - **Our proposal: *Anticipate* precise call arguments**
    - Use recorded execution semantics
    - Extract data *propagation/manipulation formulas*
    - *Emulate* taint dependency between system call *A* and *B*
      - Log *outgoing* parameters of call *A*
      - Use as input to propagation formula
      - Predicted *incoming* parameters for system call *B*
      - Compare predicted and monitored input parameters
      - Assume dependency between *A* and *B* if prediction holds

Matching Behavior Graphs

System Perspective

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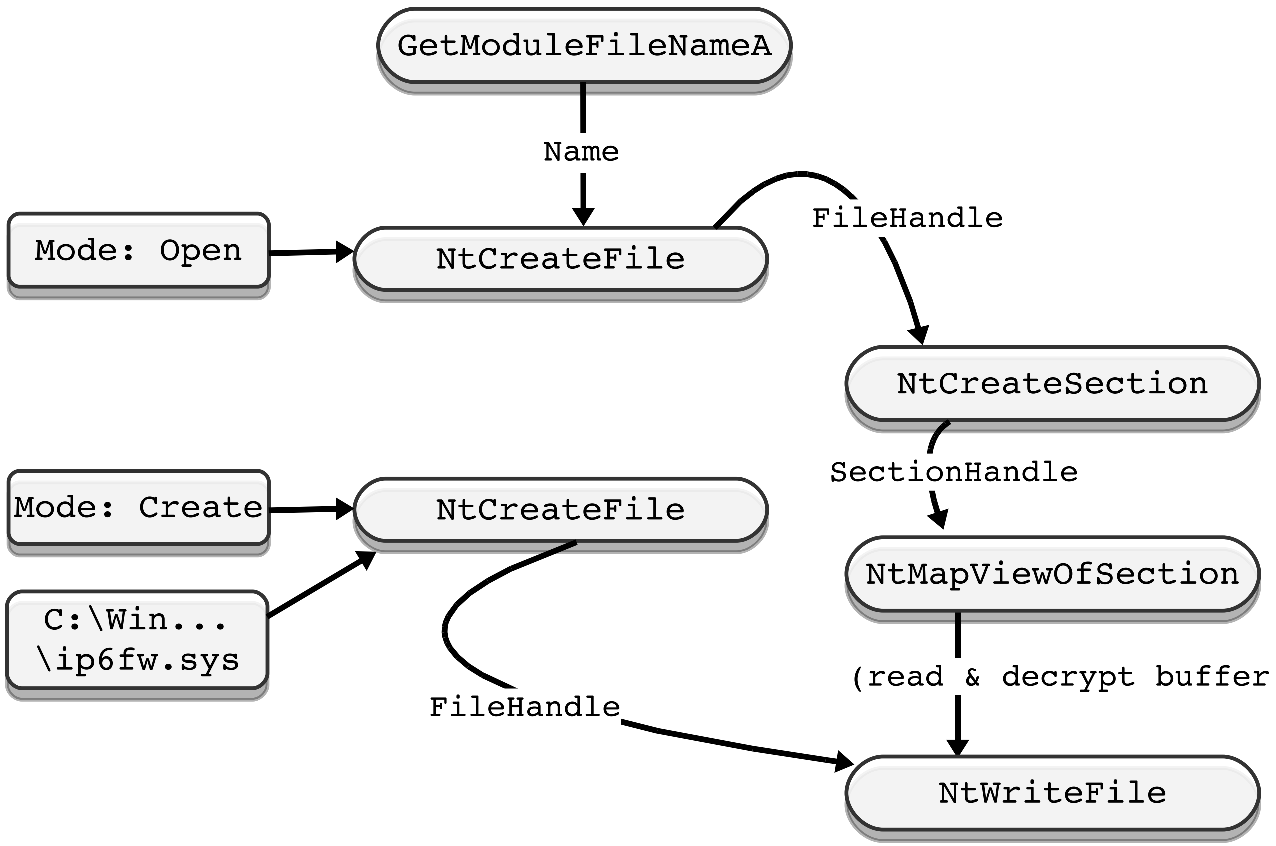

