Threat-Based Metrics for Continuous Enterprise Network Security Management

Richard Lippmann and James Riordan
MIT Lincoln Laboratory
Lexington, MA 02420-9108
{lippmann,james.riordan}@ll.mit.edu

To be Presented at
IFIP Working Group 10.4 Workshop on
Security Assessment: Metrics and Methods
24 January 2014

*This work is sponsored by the Department of Homeland Security under Contract FA8721-05-C-0002.
Opinions, interpretations, conclusions, and recommendations are those of the author and
are not necessarily endorsed by the United States Government.

Outline

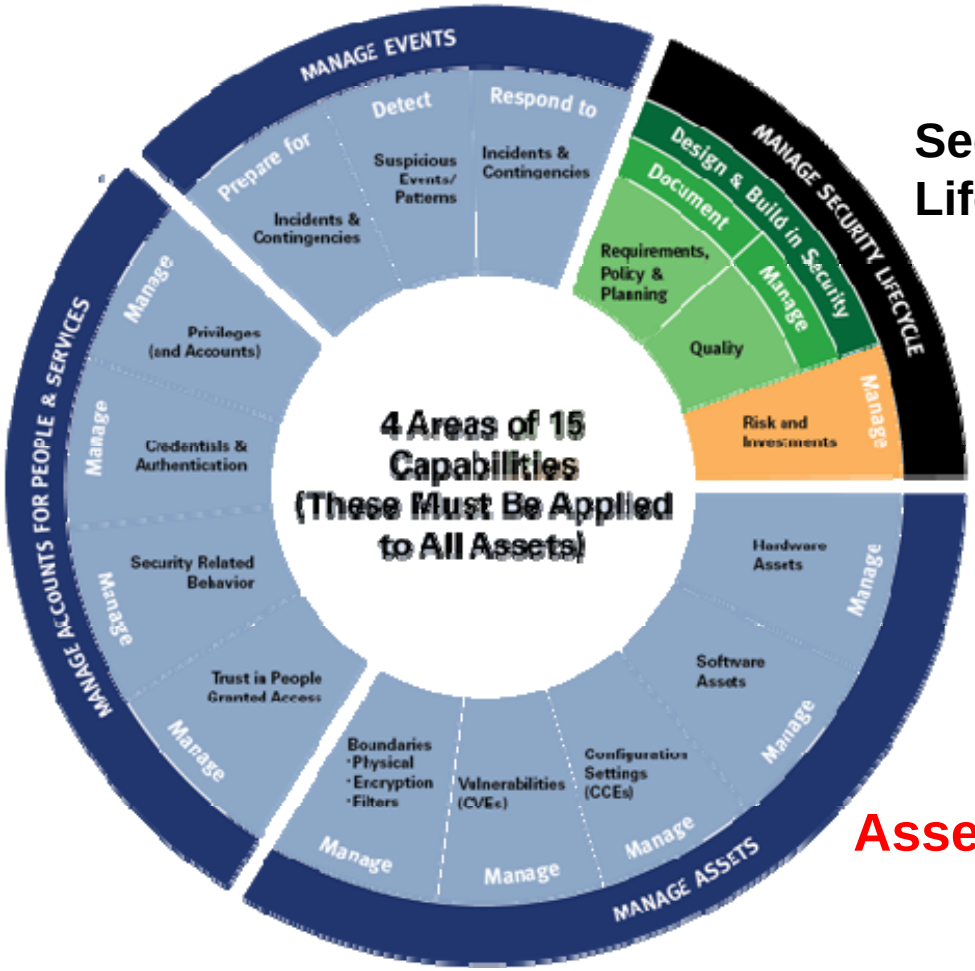
- Introduction to Continuous Diagnostics and Mitigation
- Metric Overview
- Limitations of prior metrics
- Metric LR-1: Attacker scanning for unauthorized devices
- Metric LR-3: Attackers exploiting known vulnerabilities
- Summary and future plans

