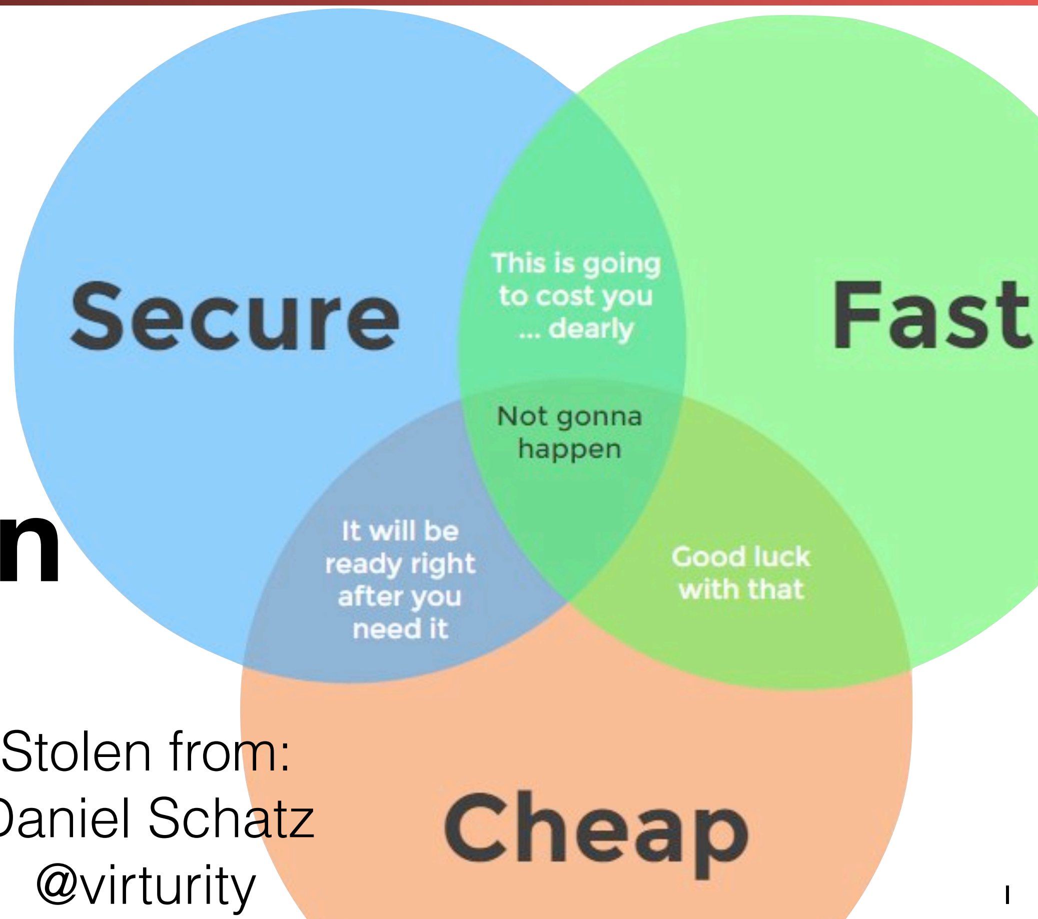
DNSSEC Continued & Intrusion Detection



Stolen from:
Daniel Schatz
@virturity

Enter DNSSEC
(DNS Security Extensions)

- An extension to the DNS protocol to enable cryptographic authentication of DNS records
  - Designed to prove the value of an answer, ***or that there is no answer***!
  - A restricted path of trust
    - Unlike the HTTPS CA (Certificate Authority) system where your browser trusts every CA to speak for every site
- With backwards compatibility:
  - Authority servers don't need to support DNSSEC
    - But clients should know that the domain is not secured
  - Recursive and stub resolvers that don't support DNSSEC must not receive DNSSEC information

Reminder: DNSSEC Record Types & Terms...

- RRSIG:
  - Effectively a certificate signing a DNS RRSET
    - Only valid for a specific interval
- DS:
  - Delegated Signer: This subdomain will use H(K) as the Key Signing Key
- DNSKEY:
  - A (raw) Public Key of the specified type
- KSK & ZSK:
  - Key Signing Key -> Key that signs the Zone Signing Key
  - Zone Signing Key -> Key that signs everything else in the zone

Putting It All Together To Lookup `www.isc.org`

`? A www.isc.org`

User's ISP's Recursive Resolver **`? A www.isc.org`**

. Authority Server (the "root")

```
? A www.isc.org
Answers:
Authority:
org. NS a0.afilias-nst.info
org. IN DS 21366 7 2 {cryptogoop}
org. IN DS 21366 7 1 {cryptogoop}
org. IN RRSIG DS 8 1 86400 20130423000000
20130415230000 20580 . {cryptogoop}
Additional:
a0.afilias-nst.info A 199.19.56.1
```

Name	Type	Value	TTL	Valid
.	DNSKEY	{cryptogoop}	N/A	Yes

Putting It All Together To Lookup `www.isc.org`

.
Authority Server
(the "root")

```
? DNSKEY .
Answers:
. IN DNSKEY  257 3 8 {cryptogoop}
. IN DNSKEY 256 3 8 {cryptogoop}
. IN RRSIG DNSKEY 8 0 172800 20130425235959
20130411000000 19036 . {cryptogoop}
Authority:
Additional:
```

User's ISP's
Recursive Resolver

? DNSKEY .

Name	Type	Value	TTL	Valid
org.	NS	a0.afilia-nst.info		No
a0.afilias-nst.info	A	199.19.56.1	86400	No
org.	DS	{cryptogoop}	86400	No
org.	DS	{cryptogoop}	86400	No
org.	RRSIG	DS {goop}	86400	No
.	DNSKEY	{cryptogoop}	N/A	Yes

Putting It All Together To Lookup `www.isc.org`

Name	Type	Value	TTL	Valid
org.	NS	a0.afilia-nst.info		No
a0.afilias-nst.info	A	199.19.56.1	86400	No
org.	DS	{cryptogoop}	86400	No
org.	DS	{cryptogoop}	86400	No
org.	RRSIG	DS {goop}	86400	No
.	DNSKEY	{cryptogoop}	172800	Yes
.	RRSIG	DNSKEY {goop}	172800	Yes
.	DNSKEY	{cryptogoop}	N/A	Yes

Putting It All Together To Lookup `www.isc.org`

User's ISP's Recursive Resolver **`? A www.isc.org`**

Name	Type	Value	TTL	Valid
org.	NS	a0.afilia-nst.info		No
a0.afilias-nst.info	A	199.19.56.1	86400	No
org.	DS	{cryptogoop}	86400	Yes
org.	DS	{cryptogoop}	86400	Yes
org.	RRSIG	DS {goop}	86400	Yes
.	DNSKEY	{cryptogoop}	172800	Yes
.	RRSIG	DNSKEY {goop}	172800	Yes
.	DNSKEY	{cryptogoop}	N/A	Yes

`org.` Authority Server

```
? A www.isc.org
Answers:
Authority:
isc.org. NS sfba.sns-pb.isc.org.
isc.org. DS {cryptogoop}
isc.org. RRSIG DS {cryptogoop}
Additional:
sfba.sns-pb.isc.org.     A 199.6.1.30
```

Putting It All Together To Lookup `www.isc.org`

User's ISP's
Recursive Resolver

Name	Type	Value	TTL	Valid
org.	NS	a0.afilia-nst.info		No
a0.afilias-nst.info	A	199.19.56.1	86400	No
org.	DS	{cryptogoop}	86400	Yes
org.	DS	{cryptogoop}	86400	Yes
org.	RRSIG	DS {goop}	86400	Yes
.	DNSKEY	{cryptogoop}	172800	Yes
.	RRSIG	DNSKEY {goop}	172800	Yes
isc.org.	DS	{cryptogoop}	86400	No
isc.org.	DS	{cryptogoop}	86400	No
isc.org.	RRSIG	DS {goop}	86400	No
isc.org.	NS	sfbay.sns-pb.isc.org	86400	No
sfbay.sns-pb.isc.org	A	149.20.64.3	86400	No
.	DNSKEY	{cryptogoop}	N/A	Yes

And so on...

