Threat Modeling Research and Machine Learning

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Topics

What is Threat Modeling?

SEI Threat Modeling Research

SEI’s Hybrid Threat Modeling Method (hTMM)

CMU MITS Student Project on Machine Learning

Machine Learning and hTMM Research

What is Threat Modeling?

Threat Modeling Definition(s)

A **threat modeling method (TMM)** is an approach for creating an abstraction of a software system, aimed at identifying attackers' abilities and goals, and using that abstraction to generate and catalog possible threats that the system must mitigate. (SEI)

Threat modeling is a methodology and a tool used to identify and classify vulnerabilities which, if exploited, would result in adverse business impact. (Microsoft/Ford Motor Company)

Threat modeling is repeatable process to find and address all threats to your product. (Microsoft)

Who Does Threat Modeling?

Vendors such as Microsoft

- Microsoft uses STRIDE and makes it freely available.

U.S. Government organizations such as the DoD

- Threat modeling is mandated for the DoD.
- Various methods are in use; some are based on NIST standards; some use checklists.

Commercial organizations such as automotive industry, finance, and so on

- Various methods are in use, including STRIDE and risk analysis approaches, such as OCTAVE, attack trees, etc.

Why Do Threat Modeling (Microsoft)?

- Produce software that's secure by design
- Because attackers think differently
- Allow you to predictably and effectively find security problems early in the process

SEI Threat Modeling Research 2015 – 2016

SEI Initial Threat Modeling Research

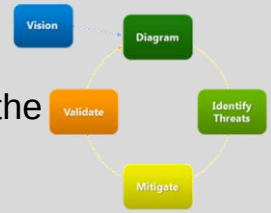
Focus on early lifecycle activities (e.g., requirements engineering, design), independent of a lifecycle model.

Evaluate competing TMMs to

- identify and test principles regarding which ones yield the most efficacy
- provide evidence about the conditions under which different ones are most effective
- allow reasoning about the confidence in threat modeling results

TMMs Studied

STRIDE

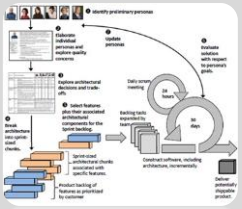


- Represents the state of the practice
- Developed at Microsoft; “lightweight STRIDE” variant adopted from Ford Motor Company
- Successive decomposition of w/r/t system components, threats

Security Cards

- Design principle: inject more creativity and brainstorming into process; move away from checklist-based approaches
- Developed at the University of Washington
- Physical resources (cards) facilitate brainstorming across several dimensions of threats
- Includes reasoning about attacker motivations, abilities

Persona non Grata (PnG)



- Design principle: make the problem more tractable by giving modelers a specific focus (here: attackers, motivations, abilities)
- Developed at DePaul University based on proven principles in HCI
- Once attackers are modeled, process moves on to targets and likely attack mechanisms

Universal weakness: empirical evaluation in the context of the software development lifecycle

STRIDE Approach

STRIDE Threat Model

Invented in 1999 by Kohnfelder & Garg; implemented at Microsoft and widely adopted

Typical implementation:

- Model system w/ Data Flow Diagrams (DFD)
- Map the DFD to Threat Categories
- Determine the threats (via threat trees)
- Document the threats and steps for prevention

