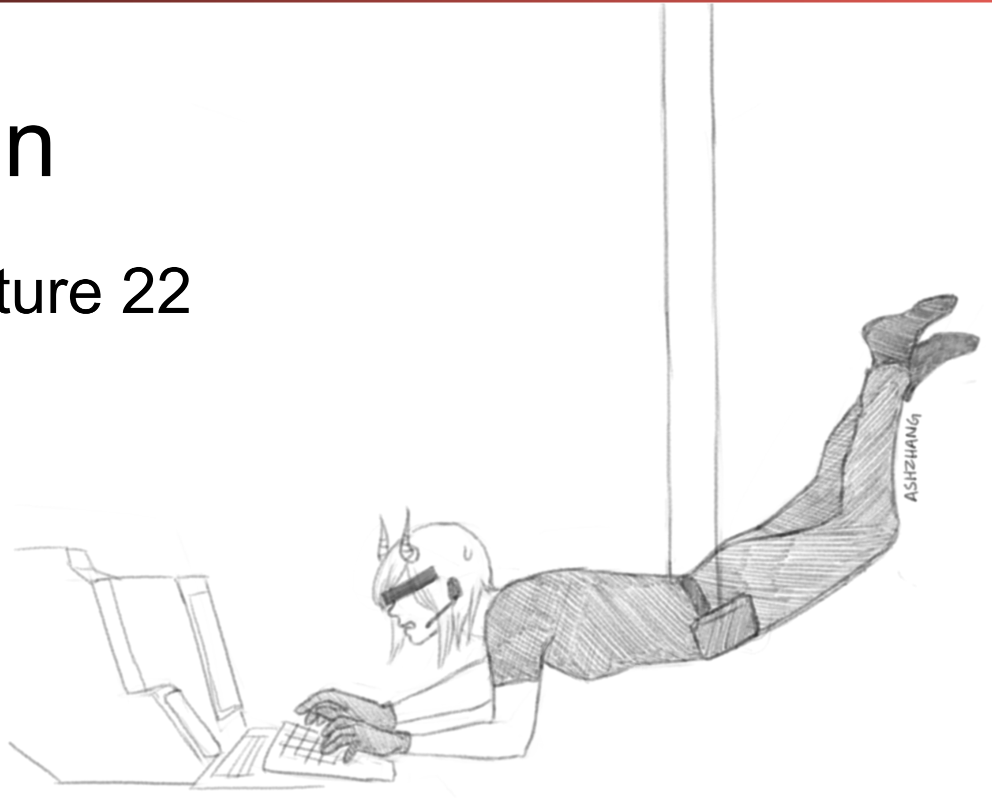
# Intrusion Detection

## CS 161 Spring 2024 - Lecture 22



# Last Time: Denial of Service



- **Availability**: Making sure users are able to use a service
  - DoS attacks availability of services
- **Application-level DoS**: Attacks the high-level applications
  - Algorithmic complexity attacks: Attack using inputs that cause the worst-case runtime of an algorithm
  - Defense: Identification, isolation, and quotas
  - Defense: Proof of work
- **Network-level DoS**: Attacks the network of a service
  - Typically floods either the network bandwidth or the packet processing capacity
  - Distributed DoS: Use multiple computers to flood a network at the same time
  - Amplified DoS: Use an amplifier to turn a small input into a large output, spoofing packets so the reply goes to the victim
  - Defense: Packet filtering
- All DoS attacks can be defended against by overprovisioning

# Last Time: SYN Cookies



- **SYN flooding**: A type of DoS that causes a server to allocate state for unfinished TCP connections, upon receiving a SYN packet
  - **SYN cookies**: Instead of allocating state when receiving a SYN, send the state back to the client in the sequence number
  - The client returns the state back to the server, which it only then allocates state for

# Last Time: Firewalls



- **Firewalls**: Defend many devices by defending the network
  - **Security policies** dictate how traffic on the network is handled
- **Packet filters**: Choose to either forward or drop packets
  - **Stateless packet filters**: Choose depending on the packet only
  - **Stateful packet filters**: Choose depending on the packet and the history of the connection
  - Attackers can subvert packet filters by splitting key payloads or exploiting the TTL
- **Proxy firewalls**: Create a connection with both sides instead of forwarding packets

# Today: Intrusion Detection



- Path traversal attacks
- Types of detectors
  - Network intrusion detection system (NIDS)
  - Host-based intrusion detection system (HIDS)
- Detection accuracy
  - False positives and false negatives
  - Base rate fallacy
  - Combining detectors
- Styles of detection
  - Signature-based detection
  - Specification-based detection
  - Anomaly-based detection
  - Behavioral detection
- Other intrusion detection strategies
  - Vulnerability scanning
  - Honeypots
  - Forensics
  - Intrusion prevention systems

# Today: Intrusion Detection



- We’ve talked about many ways to prevent attacks
- However, some not all methods are perfect: attacks will slip through our defenses
- Recall: “Detect if you can’t prevent”
- How can we detect network attacks when they happen?

# Path Traversal Attacks

# Top 25 Most Dangerous Software Weaknesses (2020)



| Rank | ID | Name | Score |
| --- | --- | --- | --- |
| [1] | CWE-79 | Improper Neutralization of Input During Web Page Generation ('Cross-site Scripting') | 46.82 |
| [2] | CWE-787 | Out-of-bounds Write | 46.17 |
| [3] | CWE-20 | Improper Input Validation | 33.47 |
| [4] | CWE-125 | Out-of-bounds Read | 26.50 |
| [5] | CWE-119 | Improper Restriction of Operations within the Bounds of a Memory Buffer | 23.73 |
| [6] | CWE-89 | Improper Neutralization of Special Elements used in an SQL Command ('SQL Injection') | 20.69 |
| [7] | CWE-200 | Exposure of Sensitive Information to an Unauthorized Actor | 19.16 |
| [8] | CWE-416 | Use After Free | 18.87 |
| [9] | CWE-352 | Cross-Site Request Forgery (CSRF) | 17.29 |
| [10] | CWE-78 | Improper Neutralization of Special Elements used in an OS Command ('OS Command Injection') | 16.44 |
| [11] | CWE-190 | Integer Overflow or Wraparound | 15.81 |
| [12] | CWE-22 | Improper Limitation of a Pathname to a Restricted Directory ('Path Traversal') | 13.67 |
| [13] | CWE-476 | NULL Pointer Dereference | 8.35 |
| [14] | CWE-287 | Improper Authentication | 8.17 |
| [15] | CWE-434 | Unrestricted Upload of File with Dangerous Type | 7.38 |
| [16] | CWE-732 | Incorrect Permission Assignment for Critical Resource | 6.95 |
| [17] | CWE-94 | Improper Control of Generation of Code ('Code Injection') | 6.53 |

