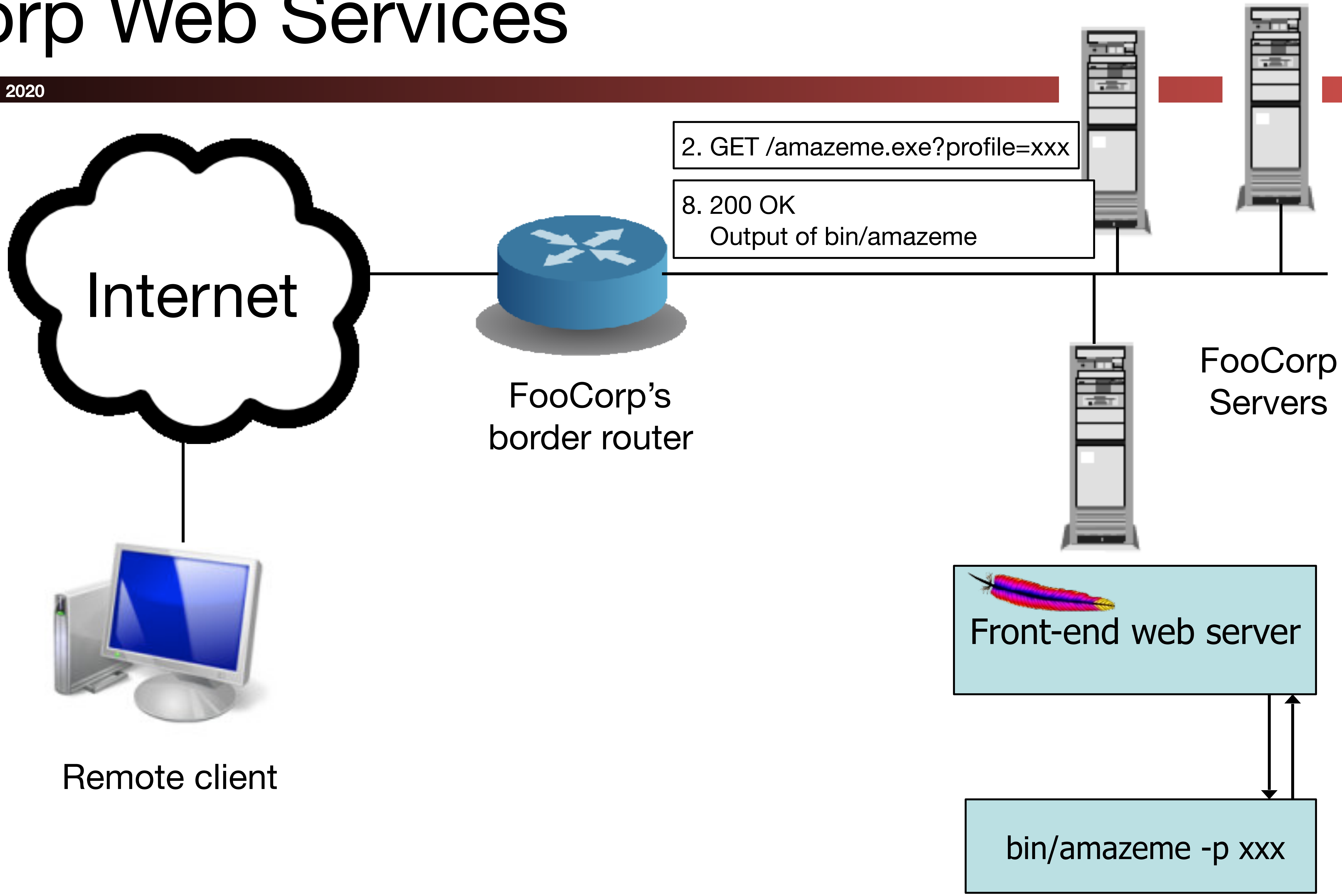
Detection

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

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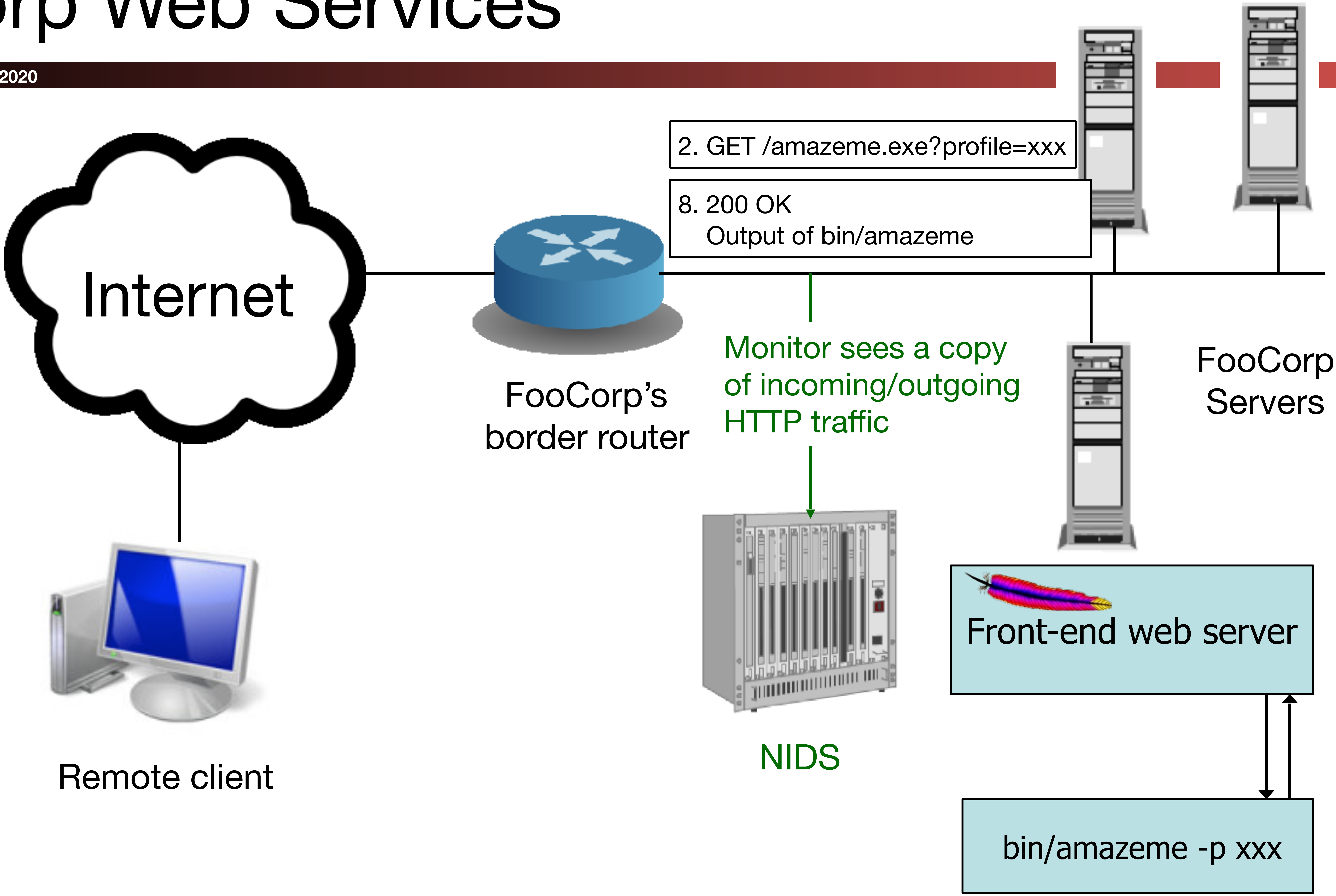

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  - (a “NIDS”: rhymes with “kids”)
  - Scan HTTP requests
  - Look for “`/etc/passwd`” and/or “`../../`”
- Pros:
  - No need to touch or trust end systems
    - Can “bolt on” security
  - Cheap: cover many systems w/ single monitor
  - Cheap: centralized management