15 Security Capabilities that Must be Managed (U.S. Department of Homeland Security)

Events

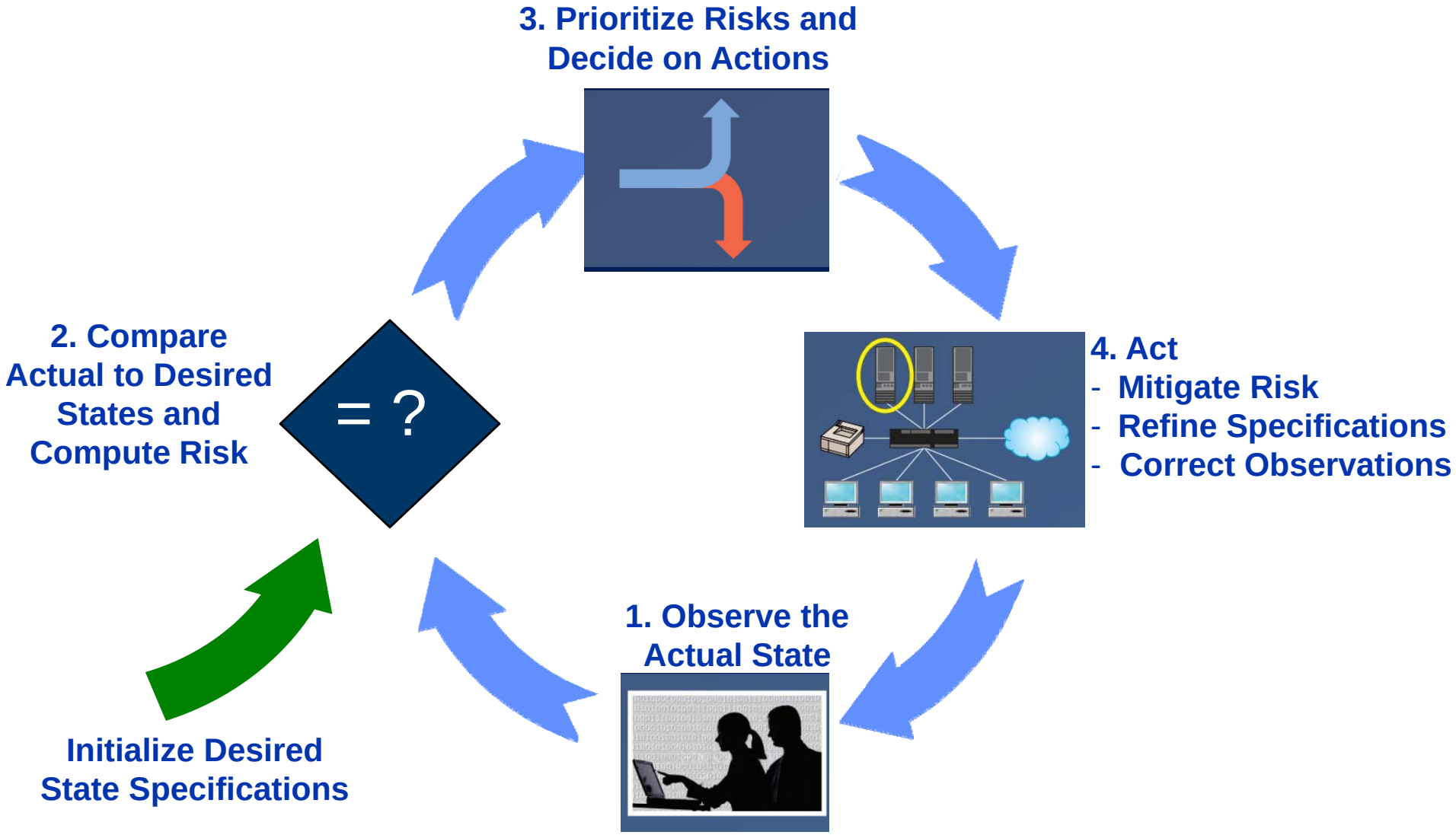
Security Lifecycle

Accounts for People and Services

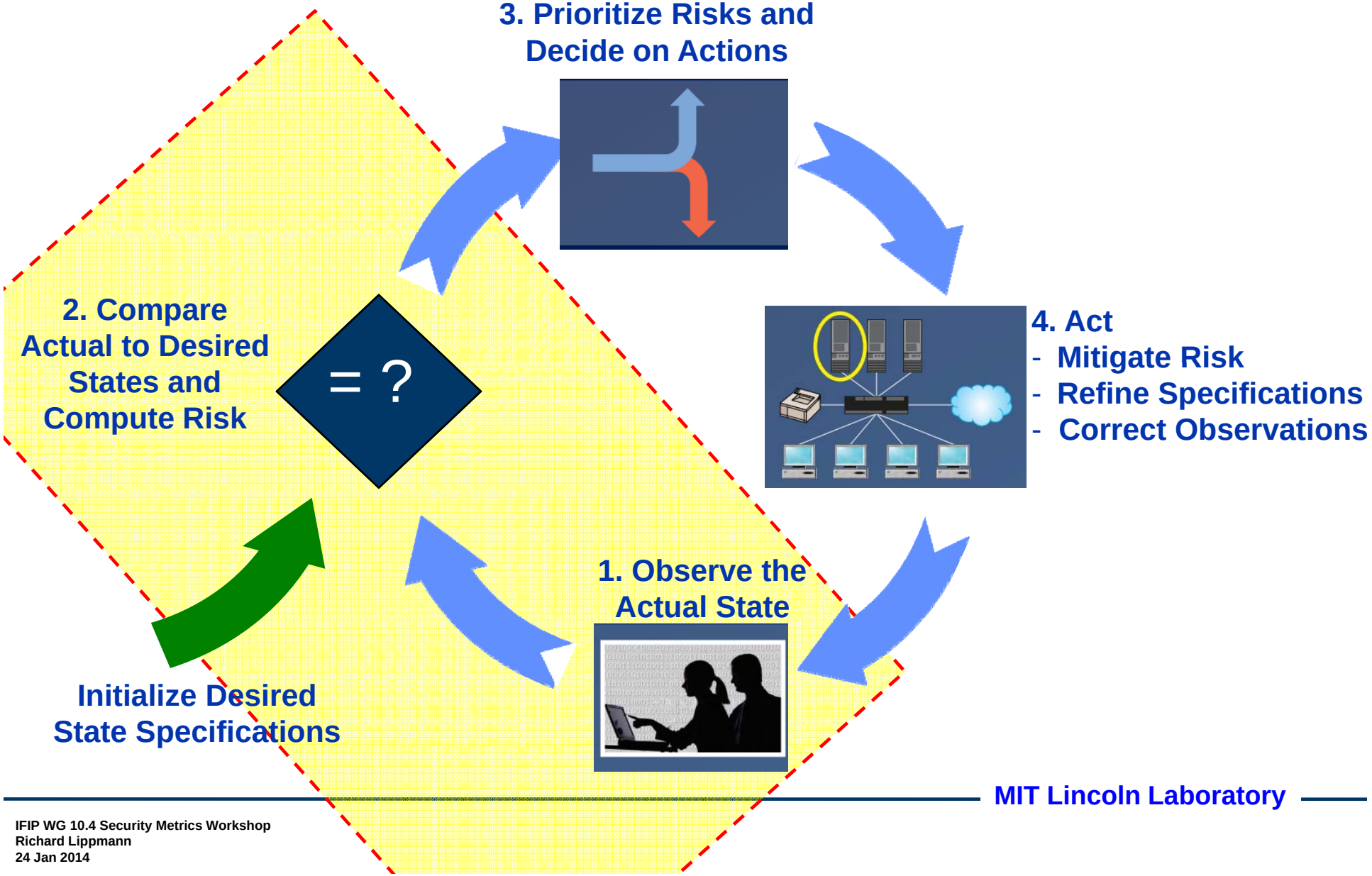


Assets

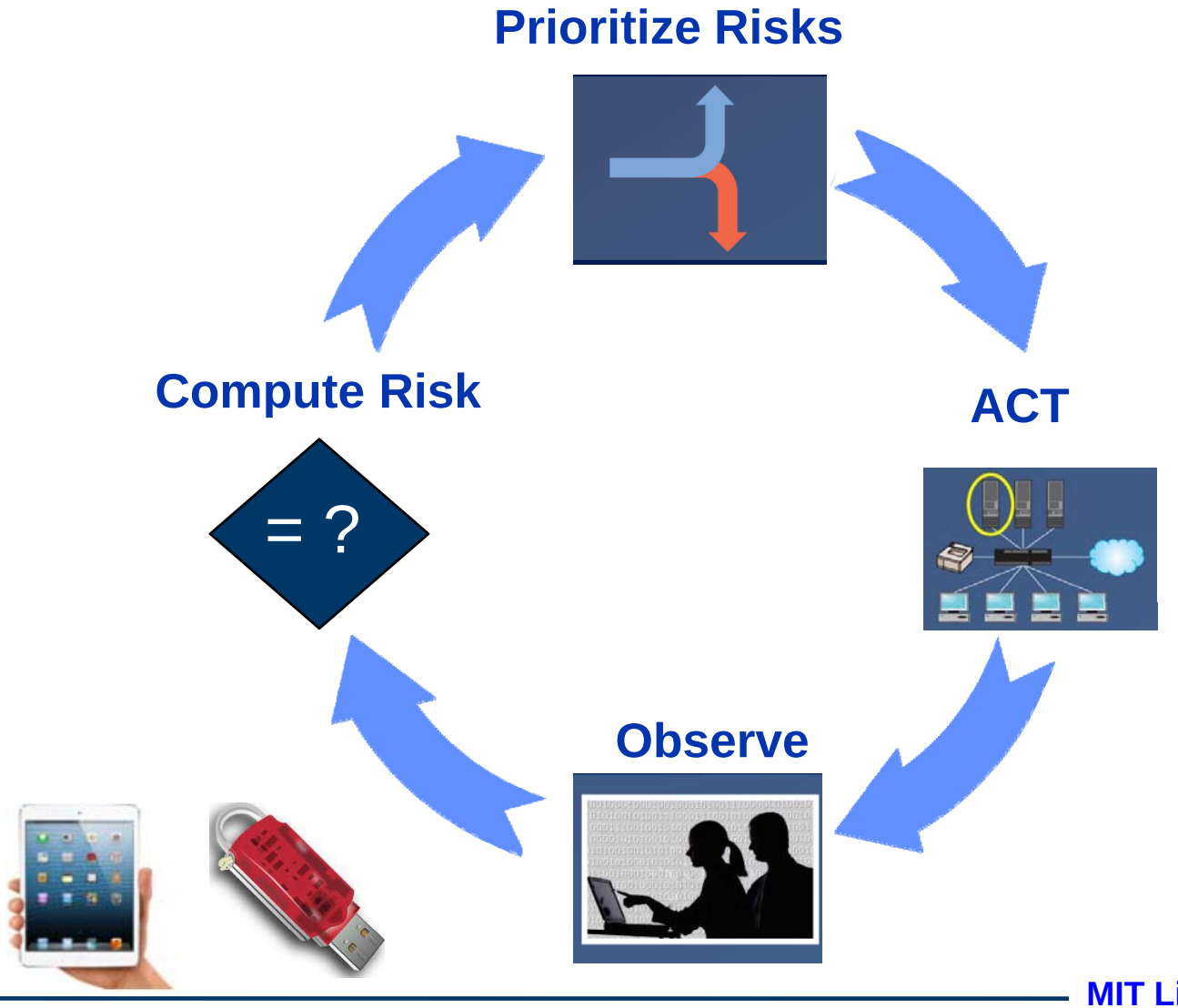
A Continuous Diagnostics and Mitigation (CDM) Process Controls Risk for Each Capability



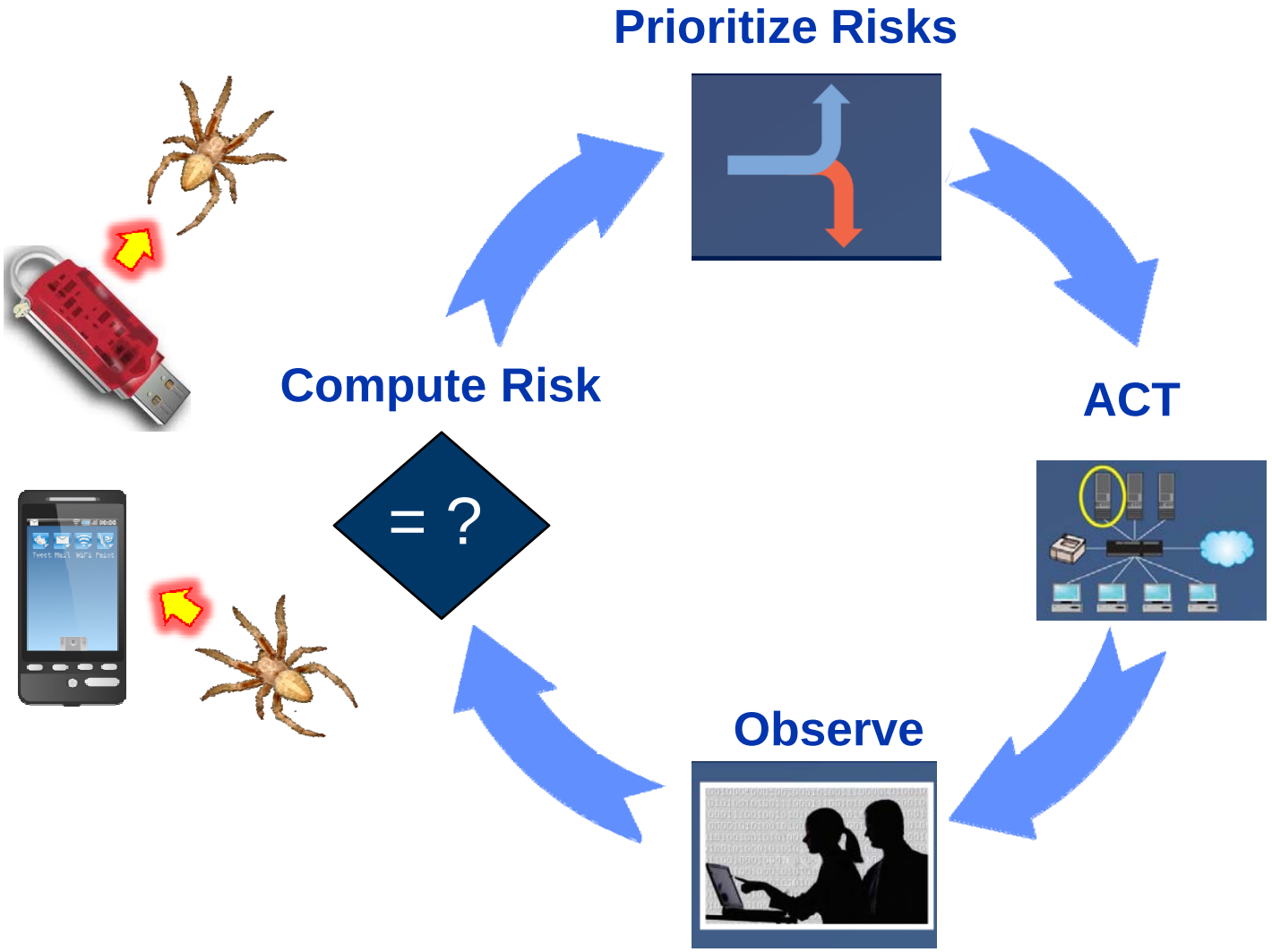
A Continuous Diagnostics and Mitigation (CDM) Process Controls Risk for Each Capability



