Week 3

Threat Modeling

CS 3923/6813: Computer Security

[*] Slides based upon materials maintained by Justin Cappos at NYU

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Security Life Cycle

So far what we have learnt helps us in design, specification and implementation mainly.

What about others?

We start with threat analysis/modeling.

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Threats, Vulnerabilities and Attacks

- A *threat* to a system is any potential occurrence, malicious or otherwise, that can have an adverse effect on the assets and resources associated with the system.
- A *vulnerability* of a system is some characteristic that makes it possible for a threat to occur.
- An *attack* on a system is some action that involves exploitation of some vulnerability in order to cause an existing threat to occur.

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Risk

- Risk: What (adverse) happens if a threat occurs?
  - Risk can exist when there is a known issue that increases the attack surface. Risk can also exist when there are non-specific issues, unexplored threat areas, or lack of depth-of-knowledge.

An essential component of Computer security risk analysis and risk management.

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Why Threat Modeling

- Helps you understand your application better.
- Discover potential design flaws and vulnerabilities
- Prioritize security analysis
- Understand overall security risk
- Develop mitigating strategies
- Provide more complete analysis

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Threat Modeling

- Threats and assets are key – vulnerabilities and attacks are only concerns if there is a threat to an asset to be concerned about.
- How do we identify and evaluate threats?
  - Arbitrary Threat or Attack Lists
    - Random and unstructured
    - Dubious completeness
  - Threat Trees / Graphs or Attack Trees / Graphs
    - More structured
    - Modular and Re-usable
    - Currently favored approach

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Threat Modeling

- Start with questions like the following:
  - Who are my potential adversaries?
  - What is their motivation, and what are their goals?
  - How much inside information do they have?
  - How much funding do they have?
  - How averse are they to risk?
  - [Be paranoid: do not underestimate the attacker's capability; do not also ignore easy/dumb attacks]
- Then enumerate threats by stepping through each of the system's assets, reviewing a list of attack goals for each asset. Assets and threats are closely correlated.

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Threat Modeling – main steps

- Understand your system
- Understand what assets/resources need to be protected
- Predict who the potential attackers are against a particular asset and what are the possible (known) attacks
- Perform risk assessment
  - Determine what is the expected risk (quantitative or qualitative) because of an attack
- Perform risk management: Employ security mechanisms (mitigation), if needed
  - Determine if they are cost effective

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STRIDE Model

- In general, threats can be classified into six classes based on their effect :
  - *Spoofing* - Using someone else's credentials to gain access to otherwise inaccessible assets.
  - *Tampering* - Changing data to mount an attack.
  - *Repudiation* - Occurs when a user denies performing an action, but the target of the action has no way to prove otherwise.
  - *Information disclosure* - The disclosure of information to a user who does not have permission to see it.
  - *Denial of service* - Reducing the ability of valid users to access resources.
  - *Elevation of privilege* - Occurs when an unprivileged user gains privileged status.

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Ranking Threats

- Used for prioritizing work
- One methodology for ranking threats is the use of DREAD (used by Microsoft!)
    - Damage Potential
    - Reproducibility
    - Exploitability Cost (or cost and ease of performing attack)
    - Affected Users
    - Discoverability

- DREAD rating is calculated by adding the rating for each component
    - For example, 3: High, 2: Medium, 1: Low
    - For a particular threat, we might have
        - Damage Potential = 3
        - Reproducibility = 3
        - Exploitability Cost (or cost and ease of performing attack) =2
        - Affected Users = 2
        - Discoverability = 2
        - Total Rating: 12, which might be regarded as High, since one can set 12–15 as High, 8–11 as Medium, and 5–7 as Low risk.

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Attack Trees

- Data structure to represent an attack
- Look at system from attackers point of view.
- The root node of the tree is the global goal of the attacker
- Children are refinements of this goal
- Nodes can be conjunctive (AND) or disjunctive (OR)

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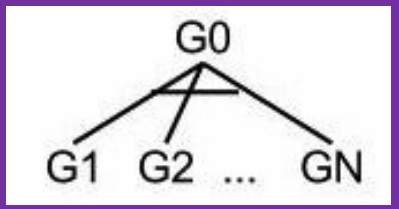
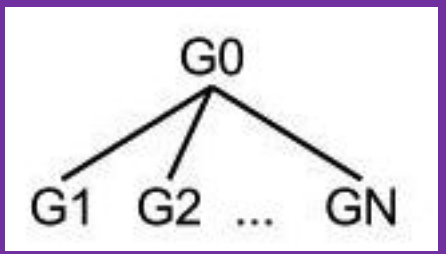
Notations for nodes

- Can be represented graphically or textually
- Conjunctive (AND) node



To achieve G0, you must achieve G1 AND G2 ... AND GN

- Disjunctive (OR) node



To achieve G0, you must achieve G1 OR G2 ... OR GN

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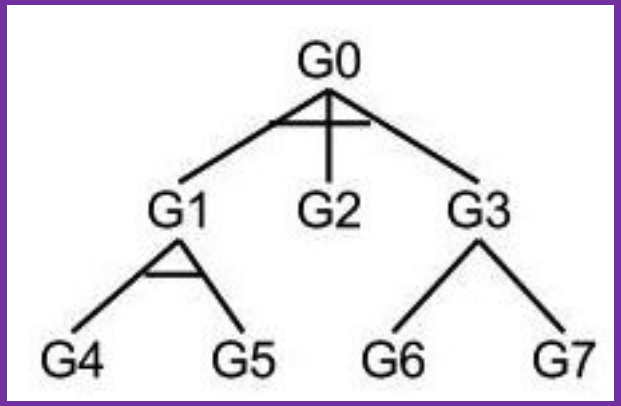
Attack Trees

- Attack trees consist of any combination of conjunctive and disjunctive nodes.
- Individual intrusion scenarios are created by depth first traversal.



So the tree to the left leads to the attack scenarios:

<G_4, G_5, G_2, G_6>

<G_4, G_5, G_2, G_7>

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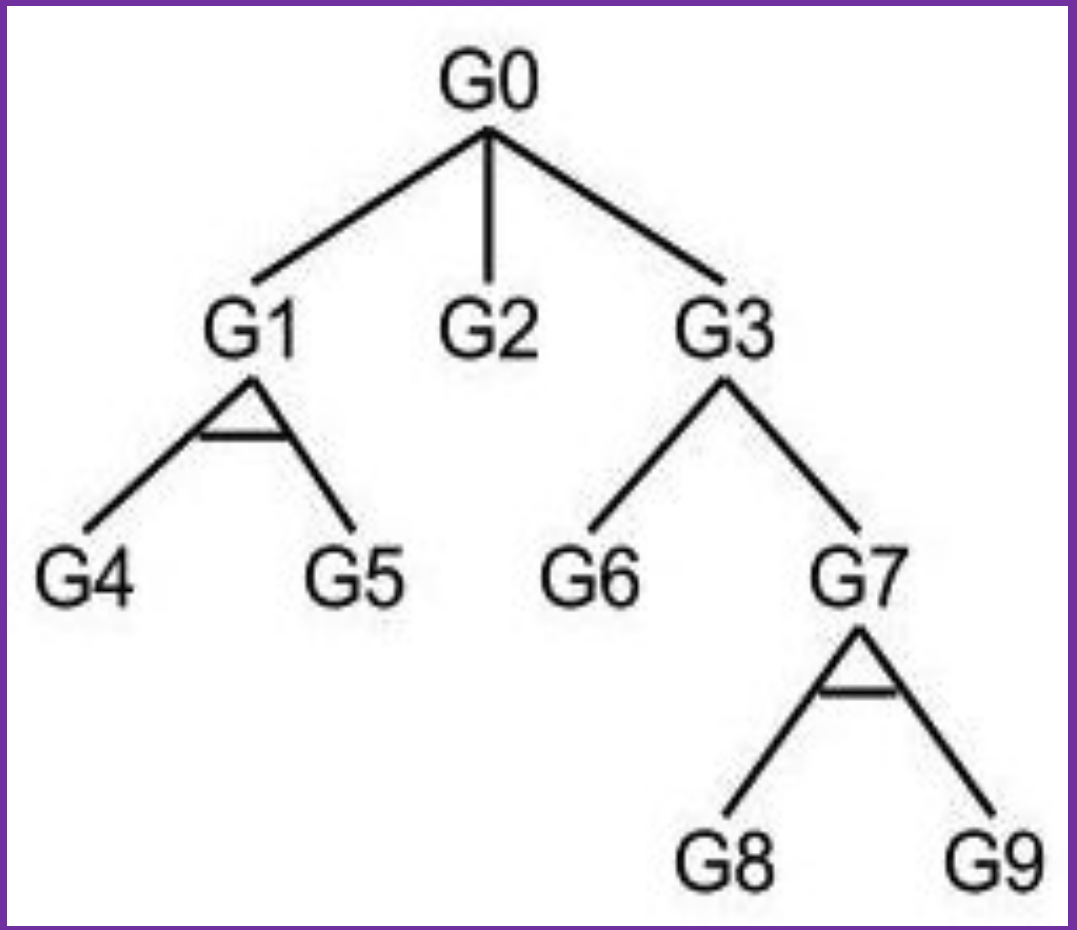
Another Example

- What are the attack scenarios for the tree below?