Inside the NIDS

`GET HTTP /fubar/ 1.1..`

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

`GET HTTP /baz/?id=1f413 1.1...`

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

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

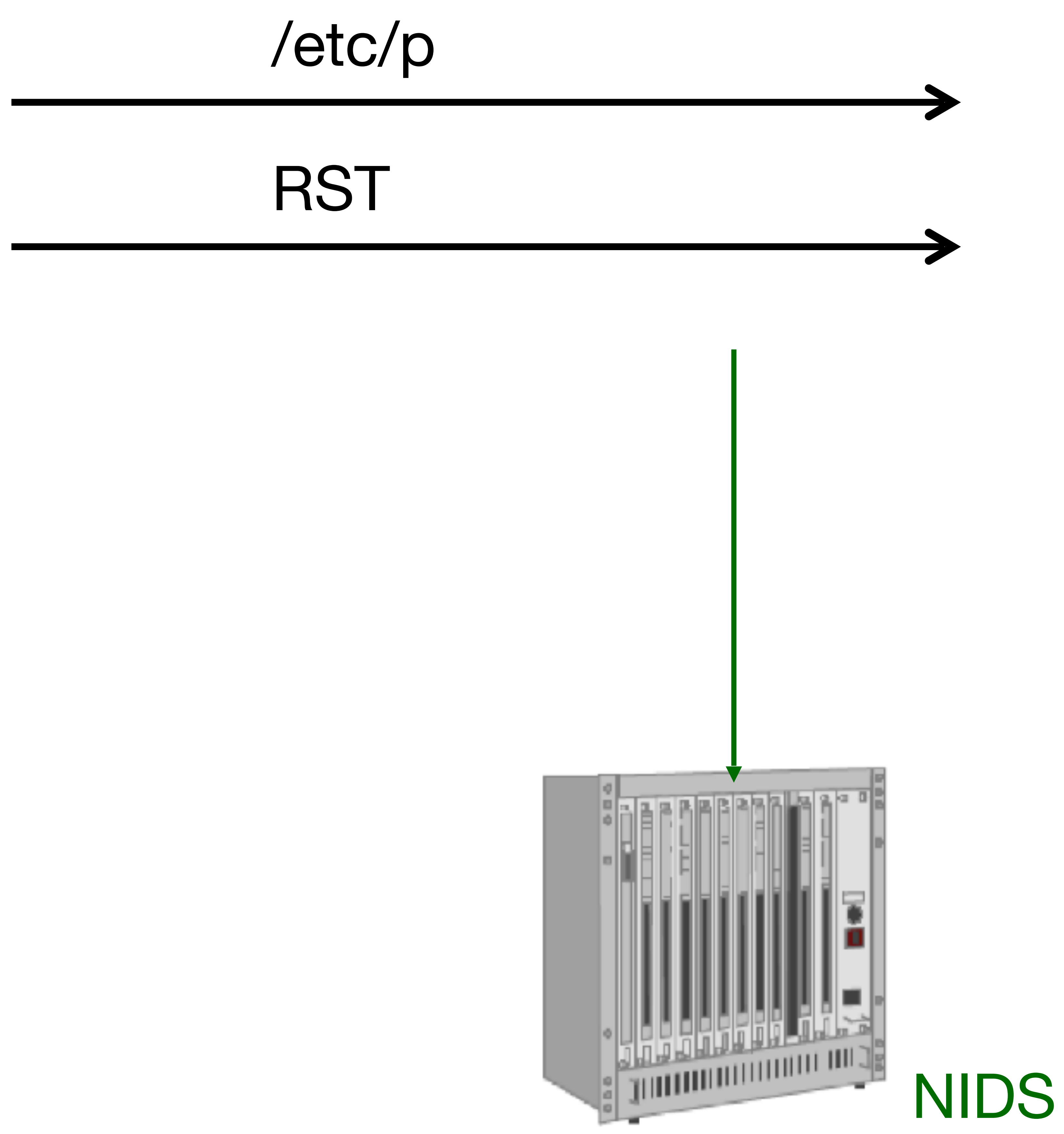
Sendmail
From = someguy@...
To = otherguy@...

