Scalability, Fidelity, and Containment in the Potemkin Virtual Honeyfarm

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Background

- Large-scale host exploitation a serious problem
  - Worms, viruses, bots, spyware...
  - Supports an emerging *economic* criminal enterprise
    - SPAM, DDoS, phishing, piracy, ID theft...
    - Two weeks ago, one group arrested—controlled 1.5 M hosts!
- Quality and sophistication of malware increasing rapidly

Motivation

- Intelligence about new threats is critical for defenders
- Principal tool is the *network honeypot*
  - Monitored system deployed for the *purpose* of being attacked
- *Honeyfarm*: Collection of honeypots
  - Provide early warning, accurate inference of global activity, cover wide range of software
- Design issues
  - Scalability: How many honeypots can be deployed
  - Fidelity: How accurately systems are emulated
  - Containment: How well innocent third parties are protected
- Challenge: tension between scalability and fidelity

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Honeyfarm Scalability/Fidelity Tradeoff

High Scalability **High Fidelity**

Honeyfarm Scalability/Fidelity Tradeoff

Physical Honeypots
(Honeynet Project)

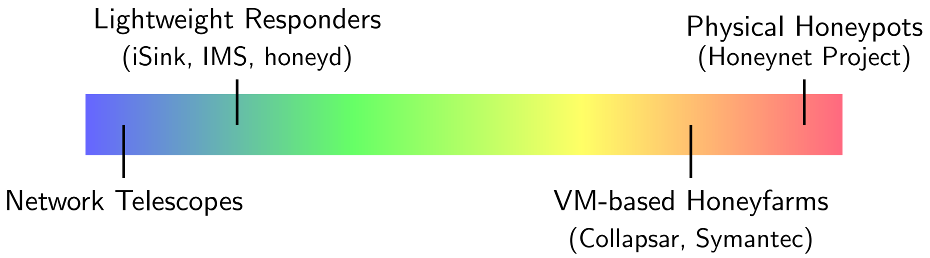
VM-based Honeyfarms
(Collapsar, Symantec)

High Scalability

High Fidelity

Execute real code

Honeyfarm Scalability/Fidelity Tradeoff



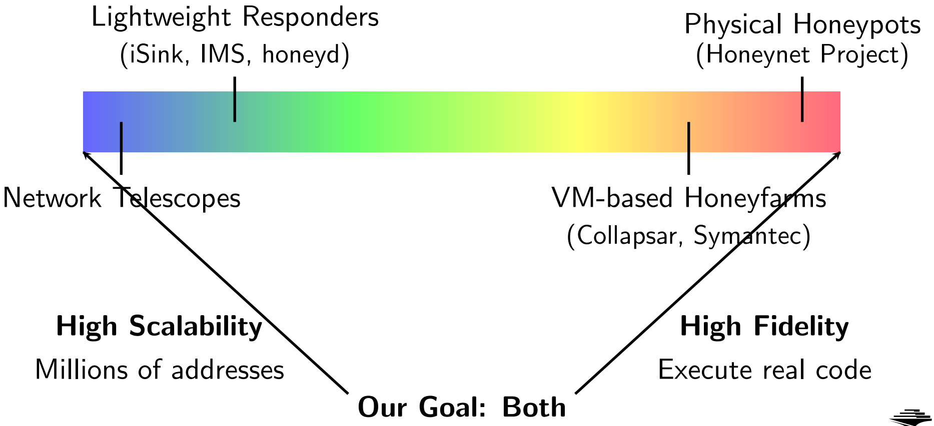
High Scalability

Millions of addresses

High Fidelity

Execute real code

Honeyfarm Scalability/Fidelity Tradeoff



Approach

- Dedicated honeypot systems are overkill
- Can provide the *illusion* of dedicated systems via aggressive resource multiplexing at network and host levels

Network-Level Multiplexing

- Most addresses don't receive traffic most of the time
  - ⇒ Apply late binding of IP addresses to honeypots
- Most traffic that is received causes no interesting effects
  - ⇒ Allocate honeypots only long enough to identify interesting behavior
  - ⇒ Recycle honeypots as soon as possible
- How many honeypots are required?
  - For a given request rate, depends upon recycling rate