# Unix File Paths

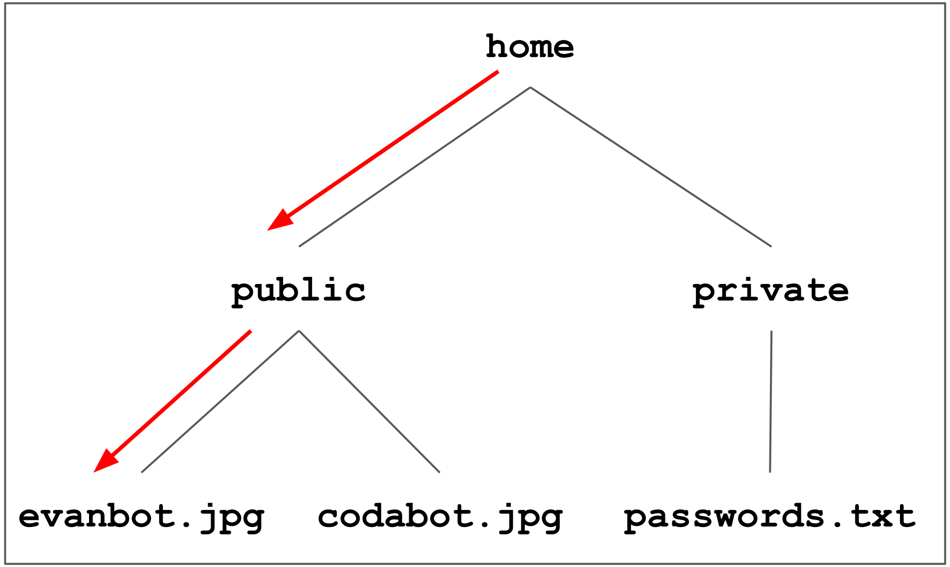


- A file path points to a file or a directory (folder) on a Unix system
- File paths have special characters
  - `/` (slash): Separates directories
  - `.` (one period): Shorthand for the current directory
  - `..` (two periods): Shorthand for the parent directory

# Unix File Paths



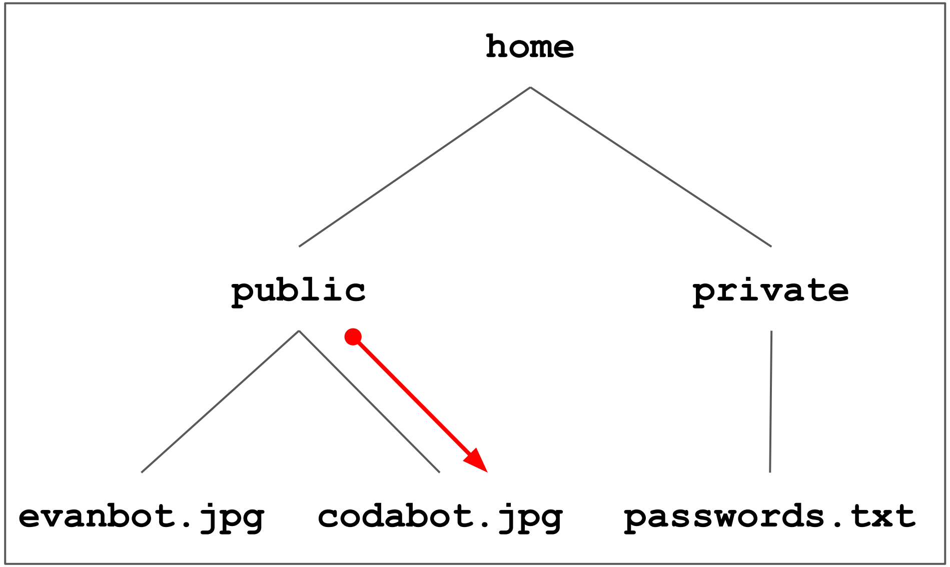
**`/home/public/evanbot.jpg`**



# Unix File Paths



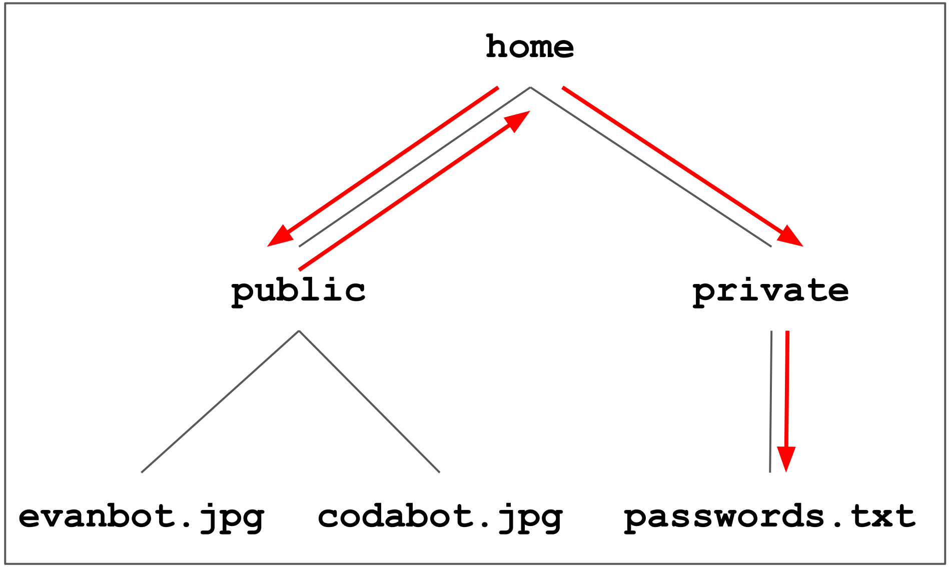
**./codabot.jpg** (Assume we're currently in **public**)



