Detecting Attacks, Part 2

CS 161: Computer Security

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Goals For Today

- General approaches (“styles”) to detecting attacks
- The fundamental problem of evasion
- Analyzing successful attacks: forensics
- (Operation of a modern HIDS/NIDS)

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, con't

- 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)

Vulnerability Signatures, con't

- What's nice about this approach?
  - Conceptually fairly simple
  - Takes care of known attacks
  - Easy to share signatures, build up libraries
  - Can detect variants of known attacks
  - Much more concise than per-attack signatures

Benefits of attack signatures

- What's problematic?
  - Can't detect novel attacks (new vulnerabilities)
  - Signatures can be hard to write / express
    - Can't just observe an attack that works …
    - … need to delve into how it works

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, con't

- What's problematic about this approach?
  - 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)

Hard to make work well - not widely used today

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, con't

- 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

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, con’t

- 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

5 Minute Break

Questions Before We Proceed?

The Problem of Evasion

- For any detection approach, we need to consider how an adversary might (try to) elude it
  - *Note: even if the approach is evadable, it can still be useful to operate in practice*
  - **But**: if it’s very easy to evade, that’s especially worrisome (security by obscurity)
- 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)

The Problem of Evasion, con't

- Some evasions exploit *deviation from the spec*
  - E.g., double-escapes for SQL injection:

    %25%32%37 ⇒ %27 ⇒ '
- Some can exploit more fundamental ambiguities:
  - Problem grows as monitoring viewpoint increasingly removed from ultimate endpoints
    - Lack of end-to-end visibility
- Particularly acute for network monitoring
- Consider detecting occurrences of the (arbitrary) string "**`root`**" inside a network connection …
  - We get a copy of each packet
  - How hard can it be?

Detecting “`root`”: Attempt #1

- Method: scan each packet for ‘r’, ‘o’, ‘o’, ‘t’
  - Perhaps using Boyer-Moore, Aho-Corasick, Bloom filters …

Packet

1 **............root........................**

Are we done?

Oops: TCP *doesn’t preserve text boundaries*

1 **............ro**

2 **ot........................**

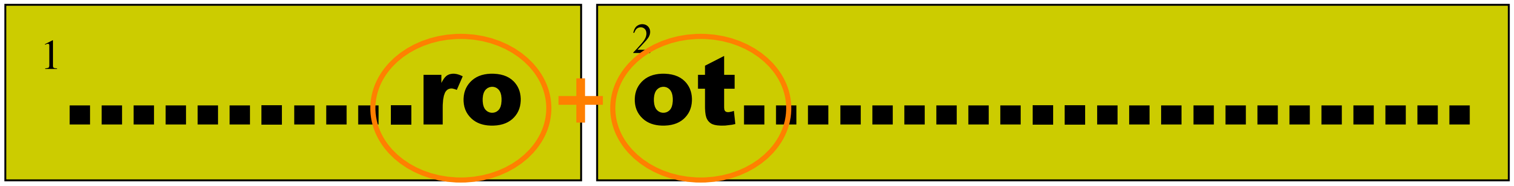
Packet #1

Packet #2

Fix?

Detecting “`root`”: Attempt #2

- Okay: remember match from end of previous packet



Packet #1

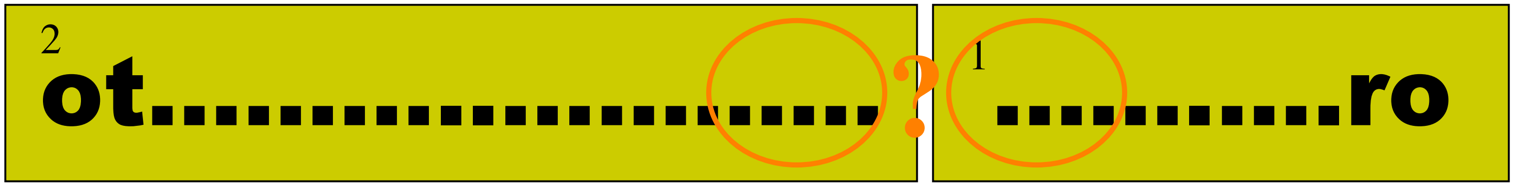
Packet #2

When 2nd packet arrives, continue working on the match

- Now we’re managing state :-(

Are we done?