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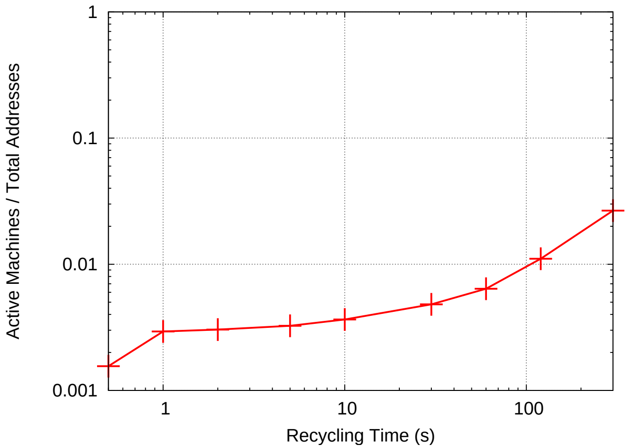
Effectiveness of Network-Level Multiplexing



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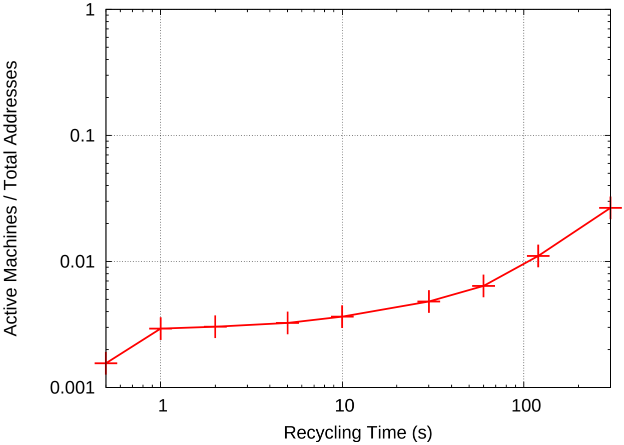

2–3 orders of magnitude improvement!

Host-Level Multiplexing

- CPU utilization in each honeypot quite low (milliseconds to process traffic)
  - ⇒ Use VMM to multiplex honeypots on a single physical machine
- Few memory pages actually modified when handling network data
  - ⇒ Share unmodified pages among honeypots within a machine
- How many virtual machines can we support?
  - Limited by unique memory required per VM

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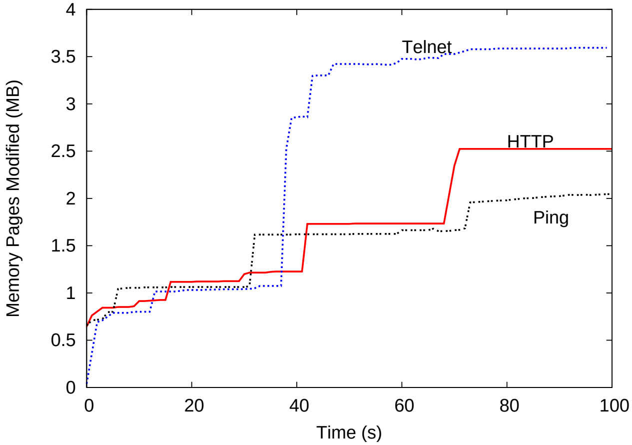