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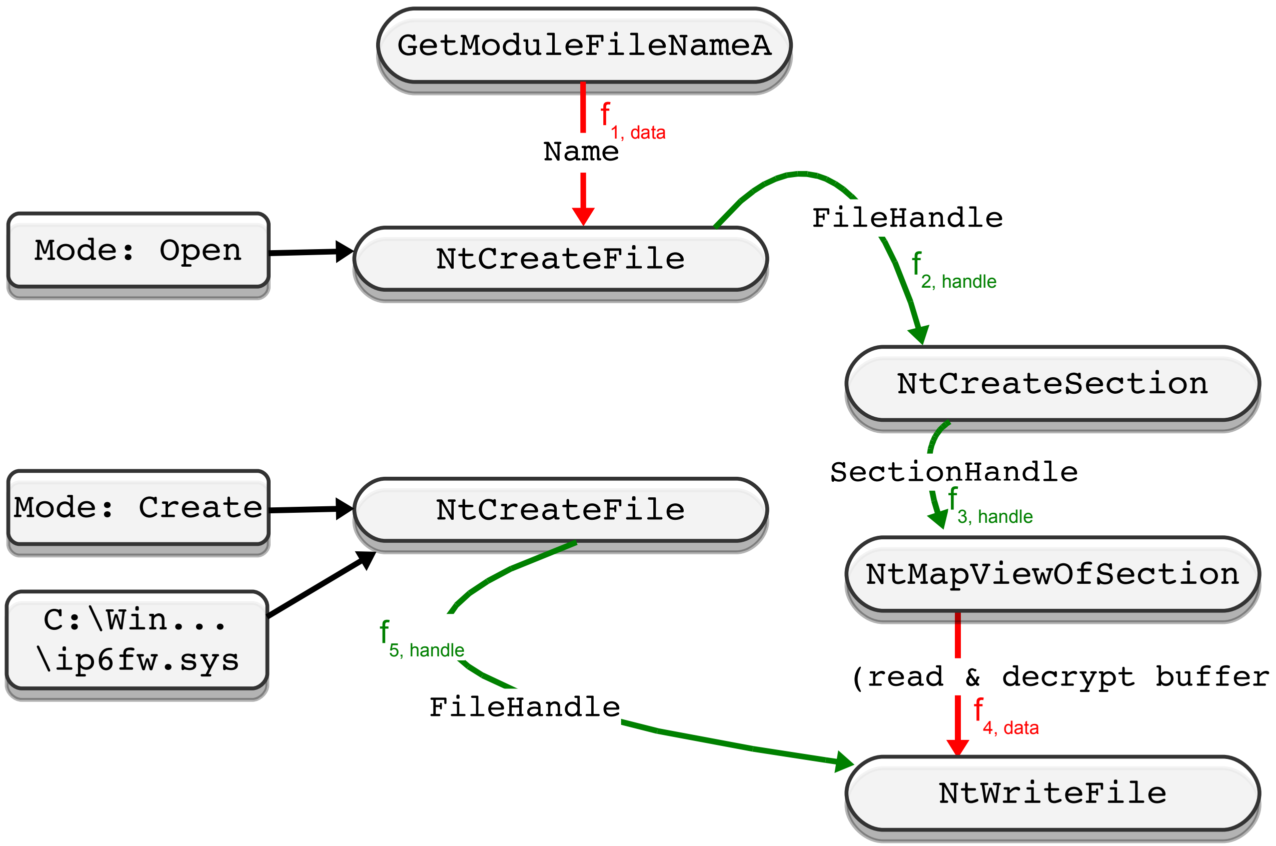