# Unix File Paths

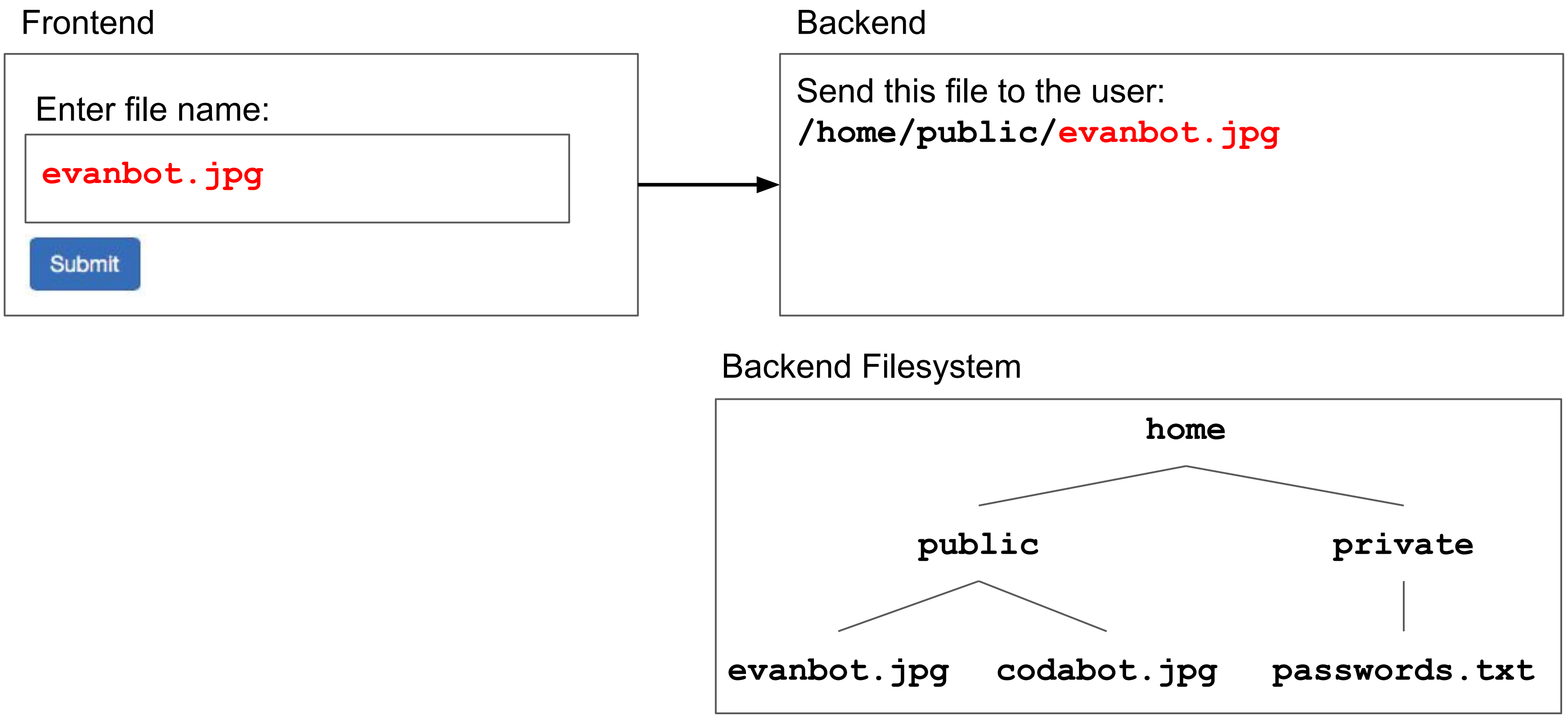


`/home/public/../private/passwords.txt`



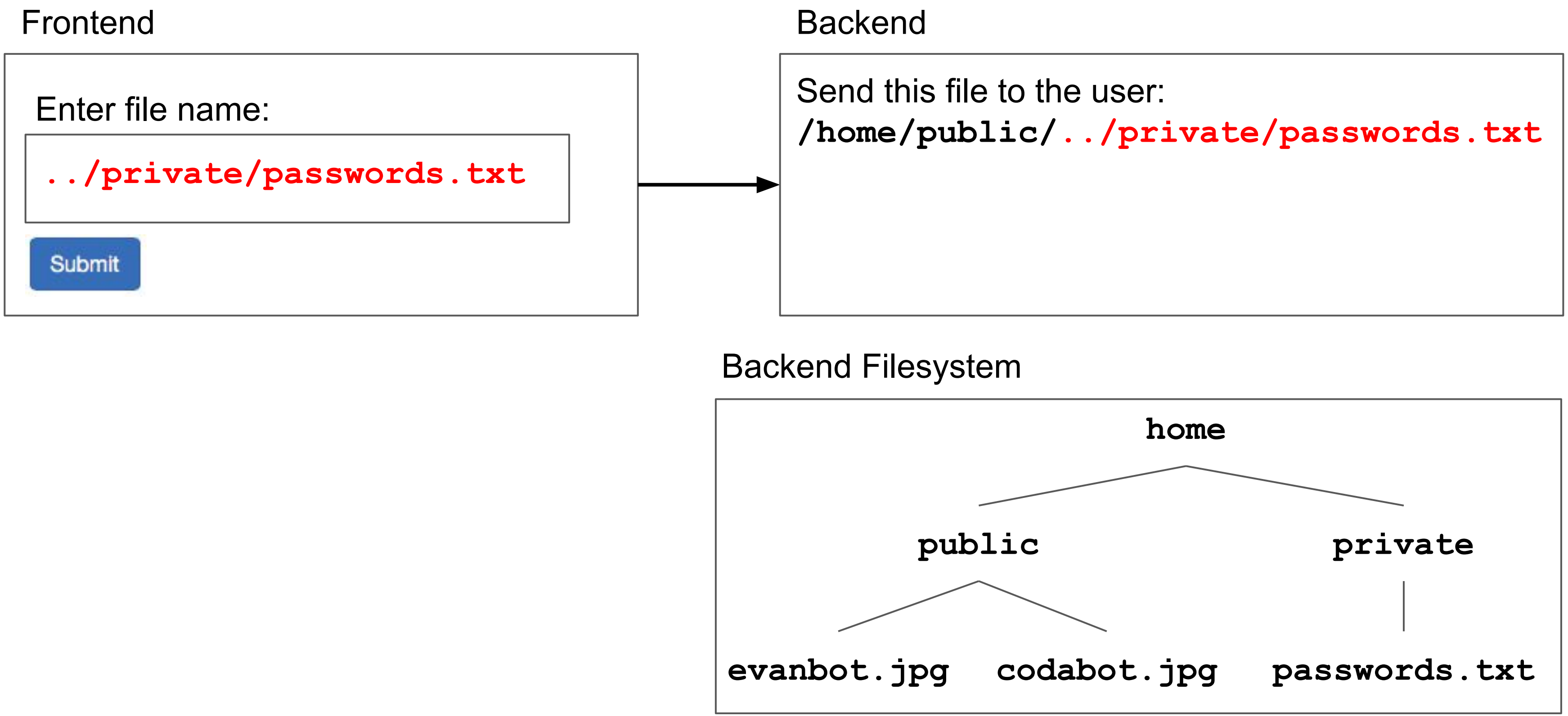
# Path Traversal Intuition





# Path Traversal Intuition





# Path Traversal Attacks



- **Path traversal attack**: Accessing unauthorized files on a remote server by exploiting Unix file path semantics
  - Often makes use of `../` to enter other directories
  - Vulnerability: User input is interpreted as a file path by the Unix file system
- Defense: Check that user input is not interpreted as a file path