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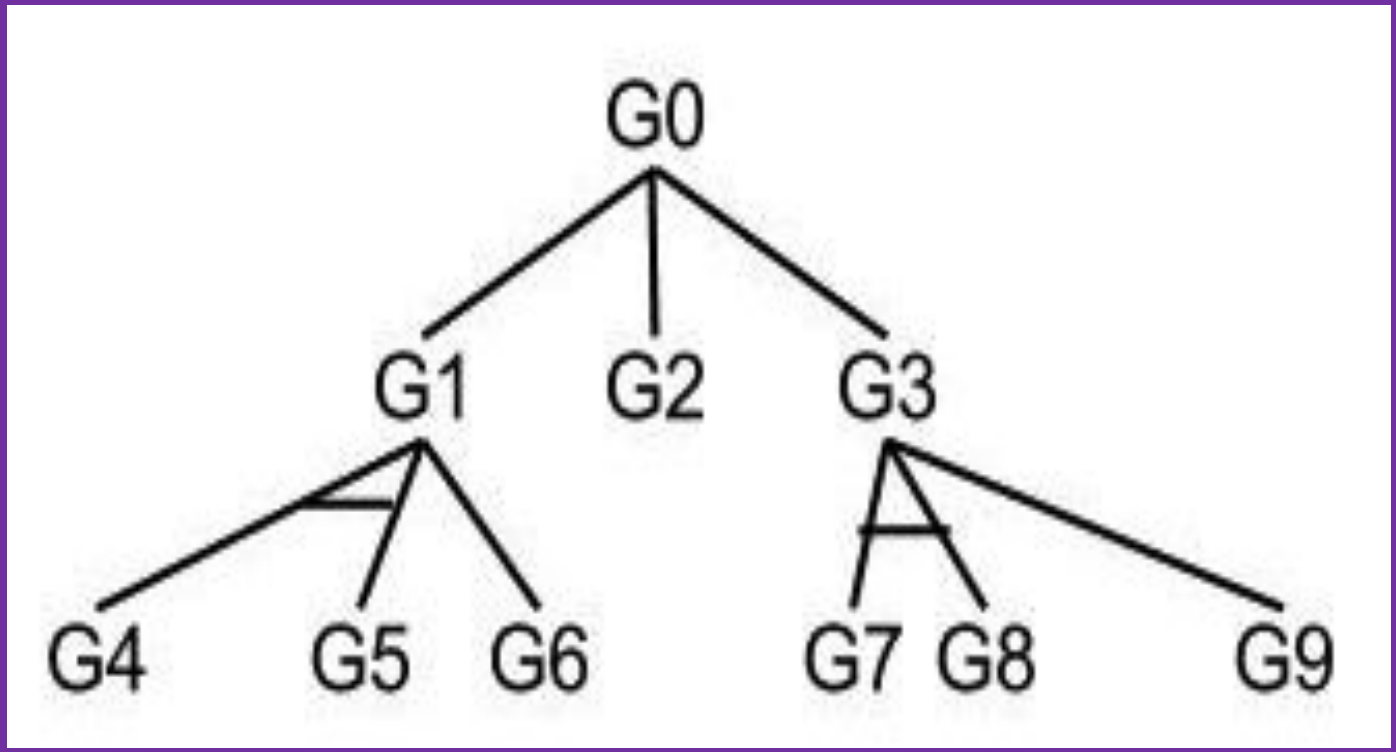
Yet another...

- What are the attack scenarios for the tree below?



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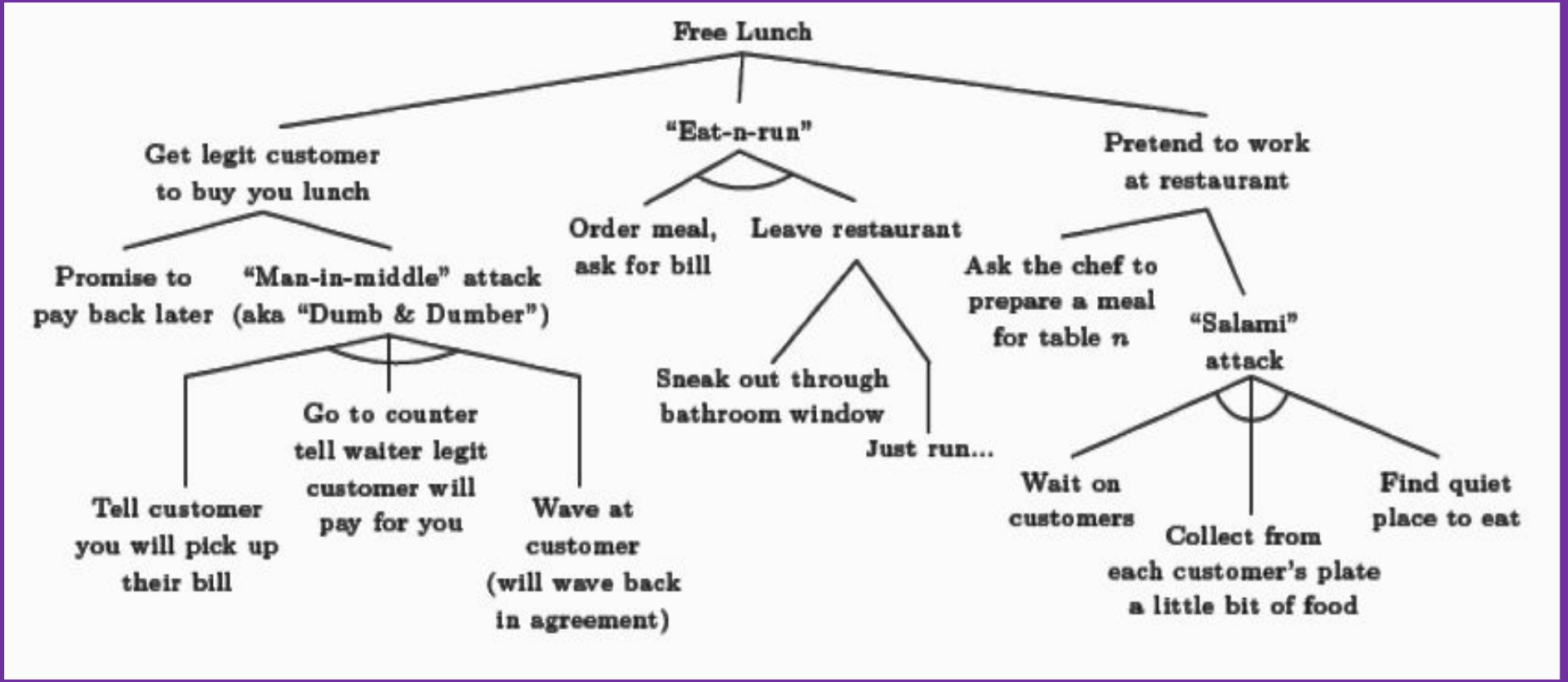
Attack Trees – a funny example



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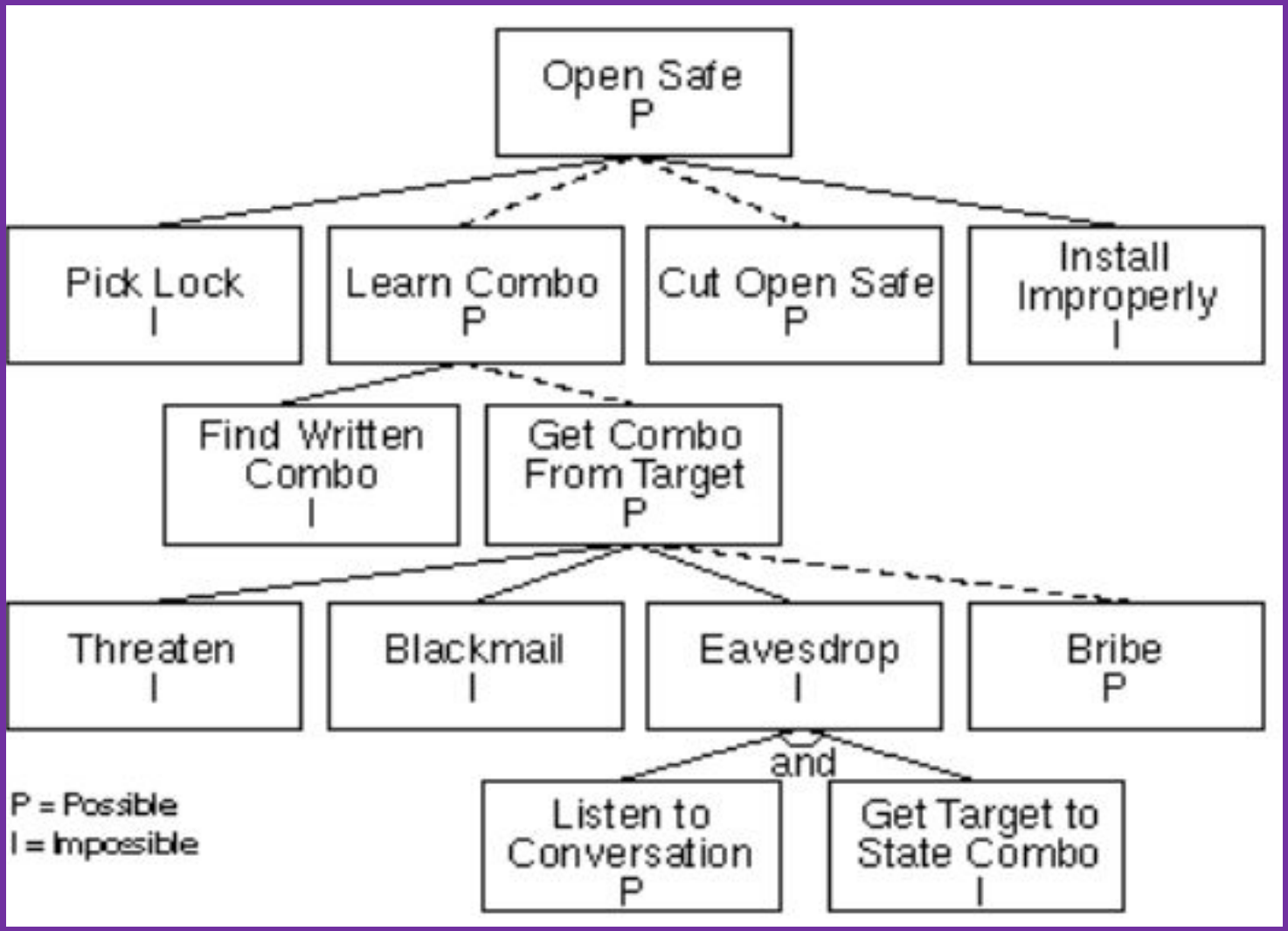
Attributes: Boolean