One Example is Managing the Use of Unauthorized Devices on a Network



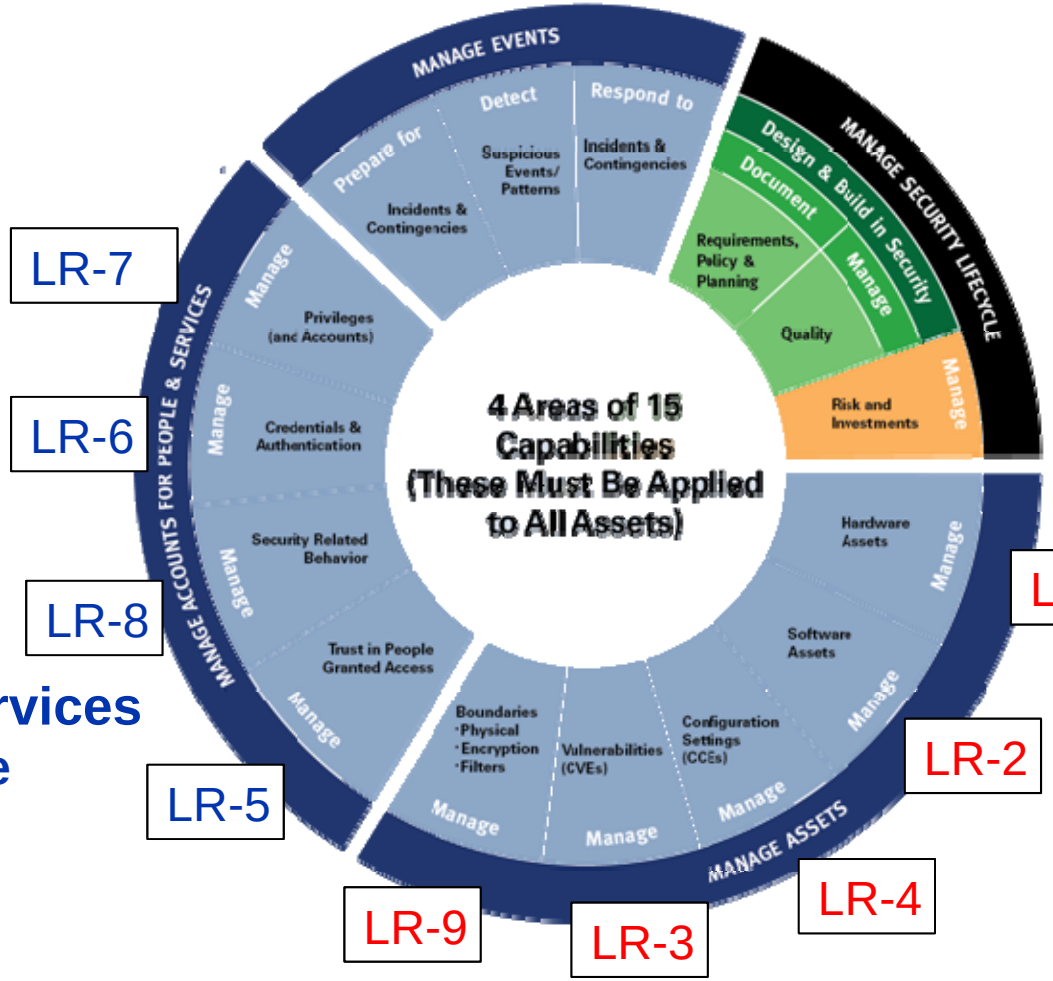
Attackers can Either Observe and Compromise Insecure Devices or Spread from Already Infected Devices



Outline

- Introduction to Continuous Diagnostics and Mitigation
- Metric Overview
- Limitations of prior metrics
- Metric LR-1: Attacker scanning for unauthorized devices
- Metric LR-3: Attackers exploiting known vulnerabilities
- Summary and future plans