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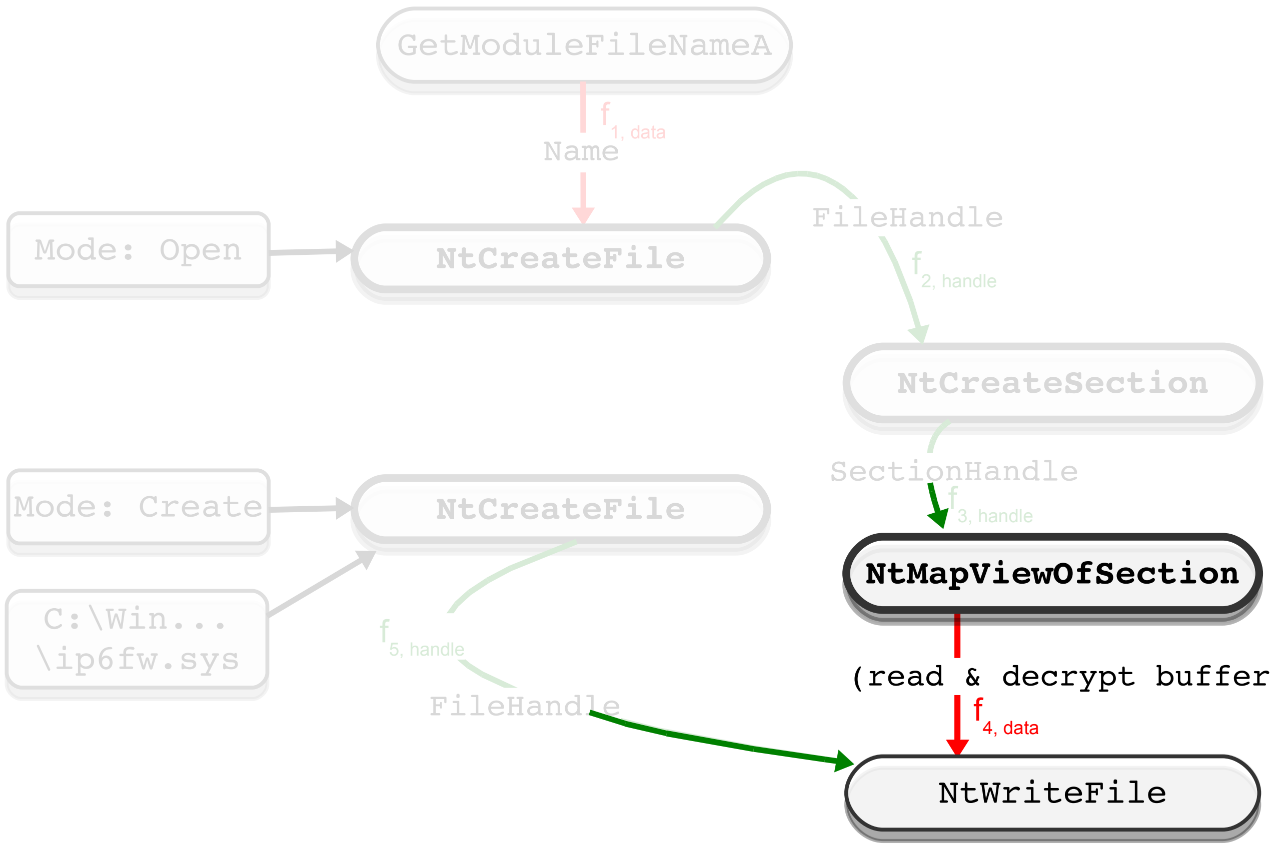