- You can assign attributes to nodes in the tree to help you reason about them
  - Can be useful in understanding what sorts of attackers can launch certain attacks
- “Possible” and “Impossible” are one way to assign attributes to the tree

An example


Open Safe
P
Pick Lock
I
Learn Combo
P
Cut Open Safe
P
Install Improperly
I
Find Written Combo
I
Get Combo From Target
P
Threaten
I
Blackmail
I
Eavesdrop
I
Bribe
P
and
Listen to Conversation
P
Get Target to State Combo
I
P = Possible
I = Impossible

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Attributes: Boolean

- "Possible" and "Impossible" are only one way to assign attributes to the tree
- Any Boolean value can be assigned to the leaf nodes and then propagated up the tree structure: AND/OR of the children node values
  - Easy vs. hard
  - Expensive vs. Inexpensive
  - Legal vs. Illegal
  - Special Equipment vs. no Special Equipment

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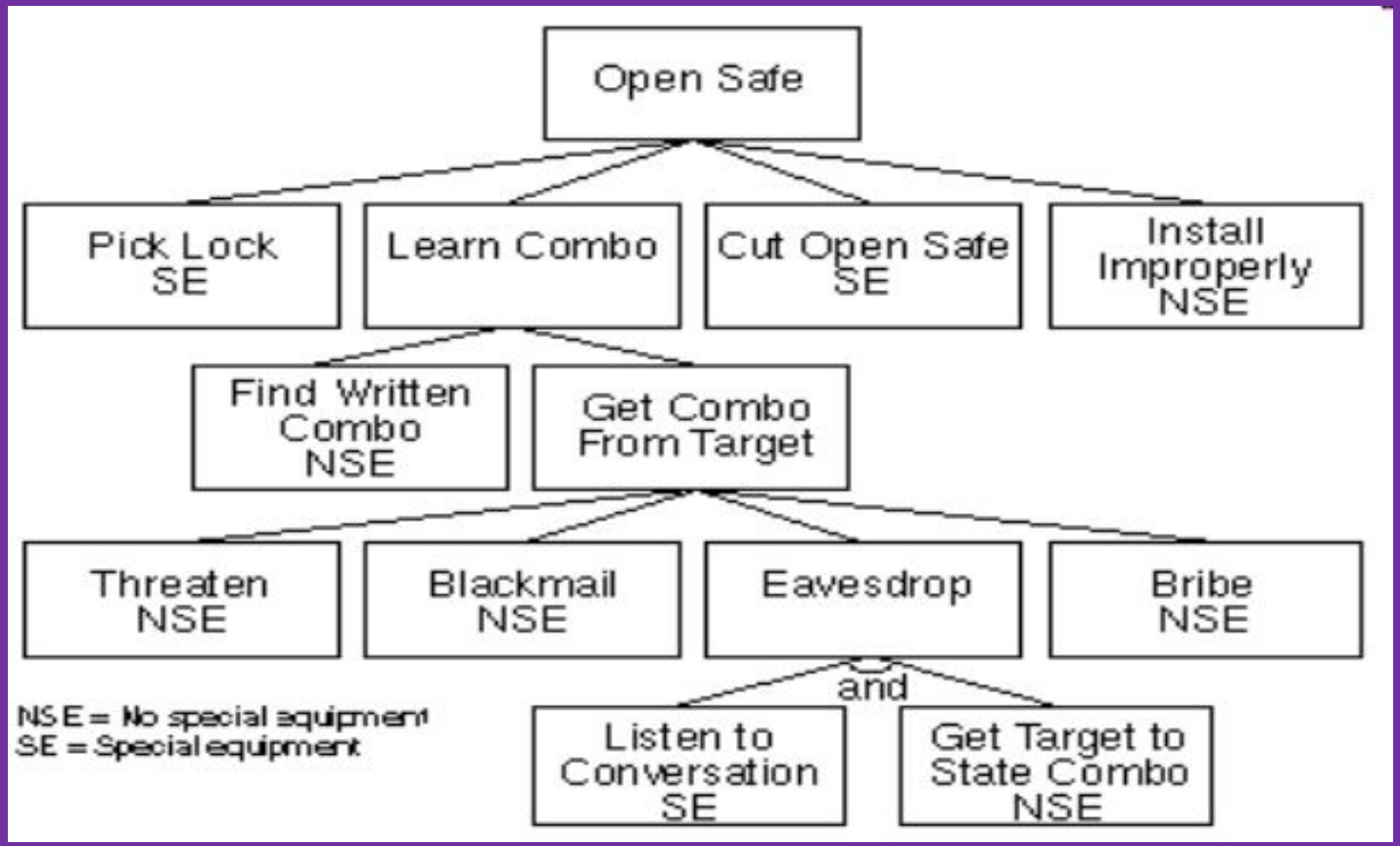
Special Equipment



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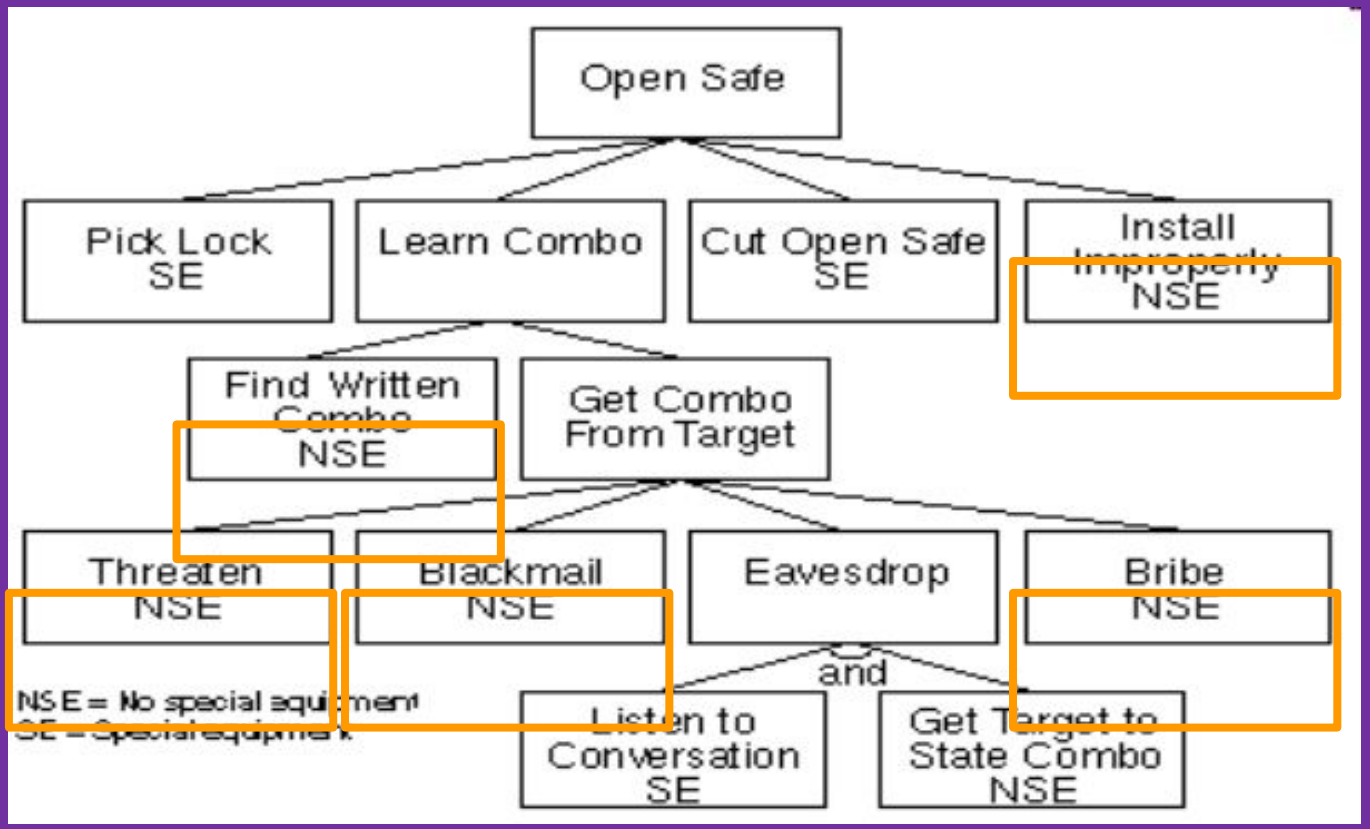
Special Equipment