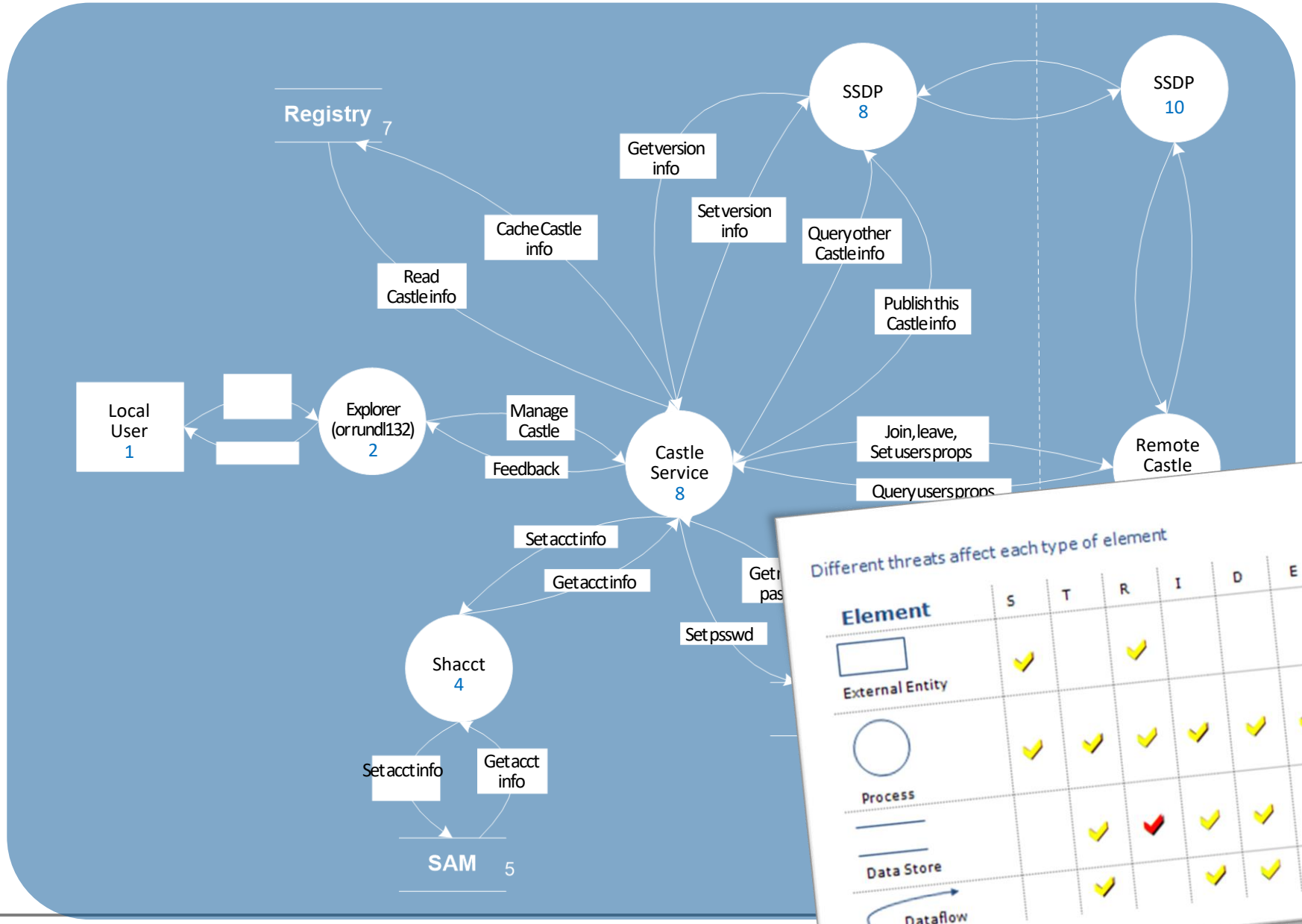
Can be implemented manually or through free SDL Threat Modeling Tool

Considered relatively easy to implement but…time-consuming and prone to different results based on implementer