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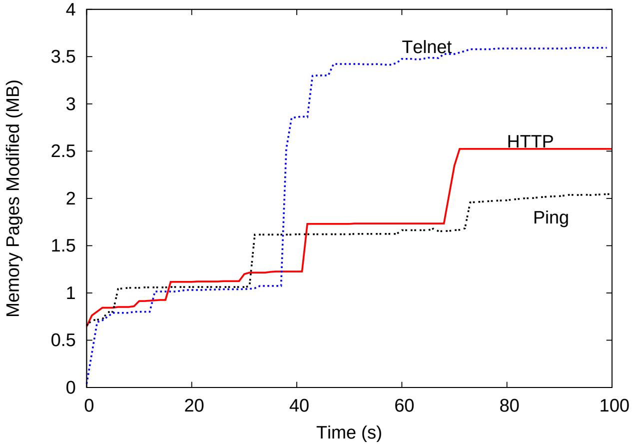
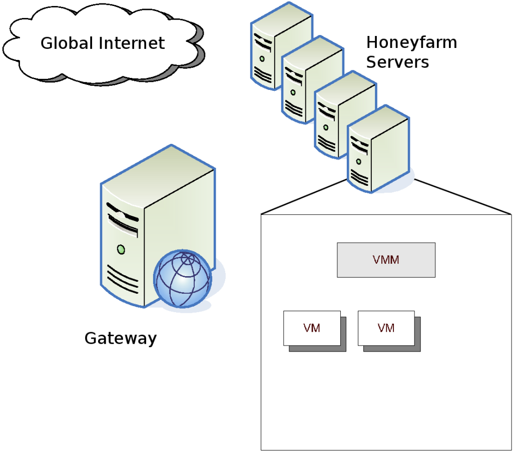


Further 2–3 orders of magnitude improvement

The Potemkin Honeyfarm Architecture



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  - Gateway
  - VMM

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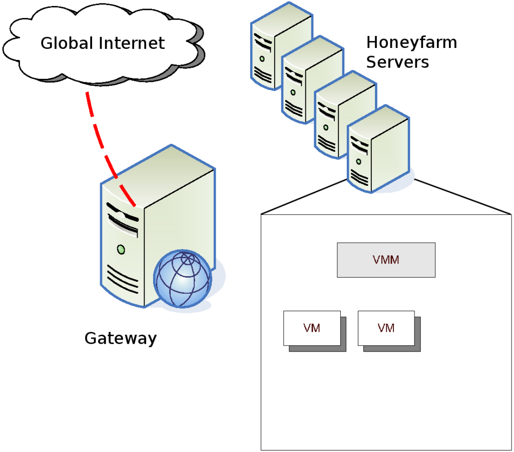

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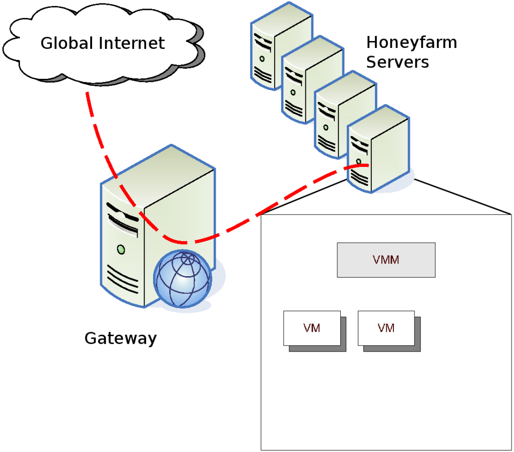

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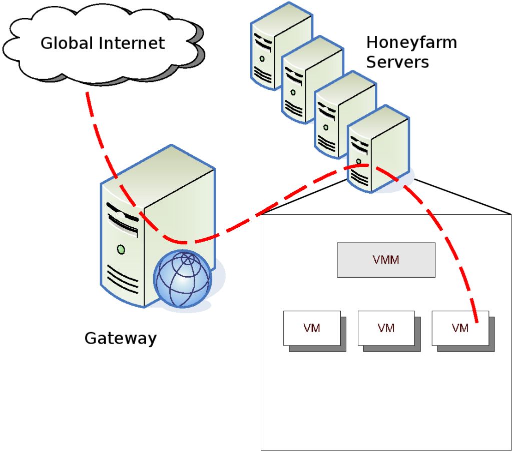
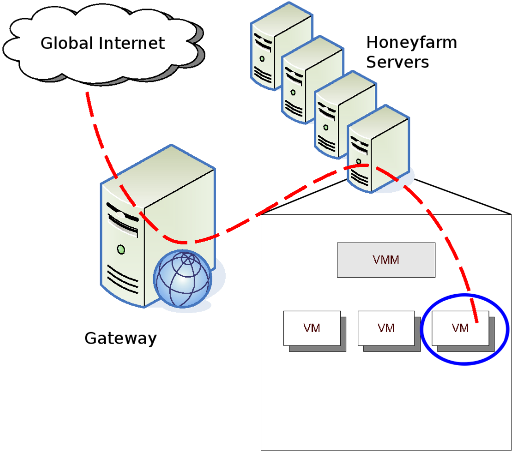