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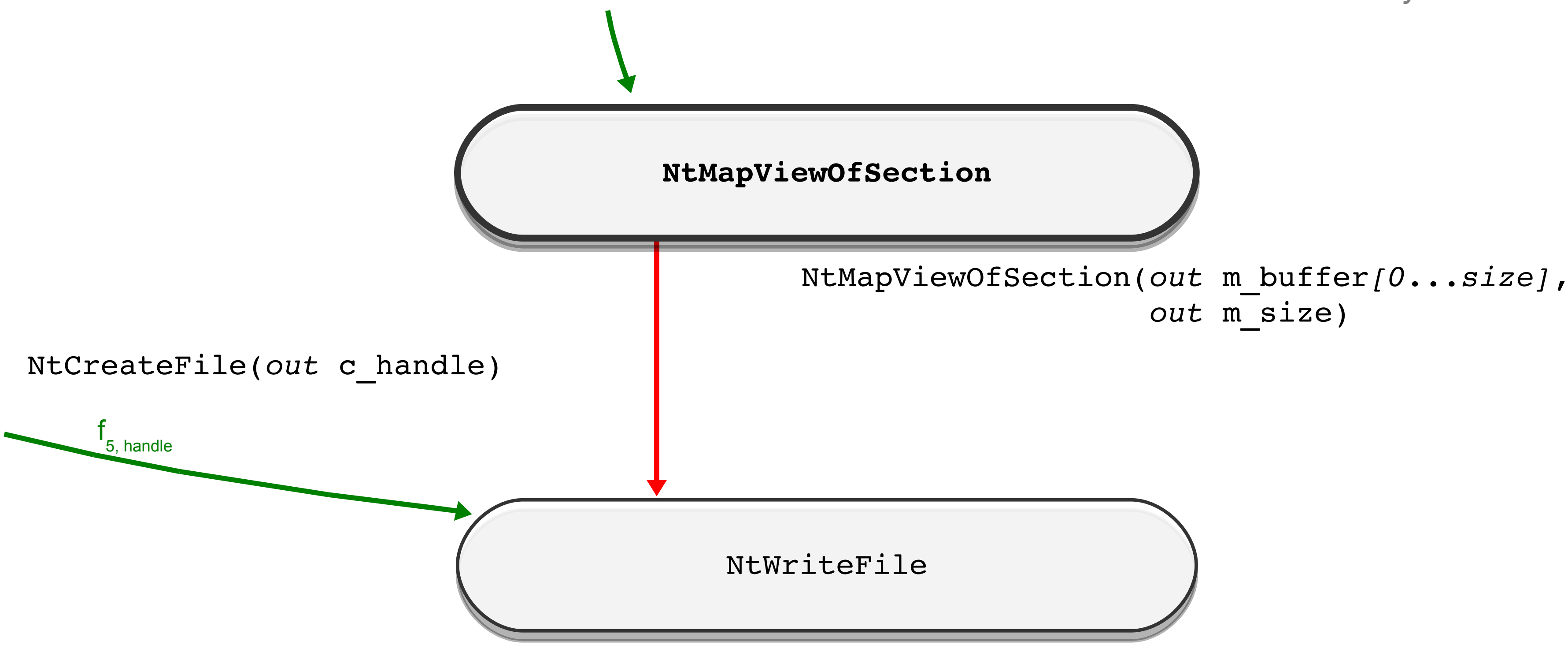

