Lines of Malicious Code:
Insights Into the Malicious Software Industry

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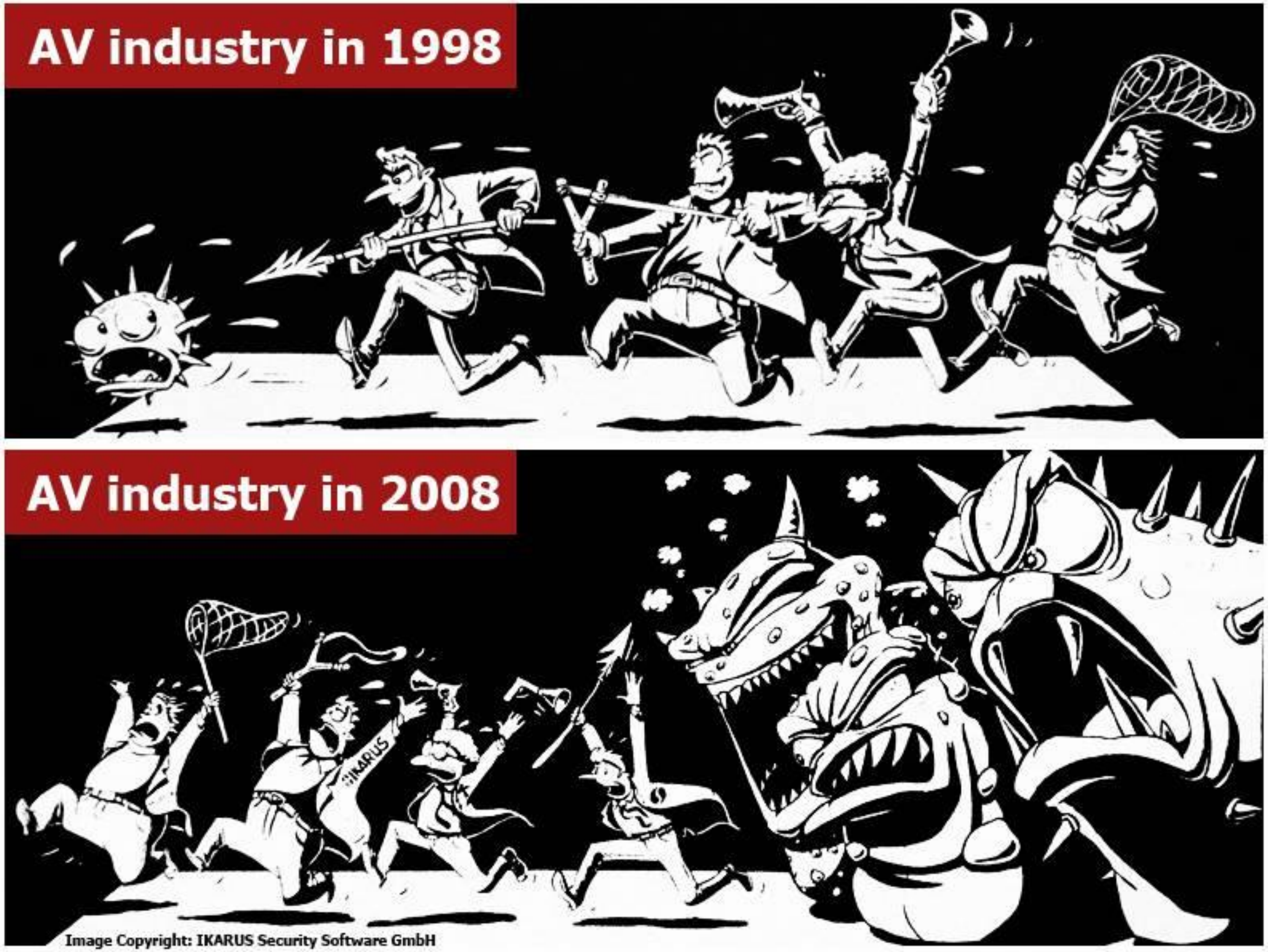
AV industry in 1998
AV industry in 2008
IKARUS
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State of Malware