- Two components:
  - Gateway
  - VMM
- Basic operation:
  - Packet received by gateway
  - Dispatched to honeyfarm server
  - VM instantiated
    - Adopts IP address

Potemkin VMM Requirements



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  - VM creation must be fast enough to maintain illusion

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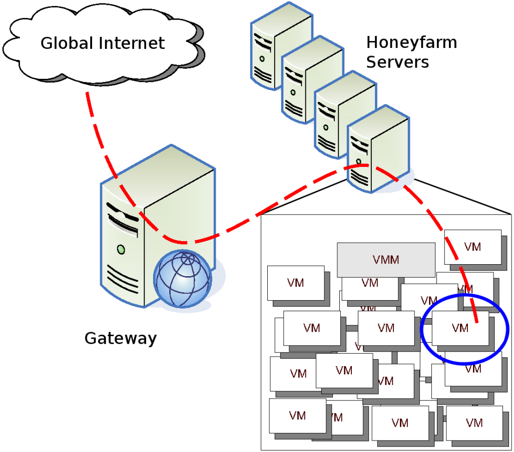

- VMs created on demand
  - VM creation must be fast enough to maintain illusion
- Many VMs created
  - Must be resource-efficient

Potemkin VMM Overview

- Modified version of Xen 3.0 (pre-release)
- **Flash cloning**
  - Fork copies from a reference honeypot VM
  - Reduces VM creation time—no need to boot
  - Applications all ready to run
- **Delta virtualization**
  - Copy-on-write sharing (between VMs)
  - Reduces per-VM state—only stores unique data
  - Further reduces VM creation time

Flash Cloning Performance

Time required to clone a 128 MB honeypot:

Control tools overhead	124 ms
Low-level clone	11 ms
Device setup	149 ms
Other management overhead	79 ms
Networking setup & overhead	158 ms
Total	521 ms

0.5 s already imperceptible to external observers unless looking for delay, but we can do even better

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Delta Virtualization Performance

- Deployed using 128 MB Linux honeypots
- Using servers with 2 GB RAM, have memory available to support $\approx$ 1000 VMs per physical host
- Currently tested with $\approx$ 100 VMs per host
  - Hits artificial resource limit in Xen, but this can be fixed

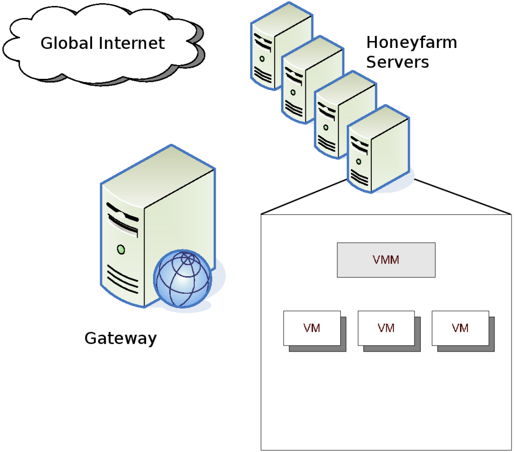
Containment Policies

- Must also care about traffic going out
- We deliberately run unpatched, insecure software in honeypots
- Containment: Should not permit attacks on third parties
- As with scalability, there is a tension between containment and fidelity
- Various containment policies we support:
  - Allow no traffic out
  - Allow traffic over established connections
  - Allow traffic back to original host
  - ...