Oops: IP doesn’t guarantee in-order arrival



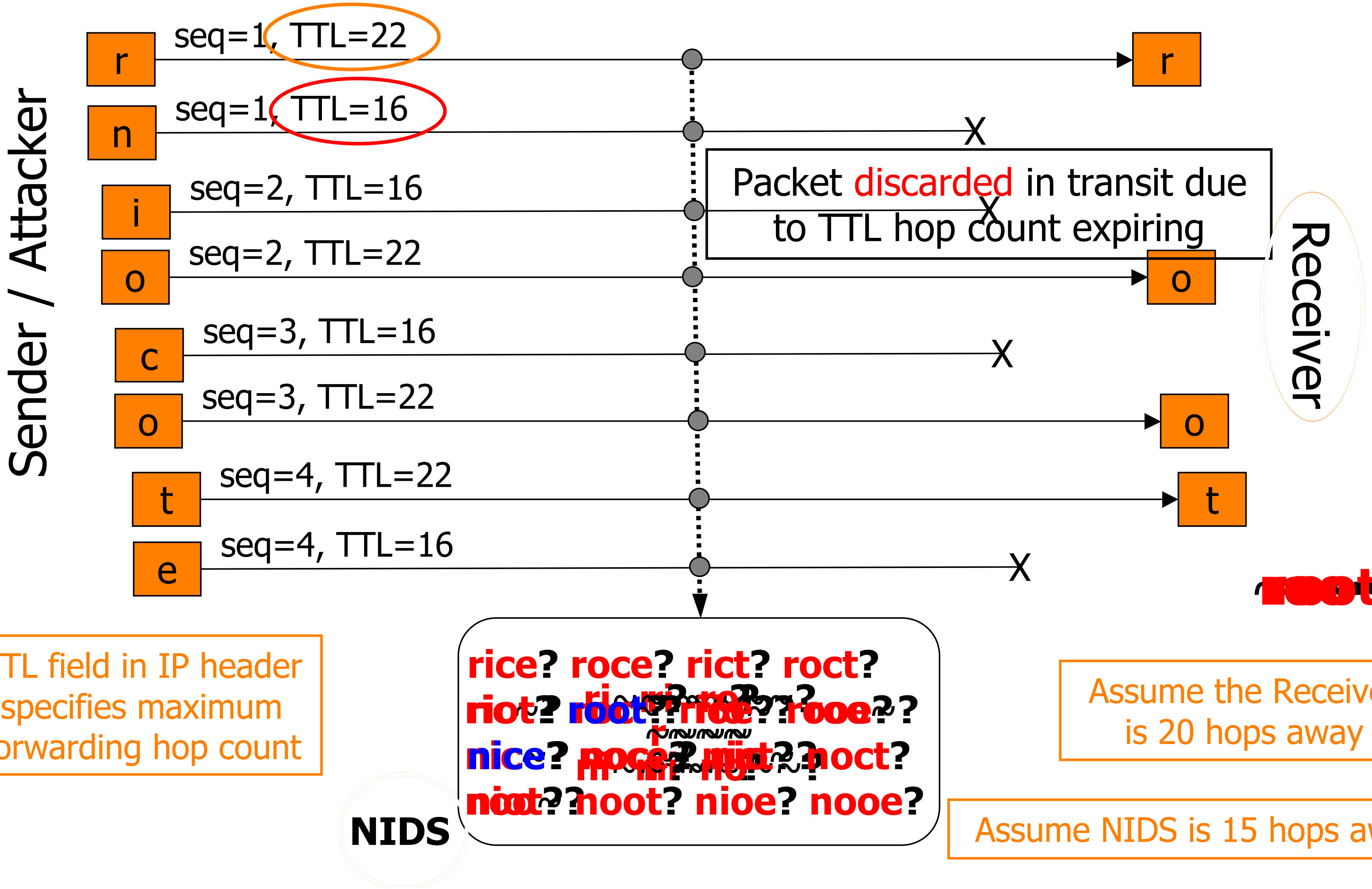
Detecting "`root`": Attempt #3

- Fix?

- We need to reassemble the entire TCP bytestream
  - Match sequence numbers
  - Buffer packets with later data (above a sequence "hole")
- Issues?
  - Potentially requires a lot of state
  - Plus: attacker can cause us to exhaust state by sending lots of data above a sequence hole

- But at least we're done, right?

Full TCP Reassembly is Not Enough



Packet discarded in transit due to TTL hop count expiring

TTL field in IP header specifies maximum forwarding hop count

Assume the Receiver is 20 hops away

Assume NIDS is 15 hops away

Inconsistent TCP Retransmissions

- Fix?
- Idea: NIDS can alert upon seeing a retransmission inconsistency, as surely it reflects someone up to no good
- This doesn't work well in practice: TCP retransmissions broken in this fashion occur in live traffic
  - Fairly rare (23 times in yesterday's ICSI traffic)
  - But real evasions much rarer still (Base Rate Fallacy)
  - ⇒ This is a *general problem* with alerting on such ambiguities
- Idea: if NIDS sees such a connection, kill it
  - Works for this case, since benign instance is already fatally broken
  - But for other evasions, such actions have collateral damage
- Idea: rewrite traffic to remove ambiguities
  - Works for network- & transport-layer ambiguities
  - But must operate in-line and at line speed

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: fix the basic observation problem
  - E.g., monitor directly at end systems

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 …

Security Advisories

The following Wireshark releases fix serious security vulnerabilities. If you are running a vulnerable version of Wireshark you should consider upgrading.

wnpa-sec-2013-09: NTLMSSP dissector overflow, fixed in 1.8.5, 1.6.13
wnpa-sec-2013-08: Wireshark dissection engine crash, fixed in 1.8.5, 1.6.13
wnpa-sec-2013-07: DCP-ETSI dissector crash, fixed in 1.8.5, 1.6.13
wnpa-sec-2013-06: ROHC dissector crash, fixed in 1.8.5
wnpa-sec-2013-05: DTLS dissector crash, fixed in 1.8.5, 1.6.13
wnpa-sec-2013-04: MS-MMC dissector crash, fixed in 1.8.5, 1.6.13
wnpa-sec-2013-03: DTN dissector crash, fixed in 1.8.5, 1.6.13
wnpa-sec-2013-02: CLNP dissector crash, fixed in 1.8.5, 1.6.13

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")
- Consider these actual emails from operational security …

Emails omitted from on-line notes

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, con’t

- *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