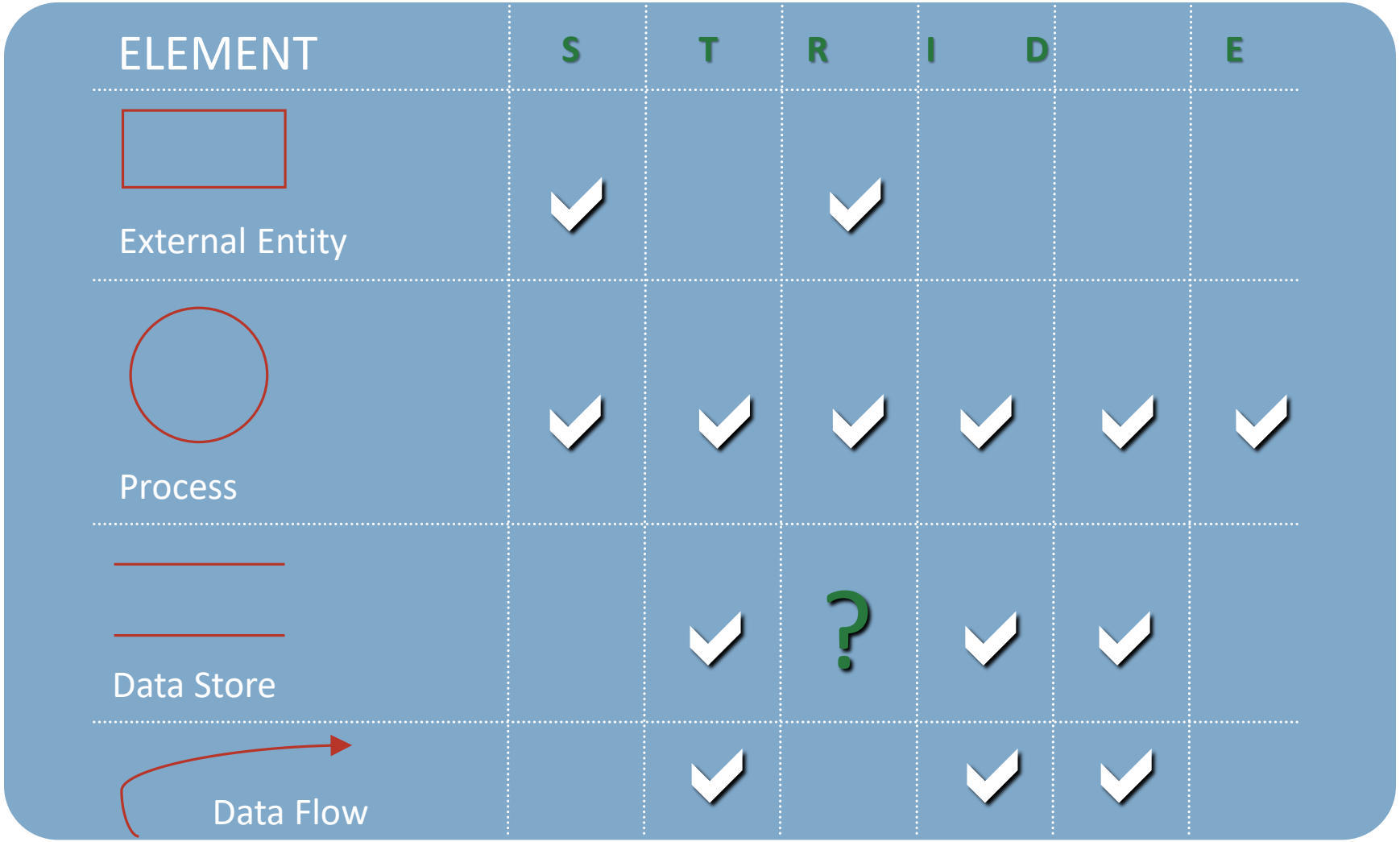
STRIDE Threat Categories:

Threat	Security Property
Spoofing	Authentication
Tampering	Integrity
Repudiation	Non-repudiation
Information Disclosure	Confidentiality
Denial of Service	Availability
Elevation of Privilege	Authorization