We Have Created Metrics for Nine of Fifteen Capabilities



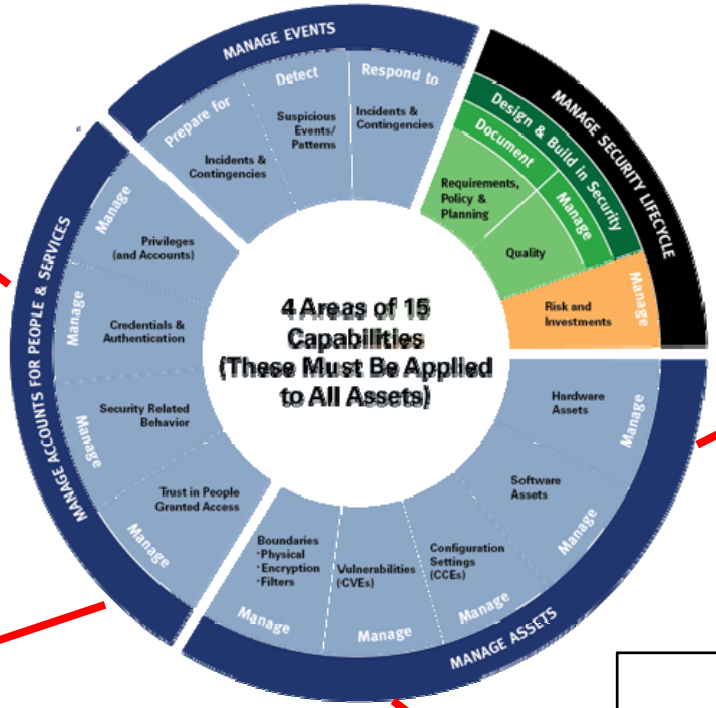
People and Services

5. Trust in People
6. Credentials
7. Accounts and Privileges
8. Behavior and Training

Assets

1. Hardware
2. Software
3. Vulnerabilities
4. Configuration
9. Boundaries

Each Metric Focuses on the Most Important Attack(s) for one Capability



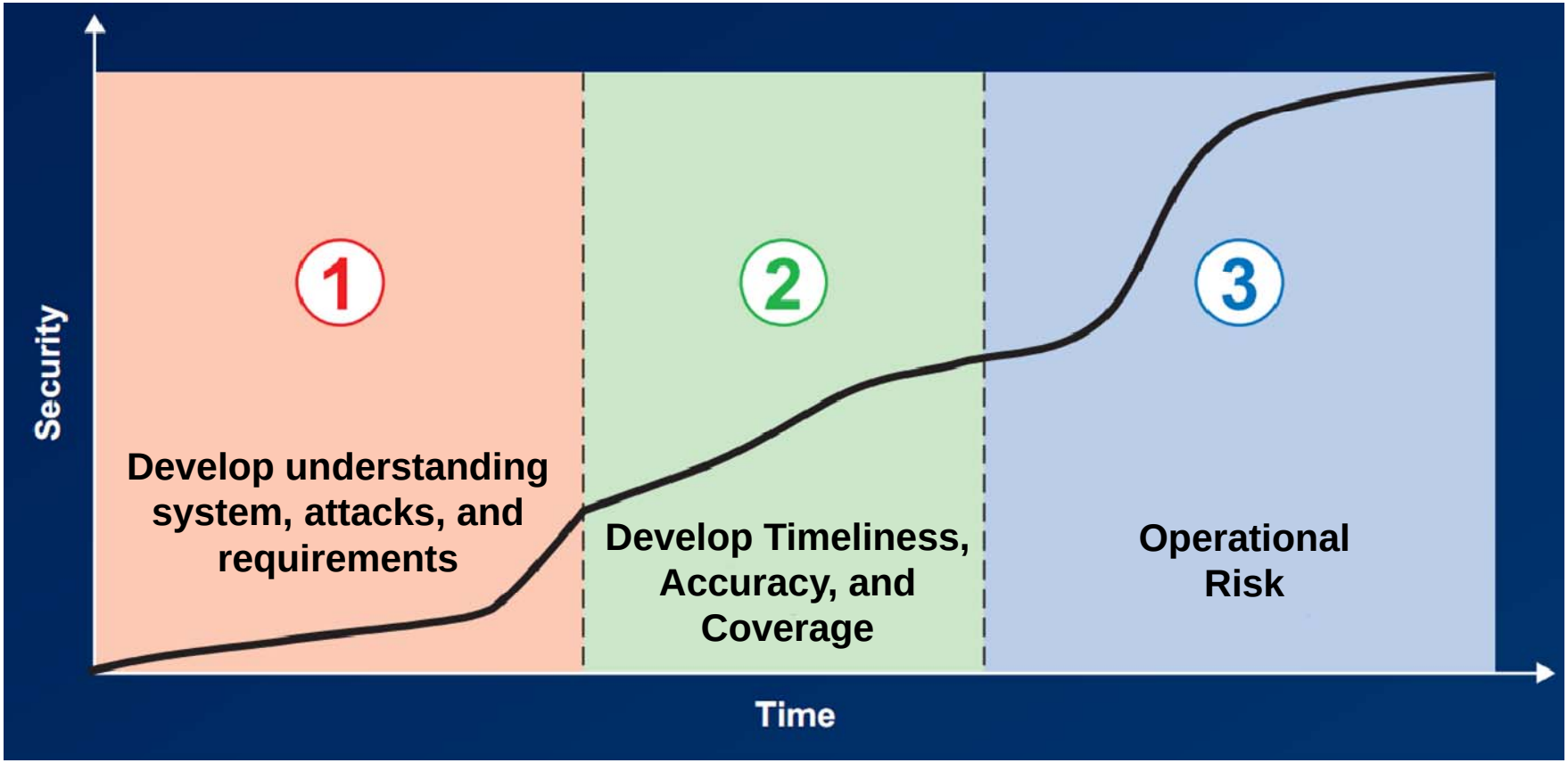
Client Side

Google Chrome

Java

Firefox

A Three-Stage Security Metric Maturity Model



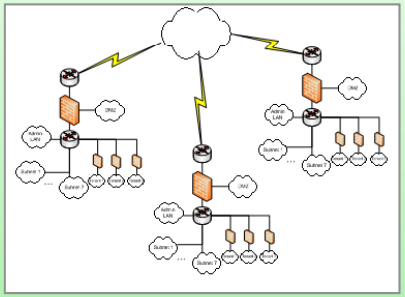
Checklist Metric

Capability Deficit Metric

Operational Risk Metric

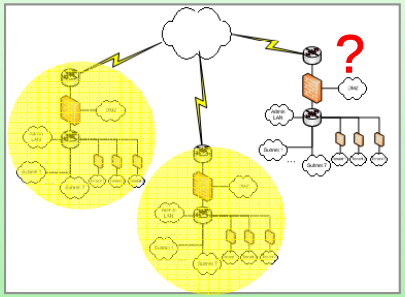
Level 2 Capability Deficit Metrics Determine If Risk Can Be Computed Accurately

Specification



Define what is required / permitted

Coverage



Perform measurements across all entities

There are few standard aspects to the Capability Deficit metric…

Timeliness

Observe frequently enough to reliably detect a short duration security event

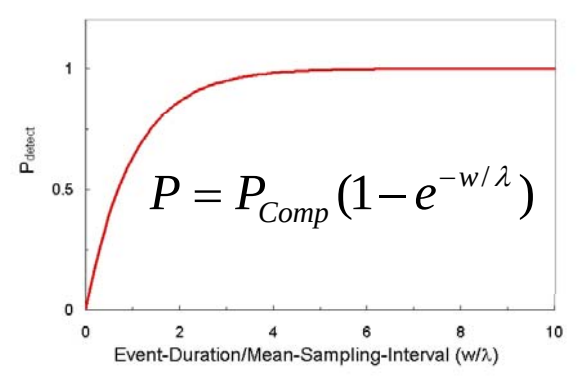
Test Error

Insecure states are correctly classified (no misclassification)

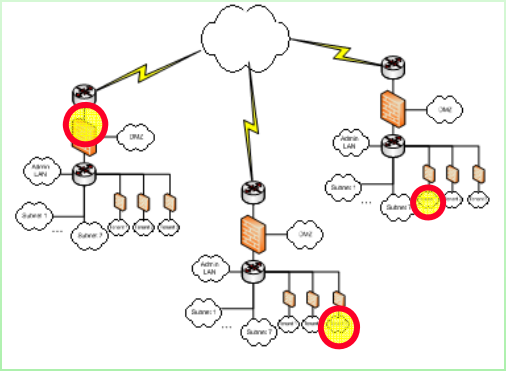
Level 3 Operational Risk Metrics Estimate the Risk Based on the Observed State

Risk = Probability of Successful Attack x Impact

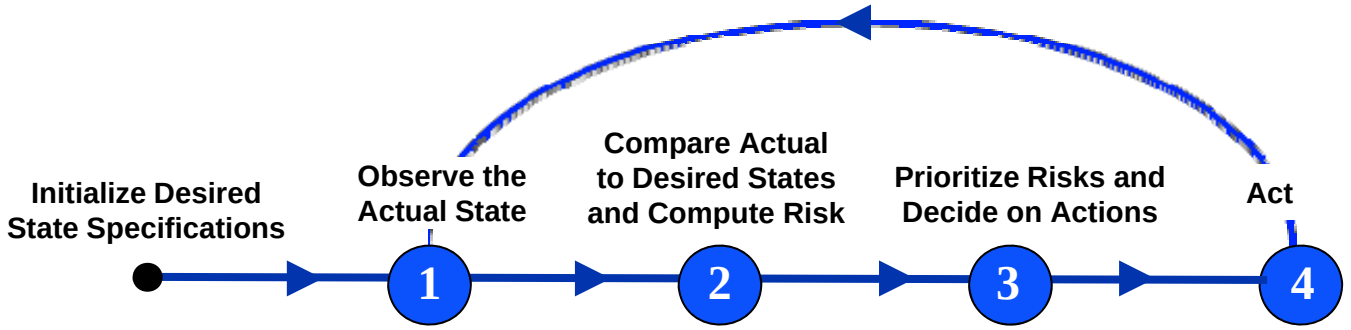
Compute Probability of Attack Success



Compute Attack Impact Based on Affected Devices



Metric Computation is Embedded in and Enables Continuous Diagnostics and Mitigation



Level 2 - Capability Metrics

(Specification, Timeliness, Accuracy, Coverage)

"*How likely am I to miss a risk condition?*"

Level 3 - Operational or Risk Metrics

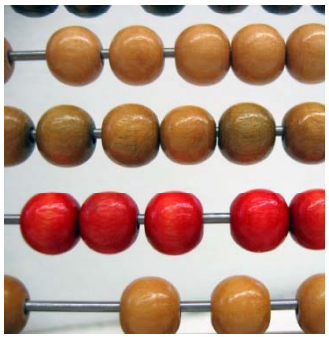
(Risk)

"*How much value, on average, is captured by this adversary?*"

Outline

- Introduction to Continuous Diagnostics and Mitigation
- Metric Overview
- Limitations of prior metrics
- Metric LR-1: Attacker scanning for unauthorized devices
- Metric LR-3: Attackers exploiting known vulnerabilities
- Summary and future plans

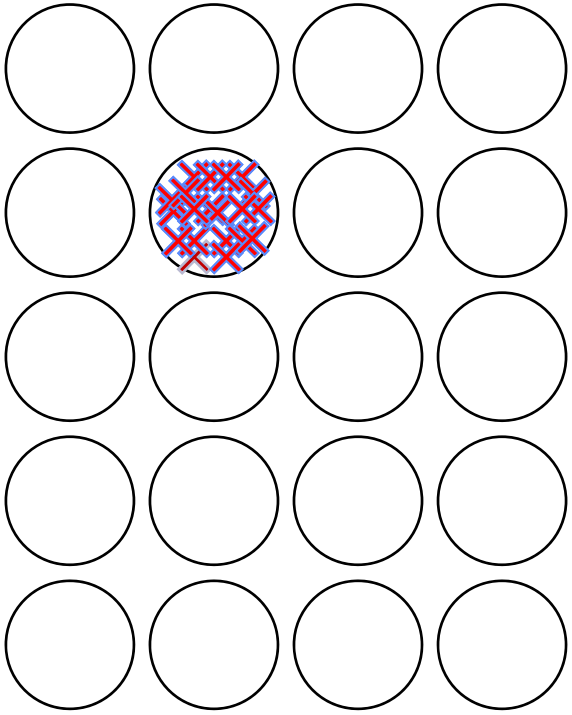
Existing Risk Metrics Can Not be Used in a Real-Time Diagnostic and Mitigation Loop