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Attributes: Continuous

- Expensive vs. Inexpensive is fine, but good to say the amount, e.g.
- Continuous values can also be assigned to the nodes of the attack tree, and can be propagated up the tree
  - OR nodes have the value of their cheapest child
  - AND nodes have the value of the sum of their children

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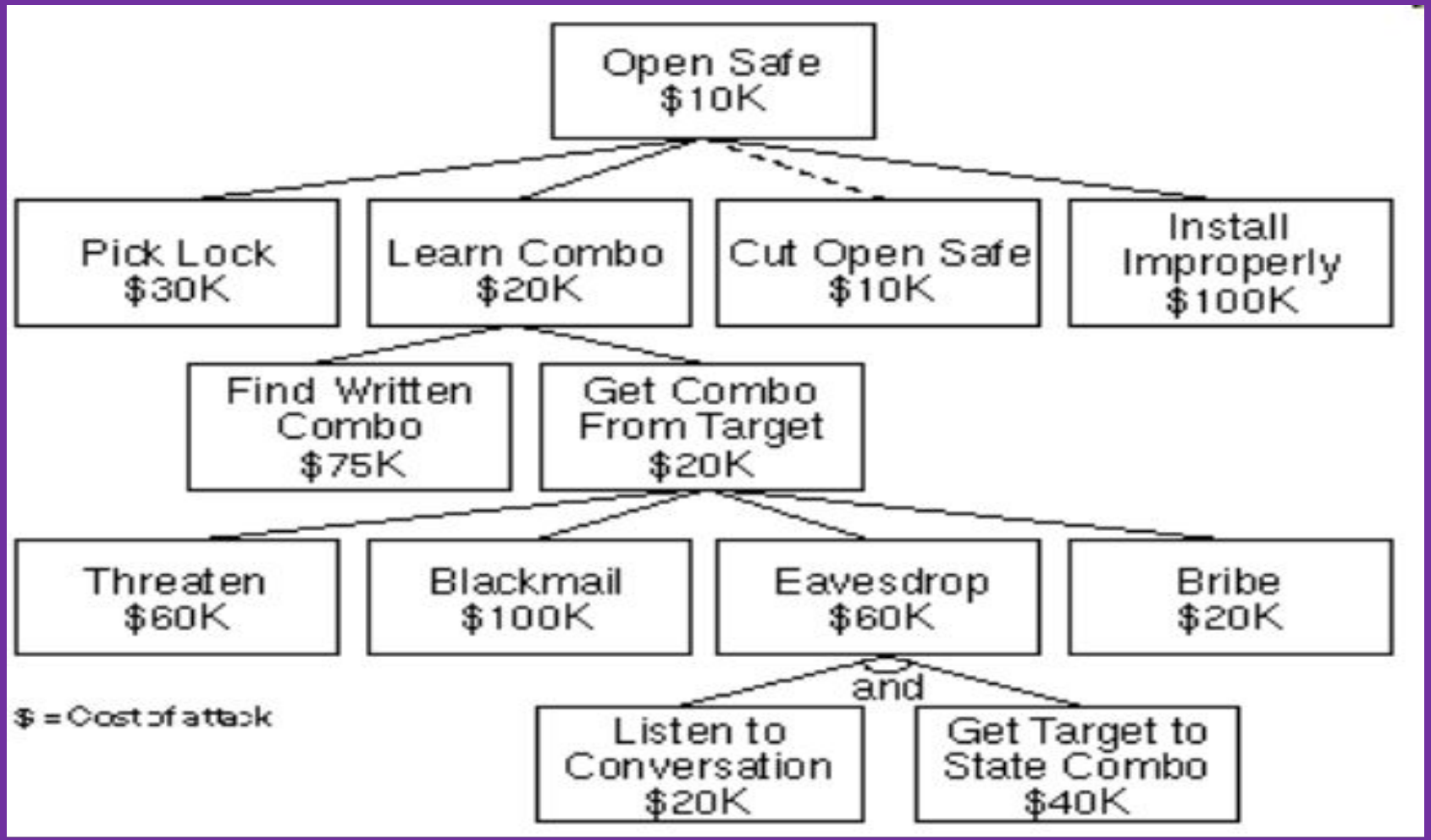
Cheapest attack



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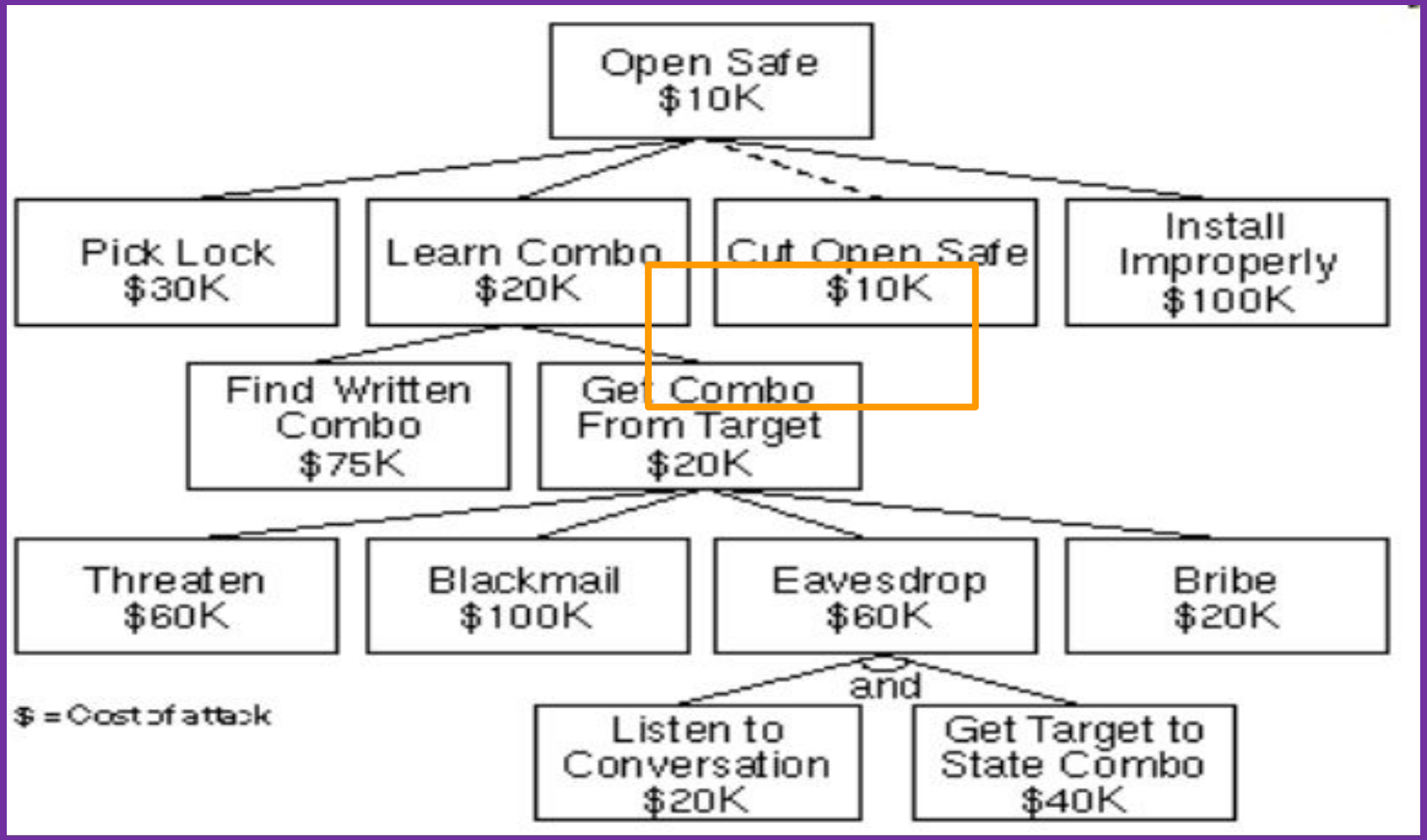
Cheapest attack