- Underground economy of cybercrime:
  spam, identity theft, DoS, Fake AV scams, …
- Malicious software industry
- Arms race against security researchers
- Overwhelming amount of samples
  - > 70,000/day in 2011 (PandaLabs)
- Need for analysis automation
- Limits of static/dynamic analysis
- Incremental updates of functionality
- Focus manual analysis on novel functionality

Approach (1/2)

- Identify focus of development effort of malware authors
- Take advantage of auto-update functionality in malware
- Collect subsequent updates of malware variants
- Identify code changes between versions
- Identify evolution of functional components
  - e.g. spam, Fake AV
- Estimate development effort
- Highlight significant code changes for further analysis

Approach (2/2)

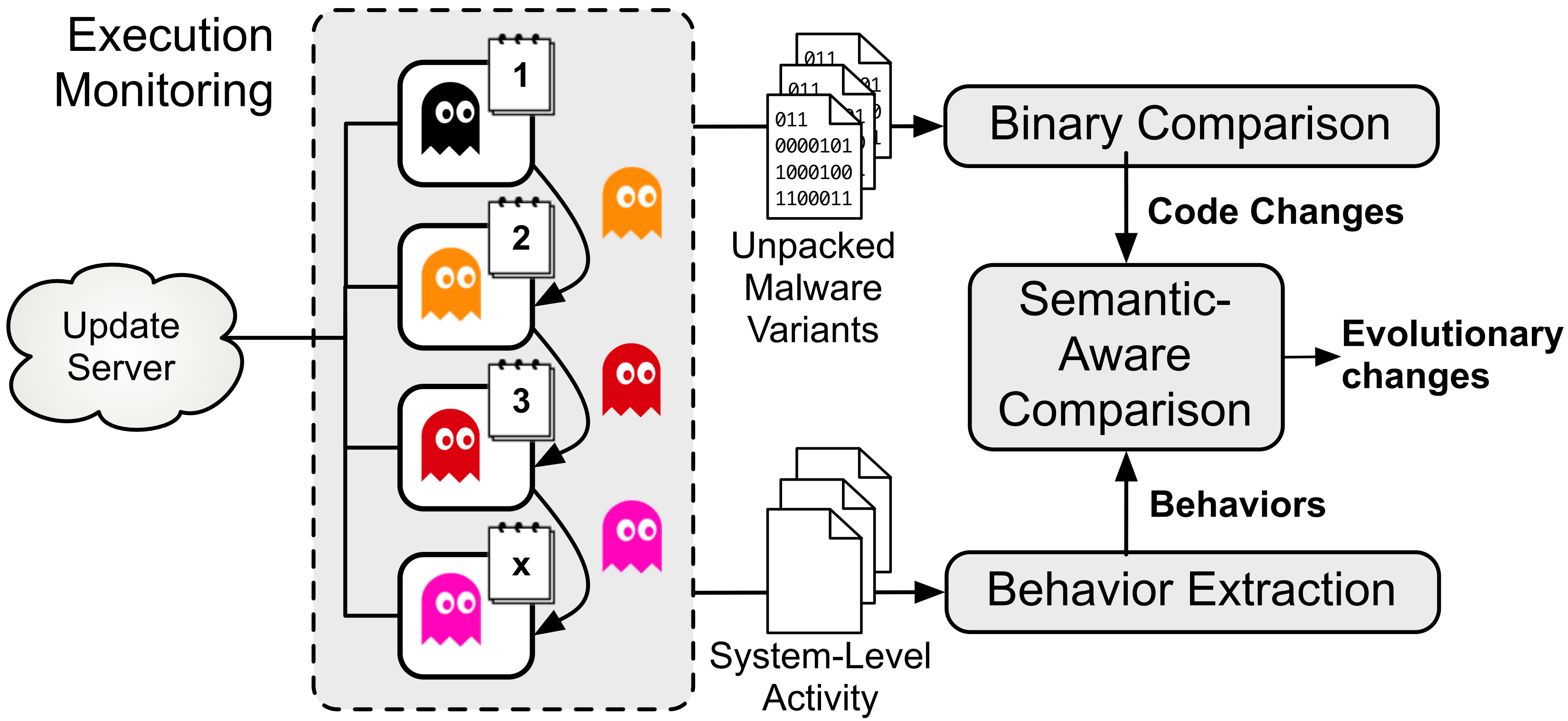
- Combination of static and dynamic analysis
- Builds upon REANIMATOR (Oakland 2010)
  - "Identifying Dormant Functionality in Malware Programs"
- Run samples in sandbox
- Let samples connect to the C&C server to update
- Find differences in binary code
- Map differences in binary code to behavior