# Types of Detectors

# Types of Detectors

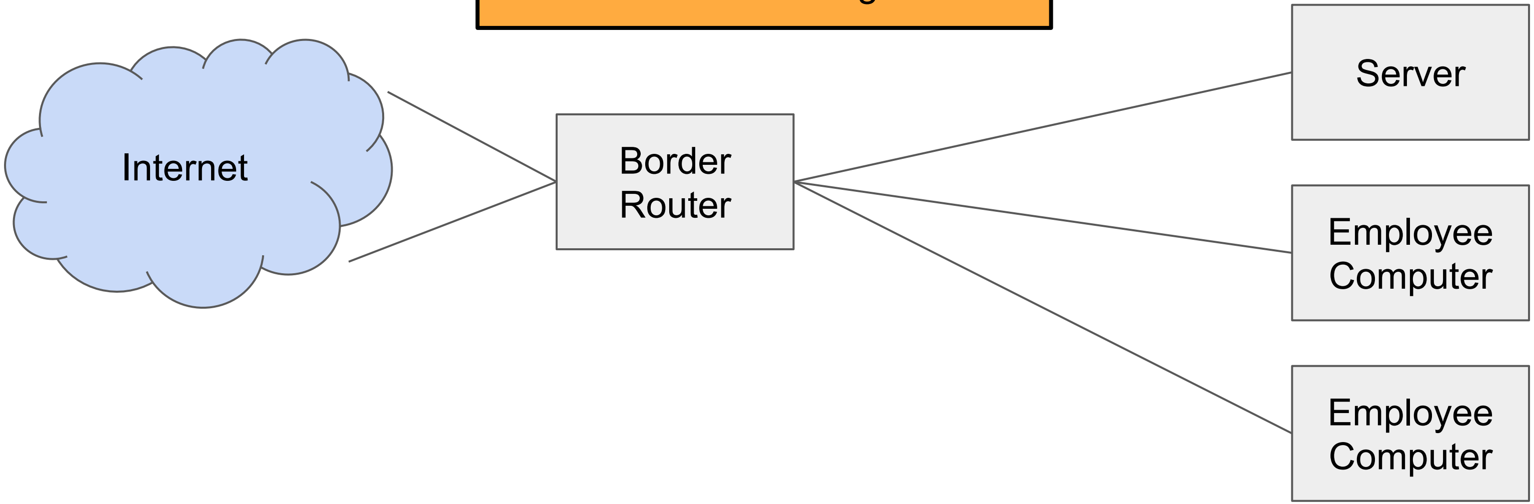


- Three types of detectors
  - Network Intrusion Detection System (NIDS)
  - Host-based Instruction Detection System (HIDS)
  - Logging
- The main difference is where the detector is deployed

# Structure of a Network



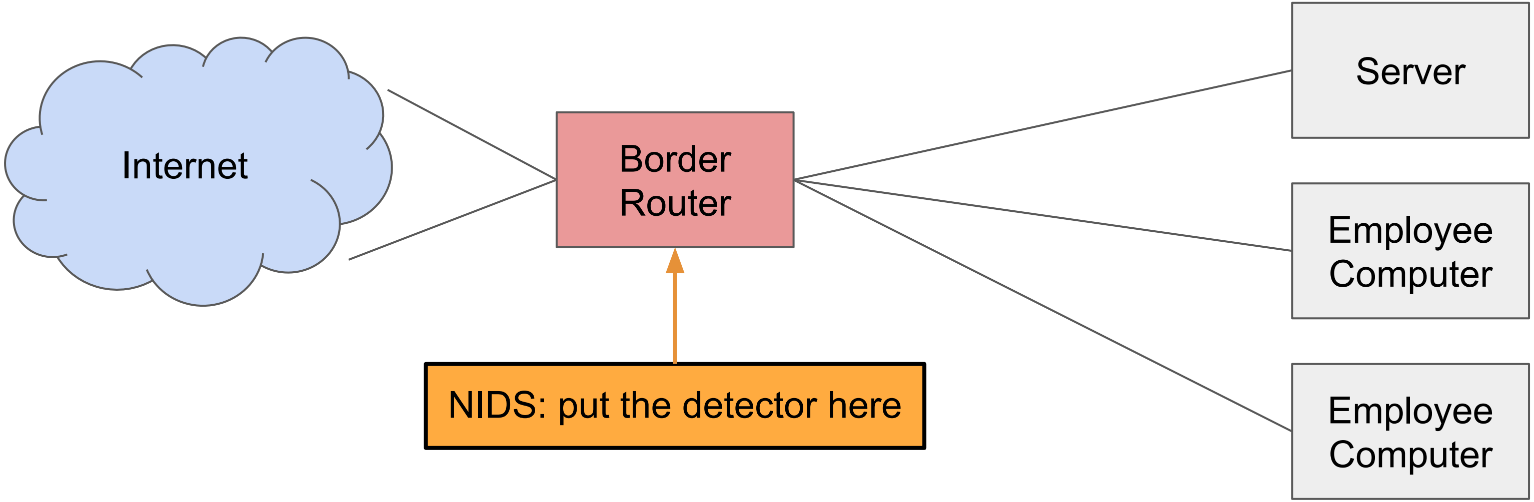
End hosts in the local network send packets to the Internet by sending it to the border router for forwarding



# Network Intrusion Detection System (NIDS)



- **Network intrusion detection system** (**NIDS**): A detector installed on the network, between the local network and the rest of the Internet
  - Monitors network traffic to detect attacks



# Network Intrusion Detection System (NIDS)



- Operation:
    - NIDS has a table of all active connections and maintains state for each connection
    - If the NIDS sees a packet not associated with any known connection, create a new entry in the table
        - Example: A connection that started before the NIDS started running
    - NIDS can be used for more sophisticated network monitoring: not only detect attacks, but analyze and understand all the network traffic

# NIDS: Benefits



- Cheap: A single detector can cover a lot of systems
- Easy to scale: As the network gets larger, add computing power to the NIDS
  - Linear scaling: Investing twice as much money gives twice as much bandwidth
- Simple management: Easy to install and manage a single detector
- End systems are unaffected
  - Doesn’t consume any resources on end systems
  - Useful for adding security on an existing system
- Smaller trusted computing base (TCB)
  - Only the detector needs to be trusted

# NIDS: Drawbacks

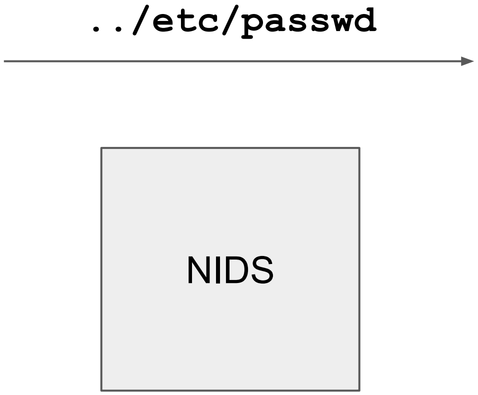


- Inconsistent or ambiguous interpretation between the detector and the end host
- How does the NIDS monitor encrypted traffic?

# Drawback: Inconsistent Interpretation



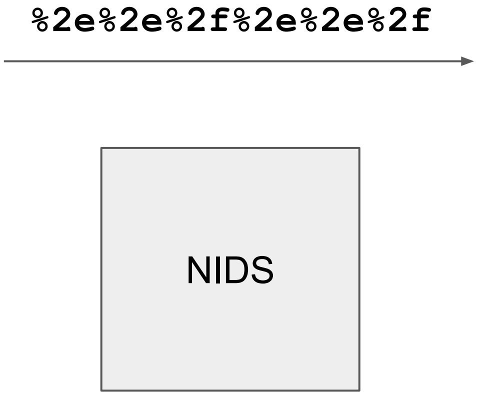
- What should the NIDS do if it sees this packet?
- This looks like a path traversal attack… Maybe it should alert
- What if the packet's TTL expires before it reaches any end host?
- Problem: What the NIDS sees doesn't exactly match what arrives at the end system



# Drawback: Inconsistent Interpretation



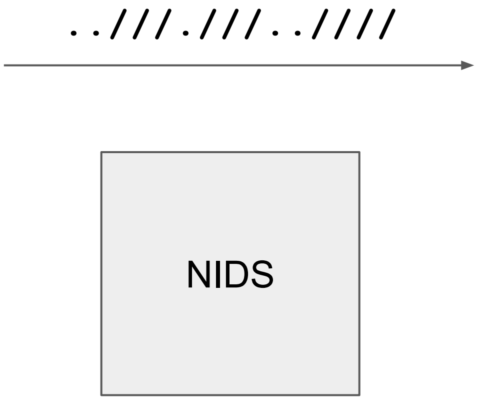
- What should the NIDS do if it sees this packet?
- This doesn't look like a path traversal attack...maybe it shouldn't alert
- This input is using URL percent encoding. If you decode it, you get **`../etc/passwd`**!
- Problem: Inputs are interpreted differently between the NIDS and the end system