Scandariato et. al, 2015; Hernan et. al., 2006


Registry 7
SSDP 8
SSDP 10
Get version info
Set version info
Query other Castle info
Cache Castle info
Read Castle info
Publish this Castle info
Local User 1
Explorer (orrundl132) 2
Manage Castle
Feedback
Castle Service 8
Join, leave, Set users props
Query users props
Remote Castle
Set acct info
Get acct info
Set psswd
Shacct 4
Set acct info
Get acct info
SAM 5
Different threats affect each type of element
Element
S
T
R
I
D
E
External Entity
Process
Data Store
Dataflow

Different Threats Affect Each Element Type

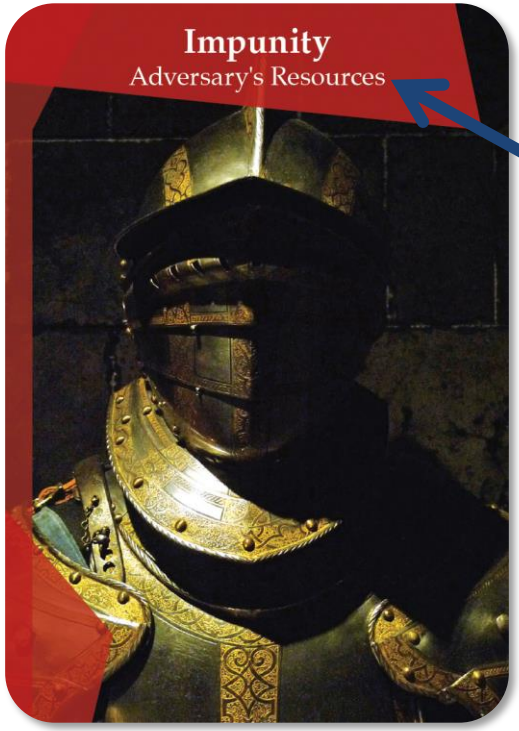


Standard Mitigations (For Microsoft Apps)

Spoofing	Authentication	To authenticate principals: • Cookie authentication • Kerberos authentication • PKI systems such as SSL/TLS and certificates To authenticate code or data: • Digital signatures
Tampering	Integrity	• Windows Vista Mandatory Integrity Controls • ACLs • Digital signatures
Repudiation	Non Repudiation	• Secure logging and auditing • Digital Signatures
Information Disclosure	Confidentiality	• Encryption • ACLS
Denial of Service	Availability	• ACLs • Filtering • Quotas
Elevation of Privilege	Authorization	• ACLs • Group or role membership • Privilege ownership • Input validation

Security Cards Approach

Example Card (Front)

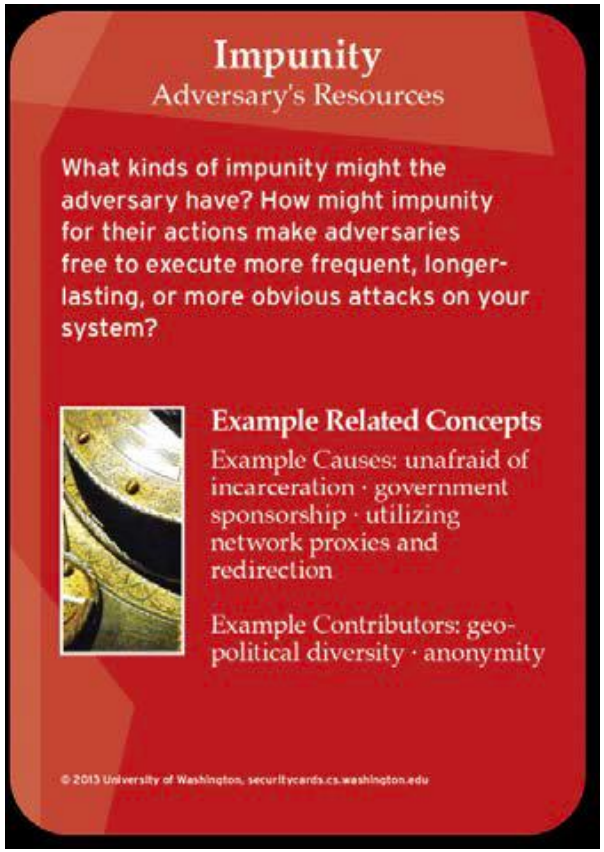


Card topic

Card dimension

Adversary's Motivations
Adversary's Resources
Adversary's Methods

Example Card (Back)