Matching Behavior Graphs

System Perspective

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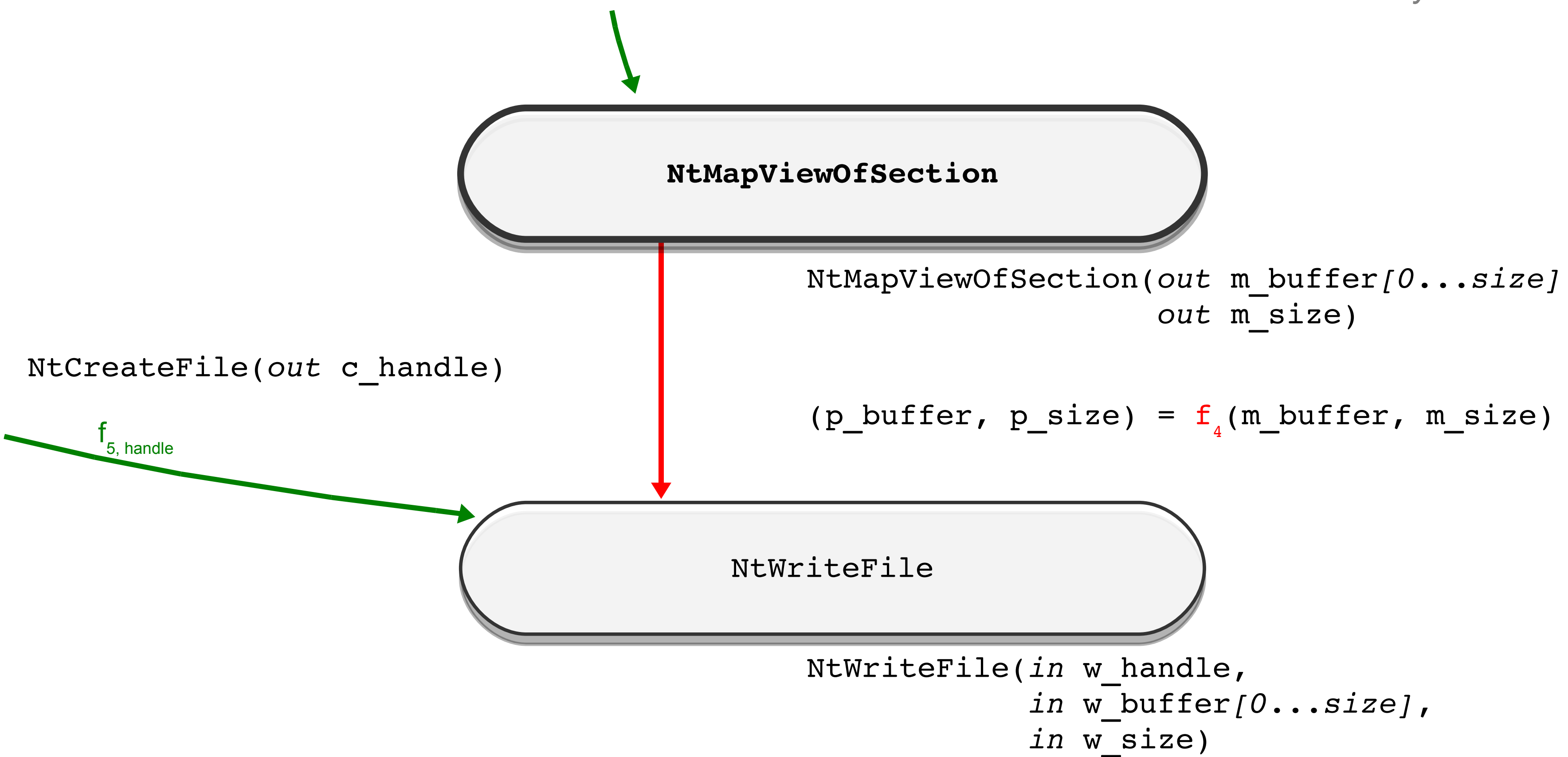
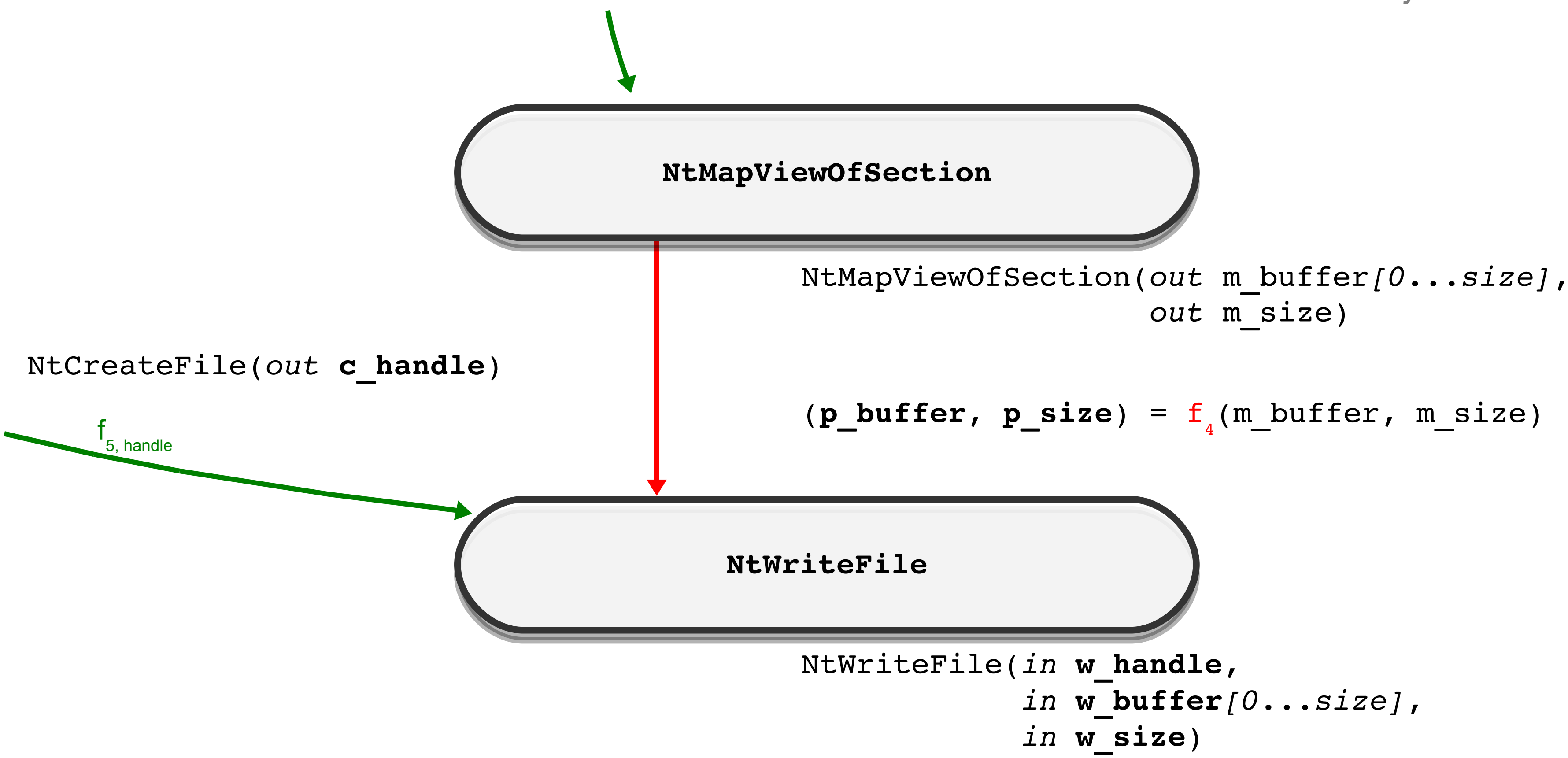