# Drawback: Inconsistent Interpretation



- What should the NIDS do if it sees this packet?
- What file on the file system does this file path refer to? It’s hard for the NIDS to know
- Problem: Information needed to interpret correctly is missing



# Evasion Attacks



- Problem: Imperfect observability
  - What the NIDS sees doesn't match what the end system sees
  - Example: The packet's time-to-live (TTL) might expire before reaching the end host
- Problem: Incomplete analysis (double parsing)
  - Inconsistency: Inputs are interpreted and parsed differently between the NIDS and the end system
  - Ambiguity: Information needed to interpret correctly is missing
- **Evasion attack**: Exploit inconsistency and ambiguity to provide malicious inputs that are not detected by the NIDS

# Evasion Attacks: Defenses



- Make sure that the NIDS and the end host are using the same interpretations
  - This can be very challenging
  - How do we detect the URL-encoded attack **`%2e%2e%2f%2e%2e%2f`**?
    Now the NIDS has to parse URL encodings!
  - How do we detect a more complicated path traversal attack `..///.///..////`?
    Now the NIDS has to parse Unix file paths!
- Impose a canonical ("normalized") form for all inputs
  - Example: Force all URLs to expand all URL encodings or not expand all URL encodings
- Analyze all possible interpretations instead of assuming one
- Flag potential evasions so they can be investigated further

# Drawback: Encrypted Traffic

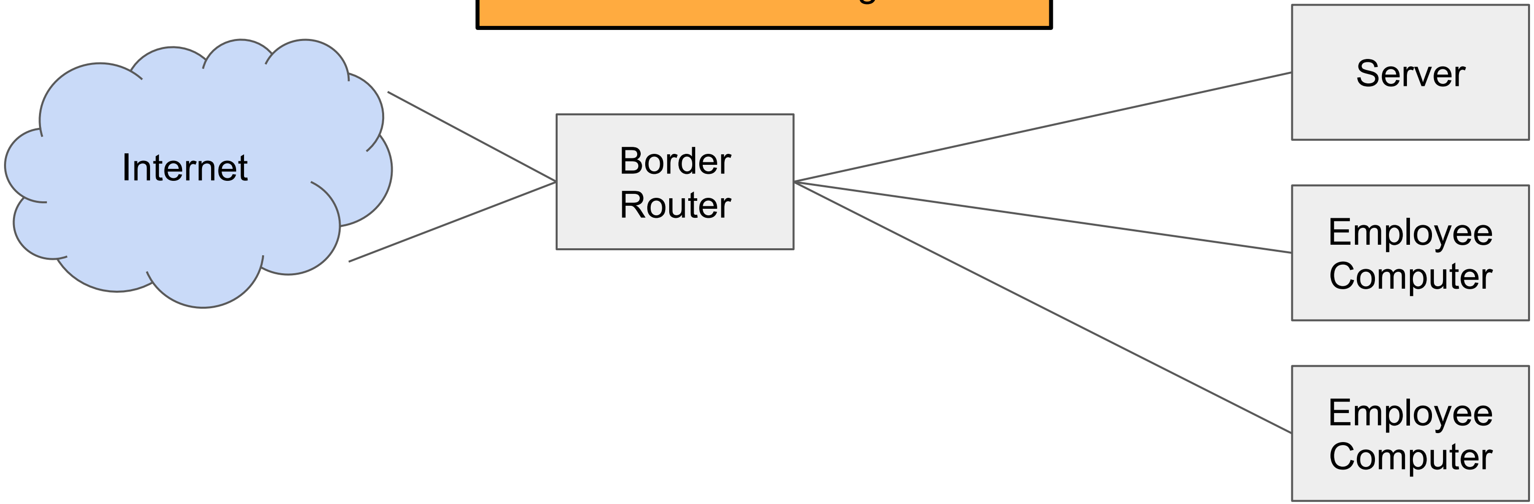


- Recall: TLS is end-to-end secure, so a NIDS can’t read any encrypted traffic
- One possible solution: Give the NIDS access to all the network’s private keys
    - Now the NIDS can decrypt messages to inspect them for attacks
    - Problem: Users have to share their private key with someone else

# Recall: Structure of a Network



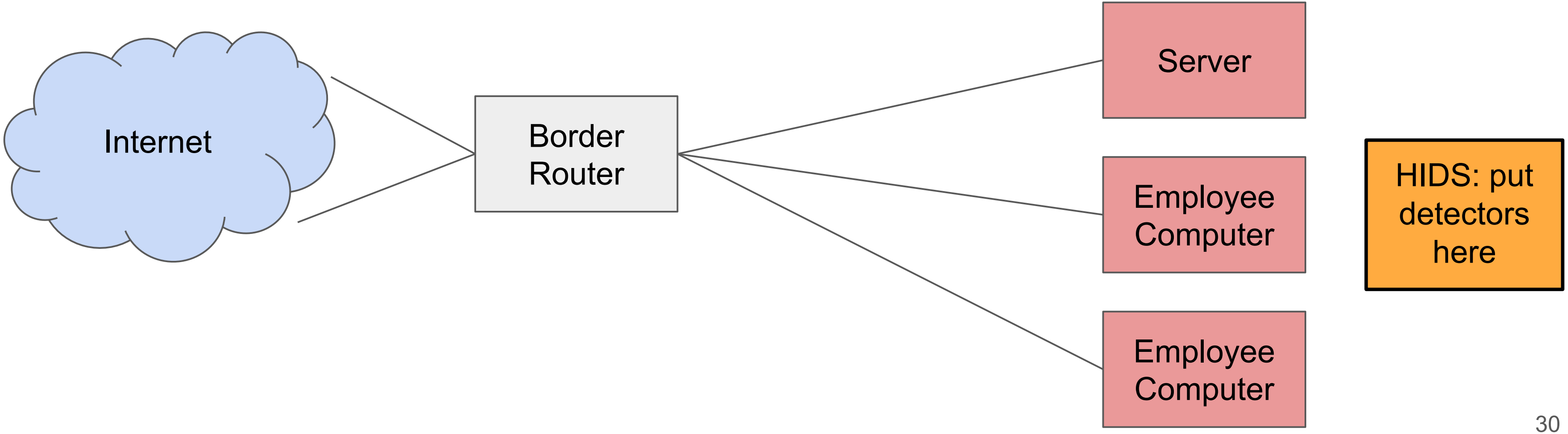
End hosts in the local network send packets to the Internet by sending it to the border router for forwarding



# Host-Based Intrusion Detection System (HIDS)



- **Host-based intrusion detection system (HIDS)**: A detector installed on each end system



# Host-Based Intrusion Detection System (HIDS)



- Benefits
  - Fewer problems with inconsistencies or ambiguities: The HIDS is on the end host, so it will interpret packets exactly the same as the end host!
  - Works for encrypted messages
  - Can protect against non-network threats too (e.g. malicious user inside the network)
  - Performance scales better than NIDS: one NIDS is more vulnerable to being overwhelmed than many HIDS
- Drawbacks
  - Expensive: Need to install one detector for every end host
  - Evasion attacks are still possible (consider Unix file name parsing)