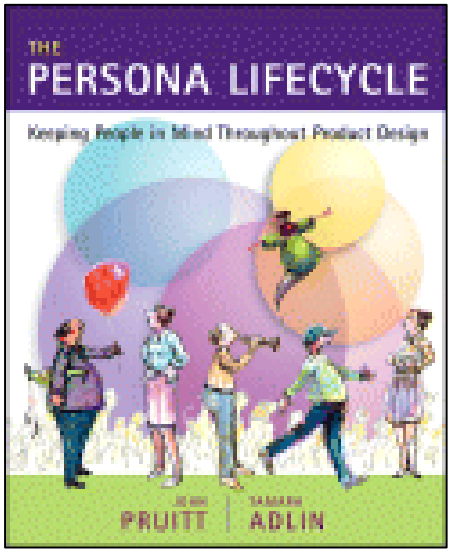


PnG Approach

What Is a Persona?

"**Personas** are detailed descriptions of imaginary people constructed out of well-understood, highly specified data about real people."

— John Pruitt & Tamara Adlin



J. Pruitt, T. Adlin. *The Persona Lifecycle: Keeping People in Mind Throughout Product Design*. Morgan Kaufman, 2006. (https://dl.acm.org/citation.cfm?id=1076976)

Example Persona

Thomas is a 76-year-old retired accountant who enjoys spending time with his grandchildren. During his retirement, he enjoys reading newspapers, working in his garden, and staying in touch with friends. He is a free spirit and enjoys exploration and technology, but only when it doesn’t get in his way.

Developing a PnG

1. **Motivations**: What is the PnG's motivations? Monetary gain? Revenge? Recognition? Laughs?
2. **Goals**: What goals does the PnG have to fulfill its motivation (i.e., what does it want to do and how does it plan to get away with it)?
3. **Skills**: What skills does it have to achieve their goal? What other assets does it have (e.g., access to infrastructure, relationships to those who have skills)?
4. **Misuse Cases**: What are the misuse cases the PnG can follow to achieve their goals?

Example PnG: Mike –1

Description: Mike worked as a contractor installing SCADA radio-controlled sewage equipment for a municipal authority. After leaving the contractor, Mike applied for a job with the municipality but was rebuffed. Feeling bitter and rejected, Mike decides to get even with the municipality and his former employer.

Goals: Cause raw sewage to leak into local parks and rivers and make the events appear as malfunctions. Create a public backlash against the contractor and municipality.

”Mike” is based on the true story of Vitek Boden, who was convicted of causing the release of sewage in Maroochy Shire Council in Queensland, Australia in 2000 after hacking the associated SCADA system. See Abrams & Weiss, *Malicious Control System Cyber Security Attack Case Study– Maroochy Water Services*, Australia, 2008. (http://www.scadahackr.com/library/Documents/Case_Studies/Case%20Study%20-%20NIST%20-%20Maroochy%20(presentation).pdf)

Example PnG: Mike –2

Skills: Extensive knowledge of SCADA equipment, including control computers, relevant programs, and radio communication protocols; access to specialized equipment

Misuse Cases:

- Steal control computer and radio equipment from his former employer.
- Using the stolen computer, construct a fake pumping control station from which to send radio signals.
- Gain remote access to the SCADA system and disable alarms at pumping stations.
- Issue radio commands (using stolen radio equipment) to instruct pumping stations to release sewage.