- BEAGLE
  - 16 malware samples from 11 families
  - > 1,000 executions, 381 distinct binaries

Outline

- **BEAGLE**
  - Step 1: Execution Monitoring
  - Step 2a: Binary Comparison
  - Step 2b: Behavior Extraction
  - Step 3: Semantic-Aware Comparison
- Experimental Results
- Conclusion

BEAGLE



Execution
Monitoring
Update
Server
1
2
3
x
011
0000101
1000100
1100011
Unpacked
Malware
Variants
System-Level
Activity
Binary Comparison
Code Changes
Semantic-
Aware
Comparison
Evolutionary
changes
Behaviors
Behavior Extraction

Step 1: Execution Monitoring

- Based on Anubis sandbox
  - Logging of Native + Windows API, dynamic taint tracing
- Stateful analysis:
  - Save analysis state (filesystem and registry changes)
  - Restore analysis state
  - Invoke persistence mechanism
- Logging of call stack for each API call
- Generic unpacker (dump memory)
- Output:
  - Unpacked binaries
  - System calls and taint dependencies

Step 2a: Binary Comparison

- Input:
  - Unpacked malware variants

- Preprocessing: Code whitelisting
  - Generic unpacker dumps all memory
  - Includes code injected into benign processes
  - Includes DLLs loaded into malware's address space
  - Identify all code (EXE and DLL) from the clean image and ignore it

Step 2a: Binary Comparison

- Refined techniques of Kruegel et al. (RAID 2005)
  - "Polymorphic Worm Detection Using Structural Information of Executables"
- Color nodes in CFG based on classes of instructions
- Shared code = finding isomorphic k-node subgraphs
- Fingerprints = hash of normalized subgraphs
- Match fingerprints between malware versions
- Output:
  - Shared/added/removed basic blocks
  - Measure of code change (Jaccard Similarity):
    # of shared BB over the total shared/added/removed BBs

Step 2b: Behavior Extraction

- Input:
  - System calls and taint dependencies from dynamic analysis
- Behavior = connected graph of system-level events
  - Nodes = system calls
  - Edges = data flow dependencies
- Define rules to detect high-level behaviors
  - e.g. Download & Execute = data flow from network to a file that is later executed
  - Unlabeled: no high-level meaning
  - Labeled: behavior matches known patterns
- Output:
  - List of behaviors with responsible code

Step 3: Semantic-Aware Comparison

- Input:
  - Labeled & unlabeled behaviors
  - Shared/added/removed BBs

- Map behavior to code
  - Dynamic analysis at system call level
  - Better scaling than instruction-level tracing
  - Mapping at function-level granularity
  - Locate function boundaries of addresses in call stack

Step 3: Semantic-Aware Comparison

- Expansion of mapping:
  - Statically identify code path between individual system calls
  - Use call stack for each system call as landmark
- Dormant functionality:
  - Locate fingerprints from active components in other executions
- Output:
  - Evolutionary changes in functional components

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- **Experimental Results**
- Conclusion

Dataset (1/2)