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
- New hotness: Network monitoring
  - Goal is not to detect attacks but just to understand everything.

Evasion

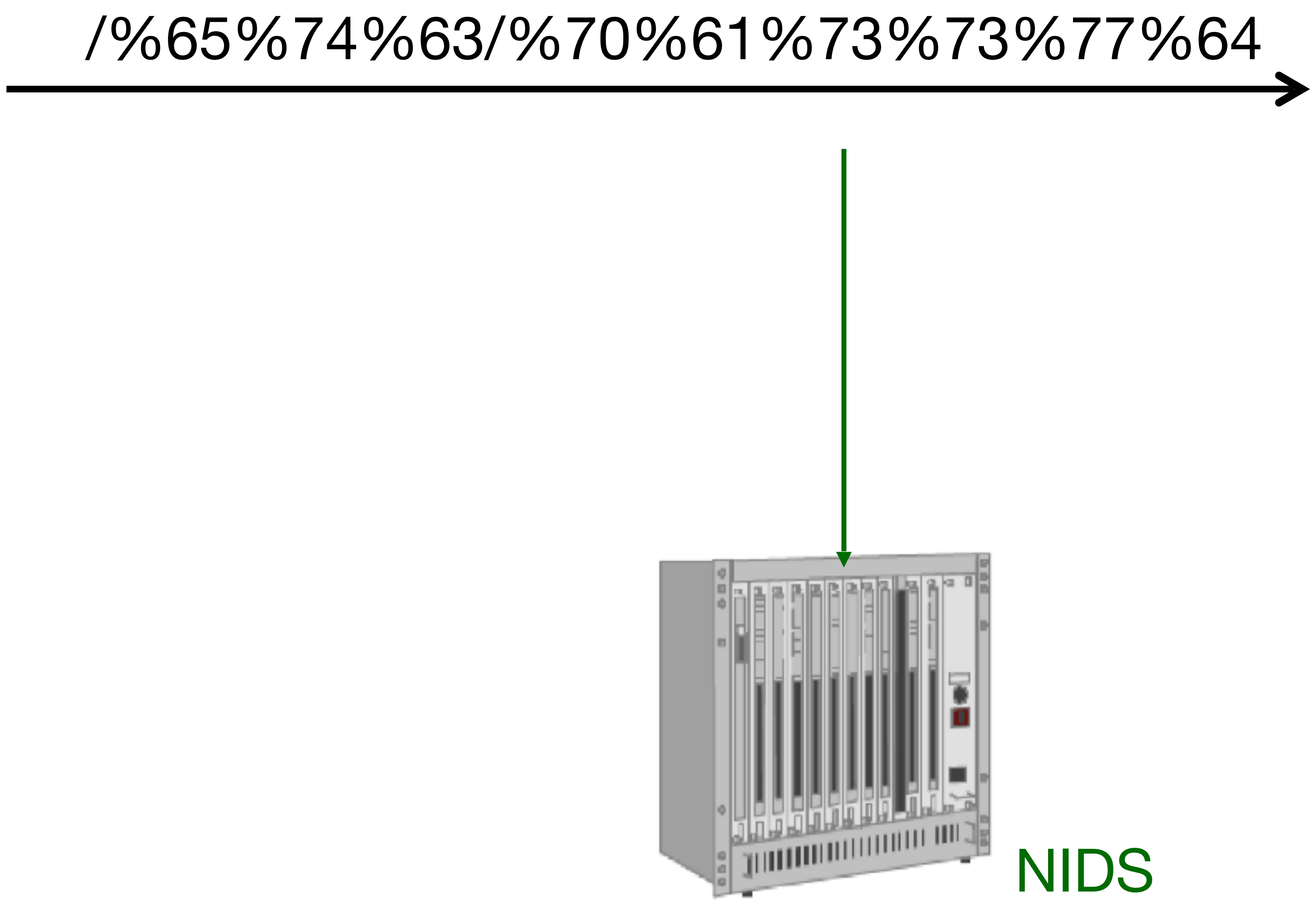
- What should NIDS do if it sees a RST packet?