Matching Behavior Graphs

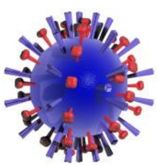
System Perspective



Extracting Behavior Graphs

Extracting Behavior Graphs

- Analyze executable in *Anubis* sandbox
  - Obtain instruction level log
    - Defeats packers
  - Obtain program flow log
  - Obtain memory access log
  - Generate *precise* taint propagation trees
    - Data/control dependencies
    - Instructions that access/generate tainted data
    - Link system calls consuming data (sinks) with all taint generating calls (sources)



Extracting Behavior Graphs

- Scan logs for *security relevant* behavior
  - Provided with a list of *interesting* system calls

- Extract graphs matching behavior
  - Include triggering system call *X*
  - Link in system calls providing tainted data to *X*
  - Analyze dependencies:
    - Label edges with *handle* dependencies
    - Call *slicer* for all *data* dependencies

Extracting Behavior Graphs

- Find encoding formula for each data dependency
- Binary *program slicing*
  - Resolve def-use chains
    - Starting at selected call invocation
    - Iterate backwards (using program flow logs)
    - Aided by *taint information* and *memory access logs*
  - Optional:
    - Symbolic execution to simplify encoding function
  - Embed into dynamically loadable library (dll)
  - Label graph edges with appropriate function (dll)

Extracting Behavior Graphs

- Resolving def-use chains
  - Three possible sources

1) Previous system call invocation
   - Replaced with stub
   - Provides input values to slice (i.e., recorded, outgoing system call parameters)

2) Immediate values
   - Implicitly encoded in binary slice (e.g., `push $0x3`)

Extracting Behavior Graphs

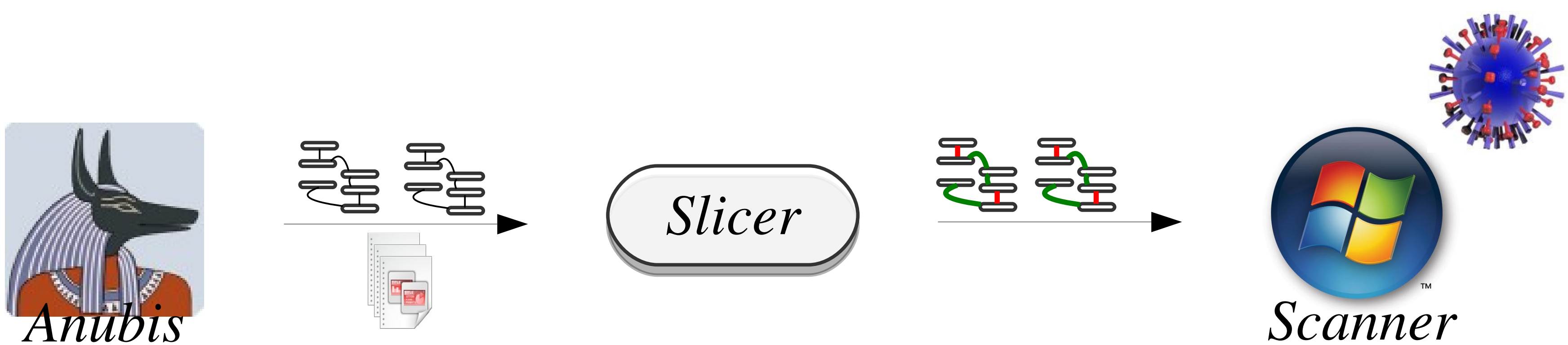
- Resolving def-use chains
  - Three possible sources