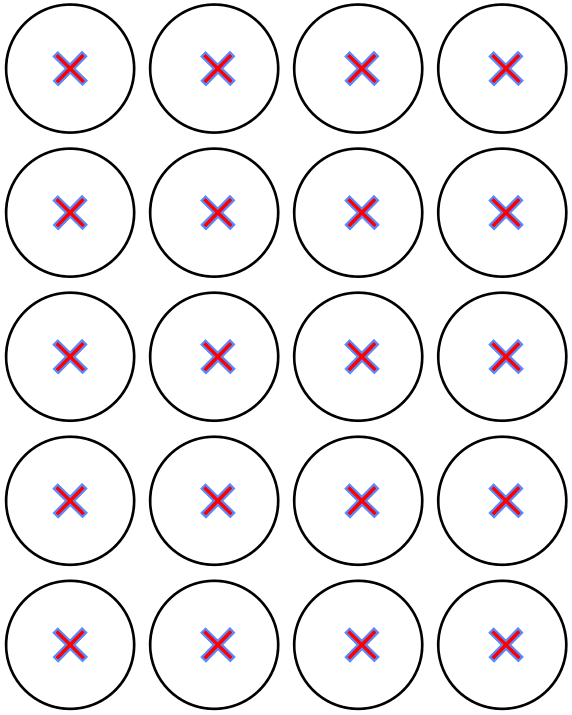
- Count- and percentage-based assessments do not model attackers correctly
  - Percentage of devices behind firewall / with anti-virus software
  - Mean / median lag of patch installation

- Other approaches are subjective and can't be automated
  - Annual Loss Expectancy = (Annual Rate)×(Loss)
  - Business Adjusted Risk = (Impact)×(Risk of Exploit)
  - Mission Oriented Risk and Design Analysis (MORDA)

A Count of Serious Vulnerabilities Can be Misleading

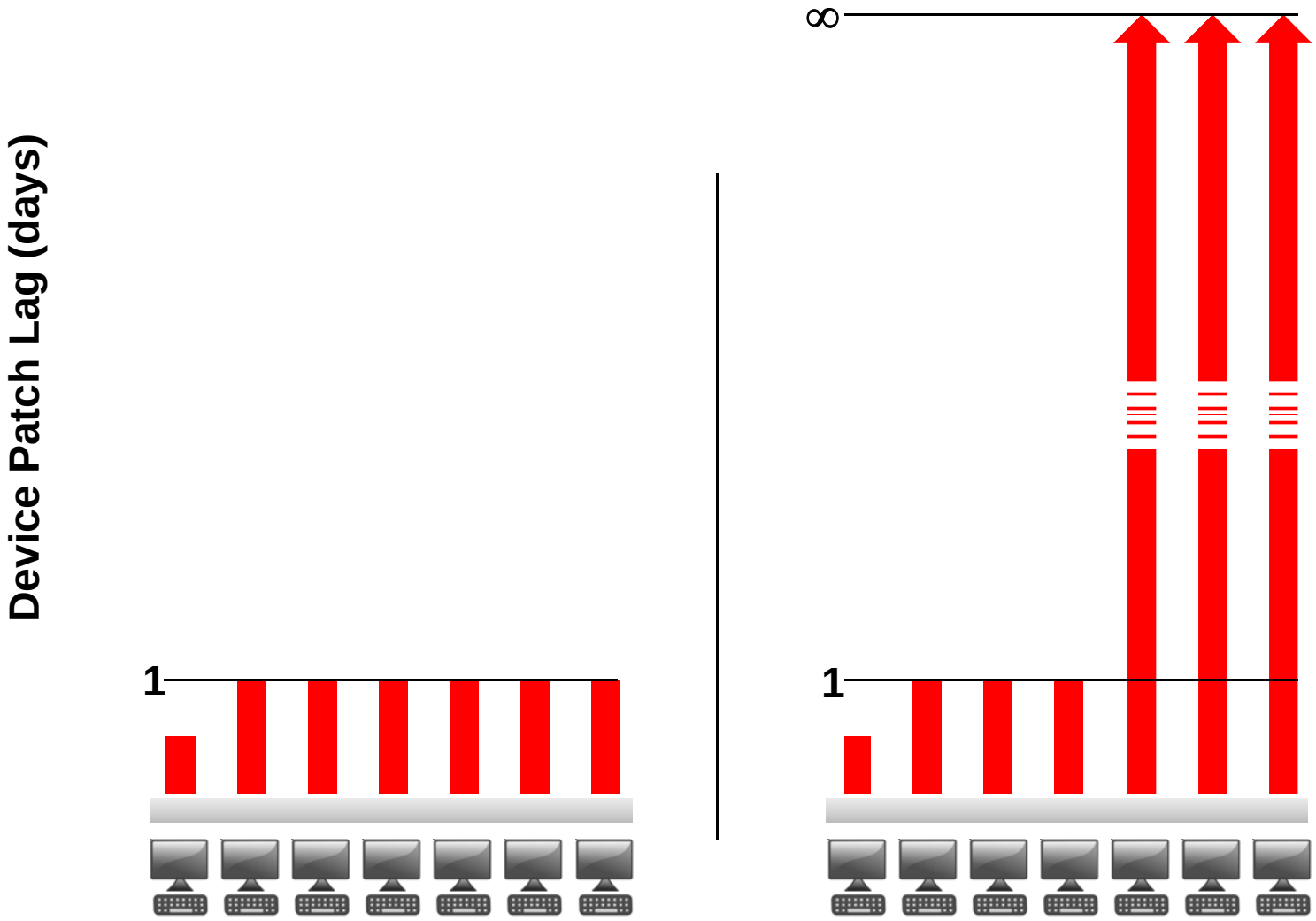


One machine with twenty serious vulnerabilities



Twenty machines each with one serious vulnerability

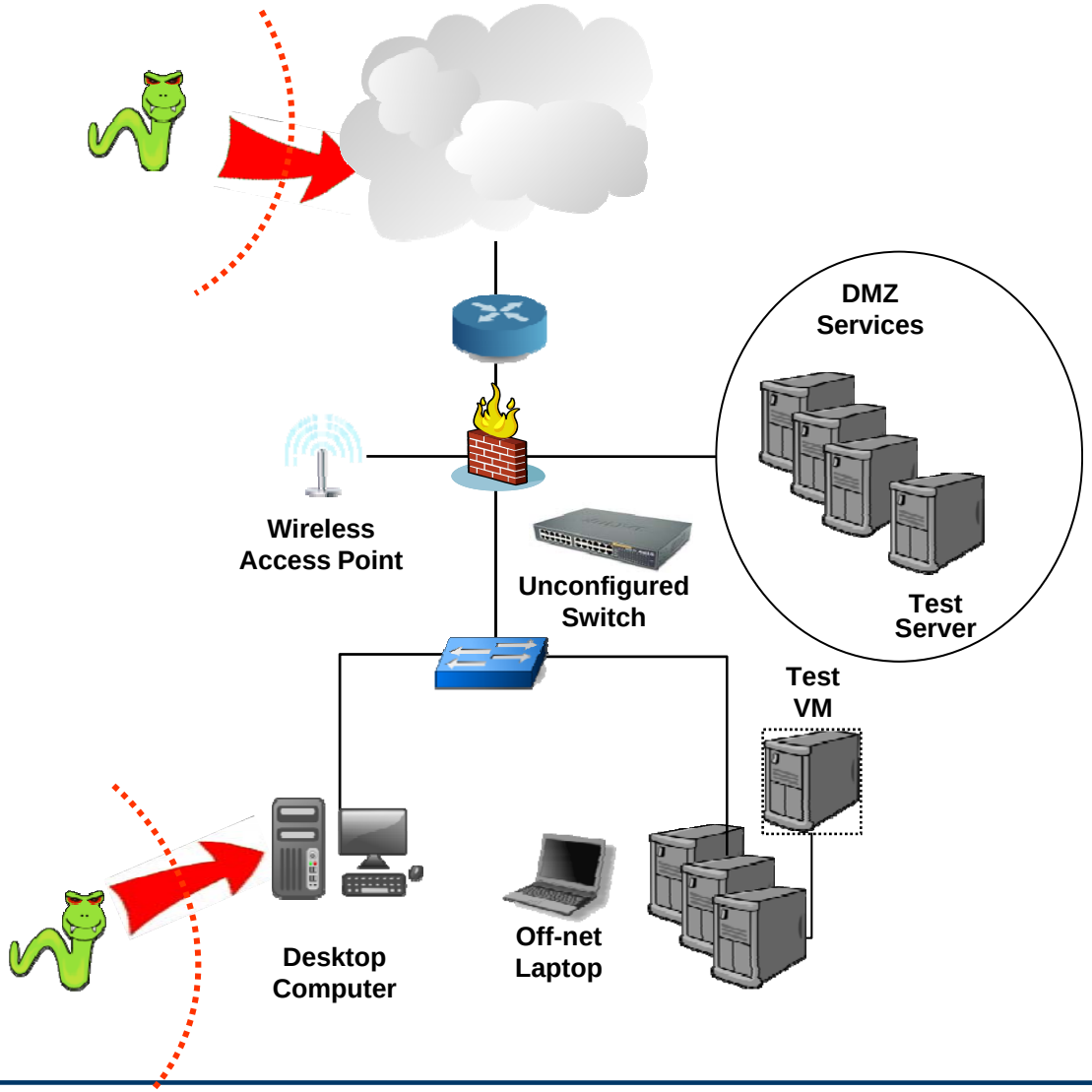
Median Patch Lag is Difficult to Interpret