- 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
  - E.g., 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 “`../../`”

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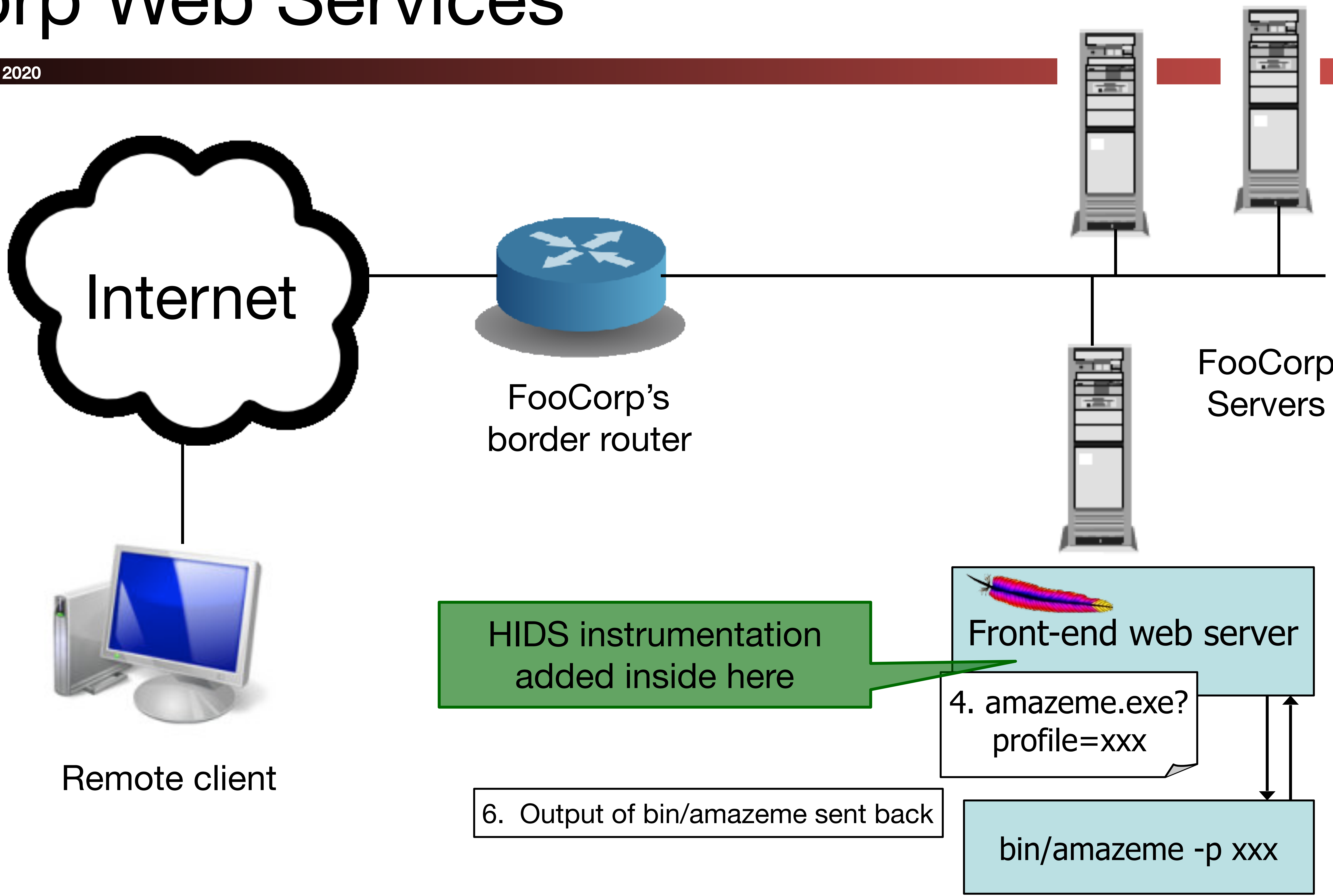