# Logging



- **Logging**: Analyze log files generated by end systems
  - Example: Each night, run a script on the log files to analyze them for attacks
- Benefits
  - Cheap: Modern web servers often already have built-in logging systems
  - Fewer problems with inconsistencies or ambiguities: The logging system works on the end host, so it will interpret packets exactly the same as the end host!
- Drawbacks
  - Unlike NIDS and HIDS, there is no real-time detection: attacks are only detected **after the attack has happened**
  - Some evasion attacks are still possible (again, consider Unix file name parsing)
  - The attacker could change the logs to erase evidence of the attack

# Detection Accuracy

# Detection Errors



- Two main types of detector errors
  - **False positive**: Detector alerts when there is no attack
  - **False negative**: Detector fails to alert when there is an attack
- Detector accuracy is often assessed in terms of the rates at which these errors occur
  - **False positive rate** (**FPR**): The probability the detector alerts, given there is no attack
  - **False negative rate** (**FNR**): The probability the detector does not alert, given there is an attack

# Perfect Detectors



- Can we build a detector with a false positive rate of 0%? How about a detector with a false negative rate of 0%?
  - Recall false positive rate: The probability the detector alerts, given there is no attack
  - Recall false negative rate: The probability the detector does not alert, given there is an attack

```
void detector_with_no_false_positives(char *input) {
    printf("Nope, not an attack!");
}
```

```
void detector_with_no_false_negatives(char *input) {
    printf("Yep, it's an attack!");
}
```

# Detection Tradeoffs



- The art of a good detector is achieving an effective balance between false positives and false negatives
- The quality of the detector depends on the system you're using it on
    - What is the rate of attacks on your system?
    - How much does a false positive cost in your system?
    - How much does a false negative cost in your system?
- Example of cost analysis: Fire alarms
    - Which is better: a very low false positive rate or a very low false negative rate?
    - Cost of a false positive: The fire department needs to inspect the building
    - Cost of a false negative: The building burns down
    - In this situation, false negatives are much more expensive!
    - We want a detector with a low false negative rate

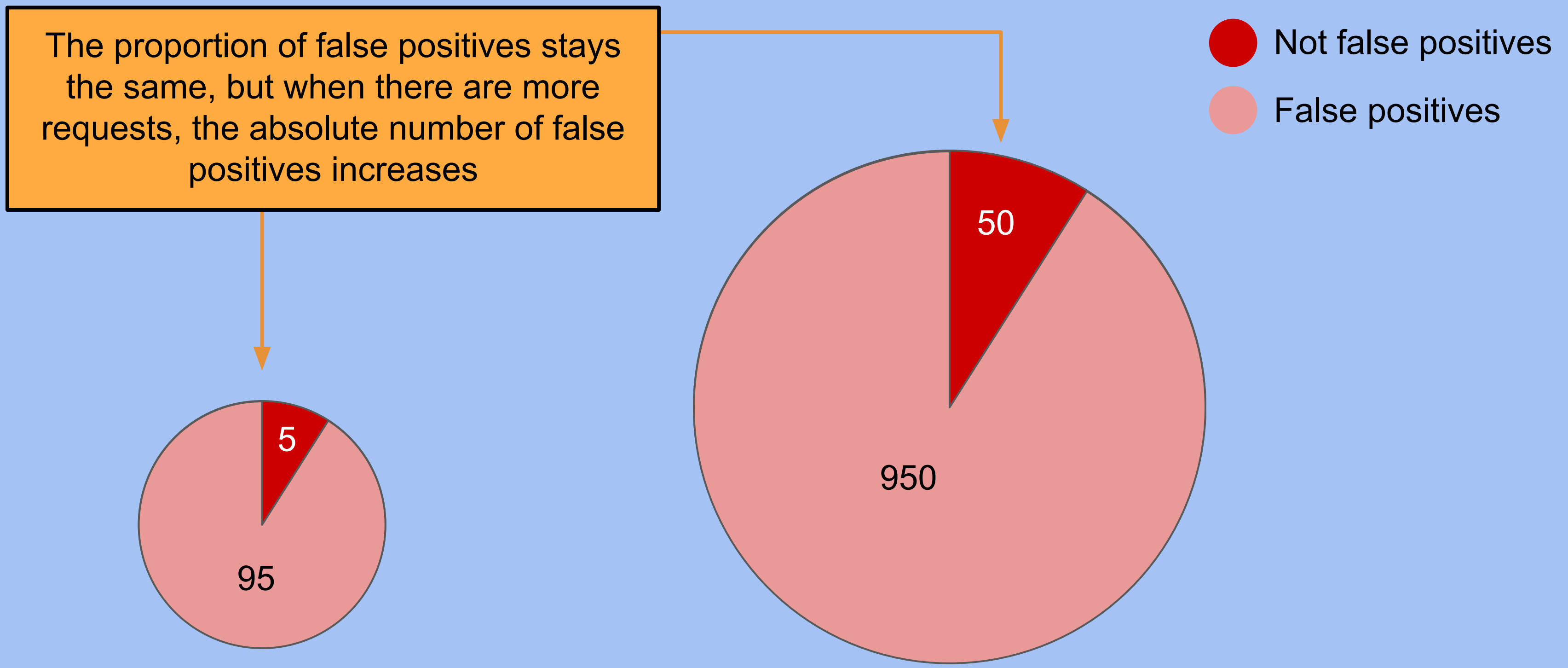
# Detection Tradeoffs



- Example of changing the base rate of attacks
  - Consider a detector with a 0.1% false positive rate (for every 1,000 non-attacks, there is one mistaken alert)
  - Scenario #1: Our server receives 1,000 non-attacks and 5 attacks per day
    - Expected number of false positives per day: 1,000 × 0.1% = 1
  - Scenario #2: Our server receives 10,000,000 non-attacks and 5 attacks per day
    - Expected number of false positives per day: 10,000,000 × 0.1% = 10,000
    - Possibly expensive if the false positives cost money to investigate
    - Example: Maybe a human has to manually examine 10,000 requests per day
  - Nothing changed about the detector: Only our environment changed
- **Takeaway**: Accurate detection is very challenging if the base rate of attacks is low!

