A Tamper-resistant Framework for Unambiguous Detection of Attacks in User Space Using Process Monitors

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Outline

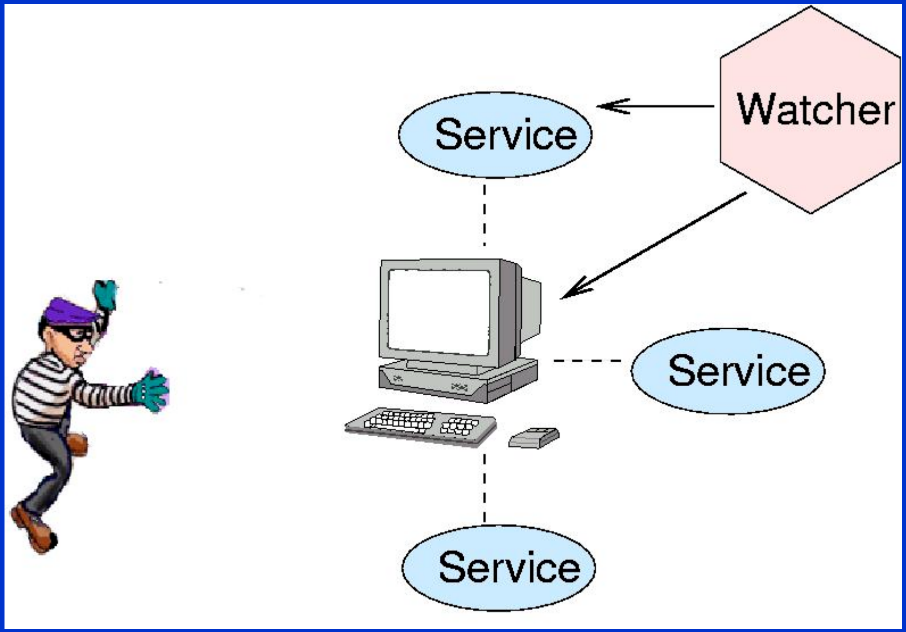
- Basic Terminology
- What is Tamper-resistant Monitoring?
- Analysis
- Simple Problem Transformation
- A New Framework
- Experimental Results
- Conclusions and Future Work

Basic Terminologies

- A *Host*
  - A computer system
- A *Service*
  - A user space program that performs some useful task
- A *Vulnerability*
  - A flaw in a program with security implications
  - An Attacker targets vulnerabilities in programs to gain elevated privileges
- An *intrusion detection system* (IDS) attempts to detect and prevent attacks

Tamper-resistant Monitoring

- Protecting user space components
  - To have secure enclaves, every component of IDS must be watched and there are no open ends
- Attacker's perspective



The Attack Model

- An attacker is successful, if:
- He compromises the service running on the host
- He disables or compromises the IDS, if one is deployed
- Note:
  - As coverage of IDS improves, the attacker's focus will be on the IDS itself
  - Who watches the watcher?

Criteria for Analysis

- Failure due to faults and failure due to attacks are not one and the same
- Each software component can potentially fail due to attacks; we just don't know how yet!
- Security of a system is only as strong as the weakest link
- Hence, even if a service is monitored by a separate detection mechanism, is the entire setup really secure?
- An IDS is a program and it too can be compromised
- So, implement it inside the kernel for tamper-resistance
- But, poor kernel implementations affect the whole system

Probabilistic Analysis

- An attacker has little knowledge about how the entire system works and the attacks are by trial and error
- Factors that determine the overall security are:
  - For each component, individual probability of failure
  - For a *n* component system - the probability of total failure
  - An attack can proceed in stages - probability of per-stage failure
  - Search space for a successful attack
- False sense of security, since an attacker will eventually learn of these weaknesses