3) Preinitialized data segments

- BSS section
  - Constants
  - Static strings
- Two-sided approach:
  - Use static values from Anubis analysis
  - Dynamically inspect running process

Extracting Behavior Graphs

- Fully automated process
  - Analyze binary
  - Generate behavior graph(s)
  - Extract propagation formulas
  - Verify graph on binary
    - Run binary & scanner on real host
    - Verify behavior graph matches (only) on intended executable



Evaluation

Evaluation

- *Effectiveness* of behavior graphs
  - Applicable to polymorphic variants of a malware *sample*?
  - General enough for whole malware *families*?

- *Efficiency of behavior graph matching*
  - Overhead through system call logging
  - Additional system load through dependency verification

Effectiveness

- Six current threats / threat families
- Identified using AV (binary) signature
- Encountered *0 false positives*

Name	*Type*	*Samples*	*Variants AV*	*Variants Our*	*Samples detected*	*Eff.*
Allaple	Exploit-based worm	50	2	1	50	1.00
Beagle	Mass-mailing worm	50	20	14	46	0.92
Mydoom	Mass-mailing worm	50	32	12	47	0.94
Mytob	Mass-mailing worm	50	20	2	41	0.82
Netsky	Mass-mailing worm	50	22	12	46	0.92
Agent	Trojan horse	50	6	3	49	0.98
Total		300	102	44	279	0.93

Effectiveness

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- Experiment:

  Can the system detect malware instances never seen by the graph generator?

Name	*Samples*	*AV variants New*	*AV variants Known*	*Samples detected*	*Eff.*
Allaple	50	0	50	45	0.90
Beagle	50	24	26	30	0.60
Mydoom	50	24	26	36	0.72
Mytob	50	46	4	5	0.10
Netsky	13	8	5	7	0.54
Agent	50	6	44	45	0.90
Total	263	108	155	168	0.63

Effectiveness

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Beagle	50	24	26	30	0.60	
Mydoom	50	24	26	36	0.72	
Mytob	50	46	4	5	0.10	
Netsky	13	8	5	7	0.54	
Agent	50	6	44	45	0.90	
Total	263	108	155	168	0.23	0.92

Efficiency

- I-O bound activity
  - Compressing, archiving
- CPU bound computation
  - Compilation, rendering

Test	*Baseline*	*Log*		*Full scanner*	
7-zip (benchmark)	114 sec	117 sec	2.3 %	118 sec	2.4 %
7-zip (compress)	318 sec	328 sec	3.1 %	333 sec	4.7 %
7-zip (archive)	213 sec	225 sec	6.2 %	231 sec	8.4 %
IE (rendering)	0.41 pages/s	0.39 pages/s	4.4 %	0.39 pages/s	4.4 %
VC++ (compile)	104 sec	117 sec	12.2 %	146 sec	39.8 %

Summary

- Behavior can be detected
  - Monitor from system perspective
  - Match against behavior graphs
  - Link graph nodes through argument dependencies
- *Handle* dependencies
  - Vital for checking
  - BUT not specific enough for doing detection
- *Data* dependencies
  - Anticipate future call arguments
  - Efficient replacement for taint dependencies
  - Provided through slicing malware semantics

Summary

- Evaluation
  - Behavior detection is fast enough for end hosts
  - Approach intrinsically robust against polymorphism and metamorphism
  - To some extent, behavior graphs are usable across malware variants

Thanks for your attention!