# Detection Tradeoffs





# Base Rate Fallacy



- Consider the detector from before: 0.1% false positive rate
  - Assume a 0% false negative rate: Every attack is detected
  - Scenario from before: Our server receives 10,000,000 non-attacks and 5 attacks per day
  - Expected number of false positives per day: 10,000,000 × 0.1% = 10,000
- You see the detector alert. What is the probability this is really an attack?
  - Of the 10,005 detections, 5 are real attacks, and 10,000 are false positives
  - There is an approximately 0.05% probability that the detector found a real attack
- Base rate fallacy: Even though the detector alerted, it's still highly unlikely that you found an attack, because of the high false positive rate
- **Takeaway**: Detecting is hard when the base rate of attacks is low

# Combining Detectors



- Can you combine two independent detectors to create a better detector?
- Parallel composition
  - Alert if either detector alerts
  - Intuition: The combination generates more alerts
  - Reduces false negative rate
  - Increases false positive rate
- Series composition
  - Alert only if both detectors alert
  - Intuition: The combination generates fewer alerts
  - Reduces false positive rate
  - Increases false negative rate
- There is no free lunch: reducing one rate usually increases the other

# Styles of Detection

# Styles of Detection



- So far we've talked about types of detectors: *what* the detector is scanning
- Now we'll talk about styles of detection: *how* the detector scans data to find attacks
- Four main styles of detection
  - Signature-based detection
  - Specification-based detection
  - Anomaly-based detection
  - Behavioral detection

# Signature-based Detection



- **Signature-based detection**: Flag any activity that matches the structure of a known attack
- Signature-based detection is **blacklisting**: Keep a list of patterns that are not allowed, and alert if we see something on the list
- Signatures can be at different network layers
  - Example: TCP/IP header fields
  - Example: URLs
  - Example: Payload of the HTTP request

# Signature-based Detection: Examples



- Example: Path traversal attacks
  - We know that `../` is often part of a path traversal attack
  - Strategy: Alert if any request contains `../`
- Example: Buffer overflows
  - We know that buffer overflows usually contain shellcode
  - Strategy: Keep a list of common shellcodes and alert if any request contains shellcode

# Signature-based Detection: Tradeoffs



- Benefits
  - Conceptually simple
  - Very good at detecting known attacks
  - Easy to share signatures and build up shared libraries of attacks
- Drawbacks
  - Won’t catch new attacks without a known signature
  - Might not catch variants of known attacks if the variant doesn’t match the signature
  - The attacker can modify their attack to avoid matching a signature
  - Simpler versions only look at raw bytes, without parsing them in context
    - May miss variants
    - May generate lots of false positives

# Specification-based Detection



- **Specification-based detection**: Specify allowed behavior and flag any behavior that isn't allowed behavior
- Specification-based detection is **whitelisting**: Keep a list of allowed patterns, and alert if we see something that is not on the list

# Specification-based Detection: Examples



- Example: Path traversal attacks
  - We have a folder where all filenames are alphanumeric (a-z, A-Z, 0-9)
  - We specify that only alphanumeric characters are allowed as input
  - Strategy: Alert if any request contains something other than alphanumeric characters
  - If an attacker tries a path traversal attack (`../`), the detector will flag it
- Example: Buffer overflows
  - Consider a program that asks for the user's age as input
  - We know that ages are numerical, so we specify that only numbers are allowed
  - Strategy: Flag input that isn't numerical
  - If an attacker tries to input shellcode (not numbers), the detector will flag it

# Specification-based Detection: Tradeoffs



- Benefits
  - Can detect new attacks we’ve never seen before
  - If we properly specify all allowed behavior, can have low false positive rate
- Drawbacks
  - Takes a lot of time and effort to manually specify all allowed behavior
  - May need to update specifications as things change

# Anomaly-based Detection



- Idea: Attacks look unusual
- **Anomaly-based detection**: Develop a model of what normal activity looks like. Alert on any activity that deviates from normal activity.
  - Example: Analyze historical logs to develop the model
- Similar to specification-based detection, but learn a model of normal behavior instead of manually specifying normal behavior

# Anomaly-based Detection: Examples



- Example: Path traversal attacks
  - Analyze characters in requests and learn that `..` only appears in attacks
  - Strategy: Alert if any request contains `..`
- Example: Buffer overflows
  - Study user inputs to a C program
  - Learn that user input usually contains characters that can be typed on a keyboard
  - Strategy: Alert if the input contains characters that can't be typed on a keyboard
  - If an attacker inputs shellcode (can't be typed on a keyboard), the detector will alert

# Anomaly-based Detection: Tradeoffs



- Benefits
    - Can detect attacks we haven’t seen before
- Drawbacks
    - Can fail to detect known attacks
    - Can fail to detect new attacks if they don’t look unusual to our model
    - What if our model is trained on bad data (e.g. data with a lot of attacks)?
    - The false positive rate might be high (lots of non-attacks look unusual)
    - If we try to reduce false positives by only flagging the most unusual inputs, the false negative rate might be high (we miss slightly unusual attacks)
- Great subject for academic research papers, but not used in practice

# Behavioral Detection



- **Behavioral detection**: Look for evidence of compromise
- Unlike the other three styles, we are not scanning the input: We're looking at the actions triggered by the input
  - Instead of looking for the exploit, we're looking for the result of the exploit
  - *Behaviors* can themselves be analyzed using blacklists (signature-based), whitelists (specification-based), or normal behavior (anomaly-based)

# Behavioral Detection: Examples



- Example: Path traversal attacks
  - Strategy: See if any unexpected files are being accessed (e.g. the passwords file)
- Example: Buffer overflows
  - Strategy: See if the program calls unexpected functions
  - Consider a C program that never calls the **`exec`** function: if the program starts running **`exec`**, there is probably an attack in progress!

# Behavioral Detection: Tradeoffs



- Benefits
  - Can detect attacks we haven't seen before
  - Can have low false positive rates if we're looking for behavior that rarely occurs in normal programs (e.g. in the **`exec`** example, there are probably no false positives!)
  - Can be cheap to implement (e.g. existing tools to monitor system calls for a program)
- Drawbacks
  - Legitimate processes could perform the behavior as well (e.g. accessing a password file)
  - Only detects attacks after they've already happened
  - Only detects successful attacks (maybe we want to detect failed attacks as well)
  - The attacker can modify their attack to avoid triggering some behavior

# Other Intrusion Detection Strategies

# Vulnerability Scanning



- Idea: Instead of detecting attacks, launch attacks on your own system first, and add defenses against any attacks that worked
- **Vulnerability scanning**: Use a tool that probes your own system with a wide range of attacks (and fix any successful attacks)
- Widely used in practice today
    - Often used to complement an intrusion detection system

# Vulnerability Scanning: Tradeoffs



- Benefits
    - Accuracy: If your scanning tool is good, it will find real vulnerabilities
    - Proactive: Prevents attacks before they happen
    - Intelligence: If your intrusion detection system alerts on an attack you know you already fixed, you can safely ignore the alert
- Drawbacks
    - Can take a lot of work
    - Not helpful for systems you can't modify
    - Dangerous for disruptive attacks (you might not know which attacks are dangerous before you run the scanning tool)

# Honeypots



- **Honeypot**: a sacrificial system with no real purpose
  - No legitimate systems ever access the honeypot
  - If anyone accesses the honeypot, they must be an intruder
  - False positives: Legitimate systems mistakenly accessing the honeypot
- Similar idea as stack canaries

# Honeypots: Examples



- Example: Hospitals
  - Employees should not read patient records
  - The hospital enters a honeypot record with a celebrity name
  - Catch any staff member who reads the honeypot record
- Example: Unsecured Bitcoin wallet
  - Leave an unsecured Bitcoin wallet on your system with a small amount of money in it
  - If the money is stolen, you know that someone has attacked your system!
- Example: Spamtrap
  - Create a fake email address that is never used for legitimate emails
  - If email gets sent to the address, it's probably spam!