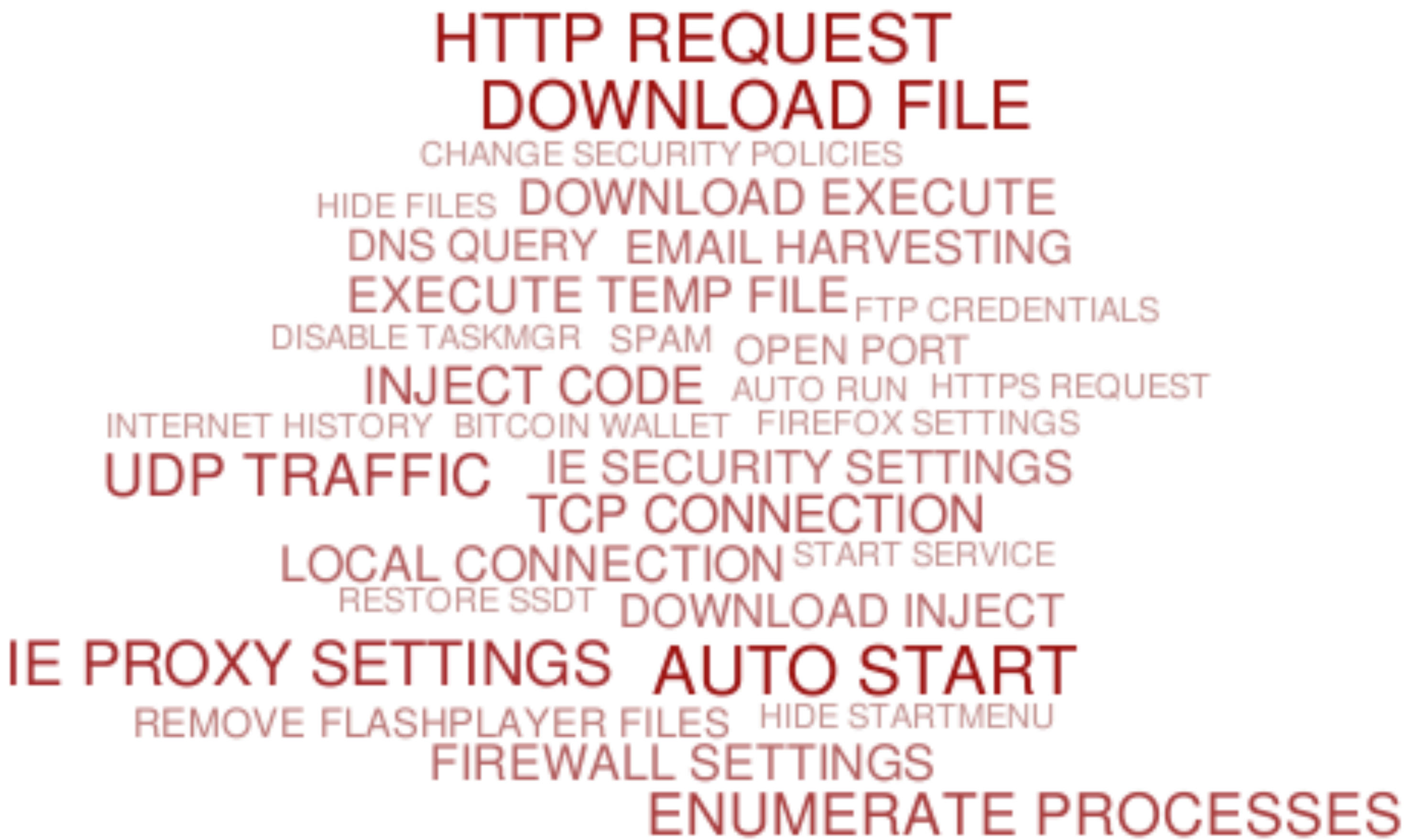
- 16 samples (11 families, 6 ZeuS)
- Sources:
  - ZeuS Tracker
  - Anubis (download & execute heuristics)
  - Top threats from Microsoft Malware Protection Center

- September 2011 - April 2012
- 15 minutes each, once a day
- 1,023 executions of 381 distinct binaries

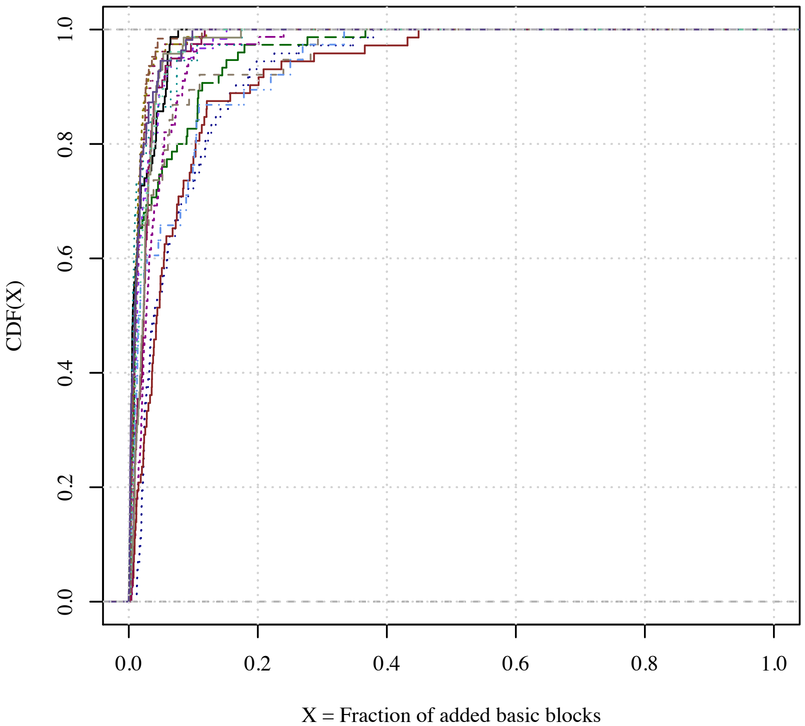
Dataset (2/2)