Deterministic Analysis

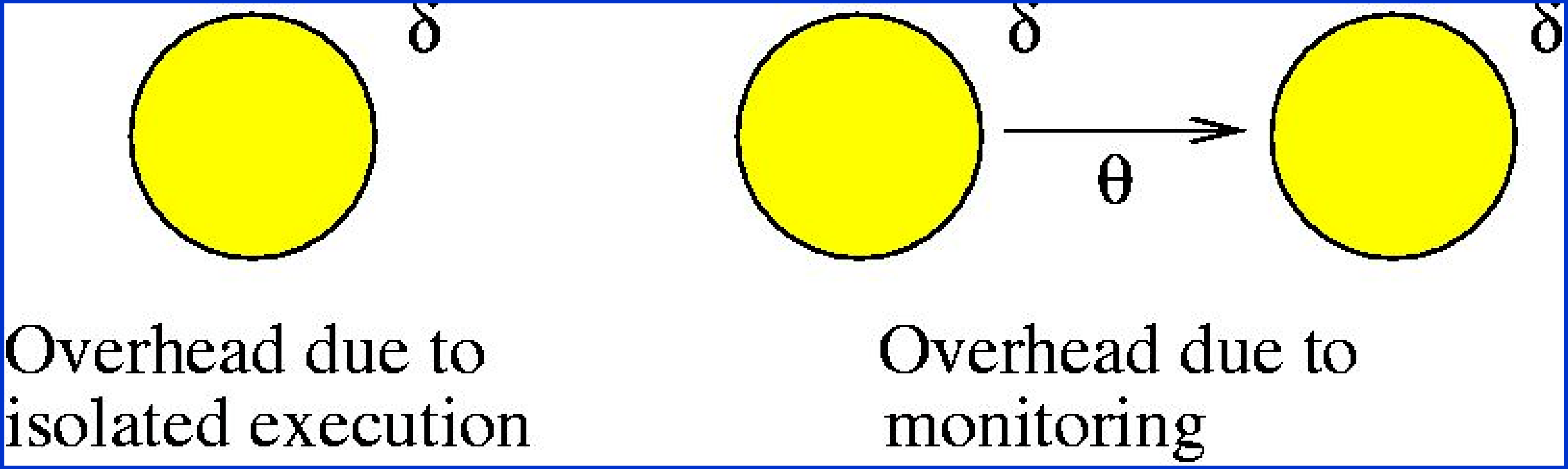
- An attacker has complete knowledge of the system and its vulnerabilities
- Factors that determine the overall security are
  - A successful attack strategy
- The only line of defense is the structure of the security mechanism

Theoretical Model

- Each process is a node
- If a process monitors another process, then there is a directed edge between the corresponding nodes
- Useful in representing and analyzing the structure of interaction
- Reduces to a graph problem
- No mutual trust among processes

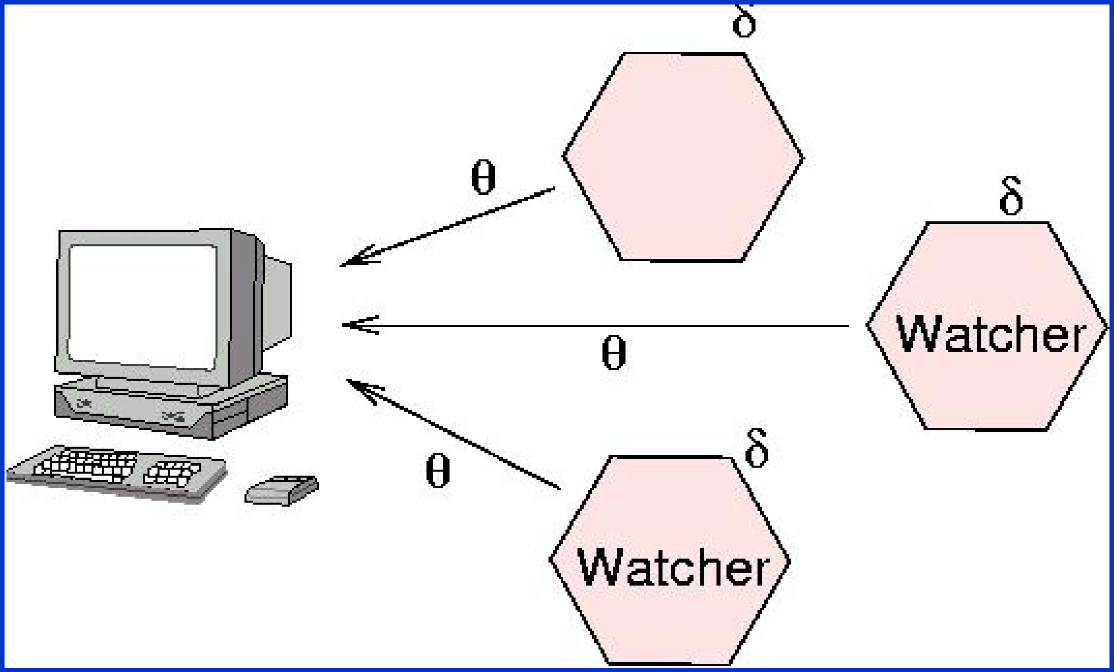
Performance Analysis

- **If a detection mechanism is deployed, then how much overhead will it incur?**