# Honeypots: Tradeoffs



- Benefits
  - Can detect attacks we haven’t seen before
  - Can analyze the attacker's actions
    - Who is the attacker?
    - What are they doing to the system?
  - Can distract the attacker from legitimate targets
- Drawbacks
  - Can be difficult to trick the attacker into accessing the honeypot
  - Building a convincing honeypot might take a lot of work
  - These drawbacks matter less if the honeypot is aimed at automated attacks (e.g. the spam detection honeypot)

# Forensics



- **Forensics**: Analyzing what happened after a successful attack
  - Important complement to detecting attacks
- Tools needed
  - Detailed logs of system activity
  - Tools for analyzing and understanding logs

# Blocking: Intrusion Prevention Systems



- Idea: If we can detect attacks, can we also block them?
- **Intrusion prevention system** (**IPS**): An intrusion detection system that also blocks attacks
  - Commonly used today
- Drawbacks
  - Not possible for retrospective analysis (e.g. logging)
  - Difficult for a detector that passively monitors traffic (e.g. an on-path NIDS)
    - Dynamically change firewall rules to block attacks?
    - Forge a RST packet to stop an attack?
    - Need to race against the attacker's malicious packets
  - False positives are expensive
    - Blocking a non-attack might affect legitimate users

# Building the Perfect IPS?



0% false negative rate


0% false positive rate

**Takeaway**: You must always have tradeoffs between false positive and false negative rates

# Attacks on Intrusion Detection Systems (IDS)

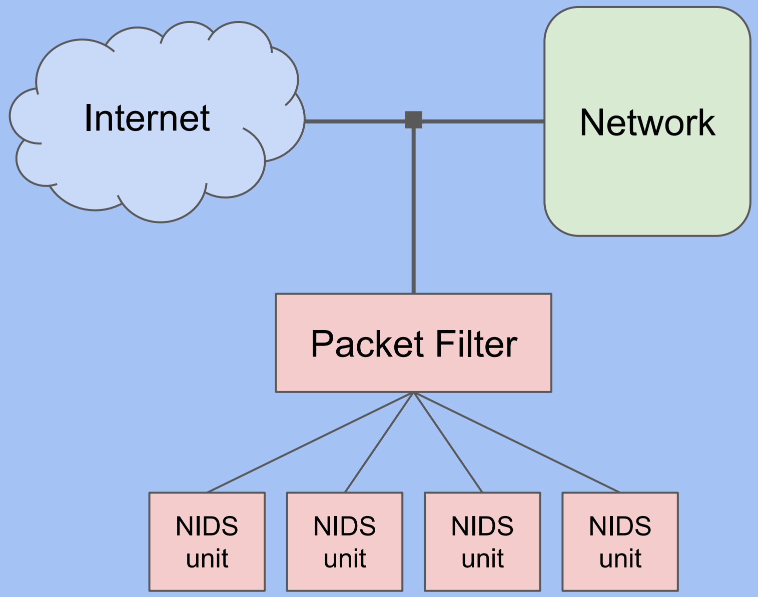


- The IDS is a system with limited resources, so it is vulnerable to DoS attacks!
  - DoS attack: Exhaust the IDS's memory
    - IDS needs to track all ongoing activity
    - Attacker generates lots of activity to consume all the IDS's memory
    - Example: Spoof TCP SYN packets to force the IDS to keep track of too many connections
  - DoS attack: Exhaust the IDS's processing power
    - Example: If the IDS uses a hash table to keep track of connections, create hash collisions to trigger worst-case complexity (algorithmic complexity attack)
- The IDS analyzes outside input, so it is vulnerable to code injection attacks!
  - Attacker supplies malicious input to exploit the IDS

# Inside A Modern IDS



- Employ **defense in depth**
- To cover all devices, use a modern NIDS:
  - Single entry point with a simple packet filter
    - Simple but effective filters can handle 1,000 Gbps
  - Parallel processing using multiple NIDS nodes
    - A single server rack slot can handle 1–5 Gbps, and scales linearly
  - In-depth detection techniques
    - Protocol analysis
    - Signature analysis on content and behavior
    - Shadow execution (execute unknown content found on the network)
    - Extensive logging
    - Automatic updates



# Inside A Modern IDS



- Cover individual devices using a HIDS on each device
    - Antivirus software is a kind of HIDS used by many corporations!
    - Block access to blacklisted sites (e.g. malware sites)
    - Detection techniques
        - Protocol analysis
        - Signature analysis on networking traffic
        - Signature analysis on memory and filesystem
        - Query a cloud database to see if a payload has been seen by other devices running the same HIDS
        - Sandboxed execution (execute a payload in a safe, inescapable environment)
            - Analyze the behavior of the program while in the sandbox

# Path Traversal Attacks: Summary



- **Path traversal attack**: Accessing unauthorized files on a remote server by exploiting Unix file path semantics
  - Often makes use of `../` to enter other directories
  - Vulnerability: User input is interpreted as a file path by the Unix file system
- Defense: Check that user input is not interpreted as a file path

# Types of Detectors: Summary



- Network Intrusion Detection System (NIDS): Installed on the network
  - Benefits: Cheap, easy to scale, simple management, end systems unaffected, small TCB
  - Drawbacks: Inconsistent interpretation (leads to evasion attacks), encrypted traffic
- Host-based Intrusion Detection System (HIDS): Installed on the end host
  - Benefits: Fewer inconsistencies, works with encrypted traffic, works inside the network, performance can scale
  - Drawbacks: Expensive, evasion attacks still possible
- Logging: Analyze logs generated by servers
  - Benefits: Cheap, fewer inconsistencies
  - Drawbacks: Only detects attacks after they happen, evasion attacks still possible, attacker could change the logs

# Detection Accuracy: Summary



- Two main types of detector errors
  - False positive: Detector alerts when there is no attack
  - False negative: Detector fails to alert when there is an attack
- Detector accuracy
  - False positive rate (FPR): The probability the detector alerts, given there is no attack
  - False negative rate (FNR): The probability the detector does not alert, given there is an attack
- Designing a good detector involves considering tradeoffs
  - What is the rate of attacks on your system?
  - How much does a false positive cost in your system?
  - How much does a false negative cost in your system?
- Accurate detection is very challenging if the base rate of attacks is low
- Detectors can be combined
  - Parallel: Fewer false negatives, more false positives
  - Series: Fewer false positives, more false negatives

# Styles of Detection: Summary



- Signature-based
  - Flag any activity that matches the structure of a known attack (blacklisting)
  - Good at detecting known attacks, but bad at detecting unknown attacks
- Specification-based
  - Specify allowed behavior and flag any behavior that isn't allowed behavior (whitelisting)
  - Can detect unknown attacks, but requires work to manually write specifications
- Anomaly-based
  - Develop a model of what normal activity looks like. Alert on any activity that deviates from normal activity.
  - Mostly seen in research papers, not in practice
- Behavioral
  - Look for evidence of compromise
  - Can cheaply detect new attacks with few false positives, but only detects after the attack

# Other Intrusion Detection Strategies: Summary



- Vulnerability scanning: Use a tool that probes your own system with a wide range of attacks (and fix any successful attacks)
  - Can accurately prevent attacks before they happen, but can be expensive
- Honeypot: a sacrificial system with no real purpose
  - Can detect attackers and analyze their actions, but may take work to trick the attacker into using the honeypot
- Forensics: Analyzing what happened after a successful attack
- Intrusion Prevention System (IPS): An intrusion detection system that also blocks attacks