Containment Implementation in Gateway

- Containment policies implemented in network gateway
- Tracks mappings between IP addresses, honeypots, and past connections
- Modular implementation in Click
- Gateway adds insignificant overhead ($\ll$ 1 ms)

Traffic Reflection



Example gateway policy: Redirect traffic back to honeyfarm

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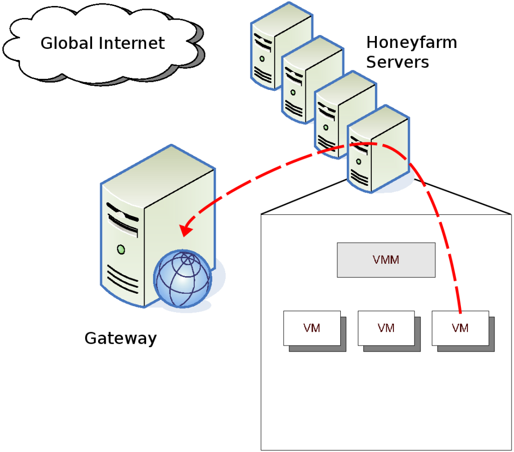

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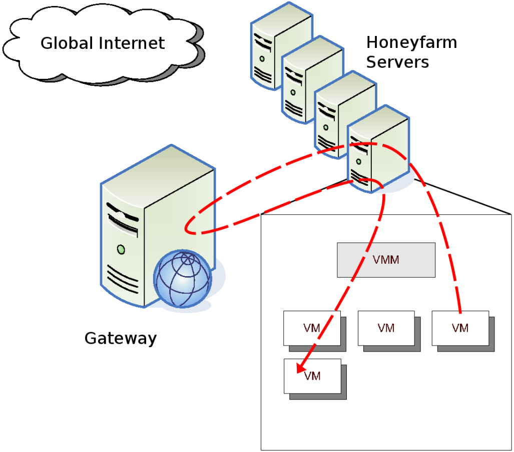


Example gateway policy: Redirect traffic back to honeyfarm

- Packets sent out to third parties. . .
- . . . may be redirected back into honeyfarm

Reuses honeypot creation functionality

Challenges

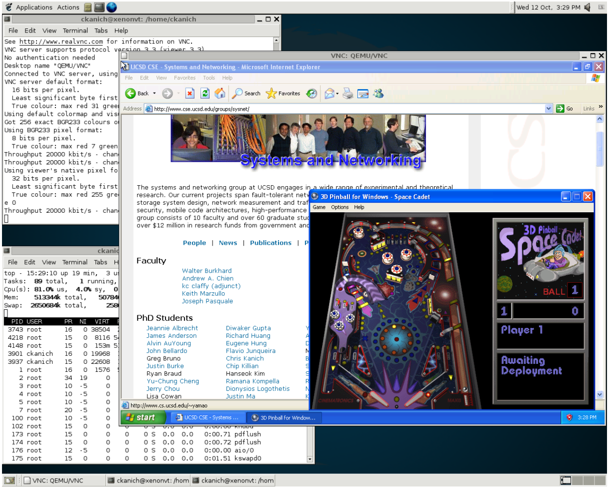
- Honeypot detection
  - If malware detects it is in a honeypot, may act differently
    - How easy it is to detect virtualization?
    - VMware detection code used in the wild
  - Open arms race between honeypot detection and camouflage
- Resource exhaustion
  - Under high load, difficult to maintain accurate illusion
    - Large-scale outbreak
    - Honeypot denial-of-service
  - Challenge is intelligently shedding load

Summary

- Can achieve both high fidelity and scalability
  - Sufficient to provide the *illusion* of scale
- Potemkin prototype: 65k addresses → 10 physical hosts
  - Largest high-fidelity honeypot that we are aware of
- Provides important tool for study of and defenses against malware

For more information:
http://www.ccied.org/

Windows on Xen



Camouflage

Malware may detect honeypot environment in various ways:

- Detect virtualization
  - Via incomplete x86 virtualization
  - Searching for characteristic hardware configurations
  - More complete virtualization can mitigate these leaks
- Detect monitoring tools
  - Network, VM-instrospection tools harder to detect
- Detect network environment
  - Containment requirement places some limits on camouflage effectiveness
  - Network security trends may be in our favor here

Honeypot Monitoring

Various means to monitor honeypots for interesting activity

- Network-level monitoring: Network intrusion detection systems, Earlybird-like detectors, . . .
- Host-level intrusion detection
- Virtual machine introspection