Abrams & Weiss, 2008

SEI Study Methodology

250+ subjects

- novice learners (SW and cyber), returning practitioners, professionals

All applied TMMs to common testbeds: systems with understandable Concept of Operations, and DoD relevance

UAV (CPS)

Aircraft maintenance app (IT)

Within-subjects design: Each team learns and applies one approach on a testbed and then learns the next and applies it on the other testbed.

The threat template, scenarios, and examples were designed to be reusable.

One of Several Results: How Frequently Is a Given Threat Type Reported?

If we know that a TMM was able to find a given threat, how confident can we be that it would be reported by a team?

- STRIDE: Great variability
- Security Cards: Able to find the most threat types, but also substantial variability across teams
- PnG: Was the most focused TMM, but showed the most consistent behavior across teams

No single TMM led to teams reporting a majority of the valid threats.

Results: Do the TMMs Help Modelers Find Important Classes of Threats?

Primary Measure

How many of the threat types identified by professionals were found by the student teams?

Other Aspects of Effectiveness

- Some types of threats were never uncovered by teams using some TMMs.
- Some TMMs led to many threat types from outside our expert set. (May be false positives or just unusual.)

Overall Impressions from the Earlier Study

STRIDE is intended to be used at a slightly later time in the lifecycle, when the system can be represented using data flow diagrams. It has more of a “cookbook” style than the other methods.

The **Security Cards** approach encourages thinking outside the box and creativity, with variability in results.

The **PnG** approach focuses more narrowly but provides consistent results.

The SEI team believed that a merger of the Security Cards and PnG approaches would produce a more consistent and complete view of threats.

Threat Modeling Research

Hybrid Threat Modeling Method 2017 – 2018

Desirable Threat Modeling Characteristics

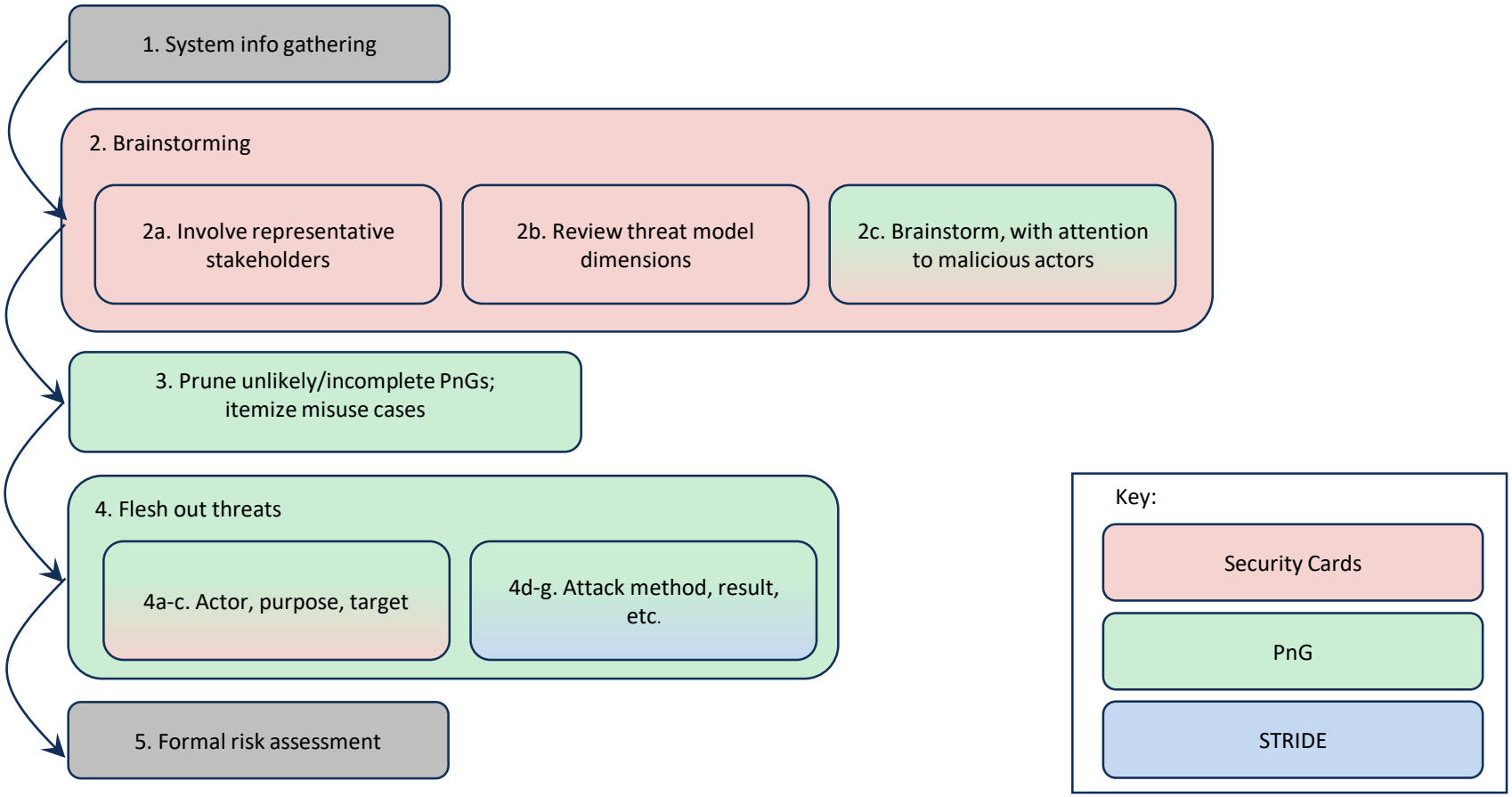
Desirable Characteristics of a Threat Modeling Method