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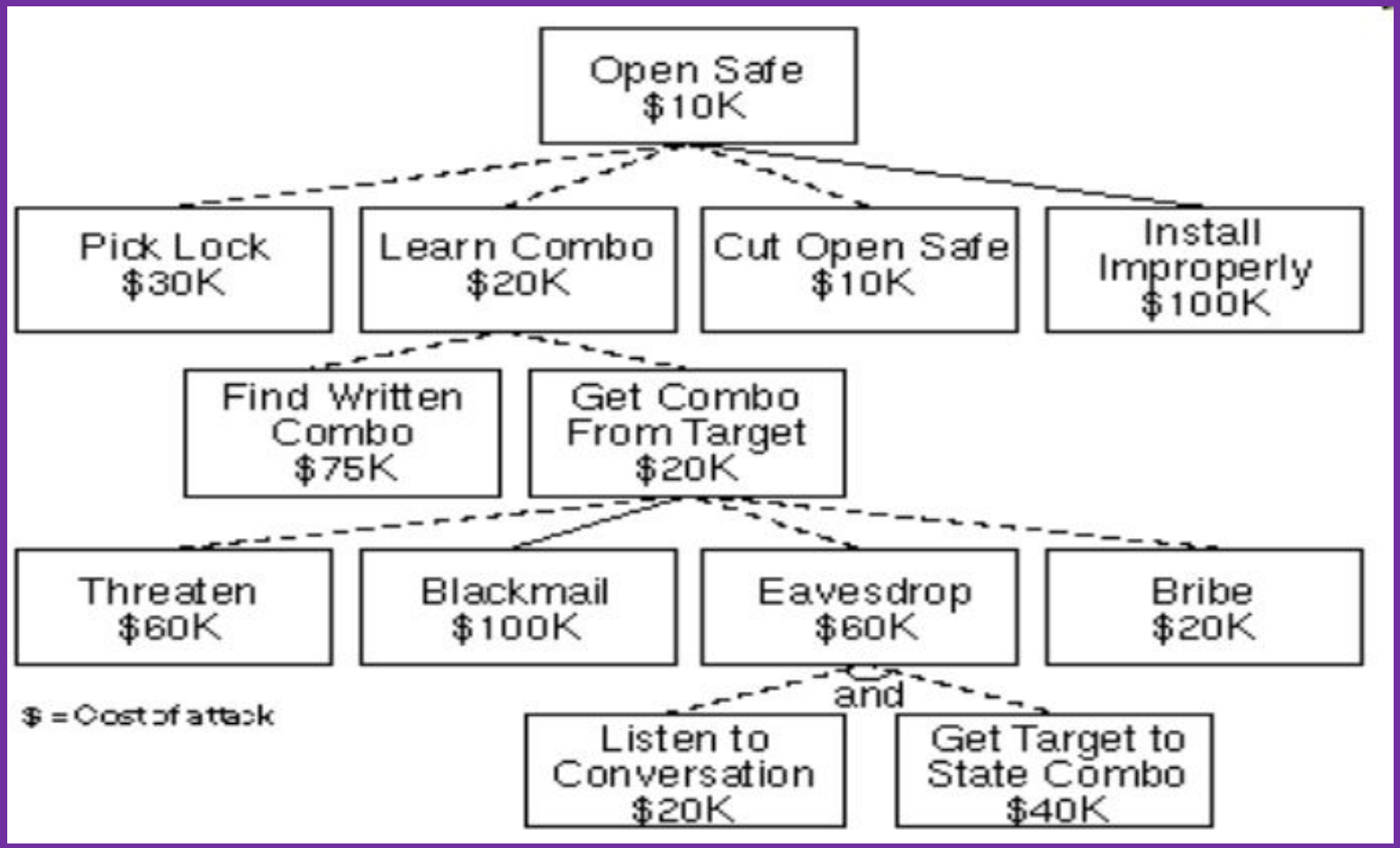
All attacks with cost < $100K



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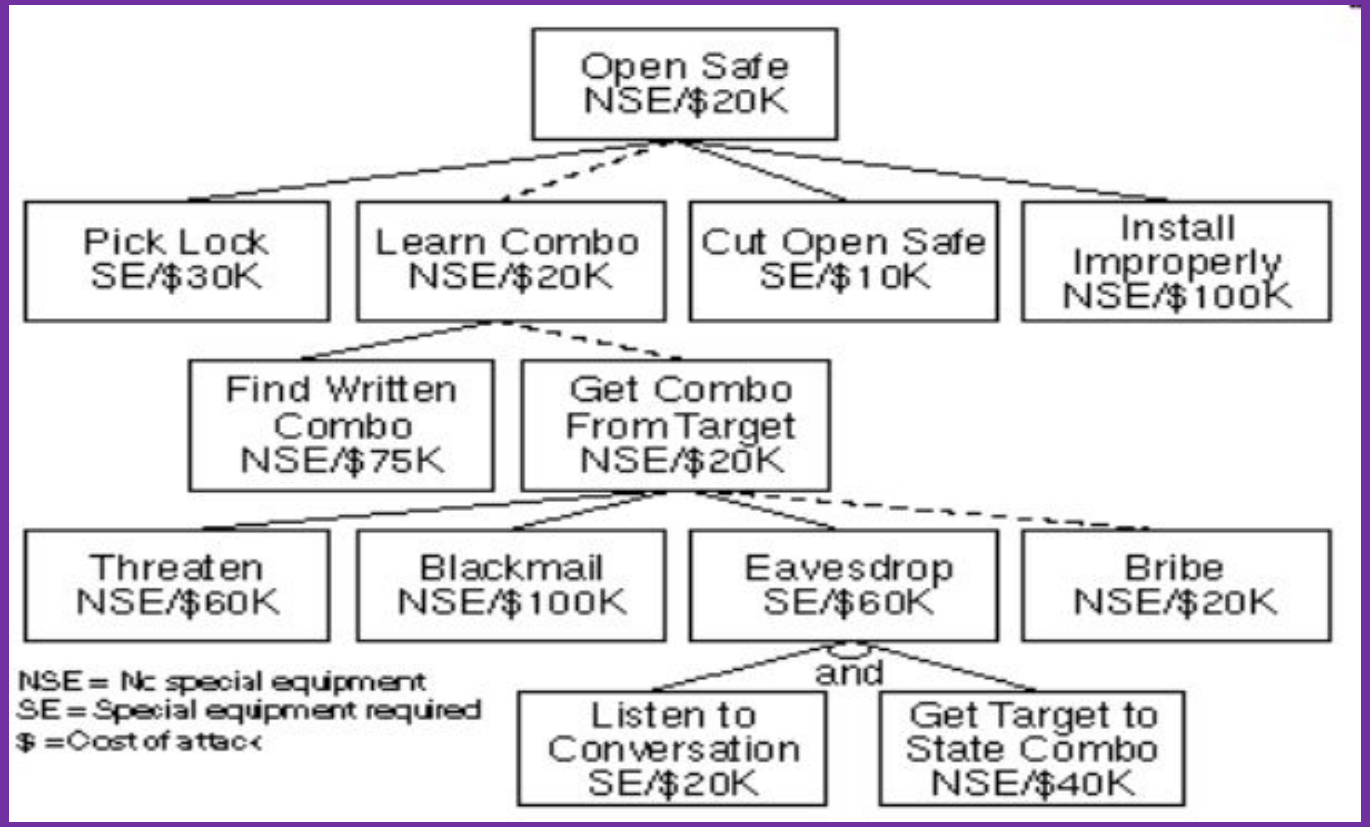
Combination of attributes: cheapest attack with no special equipment



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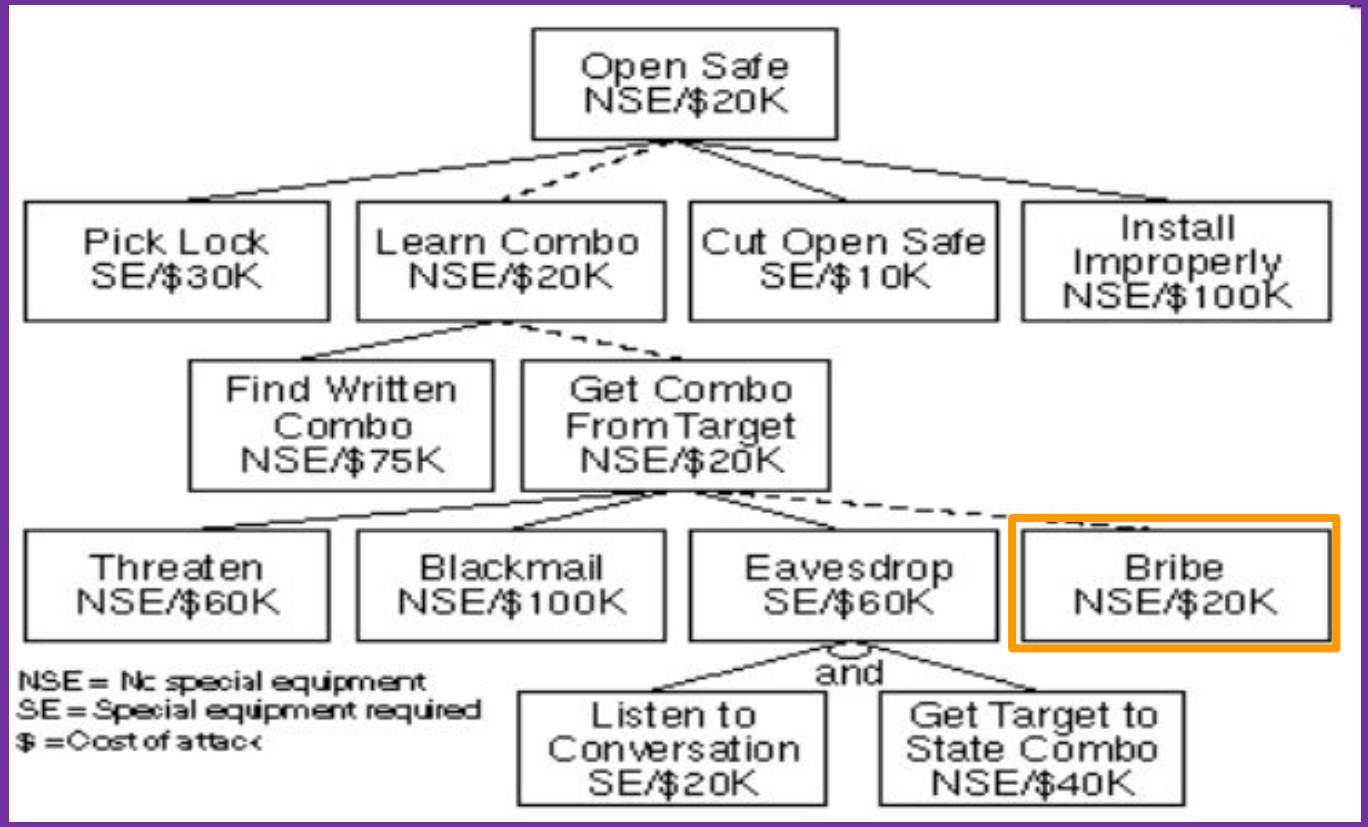
Combination of attributes: cheapest attack with no special equipment