Host-based Intrusion Detection

- 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

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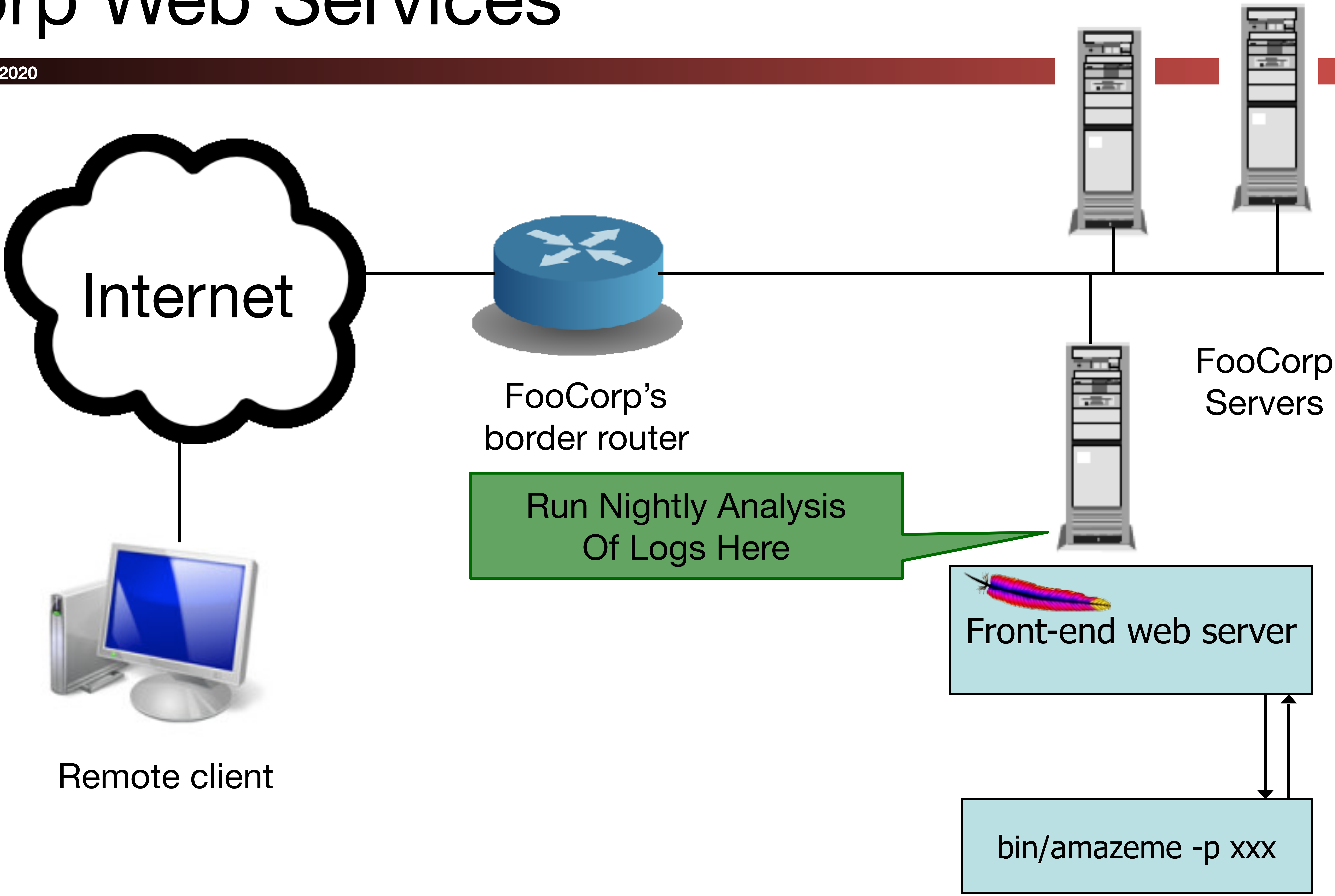

Log Analysis:
Aka "Log It All and let Splunk Sort It Out"