Outline

- Introduction to Continuous Diagnostics and Mitigation
- Metric Overview
- Limitations of prior metrics
- Metric LR-1: Attacker scanning for unauthorized devices
- Metric LR-3: Attackers exploiting known vulnerabilities
- Summary and future plans

One Attack Model in LR-1 is Attackers Looking for and Compromising Insecure Unauthorized Devices

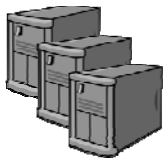


- Assume unauthorized devices are unmanaged, hence vulnerable
- Attackers observe the network to look for these devices
- Attacker may be internal or external

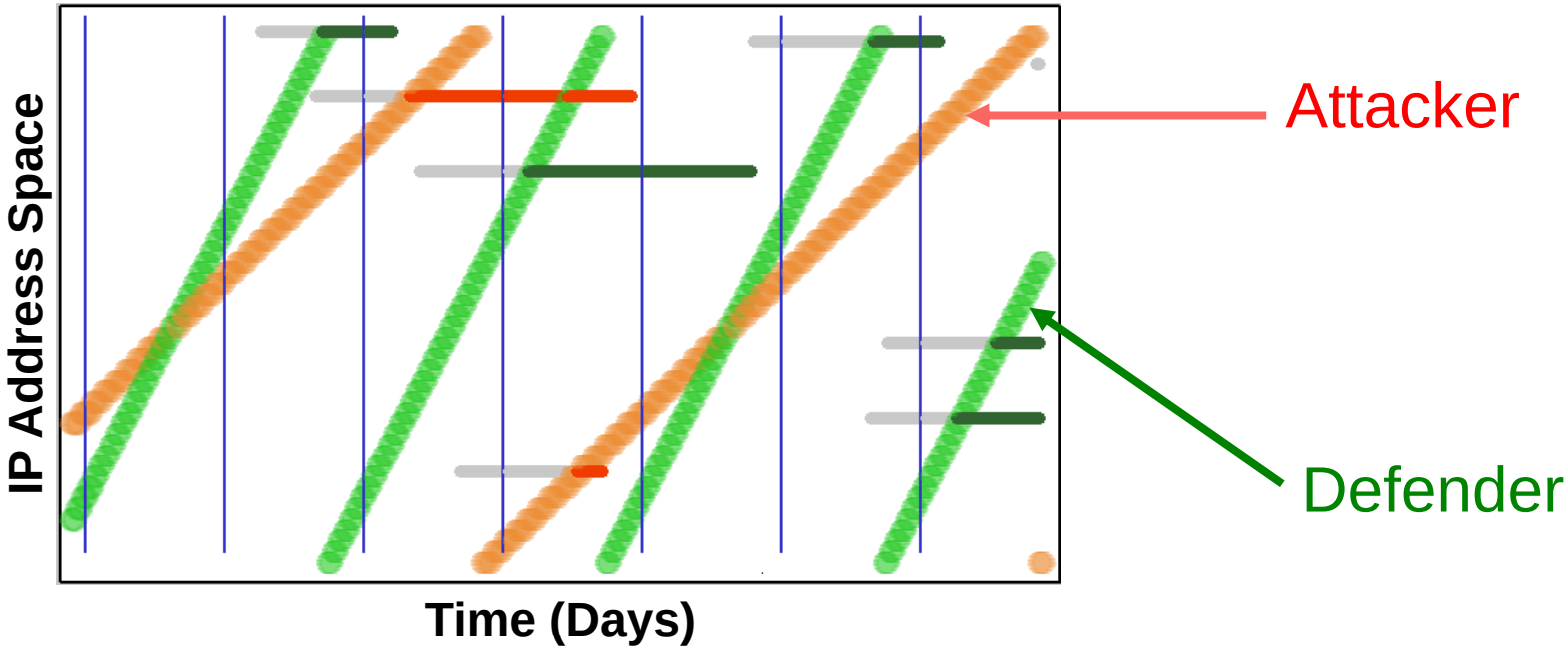
Defenders Continuously Search for and Process Discovered Unauthorized Devices

Authorized Device List

Subnet	IP Addr	MAC
ALAN	10.1.2.3	aa:12:bb:34:cc:56
BLAN	10.4.5.6	cc:12:bb:34:cc:54
DMZ	18.9.2.14	2d:ab:99:ff:83:83



We can Compute the Probability of Detecting a Finite Duration Event by Scanning

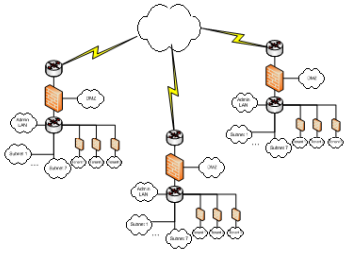


- **The probability of detection of an event of duration w with a scan interval δ is given by**

$$P_{\text{Observe}}(w,\delta) = \min\left(1, \frac{w}{\delta}\right)$$

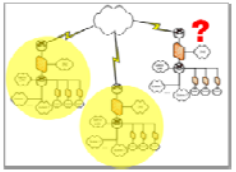
LR-1 Capability Deficit Metric Components

Specification Deficit



$$SpecD_{subnet}(i) = 1 - I_{inventory\_specified}(i)$$

Coverage Deficit



$$CovD_{subnet}(i) = 1 - I_{covered}(i)$$

Timeliness Deficit

Probability of missing an event of a specified duration W

$$TimeD\left(W, \{\delta_j\}, i\right) = \sum_{i=0}^{n-1} \left[\frac{\max\left(0, \delta_{j+1} - \delta_j - W\right)}{\left(m_{\text{end}} - m_{\text{start}} - W\right)} \right]$$

Test Error

$$TestD = P_{miss}(i)$$

given the insecure condition was observed but not recognized

Overall Capability Deficit Metric

$$CD = 1 - (1 - TimeD) \cdot (1 - CovD) \cdot (1 - TestD) \cdot (1 - SpecD)$$

The LR-1 Operational Metric Is the Asset Value of the Expected Compromised Unauthorized Devices

Sum over all unauthorized devices of the probability of each being compromised

$$OM_{Unauth} = \sum_{\substack{Unauthorized \\ Devices}} AV \cdot P(Comp \mid Observed) \cdot P_{Observed}$$

Compute probability of attacker observing the unauthorized device from the window of presence and attacker scan rate