- The process ends up requiring:
  - Ask the root for **`www.isc.org`** and the **`DNSKEY`** for **`.`**
  - Ask **`org`** for **`www.isc.org`** and the **`DNSKEY`** for **`org.`**
  - Ask **`isc.org`** for **`www.isc.org`** and the DNSKEY for **`isc.org`**
- Dig commands
  - `dig +dnssec +norecurse www.isc.org @a.root-servers.net`
  - `dig +dnssec +norecurse DNSKEY . @a.root-servers.net`
  - `dig +dnssec +norecurse www.isc.org @199.19.56.1`
  - `dig +dnssec +norecurse DNSKEY org. @199.19.56.1`
  - `dig +dnssec +norecurse www.isc.org @149.20.64.3`
  - `dig +dnssec +norecurse DNSKEY isc.org. @149.20.64.3`

Two additional complications

- ***NOERROR***:
  - The name exists but there is no record of that given type for that name
  - For DNSSEC, prove that there is no ds record
    - Says the subdomain doesn't sign with DNSSEC
- ***NXDOMAIN***:
  - The name does not exist
- **`NSEC`** (Provable denial of existence), a record with just two fields
  - Next domain name
    - The next valid name in the domain
  - Valid types for this name
    - In a bitmap for efficiency

NSEC in action

- Name is valid so **NOERROR** but no answers
- Single **NSEC** record for **www.isc.org**:
  - No names exist between **www.isc.org** and **www-dev.isc.org**
  - **www.isc.org** only has an **A**, **AAAA**, **RRSIG**, and **NSEC** record

```
nweaver% dig +dnssec TXT www.isc.org @8.8.8.8
...
;; Got answer:
;; ->>HEADER<<- opcode: QUERY, status: NOERROR, id: 20430
;; flags: qr rd ra ad; QUERY: 1, ANSWER: 0, AUTHORITY: 4, ADDITIONAL: 1
...
;; QUESTION SECTION:
;www.isc.org.                   IN      TXT

;; AUTHORITY SECTION:
...
www.isc.org.            3600    IN      NSEC    www-dev.isc.org. A AAAA RRSIG NSEC
www.isc.org.            3600    IN      RRSIG   NSEC {RRSIG DATA}
```

The Use of **NSEC**

- Proof that a name exists but no type exists for that name
  - Critical for "This subdomain doesn't support DNSSEC":
    Return an **NSEC** record with the authority stating "There is no **DS** record"
- Proof that a name does not exist
  - It falls between the two **NSEC** names
  - Plus an **NSEC** saying "there is no wildcard"
- Allows trivial domain enumeration
  - Attacker just starts at the beginning and walks through the NSEC records
    - Some consider this bad...

So **`NSEC3`**

- Rather than having the name, use a ***hash*** of the name
  - Hash Algorithm
  - Flags
- Iterations of the hash algorithm
- Salt (optional)
- The next name
- The RRTYPEs for this name
  - Otherwise acts like **`NSEC`**, just in a different space

```
nweaver% dig +dnssec TXT org @199.19.57.1
...
;; AUTHORITY SECTION:
...
h9p7u7tr2u91d0v0ljs9l1gidnp90u3h.org. 86400 IN NSEC3 1 1 1 D399EAAB
    H9Q3IMI6H6CIJ4708DK5A3HMJLEIQ0PF NS SOA RRSIG DNSKEY NSEC3PARAM
h9p7u7tr2u91d0v0ljs9l1gidnp90u3h.org. 86400 IN RRSIG NSEC3 {RRSIG}
```

Comments on NSEC3

- It doesn't ***really*** prevent enumeration
  - You get a hash-space enumeration instead, but since people chose reasonable names...
  - Just select random names until you get the entire hash space...
    - An attacker can then do a brute-force attack to find out what names exist and don't exist
- The salt is mostly pointless!
  - Since the ***whole*** name is hashed, **`foo.example.com`** and **`foo.example.org`** will have different hashes anyway
- The only way to really prevent enumeration is to dynamically sign values
  - But that defeats the purpose of DNSSEC's offline signature generation

So what can *possibly* go wrong?

- Screwups on the authority side...
  - Too many ways to count...
    - But comcast is keeping track of it:
      Follow @comcastdns on twitter
- The validator can't access DNSSEC records
- The validator can't process DNSSEC records correctly

Authority Side Screwups...

- Its quite common to screw up
- Tell your registrar you support DNSSEC when you don't
  - Took down HBO Go's launch for Comcast users and those using Google Public DNS
- Rotate your key but present old signatures
- Forget that your signatures expire

And The Recursive Resolver Must Not Be Trusted!

- Most deployments validate at the recursive resolver, not the client
  - Notably Google Public DNS and Comcast
- This provides very little practical security:
  - The recursive resolver has proven to be the biggest threat in DNS
  - And this doesn't protect you between the recursive resolver and your system
- But causes a lot of headaches
  - Comcast or Google invariably get blamed when a zone screws up
  - Fortunately this is getting less common...

DNSSEC transport

- A validating client must be able to fetch the DNSSEC related records
  - It may be through the recursive resolver
  - It may be by contacting arbitrary DNS servers on the Internet
- One of these two must work or the client ***can not validate*** DNSSEC
  - This acts to limit DNSSEC's real use:
    Signing other types such as cryptographic fingerprints (e.g. DANE)

Probe the Root
To Check For DNSSEC Transport

- Can the client get DNSSEC data from the Internet?
  - Probe every root with DO for:
    - DS for .com with RRSIG
    - DNSKEY for . with RRSIG
    - NSEC for an invalid TLD with RRSIG
- Serves two purposes:
  - Some networks have one or more bad root mirrors
    - Notably one Chinese educational network has root mirrors for all but 3 that don't support DNSSEC
  - If no information can be retrieved
    - Proxy which strips out DNSSEC information and/or can't handle DO

DNSSEC Root Transport: Results We've Seen In The Wild

- Bad news at Cafes: Hotspot gateways often proxy all DNS and can’t handle DO-enabled traffic
  - And then have DNS resolvers that can't handle DNSSEC requests!
- Confirmed the Chinese educational network “Bad root mirror” problem

Implications of
“No DNSSEC at Charbucks”

- DNSSEC failure depends on the usage.
- For name->address bindings:
  - If the recursive resolver practices proper port randomization:
    - No problem. The same “attackers” who can manipulate your DNS could do anything they want at the proxy that’s controlling your DNS traffic
  - Else:
    - Problem. Network is not secure
- For name->key bindings:
  - Unless the resolver supports it directly, you are Out of Luck
    - DNSSEC information must have an alternate channel if you want to use it to transmit keys instead of just IPs

In fact, my preferred DNSSEC policy For Client Validation

- For name->address mappings
  - Any existing APIs that don't provide DNSSEC status
  - If valid: use
  - If invalid OR no complete DNSSEC chain:
    - Begin an iterative fetch with the most precise DNSSEC-validated data
    - Use the result without question
- For name->data mappings
  - An API which returns DNSSEC status
  - If valid: Use
  - If invalid: Return DNSSEC failure status
    - Up to the application

And That's The Real Thing...