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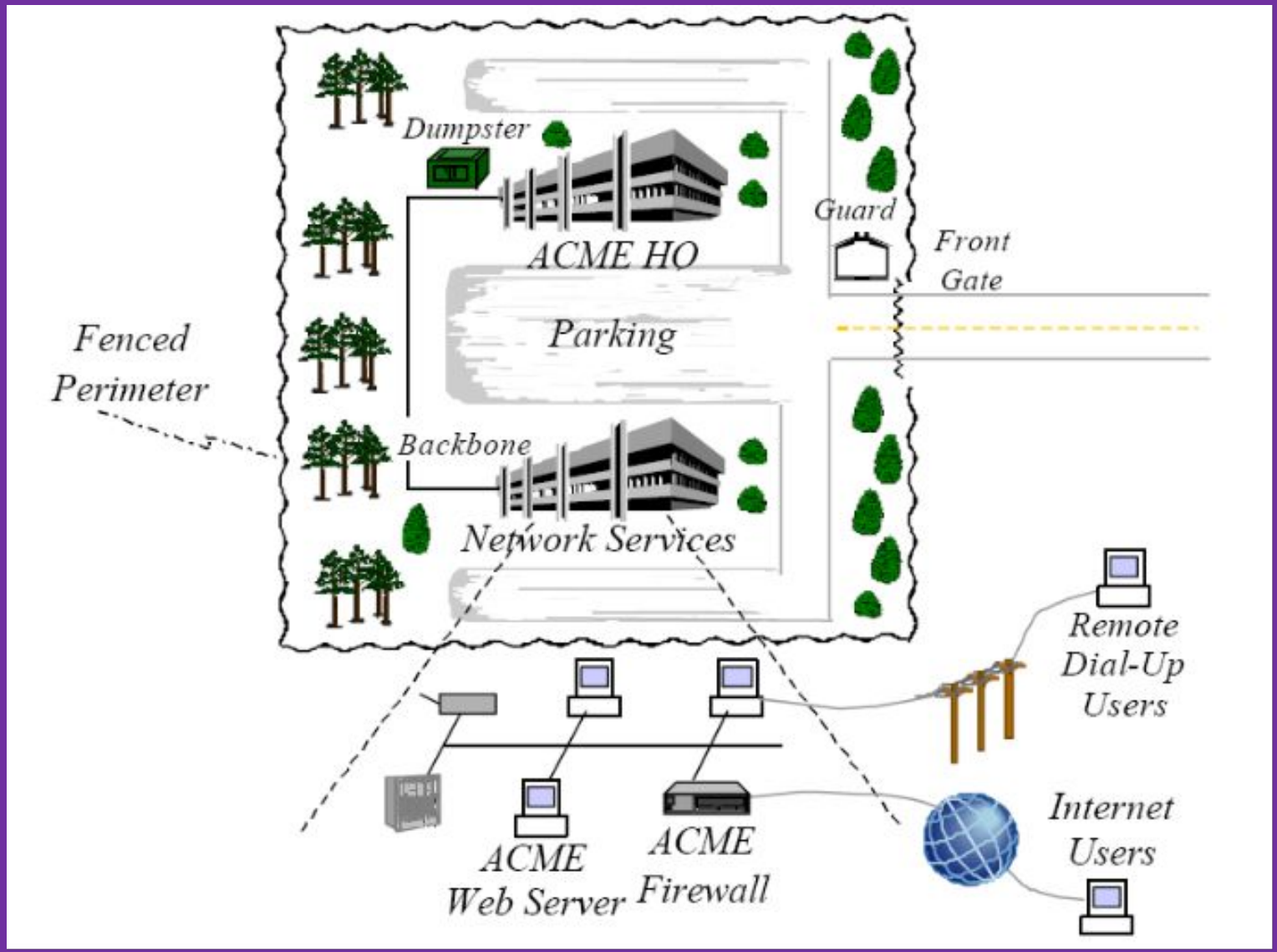
Case Study – ACME Enterprise



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ACME High Level Attack Tree

Survivability Compromise: Disclosure of ACME proprietary secrets

OR 1. Physically scavenge discarded items from ACME
- ***OR*** 1. Inspect dumpster content on-site
- 2. Inspect refuse after removal from site

2. Monitor emanations from ACME machines
- ***AND*** 1. Survey physical perimeter to determine optimal monitoring position
- 2. Acquire necessary monitoring equipment
- 3. Setup monitoring site
- 4. Monitor emanations from site

3. Recruit help of trusted ACME insider
- ***OR*** 1. Plant spy as trusted insider
- 2. Use existing trusted insider

4. Physically access ACME networks or machines
- ***OR*** 1. Get physical, on-site access to Intranet
- 2. Get physical access to external machines

5. Attack ACME intranet using its connections with Internet
- ***OR*** 1. Monitor communications over Internet for leakage
- 2. Get trusted process to send sensitive information to attacker over Internet
- 3. Gain privileged access to Web server

6. Attack ACME intranet using its connections with public telephone network (PTN)
- ***OR*** 1. Monitor communications over PTN for leakage of sensitive information
- 2. Gain privileged access to machines on intranet connected via Internet

Expansion of a node

5.3. Gain privileged access to ACME Web server

AND 1. Identify ACME domain name

2. Identify ACME firewall IP address

OR 1. Interrogate domain name server

2. Scan for firewall identification

3. Trace route through firewall to Web server

3. Determine ACME firewall access control

OR 1. Search for specific default listening ports

2. Scan ports broadly for any listening port

4. Identify ACME Web server operating system and type

OR 1. Scan OS services' banners for OS identification

2. Probe TCP/IP stack for OS characteristic information

5. Exploit ACME Web server vulnerabilities

OR 1. Access sensitive shared intranet resources directly

2. Access sensitive data from privileged account on Web server

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A Participatory Example

Stealing your bicycle

- Assume it has a bike lock
- You ride it to and from NYU

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General Concept of Risk Assessment and Management

- A **risk** consists of something of value (an **"asset" at risk**) which may lose value if a negative event occurs.
  - Example: a car and its passengers are at risk in the event of an auto accident. Other people, cars, and roadside objects are also at risk
  - Example: Money invested in a stock is at risk in the event that the price of the stock goes down and the owner has to sell
- Risk analysis/assessment is the process of
  - Identifying the assets at risk (cost of asset – cost of most expensive attack)
  - Putting quantitative (e. g., dollars) or qualitative (e. g. low/medium/high) measures on the potential loss (**impact**)
  - Putting quantitative (i. e., the probability) or qualitative (e. g. low/medium/high) measures on the likelihood of the event happening
- Risk Management is a process for planning on how to **control** those risks

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Non-IT Example 1: Stock Market Risk (simplified)

- Assume you buy 100 shares of stock at $50 per share. Potential maximum impact: $5000
- Risk management strategies:
  - Risk reduction: buy a conservative stock
  - Risk mitigation: buy a “contrary” stock (Buy Dell in addition to HP, in case HP loses significant market share to Dell)
  - Risk transfer: buy an option to sell at $40/share; reduces maximum impact to $1000 (this could also be thought of as a risk mitigation strategy)
  - Risk acceptance: If you buy the options, you accept $1000 of risk

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Non-IT Example 2: Driving risk

- Assets at risk: people's lives and health, the automobile, other property
- Negative event: auto accident
- Risk Management:
  - Risk reduction: Following DWI laws, defensive driving techniques, ABS, driving slow or just not driving on snowy days
  - Risk mitigation: Seat belts, air bags, "crumple zones" in auto design
  - Risk transfer: insurance
  - Risk acceptance: residual risk of injury, deductible on insurance