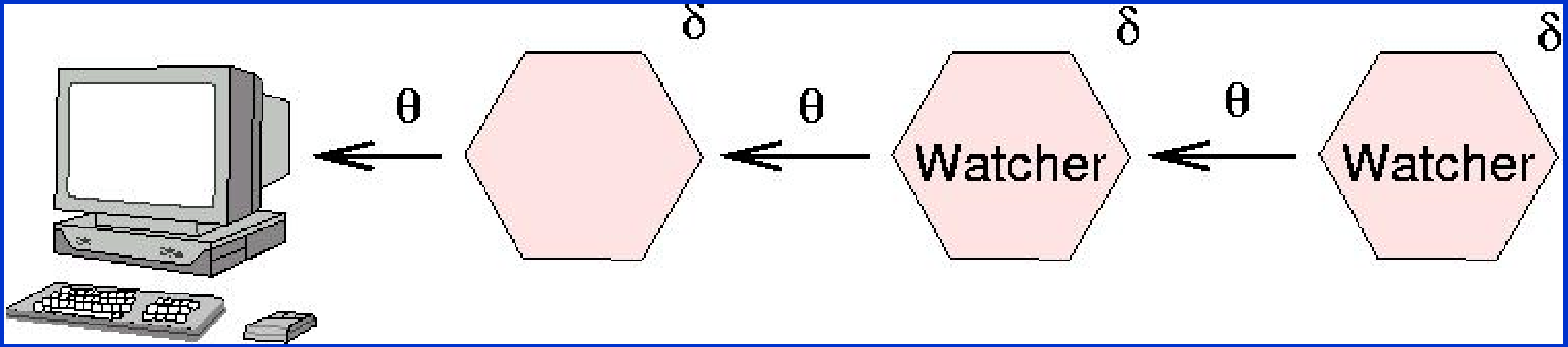
- **δ - overhead due to isolated execution**
- **θ - overhead due to monitoring**