- DNSSEC in all its *emm* glory.
- OPT records to say "I want DNSSEC"
- RRSIG records are certificates
- DNSKEY records hold public keys
- DS records hold key fingerprints
  - Used by the parent to tell the child's keys
- NSEC/NSEC3 records to prove that a name doesn't exist or there is no record of that type

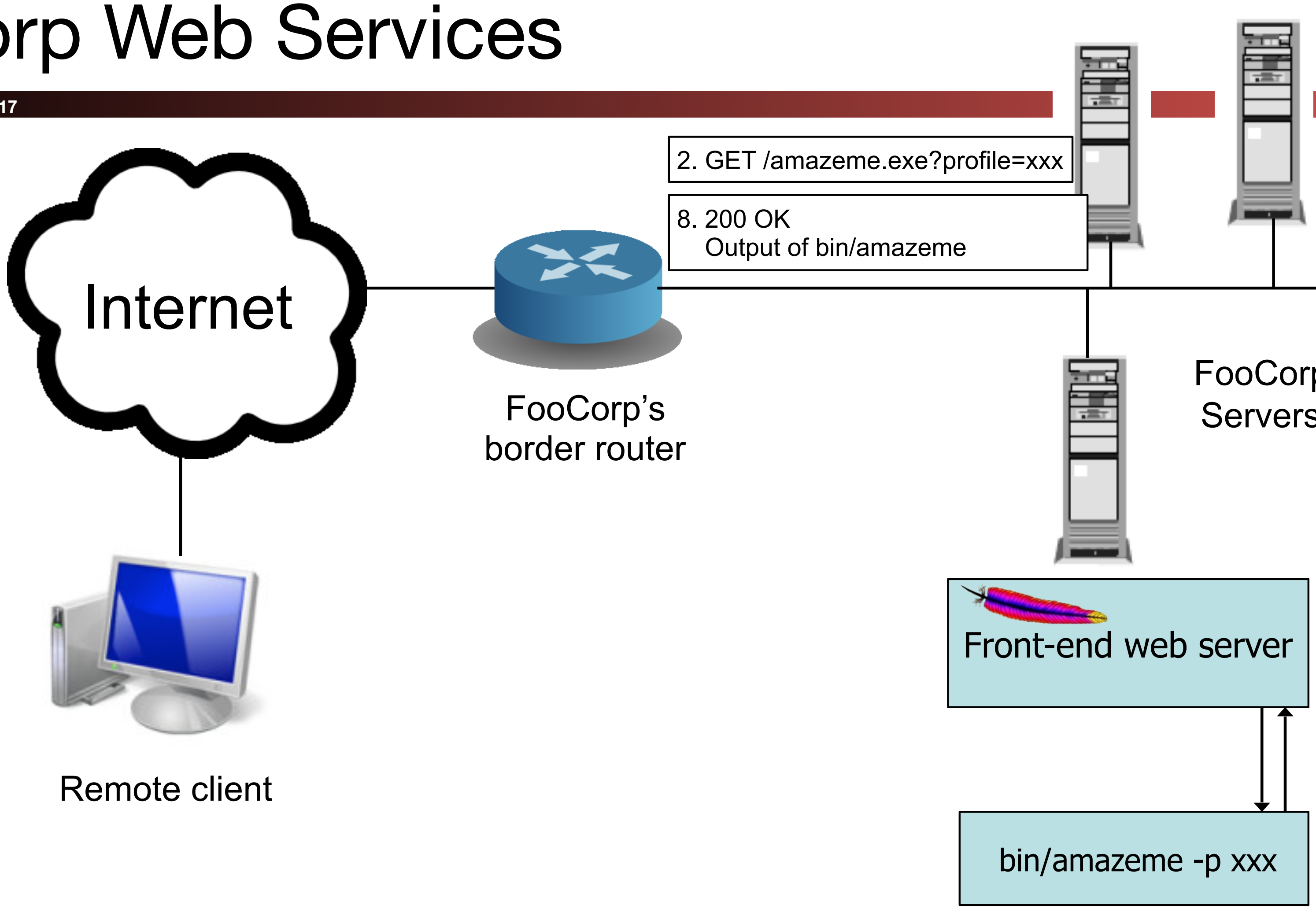
The Next Two Lectures...

- Today: The technology of detecting attacks
- Wednesday: The abuse of scalable NIDS
  - NSA bulk surveillance: XKEYSCORE
  - Chinese censorship: The "Great Firewall of China"
  - Chinese attack: The "Great Cannon"

And Project 3...

- Project 3 is now live...
- You are given a VM, scapy, and sample code...
- And get to bang on the Great Firewall of China
  - Determine a request that triggers the Great Firewall and capture packets
  - Build a function to create a TCP connection to a server and see if its being censored
  - Build a function that determines where on the path the censor exists
  - Build a function that conveys a message to the server that is ***not*** censored by the Great Firewall
- Start on the first two parts ***now!***
  - You will find that dealing with real packets and real networks can get real frustrating ***really fast***
    - EG, the bridge interface isn't getting an IP address on AirBears!?!?
  - You may also find that some home NATs may really really screw things up...
    - EG, change packet IPIDs, ports, etc, which will show up on ICMP time-expired packets.
      You have been warned!