- minimal false positives
- minimal overlooked threats
- consistent results regardless of who is doing the threat modeling
- cost-effective (doesn't waste time)
- empirical evidence to support its efficacy

Other Considerations

- has tool support
- suggests a prioritization scheme
- easy to learn, intuitive
- encourages thinking outside the box
- can be used by non-experts, or conversely, optimal for experts
- clearly superior for specific types of systems
- one reference, in addition to our own thinking (http://threatmodeler.com/successful-threat-modeling/)

Initial Hybrid Threat Modeling Method (hTMM) –1



Subsequent Activity

Applied on real-world medium-size project.

Method was tailored to interests of project managers.

Feedback on the tailored method was provided, but more general conclusions could not be derived from this case study.

Threat Modeling Research

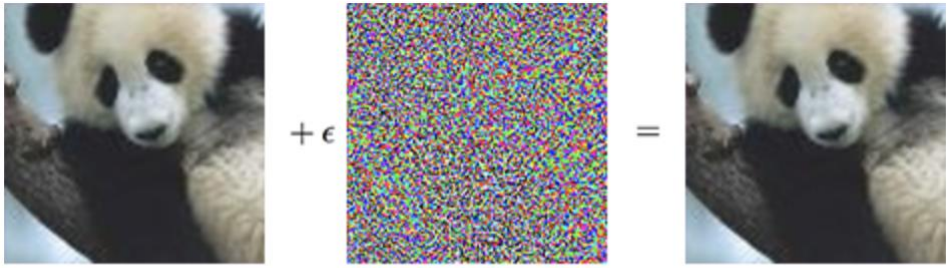
CMU MITS Student Project on Machine Learning 2018

MITS Project
Advex

Assess robustness of machine learning models against adversarial examples

What are Adversarial Examples?

- Adversarial examples are inputs to machine learning models that an attacker has intentionally designed to cause the model to make a mistake.



Source: https://blog.openai.com/adversarial-example-research

Motivation for the Project

- There are no security frameworks in place to prevent these adversarial examples from attacking a machine learning model.
- Thus, people need to make sure their models are robust enough to be safe from such adversarial examples.
- However, there are only a few resources for people to evaluate their model’s robustness against attacks.
- Current resources are not comprehensive enough for users to assess their models thoroughly.