Simple Replication



- Chameleon project at UIUC
- Can be easily compromised

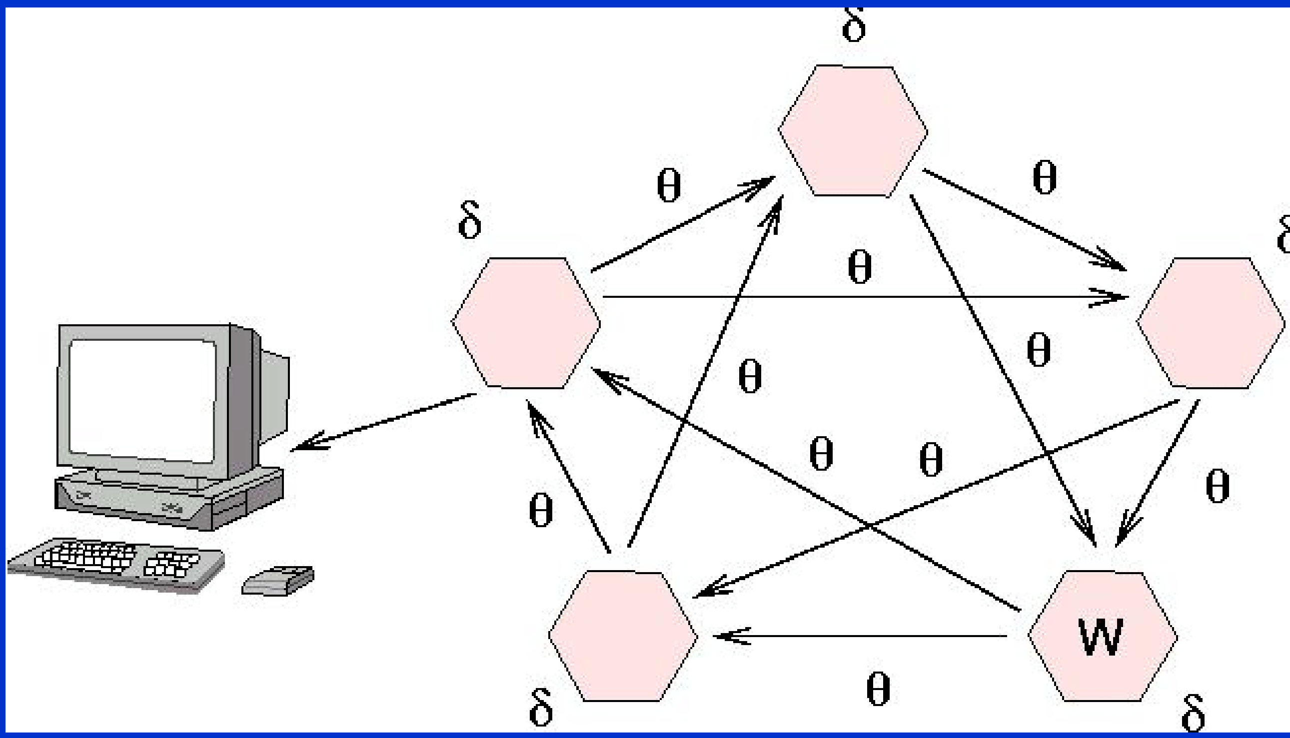
Layered Hierarchy



- An example is the AAFID project at Purdue
- Provides only a marginal increase in security

New Proposed Architecture

- **Circulant Digraph**



- **Very difficult to subvert**
- **Provides an infinite hierarchy of monitoring using finite number of monitors**

Comparison

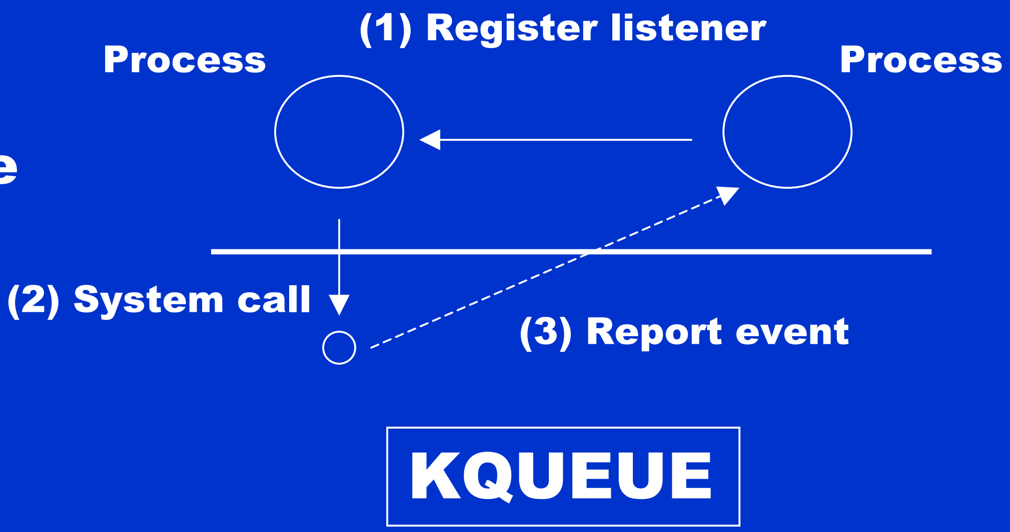
Metrics	Simple Replication	Layered Hierarchy	Circulant Digraph
Subversion by sequential attack?	Yes	Yes	No
Total Probability of Subversion	p^n	p^n	p^n
Per-stage Probability of Subversion	p	p	p^n
Degree of Incidence	0	1	d
Overhead due to isolated execution	$n.\delta$	$n.\delta$	$n.\delta$
Overhead due to monitoring	$n.\theta$	$n.\theta$	$n.d.\theta$
Total overhead	$n.\delta + n.\theta$	$n.\delta + n.\theta$	$n.\delta + n.d.\theta$