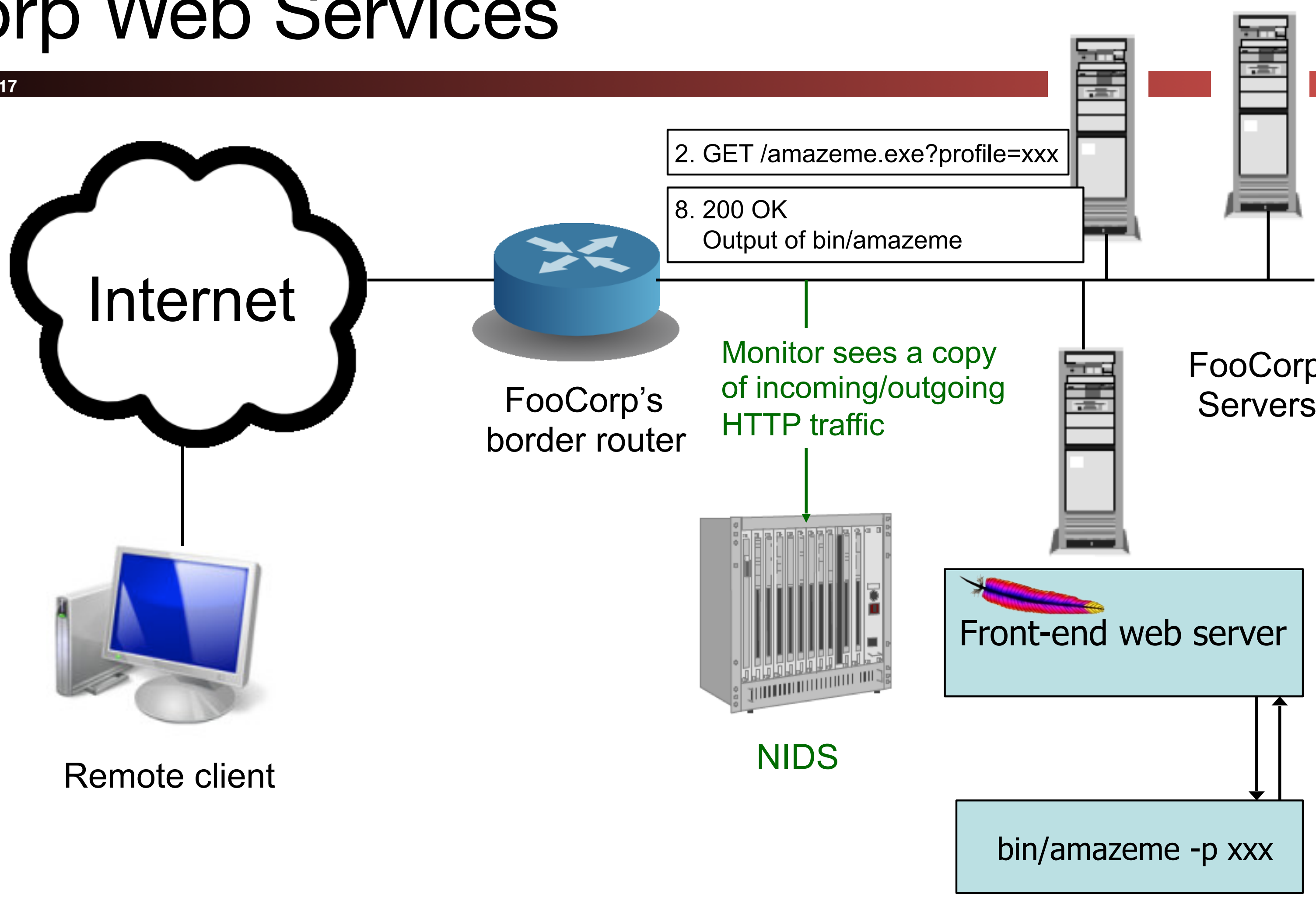
Structure of FooCorp Web Services



Network Intrusion Detection

- Approach #1: look at the network traffic
  - (a “NIDS”: rhymes with “kids”)
  - Scan HTTP requests
  - Look for “`/etc/passwd`” and/or “`../../`” in requests
    - Indicates attempts to get files that the web server shouldn't provide

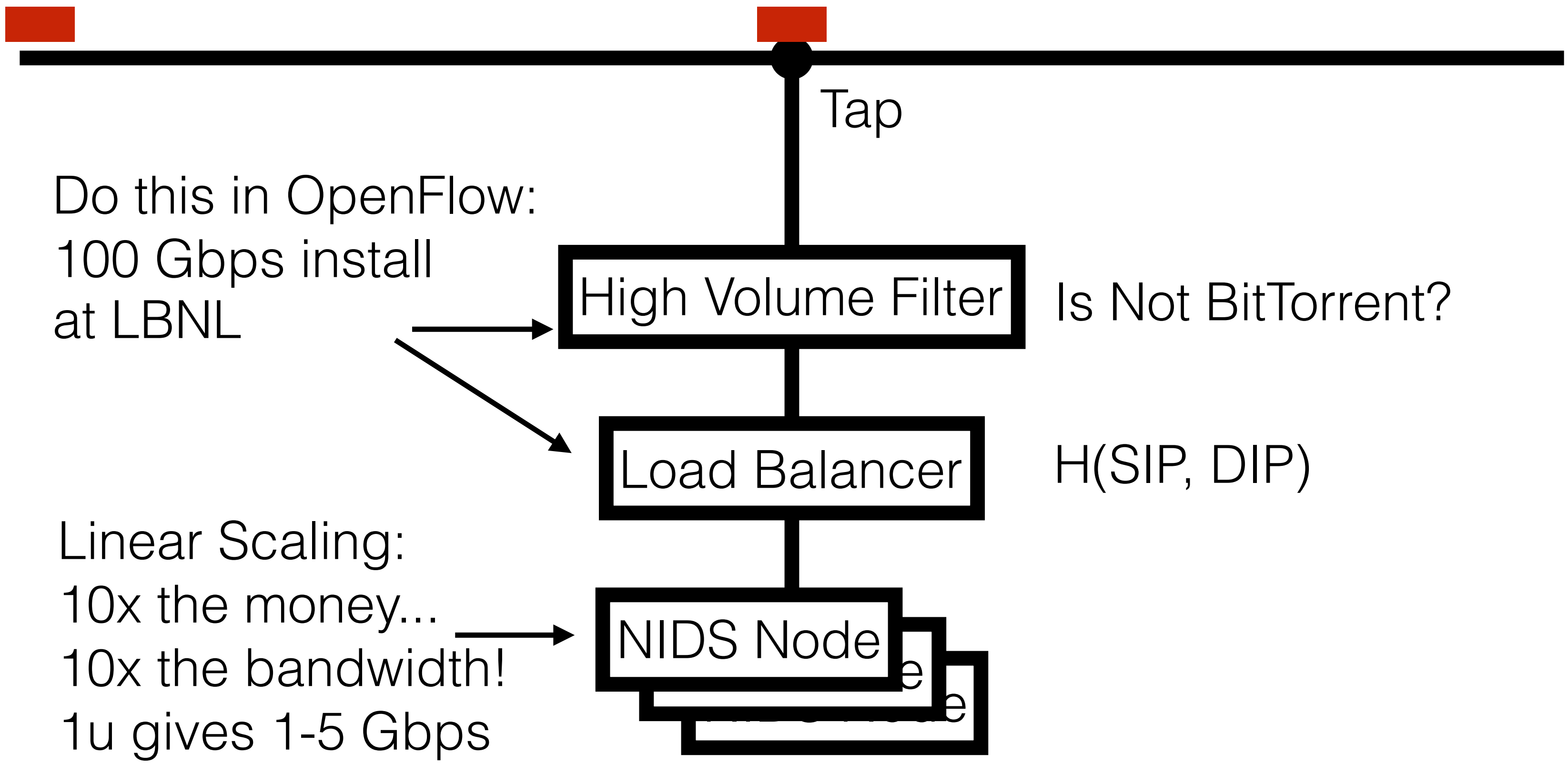
Structure of FooCorp Web Services



Network Intrusion Detection

- Approach #1: look at the network traffic
  - (a "NIDS": rhymes with "kids")
  - Scan HTTP requests
  - Look for "**`/etc/passwd`**" and/or "**`../../`**"
- Pros:
  - No need to touch or trust end systems
    - Can "bolt on" security
  - Cheap: cover many systems w/ single monitor
  - Cheap: centralized management

How They Work:
Scalable Network Intrusion Detection Systems



Inside the NIDS

`GET HT TP /fu bar/  1.1..`

HTTP Request
URL = /fubar/
Host = ...

`GET HTTP /b az/?id= 1f413 1.1...`

HTTP Request
URL = /baz/?id=...
ID = 1f413

`220  mail.domain.target  ESMTP Sendmail...`

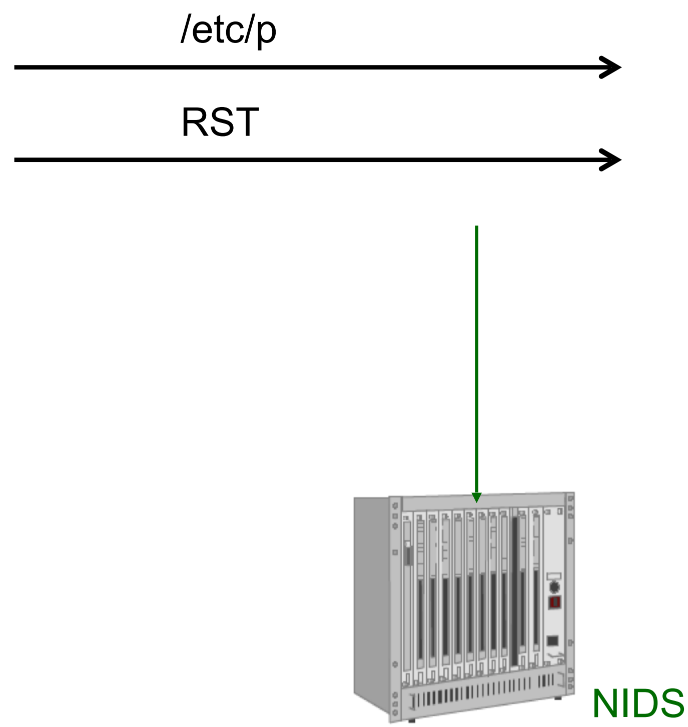
Sendmail
From = someguy@...
To = otherguy@...