Goal

- To build a website that assesses robustness of deep learning models against adversarial examples on computer vision tasks.
- The website will evaluate and provide feedback about the robustness of models uploaded by users using the Cleverhans library and ImageNet dataset.

Input: Clean Images
Output: Adversarial Examples (Images) generated by each attack method

Highlights

- By using attack methods built with different assumptions, we measure the model’s vulnerability against adversaries with different levels of capabilities.
- By controlling the amount of noise introduced in the adversarial examples, we measure the model’s vulnerability under different noise tolerance levels.
- By using attack methods that are generalizable across datasets, the assessment results will be reliable.

Features

- Scalable System
- User Friendly Web Interface
- Comprehensive and Reliable Feedback

Functional Requirements & Constraints

Functional Requirements

- Dashboard
- Model Upload Form
- Submission History
- Submission Detail
- Information Page

Business Constraints

- Budget limit for student teams
- Free to users

Technical Constraints

- Based on Cleverhans library
- Deployed on AWS
- Supports Keras only
- Targets Computer Vision models only

Summary of Prior Results

Initial research showed there is no single “best method” for threat modeling.

The hTMM was successfully applied to a small example and was then applied to a medium-size system.

The CMU MITS Project was completed and informed other machine learning research projects

Threat Modeling Research

Machine Learning and hTMM Research

Current Research Ideas - 1

Apply multiple threat modeling methods, including hTMM to systems that will employ machine learning, to try to understand which ones are effective

- Opportunity for collaboration with student teams, practitioners
- Focus on one of our prior examples, with a machine learning twist
- Develop new examples to be used threat modeling/machine learning experimentation

Current Research Ideas - 2

Examine machine learning in a different way

Can machine learning be used to improve threat modeling?

- Examine existing research on machine learning to improve resistance to attacks.
- Focus on a specific domain or one of our prior examples
  - Power (SCADA) systems
  - Drone example
- Examine whether machine learning can be used in conjunction with hTMM to improve threat modeling

Resources and References from Prior Research

SEI Technical Note: A Hybrid Threat Modeling Method: https://resources.sei.cmu.edu/library/asset-view.cfm?assetid=516617

SEI Blog Entry: A Hybrid Threat Modeling Method https://insights.sei.cmu.edu/sei_blog/2018/04/the-hybrid-threat-modeling-method.html

Conference Paper: Nancy Mead et al. Crowd Sourcing the Creation of Personae Non Gratae for Requirements-Phase Threat Modeling. IEEE International Requirements Engineering Conference Proceedings. September 2017. pp. 404-409 DOI 10.1109/RE.2017.63

SEI Certificate in Cyber Security Engineering and Software Assurance Program: https://sei.cmu.edu/education-outreach/courses/course.cfm?courseCode=V46

References for the MITS Project

https://blog.openai.com/adversarial-example-research/
https://github.com/tensorflow/cleverhans
https://www.youtube.com/watch?v=KJ1zZsia5yQ

References for ML

Detecting Stealthy False Data Injection Using Machine Learning in Smart Grid

Mohammad Esmalifalak, Lanchao Liu, Nam Nguyen, Rong Zheng, and Zhu Han

Deep Learning-Aided Cyber-Attack Detection in Power Transmission Systems

David Wilson, Yufei Tang, Jun Yan, and Zhuo Lu

SEI Blog Post: Measuring Resilience in Artificial Intelligence and Machine Learning Systems

https://insights.sei.cmu.edu/insider-threat/2019/12/measuring-resilience-in-artificial-intelligence-and-machine-learning-systems.html

The Top 10 Risks of Machine Learning Security

McGraw et al, IEEE Computer, June 2020

Threats for Machine Learning

Mark Sherman, SEI Webinar

Questions and Discussion

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