Implementation

- Requires a sense-decide-act loop
- Uses FreeBSD's *kqueue* subsystem
- Each node in the graph is a process monitor
- Multiple outgoing edges from a node are threads

kqueue subsystem

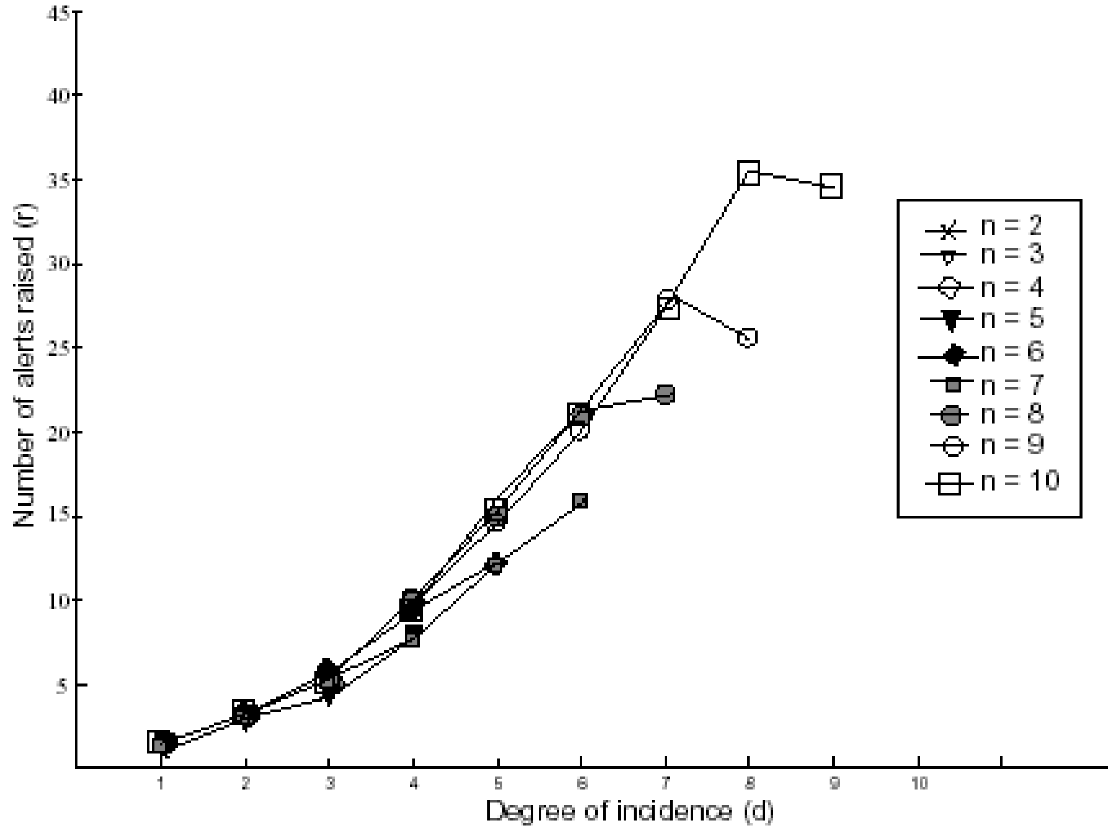
- kqueue is a replacement for select() and poll() in FreeBSD 4.5 and above
- Guaranteed event delivery
- Non-repudiation of events



Attack Scenarios

- kqueue currently supports only exit(), fork() and exec() family of system calls
- Currently, our experiments are limited to crash attacks
- All processes can be crashed using the kill() system call
- An attacker is given all information about vulnerabilities
- Are TOCTOU style attacks possible?
  - Experiments performed under heavy system load

Results



Number of alerts raised (r)
45
40
35
30
25
20
15
10
5
1
2
3
4
5
6
7
8
9
10
Degree of incidence (d)
n = 2
n = 3
n = 4
n = 5
n = 6
n = 7
n = 8
n = 9
n = 10

Interpretation

- Even with all the information, it is extremely difficult to launch a successful attack
- As degree of incidence increases, more attack alerts are raised
- So, it is enough to deploy a small number of process monitors but with a high degree

Conclusion

- Mechanisms based on no-knowledge of vulnerabilities gives a weaker sense of security
- We have presented a methodology to analyze security in terms of structure
- We show that a circulant digraph configuration is a better solution

Future Work

- The short term goal is to supplement the kqueue subsystem to support more events
  - To increase coverage
  - To detect other attacks
- The long term goal is to devise a way to provide a generic tamper-resistant wrapper around user space services
- Extend it to network level monitoring
- Our website:
  - http://www.cse.buffalo.edu/caeiae/