$$P_{\text{Observed}}(w, \Delta) = \min\left(1, \frac{w}{\Delta}\right)$$

w = Window of time unauthorized device is present

Δ = Attacker device sampling interval

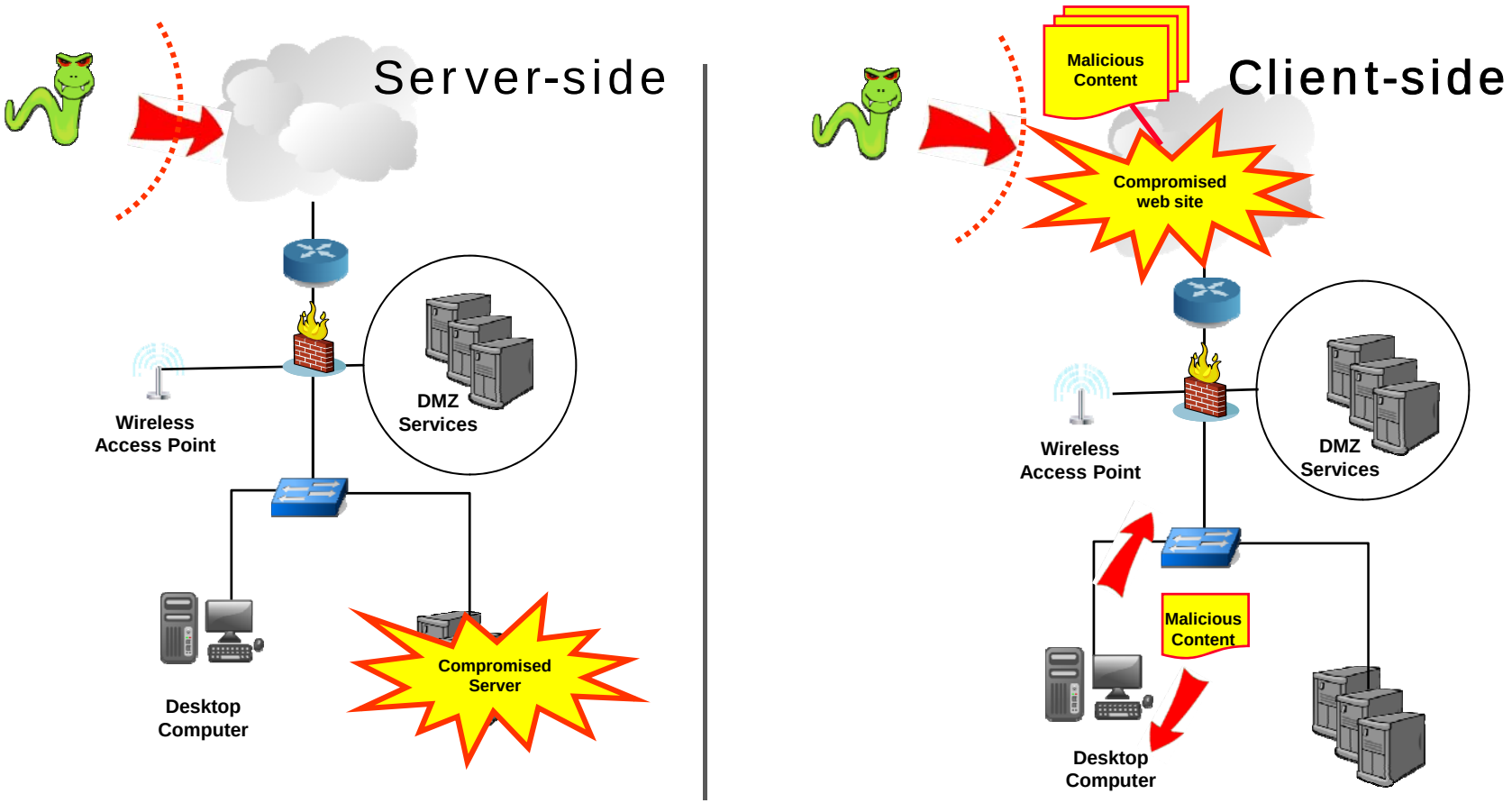
P(Comp|Observed) = Probability device is compromised given the it is observed by an attacker

AV = Asset Value for an unauthorized device

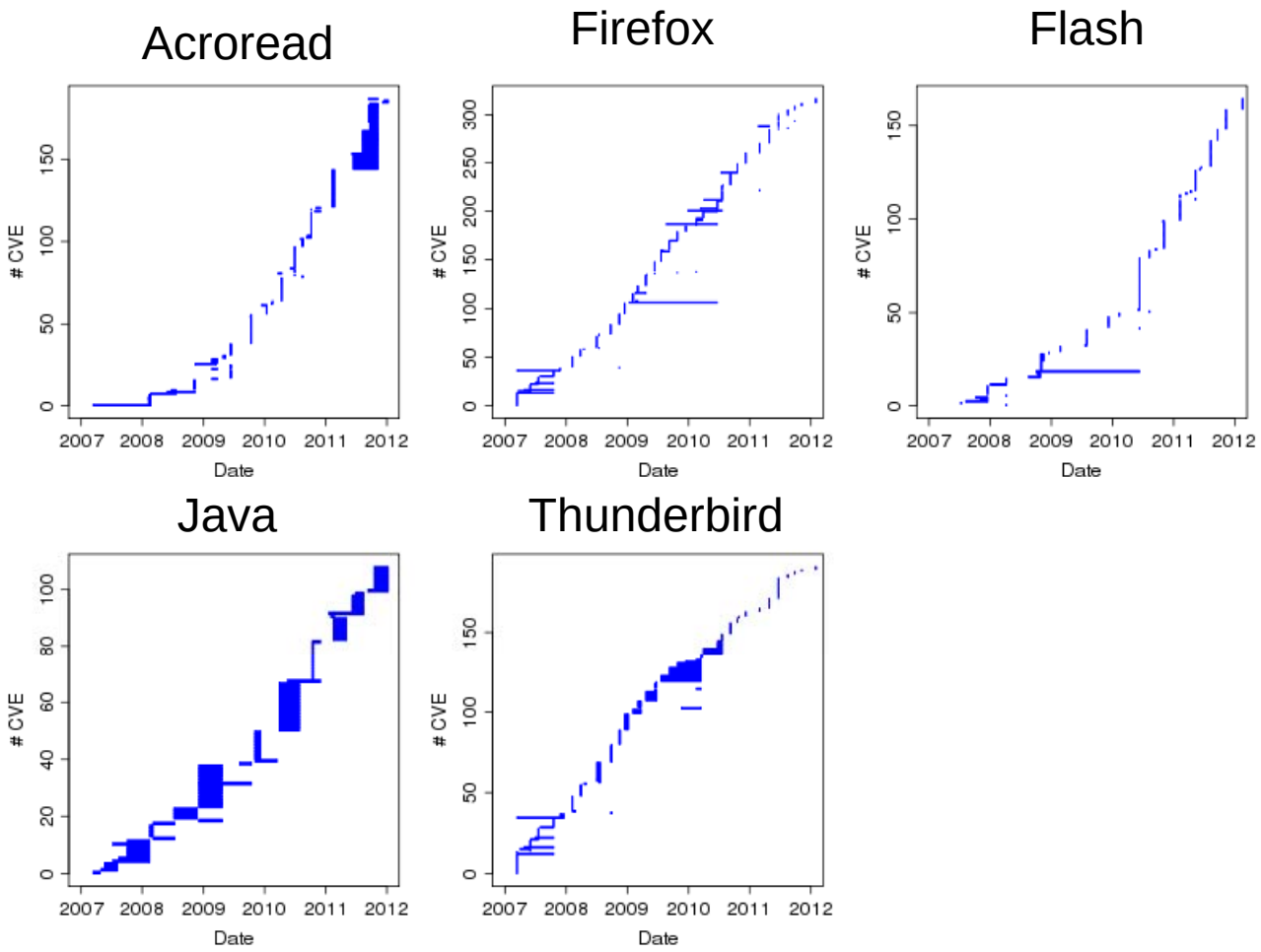
Outline

- Introduction to Continuous Diagnostics and Mitigation
- Metric Overview
- Limitations of prior metrics
- Metric LR-1: Attacker scanning for unauthorized devices
- Metric LR-3: Attackers exploiting known vulnerabilities
- Summary and future plans

Server and Client-Side Attack Models for Exploitation of Known Vulnerabilities



Client-Side Vulnerabilities Are Discovered From 20 to 60 Times Per Year for Many Client Applications



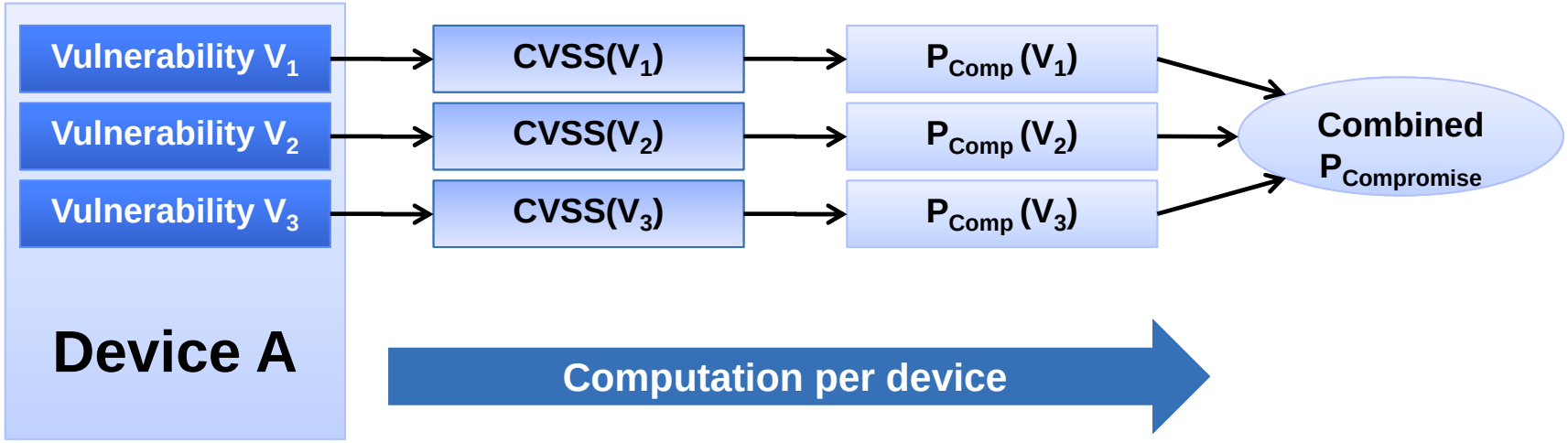
- **Vulnerability scanners and patch tools are updated following publication and patch release dates**