Network Intrusion Detection (NIDS)

- NIDS has a table of all active connections, and maintains state for each
  - e.g., has it seen a partial match of /etc/passwd?
- What do you do when you see a new packet not associated with any known connection?
  - Create a new connection: when NIDS starts it doesn't know what connections might be existing

Evasion

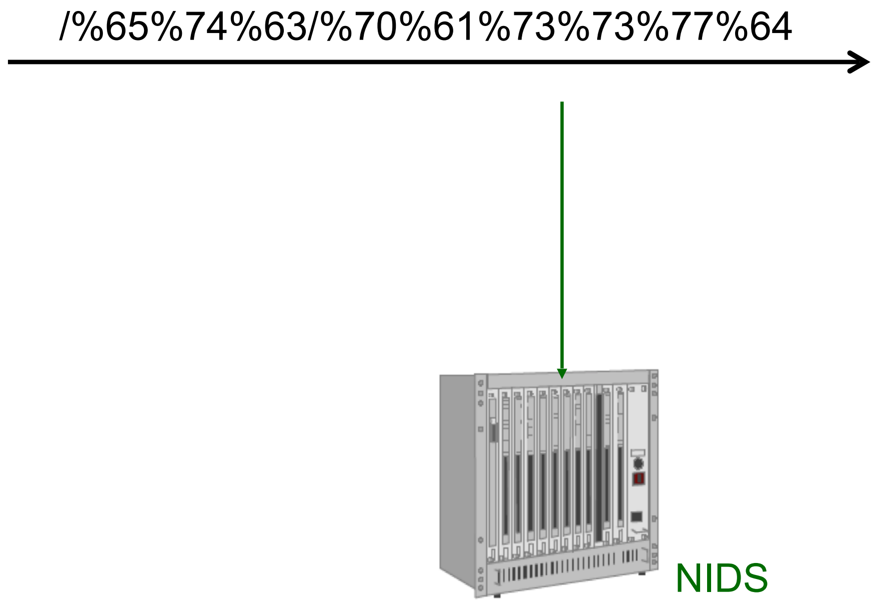
- What should NIDS do if it sees a RST packet?



- Assume RST will be received?
- Assume RST won't be received?
- Other (please specify)

Evasion

- What should NIDS do if it sees this?



- Alert – it's an attack
- No alert – it's all good
- Other (please specify)

Evasion

- Evasion attacks arise when you have “double parsing”
- ***Inconsistency*** - interpreted differently between the monitor and the end system
- ***Ambiguity*** - information needed to interpret correctly is missing

Evasion Attacks (High-Level View)

- Some evasions reflect incomplete analysis
  - In our FooCorp example, hex escapes or "`..////.//../`" alias
  - In principle, can deal with these with implementation care (make sure we fully understand the spec)
    - Of course, in practice things inevitably fall through the cracks!
- Some are due to imperfect observability
  - For instance, if what NIDS sees doesn't exactly match what arrives at the destination
  - EG, two copies of the "same" packet, which are actually different and with different TTLs

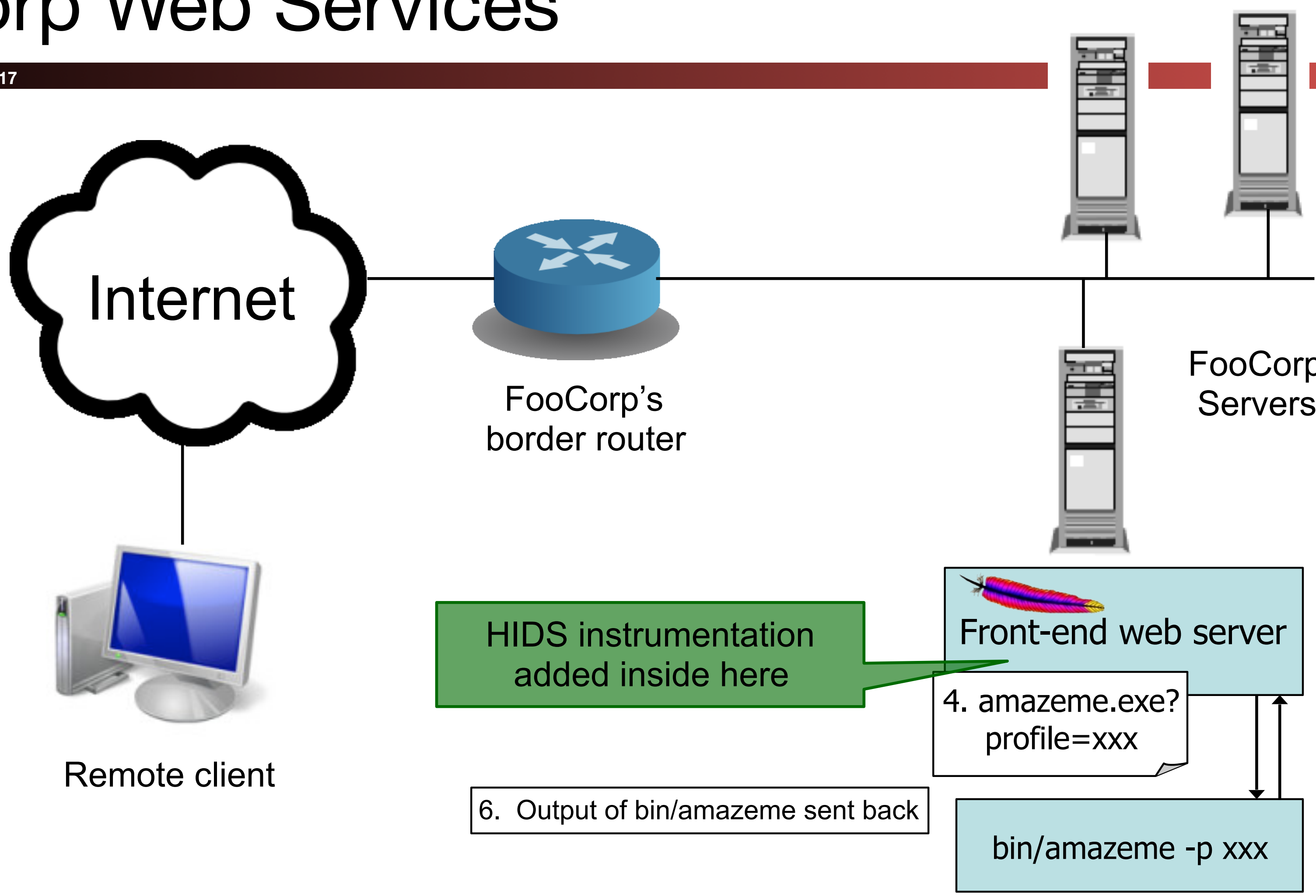
Network-Based Detection

- Issues:
  - Scan for "`/etc/passwd`"?
    - What about other sensitive files?
  - Scan for "`../../`"?
    - Sometimes seen in legit. requests (= false positive)
    - What about "`%2e%2e%2f%2e%2e%2f`"? (= evasion)
      - Okay, need to do full HTTP parsing
    - What about "`..///.///..////`"?
      - Okay, need to understand Unix filename semantics too!
  - What if it's HTTPS and not HTTP?
    - Need access to decrypted text / session key – yuck!