Family Name and Label	Source	1st day	Days	Executions	MD5s
Banload TrojanDownloader:Win32/Banload.ADE	(1)	2012-01-31	87	78	3
Cycbot Backdoor:Win32/Cycbot.G	(1)	2011-09-15	73	73	69
Dapato Worm:Win32/Cridex.B	(2)	2012-02-24	65	62	25
Gamarue Worm:Win32/Gamarue.B	(2)	2012-02-10	78	77	19
GenericDownloader TrojanDownloader:Win32/Banload.AHC	(1)	2012-01-31	82	79	5
GenericTrojan Worm:Win32/Vobfus.gen!S	(1)	2012-02-07	76	73	55
Graftor TrojanDownloader:Win32/Grobim.C	(1)	2012-02-17	37	39	22
Kelihos TrojanDownloader:Win32/Waledac.C	(2)	2012-03-03	56	38	8
Llac Worm:Win32/Vobfus.gen!N	(1)	2012-02-07	32	33	82
OnlineGames Worm:Win32/Taterf.D	(1)	2011-09-02	87	80	47
ZeuS PWS:Win32/Zbot.gen!AF `1be8884c7210e94fe43edb7edebaf15f`	(3)	2012-02-09	79	78	6
ZeuS PWS:Win32/Zbot `9926d2c0c44cf0a54b5312638c28dd37`	(3)	2012-02-15	74	73	4
ZeuS PWS:Win32/Zbot.gen!AF* `c9667edbbcf2c1d23a710bb097cddbcc`	(3)	2012-02-23	66	63	6
ZeuS PWS:Win32/Zbot.gen!AF* `dbedfd28de176cbd95e1cacdc1287ea8`	(3)	2012-02-09	79	78	4
ZeuS PWS:Win32/Zbot.gen!AF* `e77797372fbe92aa727cca5df414fc27`	(3)	2012-02-10	79	77	5
ZeuS PWS:Win32/Zbot.gen!AF* `f579baf33f1c5a09db5b7e3244f3d96f`	(3)	2012-03-03	57	55	11