We Compute the Probability of Compromising a Device for Each Vulnerability using Its CVSS Score

- **Assume that the probability of compromising a device by exploiting vulnerability *v* depends on its Common Vulnerability Scoring System (CVSS) score as**

$$P_{Compromise}(v) = \left(\frac{cvss(v)}{10} \right)^2$$

- **How do you compute the probability of compromise with multiple vulnerabilities?**



The Approach Used to Combine Vulnerabilities Depends on the Attacker Model

$P_{Compromise}$	Attacker Model
$1 - \prod (1 - P_i)$	• **Noisy Rich Attacker** – Attacker tries all available vulnerabilities until the device is successfully compromised
$\max (P_i)$	• **Stealthy Rich Attacker** – Attacker tries only the single vulnerability with the highest probability of success
$\sum P_i / N$	• **Random Attacker** – Attacker tries to exploit one vulnerability selected at random

The LR-3 Operational Metric is the Expected Captured Asset Value across Devices

$$OM = \sum_{i \epsilon Devices} AV(i) \left\{ 1 - \prod_{v \epsilon Vulns} (1 - P_{Comp}(v,i)) \right\}$$

Noisy rich attacker on all devices

$$P_{Comp}(v,i) = P_{Compromised|Observed}(v) P_{Observed}(v)$$

Probability of single vulnerability detection and compromise

$$P_{Compromise|Observed}(v) = \left(\frac{cvss(v)}{10} \right)^2$$

Probability of a successful single vulnerability compromise

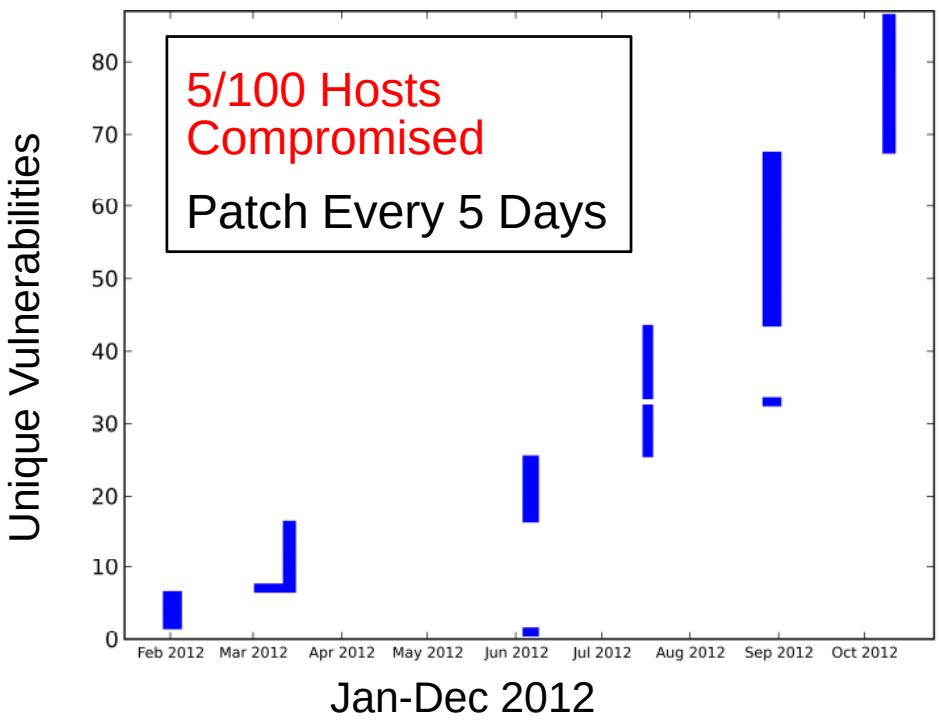
$$P_{\text{Observed}}(v,i) = \min\left(1, \frac{w_i(v)}{\Delta}\right)$$

Probability of an attacker discovering a vulnerability

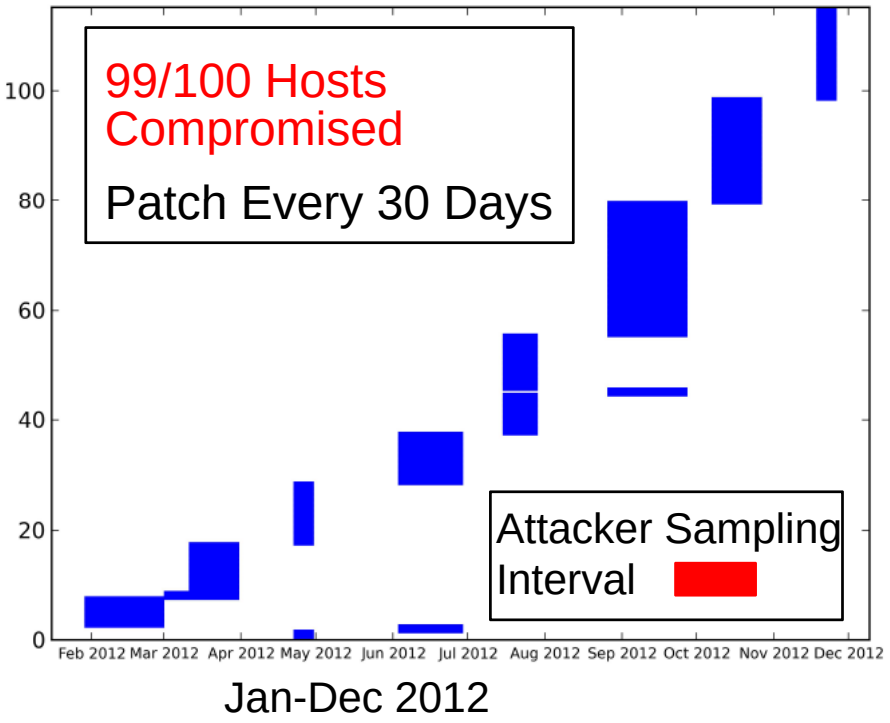
$w_i(v)$ = Window of time vulnerability v is present on device i
Δ= Attacker device sampling interval for vulnerability
AV(i) = Asset value for device i

Different Simulated Defense Strategies Lead to Large Operational Risk Metric Differences

Operational Metric = 4.9



Operational Metric = 98.6



- **Simulation has 100 Hosts each with an asset value of 1 running only Firefox**
- **Users browse to a malicious web site once every 30 days**
- **Attackers require one week after publication to field exploits on web sites**
- **Noisy rich attackers have exploits for all vulnerabilities**

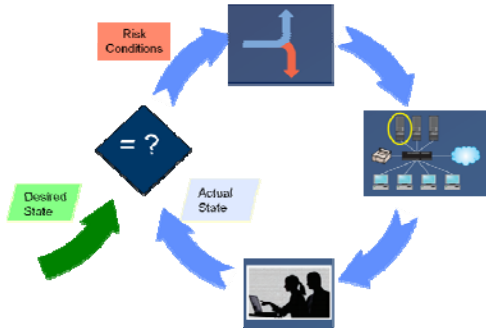
Outline

- Introduction to Continuous Diagnostics and Mitigation
- Metric Overview
- Limitations of prior metrics
- Metric LR-1: Attacker scanning for unauthorized devices
- Metric LR-3: Attackers exploiting known vulnerabilities
- Summary and future plans

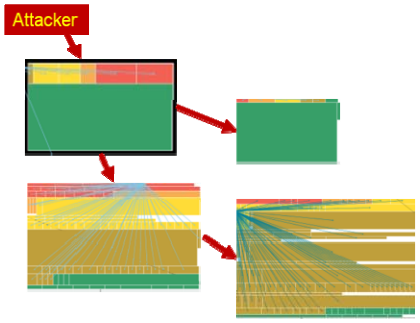
Summary

- The U.S. Department of Homeland Security (DHS) is implementing a Continuous Diagnostics and Mitigation (CDM) strategy for protecting government networks
- We will be creating metrics for 15 capabilities
- Each metric:
  - Includes up to date attacker models
  - Estimates risk from attackers
  - Includes a capability deficit component to determine if risk computations are accurate
- We are completing descriptions for the first nine metrics
- These will be used by the DHS to support continuous monitoring and risk mediation

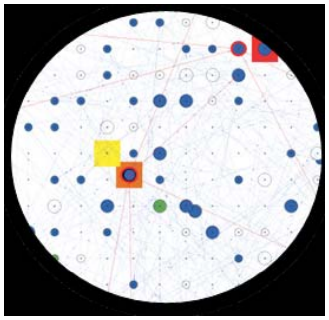
Roadmap for the Future



Continuous Diagnostics and Mitigation
(Accurate Continuous Observations,
Assess First-Step Risk,
Real-Time Operational Mitigations)



Attack Graph Analysis
(Assess Multi-Step Risk,
Prioritize and Evaluate Mitigations,
Assess Different Attackers)



Network Simulations
(Long-Term Modeling of Attacker
and Defense Strategies
and Policies)

Security Maturity Level →