Host-based Intrusion Detection

- Approach #2: instrument the web server
  - Host-based IDS (sometimes called "HIDS")
  - Scan ?arguments sent to back-end programs
    - Look for "**`/etc/passwd`**" and/or "`../../`"

Structure of FooCorp Web Services



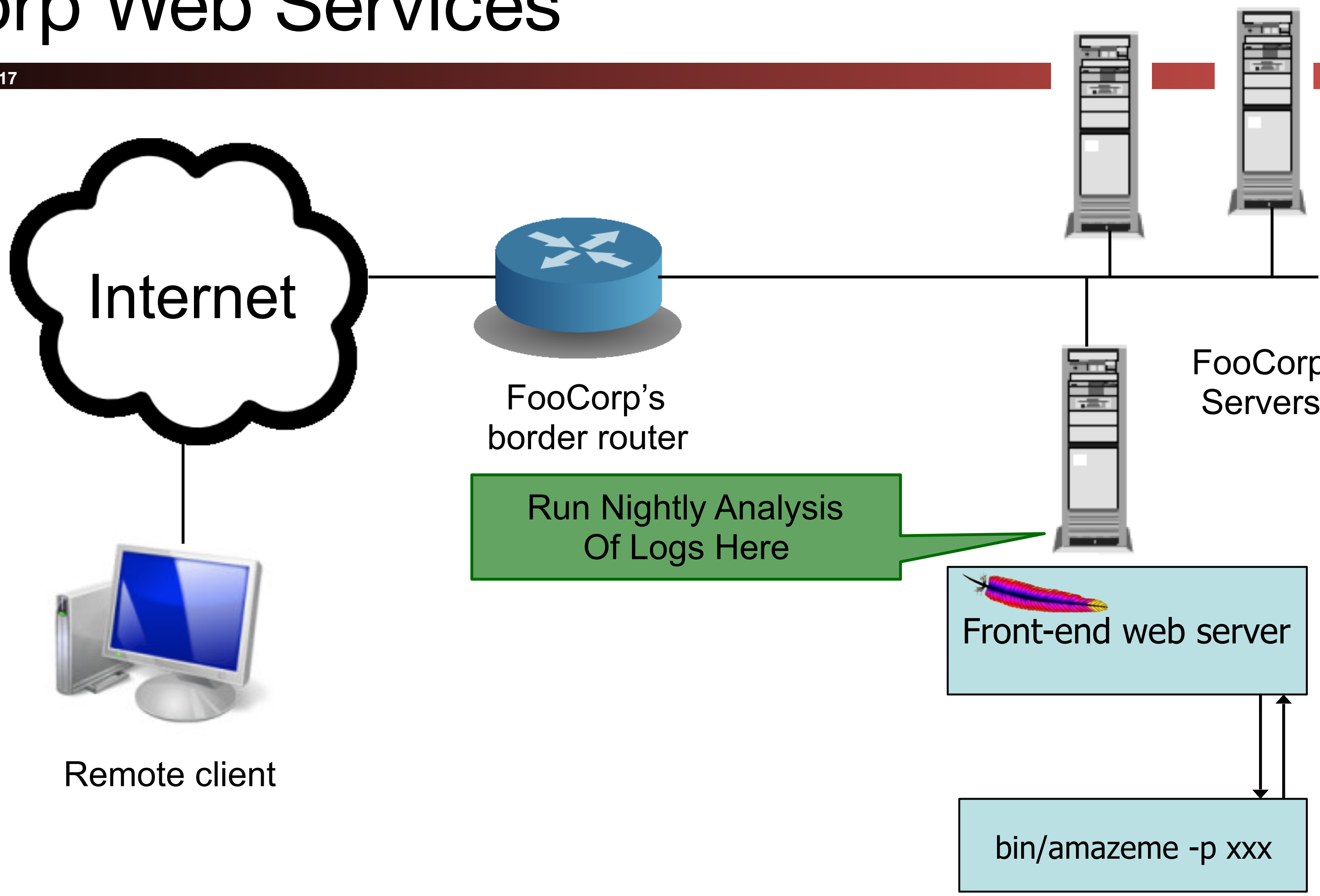
Host-based Intrusion Detection

- Approach #2: instrument the web server
  - Host-based IDS (sometimes called "HIDS")
  - Scan ?arguments sent to back-end programs
    - Look for "`/etc/passwd`" and/or "`../../`"
- Pros:
  - No problems with HTTP complexities like %-escapes
  - Works for encrypted HTTPS!
- Issues:
  - Have to add code to each (possibly different) web server
    - And that effort only helps with detecting web server attacks
  - Still have to consider Unix filename semantics ("`..////.//`")
  - Still have to consider other sensitive files

Log Analysis

- Approach #3: each night, script runs to analyze log files generated by web servers
  - Again scan ?arguments sent to back-end programs

Structure of FooCorp Web Services



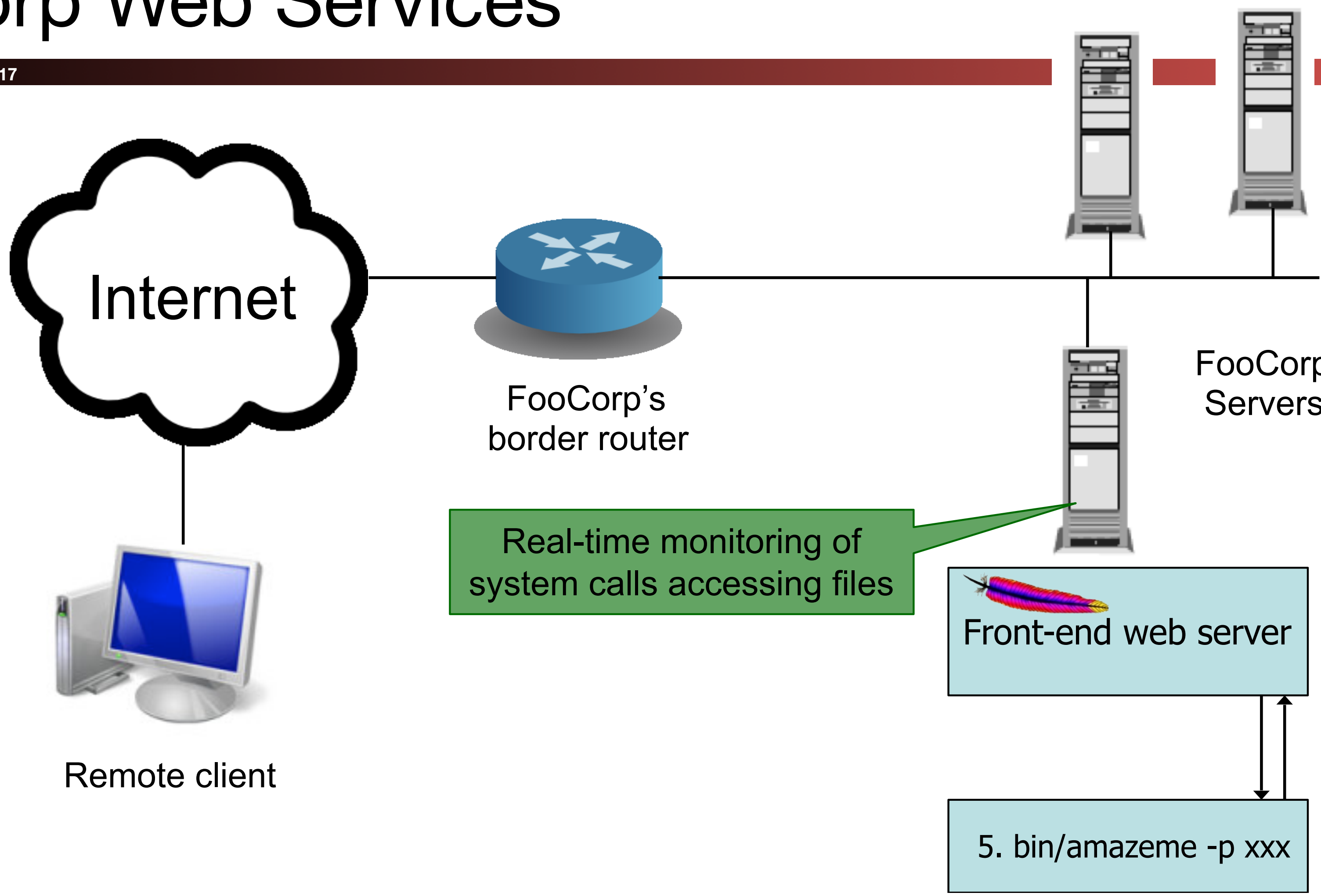
Log Analysis:
Aka "Log It All and let Splunk Sort It Out"