- 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`**

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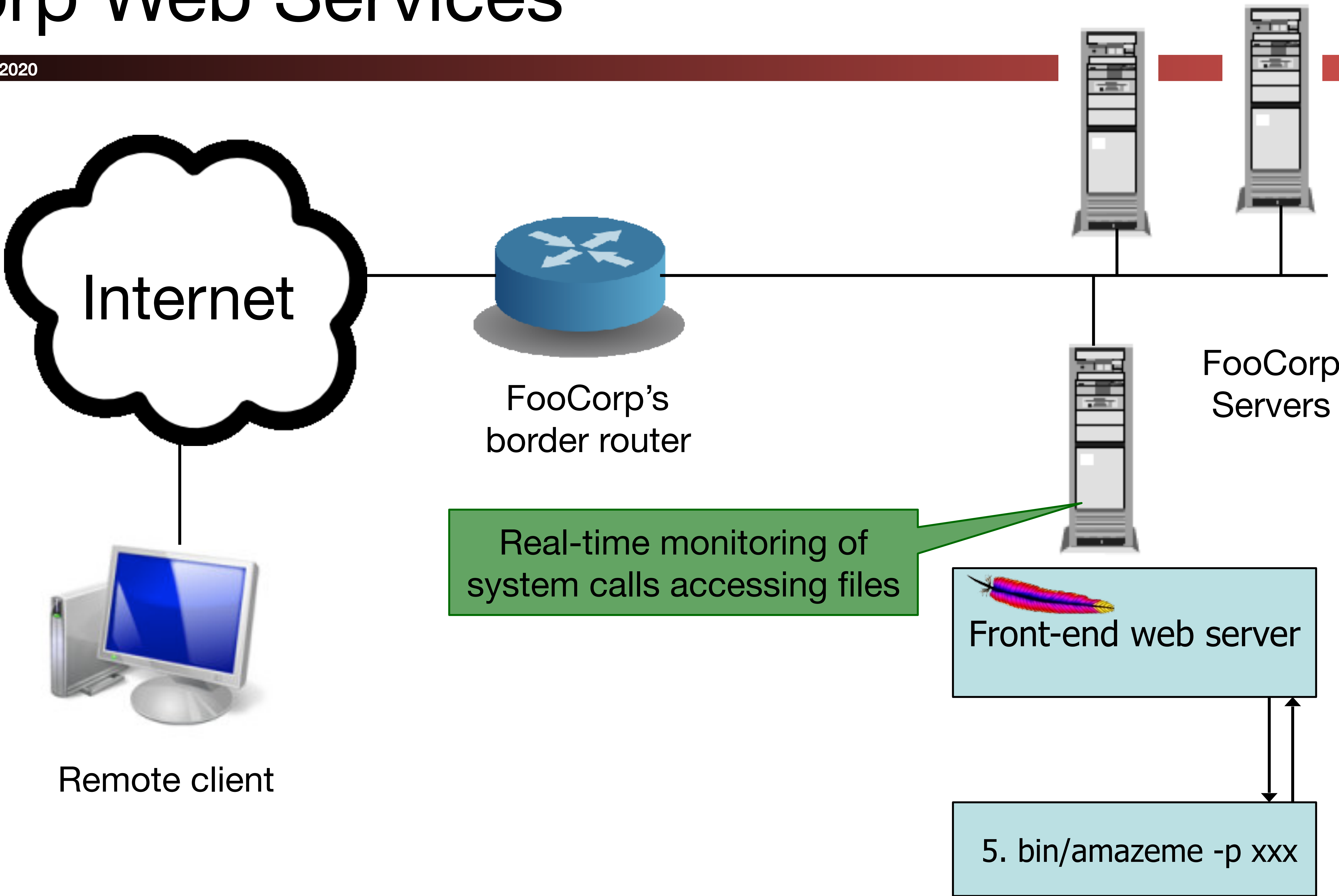

System Call Monitoring (HIDS)

- 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
- This is why new recommendations have fewer mammograms and PSA tests…

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 attempts 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 ("Antivirus")

- 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