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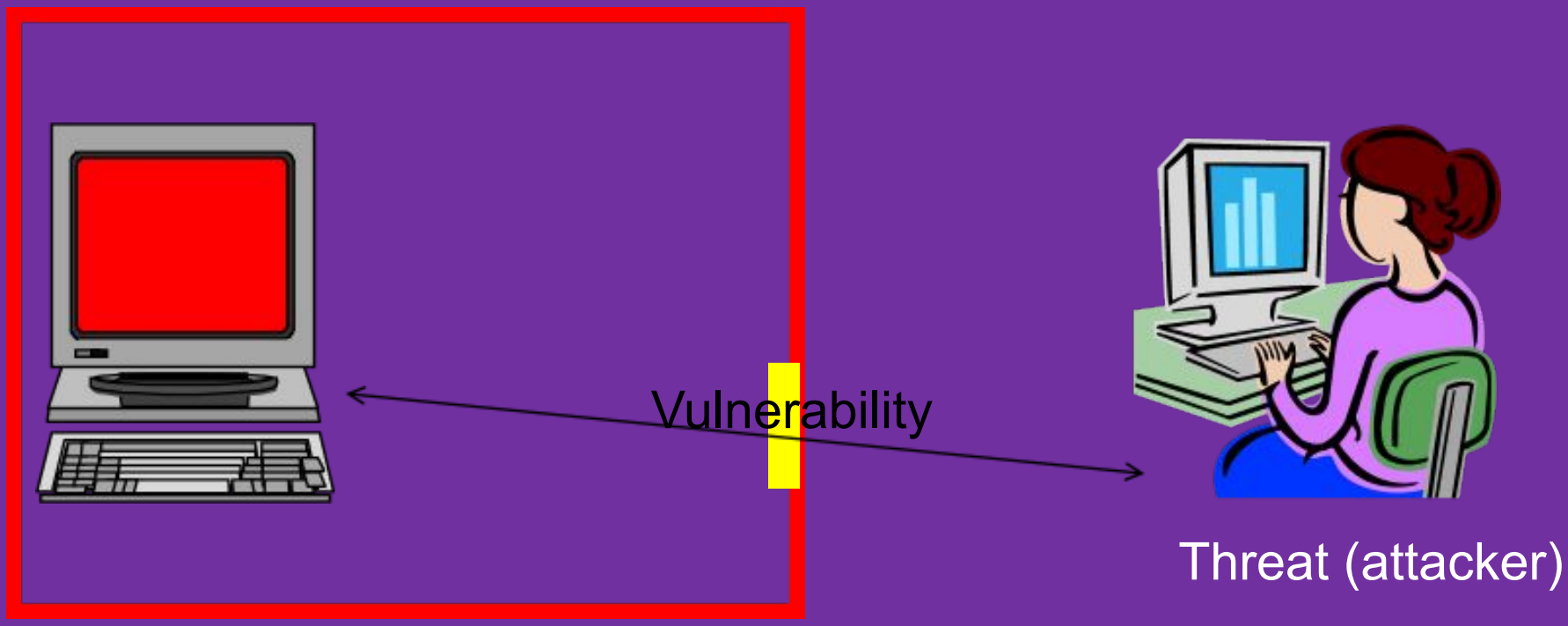
Information Security Risk Concept



Risk analysis starts with understanding what assets are potentially at risk, what the threats are. This forms the basis for finding the “sweet spot” of putting in enough security to protect the value of the assets.

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Information Security Risk Analysis

- "Risk" will usually refer to information security risk
- Negative events are often compromises of the system.
- If we are only concerned with information security risks, **any asset at risk will have to be mapped back to an IT asset at risk**
- "IT assets" refer to information, IT processes/functionality, and IT systems
- The risk management strategies that we consider are for the IT assets, but the impact is based on the real assets

Example 1

- Example: Given a system that uses personal information such as name, SSN, etc. The related IT asset at risk is the _____ of that information. The impact of a compromise is the potential for _____.

Example 1

- Example: Given a system that uses personal information such as name, SSN, etc. The related IT asset at risk is the confidentiality of that information. The impact of a compromise is the potential for identity theft.

Example 2

- Example: Given a battlefield communications system. The related IT asset is the _____ of the system, and the impact of a failure is _____.

Example 2

- Example: Given a battlefield communications system. The related IT asset is the availability and integrity of the system, and the impact of a failure is loss of life.

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“Asset at Risk” Owner vs. “IT Asset at Risk” Owner

- The owner of the asset may not be the owner of the related IT asset at risk
  - Example: an “identity” that may be stolen is an asset of that person, but the related IT asset (SSN, etc.) is under the control of many other entities.
  - Example: a civilian undercover agent (spy) transmits information to which only he has access back to a military organization. If that military organization’s system is compromised, the agent’s life may be at risk

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"Asset at Risk" Owner vs. "IT Asset at Risk" Owner

- The owner of the IT system may not suffer the impact of a compromise.
  - Example: in 2005, CardSystems (a processor of credit card transactions) system was compromised and 40 million cardholders' information was exposed. The potential impact of each compromise was on the credit card holders (fraud, identity theft) and the credit card companies (which cover all fraudulent transactions above $50 per account by law). As a result, both Visa and American Express stopped allowing CardSystems to process their transactions
- Laws may also help share risk
- Business relationships and corporate/political image
  - Target, HomeDepot, etc.

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Risk Assessment

- Assessment: measures of the impact of an event, and the probability of an event (threat agent exploiting a vulnerability)
- Quantitative (objective) and Qualitative (subjective) approaches both used.
- Quantitative approach:
  - Compute expected monetary value (impact) of loss for all “events”
  - Compute the probability of each type of expected loss
- Qualitative approach: use Low, Medium, High; ratings; other categorical scales

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Risk Management

- Once you have risk computed for each threat you can prioritize them and for each do one of the following:
  - *Accept the risk* - The risk is so low or so costly to mitigate that it is worth accepting.
  - *Transfer the risk* - Transfer the risk to somebody else via insurance, warnings etc.
  - *Remove the risk* - Remove the system component or feature associated with the risk if the feature is not worth the risk.
  - *Mitigate the risk* - Reduce the risk with countermeasures.
- The understanding of risks leads to policies, specifications and requirements.
- Appropriate security mechanisms are then developed and implemented, and then deployed

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Quantitative Methodology (terminology)

- SLE: Single Loss Expectancy
- ARO: Annualized Rate of Occurrence
- ALE: Annualized Loss Expectancy
- S: Safeguard (security mechanism)
- ALE(without S)
- ALE(with S)
- ACS(S): Annualized Cost of Safeguard S
- ANB(S): Annualized Net Benefit of S
  - = ALE(without S) – ALE(with S) – ACS(S)
- S is cost effective if ANB(S) > 0

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Common Complaint

Why do people always say that installing a security mechanism is an overhead?

- Because they anticipate the loss due to an attack to be ZERO!!!
  - ANB(S) = 0 – ACS(S)

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Quantitative Methodology: Example 1

- Suppose due to a software flaw, a company's web site sometimes leave company credit card names and numbers exposed. Each year, an average of 25 exposed numbers are exploited for credit card fraud with an average loss of $1000. A software update to correct the flaw will cost $45,000 to develop, test, and deploy, plus $5,000 per year in additional maintenance costs. The software would be used for 3 years before a planned system upgrade will replace all the software.
  - SLE = $1000
  - ARO = 25
  - ALE = $25,000
  - ACS - ($45,000/3) + $5,000 = $20,000
  - ANB = $25,000 - 0 - $20,000
- The software update is cost effective, and should be done.
- If the update costs more that $60,000, then is is not cost effective and the upgrade should not be done.

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Quantitative Methodology: Example 2

A large retailer earns $1M per day on web sales. A DDOS attack could potentially put them offline for one day. The CSO estimates the probability of a successful attack over the course of a year is 10%. A new firewall that costs $200K and has a lifespan of 4 years will block most DDOS attacks, and reduce the probability of a successful attack to 1%. Annual maintenance costs are $30,000.

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Quantitative Methodology: Example 2

SLE = $1,000,000

ARO(without S) = .1

ARO(with S) = .01

ALE(without S) = $100,000

ALE(with S) = $10,000

ACS - ($200,000/4) + $30,000 = $80,000

ANB = $100,000 - $10,000 - $80,000 = $10,000

- The firewall is cost effective and should be deployed
- If the firewall reduced the ARO to 2%, it would break even
- If the firewall reduced the ARO to 3%, it would not be cost effective

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Quantitative: Useful or Not?

- Pro:
  - Objective, independent process
  - Solid basis for cost/benefit analysis of safeguards
  - Credibility for audit, management (especially corporate management)
  - This type of approach is useful for many kinds of reliability related design questions (e. g., redundant servers, etc.), where threats and likelihood of “events” can be accurately modeled statistically
  - Quantitative risk assessment is the basis for insurance, risk managed portfolios, etc.
- Con
  - In most cases, it is difficult to enumerate all types of events and get meaningful data on probability and impact
  - Very time consuming, costly to do right
  - Many unknowns may give a false sense of control
  - Not reliable for “rare” events or “unthinkable” impacts

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Qualitative Approach

- Establish classes of loss values (“impact”), such as
  - Low, medium, high
  - Under $10K, between $10K and $1M, over $1M (used by at least one company)
  - Type of loss (e. g. compromise of credit card #, compromise of SSN, compromise of highly personal data)
  - Minor injury, significant injuries, loss of life, large scale loss of life (used by emergency response organizations to categorize non-IT events)
  - Rank ordering

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Qualitative Approach

- DoD classified information:
  - CONFIDENTIAL “shall be applied to information, the unauthorized disclosure of which reasonably could be expected to cause damage to the national security”
  - SECRET “shall be applied to information, the unauthorized disclosure of which reasonably could be expected to cause serious damage to the national security”
  - TOP SECRET “shall be applied to information, the unauthorized disclosure of which reasonably could be expected to cause exceptionally grave damage to the national security”
- According to Wikileaks' Cablegate website, out of 251,287 leaked cables, 15,652 were designated 'secret', 101,748 were designated 'confidential', and 133,887 were unclassified.