- Approach #3: each night, script runs to analyze log files generated by web servers
  - Again scan ?arguments sent to back-end programs
- Pros:
  - Cheap: web servers generally already have such logging facilities built into them
  - No problems like %-escapes, encrypted HTTPS
- Issues:
  - Again must consider filename tricks, other sensitive files
  - Can't block attacks & prevent from happening
  - Detection delayed, so attack damage may compound
  - If the attack is a compromise, then malware might be able to alter the logs before they're analyzed
    - (Not a problem for directory traversal information leak example)
    - Also can be mitigated by using a separate log server

System Call Monitoring (HIDS)

- Approach #4: monitor system call activity of backend processes
  - Look for access to **`/etc/passwd`**

Structure of FooCorp Web Services



System Call Monitoring (HIDS)

- Approach #4: monitor system call activity of backend processes
  - Look for access to /etc/passwd
- Pros:
  - No issues with any HTTP complexities
  - May avoid issues with filename tricks
  - Attack only leads to an "alert" if attack succeeded
    - Sensitive file was indeed accessed
- Issues:
  - Maybe other processes make legit accesses to the sensitive files (false positives)
  - Maybe we'd like to detect attempts even if they fail?
    - "situational awareness"

Detection Accuracy

- Two types of detector errors:
  - False positive (FP): alerting about a problem when in fact there was no problem
  - False negative (FN): failing to alert about a problem when in fact there was a problem
- Detector accuracy is often assessed in terms of rates at which these occur:
  - Define I to be the event of an instance of intrusive behavior occurring (something we want to detect)
  - Define A to be the event of detector generating alarm
- Define:
  - False positive rate = $P[A|\neg I]$
  - False negative rate = $P[\neg A|\ I]$

Perfect Detection

- Is it possible to build a detector for our example with a false negative rate of 0%?
- Algorithm to detect bad URLs with 0% FN rate:

```
void my_detector_that_never_misses(char *URL)
{
    printf("yep, it's an attack!\n");
}
```

  - In fact, it works for detecting any bad activity with no false negatives! Woo-hoo!
- Wow, so what about a detector for bad URLs that has NO FALSE POSITIVES?!
  - `printf("nope, not an attack\n");`

Detection Tradeoffs

- The art of a good detector is achieving an effective balance between FPs and FNs
- Suppose our detector has an FP rate of 0.1% and an FN rate of 2%. Is it good enough? Which is better, a very low FP rate or a very low FN rate?
  - Depends on the cost of each type of error …
    - E.g., FP might lead to paging a duty officer and consuming hour of their time; FN might lead to $10K cleaning up compromised system that was missed
  - … but also critically depends on the rate at which actual attacks occur in your environment

Base Rate Fallacy

- Suppose our detector has a FP rate of 0.1% (!) and a FN rate of 2% (not bad!)
- Scenario #1: our server receives 1,000 URLs/day, and 5 of them are attacks
  - Expected # FPs each day = 0.1% * 995 ≈ 1
  - Expected # FNs each day = 2% * 5 = 0.1 (< 1/week)
  - Pretty good!
- Scenario #2: our server receives 10,000,000 URLs/day, and 5 of them are attacks
  - Expected # FPs each day ≈ 10,000 :-(
- Nothing changed about the detector; only our environment changed
  - Accurate detection very challenging when base rate of activity we want to detect is quite low

Composing Detectors: There Is No Free Lunch

- "Hey, what if we take two (bad) detectors and combine them?"
  - Can we turn that into a good detector?
  - Note: Assumes the detectors are independent
- Parallel composition: Either detector triggers an alert
  - Reduces false negative rate (either one alerts works)
  - ***Increases*** false positive rate!
- Series composition: both detectors must trigger for an alert
  - Reduces false positive rate (since both must false positive)
  - ***Increases*** false negative rate!

Styles of Detection: Signature-Based

- Idea: look for activity that matches the structure of a known attack
- Example (from the freeware Snort NIDS):

```
alert tcp $EXTERNAL_NET any -> $HOME_NET 139
flow:to_server,established
content:"|eb2f 5feb 4a5e 89fb 893e 89f2|"
msg:"EXPLOIT x86 linux samba overflow"
reference:bugtraq,1816
reference:cve,CVE-1999-0811
classtype:attempted-admin
```

- Can be at different semantic layers
  e.g.: IP/TCP header fields; packet payload; URLs

Signature-Based Detection

- E.g. for FooCorp, search for "`../../`" or "**`/etc/passwd`**"
- What's nice about this approach?
  - Conceptually simple
  - Takes care of known attacks (of which there are zillions)
  - Easy to share signatures, build up libraries
- What's problematic about this approach?
  - Blind to novel attacks
  - Might even miss variants of known attacks ("`..///.//../`")
    - Of which there are zillions
  - Simpler versions look at low-level syntax, not semantics
    - Can lead to weak power (either misses variants, or generates lots of false positives)

Vulnerability Signatures

- Idea: don't match on known attacks, match on known problems
- Example (also from Snort):

```
alert tcp $EXTERNAL_NET any -> $HTTP_SERVERS 80
uricontent: ".ida?"; nocase; dsize: > 239; flags:A+
msg:"Web-IIS ISAPI .ida attempt"
reference:bugtraq,1816
reference:cve,CAN-2000-0071
classtype:attempted-admin
```

- That is, match URIs that invoke `*.ida?*`, have more than 239 bytes of payload, and have ACK set (maybe others too)
- This example detects any* attempt to exploit a particular buffer overflow in IIS web servers
  - Used by the "Code Red" worm
  - (Note, signature is not quite complete: also worked for `*.idb?*`)

Styles of Detection: Anomaly-Based

- Idea: attacks look peculiar.
- High-level approach: develop a model of normal behavior (say based on analyzing historical logs). Flag activity that deviates from it.
- FooCorp example: maybe look at distribution of characters in URL parameters, learn that some are rare and/or don't occur repeatedly
  - If we happen to learn that '.'s have this property, then could detect the attack even without knowing it exists
- Big benefit: potential detection of a wide range of attacks, including novel ones

Anomaly Detection Problems

- Can fail to detect known attacks
- Can fail to detect novel attacks, if don't happen to look peculiar along measured dimension
- What happens if the historical data you train on includes attacks?
- Base Rate Fallacy particularly acute: if prevalence of attacks is low, then you're more often going to see benign outliers
  - High FP rate
  - OR: require such a stringent deviation from "normal" that most attacks are missed (high FN rate)
- Proves great subject for academic papers but not generally used

Specification-Based Detection

- Idea: don't learn what's normal; specify what's allowed
- FooCorp example: decide that all URL parameters sent to foocorp.com servers must have at most one '/' in them
  - Flag any arriving param with > 1 slash as an attack
- What's nice about this approach?
  - Can detect novel attacks
  - Can have low false positives
    - If FooCorp audits its web pages to make sure they comply
- What's problematic about this approach?
  - Expensive: lots of labor to derive specifications
    - And keep them up to date as things change ("churn")

Styles of Detection: Behavioral

- Idea: don't look for attacks, look for evidence of compromise
- FooCorp example: inspect all output web traffic for any lines that match a passwd file
- Example for monitoring user shell keystrokes:
  `unset HISTFILE`
- Example for catching code injection: look at sequences of system calls, flag any that prior analysis of a given program shows it can't generate
  - E.g., observe process executing read(), open(), write(), fork(), exec() …
  - … but there's no code path in the (original) program that calls those in exactly that order!