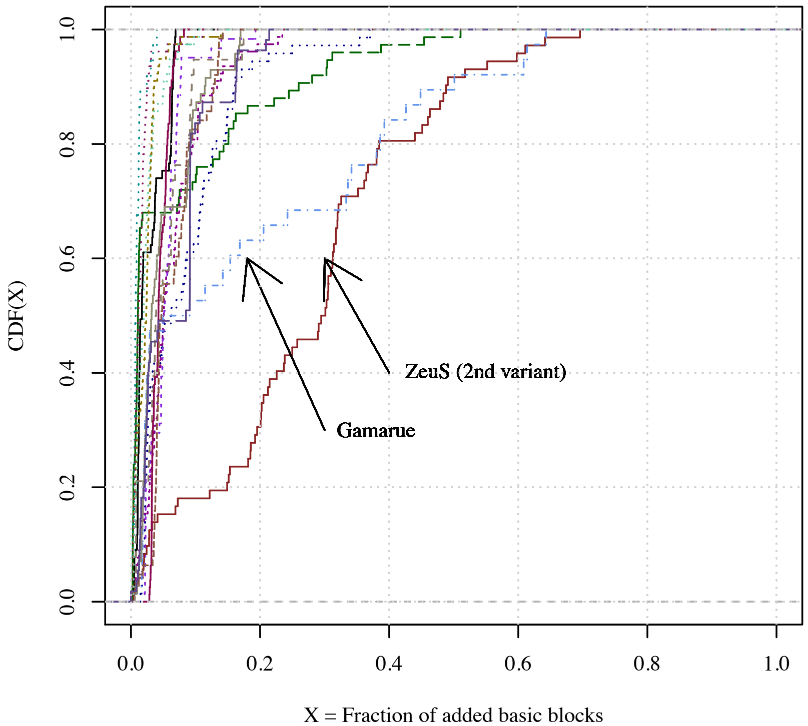
Behaviors in Dataset



Overall Code Changes

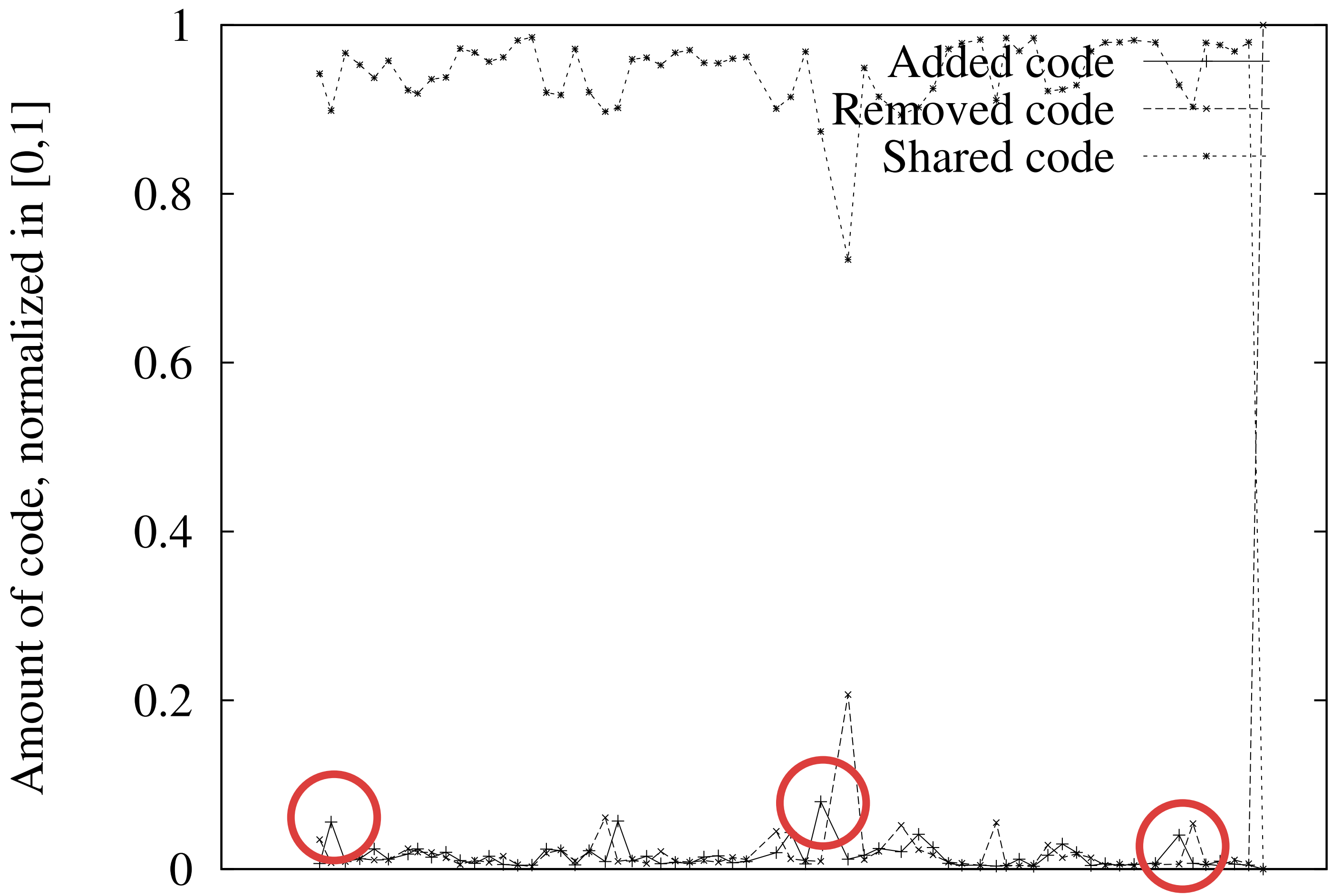


(a) $t-1$ vs. t

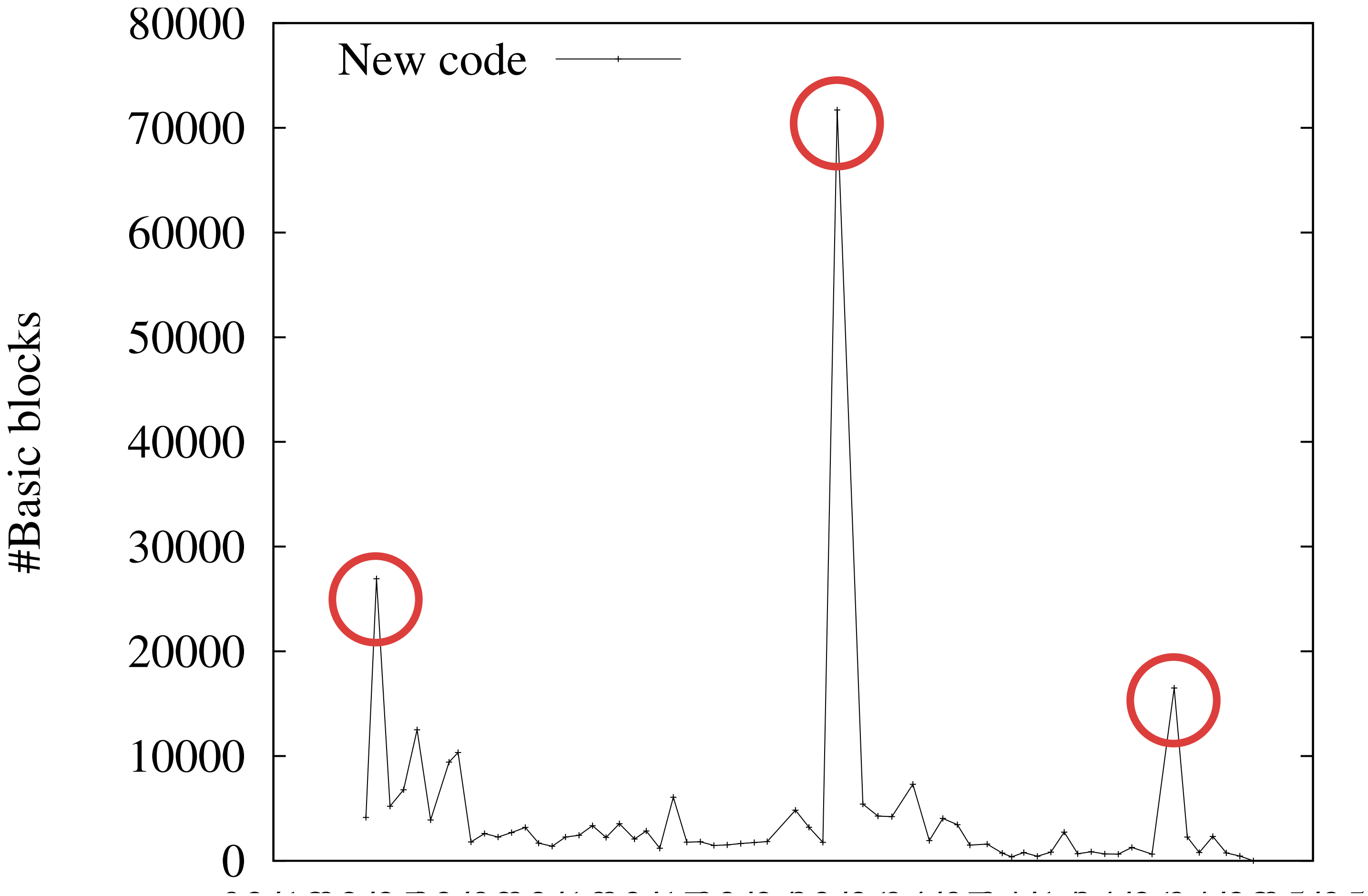


(b) t_0 vs. t

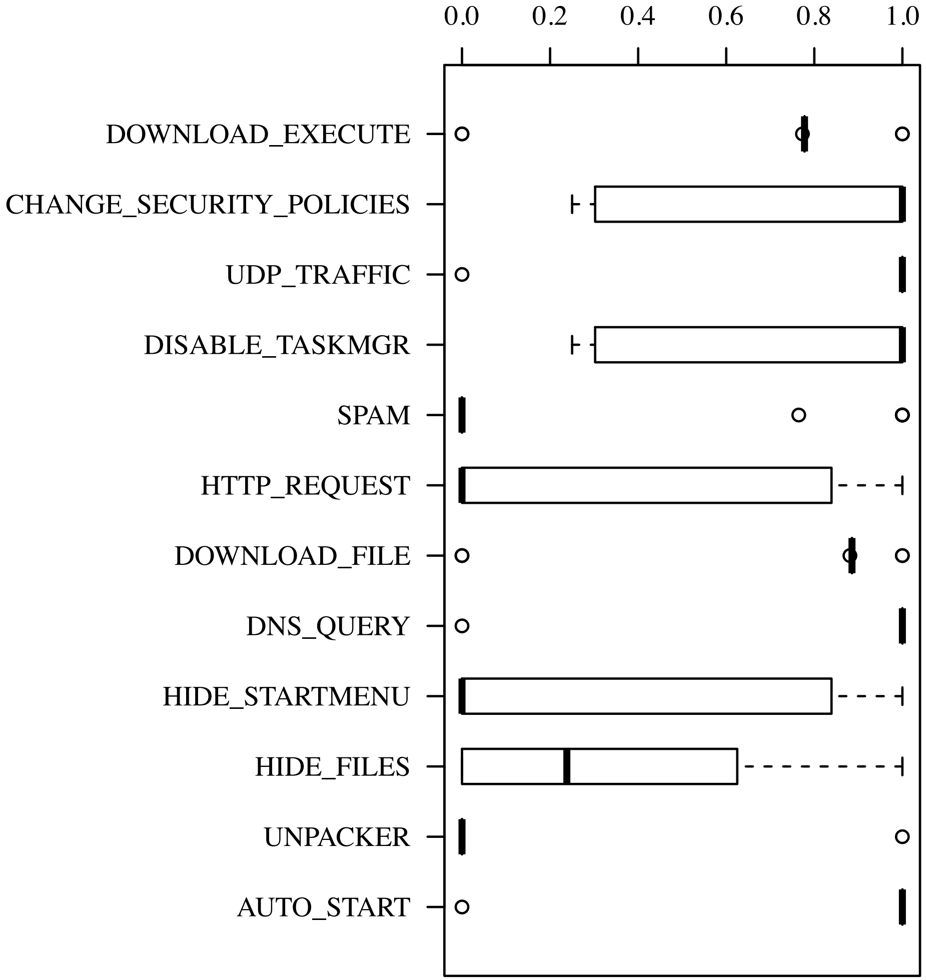
Code Changes: Zeus



Code Changes: Zeus



Behavior Evolution: Gamarue



Evaluation Results

- Core insights
  - Frequency of code changes
  - Most actively developed components
  - Overall amount of development effort

- Some families more actively developed than others
- Incremental updates reuse most of the code
- Peaks of new code added
- Pinpoint changes over individual behaviors
- Pinpoint changes over the whole dataset

Lines of Malicious Code

- Estimation of development effort:
  - Amount of source code for observed changes
- Blocks of ASM, not LoC in source
- ZeuS + 150 bots with source code:
  - 50-100 LoC/basic block
  - 14.64 LoC/basic block for ZeuS

- Significant effort of development in malware
  - Zeus: 140-180 new (peak 9,000) LoC
  - Other: 100-300 new (peak 4,600-9,000) LoC

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Limitations

- Unpacking (multi-layer or emulation-based packing)
- Dynamic analysis evasion
- Limited code coverage
- Semantics of code changes (human analysis)

- Future work:
  - Patch analysis techniques to understand how the update of a component changes the functionality
  - Automatic classification of high-level behaviors

Conclusion

- Combination of static and dynamic analysis to track evolution of malware
- Measure code changes between malware versions
- Associate observed behavior with implementing components
- Measure evolution of individual components
- Highlight interesting code changes for manual inspection
- Insights on the development efforts in malicious code

Questions?

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