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Qualitative Approach (continued)

- Establish classes of likelihood of compromise
  - Low, medium, high likelihood
- Decide on a risk management approach to each combination of (class of loss, likelihood of loss)
- Focus effort on medium to high loss and/or medium to high likelihood items

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Qualitative example: Password Manager Blocking

- Blocking password managers may make automated cracking more difficult in some cases
  - Suppose this makes 10% of account cracking attempts fail
  - However, 21% of users now use guessable passwords

Has this harmed or helped security?

http://www.wired.com/2015/07/websites-please-stop-blocking-password-managers-2015/

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Threat Modeling Summary

1. Enumerate assets
2. Determine the threats to the system
3. Perform risk assessment
4. Perform risk management
    1. If needed, perform risk mitigation by developing cost-effective security mechanisms

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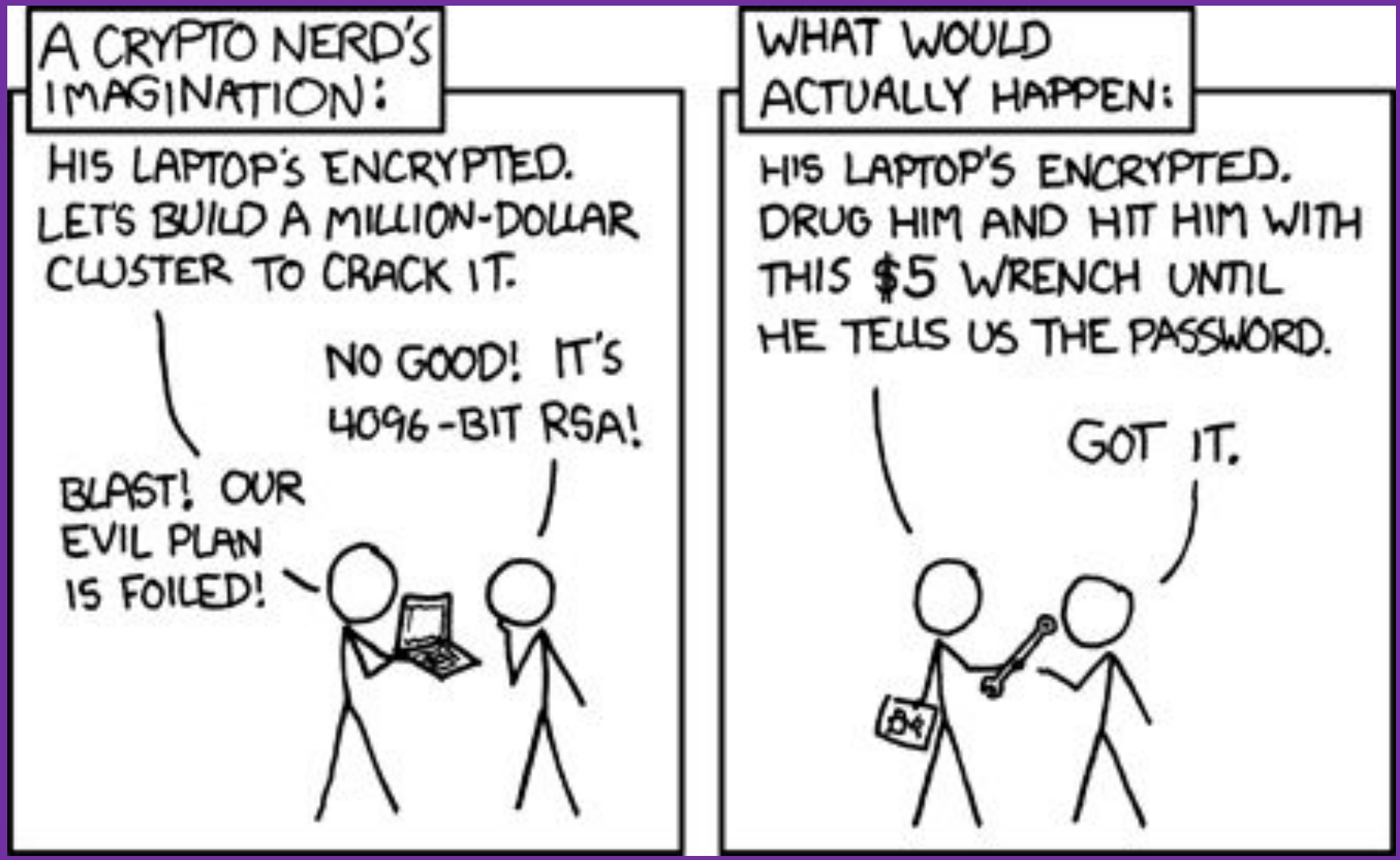
Be Realistic About Modeling Threats...



[*] comic from xkcd

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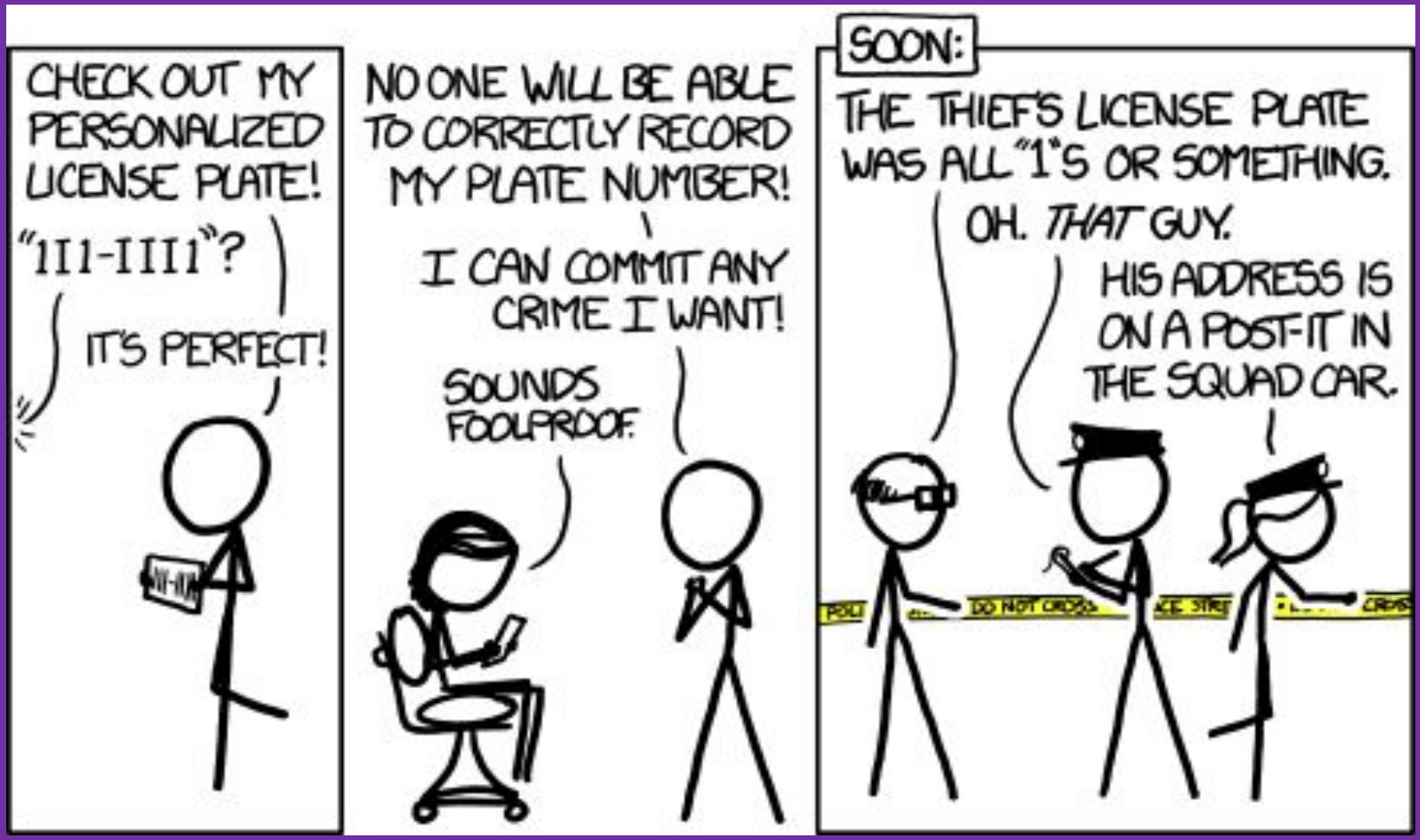
Week 3

And The Effectiveness of Defenses!



[*] comic from xkcd

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Week 3

Reading Next Week

Read: Threat Modeling as a Basis for Security Requirements
Read "Attack Trees" by Bruce Schneier
Think:
How might you get a copy of a 'do-not-duplicate' key?
Read:
http://www.forbes.com/sites/kashmirhill/2011/08/01/how-face-recognition-can-be-used-to-get-your-social-security-number/
Purpose: Think about threat modeling!
* How to crack a master lock combination (the inefficient way):
http://www.youtube.com/watch?v=PVlArw7_cz4
(the more efficient way) https://www.youtube.com/watch?v=09UgmwtL12c
* Feynman safe cracking:
http://www.youtube.com/watch?v=Waw11zhaKSk

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