Behavioral-Based Detection

- What's nice about this approach?
  - Can detect a wide range of novel attacks
  - Can have low false positives
    - Depending on degree to which behavior is distinctive
    - E.g., for system call profiling: no false positives!
  - Can be cheap to implement
    - E.g., system call profiling can be mechanized
- What's problematic about this approach?
  - Post facto detection: discovers that you definitely have a problem, w/ no opportunity to prevent it
  - Brittle: for some behaviors, attacker can maybe avoid it
    - Easy enough to not type "**`unset HISTFILE`**"
    - How could they evade system call profiling?
      - Mimicry: adapt injected code to comply w/ allowed call sequences (and can be automated!)

Summary of Evasion Issues

- Evasions arise from uncertainty (or incompleteness) because detector must infer behavior/processing it can't directly observe
  - A general problem any time detection separate from potential target
- One general strategy: impose canonical form ("normalize")
  - E.g., rewrite URLs to expand/remove hex escapes
  - E.g., enforce blog comments to only have certain HTML tags
- Another strategy: analyze all possible interpretations rather than assuming one
  - E.g., analyze raw URL, hex-escaped URL, doubly-escaped URL …
- Another strategy: Flag potential evasions
  - So the presence of an ambiguity is at least noted
- Another strategy: fix the basic observation problem
  - E.g., monitor directly at end systems

Inside a Modern HIDS ("AV")

- URL/Web access blocking:
  - Prevent users from going to known bad locations
- Protocol scanning of network traffic (esp. HTTP)
  - Detect & block known attacks
  - Detect & block known malware communication
- Payload scanning
  - Detect & block known malware
  - (Auto-update of signatures for these)
- Cloud queries regarding reputation
  - Who else has run this executable and with what results?
  - What's known about the remote host / domain / URL?

Inside a Modern HIDS

- Sandbox execution
  - Run selected executables in constrained/monitored environment
  - Analyze:
    - System calls
    - Changes to files / registry
    - Self-modifying code (polymorphism/metamorphism)
- File scanning
  - Look for malware that installs itself on disk
- Memory scanning
  - Look for malware that never appears on disk
- Runtime analysis
  - Apply heuristics/signatures to execution behavior

Inside a Modern NIDS

- Deployment inside network as well as at border
  - Greater visibility, including tracking of user identity
- Full protocol analysis
  - Including extraction of complex embedded objects
  - In some systems, 100s of known protocols
- Signature analysis (also behavioral)
  - Known attacks, malware communication, blacklisted hosts/domains
  - Known malicious payloads
  - Sequences/patterns of activity
- Shadow execution (e.g., Flash, PDF programs)
- Extensive logging (in support of forensics)
- Auto-update of signatures, blacklists

NIDS vs. HIDS

- NIDS benefits:
  - Can cover a lot of systems with single deployment
    - Much simpler management
  - Easy to "bolt on" / no need to touch end systems
  - Doesn't consume production resources on end systems
  - Harder for an attacker to subvert / less to trust
- HIDS benefits:
  - Can have direct access to semantics of activity
    - Better positioned to block (prevent) attacks
    - Harder to evade
  - Can protect against non-network threats
  - Visibility into encrypted activity
  - Performance scales much more readily (no chokepoint)
    - No issues with "dropped" packets

Key Concepts for Detection

- Signature-based vs anomaly detection
  (blacklisting vs whitelisting)
- Evasion attacks
- Evaluation metrics: False positive rate, false negative rate
- Base rate problem

Detection vs. Blocking

- If we can detect attacks, how about blocking them?
- Issues:
  - Not a possibility for retrospective analysis (e.g., nightly job that looks at logs)
  - Quite hard for detector that's not in the data path
    - E.g. How can NIDS that passively monitors traffic block attacks?
      - Change firewall rules dynamically; forge RST packets
      - And still there's a race regarding what attacker does before block
  - False positives get more expensive
    - You don't just bug an operator, you damage production activity
- Today's technology/products pretty much all offer blocking
  - Intrusion prevention systems (IPS - "eye-pee-ess")

Can We Build An IPS That Blocks All Attacks?

An Alternative Paradigm

- Idea: rather than detect attacks, launch them yourself!
- Vulnerability scanning: use a tool to probe your own systems with a wide range of attacks, fix any that succeed
- Pros?
  - Accurate: if your scanning tool is good, it finds real problems
  - Proactive: can prevent future misuse
  - Intelligence: can ignore IDS alarms that you know can't succeed
- Issues?
  - Can take a lot of work
  - Not so helpful for systems you can't modify
  - Dangerous for disruptive attacks
    - And you might not know which these are …
- In practice, this approach is prudent and widely used today
  - Good complement to also running an IDS

Styles of Detection: Honeypots

- Idea: deploy a sacrificial system that has no operational purpose
- Any access is by definition not authorized …
- … and thus an intruder
  - (or some sort of mistake)

- Provides opportunity to:
  - Identify intruders
  - Study what they're up to
  - Divert them from legitimate targets

Honeypots

- Real-world example: some hospitals enter fake records with celebrity names …
  - … to entrap staff who don't respect confidentiality
- What's nice about this approach?
  - Can detect all sorts of new threats
- What's problematic about this approach?
  - Can be difficult to lure the attacker
  - Can be a lot of work to build a convincing environment
  - Note: both of these issues matter less when deploying honeypots for automated attacks
    - Because these have more predictable targeting & env. needs
    - E.g. "spamtraps": fake email addresses to catching spambots
- A great honeypot: An unsecured Bitcoin wallet...
  - When your bitcoins get stolen, you know you got compromised!

Forensics

- Vital complement to detecting attacks: figuring out what happened in wake of successful attack
- Doing so requires access to rich/extensive logs
  - Plus tools for analyzing/understanding them
- It also entails looking for patterns and understanding the implications of structure seen in activity
  - An iterative process (“peeling the onion”)

Other Attacks on IDSs

- DoS: exhaust its memory
  - IDS has to track ongoing activity
  - Attacker generates lots of different forms of activity, consumes all of its memory
    - E.g., spoof zillions of distinct TCP SYNs …
    - … so IDS must hold zillions of connection records
- DoS: exhaust its processing
  - One sneaky form: algorithmic complexity attacks
    - E.g., if IDS uses a predictable hash function to manage connection records …
    - … then generate series of hash collisions
- Code injection (!)
  - After all, NIDS analyzers take as input network traffic under attacker's control …
    - One of the CS194 projects will be on this topic...

And, of course, our monitors have bugs...